Exhibits

A. Susanne Rust et al., *How climate change is fueling record-breaking California wildfires, heat and smog*, Los Angeles Times (Sep. 13, 2020)

B. Anne Mulkern, *Fast-Moving California Wildfires Boosted by Climate Change*, Scientific American (Aug. 24, 2020)

C. Cal FIRE, *2020 Wildfire Activity Statistics*

D. Cal FIRE, *20 Largest Wildfires in California History*

E. Tiffany Yap, et al., Center for Biological Diversity, *Built to Burn: California's Wildlands Developments Are Playing With Fire* (Feb. 2021)

F. Mingha Qiu et al., *The rising threat of wildland-urban interface fires in the era of climate change: The Los Angeles 2025 fires*, The Innovation (February 4, 2025)

G. Wenfu Tang et al., *Global expansion of wildland-urban interface (WUI) and WUI fires: insights from a multiyear worldwide unified database (WUWUI)* 2024 Environ. Res. Lett. 19 044028 (March 19, 2024)

H. Volker C. Radeloff et al., *Rapid Growth of the US wildland-urban interface raises wildfire risk*, PNAS (March 27, 2018)

I. Jon E. Keely et al., *Nexus Between Wildfire, Climate Change, and Population Growth In California*, Fremontia: Journal of the California Native Plant Society (March 2020)

J. Union of Concerned Scientists, *Infographic: Wildfires and Climate Change – Visualizing the Connection in Five Sets of Photos and Charts* (Updated May 9, 2022)

K. Westerling, A.L., Hidalgo, H.G. Cayan, D.R. and Swetnam, T.W., *Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity*, 313 Science 940 (2006)

L. D. Cayan, A. L. Luers, M. Hanemann, G. Franco, and B. Croes, *Scenarios of Climate Change in California: Overview*, CEC-500-2005-186-SF (2006)

M. California State Office of the Attorney General, *Best Practices for Analyzing and Mitigating Wildfire Impacts of Development Projects Under the California Environmental Quality Act*. (October 10, 2022)

N. San Bernardino County, *Multi-Jurisdictional Hazard Mitigation Plan* (2017)

O. SBCSentinel, *Highway 330, Closed for Two Months as A Consequence of the Line Fire, Now Open* (November 29, 2024)

P. KBHR Big Bear News, *SR-330 to Remain Closed Through February 24th for Repairs per CalTrans* (February 14, 2025)

Q. Ruben Vives, Gina Ferazzi, and Seema Mehta, *Lake fire evacuation orders lifted as firefighters make progress in San Bernardino County*, Los Angeles Times (Updated June 29, 2025)

R. National Wild and Scenic Rivers System, Information on Deep Creek from website: https://rivers.gov/apps/river/deep-california (Accessed January 5, 2026)

S. Paul M. Mayer et al., *Where the rubber meets the road: Emerging environmental impacts of tire wear particles and their chemical cocktails,* Science of the Total Environment (March 7, 2024)

T. Alexander Young et al., *Urban stormwater runoff negatively impacts lateral line development in larval zebrafish and salmon embryos,* National Institutes of Health (February 12, 2018)

U. M. J. Paul, S. D. DeLuc, M. G. Lassiter, L. C. Moorhead, P. D. Noyes, S. G. Leibowitz, *Wildfire induces changes in receiving waters: A review with considerations for water quality management*, Water Resour Res (September 15, 2022)

V. Crestline-Lake Arrowhead Water Agency, Historical Timeline from website, https://www.clawa.org/_files/ugd/a07b32_5613e3022a8c4b35981f55f04ad29534.pdf (document undated)

W. San Bernardino County, *Countywide Plan, County Policy Plan* (September 2022)

X. San Bernardino County, *Transportation Impact Study Guidelines* (July 9, 2019)

Y. Google Maps Street View screenshot of the intersection of SR-18 and Green Valley Road (image capture April 2024)

Z. State of California Governor's Office of Planning and Research, *Technical Advisory on Evaluating Transportation Impacts in CEQA* (Dec. 2018)

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EXHIBIT A

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CALIFORNIA

How climate change is fueling record-breaking California wildfires, heat and smog



Smoke and haze from wildfires hovered Thursday over San Francisco, as much of California was blanketed in smoke from a siege of wildfires and poor air quality. (Eric Risberg / Associated Press)

By SUSANNE RUST, TONY BARBOZA

SEP. 13, 2020 6 AM PT

In 2001, a team of international scientists projected that during the next 100 years, the planet's inhabitants would witness higher maximum temperatures, more hot days and heat waves, an increase in the risk of forest fires and "substantially degraded air quality" in large metropolitan areas as a result of climate change.

In just the past month, nearly two decades after the third United Nations Intergovernmental Panel on Climate Change report was issued, heat records were busted across California, more than 3 million acres of land burned , and in major metropolitan areas, such as Los Angeles and San Francisco, air pollution has skyrocketed.

"This shouldn't come as a surprise to anyone," said Michael Gerrard, director of the Sabin Center for Climate Change Law at Columbia University. "Maybe we underestimated the magnitude and speed" at which these events would occur, he said, but "we've seen this long freight train barreling down on us for decades, and now the locomotive is on top of us, with no caboose in sight."

In a matter of weeks, California has experienced six of the 20 largest wildfires in modern history and toppled all-time temperature records from the desert to the coast. Millions are suffering from some of the worst air quality in years due to heat-triggered smog and fire smoke. A sooty plume has blanketed most of the West Coast, blotting out the sun and threatening people's lungs during a deadly pandemic.

California is being pushed to extremes. And the record heat, fires and pollution all have one thing in common: They were made worse by climate change. Their convergence is perhaps the strongest signal yet that the calamity climate scientists have warned of for years isn't far off in the future; it is here today and can no longer be ignored.

"What we've been seeing in California are some of the clearest events where we can say this is climate change — that climate change has clearly made this worse," said Zeke Hausfather, a climate scientist at the Breakthrough Institute, an Oakland-based think tank. "People who have lived in California for 30, 40 years are saying this is unprecedented, it has never been this hot, it has never been this smoky in all the years I've lived here."

CALIFORNIA

Los Angeles suffers worst smog in almost 30 years

Sep. 10, 2020

Unprecedented, yes. But not unexpected.

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Since the 1980s, government and oil industry scientists have been anticipating the events that have transpired across the state this past month.

As one 1988 internal Shell Oil Co. document noted, "by the time the global warming becomes detectable it could be too late to take effective countermeasures to reduce the effects or even to stabilize the situation."

"I'm only sorry that in 1989, I could not get an audience for what I wanted to communicate," said Jim Hansen, a retired NASA researcher and early climate change scientist, of testimony he made to Congress about the issue.

Record temperatures

Each of the extremes Californians are living through right now is fueled, at least in part, by the gradual warming of the planet, which is accelerating as greenhouse gas emissions continue to rise.

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California summers are 2.5 degrees warmer than they were in the 1970s and are on track to heat up an additional 4.5 degrees by the end of the century if the world's current emissions trajectory continues, said Hausfather.

While precise attribution studies on the extreme heat waves in California in recent weeks will take time to complete, he said, they are clear examples of how climate change compounds natural weather variability to increase the likelihood of what once would have been a rare event.

"In a world without climate change, it still would have been a hot August; we still would have had some fires. But it's clear that climate change has made things notably worse," he said. "An extreme heat event that would have been 100 degrees is now 102.5 or 103 degrees, and that is actually a pretty big difference in terms of the impacts on people."

During the mid-August heat wave, Death Valley soared to 130 degrees, one of the hottest temperatures ever recorded on Earth.

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Another ferocious heat wave over the Labor Day weekend brought Death Valley-like heat to other areas. Los Angeles County had its hottest temperature on record when Woodland Hills hit 121 degrees Sept. 6. At Cal Poly San Luis Obispo, it reached 120 degrees, the highest reading since record-keeping began in 1869, in an area that is less than 10 miles from the Pacific Ocean.

CALIFORNIA

A sizzling summer: Hottest August on record in California

Sep. 10, 2020

John Lindsey, a marine meteorologist with Pacific Gas and Electric, said the mercury rose to unprecedented levels in San Luis Obispo due to hot, downslope winds blowing from the northeast. They are known locally as Santa Lucia winds and can increase temperatures by 5.5 degrees for every 1,000 feet they descend.

“It was just rip-roaring hot,” said Lindsey, who has forecast weather along the Central Coast since 1991. “You just don’t expect Death Valley temperatures along coastal California.”

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Lindsey, who acknowledges that he was a bit of a climate skeptic in the past, said seeing the increase in seawater temperatures, in particular, over many years "was a real epiphany or wake-up call."

"By now, there's no doubt in most people's minds that the atmosphere is warming and the ocean is warming," he said. "With the way greenhouse gases are increasing, in my mind, there's no doubt that we're causing this. It's human activity that's causing this. So I'm concerned about the future. And that's somebody who's very skeptical."

Global warming has increased the odds of unprecedented heat extremes across more than 80% of the planet and "has doubled or even, in some areas, tripled the odds of record-setting hot events" in California and the Western U.S., said Stanford University climate scientist Noah Diffenbaugh.

An unprecedented firestorm

When it comes to wildfires, "what we've had in California over the last three to four weeks is unprecedented in our historical experience," Diffenbaugh said.

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"This is more extreme than any other year in living memory," he said, and is consistent with the impact of global warming.

Research by Diffenbaugh and colleagues that was published last month found that the number of days with extreme wildfire weather in California has more than doubled since the early 1980s, primarily due to warming temperatures drying out vegetation.

"It means that even with no change in the frequency of strong wind events, even with no change in the frequency of lightning, the risk of wildfire and risk of large, rapidly growing wildfires goes up as a result of the effect of that warming," he said.

California wildfires map: What's burning now

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And it's that atmospheric warming that has set the stage for the fires raging throughout the western U.S., said Park Williams, a hydroclimatologist at Columbia University's Lamont-Doherty Earth Observatory.

"If we think of the atmosphere as a giant sponge that's always trying to extract water from the landscape, then temperature increases the sponginess," he said.

As soils become drier, heat waves become more intense. That's because the energy in the atmosphere is no longer being used in evaporation but is just building up heat. And as heat increases and soils — and, therefore, fuel for fires — dry out, the risk grows, laying the foundation for the type of wild and destructive fires we are now observing.

"That's why, I think, you keep reading quotes from these firefighters who say they are seeing fire behavior unlike anything they've seen before," he said. "As we go out in the future, in a world with this exponentially growing risk … we're going to see fires far different than we've seen before."

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He noted that fires are not unusual in California — they are an integral part of the state's history and landscape. Bad forest management, combined with human behavior — intentional and unintentional starting of fires — have contributed to the problem. But the effect of climate change is real and growing.

"We have seen the rapid warming of California summers really turbocharge the type of conditions that are suitable for rapid growth of wildfires," Hausfather said. "We see fires growing from essentially nothing to a quarter of a million acres in one day. And that's because the conditions are ripe, and temperature plays a large role."

John Abatzoglou, associate professor in the Department of Management of Complex Systems at UC Merced, agreed.

“What we are seeing play out does indeed have human fingerprints on it, including those from climate change,” he said.

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“We can see how warm and dry years catalyze these fires,” he said, adding, however, that for fires to start, “they need to have ignitions. But the heat and dryness have absolutely set the table for widespread fire activity.”

Dreadful air quality

It was no coincidence that ozone pollution levels in downtown Los Angeles spiked to their highest levels since the mid-1990s on a day in which temperatures reached an all-time high for the county, said Cesunica Ivey, an assistant professor of chemical and environmental engineering at UC Riverside who studies air quality.

The global rise in temperatures observed over decades is also occurring locally, she said, “and these frequently occurring heat waves, this upward trend in basin-wide average temperature, is contributing to ozone exacerbation.”

CALIFORNIA

Rarely have so many Californians been exposed to such gloomy, unhealthy air

Sep. 10, 2020

Southern California regulators have seen decades of progress fighting smog stymied in recent years by hotter weather and stronger, more persistent inversion layers that trap pollution near the ground. Their efforts are being hindered by rising temperatures from climate change, according to air quality experts.

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That's because hotter weather speeds up the photochemical reactions that turn pollutants from vehicle tailpipes and other sources into ozone, the invisible, lung-damaging gas in summer smog. Studies show that ozone levels are about two parts per billion higher than they would be without global warming.

What precisely is driving changes such as elevated smog levels can be hard to tease out in the middle of an extreme event because so much is happening at once, with multiple hazards piling on top of each other in a vicious feedback loop.

The recent heat spells, for instance, both fueled smog formation and led to power outages. Gov. Gavin Newsom suspended air quality rules on power plants and other polluters to ease strain on the grid, allowing more emissions to sully the air. The COVID-19 pandemic has added an additional layer of complexity at a time when Californians are trying to protect their homes, lungs and bodies from threats that seem to be coming from all sides.

"When you add COVID, extreme heat, wildfires and air pollution all together, they're all detrimental to public health, and it just makes things worse," said Yifang Zhu, a professor of environmental health sciences at UCLA Fielding School of Public Health who studies air pollution and its effects. "These stressors are happening at the same time. So the impact is cumulative and maybe even synergistic to each other."

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That cascading effect, in which one extreme compounds another, is a feature of global warming that experts have long warned about.

Ivey, of UC Riverside, said she and other scientists aren't surprised to see so many extremes hitting simultaneously, "but to see it playing out is scary."

"It's one of those moments where ozone converged with record acres burned and a heat wave," she said. "If the writing isn't on the wall, then I don't know what to tell folks."

Global warming is also fueling increases in wildfire pollution, a mix of soot particles and gases that can fuel ozone formation and dramatically worsen smog. Those added emissions are only going to get worse as the severity and frequency of fires increases.

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“People may not directly connect local air pollution to global climate change, but they are intertwined,” said Zhu. “They are two sides of the same coin.”

What this year’s extreme heat, fire and air quality degradation is showing, said Columbia’s Williams, is that we are, in a sense, blindly stepping off a cliff from a world in which we could somewhat predict what was going to happen, based on decades and centuries of data.

“We’re finding that we’ve lost complete control,” he said. “The baselines we’ve used for decades no longer apply. There really isn’t a normal anymore.”

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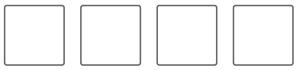
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E&E NEWS

CLIMATE

Fast-Moving California Wildfires Boosted by Climate Change

Nearly two dozen large blazes have burnt more than 1 million acres of the state

By Anne C. Mulkern, E&E News on August 24, 2020



Embers blow off a burned tree after the LNU Lightning Complex Fire burned through the area on August 18, 2020 in Napa, California. Credit: Justin Sullivan *Getty Images*

Firefighters battled nearly two dozen wildfires in California yesterday after a week of raging blazes blackened more than 1 million acres across the state.

The fast-moving fires, which are seen by many scientists as a sign of climate change, have killed five people, destroyed more than 1,000 structures and forced thousands to flee. More than 238,000 people either evacuated or were ready to go as more thunderstorms threatened to light new fires yesterday afternoon, according to officials.

Still-active fires are affecting at least 23 counties in Northern California, stretching from Butte to Fresno. Two of the blazes rank among the largest in state history.

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The LNU Lightning Complex Fire, a group of fires centered in Napa and Sonoma counties, has grown into the second-largest blaze ever seen in California. The SCU Lightning Complex Fire, a cluster of blazes in Santa Clara, Alameda and nearby counties, is the third-largest.

Altogether, the fires have burned an area the size of Rhode Island.

"The scope [of the damage] is absolutely astonishing," said Daniel Swain, a climate scientist at UCLA. It's "hard to impress on people just how vast the acreage burned is, especially considering there were no strong offshore winds" to drive the spread.

President Trump on Saturday issued a major disaster declaration to fulfill a request by Gov. Gavin Newsom (D) to bolster the state's emergency resources. Meanwhile, the National Weather Service issued a red flag warning for more thunderstorms and lightning through today.

The racing flames show how climate change is affecting the nation's most populous state, experts said. Hotter temperatures, less dependable precipitation and snowpack that melts sooner lead to drier soil and parched vegetation. Climate change also affects how much moisture is in the air, Swain said.

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"It's actually drying out the air during these extreme heat events," which zaps plants of additional moisture, Swain said. That left much of the state a tinderbox when hundreds of lightning strikes scorched the countryside last week.

"This is really a testament to how dry the vegetation is, in terms of how quickly these fires spread when they were ignited by lightning," he said.

The amount of land burned last week is more than the total burned in all of 2018, and more than double the amount burned in 2017, according to data released by the California Department of Forestry and Fire Protection (Cal Fire).

Celebrating 175 Years of Discovery Learn More

The fires on Saturday burned part of the oldest state park in California, Big Basin Redwoods State Park in Santa Cruz County. Flames damaged historic buildings, the campground and "all of the infrastructure," said Christine McMorrow, a spokeswoman with Cal Fire. It wasn't known whether redwood trees were engulfed.

The blazes threaten to outpace the state's ability to respond. Nearly all of Cal Fire's crews are in the field, with some working 72-hour shifts. Oregon, Washington, Nevada, New Mexico, Texas and other states sent firefighters, equipment or both. Officials said more than 13,000 fire personnel were on the scene.

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"We have more people, but it's not enough," Newsom said at a Friday news conference. "We have more air support, but it's not enough."

REPEAT FIRE TRAUMA

Fires erupted beginning Aug. 15 when more than 1,200 lightning strikes hit the baking landscape within 72 hours.

Those came "the exact week that we were experiencing some of the hottest temperatures ever recorded in human history, 130-degree temperatures in the southern part of the state," Newsom said. It was "maybe the hottest modern recorded temperature in the history of the world," he said.

He was referring to the temperature of 130 degrees Fahrenheit on Aug. 16 in Death Valley, a high not reached on Earth in 89 years. The highest temperature ever recorded on the planet is 134 Fahrenheit. It was reached in 1913 in Death Valley. Its accuracy is

disputed by some observers because there was a lack of modern technology (*Climatewire*, Aug. 18).

Altogether, more than 12,000 lightning strikes hit California last week, igniting over 600 fires. Firefighters knocked down smaller ones, but others merged into major "complex" fires.

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The week was filled with horror stories and heroic efforts. Volunteers helped evacuate senior citizens from a Vacaville retirement home in the middle of the night as a fire raced toward the facility. Others helped rescue "dozens and dozens of individuals with intellectual disabilities" in Santa Clara, Newsom said.

Hundreds saw their homes destroyed.

"Tuesday night when I went to bed, I had a beautiful home on a beautiful ranch," Hank Hanson, 81, of Vacaville, told the Associated Press. "By Wednesday night, I have nothing but a bunch of ashes."

State Assemblywoman Cecilia Aguiar-Curry, who represents the Napa wine region, said at a news conference Friday that she has "half a dozen really good friends who don't have a home right now."

The American Red Cross, wary of the coronavirus pandemic, put some survivors in hotel rooms so they could be separated from other evacuees, said Jim Burns, a Red Cross spokesman. Others went to evacuation shelters where protocols were in place to keep people spaced out. The Red Cross was also talking to colleges to see whether dorm rooms were available.

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The fires swept across heavily populated cities that have endured major fires in recent years. Susan Gorin, a Sonoma County supervisor, lost her home in the 2017 Tubbs Fire, a blaze that killed 22 people. She built a new house in the same location; on Friday, she found ashes on her patio from a nearby firestorm.

"It just seems so terrifyingly familiar," Gorin said as she traveled to Lake Tahoe to escape the smoke and mayhem. "This is now the third major fire in four years. We are battle-weary."

CLIMATE CONNECTION SCRUTINIZED

Swain with UCLA and other scientists earlier this year published a study that said climate change has doubled the number of extreme-risk days for California wildfires.

It said temperatures statewide rose 1.8 degrees Fahrenheit since 1980, while precipitation dropped 30%. That doubled the number of autumn days that offer extreme conditions for the ignition of wildfires (*Climatewire*, April 3).

The heat is expected to get worse with time. Climate models estimate that average state temperatures will climb 3 degrees Fahrenheit by 2050 unless the world makes sharp cuts in greenhouse gas emissions, said Michael Wehner, a senior scientist at Lawrence Berkeley National Laboratory.

Even with emissions cuts, average temperatures would rise 2 degrees by midcentury, he said.

Jon Keeley, a senior scientist at the U.S. Geological Survey Western Ecological Research Center, argued that the study from Swain and others failed to show that hotter temperatures are driving wildfires.

"Show us data that shows that level of temperature increase is actually associated with increased fire activity," Keeley said. "They don't show that."

Keeley added, "We ought to be much more concerned with ignition sources than a 1- to 2-degree change in temperature."

A big contributor to large California fires is that the state has focused on extinguishing blazes for about a century rather than allowing for controlled burns, he said. That has caused dead vegetation to accumulate.

Trump has accused California of failing to "sweep" its forests, which he has linked to fires in the state.

Keeley said that "we don't sweep forests here in the U.S., but what we do is prescription burning. ... It's potentially the same thing. It's modifying the fuels prior to a fire."

Swain, the UCLA climate scientist, said global warming is affecting how big fires get and how fast they move.

"What happens when they start burning, what is the character of those fires, and is it changing?" Swain asked. "The answer is yes."

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EXHIBIT C

2020

Wildfire Activity Statistics



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2020 Wildfire Activity Statistics

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Acknowledgements
We wish to acknowledge and thank all who supplied data, resources, professional expertise, and assisted in the review of the reports.

Table of Contents

Foreword — Wildfire Activity Statistics iii-iv

2020 Statewide Fire Summary
Table 1. Protection Areas by Wildfire Agency — Fires and Acres 1
Table 2. The Top Five Fires by Acreage Burned 1

AREA PROTECTED
Map 1. State Responsibility Area (SRA) 2
Table 3. State Responsibility Area, Acres Protected by State and Other Agencies 3-4
Map 2. CAL FIRE — Direct Protection Area (DPA) 5
Table 4. CAL FIRE — Direct Protection Area, Acres Protected by Jurisdiction 6-7

WILDFIRE STATISTICS — CALIFORNIA WILDFIRE AGENCIES
Table 5. Large Fires 300 Acres and Greater — State and Contract Counties Direct Protection Area 8-10
Table 6. Large Fires 300 Acres and Greater — Other Agencies Direct Protection Area 11-13
Table 7. Number of Fires and Acres Burned by Cause and by Size in Contract Counties 14-15

WILDFIRE STATISTICS — CAL FIRE

Fires
Table 8. Number of Fires by Cause, by Unit 16
Table 9. Number of Fires by Cause, by County 17-18
Table 10. Number of Fires and Acres Burned by Cause — Detailed 19-21
Table 11. Number of Fires by Size, by Unit 22
Table 12. Number of Fires by Size, by County 23-24

Acres Burned
Table 13. Number of Acres Burned by Cause, by Unit 25
Table 14. Number of Acres Burned by Cause, by County 26-27
Table 15. Number of Acres Burned by Vegetation Type, by Unit 28
Table 16. Number of Acres Burned by Vegetation Type, by County 29-30

Dollar Damage
Table 17. Dollar Damage by Cause, by Unit 31
Table 18. Dollar Damage by Cause, by County 32-33
Table 19. Dollar Damage by Size, by Unit 34
Table 20. Dollar Damage by Size, by County 35-36

Fire Activity Statewide
Graphic Figure 1. Percent of Fires by Cause 37
Graphic Figure 2. Number of Acres Burned — 2011-2020 38
Graphic Figure 3. Number of Fires — 2011-2020 39
Graphic Figure 4. Number of Fires by Cause — 2020, 2019, and 5 Year Average 40
Graphic Figure 5. Fires and Acres — 2020, 2019, and 5 Year Average 41
Graphic Figure 6. Fires and Acres by Region — 2020, 2019, and 5 Year Average 42
Graphic Figure 7. Arson Fires and Acres — 2011-2020 43
Graphic Figure 8. Number of Fires by Time of the Day 44
Graphic Figure 9. Number of Fires and Acres Burned by Month 45
Graphic Figure 10. Structures Destroyed — 2000-2020 46

Glossary 47-48

FOREWORD
WILDFIRE ACTIVITY STATISTICS

The California Department of Forestry and Fire Protection (CAL FIRE), under the direction of the State Board of Forestry and Fire Protection, provides the annual Wildfire Activity Statistics report. Although it contains other information, this report is primarily a statistical record of wildfire incidents responded to by CAL FIRE personnel and resources, performing the State/CAL FIRE mission, using State funding within CAL FIRE Direct Protection Area (DPA).

The existing overall fire protection system involving CAL FIRE and California as a whole is rather complex. A number of technical terms are utilized, and the use of fire statistics typically presupposes some understanding of the overall framework. A description of this framework can be found at (https://www.fire.ca.gov/programs/communications/); and in the Glossary of terms at the end of this document.

The first Forest Fire Summary (RED BOOK) was published in 1943 and has continued to this date. Prior to 1989, data and statistics were tabulated manually; today, statistics are derived from an automated database. CAL FIRE began electronically entering incident data into the Emergency Activity Reporting System (EARS) on July 1, 1989. Starting at the end of 2006, CAL FIRE began reporting incidents using a web-based subscription service called California All Incident Reporting System (CAIRS). In 2020, CAL FIRE began reporting incidents using a web-based subscription service called CAL FIRE Incident Reporting System (CALFIRS). This data is imported into the California Incident Data and Statistics (CalStats) database by CAL FIRE staff and the data is uploaded annually to the National Database maintained by the United States Fire Administration (USFA). **Due to the changes in data collection, methods, and systems over the years, information may not always be comparable and data may be of differing accuracy or completeness.**

Throughout this report, the statistics are displayed by **who** provides the wildfire protection. Forces include CAL FIRE personnel and resources, CAL FIRE employees working under a local government agreement, Contract County personnel, and federal firefighting resources. The second part of the statistical reporting is **where** the protection is provided. Areas are categorized as State Responsibility Area (SRA) or DPA.

SRA is State and privately-owned forest, watershed, and rangeland for which the primary financial responsibility of preventing and suppressing wildfires rests with the State (Map 1).

The term “Direct Protection Area” is applied to indicate when a particular fire protection organization has the primary responsibility for responding to an uncontrolled fire and for directing the suppression activity. Thus, in addition to lands in SRA, CAL FIRE may have “direct protection” responsibility on lands in federal jurisdiction. At the same time, federal agencies, such as the U.S. Forest Service, may have “direct protection” responsibility for lands in SRA. The lands in SRA and federal areas for which CAL FIRE has “direct protection” responsibility for fire protection responses are depicted on Map 2.

The State contracts with six counties to provide protection of SRA within their boundaries. These counties [Kern, Los Angeles, Marin, Orange, Santa Barbara, and Ventura] are referred to as Contract Counties.

CAL FIRE provides fire protection services to many California citizens through the administration of 150 cooperative fire protection agreements in cities, districts, and 36 of the State's 58 counties. Wildfire statistics associated with incidents where local government reimburses CAL FIRE for services are displayed in Table 1.

This report also includes a statewide summary of California wildfires and a listing of wildfires over three hundred acres for all wildfire agencies (Table 5). The statistical information in this report is gathered from data in the previously defined CALFIRS and Incident Status Summaries (ICS-209) on the National Fire and Aviation Management (FAMWEB) website http://fam.nwcg.gov/fam-web/ .

Beginning mid-August, dry conditions, combined with severe lighting storms sparked what became known as the “2020 Fire Siege.” These resulting wildfires led to over 4 million acres burned, making 2020 one of the worst fire seasons on record. Many of these incidents originated and burned in Federal Responsibility Area (FRA) and as such, not all fires and acres burned in the Siege are reflected in tables 8 through 21. More detailed information on the 2020 Fire Siege from the perspective of CAL FIRE can be found at this link: https://www.fire.ca.gov/media/hsviuuv3/cal-fire-2020-fire-siege.pdf

Additional Wildfire Activity Statistics for previous years can be found at the following website: https://www.fire.ca.gov/stats-events/ .

2020 STATEWIDE FIRE SUMMARY

During 2020, wildfire firefighting agencies responded to 8,648 fires that burned 4,304,379 acres. For wildfire agencies, this represents a 21% increase in the number of fires and a 1,452% increase in acres burned from 2019. CAL FIRE, through State funded and local government contracts, reported 6,350 wildfire incidents that burned 1,475,943 acres, which represents an 8% increase in fires and a 976% increase in acres burned from 2019.

Table 1. Protection Areas by Wildfire Agency—Fires and Acres

Direct Protection Area	Fires	Acres Burned
CAL FIRE – (State Responsibility)	3,501	1,458,881
CAL FIRE – (Local Government Contracts)	2,849	17,062
Contract Counties	466	54,762
United States Forest Service	1,421	2,520,946
Bureau of Land Management	217	142,201
National Park Service	79	76,796
Bureau of Indian Affairs	97	22,210
United States Fish and Wildlife Service	13	45
Military	5	11,476
2020 Total	8,648	4,304,379
5 Year Average (2016-2020) All Agencies	**8,198**	**1,794,819**
5 Year Average CAL FIRE (2016-2020) Includes Local Govt. Contracts	**5,903**	**634,018**

Federal agencies provide their fire statistics as a courtesy to CAL FIRE.

Table 2. The Top Five Fires for 2020 by Acreage Burned

Fire Name	County	Start Date	Acres Burned	Fire Cause	Structures Destroyed
August Complex **(Includes West Zone)**	Trinity, Tehama, Glenn, Lake, Mendocino	08/17/21	1,032,648	Lightning	89
SCU Lightning Complex	Contra Costa, Santa Clara, Alameda, San Joaquim, Stanislaus	08/16/21	396,625	Lightning	225
Creek	Fresno, Madera	09/04/21	379,895	Undetermined	858
LNU Lightning Complex	Napa, Lake, Sonoma, Solano	08/17/21	363,220	Lightning	1,491
North Complex	Butte, Plumas	08/17/21	318,935	Lightning	2,352

Source: Redbook, Table 5, Large Fires 300 Acres and Greater – State and Contract Counties Direct Protection Areas and Table 6, Large Fires 300 Acres and Greater - Other Agencies Direct Protection Areas.

Map 1. State Responsibility Area (SRA)

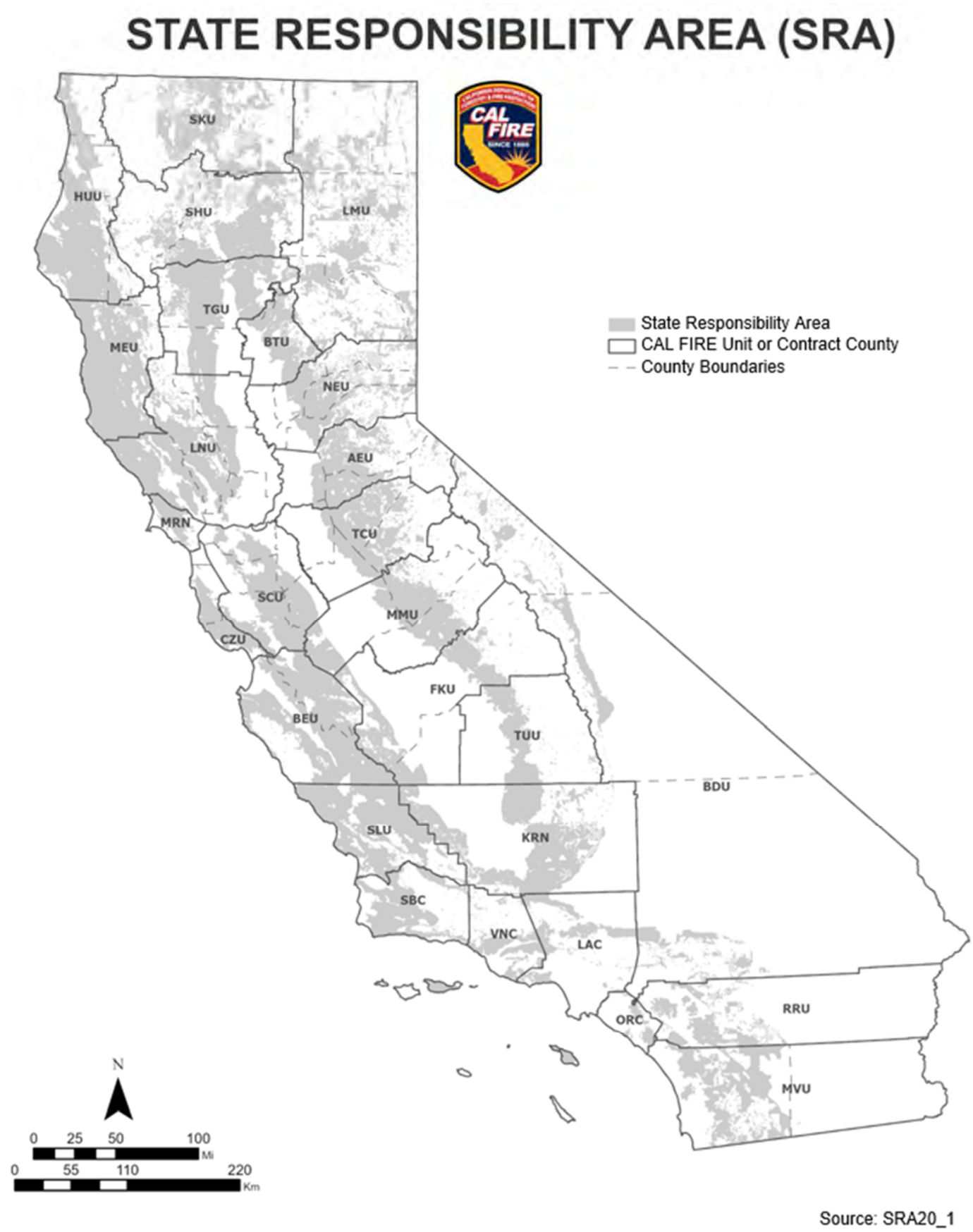


Table 3. State Responsibility Area, Acres Protected by State and Other Agencies (2020)*

COUNTY	CAL FIRE	USFS	BLM	NPS	CC	Other FED	TOTAL
Alameda	246,200	0	0	0	0	0	246,200
Alpine	0	34,000	400	0	0	0	34,400
Amador	279,700	8,400	0	0	0	0	288,100
Butte	500,800	35,300	0	0	0	0	536,100
Calaveras	524,400	2,300	0	0	0	0	526,700
Colusa	241,500	5,100	0	0	0	0	246,600
Contra Costa	193,200	0	0	0	0	0	193,200
Del Norte	172,600	16,700	0	800	0	0	190,100
El Dorado	404,900	143,600	0	0	0	0	548,500
Fresno	774,800	28,900	0	0	0	0	803,700
Glenn	290,100	7,400	0	0	0	0	297,500
Humboldt	1,542,800	69,400	0	400	0	0	1,612,600
Imperial	1,800	0	0	0	0	0	1,800
Inyo	308,100	11,600	16,900	0	0	0	336,600
Kern	0	29,300	152,000	0	1,642,600	0	1,823,900
Kings	149,000	0	0	0	0	0	149,000
Lake	355,600	40,000	0	0	0	0	395,600
Lassen	592,200	80,900	377,600	0	0	0	1,050,700
Los Angeles	0	28,200	0	0	469,800	0	498,000
Madera	368,100	9,700	0	0	0	0	377,800
Marin	0	0	0	0	199,800	0	199,800
Mariposa	426,900	16,200	0	500	0	0	443,600
Mendocino	1,838,700	21,700	0	0	0	0	1,860,400
Merced	393,900	0	0	0	0	0	393,900
Modoc	371,500	187,500	73,100	0	0	0	632,100
Mono	2,500	92,200	161,100	0	0	0	255,800
Monterey	1,250,600	38,000	0	0	0	0	1,288,600
Napa	360,400	0	0	0	0	0	360,400
Nevada	299,400	84,400	0	0	0	0	383,800
Orange	0	2,500	0	0	104,100	0	106,600
Placer	275,100	85,100	0	0	0	0	360,200
Plumas	96,600	342,100	100	0	0	0	438,800
Riverside	555,400	26,100	48,500	0	2,600	0	632,600
Sacramento	113,500	0	0	0	0	0	113,500
San Benito	729,000	0	0	0	0	0	729,000
San Bernardino	311,100	38,500	0	0	0	0	349,600
San Diego	1,088,100	79,600	0	0	0	0	1,167,700
San Francisco	0	0	0	0	0	0	0
San Joaquin	150,200	0	0	0	0	0	150,200
San Luis Obispo	1,406,500	40,200	81,500	0	1,700	0	1,529,900

Table 3. (continued) State Responsibility Area, Acres Protected by State and Other Agencies (2020) *

COUNTY	CAL FIRE	USFS	BLM	NPS	CC	Other FED	TOTAL
San Mateo	176,100	0	0	0	0	0	176,100
Santa Barbara	0	65,800	0	55,200	667,700	1,200	789,900
Santa Clara	554,700	0	0	0	0	0	554,700
Santa Cruz	228,600	0	0	0	0	0	228,600
Shasta	1,142,700	219,000	0	2,500	0	0	1,364,200
Sierra	0	155,500	2,300	0	0	0	157,800
Siskiyou	1,012,000	352,400	0	0	0	0	1,364,400
Solano	86,900	0	0	0	0	0	86,900
Sonoma	794,000	0	0	0	0	0	794,000
Stanislaus	448,000	0	0	0	0	0	448,000
Sutter	0	0	0	0	0	0	0
Tehama	1,148,900	136,800	0	0	0	0	1,285,700
Trinity	259,200	228,900	0	400	0	0	488,500
Tulare	573,300	11,700	11,300	2,500	0	300	599,100
Tuolumne	299,000	58,700	0	1,500	0	0	359,200
Ventura	0	48,300	0	0	305,100	0	353,400
Yolo	179,300	0	0	0	0	0	179,300
Yuba	184,300	30,000	0	0	0	0	214,300
TOTAL	**23,702,200**	**2,912,000**	**924,800**	**63,800**	**3,393,400**	**1,500**	**30,997,700**

CAL FIRE - California Department of Forestry and Fire Protection
USFS - United States Forest Service
BLM - Bureau of Land Management
NPS - National Park Service
CC - Contract County
Other FED - Other Federal Fire Protection Agency

*Acres rounded to nearest hundred
Source: SRA20_1, DirectProtectionAreas 20_2
Map and data prepared by CAL FIRE Fire and Resource Assessment Program (FRAP)

Map 2. CAL FIRE - Direct Protection Area (DPA)

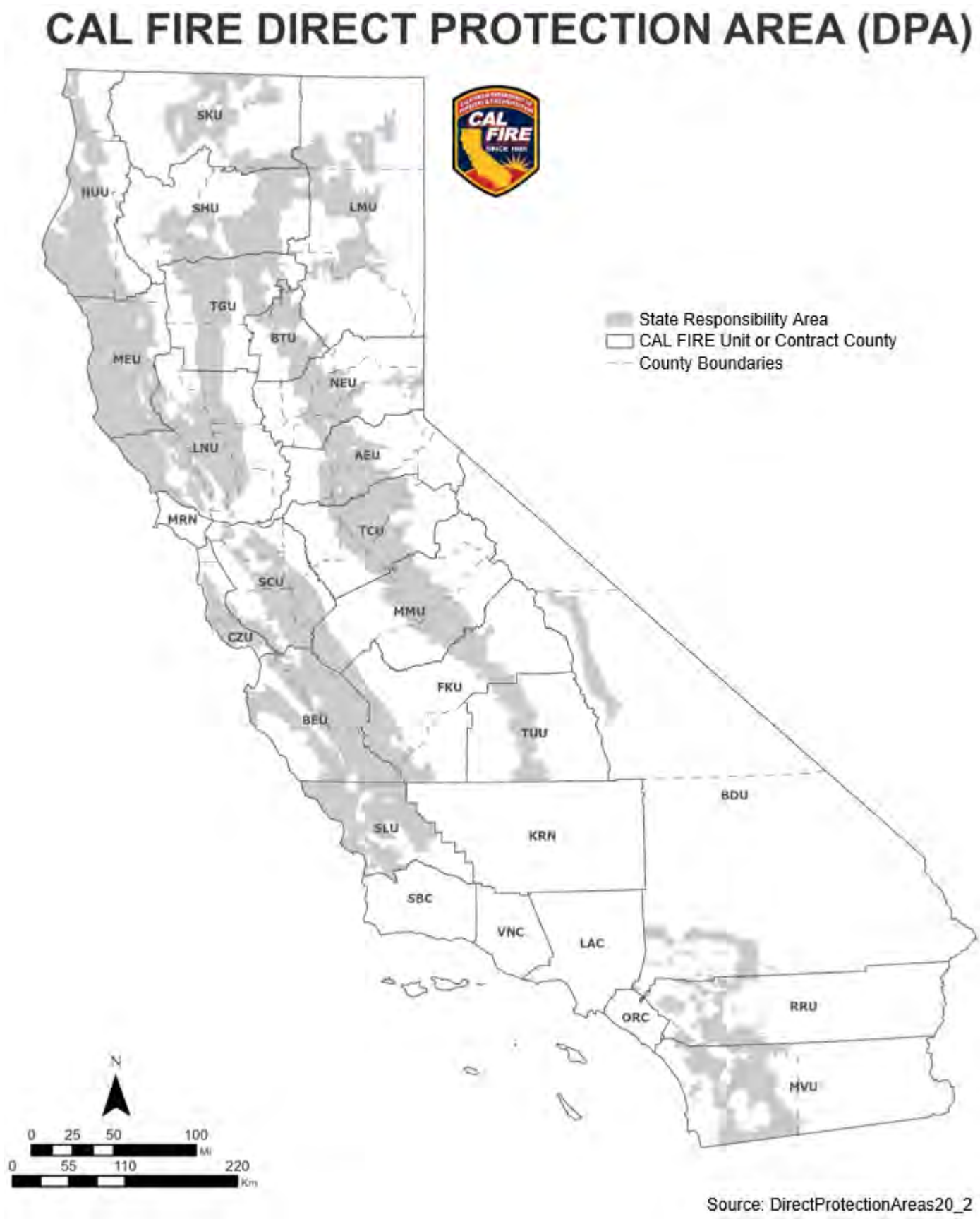


Table 4. CAL FIRE Direct Protection Area, Acres by Jurisdiction (2020) *

COUNTY	STATE	FEDERAL	CDFLWC	TOTAL ACRES
Alameda	245,900	200	0	246,100
Alpine	0	0	0	0
Amador	279,600	13,800	0	293,400
Butte	500,700	60,300	900	561,900
Calaveras	524,400	98,900	0	623,300
Colusa	241,500	44,300	0	285,800
Contra Costa	193,200	100	0	193,300
Del Norte	172,300	15,900	0	188,200
El Dorado	404,900	66,300	0	471,200
Fresno	774,800	197,000	0	971,800
Glenn	290,100	12,300	0	302,400
Humboldt	1,542,100	126,400	500	1,669,000
Imperial	1,800	13,900	0	15,700
Inyo	308,100	146,000	0	454,100
Kern	0	0	0	0
Kings	149,000	1,700	0	150,700
Lake	355,600	126,700	0	482,300
Lassen	592,100	372,000	0	964,100
Los Angeles	0	0	0	0
Madera	368,100	44,400	0	412,500
Marin	0	0	0	0
Mariposa	426,900	88,900	0	515,800
Mendocino	1,838,400	156,800	0	1,995,200
Merced	393,800	33,400	0	427,200
Modoc	371,500	144,700	0	516,200
Mono	2,400	3,800	0	6,200
Monterey	1,250,000	39,700	0	1,289,700
Napa	360,400	63,100	0	423,500
Nevada	299,400	37,800	7,900	345,100
Orange	0	0	3,000	3,000
Placer	275,100	61,700	1,600	338,400
Plumas	96,600	21,700	0	118,300
Riverside	555,400	170,700	12,100	738,200
Sacramento	113,500	100	0	113,600
San Benito	728,800	82,800	0	811,600
San Bernardino	311,000	181,900	18,400	511,300
San Diego	1,087,900	317,600	0	1,405,500
San Francisco	0	0	0	0
San Joaquin	150,100	300	0	150,400
San Luis Obispo	1,405,900	47,700	0	1,453,600
San Mateo	176,100	100	0	176,200
Santa Barbara	0	0	0	0
Santa Clara	554,100	1,500	0	555,600

Table 4. (continued) CAL FIRE Direct Protection Area, Acres by Jurisdiction (2020) *

COUNTY	STATE	FEDERAL	CDFLWC	TOTAL ACRES
Santa Cruz	228,600	5,900	0	234,500
Shasta	1,142,700	275,800	0	1,418,500
Sierra	0	0	0	0
Siskiyou	1,011,900	248,700	0	1,260,600
Solano	86,900	2,100	1,400	90,400
Sonoma	793,700	23,700	0	817,400
Stanislaus	448,000	1,800	0	449,800
Sutter	0	0	0	0
Tehama	1,148,900	81,200	0	1,230,100
Trinity	259,200	85,700	0	344,900
Tulare	573,000	48,100	0	621,100
Tuolumne	299,000	87,500	0	386,500
Ventura	0	0	0	0
Yolo	179,300	29,400	0	208,700
Yuba	184,200	6,800	0	191,000
TOTAL	**23,696,900**	**3,691,200**	**45,800**	**27,433,900**

STATE - State of California
FEDERAL - Federal Lands
CDFLWC - CAL FIRE Local Wildland Contract

*Acres rounded to nearest hundred
Source: DirectProtectionAreas20_2, SRA20_1
Map and data prepared by CAL FIRE Fire and Resource Assessment Program (FRAP)

Table 5. Large Fires 300 Acres and Greater - State and Contract Counties Direct Protection Area

			Date		Origin	Acres Burned	Veg.		Structures		Fatalities	
Incident #	County	Fire Name	Start	Cont.	DPA	Total	Type	Cause	Dest.	Dam.	Fire	Civil
NEU-11799	PLACER	AMORUSO	06/01/20	06/01/20	CAL FIRE	670	G	EQUIPMENT USE				
LNU-8419	SOLANO	QUAIL	06/06/20	06/13/20	CAL FIRE	1,837	T	FIREARMS	5	12		
SLU-7149	SAN LUIS OBISPO	SODA	06/10/20	06/10/20	CAL FIRE	1,680	G	VEHICLE				
VNC-45530	VENTURA	ELIZABETH	06/10/20	06/12/20	CC	300	B	UNDETERMINED				
VNC-45754	VENTURA	LIME	06/10/20	06/16/20	CC	803	B, G	UNDETERMINED				
AEU-16543	SACRAMENTO	GRANT	06/12/20	06/19/20	CAL FIRE	5,042	G	EQUIPMENT USE		1		
SBC-12322	SANTA BARBARA	DRUM	06/14/20	06/17/20	CC	696	B, G	ELECTRICAL POWER				
FKU-8094	FRESNO	EAGLE	06/15/20	06/13/20	CAL FIRE	300	G	UNDETERMINED				
SLU-7409	SAN LUIS OBISPO	AVILA	06/15/20	06/20/20	CAL FIRE	445	B, G	UNDER INVESTIGATION		1		
BEU-2847	SAN BENITO	BITTER	06/16/20	06/20/20	CAL FIRE	813	B, G	VEHICLE				
TCU-6494	CALAVERAS	WALKER	06/16/20	06/21/20	CAL FIRE	1,455	B, G	EQUIPMENT USE	2	2		
BEU-2986	MONTEREY	RICO	06/22/20	06/23/20	CAL FIRE	348	G	ELECTRICAL POWER				
TUU-298	TULARE	GRADE	06/22/20	06/25/20	CAL FIRE	1,050	G	UNDER INVESTIGATION				
MMU-13431	MERCED	PASS	06/28/20	06/30/20	CAL FIRE	2,192	B, G	ELECTRICAL POWER				
KRN-27271	KERN	BENA	07/01/20	07/05/20	CC	4,000	B, G	EQUIPMENT USE				
MMU-13801	MADERA	BONADELLE	07/02/20	07/03/20	CAL FIRE	500	G	EQUIPMENT USE				
SCU-4669	SANTA CLARA	PARK	07/04/20	07/08/20	CAL FIRE	353	B, G	PLAYING WITH FIRE				
SLU-8435	SAN LUIS OBISPO	LAKE	07/04/20	07/05/20	CAL FIRE	583	G	VEHICLE	1			
LAC-197926	LOS ANGELES	SOLEDAD	07/05/20	07/06/20	CC	1,525	B, G	MISCELLANEOUS				
SCU-4686	SANTA CLARA	CREWS	07/05/20	07/20/20	CAL FIRE	5,513	B, G	ELECTRICAL POWER	4			
FKU-10219	FRESNO	MINERAL	07/13/20	07/26/20	CAL FIRE	29,667	B, G	STRUCTURE	7			
BEU-3441	SAN BENITO	COYOTE	07/15/20	07/18/20	CAL FIRE	1,485	B, G	UNDER INVESTIGATION	1			
LMU-3874	LASSEN	HOG	07/18/20	08/28/20	CAL FIRE	9,564	T	UNDER INVESTIGATION	2			
SKU-5356	SISKIYOU	BADGER	07/18/20	07/28/20	CAL FIRE	557	B, G, T	VEHICLE				
SHU-7049	SHASTA	PLATINA	07/19/20	07/27/20	CAL FIRE	333	B, G	DEBRIS BURNING				

The information on this list is gathered from the ICS 209 incident reports and Damage Inspection (DINS) database, then verified in the California Incident Data and Statistics (CalStats) database and includes information on fire activity within the Direct Protection Areas of CAL FIRE and Contract Counties.

Table 5. (continued) Large Fires 300 Acres and Greater - State and Contract Counties Direct Protection Area

			Date		Origin	Acres Burned	Veg.		Structures		Fatalities	
Incident #	County	Fire Name	Start	Cont.	DPA	Total	Type	Cause	Dest.	Dam.	Fire	Civil
LMU-3917	LASSEN	GOLD	07/20/20	09/29/20	CAL FIRE	22,614	B, T	UNDETERMINED	13	5		
FKU-10922	FRESNO	WILD	07/25/20	07/25/20	CAL FIRE	1,040	G	ARSON				
LAC-222638	LOS ANGELES	RIDGE	07/27/20	07/27/20	CC	321	B, G, T	UNDETERMINED				
MMU-16043	MERCED	COTTONWOOD	07/27/20	07/29/20	CAL FIRE	788	G	VEHICLE				
SLU-9669	SAN LUIS OBISPO	BRANCH	07/28/20	08/03/20	CAL FIRE	3,222	G	VEHICLE	8			
AEU-22430	SACRAMENTO	CLAY	07/29/20	07/29/20	CAL FIRE	741	G	SMOKING				
FKU-11181	FRESNO	LINCOLN	07/29/20	07/29/20	CAL FIRE	640	G	ARSON				
RRU-96640*	RIVERSIDE	APPLE	07/31/20	11/18/20	CAL FIRE	33,424	B, G	VEHICLE	13	6		
SLU-9866	SAN LUIS OBISPO	POND	08/01/20	08/09/20	CAL FIRE	2,005	B, G	STRUCTURE	4	1		
LNU-12277	COLUSA	SITES	08/02/20	08/06/20	CAL FIRE	560	B, T	UNDER INVESTIGATION	1	1		
SLU-10018	SAN LUIS OBISPO	PASS	08/04/20	08/05/20	CAL FIRE	322	G	VEHICLE				
AEU-24350	SACRAMENTO	MEISS	08/13/20	08/15/20	CAL FIRE	512	G	FIREARMS				
FKU-12279	FRESNO	HILLS	08/15/20	09/27/20	CAL FIRE	2,121	B, G	LIGHTNING			1	
SLU-10533	SAN LUIS OBISPO	WHALE	08/15/20	08/18/20	CAL FIRE	320	G	LIGHTNING				
BEU-4024	MONTEREY	RIVER	08/16/20	09/04/20	CAL FIRE	48,088	B, G	LIGHTNING	30	13		
CZU-5205*	SAN MATEO, SANTA CRUZ	CZU AUGUST LIGHTNING COMPLEX	08/16/20	09/22/20	CAL FIRE	86,509	B, T	LIGHTNING	1,490	140		1
SCU-5740*	CONTRA COSTA, SANTA CLARA, ALAMEDA, SAN JOAQUIN, STANISLAUS	SCU LIGHTNING COMPLEX	08/16/20	09/15/20	CAL FIRE	396,625	B, G	LIGHTNING	225	26		
BTU-9979*	BUTTE, TEHAMA, GLENN	BUTTE TEHAMA GLENN COMPLEX	08/17/20	09/16/20	CAL FIRE	19,609	T	LIGHTNING				
LNU-13407*	NAPA, LAKE, SONOMA, SOLANO	LNU LIGHTNING COMPLEX	08/17/20	09/22/20	CAL FIRE	363,220	B, G, T	LIGHTNING	1,491	232		5
MEU-10843*	TRINITY, TEHAMA, GLENN, LAKE, MENDOCINO	AUGUST COMPLEX WEST ZONE	08/17/20	10/15/20	CAL FIRE	143,181	B, G, T	LIGHTNING	55	6		
NEU-19231	NEVADA	JONES	08/17/20	09/06/20	CAL FIRE	705	B, T	LIGHTNING	18	3		
VNC-30441 LAC-246170	VENTURA, LOS ANGELES	HOLSER	08/17/20	08/22/20	CC	2,189	B, G	EQUIPMENT USE				
BEU-4081	MONTEREY	CARMEL	08/18/20	09/06/20	CAL FIRE	6,901	B, G	VEHICLE	73	7		

The information on this list is gathered from the ICS 209 incident reports and Damage Inspection (DINS) database, then verified in the California Incident Data and Statistics (CalStats) database and includes information on fire activity within the Direct Protection Areas of CAL FIRE and Contract Counties.

Table 5. (continued) Large Fires 300 Acres and Greater - State and Contract Counties Direct Protection Area

			Date		Origin	Acres Burned	Veg.		Structures		Fatalities	
Incident #	County	Fire Name	Start	Cont.	DPA	Total	Type	Cause	Dest.	Dam.	Fire	Civil
MEU-9786	MENDOCINO	CREEK	08/18/20	08/26/20	CAL FIRE	820	B, G	VEHICLE	3			
TCU-9353	CALAVERAS	SALT	08/18/20	08/24/20	CAL FIRE	1,783	B, G	EQUIPMENT USE				
TCU-9457	TUOLUMNE	MOC	08/20/20	08/31/20	CAL FIRE	2,857	B, G	EQUIPMENT USE	2	1		
MMU-19014	MADERA	HENSLEY #2	08/30/20	08/30/20	CAL FIRE	400	G	ARSON				
BDU-12925	SAN BERNARDINO	EL DORADO	09/05/20	11/16/20	CAL FIRE	22,744	B, G, T	PYROTECHNICS	14	2	1	
MEU-10700	MENDOCINO	OAK	09/07/20	09/25/20	CAL FIRE	1,100	G, T	STRUCTURE	56	1		
NEU-21423	YUBA	WILLOW	09/09/20	09/09/20	CAL FIRE	1,311	B, G, T	ARSON	11	5		
RRU-119353	RIVERSIDE	SNOW	09/17/20	09/24/20	CAL FIRE	6,254	B, G, T	VEHICLE				
LNU-15947*	NAPA, SONOMA	GLASS	09/27/20	10/20/20	CAL FIRE	67,484	B, G, T	UNDETERMINED	1,528	282		
SHU-9978*	SHASTA	ZOGG	09/27/20	10/14/20	CAL FIRE	56,338	B, G	ELECTRICAL POWER	204	27		4
RRU-124873	RIVERSIDE	CANDY	09/29/20	09/30/20	CAL FIRE	454	G	ARSON				
ORC-121364	ORANGE	SILVERADO	10/26/20	11/07/20	CC	12,466	B, G	UNDER INVESTIGATION	5	11		
ORC-121612	ORANGE	BLUE RIDGE	10/26/20	11/07/20	CC	13,694	B, G	UNDETERMINED	1	12		
ORC-136890	ORANGE	BOND	12/02/20	12/11/20	CC	6,686	B, G	STRUCTURE	31	21		
RRU-160421	RIVERSIDE	SANDERSON	12/13/20	12/13/20	CAL FIRE	1,954	G	CAMPFIRE				
SUBTOTAL						**1,403,713**			**5,298**	**818**	**2**	**10**

The information on this list is gathered from the ICS 209 incident reports and Damage Inspection (DINS) database, then verified in the California Incident Data and Statistics (CalStats) database and includes information on fire activity within the Direct Protection Areas of CAL FIRE and Contract Counties.

*Some of the complex incidents in this list are comprised of more than one CALFIRS report to account for multiple ignitions, jurisdictions, or counties. These reports combined amount to the total acres and other loss figures of the incident.

Table 6. Large Fires 300 Acres and Greater - Other Agencies Direct Protection Areas

			Date		Origin	Acres Burned	Veg.		Structures		Fatalities	
Incident #	County	Fire Name	Start	Cont.	DPA	Total	Type	Cause	Dest.	Dam.	Fire	Civil
KCF	KINGS	INTERSTATE 5	05/03/20	05/03/20	LOCAL	2,060	G	UNDETERMINED				
BOB-6492	SAN LUIS OBISPO	RANGE	05/27/20	05/28/20	MIL	5,000	G	UNDETERMINED				
CNP-1216	SANTA BARBARA	SCORPION	05/31/20	06/05/20	NPS	1,395	B, G	UNDETERMINED				
MCP-1474	SAN DIEGO	INDIA	06/09/20	06/16/20	MIL	1,100	B, G	UNDETERMINED				
SNF-593	FRESNO	HOG	06/14/20	06/15/20	USFS	533	B, G	UNDETERMINED				
MNP-9202	SAN BERNARDINO	IVANPAH	06/22/20	06/26/20	NPS	1,088	B, G	UNDETERMINED				
NOD-3218	LASSEN	R-2	06/23/20	06/25/20	BLM	563	B, G	UNDETERMINED				
ANF-2440	LOS ANGELES	ROWHER	07/01/20	07/09/20	USFS	616	B, G	PLAYING WITH FIRE				
BEA	YUBA	VALLEY	07/15/20	07/15/20	MIL	500	G	UNDETERMINED				
MDF-487	SISKIYOU, MODOC	JULY COMPLEX	07/22/20	08/22/20	USFS	83,261	B, G, T	LIGHTNING	15			
YNP-54	MARIPOSA	BLUEJAY	07/24/20	11/19/20	NPS	6,922	T	LIGHTNING				
PNF-976	LASSEN	ADAMS	07/26/20	07/31/20	USFS	918	B, G, T	LIGHTNING				
SRF-656	HUMBOLDT	RED SALMON COMPLEX	07/28/20	11/16/20	USFS	144,698	B, G, T	LIGHTNING				
LNF-4290	TEHAMA	STUMP	08/01/20	08/13/20	USFS	684	T	LIGHTNING				
BEA	YUBA	BEALE	08/02/20	08/03/20	MIL	600	G	UNDETERMINED				
CCD-30547	LASSEN, WASHOE (NV)	NORTH	08/02/20	08/08/20	BLM	6,882	B, G	UNDETERMINED		1		
CND-2309	KERN	STAGECOACH	08/03/20	08/14/20	BLM	7,760	B, T	EQUIPMENT USE	31	4	1	
SNF-1160	FRESNO	TRIMMER	08/03/20	09/01/20	USFS	594	B, T	UNDETERMINED				
YNP-75	TUOLUMNE	WOLF	08/11/20	11/19/20	NPS	2,057	T	LIGHTNING				
ANF-3273	LOS ANGELES	LAKE	08/12/20	09/30/20	USFS	31,089	B, G, T	UNDETERMINED	34	6		
ANF-3289	LOS ANGELES	RANCH 2	08/13/20	09/03/20	USFS	4,237	B, G	ARSON				
TNF-1600	SIERRA	LOYALTON	08/14/20	08/30/20	USFS	47,029	G, T	LIGHTNING	35			

Table 6. (continued) Large Fires 300 Acres and Greater - Other Agencies Direct Protection Areas

			Date		Origin	Acres Burned	Veg.		Structures		Fatalities	
Incident #	County	Fire Name	Start	Cont.	DPA	Total	Type	Cause	Dest.	Dam.	Fire	Civil
MNP-12356	SAN BERNARDINO	DOME	08/15/20	08/22/20	NPS	43,273	B, G	LIGHTNING	6			
INF-2140	MONO	BEACH	08/16/20	08/28/20	USFS	3,780	B, T	LIGHTNING				
KNP-80	TULARE	RATTLESNAKE	08/16/20	12/31/20	NPS	8,419	B, T	LIGHTNING				
MNF-753	TRINITY, TEHAMA, GLENN, LAKE, MENDOCINO	AUGUST COMPLEX	08/17/20	11/15/20	USFS	889,467	B, T	LIGHTNING	34	4	1	
NOD-4682	LASSEN	R-5	08/17/20	08/19/20	BLM	471	B, G	UNDETERMINED				
PNF-1299	PLUMAS	SHEEP	08/17/20	09/09/20	USFS	29,570	B, G, T	LIGHTNING	26	2		
PNF-1308*	PLUMAS, BUTTE	NORTH COMPLEX	08/17/20	11/30/20	USFS	318,935	B, G, T	LIGHTNING	2,352	119		16
LPF-2428	MONTEREY	DOLAN	08/18/20	12/31/20	USFS	124,924	B, G, T	UNDETERMINED	19	4		
NOD-4727	LASSEN	W-5 COLD SPRINGS	08/18/20	09/13/20	BLM	84,817	B, T	LIGHTNING	1			
RNP-12009	MARIN	WOODWARD	08/18/20	10/01/20	NPS	4,929	B, G, T	LIGHTNING				
SQF-2622	TULARE	SQF COMPLEX	08/19/20	01/07/21	USFS	175,019	G, T	LIGHTNING	232	12		
KNP-91	TULARE	MORAINE	08/21/20	12/31/20	NPS	1,316	B, T	LIGHTNING				
HTF-30684	MONO	SLINK	08/29/20	10/15/20	USFS	26,759	B, G, T	LIGHTNING	2			
SHF-1376	TRINITY	HOBO	09/01/20	09/10/20	USFS	413	B, G, T	UNDETERMINED				
SNF-1392*	FRESNO, MADERA	CREEK	09/04/20	12/31/20	USFS	379,895	T	UNDETERMINED	858	71		
CNF-2833	SAN DIEGO	VALLEY	09/05/20	09/24/20	USFS	16,390	B, G	UNDETERMINED	64	11		
ANF-3687	LOS ANGELES	BOBCAT	09/06/20	11/30/20	USFS	115,997	B, T	UNDETERMINED	169	47		
ENF-27219	EL DORADO	FORK	09/08/20	11/08/20	USFS	1,673	T	UNDETERMINED				
KNF-7035	SISKIYOU	SLATER	09/08/20	11/15/20	USFS	157,270	B, T	UNDETERMINED	353	24		2
SNF-1402	FRESNO	BULLFROG	09/08/20	11/15/20	USFS	1,185	B, G, T	UNDETERMINED				
KNF-7084	SISKIYOU	DEVIL	09/09/20	11/15/50	USFS	8,857	T	UNDETERMINED				
KNF-7241	SISKIYOU	FOX	09/14/20	09/30/20	USFS	2,188	B, T	HUMAN				

Table 6. (continued) Large Fires 300 Acres and Greater - Other Agencies Direct Protection Areas

			Date		Origin	Acres Burned	Veg.		Structures		Fatalities	
Incident#	County	Fire Name	Start	Cont.	DPA	Total	Type	Cause	Dest.	Dam.	Fire	Civil
LPF3161	MONTEREY	COLEMAN	10/18/20	11/15/20	USFS	574	B, G	UNDETERMINED				
NOD-6431	LASSEN	LAURA 2	11/17/20	11/23/20	BLM	2,800	B, G	UNDETERMINED	42	7		
OVD-30860	MONO	MOUNTAIN VIEW	11/17/20	11/30/20	BLM	20,385	B, G	UNDETERMINED	97			1
COR-12597	RIVERSIDE	AIRPORT	12/01/20	12/17/20	LOCAL	1,087	B, G	UNDETERMINED				
MVU-20846	SAN DIEGO	CREEK 5	12/23/20	12/28/20	MIL	4,276	B, G	UNDETERMINED				
SUBTOTAL						**2,774,255**			**4,370**	**312**	**2**	**19**
STATE, CONTRACT COUNTIES, AND OTHER AGENCIES DPA TOTAL						**4,117,968**			**9,668**	**1,130**	**4**	**29**

The information on this list is not a complete or final list of other agency large fires. This information is gathered from the ICS 209 incident reports. Federal agencies are not obligated to provide reports to CAL FIRE on fire activity within their jurisdiction. CAL FIRE assisted on these fires with either equipment or resources.

Origin DPA = The agency on whose Direct Protection Area (DPA) the fires started.
Acres Burned = Acres burned in CAL FIRE area, other agencies and total area burned.
Structures Destroyed = Residence, commercial property, outbuilding or other structure that is declared unusable.
Structures Damaged = Residence, commercial property, outbuilding or other structure that its usefulness or value is impaired.
Fatalities = Death of civilian or fire service personnel assigned to the incident.

T = Timber
B = Brush
W = Woodland
G = Grass
A = Agricultural Products

LOCAL = Local Fire Departments
CC = Contract Counties
MIL = Military Land

BLM = Bureau of Land Management
BIA = Bureau of Indian Affairs
FWS = Fish and Wildlife Service
NPS = National Park Service
USFS = United States Forest Service

*Some of the complex incidents in this list are comprised of more than one CALFIRS report to account for multiple ignitions, jurisdictions, or counties. These reports combined amount to the total acres and other loss figures of the incident.

Table 7. Number of Fires and Acres Burned by Cause and by Size in Contract Counties

Number of Fires by Cause

Contract Counties	Total	Arson	Campfire	Debris Burning	Electrical Power	Equip. Use	Ltng.	Misc.	P-W-F	Railroad	Smoking	Undet.	Vehicle
Kern	146	4	0	5	10	25	4	21	0	0	0	76	1
Los Angeles	140	11	8	9	4	21	1	31	12	0	7	35	1
Marin	3	0	0	0	0	0	0	3	0	0	0	0	0
Orange	45	0	1	4	2	5	1	15	0	0	4	11	2
Santa Barbara	73	3	0	5	3	4	0	57	0	0	1	0	0
Ventura	59	0	0	0	0	3	2	38	0	0	0	15	1
TOTAL	466	18	9	23	19	58	8	165	12	0	12	137	5

Number of Acres Burned by Cause

Contract Counties	Total	Arson	Campfire	Debris Burning	Electrical Power	Equip. Use	Ltng.	Misc.	P-W-F	Railroad	Smoking	Undet.	Vehicle
Kern	13,617	12	0	36	34	12,043	25	481	0	0	0	895	91
Los Angeles	3,781	614	11	134	3	411	1	1,657	195	0	5	749	1
Marin	0	0	0	0	0	0	0	0	0	0	0	0	0
Orange	32,894	0	0	1	10	9	0	6,686	0	0	8	26,173	7
Santa Barbara	1,151	21	0	6	701	22	0	400	0	0	1	0	0
Ventura	3,319	0	0	0	0	1,965	7	188	0	0	0	1,159	0
TOTAL	54,762	647	11	177	748	14,450	33	9,412	195	0	14	28,976	99

Data provided by the Contract Counties and collected from the California Incident Data and Statistics (CalStats) database.

Table 7. (continued) Number of Fires and Acres Burned by Cause and by Size in Contract Counties

Number of Fires by Size

Contract Counties	Total	A< .25 acres or <	B .26-9.99 acres	C 10-99 acres	D 100-299 acres	E 300-999 acres	F 1000-4999 acres	G 5000 acres >
Kern	146	53	63	24	4	0	1	1
Los Angeles	140	41	84	7	5	2	1	0
Marin	3	3	0	0	0	0	0	0
Orange	45	33	7	2	0	0	0	3
Santa Barbara	73	2	62	7	1	1	0	0
Ventura	59	40	13	2	1	2	1	0
TOTAL	466	172	229	42	11	5	3	4

Data provided by the Contract Counties and collected from the California Incident Data and Statistics (CalStats) database.

Table 8. Number of Fires by Cause, by Unit

	Total	Arson	Camp-fire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Rail-road	Smoking	Undet.	Vehicle
NORTHERN REGION													
Amador-El Dorado	302	19	10	102	24	31	3	26	5	0	9	42	31
Butte	157	15	4	28	6	23	29	12	2	1	2	21	14
Humboldt-Del Norte	63	9	5	3	8	5	7	7	0	0	0	9	10
Lassen-Modoc	104	15	15	18	7	9	2	5	1	0	2	18	12
Mendocino	109	5	6	14	1	8	56	3	1	0	0	12	3
Nevada-Yuba-Placer	318	31	15	39	47	37	29	29	6	0	1	38	46
San Mateo-Santa Cruz	137	22	4	35	7	10	14	15	0	0	2	13	15
Santa Clara	304	12	8	89	33	33	12	34	6	2	1	52	22
Shasta-Trinity	196	28	3	4	24	17	19	15	6	0	3	23	54
Siskiyou	217	40	9	56	19	20	11	11	3	0	10	13	25
Sonoma-Lake-Napa	101	0	3	9	10	7	33	4	0	1	1	23	10
Tehama-Glenn	112	6	0	23	11	22	20	10	3	0	0	9	8
TOTAL	2,120	202	82	420	197	222	235	171	33	4	31	273	250
SOUTHERN REGION													
Fresno-Kings	117	11	2	8	8	5	2	18	4	1	2	42	14
Madera-Mariposa	125	5	1	6	26	20	2	11	4	1	0	27	22
Riverside	89	13	2	8	21	13	2	5	2	0	0	17	6
San Benito-Monterey	184	20	2	53	22	15	3	15	4	0	2	15	33
San Bernardino	180	11	2	19	8	28	1	20	7	0	0	57	27
San Diego	230	25	5	7	12	25	1	41	17	0	10	61	26
San Luis Obispo	145	2	8	7	19	18	7	16	5	0	1	31	31
Tulare	248	20	5	49	19	26	10	26	2	0	1	64	26
Tuolumne-Calaveras	63	11	1	2	3	9	1	3	2	0	0	17	14
TOTAL	1,381	118	28	159	138	159	29	155	47	2	16	331	199
STATE TOTAL	3,501	320	110	579	335	381	264	326	80	6	47	604	449

Table 9. Number of Fires by Cause, by County

COUNTY	Total	Arson	Campfire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Rail-road	Smoking	Undet.	Vehicle
Alameda	61	8	0	1	10	5	4	6	1	0	1	7	18
Alpine	0	0	0	0	0	0	0	0	0	0	0	0	0
Amador	73	8	1	24	8	7	0	7	0	0	2	7	9
Butte	153	15	4	28	6	23	25	12	2	1	2	21	14
Calaveras	119	7	2	24	10	14	5	18	1	0	0	23	15
Colusa	12	0	1	2	0	0	2	2	0	0	0	2	3
Contra Costa	52	9	2	0	10	7	5	3	0	0	0	6	10
Del Norte	13	5	4	3	0	0	0	0	0	0	0	1	0
El Dorado	197	9	9	76	13	17	1	16	5	0	6	28	17
Fresno	76	12	2	8	18	13	1	5	2	0	0	10	5
Glenn	16	0	0	1	0	2	11	1	0	0	0	0	1
Humboldt	91	10	11	15	7	9	2	5	1	0	2	17	12
Imperial	1	0	0	0	0	0	0	0	0	0	0	1	0
Inyo	17	2	0	2	2	0	0	1	0	0	0	8	2
Kings	13	1	0	0	3	0	1	0	0	0	0	7	1
Lake	80	10	2	8	8	9	11	6	3	0	1	11	11
Lassen	76	0	3	5	0	6	49	2	1	0	0	8	2
Madera	78	10	2	22	11	6	0	9	2	0	0	6	10
Mariposa	73	6	0	31	9	7	2	4	2	0	2	4	6
Mendocino	137	22	4	35	7	10	14	15	0	0	2	13	15
Merced	33	4	0	0	2	2	1	2	0	0	0	5	17
Modoc	26	5	0	7	1	1	7	1	0	0	0	3	1
Mono	0	0	0	0	0	0	0	0	0	0	0	0	0
Monterey	98	5	1	6	20	18	2	6	2	1	0	21	16
Napa	61	7	2	9	13	9	9	2	1	0	0	1	8
Nevada	115	2	2	49	15	8	8	10	2	0	0	13	6
Placer	115	7	2	27	12	13	1	13	3	2	1	26	8

Table 9. (continued) Number of Fires by Cause, by County

COUNTY	Total	Arson	Campfire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Rail-road	Smoking	Undet.	Vehicle
Plumas	9	0	3	2	0	1	2	0	0	0	0	1	0
Riverside	230	25	5	7	12	25	1	41	17	0	10	61	26
Sacramento	25	0	0	1	3	6	2	3	0	0	1	5	4
San Benito	27	0	0	0	6	2	0	5	2	0	0	6	6
San Bernardino	100	9	2	6	6	5	2	17	4	1	2	34	12
San Diego	179	11	2	19	8	28	1	20	7	0	0	56	27
San Francisco	0	0	0	0	0	0	0	0	0	0	0	0	0
San Joaquin	33	4	1	2	0	5	7	0	0	0	1	8	5
San Luis Obispo	145	2	8	7	19	18	7	16	5	0	1	31	31
San Mateo	18	2	0	0	3	2	2	1	0	0	0	3	5
Santa Clara	59	8	1	2	4	4	4	6	5	0	1	7	17
Santa Cruz	45	7	5	3	5	3	5	6	0	0	0	6	5
Shasta	181	29	8	47	16	18	6	11	2	0	8	13	23
Sierra	0	0	0	0	0	0	0	0	0	0	0	0	0
Siskiyou	101	0	3	9	10	7	33	4	0	1	1	23	10
Solano	21	3	0	3	3	3	1	1	0	0	0	2	5
Sonoma	129	11	10	13	22	14	5	13	2	0	0	22	17
Stanislaus	33	4	0	1	1	2	2	2	0	0	0	14	7
Sutter	0	0	0	0	0	0	0	0	0	0	0	0	0
Tehama	98	6	0	22	11	20	11	9	3	0	0	9	7
Trinity	36	11	1	9	3	2	5	0	1	0	2	0	2
Tulare	63	11	1	2	3	9	1	3	2	0	0	17	14
Tuolumne	94	10	2	24	8	7	2	6	1	0	1	24	9
Yolo	15	0	0	4	1	2	1	5	0	0	0	0	2
Yuba	74	3	4	13	6	12	3	11	1	0	0	13	8
STATE TOTAL	3,501	320	110	579	335	381	264	326	80	6	47	604	449

Contract County statistics can be found in Table 7.

Table 10. Number of Fires and Acres Burned by Cause — Detailed

CAL FIRE Wildland Fire Cause	Incident Count	% of Total Incident Count	Incident Count Acres Burned => 10	Acres Burned	% of Total Acres Burned
ARSON	**320**	**9%**	**24**	**44,609**	**3%**
HOT START	**120**		**8**	**1,049**	
IGNITABLE LIQUID	**2**		**1**	**21**	
INCENDIARY DEVICE	**26**		**0**	**24**	
OTHER	**28**		**2**	**228**	
UNDETERMINED	**144**		**13**	**43,287**	
CAMPFIRE	**110**	**3%**	**3**	**421**	**0%**
NO PERMIT	**43**		**1**	**228**	
OTHER	18		1	201	
PROPER CLEARANCE	7		0	1	
TOOLS PRESENT	1		0	1	
UNDETERMINED	17		0	25	
PERMIT	**3**		**0**	**0**	
OTHER	1		0	0	
PROPER CLEARANCE	1		0	0	
UNDETERMINED	1		0	0	
UNDETERMINED	**64**		**2**	**193**	
DEBRIS BURNING	**579**	**17%**	**21**	**1,471**	**0%**
COMMERCIAL USE	**37**		**1**	**61**	
NO PERMIT/PROPER CLEARANCES	14		0	14	
NO PERMIT/TOOLS PRESENT	4		1	18	
PERMIT/PROPER CLEARANCES	7		0	7	
PERMIT/TOOLS PRESENT	4		0	16	
UNDETERMINED	8		0	6	
OTHER	**40**		**3**	**321**	
RESIDENTIAL USE	**460**		**15**	**1,011**	
NO PERMIT/PROPER CLEARANCES	157		5	277	
NO PERMIT/TOOLS PRESENT	65		1	58	
PERMIT/PROPER CLEARANCES	68		2	98	
PERMIT/TOOLS PRESENT	90		2	100	
UNDETERMINED	80		5	478	
UNDETERMINED	**42**		**2**	**78**	
ELECTRICAL POWER	**335**	**10%**	**31**	**59,334**	**4%**
ANIMALS	**27**		**7**	**437**	
HARDWARE	**52**		**2**	**71**	
LINE SLAP	**33**		**2**	**2,235**	
LINES DOWN	**107**		**11**	**909**	
OTHER	**47**		**4**	**214**	
UNDETERMINED	**26**		**0**	**55**	
VEGETATION CONTACT	**43**		**5**	**55,413**	

Table 10. (continued) Number of Fires and Acres Burned by Cause — Detailed

CAL FIRE Wildland Fire Cause	Incident Count	% of Total Incident Count	Incident Count Acres Burned => 10	Acres Burned	% of Total Acres Burned
EQUIPMENT USE	**381**	**11%**	**38**	**12,968**	**1%**
COMMERCIAL USE	**88**		**10**	**5,385**	
MOBILE EQUIPMENT/CHAFF	2		0	2	
MOBILE EQUIPMENT/HOT EXHAUST	4		1	20	
MOBILE EQUIPMENT/MECHANICAL	10		1	45	
MOBILE EQUIPMENT/ROCK STRIKE	25		3	140	
OTHER	7		1	21	
PORTABLE EQUIPMENT/CHAFF	1		0	0	
PORTABLE EQUIPMENT/HOT EXHAUST	4		0	1	
PORTABLE EQUIPMENT/MECHANICAL	1		0	1	
PORTABLE EQUIPMENT/ROCK STRIKE	8		1	13	
PORTABLE EQUIPMENT/WELDING/GRINDING	13		3	5,127	
UNDETERMINED	13		0	15	
NON-COMMERCIAL USE	**242**		**25**	**7,439**	
MOBILE EQUIPMENT/CHAFF	10		1	121	
MOBILE EQUIPMENT/HOT EXHAUST	10		1	40	
MOBILE EQUIPMENT/MECHANICAL	20		2	60	
MOBILE EQUIPMENT/ROCK STRIKE	70		7	634	
OTHER	16		2	45	
PORTABLE EQUIPMENT/CHAFF	2		0	5	
PORTABLE EQUIPMENT/HOT EXHAUST	13		1	35	
PORTABLE EQUIPMENT/MECHANICAL	17		1	31	
PORTABLE EQUIPMENT/ROCK STRIKE	17		1	45	
PORTABLE EQUIPMENT/WELDING/GRINDING	49		5	3,345	
UNDETERMINED	18		4	3,078	
OTHER	**22**		**2**	**115**	
UNDETERMINED	**29**		**1**	**27**	
LIGHTNING	**264**	**8%**	**65**	**1,159,009**	**79%**
MISCELLANEOUS	**326**	**9%**	**32**	**39,523**	**3%**
EXPLOSIVE DEVICE	**1**		**1**	**512**	
EXPOSURE (STRUCTURE)	**3**		**1**	**1,710**	
FIREWORKS	**56**		**5**	**182**	
DANGEROUS	31		4	138	
SAFE AND SANE	2		0	0	
UNDETERMINED	23		1	44	
GLASS REFRACTION	**2**		**0**	**1**	
OTHER	**200**		**14**	**34,616**	

Table 10. (continued) Number of Fires and Acres Burned by Cause — Detailed

CAL FIRE Wildland Fire Cause	Incident Count	% of Total Incident Count	Incident Count Acres Burned => 10	Acres Burned	% of Total Acres Burned
SHOOTING	**31**		**10**	**2,427**	
AMMUNITION/COPPER JACKET	5		1	128	
AMMUNITION/LEAD	2		1	109	
AMMUNITION/STEEL CORE	1		0	2	
OTHER	1		0	2	
TARGET/EXPLODING	2		0	2	
TARGET/METAL	8		1	39	
TARGET/OTHER	2		1	15	
TARGET/ROCK	3		2	1,859	
UNDETERMINED	7		4	271	
SPONTANEOUS COMBUSTION	**33**		**1**	**75**	
PLAYING WITH FIRE	**80**	**2%**	**3**	**111**	**0%**
10-13 YEARS OLD	**7**		**0**	**2**	
14+ YEARS OLD	**15**		**1**	**27**	
5-9 YEARS OLD	**11**		**0**	**5**	
UNDETERMINED	**47**		**2**	**77**	
RAILROAD	**6**	**0%**	**0**	**2**	**0%**
MECHANICAL	**2**		**0**	**1**	
UNDETERMINED	**4**		**0**	**1**	
SMOKING	**47**	**1%**	**2**	**818**	**0%**
OTHER	**4**		**0**	**1**	
SMOKING MATERIAL	**30**		**1**	**758**	
SMOKING PARAPHERNALIA	**4**		**0**	**1**	
UNDETERMINED	**9**		**1**	**58**	
UNDETERMINED	**604**	**17%**	**52**	**112,949**	**8%**
VEHICLE	**449**	**13%**	**51**	**27,668**	**2%**
CHAFF	**10**		**0**	**21**	
EXHAUST	**97**		**10**	**9,693**	
EXPOSURE (VEHICLE)	**3**		**2**	**802**	
MECHANICAL	**81**		**11**	**6,415**	
OTHER	**51**		**6**	**1,582**	
TRAFFIC COLLISION	**46**		**5**	**484**	
UNDETERMINED	**161**		**17**	**8,671**	
TOTAL WILDLAND FIRE INCIDENTS	**3,501**	**100%**	**322**	**1,458,881**	**100%**

Table 11. Number of Fires by Size, by Unit

		A	B	C	D	E	F	G
	Total	.25 acres or <	.26-9.99 acres	10-99 acres	100-299 acres	300-999 acres	1000-4999 acres	5000 acres >
NORTHERN REGION								
Amador-El Dorado	302	177	112	10	0	2	0	1
Butte	157	53	81	12	6	2	0	3
Humboldt-Del Norte	63	38	21	1	1	0	0	2
Lassen-Modoc	104	62	39	2	1	0	0	0
Mendocino	109	38	59	10	0	0	0	2
Nevada-Yuba-Placer	318	126	157	17	4	1	4	9
San Mateo-Santa Cruz	137	49	78	5	2	1	1	1
Santa Clara	304	138	156	7	1	1	1	0
Shasta-Trinity	196	44	111	27	6	2	2	4
Siskiyou	217	77	126	8	3	1	0	2
Sonoma-Lake-Napa	101	60	35	5	0	1	0	0
Tehama-Glenn	112	30	64	10	3	1	1	3
TOTAL	2,120	892	1,039	114	27	12	9	27
SOUTHERN REGION								
Fresno-Kings	117	55	54	4	2	0	0	2
Madera-Mariposa	125	44	62	11	3	2	1	2
Riverside	89	20	56	10	0	0	1	2
San Benito-Monterey	184	59	102	11	7	2	2	1
San Bernardino	180	82	92	5	1	0	0	0
San Diego	230	64	144	17	2	1	0	2
San Luis Obispo	145	51	75	8	4	4	3	0
Tulare	248	91	141	13	0	0	3	0
Tuolumne-Calaveras	63	17	39	3	2	0	1	1
TOTAL	1,381	483	765	82	21	9	11	10
STATE TOTAL	3,501	1,375	1,804	196	48	21	20	37

Table 12. Number of Fires by Size, by County

		A	B	C	D	E	F	G
COUNTY	Total	.25 acres or <	.26-9.99 acres	10-99 acres	100-299 acres	300-999 acres	1000-4999 acres	5000 acres >
Alameda	61	8	38	8	4	1	1	1
Alpine	0	0	0	0	0	0	0	0
Amador	73	47	25	1	0	0	0	0
Butte	153	53	80	11	5	2	0	2
Calaveras	119	41	69	7	0	0	2	0
Colusa	12	5	2	2	1	1	1	0
Contra Costa	52	6	33	11	0	1	1	0
Del Norte	13	10	3	0	0	0	0	0
El Dorado	197	119	73	5	0	0	0	0
Fresno	76	18	47	8	0	0	1	2
Glenn	16	2	7	3	1	1	0	2
Humboldt	91	52	36	2	1	0	0	0
Imperial	1	1	0	0	0	0	0	0
Inyo	17	10	7	0	0	0	0	0
Kings	13	2	9	2	0	0	0	0
Lake	80	39	35	4	0	0	1	1
Lassen	76	30	40	4	0	0	0	2
Madera	78	32	37	3	4	1	0	1
Mariposa	73	22	45	4	2	0	0	0
Mendocino	137	49	78	5	2	1	1	1
Merced	33	5	20	4	1	1	2	0
Modoc	26	5	15	6	0	0	0	0
Mono	0	0	0	0	0	0	0	0
Monterey	98	38	46	8	3	1	0	2
Napa	61	20	34	3	0	0	0	4
Nevada	115	50	64	0	0	1	0	0
Placer	115	62	50	3	0	0	0	0

Table 12. (continued) Number of Fires by Size, by County

		A	B	C	D	E	F	G
SOUTHERN REGION	**Total**	**.25 acres or <**	**.26-9.99 acres**	**10-99 acres**	**100-299 acres**	**300-999 acres**	**1000-4999 acres**	**5000 acres >**
Plumas	**9**	**3**	**4**	**0**	**1**	**0**	**0**	**1**
Riverside	**230**	**64**	**144**	**17**	**2**	**1**	**0**	**2**
Sacramento	**25**	**6**	**13**	**3**	**0**	**2**	**0**	**1**
San Benito	**27**	**6**	**16**	**3**	**0**	**1**	**1**	**0**
San Bernardino	**100**	**45**	**47**	**4**	**2**	**0**	**0**	**2**
San Diego	**179**	**81**	**92**	**5**	**1**	**0**	**0**	**0**
San Francisco	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
San Joaquin	**33**	**18**	**8**	**5**	**1**	**0**	**0**	**1**
San Luis Obispo	**145**	**51**	**75**	**8**	**4**	**4**	**3**	**0**
San Mateo	**18**	**10**	**7**	**0**	**0**	**0**	**0**	**1**
Santa Clara	**59**	**24**	**30**	**4**	**0**	**0**	**0**	**1**
Santa Cruz	**45**	**28**	**14**	**1**	**1**	**0**	**0**	**1**
Shasta	**181**	**62**	**108**	**7**	**2**	**1**	**0**	**1**
Sierra	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Siskiyou	**101**	**60**	**35**	**5**	**0**	**1**	**0**	**0**
Solano	**21**	**3**	**13**	**2**	**1**	**0**	**1**	**1**
Sonoma	**129**	**56**	**65**	**3**	**2**	**0**	**1**	**2**
Stanislaus	**33**	**5**	**20**	**6**	**1**	**0**	**0**	**1**
Sutter	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tehama	**98**	**28**	**58**	**8**	**2**	**0**	**1**	**1**
Trinity	**36**	**15**	**18**	**1**	**1**	**0**	**0**	**1**
Tulare	**63**	**17**	**39**	**3**	**2**	**0**	**1**	**1**
Tuolumne	**94**	**38**	**55**	**0**	**0**	**0**	**1**	**0**
Yolo	**15**	**3**	**8**	**3**	**0**	**0**	**0**	**1**
Yuba	**74**	**26**	**42**	**4**	**1**	**0**	**1**	**0**
STATE TOTAL	**3,501**	**1,375**	**1,804**	**196**	**48**	**21**	**20**	**37**

Contract County statistics can be found in Table 7.

Table 13. Number of Acres Burned by Cause, by Unit

	Total	Arson	Camp-fire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Rail-road	Smoking	Undet.	Vehicle
NORTHERN REGION													
Amador-El Dorado	6,788	3	1	136	99	5,105	8	582	1	0	790	35	28
Butte	207,320	25	4	23	8	50	206,925	3	2	1	0	208	71
Humboldt-Del Norte	84,994	28	6	1	3	0	84,943	2	0	0	0	6	5
Lassen-Modoc	188	7	8	33	4	116	2	5	1	0	1	6	5
Mendocino	13,860	5	3	97	5	43	84	2	0	0	0	13,594	27
Nevada-Yuba-Placer	379,767	41,284	4	51	217	218	269,749	1,881	6	0	0	65,885	472
San Mateo-Santa Cruz	32,201	16	171	70	3	167	29,932	1,118	0	0	2	8	714
Santa Clara	2,469	1,414	2	64	24	68	713	62	3	1	1	97	20
Shasta-Trinity	394,496	307	2	3	419	68	392,896	226	14	0	1	23	537
Siskiyou	100,006	293	3	399	53,902	32	45,002	18	11	0	6	299	41
Sonoma-Lake-Napa	382	0	0	21	9	6	20	1	0	0	1	112	212
Tehama-Glenn	70,769	5	0	342	1,377	107	68,694	38	4	0	0	174	28
TOTAL	1,293,240	43,387	204	1,240	56,070	5,980	1,098,968	3,938	42	2	802	80,447	2,160
SOUTHERN REGION													
Fresno-Kings	7,715	13	1	12	15	4	0	3,505	2	0	2	28	4,133
Madera-Mariposa	55,140	114	195	1	622	326	44,530	8	8	0	0	1,603	7,733
Riverside	54,556	37	0	7	109	125	2,150	29,671	4	0	0	22,451	2
San Benito-Monterey	14,457	727	0	103	2,363	108	3,983	198	4	0	7	5,912	1,052
San Bernardino	386	7	0	6	3	14	0	8	3	0	0	322	23
San Diego	7,658	274	8	2	14	51	4	169	35	0	6	292	6,803
San Luis Obispo	8,576	1	10	53	74	186	407	1,783	0	0	0	538	5,524
Tulare	6,692	28	2	47	62	6,166	6	16	1	0	1	174	189
Tuolumne-Calaveras	10,461	21	1	0	2	6	8,961	227	12	0	0	1,182	49
TOTAL	165,641	1,222	217	231	3,264	6,986	60,041	35,585	69	0	16	32,502	25,508
STATE TOTAL	1,458,881	44,609	421	1,471	59,334	12,966	1,159,009	39,523	111	2	818	112,949	27,668

Table 14. Number of Acres Burned by Cause, County

COUNTY	Total	Arson	Campfire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Railroad	Smoking	Undet.	Vehicle
Alameda	25,141	14	0	1	364	16	24,271	140	2	0	1	8	324
Alpine	0	0	0	0	0	0	0	0	0	0	0	0	0
Amador	87	1	0	13	9	3	0	3	0	0	47	2	9
Butte	173,004	25	4	23	8	50	172,609	3	2	1	0	208	71
Calaveras	3,546	20	1	28	49	3,255	4	13	0	0	0	79	97
Colusa	878	0	0	19	0	0	134	22	0	0	0	564	139
Contra Costa	3,490	48	2	0	42	42	3,277	38	0	0	0	10	31
Del Norte	4	1	2	1	0	0	0	0	0	0	0	0	0
El Dorado	183	2	1	27	21	47	0	45	1	0	2	19	18
Fresno	54,468	36	0	7	65	125	2,121	29,671	4	0	0	22,438	1
Glenn	34,428	0	0	12	0	7	34,393	8	0	0	0	0	8
Humboldt	183	6	6	31	4	116	2	5	1	0	1	6	5
Imperial	0	0	0	0	0	0	0	0	0	0	0	0	0
Inyo	7	2	0	0	0	0	0	1	0	0	0	4	0
Kings	88	0	0	0	44	0	29	0	0	0	0	13	2
Lake	18,595	8	0	2	4	10	18,480	2	3	0	0	39	47
Lassen	13,679	0	2	2	0	41	32	2	0	0	0	13,591	9
Madera	6,914	615	0	46	16	12	0	177	2	0	0	5,906	140
Mariposa	542	8	0	58	155	91	192	6	2	0	7	2	21
Mendocino	32,201	16	171	70	3	167	29,932	1,118	0	0	2	8	714
Merced	7,001	104	0	0	2,192	5	3,791	15	0	0	0	4	890
Modoc	177	5	0	94	5	1	52	0	0	0	0	2	18
Mono	0	0	0	0	0	0	0	0	0	0	0	0	0
Monterey	52,762	114	195	2	571	323	44,530	2	1	0	0	115	6,909
Napa	213,211	41,268	0	5	27	28	132,466	5	1	0	0	39,343	68
Nevada	779	0	0	39	7	7	710	6	1	0	0	6	3
Placer	121	2	0	16	10	48	0	28	1	1	1	11	3

Table 14. (continued) Number of Acres Burned by Cause, by County

COUNTY	Total	Arson	Camp-fire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Rail-road	Smoking	Undet.	Vehicle
Plumas	34,286	0	1	1	0	1	34,282	0	0	0	0	1	0
Riverside	7,658	274	8	2	14	51	4	169	35	0	6	292	6,803
Sacramento	6,426	0	0	6	69	5,053	8	534	0	0	741	14	1
San Benito	2,378	0	0	0	51	3	0	5	7	0	0	1,488	824
San Bernardino	7,708	11	1	12	15	4	0	3,504	2	0	2	24	4,133
San Diego	386	7	0	6	3	14	0	8	3	0	0	322	23
San Francisco	0	0	0	0	0	0	0	0	0	0	0	0	0
San Joaquin	24,598	33	0	91	0	47	24,353	0	0	0	0	2	72
San Luis Obispo	8,576	1	10	53	74	186	407	1,783	0	0	0	538	5,524
San Mateo	22,698	5	0	0	1	0	22,685	0	0	0	0	5	2
Santa Clara	165,309	10	0	0	13	9	165,203	48	12	0	0	3	11
Santa Cruz	62,296	23	7	1	2	0	62,259	1	0	0	0	1	2
Shasta	54,878	189	3	381	53,898	31	5	18	10	0	4	299	40
Sierra	0	0	0	0	0	0	0	0	0	0	0	0	0
Siskiyou	382	0	0	21	9	6	20	1	0	0	1	112	212
Solano	22,648	2	0	2	9	6	20,574	1,837	0	0	0	121	97
Sonoma	82,478	7	4	12	171	169	56,270	8	2	0	0	25,818	17
Stanislaus	176,261	205	0	1	0	2	175,793	1	0	0	0	76	183
Sutter	0	0	0	0	0	0	0	0	0	0	0	0	0
Tehama	36,374	5	0	330	1,377	99	34,335	30	4	0	0	174	20
Trinity	45,129	104	0	18	4	2	44,997	0	1	0	2	0	1
Tulare	10,461	21	1	0	2	6	8,961	227	12	0	0	1,182	49
Tuolumne	2,935	5	1	18	13	2,865	1	2	1	0	1	19	9
Yolo	41,956	0	0	10	5	4	41,825	8	0	0	0	0	104
Yuba	1,571	1,412	1	10	8	14	2	29	1	0	0	80	14
STATE TOTAL	1,458,881	44,609	421	1,471	59,334	12,966	1,159,009	39,523	111	2	818	112,949	27,668

Contract County statistics can be found in Table 7.

Table 15. Number of Acres Burned by Vegetation Type, by Unit

	Total	Brush	Grass	Timber	Woodland	Other
NORTHERN REGION						
Amador-El Dorado	6,788	41	6,677	16	54	0
Butte	207,320	47	336	206,935	2	0
Humboldt-Del Norte	84,994	6	29	84,959	0	0
Lassen-Modoc	188	0	141	45	2	0
Mendocino	13,860	25	7,108	6,658	69	0
Nevada-Yuba-Placer	379,767	370,700	3,542	5,516	9	0
San Mateo-Santa Cruz	32,201	4	1,559	30,637	1	0
Santa Clara	2,469	1,331	378	749	11	0
Shasta-Trinity	394,496	39	394,438	9	10	0
Siskiyou	100,006	45	54,897	45,030	34	0
Sonoma-Lake-Napa	382	249	47	59	27	0
Tehama-Glenn	70,769	34,692	2,715	33,359	3	0
TOTAL	1,293,240	407,179	471,867	413,972	222	0
SOUTHERN REGION						
Fresno-Kings	7,715	20	7,691	2	2	0
Madera-Mariposa	55,140	4	55,132	3	1	0
Riverside	54,556	2	2,491	52,037	26	0
San Benito-Monterey	14,457	8	8,636	5,811	2	0
San Bernardino	386	276	108	2	0	0
San Diego	7,658	4,490	3,167	1	0	0
San Luis Obispo	8,576	2,107	6,467	2	0	0
Tulare	6,692	10	6,645	18	19	0
Tuolumne-Calaveras	10,461	0	1,499	8,962	0	0
TOTAL	165,641	6,917	91,836	66,838	50	0
STATE TOTAL	1,458,881	414,096	563,703	480,810	272	0

Table 16. Number of Acres Burned by Vegetation Type, by County

COUNTY	Total	Brush	Grass	Timber	Woodland	Other
Alameda	25,141	0	25,135	6	0	0
Alpine	0	0	0	0	0	0
Amador	87	1	32	3	51	0
Butte	173,004	46	337	172,619	2	0
Calaveras	3,546	6	3,511	11	18	0
Colusa	878	152	726	0	0	0
Contra Costa	3,490	25	3,464	1	0	0
Del Norte	4	0	2	2	0	0
El Dorado	183	19	148	12	4	0
Fresno	54,468	2	2,403	52,037	26	0
Glenn	34,428	0	1,071	33,354	3	0
Humboldt	183	0	138	43	2	0
Imperial	0	0	0	0	0	0
Inyo	7	4	3	0	0	0
Kings	88	0	88	0	0	0
Lake	18,595	15,366	96	3,133	0	0
Lassen	13,679	4	7,023	6,614	38	0
Madera	6,914	2	1,112	5,799	1	0
Mariposa	542	5	523	14	0	0
Mendocino	32,201	4	1,559	30,637	1	0
Merced	7,001	0	7,001	0	0	0
Modoc	177	21	83	43	30	0
Mono	0	0	0	0	0	0
Monterey	52,762	4	52,754	3	1	0
Napa	213,211	213,067	133	8	3	0
Nevada	779	5	39	725	10	0
Placer	121	4	105	10	2	0

Table 16. (continued) Number of Acres Burned by Vegetation Type, by County

COUNTY	Total	Brush	Grass	Timber	Woodland	Other
Plumas	34,286	0	1	34,283	2	0
Riverside	7,658	4,490	3,167	1	0	0
Sacramento	6,426	21	6,405	0	0	0
San Benito	2,378	0	2,377	1	0	0
San Bernardino	7,708	16	7,688	2	2	0
San Diego	386	276	108	2	0	0
San Francisco	0	0	0	0	0	0
San Joaquin	24,598	0	24,598	0	0	0
San Luis Obispo	8,576	2,107	6,467	2	0	0
San Mateo	22,698	5	4	22,689	0	0
Santa Clara	165,309	14	165,283	2	10	0
Santa Cruz	62,296	1	26	62,269	0	0
Shasta	54,878	44	54,791	24	19	0
Sierra	0	0	0	0	0	0
Siskiyou	382	249	47	60	26	0
Solano	22,648	20,575	2,073	0	0	0
Sonoma	82,478	79,715	384	2,373	6	0
Stanislaus	176,261	1	176,260	0	0	0
Sutter	0	0	0	0	0	0
Tehama	36,374	34,692	1,644	38	0	0
Trinity	45,129	1	108	45,006	14	0
Tulare	10,461	0	1,499	8,962	0	0
Tuolumne	2,935	4	2,924	6	1	0
Yolo	41,956	41,825	129	2	0	0
Yuba	1,571	1,323	234	14	0	0
STATE TOTAL	1,458,881	414,096	563,703	480,810	272	0

Contract County statistics can be found in Table 7.

Table 17. Dollar Damage by Cause, by Unit

	Total	Arson	Camp-fire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Rail-road	Smoking	Undet.	Vehicle
NORTHERN REGION													
Amador-El Dorado	$3,644,362	$0	$3,000	$1,010,406	$58,100	$1,511,500	$0	$856,002	$0	$0	$0	$6,402	$198,952
Butte	$38,209,457	$3,002	$500	$0	$0	$81,054	$38,000,000	$2,300	$1	$0	$0	$109,100	$13,500
Humboldt-Del Norte	$5,000,200	$0	$0	$0	$0	$200	$5,000,000	$0	$0	$0	$0	$0	$0
Lassen-Modoc	$944,850	$0	$1,000	$305,500	$20,100	$595,850	$0	$21,300	$0	$0	$0	$0	$1,100
Mendocino	$1,505,832	$0	$2,000	$110	$0	$2,000	$1,210	$0	$0	$0	$0	$1,500,512	$0
Nevada-Yuba-Placer	$2,748,063,917	$300,010,000	$2,100	$501	$640,260	$229,100	$738,070,000	$3,474,205	$1,000	$0	$5,000	$1,705,281,250	$350,501
San Mateo-Santa Cruz	$246,704	$55,000	$3,000	$100	$10,000	$18,000	$604	$140,000	$0	$0	$0	$20,000	$0
Santa Clara	$2,989,562	$2,510,000	$1,000	$74,252	$34,400	$219,710	$0	$63,400	$200	$0	$0	$9,700	$76,900
Shasta-Trinity	$543,977,107	$3,325	$0	$0	$58,150	$18,550	$543,585,200	$101,650	$0	$0	$0	$2,002	$208,230
Siskiyou	$117,483,850	$323,100	$0	$30,000	$50,390,650	$612,800	$66,000,000	$600	$0	$0	$23,000	$94,000	$9,700
Sonoma-Lake-Napa	$686,650	$0	$50	$2,500	$354,500	$5,300	$0	$300,000	$0	$0	$500	$10,300	$13,500
Tehama-Glenn	$6,745,456	$1,150	$0	$67,000	$28,700	$403,972	$6,206,200	$5,350	$1,010	$0	$0	$26,950	$5,124
TOTAL	$3,469,497,947	$302,905,577	$12,650	$1,490,369	$51,594,860	$3,698,036	$1,396,863,214	$4,964,807	$2,211	$0	$28,500	$1,707,060,216	$877,507
SOUTHERN REGION													
Fresno-Kings	$90,131,914	$6,002	$0	$0	$1,000	$2,500	$0	$90,031,700	$0	$0	$0	$4,212	$86,500
Madera-Mariposa	$379,795	$1,830	$0	$0	$77,850	$1,705	$0	$200	$20,000	$0	$0	$252,400	$25,810
Riverside	$380,024,372	$520	$8,000	$56,000	$6,292	$15,100	$263,630	$300	$0	$0	$0	$379,673,930	$600
San Benito-Monterey	$35,606,255	$1,152,250	$0	$357,230	$215,960	$52,350	$4,000	$5,000	$0	$0	$0	$33,793,950	$25,515
San Bernardino	$1,049,225	$1,000	$0	$2,600	$12,750	$4,800	$0	$4,125	$250	$0	$0	$758,200	$265,500
San Diego	$8,066,503	$50,702	$3,000	$0	$62,000	$19,500	$0	$25,601	$500	$0	$100	$7,000	$7,898,100
San Luis Obispo	$577,022	$0	$50	$3,000	$8,120	$62,000	$12,000	$37,300	$1,050	$0	$0	$12,652	$440,850
Tulare	$1,043,373	$12,100	$100	$157,013	$22,450	$481,595	$400	$153,390	$0	$0	$0	$143,071	$73,254
Tuolumne-Calaveras	$278,541,759	$98	$0	$0	$0	$350	$278,400,000	$100	$260	$0	$0	$93,000	$47,951
TOTAL	$795,420,218	$1,224,502	$11,150	$575,843	$406,422	$639,900	$278,680,030	$90,257,716	$22,060	$0	$100	$414,738,415	$8,864,080
STATE TOTAL	$4,264,918,165	$304,130,079	$23,800	$2,066,212	$52,001,282	$4,337,936	$1,675,543,244	$95,222,523	$24,271	$0	$28,600	$2,121,798,631	$9,741,587

*Definition of what Dollar Damage entails can be found in the Glossary.

Table 18. Dollar Damage by Cause, by County

COUNTY	Total	Arson	Camp-fire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Rail-road	Smoking	Undet.	Vehicle
Alameda	$101,020,955	$2,625	$0	$0	$1,300	$500	$100,819,200	$100,000	$0	$0	$0	$0	$97,330
Alpine	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Amador	$19,300	$0	$0	$200	$100	$0	$0	$11,000	$0	$0	$0	$0	$8,000
Butte	$8,209,457	$3,002	$500	$0	$0	$81,054	$8,000,000	$2,300	$1	$0	$0	$109,100	$13,500
Calaveras	$834,351	$11,300	$100	$156,683	$14,950	$397,475	$0	$150,720	$0	$0	$0	$30,771	$72,352
Colusa	$140,500	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$40,000	$100,500
Contra Costa	$99,700	$700	$0	$0	$850	$15,000	$46,000	$1,650	$0	$0	$0	$0	$35,500
Del Norte	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
El Dorado	$1,090,562	$0	$3,000	$10,206	$44,500	$11,500	$0	$825,002	$0	$0	$0	$5,402	$190,952
Fresno	$380,024,372	$520	$8,000	$56,000	$6,292	$15,100	$263,630	$300	$0	$0	$0	$379,673,930	$600
Glenn	$4,244,900	$0	$0	$22,400	$0	$14,500	$4,204,400	$3,000	$0	$0	$0	$0	$600
Humboldt	$944,850	$0	$1,000	$305,500	$20,100	$595,850	$0	$21,300	$0	$0	$0	$0	$1,100
Imperial	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Inyo	$4	$2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$2	$0
Kings	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Lake	$82,183,550	$10,000	$100	$0	$5,000	$5,500	$81,000,000	$1,000,200	$1,000	$0	$5,000	$750	$156,000
Lassen	$1,503,732	$0	$0	$10	$0	$2,000	$1,210	$0	$0	$0	$0	$1,500,512	$0
Madera	$34,923,990	$700,000	$0	$356,230	$2,060	$50,000	$0	$4,800	$0	$0	$0	$33,790,700	$20,200
Mariposa	$670,500	$452,050	$0	$1,000	$203,800	$2,150	$4,000	$0	$0	$0	$0	$3,000	$4,500
Mendocino	$246,704	$55,000	$3,000	$100	$10,000	$18,000	$604	$140,000	$0	$0	$0	$20,000	$0
Merced	$11,765	$200	$0	$0	$10,100	$200	$0	$200	$0	$0	$0	$250	$815
Modoc	$100	$0	$0	$100	$0	$0	$0	$0	$0	$0	$0	$0	$0
Mono	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Monterey	$70,490	$1,830	$0	$0	$54,850	$1,700	$0	$100	$0	$0	$0	$2,000	$10,010
Napa	$1,129,079,102	$300,000,000	$0	$1	$12,000	$200,100	$3,550,000	$0	$0	$0	$0	$825,300,000	$17,001
Nevada	$152,362	$0	$0	$73,452	$100	$1,510	$0	$60,000	$0	$0	$0	$7,700	$9,600
Placer	$311,400	$10,000	$0	$800	$20,300	$209,600	$0	$3,200	$200	$0	$0	$2,000	$65,300

*Definition of what Dollar Damage entails can be found in the Glossary.

COUNTY	Total	Arson	Camp-fire	Debris Burning	Elec. Power	Equip. Use	Ltng.	Misc.	P-W-F	Rail-road	Smoking	Undet.	Vehicle
Plumas	$30,002,000	$0	$2,000	$0	$0	$0	$30,000,000	$0	$0	$0	$0	$0	$0
Riverside	$8,066,503	$50,702	$3,000	$0	$62,000	$19,500	$0	$25,601	$500	$0	$100	$7,000	$7,898,100
Sacramento	$1,533,500	$0	$0	$0	$13,500	$1,500,000	$0	$20,000	$0	$0	$0	$0	$0
San Benito	$309,305	$0	$0	$0	$23,000	$5	$0	$100	$20,000	$0	$0	$250,400	$15,800
San Bernardino	$90,131,910	$6,000	$0	$0	$1,000	$2,500	$0	$90,031,700	$0	$0	$0	$4,210	$86,500
San Diego	$1,049,225	$1,000	$0	$2,600	$12,750	$4,800	$0	$4,125	$250	$0	$0	$758,200	$265,500
San Francisco	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
San Joaquin	$70,131,020	$0	$0	$1,000,000	$0	$9,020	$69,120,400	$0	$0	$0	$0	$1,200	$400
San Luis Obispo	$577,022	$0	$50	$3,000	$8,120	$62,000	$12,000	$37,300	$1,050	$0	$0	$12,652	$440,850
San Mateo	$3,000,100	$0	$0	$0	$0	$100	$3,000,000	$0	$0	$0	$0	$0	$0
Santa Clara	$304,571,052	$0	$0	$0	$56,000	$3,050	$304,480,000	$0	$0	$0	$0	$2,002	$30,000
Santa Cruz	$2,000,100	$0	$0	$0	$0	$100	$2,000,000	$0	$0	$0	$0	$0	$0
Shasta	$50,761,750	$103,000	$0	$19,000	$50,382,650	$132,800	$0	$600	$0	$0	$20,500	$94,000	$9,200
Sierra	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Siskiyou	$686,650	$0	$50	$2,500	$354,500	$5,300	$0	$300,000	$0	$0	$500	$10,300	$13,500
Solano	$224,590,500	$0	$0	$0	$0	$3,000	$222,300,000	$2,250,000	$0	$0	$0	$500	$37,000
Sonoma	$1,302,549,765	$0	$2,000	$500	$123,260	$500	$422,220,000	$224,005	$0	$0	$0	$879,940,000	$39,500
Stanislaus	$69,175,400	$700	$0	$0	$400	$100	$69,120,000	$100	$0	$0	$0	$9,100	$45,000
Sutter	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Tehama	$2,500,556	$1,150	$0	$44,600	$28,700	$389,472	$2,001,800	$2,350	$1,010	$0	$0	$26,950	$4,524
Trinity	$66,722,100	$220,100	$0	$11,000	$8,000	$480,000	$66,000,000	$0	$0	$0	$2,500	$0	$500
Tulare	$278,541,759	$98	$0	$0	$0	$350	$278,400,000	$100	$260	$0	$0	$93,000	$47,951
Tuolumne	$189,002	$100	$0	$330	$7,100	$75,000	$0	$2,570	$0	$0	$0	$103,000	$902
Yolo	$9,520,500	$0	$0	$0	$500,000	$20,000	$9,000,000	$0	$0	$0	$0	$0	$500
Yuba	$2,525,800	$2,500,000	$1,000	$0	$14,000	$8,600	$0	$200	$0	$0	$0	$0	$2,000
STATE TOTAL	$4,264,918,165	$304,130,079	$23,800	$2,066,212	$52,001,282	$4,337,936	$1,675,543,244	$95,222,523	$24,271	$0	$28,600	$2,121,798,631	$9,741,587

Contract County statistics can be found in Table 7.

*Definition of what Dollar Damage entails can be found in the Glossary.

Table 19. Dollar Damage by Size, by Unit

		A	B	C	D	E	F	G
	Total	.25 acres or <	.26-9.99 acres	10-99 acres	100-299 acres	300-999 acres	1000-4999 acres	5000 acres >
NORTHERN REGION								
Amador-El Dorado	$3,644,362	$64,756	$825,106	$1,234,500	$0	$20,000	$0	$1,500,000
Butte	$38,209,457	$11,652	$80,805	$117,000	$0	$0	$0	$38,000,000
Humboldt-Del Norte	$5,000,200	$200	$0	$0	$0	$0	$0	$5,000,000
Lassen-Modoc	$944,850	$74,950	$869,400	$500	$0	$0	$0	$0
Mendocino	$1,505,832	$0	$3,222	$2,610	$0	$0	$0	$1,500,000
Nevada-Yuba-Placer	$2,748,063,917	$1,654,360	$891,557	$18,000	$0	$40,000	$2,550,000	$2,742,910,000
San Mateo-Santa Cruz	$246,704	$2,000	$224,704	$20,000	$0	$0	$0	$0
Santa Clara	$2,989,562	$130,802	$155,760	$203,000	$0	$0	$2,500,000	$0
Shasta-Trinity	$543,977,107	$7,602	$304,025	$80,280	$0	$6,000	$59,200	$543,520,000
Siskiyou	$117,483,850	$233,300	$1,211,550	$9,000	$20,000	$10,000	$0	$116,000,000
Sonoma-Lake-Napa	$686,650	$23,550	$663,100	$0	$0	$0	$0	$0
Tehama-Glenn	$6,745,456	$2,850	$464,232	$73,624	$59,350	$145,400	$0	$6,000,000
TOTAL	$3,469,497,947	$2,206,022	$5,693,461	$1,758,514	$79,350	$221,400	$5,109,200	$3,454,430,000
SOUTHERN REGION								
Fresno-Kings	$90,131,914	$16,510	$93,204	$1,000	$21,200	$0	$0	$90,000,000
Madera-Mariposa	$379,795	$12,215	$30,700	$24,530	$52,750	$9,600	$250,000	$0
Riverside	$380,024,372	$16,020	$61,492	$10,730	$0	$0	$263,630	$379,672,500
San Benito-Monterey	$35,606,255	$7,400	$1,012,355	$555,200	$381,300	$100,000	$10,000	$33,540,000
San Bernardino	$1,049,225	$795,025	$254,200	$0	$0	$0	$0	$0
San Diego	$8,066,503	$17,000	$88,903	$27,600	$8,000	$50,000	$0	$7,875,000
San Luis Obispo	$577,022	$6,850	$62,070	$65,600	$10,002	$500	$432,000	$0
Tulare	$1,043,373	$219,883	$227,490	$204,000	$0	$0	$392,000	$0
Tuolumne-Calaveras	$278,541,759	$14,600	$29,709	$7,450	$10,000	$0	$80,000	$278,400,000
TOTAL	$795,420,218	$1,105,503	$1,860,123	$896,110	$483,252	$160,100	$1,427,630	$789,487,500
STATE TOTAL	$4,264,918,165	$3,311,525	$7,553,584	$2,654,624	$562,602	$381,500	$6,536,830	$4,243,917,500

*Definition of what Dollar Damage entails can be found in the Glossary.

Table 20. Dollar Damage by Size, by County

		A	B	C	D	E	F	G
COUNTY	**Total**	**.25 acres or <**	**.26-9.99 acres**	**10-99 acres**	**100-299 acres**	**300-999 acres**	**1000-4999 acres**	**5000 acres >**
Alameda	**$101,020,955**	**$2,500**	**$185,625**	**$13,630**	**$0**	**$0**	**$19,200**	**$100,800,000**
Alpine	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Amador	**$19,300**	**$2,100**	**$17,200**	**$0**	**$0**	**$0**	**$0**	**$0**
Butte	**$8,209,457**	**$11,652**	**$80,805**	**$117,000**	**$0**	**$0**	**$0**	**$8,000,000**
Calaveras	**$834,351**	**$210,743**	**$44,608**	**$187,000**	**$0**	**$0**	**$392,000**	**$0**
Colusa	**$140,500**	**$100,500**	**$0**	**$0**	**$0**	**$40,000**	**$0**	**$0**
Contra Costa	**$99,700**	**$5,100**	**$31,950**	**$16,650**	**$0**	**$6,000**	**$40,000**	**$0**
Del Norte	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
El Dorado	**$1,090,562**	**$61,656**	**$807,906**	**$221,000**	**$0**	**$0**	**$0**	**$0**
Fresno	**$380,024,372**	**$16,020**	**$61,492**	**$10,730**	**$0**	**$0**	**$263,630**	**$379,672,500**
Glenn	**$4,244,900**	**$100**	**$19,400**	**$24,400**	**$55,600**	**$145,400**	**$0**	**$4,000,000**
Humboldt	**$944,850**	**$74,950**	**$869,400**	**$500**	**$0**	**$0**	**$0**	**$0**
Imperial	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Inyo	**$4**	**$0**	**$4**	**$0**	**$0**	**$0**	**$0**	**$0**
Kings	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Lake	**$82,183,550**	**$1,146,800**	**$36,750**	**$0**	**$0**	**$0**	**$0**	**$81,000,000**
Lassen	**$1,503,732**	**$0**	**$1,222**	**$2,510**	**$0**	**$0**	**$0**	**$1,500,000**
Madera	**$34,923,990**	**$5,800**	**$553,390**	**$350,000**	**$374,800**	**$100,000**	**$0**	**$33,540,000**
Mariposa	**$670,500**	**$1,400**	**$457,850**	**$204,750**	**$6,500**	**$0**	**$0**	**$0**
Mendocino	**$246,704**	**$2,000**	**$224,704**	**$20,000**	**$0**	**$0**	**$0**	**$0**
Merced	**$11,765**	**$200**	**$1,115**	**$450**	**$0**	**$0**	**$10,000**	**$0**
Modoc	**$100**	**$0**	**$0**	**$100**	**$0**	**$0**	**$0**	**$0**
Mono	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Monterey	**$70,490**	**$11,910**	**$3,300**	**$2,530**	**$52,750**	**$0**	**$0**	**$0**
Napa	**$1,129,079,102**	**$218,000**	**$11,102**	**$0**	**$0**	**$0**	**$0**	**$1,128,850,000**
Nevada	**$152,362**	**$65,702**	**$86,660**	**$0**	**$0**	**$0**	**$0**	**$0**
Placer	**$311,400**	**$63,900**	**$44,500**	**$203,000**	**$0**	**$0**	**$0**	**$0**

*Definition of what Dollar Damage entails can be found in the Glossary.

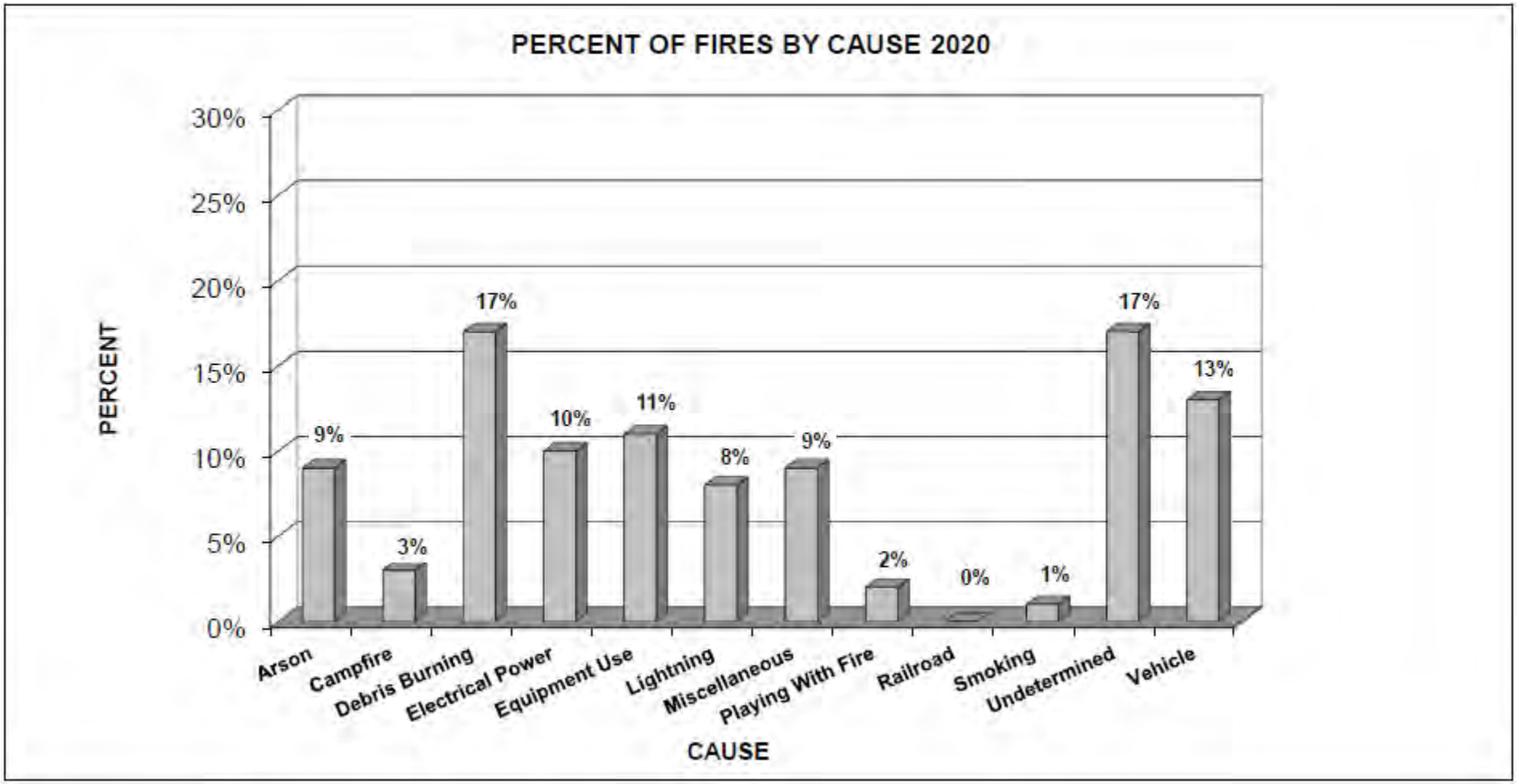
Table 20. (continued) Dollar Damage by Size, by County

		A	B	C	D	E	F	G
COUNTY	**Total**	**.25 acres or <**	**.26-9.99 acres**	**10-99 acres**	**100-299 acres**	**300-999 acres**	**1000-4999 acres**	**5000 acres >**
Plumas	**$30,002,000**	**$0**	**$2,000**	**$0**	**$0**	**$0**	**$0**	**$30,000,000**
Riverside	**$8,066,503**	**$17,000**	**$88,903**	**$27,600**	**$8,000**	**$50,000**	**$0**	**$7,875,000**
Sacramento	**$1,533,500**	**$0**	**$0**	**$13,500**	**$0**	**$20,000**	**$0**	**$1,500,000**
San Benito	**$309,305**	**$305**	**$27,400**	**$22,000**	**$0**	**$9,600**	**$250,000**	**$0**
San Bernardino	**$90,131,910**	**$16,510**	**$93,200**	**$1,000**	**$21,200**	**$0**	**$0**	**$90,000,000**
San Diego	**$1,049,225**	**$795,025**	**$254,200**	**$0**	**$0**	**$0**	**$0**	**$0**
San Francisco	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
San Joaquin	**$70,131,020**	**$1,120**	**$900**	**$1,009,000**	**$0**	**$0**	**$0**	**$69,120,000**
San Luis Obispo	**$577,022**	**$6,850**	**$62,070**	**$65,600**	**$10,002**	**$500**	**$432,000**	**$0**
San Mateo	**$3,000,100**	**$100**	**$0**	**$0**	**$0**	**$0**	**$0**	**$3,000,000**
Santa Clara	**$304,571,052**	**$2**	**$41,050**	**$50,000**	**$0**	**$0**	**$0**	**$304,480,000**
Santa Cruz	**$2,000,100**	**$100**	**$0**	**$0**	**$0**	**$0**	**$0**	**$2,000,000**
Shasta	**$50,761,750**	**$30,200**	**$693,050**	**$8,500**	**$20,000**	**$10,000**	**$0**	**$50,000,000**
Sierra	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Siskiyou	**$686,650**	**$23,550**	**$663,100**	**$0**	**$0**	**$0**	**$0**	**$0**
Solano	**$224,590,500**	**$0**	**$40,000**	**$500**	**$0**	**$0**	**$2,250,000**	**$222,300,000**
Sonoma	**$1,302,549,765**	**$189,060**	**$283,705**	**$17,000**	**$0**	**$0**	**$300,000**	**$1,301,760,000**
Stanislaus	**$69,175,400**	**$50**	**$47,350**	**$8,000**	**$0**	**$0**	**$0**	**$69,120,000**
Sutter	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Tehama	**$2,500,556**	**$2,750**	**$444,832**	**$49,224**	**$3,750**	**$0**	**$0**	**$2,000,000**
Trinity	**$66,722,100**	**$203,100**	**$518,500**	**$500**	**$0**	**$0**	**$0**	**$66,000,000**
Tulare	**$278,541,759**	**$14,600**	**$29,709**	**$7,450**	**$10,000**	**$0**	**$80,000**	**$278,400,000**
Tuolumne	**$189,002**	**$8,970**	**$180,032**	**$0**	**$0**	**$0**	**$0**	**$0**
Yolo	**$9,520,500**	**$0**	**$520,000**	**$500**	**$0**	**$0**	**$0**	**$9,000,000**
Yuba	**$2,525,800**	**$1,200**	**$24,600**	**$0**	**$0**	**$0**	**$2,500,000**	**$0**
STATE TOTAL	**$4,264,918,165**	**$3,311,525**	**$7,553,584**	**$2,654,624**	**$562,602**	**$381,500**	**$6,536,830**	**$4,243,917,500**

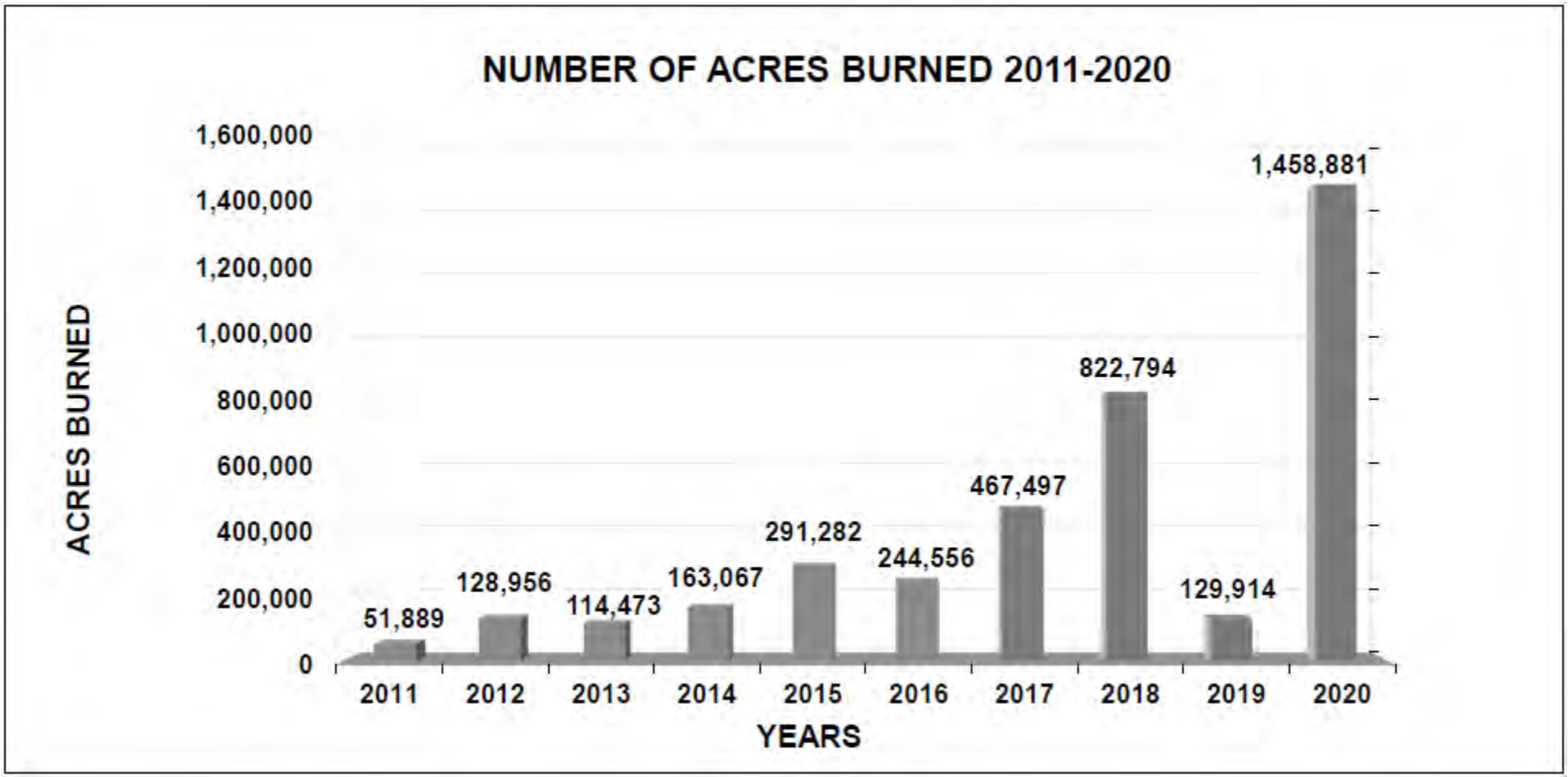
Contract County statistics can be found in Table 7.

*Definition of what Dollar Damage entails can be found in the Glossary.

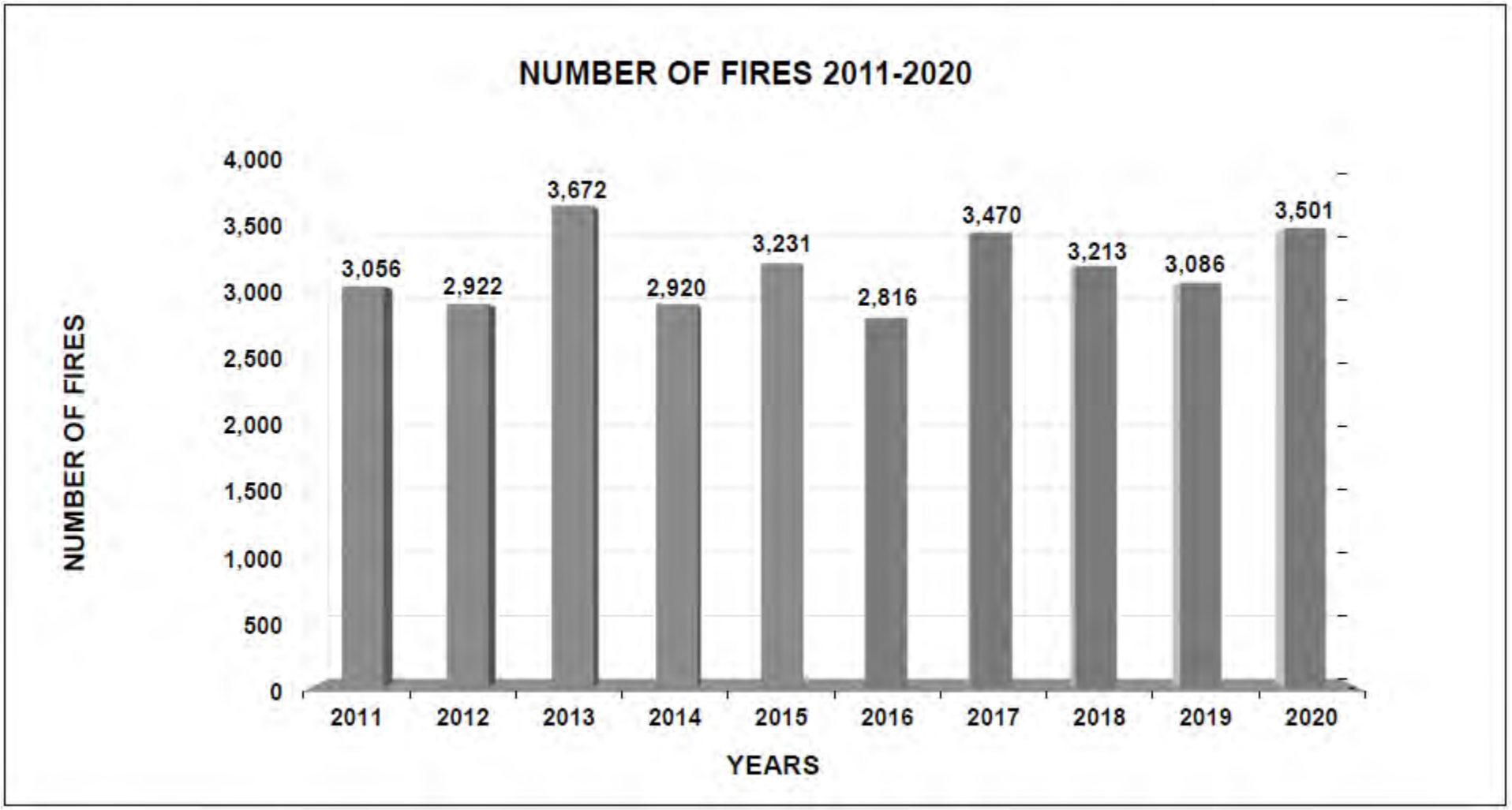
Graphic Figure 1. Percent of Fires by Cause



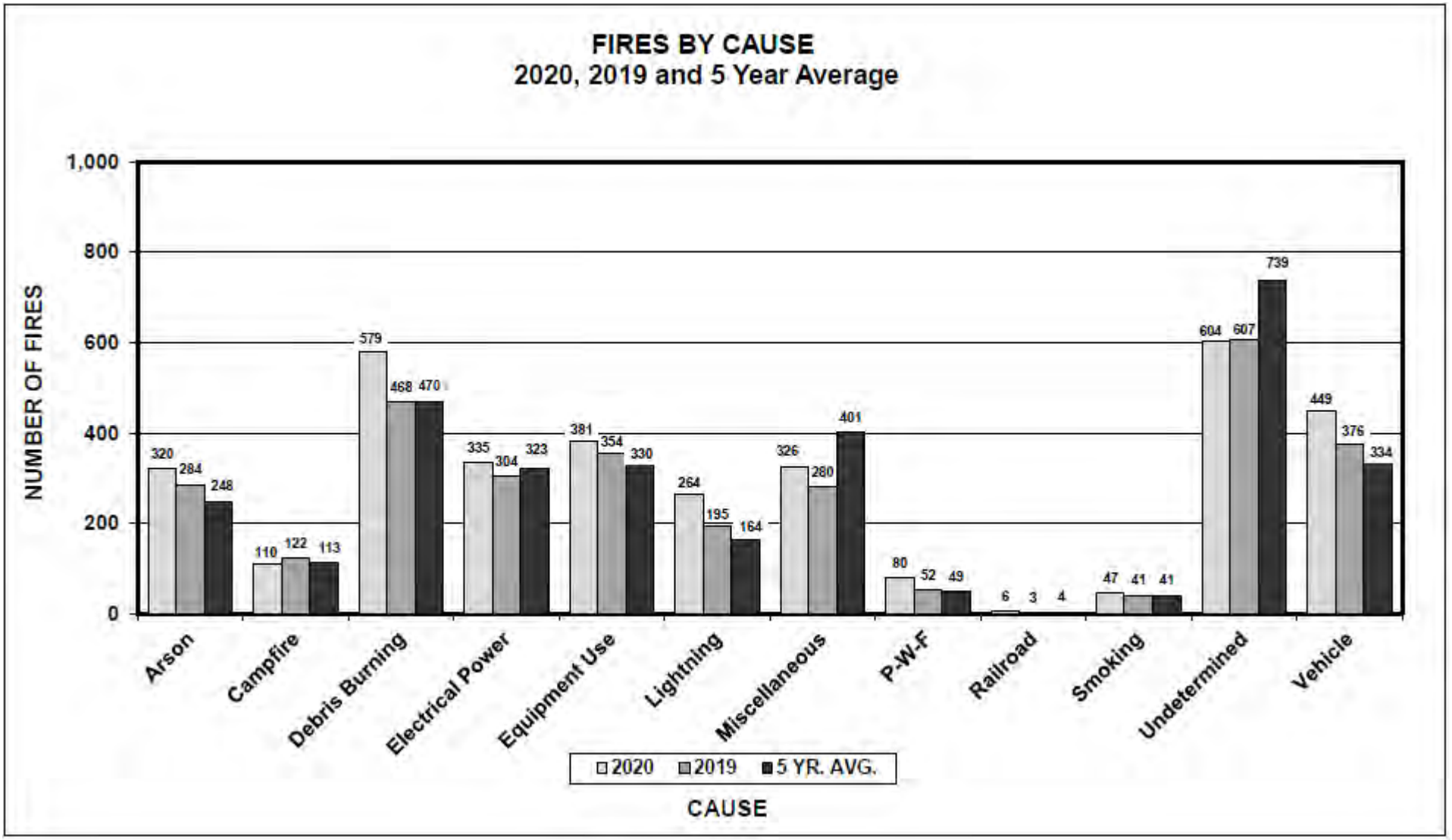
Graphic Figure 2. Number of Acres Burned — 2011-2020



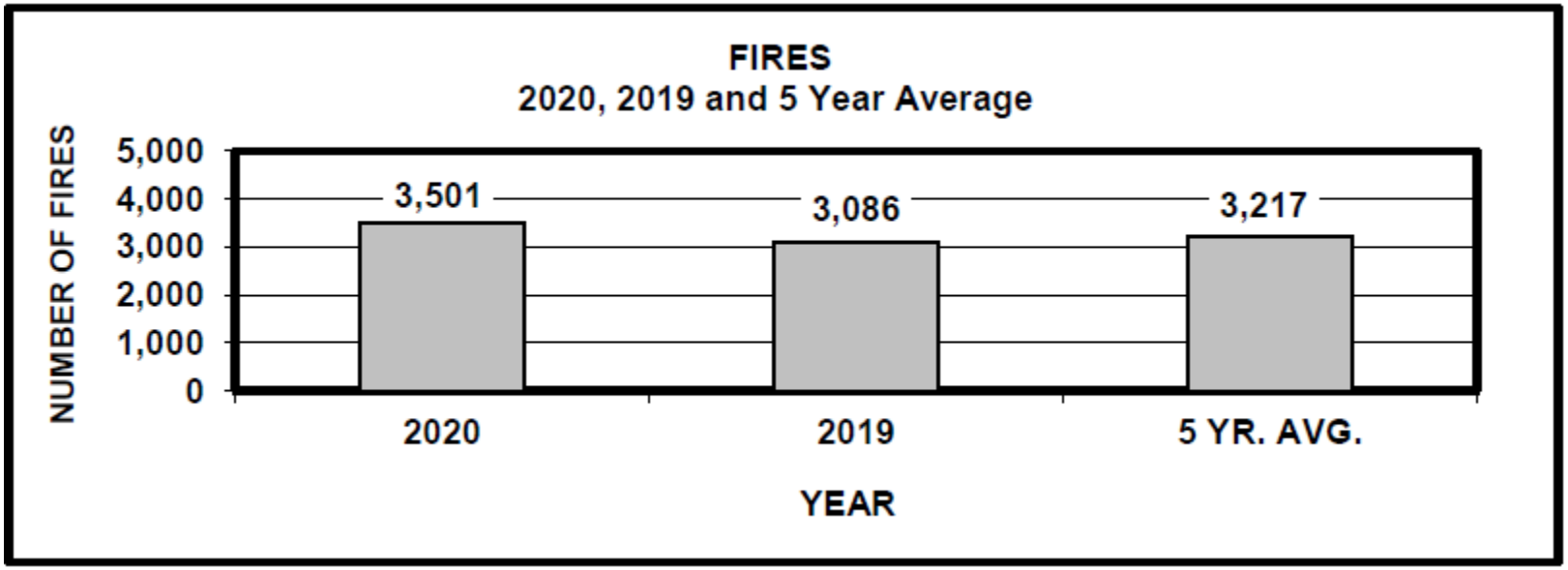
Graphic Figure 3. Number of Fires — 2011-2020

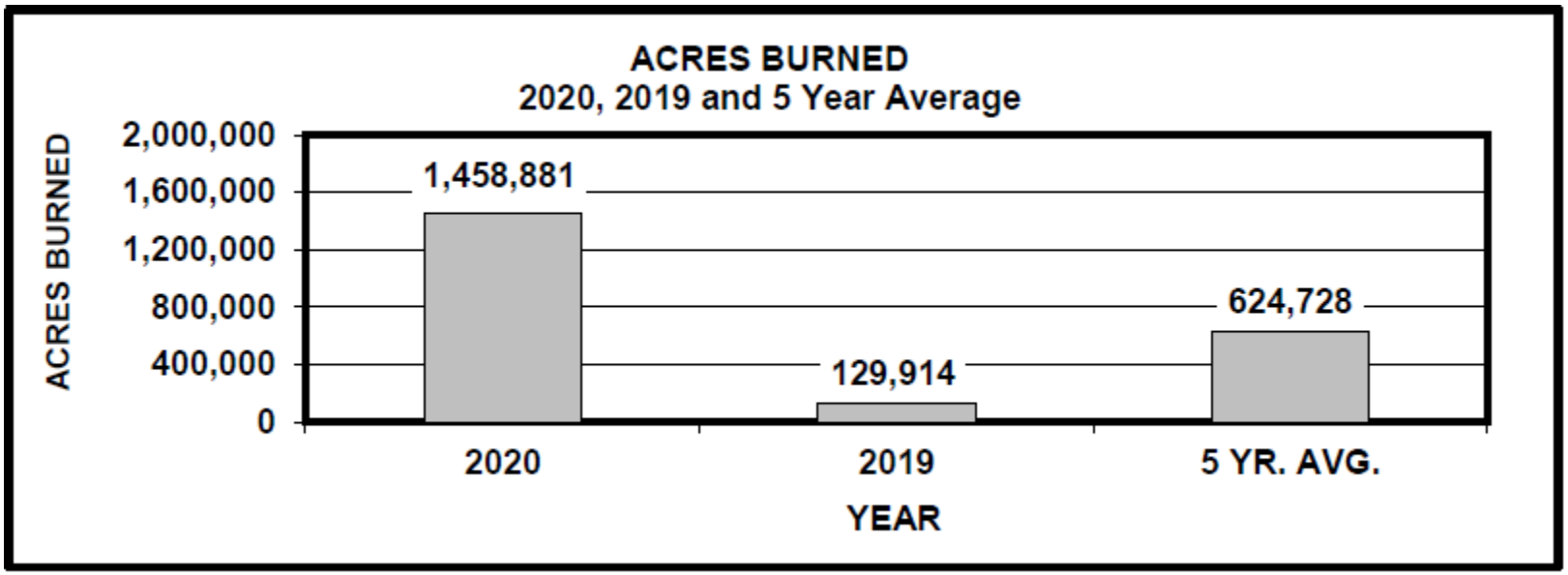


Graphic Figure 4. Number of Fires by Cause — 2020, 2019, and 5 Year Average

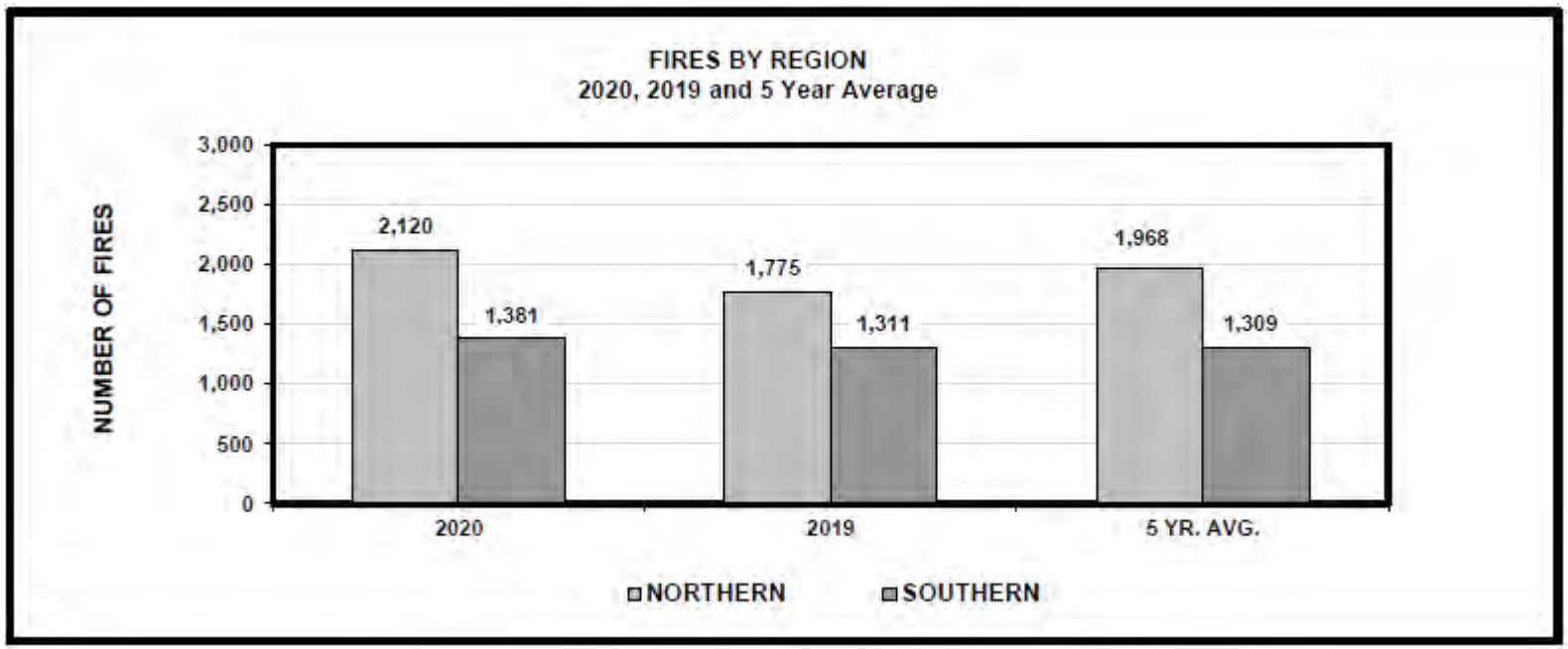


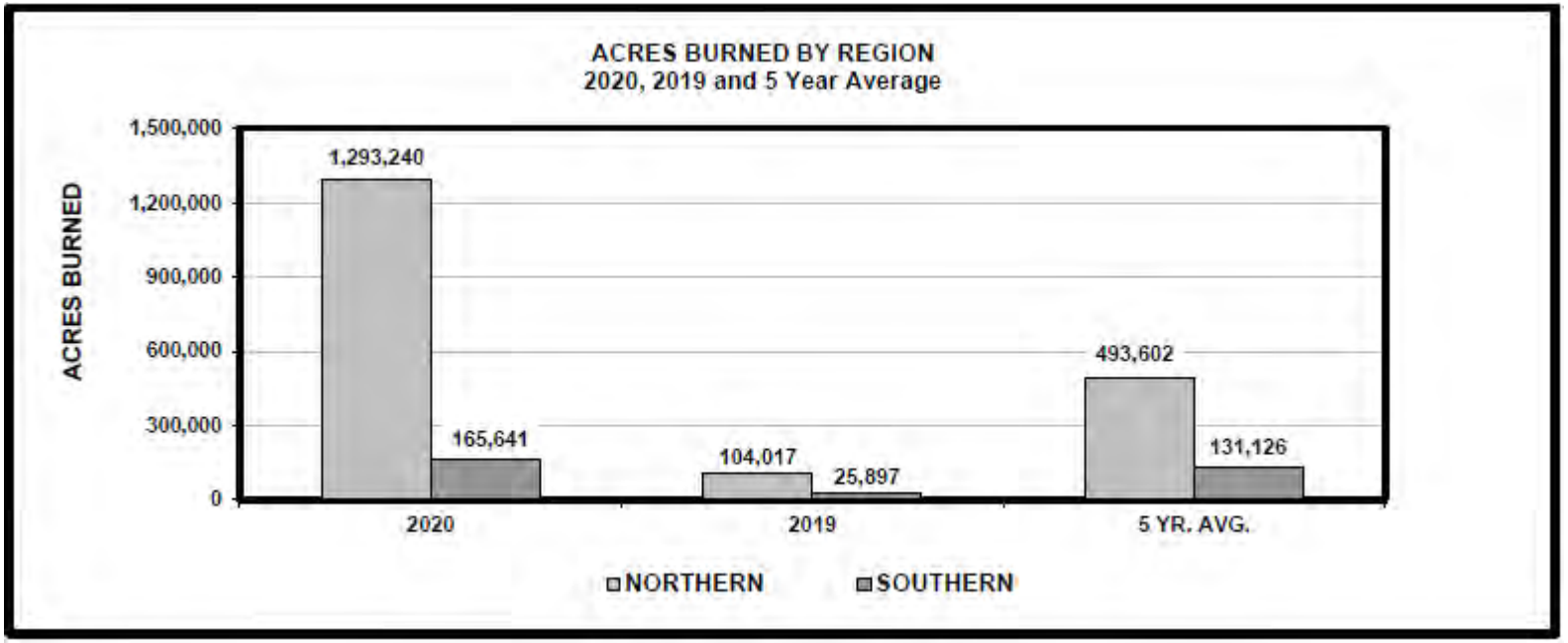
Graphic Figure 5. Fires and Acres — 2020, 2019, and 5 Year Average



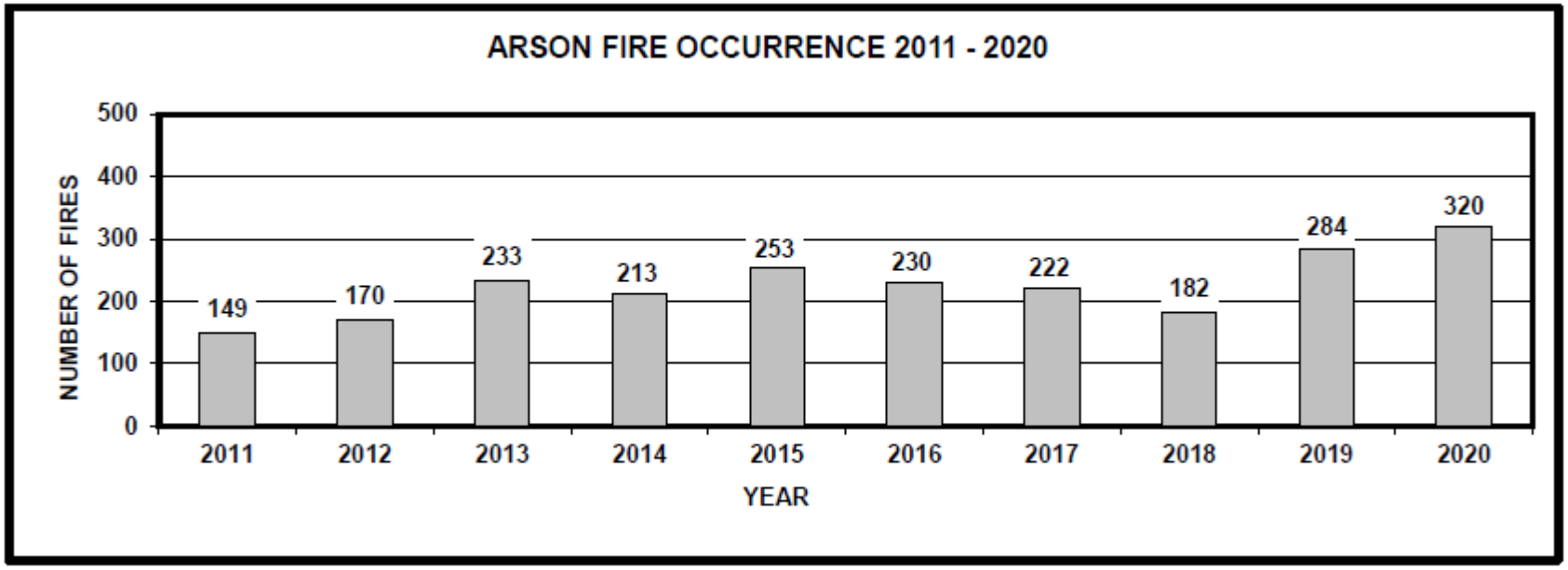


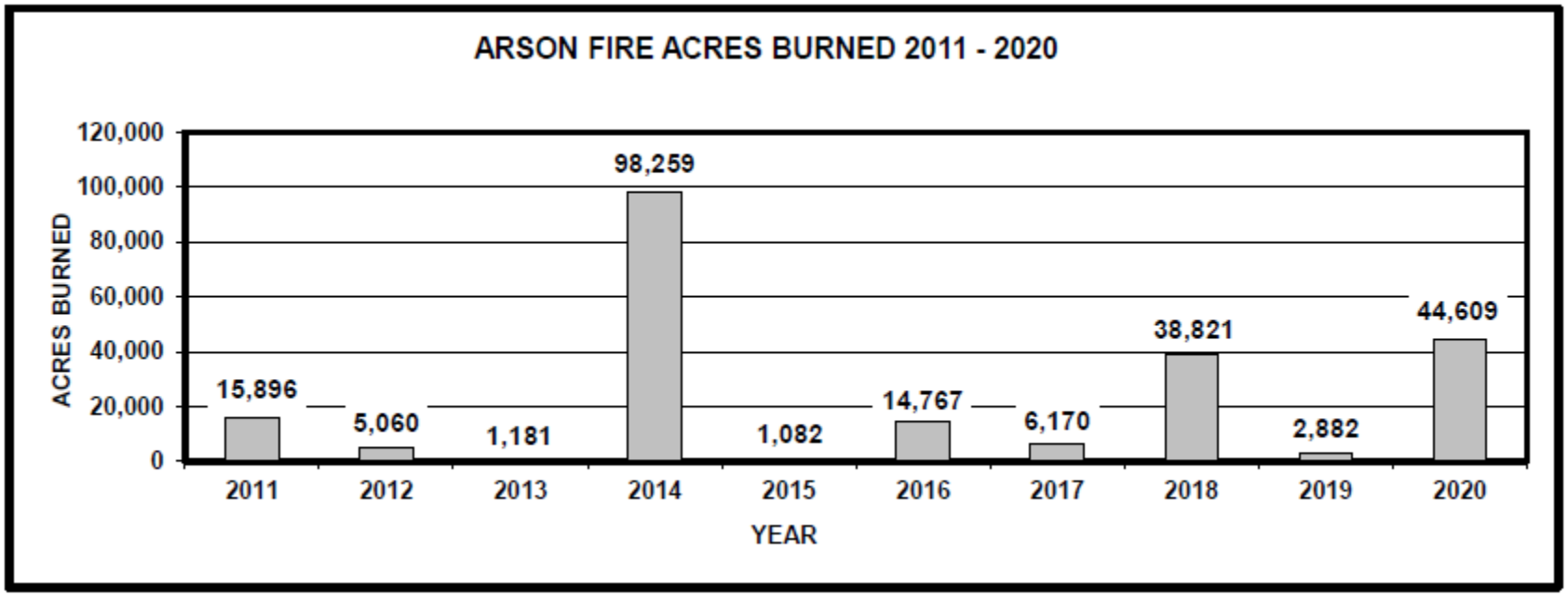
Graphic Figure 6. Fires and Acres by Region — 2020, 2019, and 5 Year Average



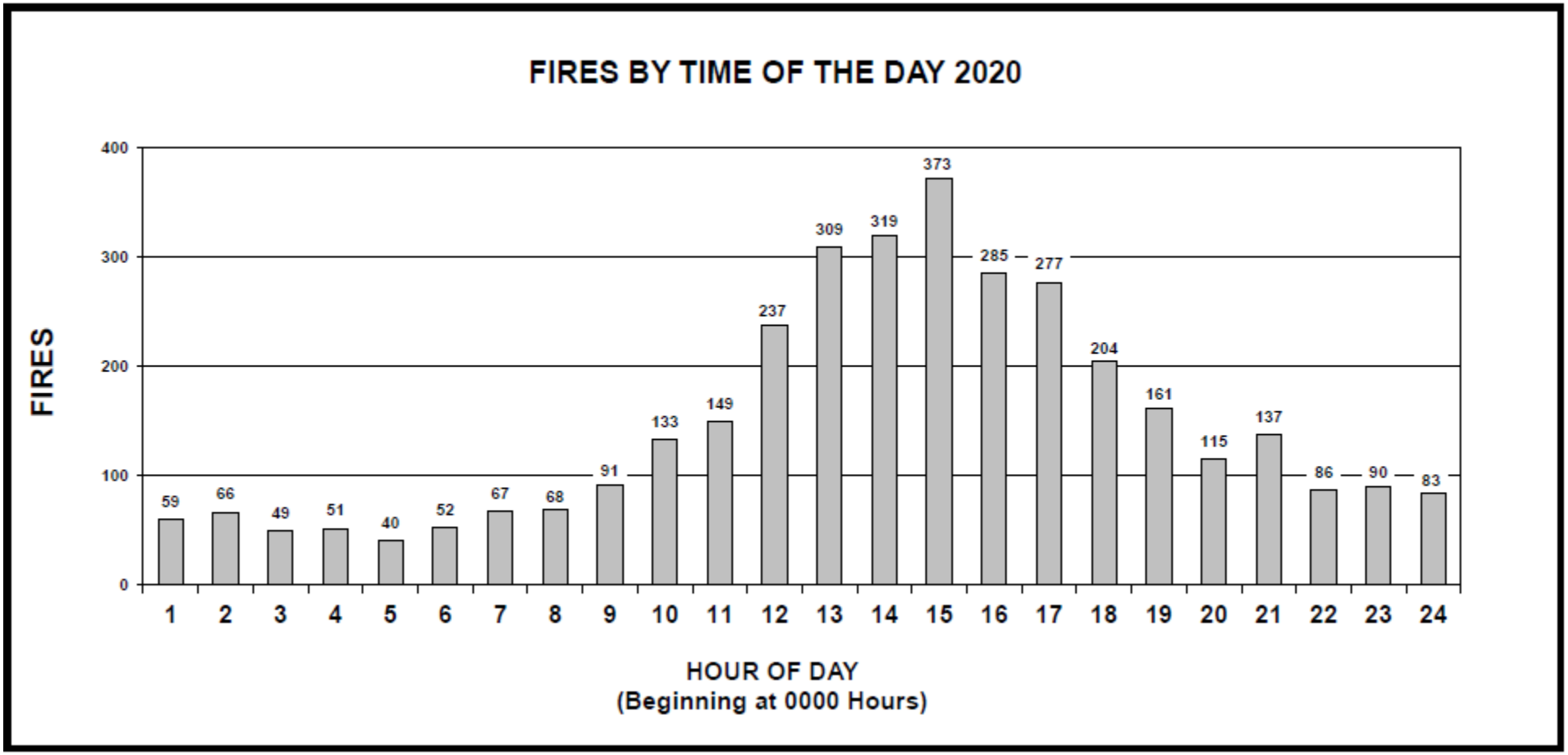


Graphic Figure 7. Number of Arson Fires and Acres — 2011-2020

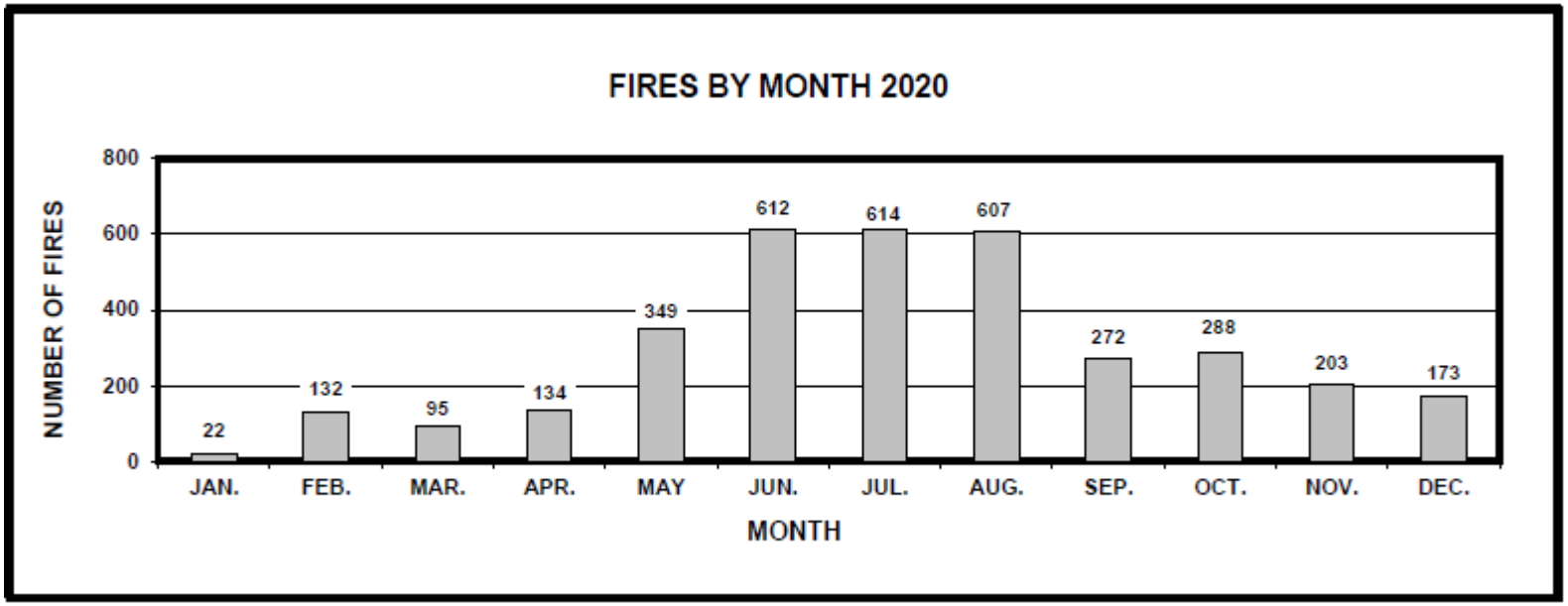


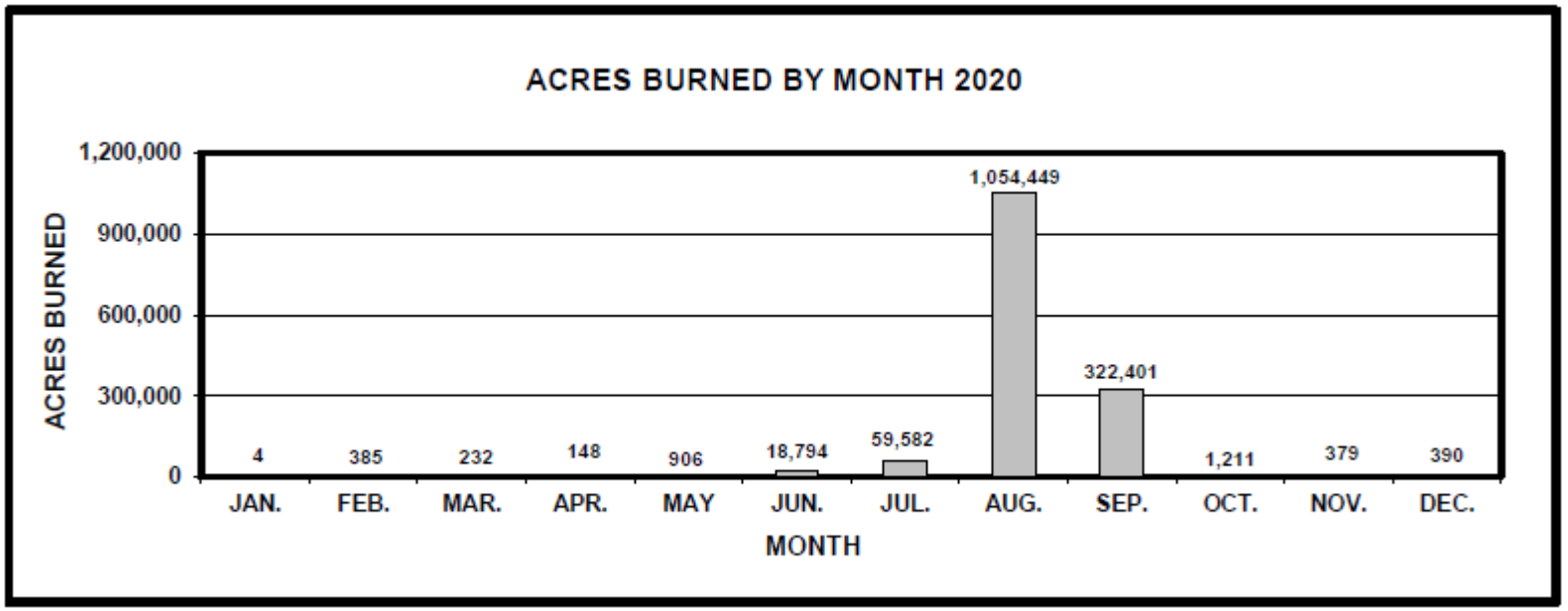


Graphic Figure 8. Number of Fires by Time of the Day

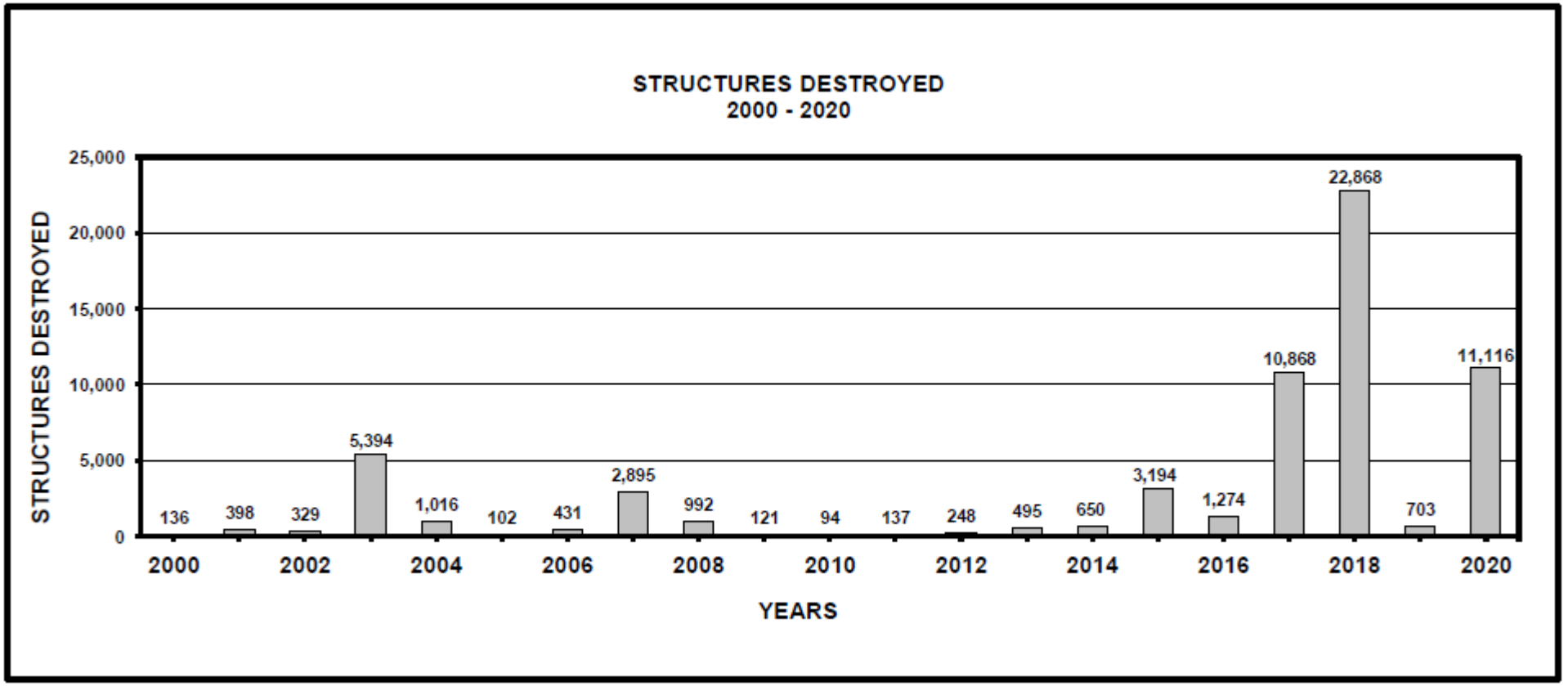


Graphic Figure 9. Number of Fires and Acres Burned by Month





Graphic Figure 10. Structures Destroyed — 1999-2020



The information on this list includes data on fire activity within the Direct Protection Areas of CAL FIRE and Contract Counties. This information is gathered from the ICS 209 incident reports, the CAL FIRE Incident Reporting System (CALFIRS), and CAL FIRE Damage Inspection (DINS) reports.

Structures Destroyed = Residence, commercial property, outbuilding or other structure that is declared lost.

2003 includes the Cedar Fire, which destroyed 2,820 structures.
2015 includes the Valley Fire, which destroyed 1,958 structures, and the Butte Fire, which destroyed 965 structures.
2016 includes the Erskine, Bluecut, Sand, and Clayton fires, which destroyed a combined total of 1,023 structures.
2017 includes the Thomas Fire, which destroyed 1,060 structures, as well as the Mendocino Lake Complex, Central LNU Complex, Southern LNU Complex and NEU Wind Complex incidents, which destroyed a combined total of 8,886 structures. These complex incidents were comprised of the Redwood Valley, Sulphur, Tubbs, Nuns, Pocket, Atlas, Cascade, La Porte, McCourtney, and Lobo fires.
2018 includes the Carr, Camp, and Woolsey fires, which destroyed 1,614 structures, 18,804 structures, and 1,185 structures, respectively.
2020 includes the group of incidents known as the “2020 Fire Siege,” which destroyed a combined total of over 9,000 structures.

GLOSSARY

ARSON – To unlawfully and intentionally damage, or attempt to damage, any real or personal property by fire or incendiary device.

CAMPFIRE – Outside fire used for cooking, warmth, lighting, ceremonial or aesthetic purposes.

CONTRACT COUNTIES – PRC §4133 and Section 55607 of the Government Code permit the CAL FIRE Director to contract with counties for protection of State Responsibility Area (SRA). In California, CAL FIRE contracts with six counties to provide fire-protection and prevention services in SRA. The counties of Kern, Los Angeles, Marin, Orange, Santa Barbara and Ventura are Contract Counties.

DEBRIS BURNING – Outside fire for vegetation, waste, or trash disposal.

DIRECT PROTECTION AREA (DPA) – The area for which a particular fire protection organization has the primary responsibility by law or contract for attacking an uncontrolled fire and directing the suppression activities.

DOLLAR DAMAGE – Estimates of the total property and contents dollar loss in terms of replacement in like kind and quantity. This estimation of the dollar loss includes property and contents damaged by fire, smoke, water, and overhaul. This does not include suppression costs or indirect loss, such as business interruption.

ELECTRICAL POWER – Fire ignited by electrical power distribution or transmission.

EQUIPMENT USE – Fire ignited by the use or failure of mechanical or electrical equipment. Does not include fire ignited by powerlines.

FOREST FIRE – A fire burning uncontrolled on land covered entirely or in part by timber, brush, grass, grain or other flammable vegetation.

LIGHTNING – Fire ignited by lightning discharge.

LOCAL GOVERNMENT – A fire department, especially of a municipal government, whose purpose is preventing and extinguishing fires.

LOCAL GOVERNMENT CONTRACT – PRC §4142 allows CAL FIRE to contract with local governments to provide fire protection and emergency services through the administration of 146 cooperative fire protection agreements in 35 of the State's 58 counties, 25 cities, 31 fire districts and 34 other special districts and service areas.

MISCELLANEOUS – Fire ignited by events or activities that are not classified as arson, campfire, debris burning, equipment use, lightning, playing with fire, powerline, railroad, smoking, vehicle, or undetermined.

OUTBUILDING – A building that is separate from a main building and located on the same property.

PLAYING WITH FIRE (P-W-F) – Fire ignited unintentionally by children while playing or experimenting with fire or fire-causing devices.

RAILROAD – Fire ignited by rail transport vehicles or fire ignited on or near railroad right-of-way.

SMOKING – Fires ignited by smoking tobacco or other smoking material; includes matches, lighters, or other heat sources used in smoking.

STATE RESPONSIBILITY AREA (SRA) – Areas of the State in which the financial responsibility of preventing and suppressing fires has been determined by the State Board of Forestry and Fire Protection, to be primarily the responsibility of the State, PRC §4102.

STRUCTURE – An assembly of materials forming a construction for occupancy or use to serve a specific purpose, includes enclosed building, fixed portable building or mobile home.

UNCONTROLLED FIRE – Any fire which threatens to destroy life, property, or resources and either: (1) is unattended by any person; (2) is attended by persons unable to prevent its unrestricted spread; and (3) is burning with such velocity or intensity that it could not be readily controlled with ordinary tools available to persons at the fire scene.

UNDETERMINED – A fire that has been investigated and has insufficient information to classify further, a fire that is under investigation, or a fire that has not yet been investigated.

VEHICLE – Fire ignited by mobile property which include: Passenger automobile, bus, school bus, off road recreational, motor home, travel trailer, camping trailer, mobile home or office designed to be towed, motorcycle or scooter.

WILDFIRE – Any uncontrolled fire spreading through vegetative fuels that threatens to destroy life, property, or resources, PRC §4103 and 4104.

WILDLAND-URBAN INTERFACE – A geographical area identified by the State as a “Fire Hazard Severity Zone” in accordance with the PRC §4201 through 4204 and Government Code §51175 through 51189, or other areas designed to be at a significant risk from wildfires.

EXHIBIT D

Top 20 Largest California Wildfires

	FIRE NAME (CAUSE)	DATE	COUNTY	ACRES	STRUCTURES	DEATHS
1	**AUGUST COMPLEX** *(Lightning)*	August 2020	Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, & Colusa	**1,032,648**	935	1
2	**DIXIE** *(Powerlines)*	July 2021	Butte, Plumas, Lassen, Shasta & Tehama	**963,309**	1,311	1
3	**MENDOCINO COMPLEX** *(Human Related)*	July 2018	Colusa, Lake, Mendocino & Glenn	**459,123**	280	1
4	**SCU LIGHTNING COMPLEX** *(Lightning)*	August 2020	Stanislaus, Santa Clara, Alameda, Contra Costa, & San Joaquin	**396,625**	225	0
5	**CREEK** *(Undetermined)*	September 2020	Fresno & Madera	**379,895**	858	0
6	**LNU LIGHTNING COMPLEX** *(Lightning/Arson)*	August 2020	Napa, Solano, Sonoma, Yolo, Lake, & Colusa	**363,220**	1,491	6
7	**NORTH COMPLEX** *(Lightning)*	August 2020	Butte, Plumas & Yuba	**318,935**	2,352	15
8	**THOMAS** *(Powerlines)*	December 2017	Ventura & Santa Barbara	**281,893**	1,060	2
9	**CEDAR** *(Human Related)*	October 2003	San Diego	**273,246**	2,820	15
10	**RUSH** (*Lightning*)	August 2012	Lassen	**271,911 CA / 43,666 NV**	0	0
11	**RIM** *(Human Related)*	August 2013	Tuolumne	**257,314**	112	0
12	**ZACA** *(Human Related)*	July 2007	Santa Barbara	**240,207**	1	0
13	**CARR** *(Human Related)*	July 2018	Shasta County & Trinity	**229,651**	1,614	8
14	**MONUMENT** (*Lightning*)	July 2021	Trinity	**223,124**	28	0
15	**CALDOR** *(Human Releated)*	August 2021	Alpine, Amador, & El Dorado	**221,835**	1,005	1
16	**MATILIJA** *(Undetermined)*	September 1932	Ventura	**220,000**	0	0
17	**RIVER COMPLEX** *(Lightning)*	July 2021	Siskiyou & Trinity	**199,359**	122	0
18	**WITCH** (*Powerlines*)	October 2007	San Diego	**197,990**	1,650	2
19	**KLAMATH THEATER COMPLEX** *(Lightning)*	June 2008	Siskiyou	**192,038**	0	2
20	**MARBLE CONE** *(Lightning)*	July 1977	Monterey	**177,866**	0	0

There is no doubt that there were fires with significant acreage burned in years prior to 1932, but those records are less reliable, and this list is meant to give an overview of the large fires in more recent times. This list does not include fire jurisdiction. These are the Top 20 regardless of whether they were state, federal, or local responsibility.

*Numbers not final.

10/24/2022

EXHIBIT
E



BUILT TO BURN

California's Wildlands Developments Are Playing With Fire

Center for Biological Diversity • February 2021



Satellite image of the 2018 Camp Fire near Paradise, California / NASA.

BUILT TO BURN:

California's Wildlands Developments Are Playing With Fire

Bold Land-use Reforms Needed Now to Ensure Safer, Sustainable Future

A report by the Center for Biological Diversity:
Tiffany Yap, DEnv/PhD, Senior Scientist
J.P. Rose, Staff Attorney
Peter Broderick, Staff Attorney
Aruna Prabhala, Urban Wildlands Program Director, Senior Attorney

February 2021
Published by the Center for Biological Diversity
BiologicalDiversity.org

Cover photo: Aftermath of the 2017 Tubbs Fire in the Coffey Park neighborhood of Santa Rosa, California / Bay Area Media Masters, CC-BY



Guenoc Valley area, where the 2020 LNU Complex Fire burned through / Drew Bird Photography

EXECUTIVE SUMMARY

Wildfires have occurred on California's landscapes for millennia. They're a natural and necessary process for many of California's ecosystems. But some of the recent fires have been exceptionally harmful to communities.

Since 2015 almost 200 people in the state have been killed in wildfires, more than 50,000 structures have burned down, hundreds of thousands have had to evacuate their homes and endure power outages, and millions have been exposed to unhealthy levels of smoke and air pollution. Meanwhile costs for fire suppression and damages have skyrocketed.

Policymakers must reckon with California's wildfire history and acknowledge that reckless land-use policies are increasing wildfire risk and putting more people in harm's way. Legislation that prioritizes the following proactive measures is needed immediately:

- Stop building new homes in highly fire-prone wildlands;
- Retrofit existing homes with high fire risk.

Where we place homes influences fire risk. Almost all contemporary wildfires in California, 95-97%, are caused by human sources such as power lines, car sparks and electrical equipment. Building new developments in highly fire-prone wildlands increases unintentional ignitions and places more people in danger.

Hotter, drier and windier conditions due to climate change make the landscape more conducive to wildfire ignitions and spread.

Most destruction to human communities from fire has been caused by wind-driven, human-ignited fires in highly fire-prone shrubland habitats. More than 2 million homes have high fire risk, and local governments

continue to approve new construction in highly fire-prone wildlands. Such reckless sprawl development endangers all Californians.

Elected officials and planners need to consider the state's complex fire history and fire ecology to implement smarter land use that protects people and native biodiversity. Many of California's ecosystems have adaptations to survive and thrive with wildfires. But long-term fire resilience is varied depending on the habitat type and fire regime (i.e., the frequency, intensity, severity, spatial complexity and seasonality of fire over time). Changes to fire regimes threaten human communities as well as native habitats and wildlife.

Increased human ignitions due to sprawl development in highly fire-prone native shrublands are harmful to people and biodiversity. Native shrubland habitats, like chaparral and sage scrub, are adapted to high severity wildfires at relatively infrequent intervals ranging between 30 to 130 years or more. But increased fire frequency in these habitats is causing type conversion to non-native grasses and forbs that burn more easily throughout more of the year. This altered fire regime endangers human communities and the unique biodiversity those habitats support.

If California policymakers continue to expand development into highly fire-prone wildlands and dismiss the need for home hardening in high fire-risk areas, then more destructive fires will ignite and more structures will burn. More people will be killed by fires and have extended exposure to hazardous smoke. More firefighters and first responders will be put at risk. Some biodiversity and unique ecosystems will be lost. Fire suppression and recovery costs will continue to rise.

We must change these destructive land-use policies and prepare our communities to safely coexist with wildfire.

CALIFORNIANS FACING UNPRECEDENTED WILDFIRE IMPACTS

Wildfires have occurred on California's landscapes for millennia. Lightning strikes and indigenous burning drove fire regimes that varied by habitat, frequency, size, extent and seasonality (Kimmerer and Lake 2001; Stephens et al. 2007; Anderson 2018).

Approximately 4.4 to 11.9 million acres of land are estimated to have burned in California every year prior to European colonization due to lightning-caused fires and cultural burning (Stephens et al. 2007). But in the past 200 years, California's highly diverse habitats and their historical fire regimes have been disrupted (Stephens and Sugihara 2018). The impacts on human communities due to these changes have now become clear.



Pyrocumulus cloud from the 2020 Ranch 2 Fire near Azusa, California / Russ Allison Loar, Flickr CC-BY-ND

Recent fires have been exceptionally destructive to California communities (Figure 1a). Based on fire records from the past 100 years, fires have become deadlier and more destructive, and large fires are occurring at an increasing rate (Stephens and Sugihara 2018). Seventeen of the 20 largest wildfires, 18 of the 20 most destructive wildfires, and 11 of the 20 deadliest wildfires have occurred after 2003 (Cal Fire 2020a, 2020b, 2020c).

Meanwhile the cost of fire suppression and damages in areas managed by the California Department of Forestry and Fire (Cal Fire) has skyrocketed to more than $23 billion during the 2015-2018 fire seasons (Figure 1b). After adjusting for inflation, this is more than double the wildfire cost for the previous 26 years of records combined. These harmful trends will continue unless policymakers reckon with the reckless land-use policies that put our communities in harm's way.

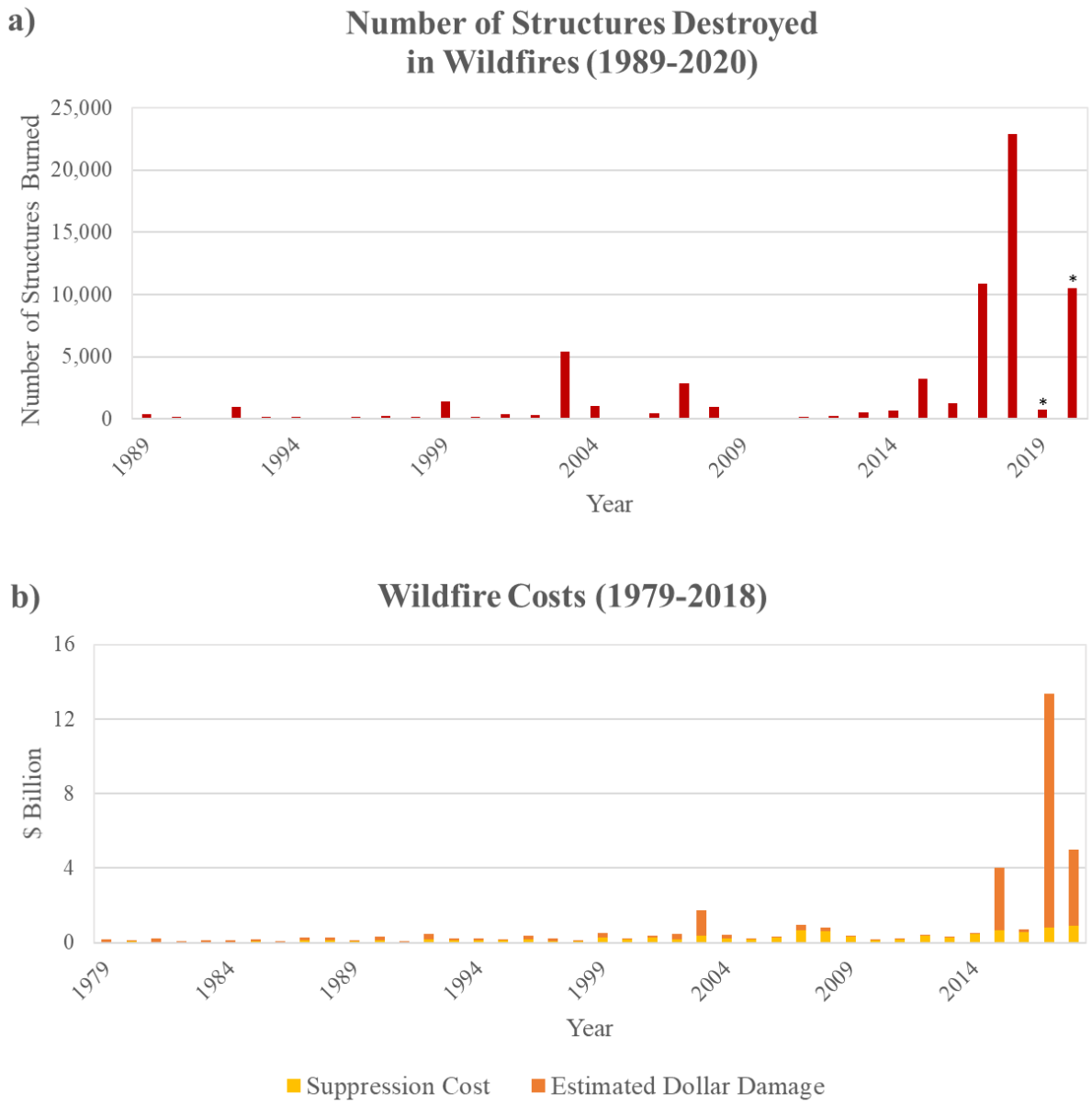


Figure 1. *Wildfire destruction and costs over time. (a) Number of structures destroyed from 1989 to 2020 (*2019 and 2020 statistics are not finalized) and (b) Cal Fire wildfire-suppression and damage costs from 1979 to 2018, adjusted for inflation. Data source: Cal Fire (https://www.fire.ca.gov/stats-events/).*



Owl soars over fire / U.S. Fish and Wildlife Service

SPRAWL DISRUPTS FIRE REGIMES AND MAKES WILDLIFE MORE VULNERABLE TO FIRE

Wildfires are a natural and necessary process in many of California's ecosystems, providing essential habitat for numerous species. For example, woodpeckers and many other animals of the Sierra Nevada rely on wildfire to create the dead trees, shrubs and post-fire vegetation within which these animals find the food they need to survive (e.g., Bond et al. 2009; Campos and Burnett 2015; Taillie et al. 2018; Blakey et al. 2019; Stillman et al. 2019). The critical role of wildfire in Sierra Nevada forests has been dramatically disrupted, however, by development, logging and fire suppression. As a result, these forests have a deficit of wildfire, meaning there's much less fire in these forests than there was historically — prior to 1800, an estimated 20 to 53 times more forest area burned each year in California than in recent decades (Stephens et al. 2007).

Researchers therefore recommend that more wildfires be allowed to burn each year in the backcountry, instead of being suppressed, in order to allow Sierra Nevada forests to rejuvenate and support the region's exceptional biodiversity. Continued sprawl development in these landscapes is an expanding impediment to efforts to restore natural fire regimes at any level.

California's shrubland habitats, on the other hand, such as chaparral and sage scrub, are experiencing a very different relationship with fire. These ecosystems are adapted to high-severity wildfires at relatively infrequent intervals ranging from 30 to 130 years or more (Keeley and Fotheringham 2001; Stephens et al. 2007; Keeley and Syphard 2018; Baker and Halsey 2020), but increased fire frequency from human ignition sources due to sprawl development is now causing these shrubland habitats to receive too much fire. This altered fire regime is the primary driver of habitat degradation and loss of biodiversity in these ecosystems (Keeley 2005) and leads to conversion of these important habitats to non-native grasses and forbs that burn more easily throughout more of the year, thereby compounding the problem of too much fire (Keeley 2005; Syphard et al. 2009; Balch et al. 2013; Sugihara et al. 2018; Syphard et al. 2019). Any additional sprawl development in these highly fire-prone habitats further undermines efforts to restore natural fire regimes and reduce human ignitions in these areas.

In addition to disrupting fire regimes, human activities have also put many of California's wild animals at risk of extinction. As a result, fire can sometimes have harmful consequences to endangered species that now only exist in very small, isolated populations due to massive habitat loss and fragmentation from sprawl development combined with other threats.

For example, two mountain lion deaths in the Santa Monica Mountains were attributed in part to the 2018 Woolsey Fire (Figure 2). Although mountain lions are highly mobile and generally able to move away from wildfires, these lions were unable to escape to safety because they were boxed in by roads and development. Such deaths can further destabilize the small mountain lion population that's already facing numerous other threats, including low genetic diversity, vehicle strikes and rodenticide poisoning, and make them more vulnerable to local extinction (Benson et al. 2016; Benson et al. 2019).

Similarly, researchers fear, post-fire landslides after the 2020 Bobcat Fire could be the end for remnant populations of sensitive species in the San Gabriel mountains that have been hard hit by sprawl development combined with disease, non-native predators and other threats, including Santa Ana suckers, unarmored threespine stickleback fish, speckled dace, arroyo chub, mountain yellow-legged frogs and western pond turtles (Figure 2) (Sahagun 2020). While historically these species would have been able to recolonize from neighboring populations after the loss of individuals or populations to fire impacts, that ability is now limited by the species' current small and fragmented population structure. Continued alteration of historical fire regimes due to sprawl development will further endanger those remnant populations.



Figure 2. *The burned paws of P-64, an adult male mountain lion whose death was attributed to the 2018 Woolsey Fire (left), and a mountain yellow-legged frog, whose remnant populations in the San Gabriel Mountains are threatened by post-fire landslides in the wake of the 2020 Bobcat Fire (right). Photo credits: National Park Service and U.S. Geological Survey (Adam Backlin).*

POOR LAND-USE PLANNING FUELS MORE DESTRUCTIVE FIRES

Reckless land-use planning is causing fires to be more destructive. Development in highly fire-prone areas increases unintentional ignitions, places more people at risk, and destroys native shrubland habitats that support high levels of biodiversity. Almost all contemporary wildfires in California (95-97%) are caused by humans in the wildland urban interface (Syphard et al. 2007; Balch et al. 2017; Radeloff et al. 2018; Syphard and Keeley 2020).

For example, the 2019 Kincade Fire, 2018 Camp and Woolsey fires, and 2017 Tubbs and Thomas fires were sparked by powerlines or electrical equipment. And although many of the 2020 fires were sparked by a lightning storm, the Apple Fire was caused by sparks from a vehicle, the El Dorado Fire was caused by pyrotechnics at a gender-reveal celebration, the Blue Ridge Fire was likely caused by a house fire, and electrical equipment is suspected to have ignited the Silverado and Zogg fires.

More than a million homes were built in the wildland-urban interface between 1990 and 2010 (Radeloff et al. 2018), and more than 2 million homes are located in high fire-risk areas (Verisk 2020). Such development in California's highly fire-prone wildlands is increasing wildfire frequency while placing more people in harm's way.

Recent fires highlight this issue: 15 of the 20 most destructive California wildfires have occurred in the past five years (Cal Fire 2020b). If current land-use practices continue, scientists estimate, 640,000 to 1.2 million new homes will be built in the state's highest wildfire-risk areas by 2050 (Mann et al. 2014), which will only worsen the devastating trend.

The contrast between the 1964 Hanly Fire and 2017 Tubbs Fire offers a poignant example of how expanding development in highly fire-prone areas increases fire risk. Both fires were caused by people: It's believed that the Hanly Fire was started by a hunter either discarding a cigarette or burning debris, while the Tubbs Fire was caused by faulty electrical equipment on private property.

These fires had similar footprints (Figure 2), yet the Tubbs Fire burned more than 5,500 structures and killed at least 22 people, while the 1964 Hanly Fire only burned about 100 structures and killed no one. From 1964 to 2017 the population of nearby Santa Rosa grew from 30,000 to 170,000 people — sprawl development had extended farther into fire-prone wildlands and put more people at fire risk (Figure 3) (Keeley and Syphard 2019).

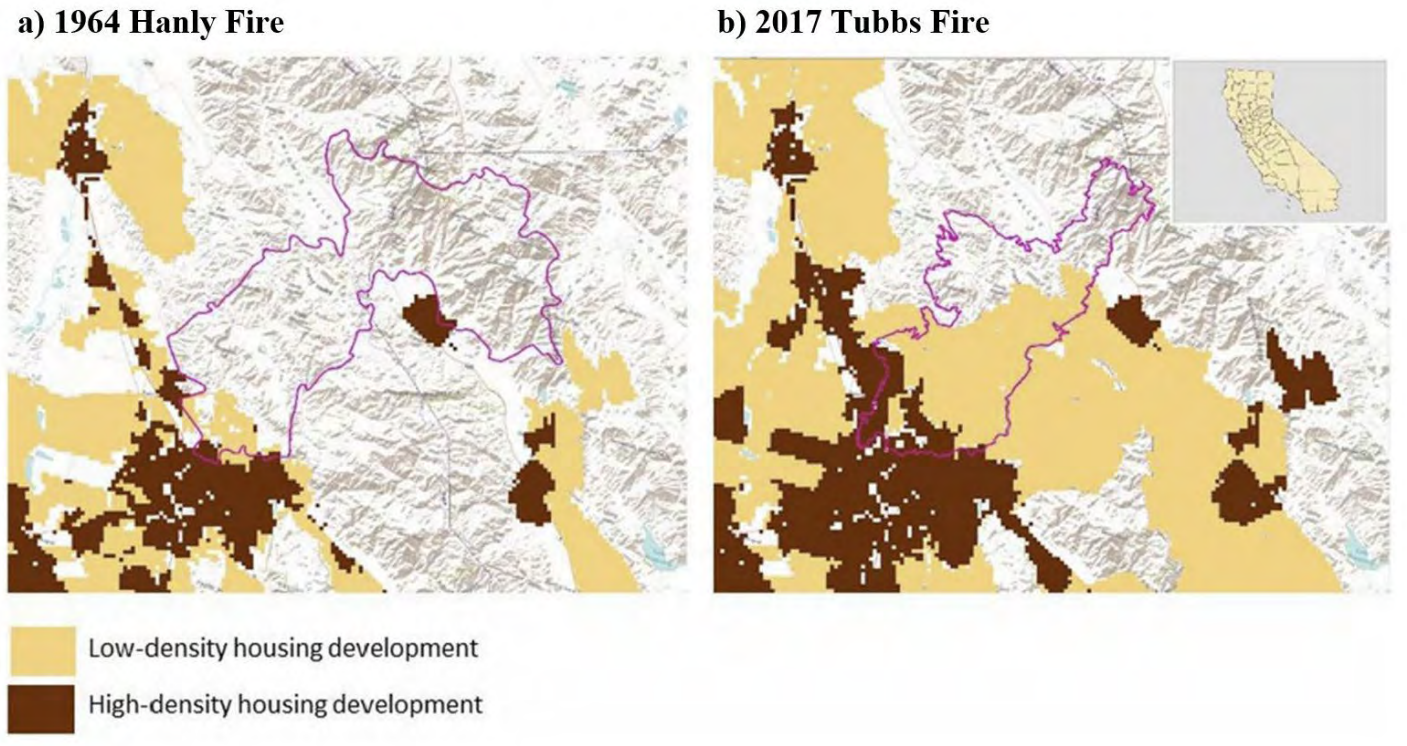


Figure 3. *A tale of two fires: the 1964 Hanly Fire (a) and the 2017 Tubbs Fire (b). Despite the simliar fire footprints (shown with the purple line), the Hanly Fire caused no deaths, and only about 100 structures were destroyed, while the Tubbs Fire killed 22 people and destroyed more than 5,500 structures. Note the extension of housing development within the fire footprint after the Hanly Fire (Keeley and Syphard 2019).*

Most destruction to human communities from fire has been caused by human-ignited fires in mixed shrubland habitats (Syphard 2020). Native shrublands like chaparral and sage scrub are highly diverse and adapted to high-intensity, relatively infrequent fires.



The 2017 Thomas Fire near the city of Ventura, California / European Space Agency

Placing developments in these highly fire-prone habitats ultimately increases fire threat over time. Continued sprawl is causing more frequent fires, which convert shrublands to non-native grasses that ignite more easily throughout more of the year. This perpetuates a dangerous cycle that increases wildfire ignitions, extends the fire season, and eliminates native shrubland habitats and biodiversity.

Wind is another important factor in wildfire risk. Foehn winds, referred to as the Santa Ana winds in the south and the Diablo or North winds in the north, commonly occur in the fall. These are dry, warm, strong winds that can spread fires dangerously fast. Winds were clocked at 40 to 95 miles per hour during the 2020 wildfire season. Wind-driven fires can cover 25,000 acres in one to two days as embers are blown ahead of the fires and toward adjacent fuels like flammable vegetation and/or structures (Syphard et al. 2011).

The 2018 Hill Fire in Ventura County spread three miles in 15 minutes (County of Los Angeles 2019). The speed at which these wind-driven fires can spread may overwhelm and outpace even the most experienced and capable agencies (County of Los Angeles 2019). And in some cases, high winds in developed areas may play a role in initiating wildfires. The 2018 Woolsey Fire, which killed three people and burned more than 1,600 structures, was sparked by powerlines that were knocked down by strong winds.

In addition, progressively hotter, drier and windier conditions due to climate change are making it easier for wildfires to ignite and spread. The number of days with extreme fire weather conditions in California has doubled since 1980, and further climate change will amplify that trend (Goss et al. 2020).

It's time for California to acknowledge that land use influences wildfire risk. Placing more homes in highly fire-prone areas increases the chances of causing larger and more destructive wildfires (Keeley and Syphard 2019; Syphard and Keeley 2020).

POLICYMAKERS CONTINUE APPROVING SPRAWL DEVELOPMENT IN HIGHLY FIRE-PRONE AREAS

Local officials continue to approve sprawl projects in high-wildfire zones. For example, in December 2018 the Los Angeles County Board of Supervisors approved the 19,000-home Centennial development in high and very high fire-hazard severity zones on the remote northern edge of the county (Agrawal 2018a). Between 1964 and 2015, Cal Fire documented 31 wildfires larger than 100 acres within five miles of the 12,000-acre development site, including four within the project's boundaries (Figure 4a) (Agrawal 2018b).

Similarly, in April 2019 the board approved the 3,150-home Northlake development, which sits in a very high fire-hazard severity zone. Multiple fires have burned the Northlake project footprint over the last few years (Figure 4b). Both projects were approved by a 4-1 vote, with Supervisor Sheila Kuehl casting the lone opposition vote.

a) Centennial Development **b) Northlake Development**

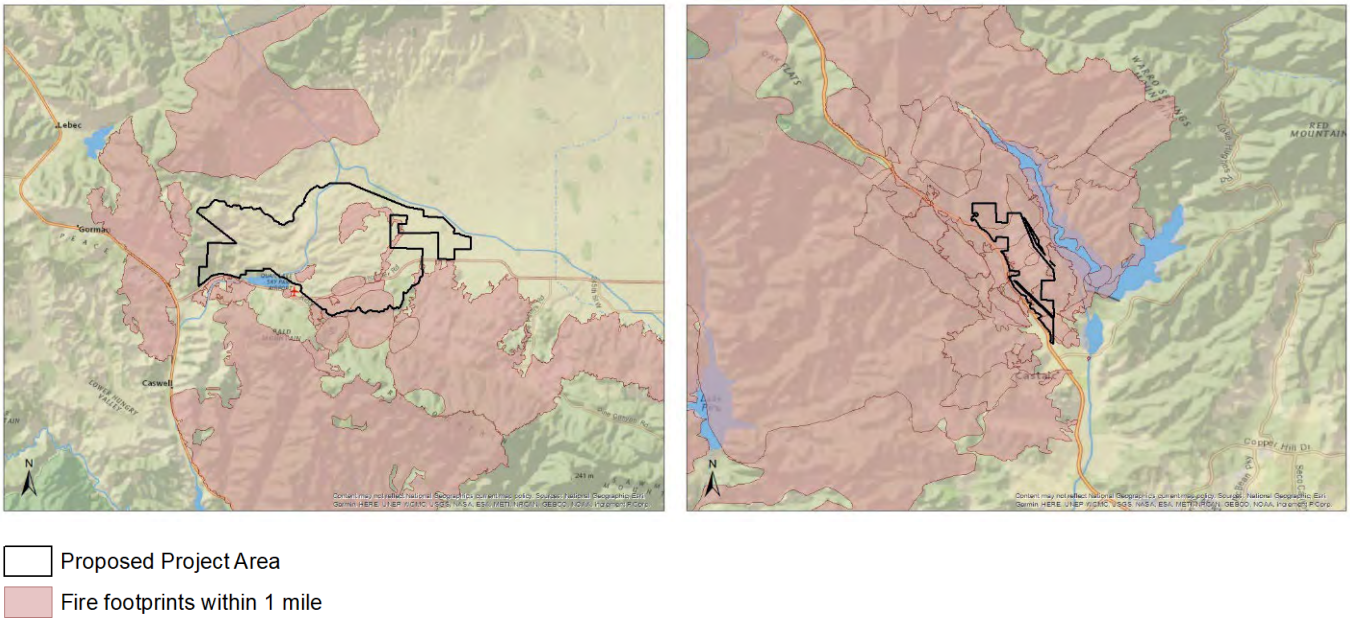


Figure 4: *Wildfire burned areas in and near the recently approved development projects of Centennial (a) and Northlake (b). Black outlines indicate development areas, and red indicates previously burned areas.*

This is a trend that's likely to continue throughout the greater Los Angeles region. The Southern California Association of Government's Regional Transportation Plan, which covers Imperial, Los Angeles, Orange, Riverside, San Bernardino and Ventura counties and was approved in September 2020, estimates that an additional 154,300 housing units will be built in very high fire-hazard zones by 2045 (SCAG 2020).

San Diego County has similarly persisted in authorizing new sprawl development in rural, highly fire-prone areas of the county. In 2018 the county approved the 2,000-unit Newland Sierra project, which would have been constructed on 2,000 acres in a very high wildfire-hazard zone. Voters repealed the county's approval by referendum in March 2020, in part due to fire concerns. Also in 2018 the county approved the fire-prone Harmony Grove South and Valiano projects, with approximately 800 combined housing units. A judge halted these projects in 2020 after finding that San Diego county hadn't adequately addressed the safety and evacuation of potential new residents.

In 2019 and 2020, San Diego County approved two more new development projects (Otay Village 14 and Otay Village 13, respectively) with over 3,000 housing units on a combined 3,000 acres in the ecologically sensitive Otay region. The project sites have been burned in several separate fires over the past two decades. In a letter to the county urging it not to approve the Otay Village 13 project, the California attorney general cited "the increased risk of wildfire that the Project will create."

Los Angeles and San Diego counties were named the top two counties in the state with the highest number of housing units located in high wildfire-risk areas (Verisk 2020). Together these counties and their local governments have recently approved the construction of more than 30,000 homes for almost 100,000 people in highly fire-prone areas (Table 1).

Table 1. *Approved development projects located in highly fire-prone areas in Los Angeles and San Diego counties. Number of people were estimated using 2019 U.S. Census data.*

County/Local Government	Approved Housing Project (Year Approved)	Number of Housing Units	Number of People	Status
Los Angeles	Centennial (2018)	19,333	57,806	Lawsuit is ongoing
Los Angeles	Northlake (2019)	3,150	9,419	Project blocked after successful litigation
San Diego	Newland Sierra (2018)	2,135	6,127	Project blocked after a successful referendum
San Diego	Harmony Grove South (2018)	453	1,300	Project blocked after successful litigation
San Diego	Valiano (2018)	326	936	Project blocked after successful litigation
San Diego	Otay Village 14 (2019)	1,119	3,212	Lawsuit is ongoing
San Diego	Otay Village 13 (2020)	1,938	5,562	Lawsuit is ongoing
City of Santee	Fanita Ranch	2,949	8,464	Lawsuit is ongoing
Total		**31,403**	**92,826**	

The problem of runaway development in risky areas is not confined to Southern California. For example, in 2020 Lake County approved a massive new luxury residential and resort project on 16,000 acres in the Guenoc Valley, northwest of Sacramento, over the objections of fire experts and the attorney general, who cited concerns about the project's risks to public safety. At the time the county was considering the project, the site had experienced at least five fires since 2006. Less than two months after the county's approval the site burned yet again in the 2020 LNU Complex Fire.

WILDFIRE IMPACTS DISPROPORTIONATELY AFFECT LOW-INCOME, MINORITY COMMUNITIES

Impacts of wildfire disproportionately affect vulnerable communities with less adaptive capacity to respond to and recover from hazards like wildfire. Low-income and minority communities, especially Native American, Black, Latinx and Southeast Asian communities, are the most marginalized groups when wildfires occur (Davies et al. 2018).

Past environmental hazards have shown that those in at-risk populations (e.g., low-income, elderly, disabled, non-English-speaking, homeless) often have limited resources for disaster planning and preparedness (Richards 2019). Vulnerable groups also have fewer resources to have cars to evacuate, buy fire insurance, implement defensible space around their homes, or rebuild, and they have less access to disaster relief during recovery (Fothergill and Peak 2004; Morris 2018; Harnett 2018; Davis 2018; Richards 2019).



The 2020 Apple Fire north of Beaumont, California / Brody Hessin, CC-BY

In addition, emergency services often miss at-risk individuals when disasters happen because of limited capacity or language constraints (Richards 2019). For example, evacuation warnings are often not conveyed to disadvantaged communities (Davies et al. 2018). In the aftermath of wildfires and other environmental disasters, news stories have repeatedly documented the lack of multilingual evacuation warnings leaving non-English speakers in danger. (Gerety 2015; Axelrod 2017; Banse 2018; Richards 2019). Survivors are left without resources to cope with the death of loved ones, physical injuries and emotional trauma from the chaos that wildfires have inflicted on their communities.

Health impacts from wildfires, particularly increased air pollution from fine particulates ($PM_{2.5}$) in smoke, also disproportionately affect vulnerable populations, including low-income communities, people of color, children, the elderly and people with pre-existing medical conditions (Künzli et al. 2006; Delfino et al. 2009; Reid et al. 2016; Hutchinson et al. 2018; Jones et al. 2020).

Increased $PM_{2.5}$ levels during wildfire events have been associated with increased respiratory and cardiovascular emergency room visits and hospitalizations, which were disproportionately higher for low socioeconomic status communities and people of color (Reid et al. 2016; Liu et al. 2017; Hutchinson et al. 2018; Jones et al. 2020). Similarly, asthma admissions were found to have increased by 34% due to smoke exposure from the 2003 wildfires in Southern California, with elderly and child age groups being the most affected (Künzli et al. 2006).

Farmworkers, who are majority people of color, often have less access to healthcare due to immigration or economic status. They are more vulnerable to the health impacts of poor air quality due to increased exposure to air pollution as they work. Yet farmworkers often have to continue working while fires burn, and smoke fills the air, or risk not getting paid (Herrera 2018; Parshley 2018; Kardas-Nelson et al. 2020).

Unprecedented California wildfires are increasing negative health impacts within and beyond its borders. A recent study found that wildfire smoke now accounts for up to 50% of ambient fine particle pollution in the western United States (Burke et al. 2021). Land-use planning must improve now.



The 2018 Camp Fire near Paradise, California / U.S. Department of Agriculture

CALIFORNIA CAN FORGE A SAFER FUTURE

Policymakers must reckon with California's wildfire history and acknowledge that reckless land-use policies are increasing wildfire risk and putting more people in harm's way. The combination of sprawl development in highly fire-prone wildlands and altered fire regimes endangers communities.

Legislation that prioritizes the following proactive measures is needed immediately:

- Stop building new homes in highly fire-prone areas;
- Retrofit existing homes with high fire risk.

Stop Building New Homes in Highly Fire-prone Wildlands

The science is clear. Placing more homes and people in highly fire-prone areas leads to more human-caused ignitions and puts more people in danger. California should prohibit new development in high fire-risk areas to keep people safe and protect its rich biodiversity.

Californians broadly support this approach — 3 out of 4 want to restrict housing developments in wildfire-prone areas, according to a 2019 poll (Dillon 2019). Yet local governments like Los Angeles and San Diego counties continue to push for sprawl development in such areas.

Developers claim that compliance with building codes written in 2008 will make their developments fire safe. This is misleading and produces a false sense of security.

While some measures can reduce fire risk, they do not make structures or communities fireproof. In an analysis that included more than 40,000 structures exposed to wildfire between 2013 and 2018 in California, many "fire-safe" structures were destroyed (Syphard and Keeley 2019). And although an analysis conducted in the aftermath of the 2017 Camp Fire showed that new building codes improved home survival, with 51% of homes built to code undamaged compared to 18% of homes built prior to 2008, about half of the homes built to fire-safety codes were still destroyed in the blaze (Kasler and Reese 2019).

The best way to limit fire risk is to avoid building homes in highly fire-prone wildlands.



The 2009 Station Fire in La Crescenta, California / Anthony Citrano, CC-BY-NC-ND

Retrofit Existing Homes With High Fire Risk

Although there are steps that can be taken to reduce risk, they do not guarantee safety from fire. Limiting new development in highly fire-prone areas is critical to reducing risk. But for homes already in high fire-risk areas, home-hardening is important to minimize the chances of human ignitions and fire spread.

It is estimated that more than 2 million homes are located in high fire-risk areas (Verisk 2020). Investing resources primarily in fire suppression without adequately addressing the human-related cause of the fires will not reduce wildfire losses (Stephens et al. 2009). State funds must be equitably distributed to retrofit existing communities in fire-prone areas to reduce the chances of unintentional ignitions and minimize spread should a fire ignite.

Retrofits should include ember-resistant vents, fire-resistant roofs and irrigated defensible space immediately adjacent to (i.e., within 100 feet of) structures. Although such features do not make homes fireproof, they have been shown to improve the chances of structure survival in fires (Syphard et al. 2014; Syphard et al. 2017). External sprinklers with an independent water source could reduce structures' flammability when fires occur (California Chaparral Institute 2018). Rooftop solar and clean energy microgrids could reduce fire risk from utilities' infrastructure during extreme weather (Roth 2019).

The state must also engage, prepare and train homeowners to harden their homes, reduce the risk of fire ignitions and spread, and be ready to safely defend their homes or evacuate early when needed (Stephens et al. 2009). As communities rebuild from recent wildfire destruction, now is the time to instill a culture of coexistence with wildfire.

California policymakers can help our state meet this crucial challenge. Strong land use policies that consider the state's diverse fire history and ecology will help improve our relationship with wildfire and ensure a safer and healthier future for both humans and wildlife.

REFERENCES CITED

Agrawal, N. (2018a, December 4). LA County considers building a new city where fire hazard is high. Is Tejon Ranch worht the risk? Los Angeles Times.

Agrawal, N. (2018b, December 11). Supervisors OK 19,000-home development at Tejon Ranch. Los Angeles Times.

Anderson, K. (2018). The Use of Fire by Native Americans in California. In J. W. Van Wagtendonk, N. G. Sugihara, S. L. Stephens, A. E. Thode, K. E. Shaffer, & J. A. Fites-Kaufman (Eds.), Fire in California's Ecosystems.

Axelrod, J. (2017, December 13). California Wildfires Spark Issues of Bilingual Emergency Communications. American City and County.

Baker, B., & Halsey, R. W. (2020). California Chaparral and Woodlands. Reference Module in Earth Systems and Environmental Sciences, 1–12.

Balch, J. K., Bradley, B. A., Abatzoglou, J. T., Nagy, R. C., Fusco, E. J., & Mahood, A. L. (2017). Human-started wildfires expand the fire niche across the United States. Proceedings of the National Academy of Sciences, 114(11), 2946–2951.

Balch, J. K., Bradley, B. A., D'Antonio, C. M., & Gómez-Dans, J. (2013). Introduced annual grass increases regional fire activity across the arid western USA (1980-2009). Global Change Biology, 19, 173–183.

Banse, T. (2018, April 20). How Do You Say 'Evacuate' in Tagalog? In a Disaster, English Isn't Always Enough. Northwest Public Broadcasting.

Benson, J. F., Mahoney, P. J., Sikich, J. A., Serieys, L. E. K., Pollinger, J. P., Ernest, H. B., & Riley, S. P. D. (2016). Interactions between demography, genetics, and landscape connectivity increase extinction probability for a small population of large carnivores in a major metropolitan area. Proceedings of the Royal Society B: Biological Sciences, 283(1837), 20160957.

Benson, J. F., Mahoney, P. J., Vickers, T. W., Sikich, J. A., Beier, P., Riley, S. P. D., … Boyce, W. M. (2019). Extinction vortex dynamics of top predators isolated by urbanization. Ecological Applications, 29(3), e01868.

Blakey, R. V., Webb, E. B., Kesler, D. C., Siegel, R. B., Corcoran, D., & Johnson, M. (2019). Bats in a changing landscape: Linking occupancy and traits of a diverse montane bat community to fire regime. Ecology and Evolution, 9, 5324–5337.

Bond, M. L., Lee, D. E., Siegel, R. B., & Ward, J. P. (2009). Habitat use and selection by California spotted owls in a postfire landscape. Journal of Wildlife Management, 73(7), 1116–1124.

Burke, M., Driscoll, A., Xue, J., Heft-Neal, S., Burney, J., & Wara, M. (2021). The changing risk and burden of wildfire in the United States. Proceedings of the National Academy of Sciences, 118(2), e2011048118.

California Department of Forestry and Fire Protection (Cal Fire). (2020a). Top 20 Deadliest California Wildfires.

California Department of Forestry and Fire Protection (Cal Fire). (2020b). Top 20 Largest California Wildfires.

California Department of Forestry and Fire Protection (Cal Fire). (2020c). Top 20 Most Destructive California Wildfires.

California Chaparral Institute. (2018). Independent external sprinklers to protect your home during a wildfire.

Campos, B. R., & Burnett, R. D. (2015). Avian Monitoring of the Storrie and Chips Fire Areas 2014 Report.

County of Los Angeles. (2019). After Action Review of the Woolsey Fire. After Action Review of the Woolsey Fire.

Davies, I. P., Haugo, R. D., Robertson, J. C., & Levin, P. S. (2018). The unequal vulnerability of communities of color to wildfire. PLoS ONE, 13(11), 1–15.

Davis, M. (2018, December 5). A tale of two wildfires: devastation highlights California's stark divide. The Guardian.

Delfino, R. J., Brummel, S., Wu, J., Stern, H., Ostro, B., Lipsett, M., … Gillen, D. L. (2009). The relationship of respiratory and cardiovascular hospital admissions to the southern California wildfires of 2003. Occupational and Environmental Medicine, 66(3), 189–197.

Dillon, L. (2019, June 18). More homes in wildfire zones? High number of Californians say no , poll says. LA

Times.
Fothergill, A., & Peak, L. A. (2004). Poverty and disasters in the United States: A review of recent sociological findings. Natural Hazards, 34, 89–110.
Gerety, R. M. (2015, September 1). Farm Workers in Wildfire Areas Aren't Always Aware of Evacuation Plans. National Public Radio Morning Edition.
Goss, M., Swain, D. L., Abatzoglou, J. T., Sarhadi, A., Kolden, C. A., Williams, A. P., & Diffenbaugh, N. S. (2020). Climate change is increasing the likelihood of extreme autumn wildfire conditions across California. Environmental Research Letters, 15.
Harnett, S. (2018, September 19). Low-Income Communities Struggle to Recover After a Wildfire. KQED.
Herrera, J. (2018, November 14). As Wildire Smoke Fills the Air, Farmworkers Continue to Labor in the Fields. Pacific Standard.
Hutchinson, J. A., Vargo, J., Milet, M., French, N. H. F., Billmire, M., Johnson, J., & Hoshiko, S. (2018). The San Diego 2007 wildfires and Medi-Cal emergency department presentations, inpatient hospitalizations, and outpatient visits: An observational study of smoke exposure periods and a bidirectional case-crossover analysis. PLoS Medicine, 15(7), e1002601.
Jones, C. G., Rappold, A. G., Vargo, J., Cascio, W. E., Kharrazi, M., McNally, B., & Hoshiko, S. (2020). Out-of-Hospital Cardiac Arrests and Wildfire-Related Particulate Matter During 2015-2017 California Wildfires. Journal of the American Heart Association, 9(8), e014125.
Kardas-Nelson, M., Alvarenga, J., & Tuirán, R. A. (2020, October 6). Farmworkers forced to put harvest over health during wildfires. Investigate West.
Kasler, D., & Reese, P. (2019, April 11). The weakest link: Why your house may burn while your neighbor's survives the next wildfire. Sacramento Bee.
Keeley, J. E. (2005). Fire as a threat to biodiversity in fire-type shrublands. Planning for biodiversity: bringing research and management together. USDA Forest Service General Technical Report PSW-GTR-195.
Keeley, J. E., & Fotheringham, C. J. (2001). Historic fire regime in southern California shrublands. Conservation Biology, 15(6), 1536–1548.
Keeley, J. E., & Syphard, A. D. (2018). South Coast Bioregion. In Fire in California's Ecosystems (pp. 319–351). Berkeley, CA: University of California Press.
Keeley, J. E., & Syphard, A. D. (2019). Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. Fire Ecology, 15(24).
Kimmerer, R. W., & Lake, F. K. (2001). The role of indigenous burning in land management. Journal of Forestry, 99(11), 36–41.
Künzli, N., Avol, E., Wu, J., Gauderman, W. J., Rappaport, E., Millstein, J., … Peters, J. M. (2006). Health effects of the 2003 Southern California wildfires on children. American Journal of Respiratory and Critical Care Medicine, 174, 1221–1228.
Liu, J. C., Wilson, A., Mickley, L. J., Ebisu, K., Sulprizio, M. P., Wang, Y., … Bell, M. L. (2017). Who among the elderly is most vulnerable to exposure to and health risks of fine particulate matter from wildfire smoke? American Journal of Epidemiology, 186(6), 730–735.
Mann, M. L., Berck, P., Moritz, M. A., Batllori, E., Baldwin, J. G., Gately, C. K., & Cameron, D. R. (2014). Modeling residential development in California from 2000 to 2050: Integrating wildfire risk, wildland and agricultural encroachment. Land Use Policy, 41, 438–452.
Morris, B. (2018, April 23). How the Ultra-Wealthy are Making Themselves Immune to Natural Disasters.
Parshley, L. (2018, December 7). The Lingering Effects of Wildfires Will Disproportionately Hurt People of Color. Vice, pp. 1–11.
Radeloff, V. C., Helmers, D. P., Kramer, H. A., Mockrin, M. H., Alexandre, P. M., Bar-Massada, A., … Stewart, S. I. (2018). Rapid growth of the US wildland-urban interface raises wildfire risk. Proceedings of the National Academy of Sciences, 115(13), 3314–3319.
Reid, C. E., Jerrett, M., Tager, I. B., Petersen, M. L., Mann, J. K., & Balmes, J. R. (2016). Differential respiratory health effects from the 2008 northern California wildfires: A spatiotemporal approach. Environmental Research, 150, 227–235.

Richards, R. (2019, July 25). After the Fire: Vulnerable Communities Respond and Rebuild. Center for American Progress.
Roth, S. (2019, March 14). California's wildfire threat could be an opportunity for clean- energy microgrids - Los Angeles Times. Los Angeles Times.
Sahagun, L. (2020, November 1). Rescue operations underway in the San Gabriel Mountains for rare species marooned by wildfire. Los Angeles Times.
Southern California Association of Governments (SCAG). (2020). Certified Final Connect SoCal Program Environmental Impact Report.
Stephens, S. L., Adams, M. A., Handmer, J., Kearns, F. R., Leicester, B., Leonard, J., & Moritz, M. A. (2009). Urban-wildland fires: How California and other regions of the US can learn from Australia. Environmental Research Letters, 4, 014010.
Stephens, S. L., Martin, R. E., & Clinton, N. E. (2007). Prehistoric fire area and emissions from California's forests, woodlands, shrublands, and grasslands. Forest Ecology and Management, 251(3), 205–216.
Stephens, S. L., & Sugihara, N. G. (2018). Fire Management and Policy since European Settlement. In J. W. Van Wagtendonk, N. G. Sugihara, S. L. Stephens, A. E. Thode, K. E. Shaffer, & J. A. Fites-Kaufman (Eds.), Fire in California's Ecosystems. UC Berkeley.
Stillman, A. N., Siegel, R. B., Wilkerson, R. L., Johnson, M., & Tingley, M. W. (2019). Age-dependent habitat relationships of a burned forest specialist emphasise the role of pyrodiversity in fire management. Journal of Applied Ecology, 56(4), 880–890.
Sugihara, N. G., Van Wagtendonk, J. W., Fites-Kaufman, J., Shaffer, K., & Thode, A. E. (2018). The Future of Fire in California's Ecosystems. In Fire in California's Ecosystems (pp. 538–544).
Syphard, A. D. (2020). A Conversation About Fire Resliency. Sierra Club Redwood Chapter Presentation.
Syphard, A. D., Brennan, T. J., & Keeley, J. E. (2014). The role of defensible space for residential structure protection during wildfires. International Journal of Wildland Fire, 23(8), 1165–1175.
Syphard, A. D., Brennan, T. J., & Keeley, J. E. (2017). The importance of building construction materials relative to other factors affecting structure survival during wildfire. International Journal of Disaster Risk Reduction, 21, 140–147.
Syphard, A. D., Brennan, T. J., & Keeley, J. E. (2019). Drivers of chaparral type conversion to herbaceous vegetation in coastal Southern California. Diversity and Distributions, 25, 90–101.
Syphard, A. D., & Keeley, J. E. (2019). Factors associated with structure loss in the 2013–2018 California wildfires. Fire, 2(3), 49.
Syphard, A. D., & Keeley, J. E. (2020). Why are so many structures burning in California. Fremontia, 47(2), 28–35.
Syphard, A. D., Keeley, J. E., & Brennan, T. J. (2011). Comparing the role of fuel breaks across southern California national forests. Forest Ecology and Management, 261(11), 2038–2048.
Syphard, A. D., Radeloff, V. C., Hawbaker, T. J., & Stewart, S. I. (2009). Conservation threats due to human-caused increases in fire frequency in mediterranean-climate ecosystems. Conservation Biology, 23(3), 758–769.
Syphard, A. D., Radeloff, V. C., Keeley, J. E., Hawbaker, T. J., Clayton, M. K., Stewart, S. I., … Hammer, R. B. (2007). Human influence on California fire regimes. Ecological Society of America, 17(5), 1388–1402.
Taillie, P. J., Burnett, R. D., Roberts, L. J., Campos, B. R., Peterson, M. N., & Moorman, C. E. (2018). Interacting and non-linear avian responses to mixed-severity wildfire and time since fire. Ecosphere, 9(6).
Verisk. (2020). FireLine State Risk Report – California.

EXHIBIT F

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COMMENTARY

The rising threats of wildland-urban interface fires in the era of climate change: The Los Angeles 2025 fires

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Received: January 13, 2025; Accepted: February 1, 2025; Published Online: February 4, 2025; https://doi.org/10.1016/j.xinn.2025.100835

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Citation: Qiu M., Chen D., Kelp M., et al., (2025). The rising threats of wildland-urban interface fires in the era of climate change: The Los Angeles 2025 fires. The Innovation **6(5)**, 100835.

The Los Angeles metropolitan area, home to over 18 million residents, has been surrounded by multiple fast-growing fires since January 7, 2025. As of January 23, these fires are estimated to have burned over 50,000 acres of land and destroyed at least 16,000 structures. Over 180,000 people have been ordered to evacuate, and at least 27 people are reported to have died in these fires. Preliminary estimates suggest that the economic loss of the Los Angeles 2025 fires could exceed 250 billion US dollars. Figure 1 shows the main areas affected by the current wildfires, a comparison with previous major wildfires, and their impacts on air quality.

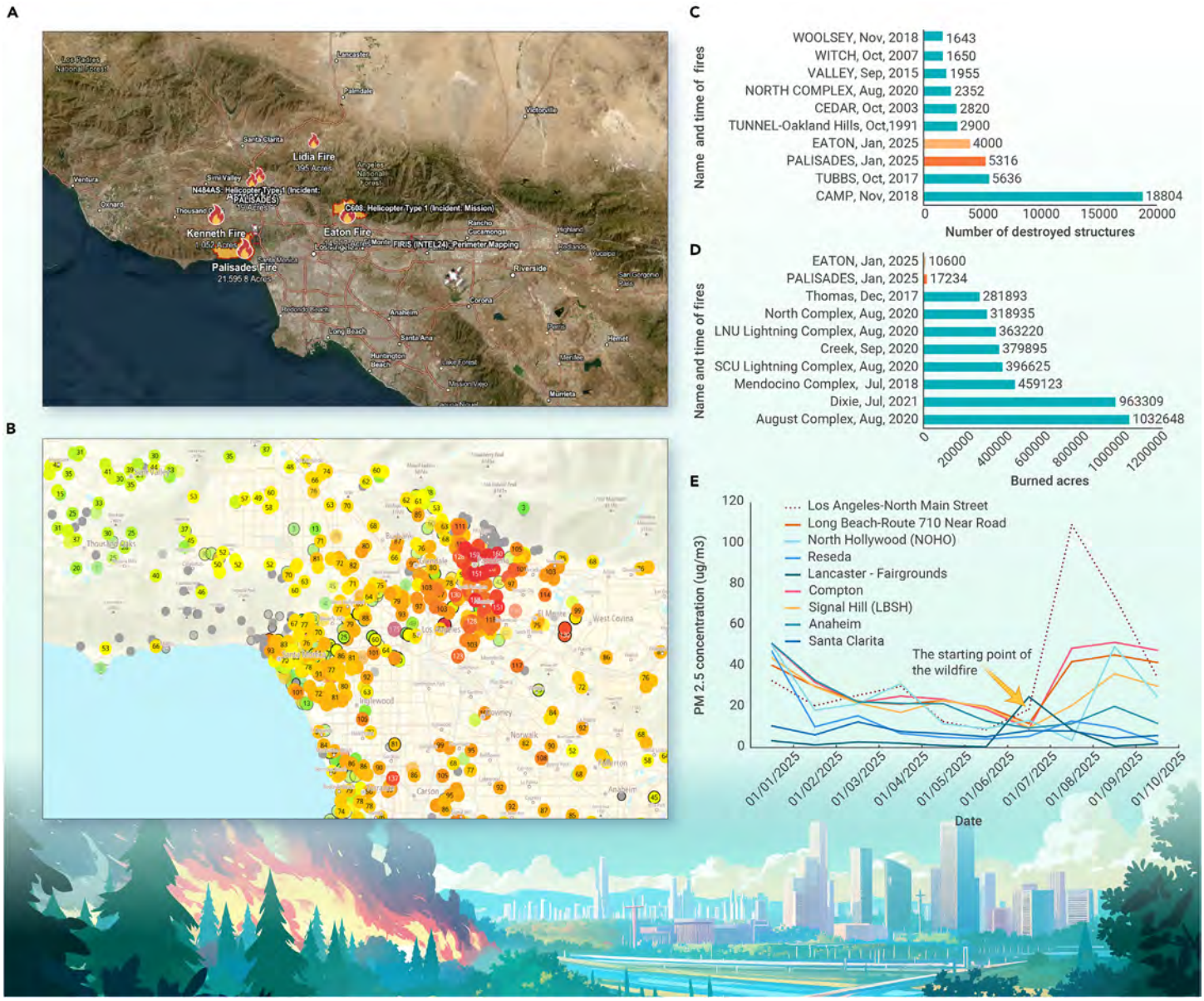


Figure 1. 2025 Los Angeles wildfires and impacts (A) Burned areas as of January 13 (data source: CalFire). (B) 7-day average PM2.5 air quality index in the Los Angeles metropolitan area from January 5 to 11 (data source: PurpleAir). (C) Comparison with the eight most destructive wildfires in California's history. (D) Comparison with the eight wildfires with the largest burned area in California's history (estimates as of January 23). (E) PM2.5 concentrations ($\mu g/m^3$) measured at monitoring sites in Los Angeles (data source: https://www.epa.gov/outdoor-air-quality-data/download-daily-data).

These fires are only the latest examples of record-breaking fires in the western US and fire-prone regions worldwide. What sets the 2025 Los Angeles fires apart, however, is their proximity to densely populated urban areas. These fires are occurring in areas extremely close to where people live—areas that are also known as the wildland-urban interface (WUI). Because of the fire point locations, these WUI fires are particularly damaging to nearby property and communities, making it difficult for people to evacuate effectively. As of January 23, the Los Angeles fires are already ranked as some of the most destructive fires in terms of the number of structures destroyed in California's history, despite its smaller burned area compared to past fires (Figures 1C and 1D).

WUI fires are increasing throughout the US, mainly driven by two reasons. First, the WUI is expanding as land-use planning has pushed houses closer to forested areas. The number of houses within wildfire boundaries in the US has doubled since the 1990s.[1] In California alone, the number of WUI houses increased by 244,000 in 2020 compared to 2010. Both Pacific Palisades and Altadena—two of the most heavily impacted communities during the 2025 Los Angeles fires—are located in the WUI, according to the US Forest Service. WUI expansions have also increased fire ignition risks from human activities. Second, the warming climate has significantly increased fuel aridity and fire weather risks, which in turn have increased the likelihood of fires in the western US. The 2025 Los Angeles fires are fueled by extreme wind conditions, with wind speeds exceeding 100 miles per hour in certain areas. These strong and dry winds, known as Santa Ana Winds in Southern California, originate from inland areas and often occur in autumn and winter. While these wind patterns are a natural phenomenon in Southern California, they increasingly overlap with hot and dry weather conditions due to climate change, and this dangerous combination creates the perfect conditions for wildfires to spread.[2]

Wildfires also create substantial damage beyond the immediate fire perimeters. Smoke generated by fires can travel far distances and negatively influence physical and mental health outcomes (Figures 1B and 1E). WUI fires might be particularly damaging to human health, as combustions of building materials release large quantities of smoke with high amounts of toxic elements (e.g., heavy metals) to population centers downwind. Beyond the direct effects on air quality, health, and economic losses, wildfires also release large quantities of greenhouse gases, which further amplify the existing climate feedback, accelerate global warming, and lead to more frequent extreme weather events in the future.

Southern California is not the only place in the world that is experiencing rising threats from WUI fires. In the summer of 2024 alone, two devastating fires also occurred in Portugal and Greece. The Greece wildfires occurred only 22 miles from its capital city, Athens. Global landscape fires (which include wildfires, agricultural fires, and prescribed burning) are estimated to lead to over 1.5 million deaths each year and are projected to continue to rise in future climate.[3] While the global mortality estimates associated with WUI fires remain unclear, the health impacts of WUI fires have emerged as an important concern given the rapid increase in burned areas of WUI fires despite a decline in total fire-burned areas.[4]

Mitigating the threats of WUI fires (and wildfires in general) requires ambitious, innovative, and comprehensive changes in a variety of public policies related to infrastructure, air quality, public health, land management, public awareness, and insurance markets. However, existing policies either do not account for the changing wildfire risks or were designed under outdated fire regimes. For example, air pollution from wildfires is often exempted from air quality regulations under the Clean Air Act, as these events are viewed as beyond the control of local jurisdictions. However, with the increasing contributions of wildfires to ambient air pollution, air quality regulations that consider wildfire pollution impacts and measures to protect public health during wildfire episodes may become necessary. Leading climate change impact assessment tools, such as those models that are used to calculate the monetary benefits of carbon emissions reductions, rarely account for the damages from climate-induced wildfires, despite a recent study finding that this damage is likely among the most costly consequences of a warming climate in the US.[5] Energy infrastructures are also widely unprepared for the rising wildfire risks—utility companies in California have already spent billions of dollars to upgrade the energy infrastructure due to the increasing wildfire risks, with the cost inequitably distributed across consumers.

These challenges highlight the urgency of global climate actions to reduce greenhouse gas emissions to limit future warming levels and ultimately control wildfire risks. At the same time, policymakers should prioritize designing and implementing adaptation strategies to increase the community's resilience to WUI fires and better protect property and human health. These strategies may include expanding fuel treatment measures (such as mechanical thinning and prescribed fires) in WUI, mitigating potential fire risk factors (such as aged power infrastructure), building defensible spaces, house hardening, and improving indoor filtration to protect health when fire and smoke do occur.

REFERENCES

1. Radeloff, V.C., Mockrin, M.H., Helmers, D. et al. (2023). Rising wildfire risk to houses in the United States, especially in grasslands and shrublands. *Science* **382**:702–707. DOI:https://doi.org/10.1126/science.ade9223.
2. Goss, M., Swain, D.L., Abatzoglou, J.T. et al. (2020). Climate change is increasing the likelihood of extreme autumn wildfire conditions across California. *Environ. Res. Lett.* **15**:094016. DOI:https://doi.org/10.1088/1748-9326/ab83a7.
3. Xu, R., Ye, T., Huang, W. et al. (2024). Global, regional, and national mortality burden attributable to air pollution from landscape fires: a health impact assessment study. *Lancet* **404**:2447–2459. DOI:https://doi.org/10.1016/S0140-6736(24)02251-7.
4. Tang, W., He, C., Emmons, L. et al. (2024). Global expansion of wildland-urban interface (WUI) and WUI fires: insights from a multiyear worldwide unified database (WUWUI). *Environ. Res. Lett.* **19**:044028. DOI:https://doi.org/10.1088/1748-9326/ad31da.
5. Qiu, M., Li, J., Gould, C. et al. (2024). Mortality burden from wildfire smoke under climate change (National Bureau of Economic Research), p. w32307. DOI:https://doi.org/10.3386/w32307.

ACKNOWLEDGMENTS

G.H. acknowledges support from NASA (#80NSSC23K0028), NSF (#2101044), and the Stony Brook OVPR Seed Grant. M.D.Y. acknowledges support from NIH (#R01ES036566). The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

EXHIBIT G

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Global expansion of wildland-urban interface (WUI) and WUI fires: insights from a multiyear worldwide unified database (WUWUI)

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IOP Publishing Environ. Res. Lett. 19 (2024) 044028 https://doi.org/10.1088/1748-9326/ad31da

ENVIRONMENTAL RESEARCH LETTERS

LETTER

Global expansion of wildland-urban interface (WUI) and WUI fires: insights from a multiyear worldwide unified database (WUWUI)

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Keywords: wildland-urban interface, fire, burned area, future projection, MODIS, fire counts, CESM2

Supplementary material for this article is available online

OPEN ACCESS

RECEIVED
11 December 2023

REVISED
26 February 2024

ACCEPTED FOR PUBLICATION
8 March 2024

PUBLISHED
19 March 2024

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Abstract

Fires in the wildland-urban interface (WUI) are an important issue globally. To understand the change of WUI, we develop a 9 km worldwide unified wildland-urban interface database for 2001–2020 with Random Forest models and satellite data. We find that WUI has been increasing in all populated continents from 2001 to 2020 and the global relative increase is 24%, with the largest relative increase (∼59%) over Africa. Global total fire counts decrease by 10% from 2005 to 2020, whereas the WUI fraction of fire counts increases by 23%. The global total burned area decreases by 22% from 2005 to 2020, whereas the WUI fraction of burned area increases by 35%. These are mainly due to the expansion of WUI area. On all the populated continents, the WUI fractions of fire counts are higher than the WUI fractions of burned area, implying that WUI fires tend to have smaller sizes than wildland fires. We also project future WUI changes for the years 2030 and 2040, together with the projection of future fire burned area under different shared socioeconomic pathways (SSP) scenarios in the Community Earth System Model version 2 (CESM2). The projected global WUI fraction (excluding Antarctica and the oceans) is 5.9% in 2040 compared to 4.8% in 2020. The global WUI fraction of burned area is projected to increase from now to 2040 under most scenarios analyzed in this study, unless the WUI area stays at the 2020 level together with the projected burned area under SSP4-4.5. This study is a first step to understanding the changes of WUI fires at the global scale and demonstrates a growing importance of WUI fires. The global multi-year WUI and WUI fire datasets developed in this study can facilitate future work quantifying the impacts of WUI fires on air quality and climate.

1. Introduction

The wildland-urban interface (WUI) is the geographic area where anthropogenic urban land use and wildland vegetation come into contact or intermingle (e.g. chAs-Amil *et al* 2013, Modugno *et al* 2016, Masoudvaziri *et al* 2021). The technical definition of WUI has not been unequivocally determined (Stewart *et al* 2009, Mell *et al* 2010, Platt 2010). Different definitions have been used in different countries/regions (e.g Theobald and Romme 2007, Galiana-Martina *et al* 2011, Herrero-Corral *et al* 2012, Chas-Amil *et al* 2013, Price and Bradstock 2014, Thomas and Butry 2014, Modugno *et al* 2016, Johnston and Flannigan 2017, Miranda *et al* 2020, Sarricolea *et al* 2020). A widely used WUI definition is the USA Federal Register definition (USDA and USDI 2001), which includes Intermix and Interface. Intermix refers to areas with $\geqslant$6.18 houses per km^2 and $\geqslant$50% cover of wildland vegetation; while Interface refers to areas with $\geqslant$6.18 houses per km^2 and $<$50% cover of vegetation located $<$2.4 km from an area $\geqslant$5 km^2 in size that is $\geqslant$75% vegetated. The USA Federal Register definition does not consider industrial structures and infrastructure while some other WUI definitions include all artificial surfaces (e.g. Modugno *et al* 2016, Johnston and Flannigan 2017).

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The concept of WUI has existed for decades in the fire management community (e.g. Davis 1990, Ewert 1993, Stewart *et al* 2007, Jaffe *et al* 2020). However, our understanding of WUI fires and their impacts on atmospheric chemistry and air quality is limited compared to that of wildland fires. Fires in WUI are an important issue and require more research and better understanding for a few reasons. (1) In WUI, there are more human ignitions compared to wildland (Price *et al* 2014, Radeloff *et al* 2018). (2) WUI fires are closer to humans and properties and can cause significant destruction and economic losses. As an example, the 2003 Cedar Fire in California destroyed more than 3000 homes (Manzello *et al* 2014). (3) WUI fires can have severe impacts on air quality and public health due to emissions of some toxic species. As an example, the emission factor of dioxins is around five orders of magnitude greater for urban fuels compared with biomass (Holder *et al* 2023). (4) WUI fires will become even more important in the future. For instance, previous studies indicated WUI is expanding in some countries or regions (e.g. Liu *et al* 2015, Radeloff *et al* 2018). Fire activities are also projected to increase due to climate change (e.g. Pechony and Shindell 2010, Flannigan *et al* 2013, Veira *et al* 2016, Abatzoglou *et al* 2019, Di Virgilio *et al* 2019, Tang *et al* 2023). Moreover, WUI expansion and fire activity increase can have a combined effect that is greater than the sum of their individual effects if WUI expands into regions of higher wildfire risk than the existing WUI (Liu *et al* 2015).

WUI fire studies have focused on just a few countries and regions in the past, even though WUI fire is a global issue (Bento-Gonçalves *et al* 2020). Recently, a global WUI map has been developed for the year 2020 at a 10 m spatial resolution (Schug *et al* 2023a, 2023b; hereafter the Schug-WUI map) to study the global distribution of WUI and WUI fires. The Schug-WUI map uses the USA Federal Register definition and is developed based on remote sensing-derived datasets (Zanaga *et al* 2021, Pesaresi and Politis 2022). However, the Schug-WUI map is only available for one specific year. To understand the changes in WUI and WUI fires, we develop a multiyear worldwide unified wildland-urban interface (WUWUI) database for 2001–2020 (Tang *et al* 2024) by leveraging Random Forest models, the Schug-WUI map, and other satellite and socioeconomic data (the WUWUI dataset can be accessed through https://zenodo.org/records/10703310). The WUWUI database provides a globally consistent picture for applications such as consistently tracking the change of global WUI, understanding WUI fires at the global scale, and intercomparing temporal evolution of WUI and WUI fires among different regions. The WUWUI dataset developed here is not intended to replace, but to complement, the existing WUI datasets. WUI maps developed specifically for regions of interest with high spatial resolution are needed when focusing on a specific region or local details. In addition, we project future WUI changes for the years 2030 and 2040, and analyze them together with projected future fire burned area under different shared socioeconomic pathways (SSP) scenarios in the Community Earth System Model version 2 (CESM2).

2. Data and methods

2.1. Data used to develop the WUWUI database

Several MODIS satellite products and population density data (summarized in table 1) are used as input predictors for the Random Forest models (table 1). These variables are chosen to include relevant information to WUI or can reflect the features of WUI, and meanwhile avoid redundant information. For the land cover type data, we calculate the fractions of each land cover type as predictors within 9 km × 9 km grids, and the mean distance between urban pixels within each grid as another predictor. For the other MODIS variables above, we calculate the means and standard deviations of each variable as predictors within each 9 km × 9 km grid (figure S1). To reflect impacts of potential spatial connections between neighboring grids, we also use the values of the aforementioned variables from the surrounding area as additional predictors for a given grid. I.e. in addition to calculating the aforementioned variables within the 9 km × 9 km, we also calculated the same variables within an 18 km × 18 km grid centered with the 9 km × 9 km grid. (figure S1).

2.2. Random forest models

We use the Schug-WUI map for 2020 (Schug *et al* 2023b) as the 'truth' map, and MODIS satellite products and population data as predictors to train a series of Random Forest models for individual continents. The WUWUI map is developed at the 9 km × 9 km (1/12 degree latitude × 1/12 degree longitude) resolution as a tradeoff between spatial resolution, performance of the Random Forest models, and usefulness for applications (e.g. typical global climate and air quality modeling). Based on our tests, at the 4 km resolution, the model performance is not as good as it is at 9 km resolution, whereas at 12 km resolution, the model performance is close to 9 km resolution. Therefore, we decide to use 9 km resolution to perform analyses. Therefore, the Schug-WUI map and predictors are all aggregated to 9 km × 9 km resolution to develop Random Forest models which predict WUI area fraction in each 9 km × 9 km grid. 75% (25%) of the data for each continent are randomly selected as a training (test) set. We use the Grid Search algorithm to optimize a few other relevant model hyper-parameters (e.g. tree numbers, the number of predictor variables to select at random for each decision split, and the threshold for the minimum size of a leaf node) to achieve the best model performance. The finally selected values for

Table 1. Satellite and population data used as input for the Random Forest models.

Data product	Versions	Spatial resolution	Temporal resolution	Variables from satellite products used	Derived variables used in the Random Forest model
MODIS/Terra + Aqua Land Cover Type Yearly	MCD12Q1 v6.1 (Friedl and Sulla-Menashe 2019)	500 m	Yearly	LC_Type1	landcover_fraction_in_the_grid_Barren, landcover_fraction_in_the_grid_Forests, landcover_fraction_in_the_grid_Savannas, landcover_fraction_in_the_grid_Urban, landcover_fraction_in_the_grid_Wetlands, landcover_fraction_in_the_grid_Croplands, landcover_fraction_in_the_grid_Grasslands, landcover_fraction_in_the_grid_Shrublands, landcover_fraction_in_the_grid_Water, urban_pixel_mean_distance_in_the_grid, urban_pixel_total_distance_in_the_grid, landcover_fraction_in_the_surrounding_grid_Barren, landcover_fraction_in_the_surrounding_grid_Forests, landcover_fraction_in_the_surrounding_grid_Savannas, landcover_fraction_in_the_surrounding_grid_Urban, landcover_fraction_in_the_surrounding_grid_Wetlands, landcover_fraction_in_the_surrounding_grid_Croplands, landcover_fraction_in_the_surrounding_grid_Grasslands, landcover_fraction_in_the_surrounding_grid_Shrublands, landcover_fraction_in_the_surrounding_grid_Water, urban_pixel_mean_distance_in_the_surrounding_grid, urban_pixel_total_distance_in_the_surrounding_grid
MODIS/Terra + Aqua Albedo Daily	MCD43A3 v6.1 (Schaaf and Wang 2015)	500 m	Daily data averaged for summer mean	Albedo_WSA_Band2, Albedo_WSA_Band5	mean_of_Albedo_Band2_in_the_grid, standard_deviation_of_Albedo_Band2_in_the_grid, mean_of_Albedo_Band5_in_the_grid, standard_deviation_of_Albedo_Band5_in_the_grid

(Continued.)

Table 1. (Continued.)

Data product	Versions	Spatial resolution	Temporal resolution	Variables from satellite products used	Derived variables used in the Random Forest model
MODIS/Terra Vegetation Indices 16-Day	MOD13Q1 v6.1 (Didan 2015)	250 m	16 days data averaged for summer mean	250 m 16 d NDVI	mean_of_summer_time_NDVI_in_the_grid, standard_deviation_of_summer_time_NDVI_in_the_grid
MODIS/Terra Vegetation Continuous Fields Yearly	MOD44B v6.1 (DiMiceli *et al* 2015)	250 m	Yearly	Percent_Tree_Cover, Percent_NonTree_Vegetation, Percent_NonVegetated	mean_of_Percent_Tree_Cover_in_the_grid, standard_deviation_of_Percent_Tree_Cover_in_the_grid, mean_of_Percent_NonTree_Vegetation_in_the_grid, standard_deviation_of_NonTree_Vegetation_in_the_grid, mean_of_Percent_NonVegetated_in_the_grid, standard_deviation_of_Percent_NonVegetated_in_the_grid, mean_of_Percent_Tree_Cover_in_the_surrounding_grid, standard_deviation_of_Percent_Tree_Cover_in_the_surrounding_grid, mean_of_Percent_NonTree_Vegetation_in_the_surrounding_grid, standard_deviation_of_NonTree_Vegetation_in_the_surrounding_grid, mean_of_Percent_NonVegetated_in_the_surrounding_grid, standard_deviation_of_Percent_NonVegetated_in_the_surrounding_grid
Population density	GHS-POP (Schiavina *et al* 2022)	1 km	Yearly	Population density	Mean_Population_Density_in_the_grid

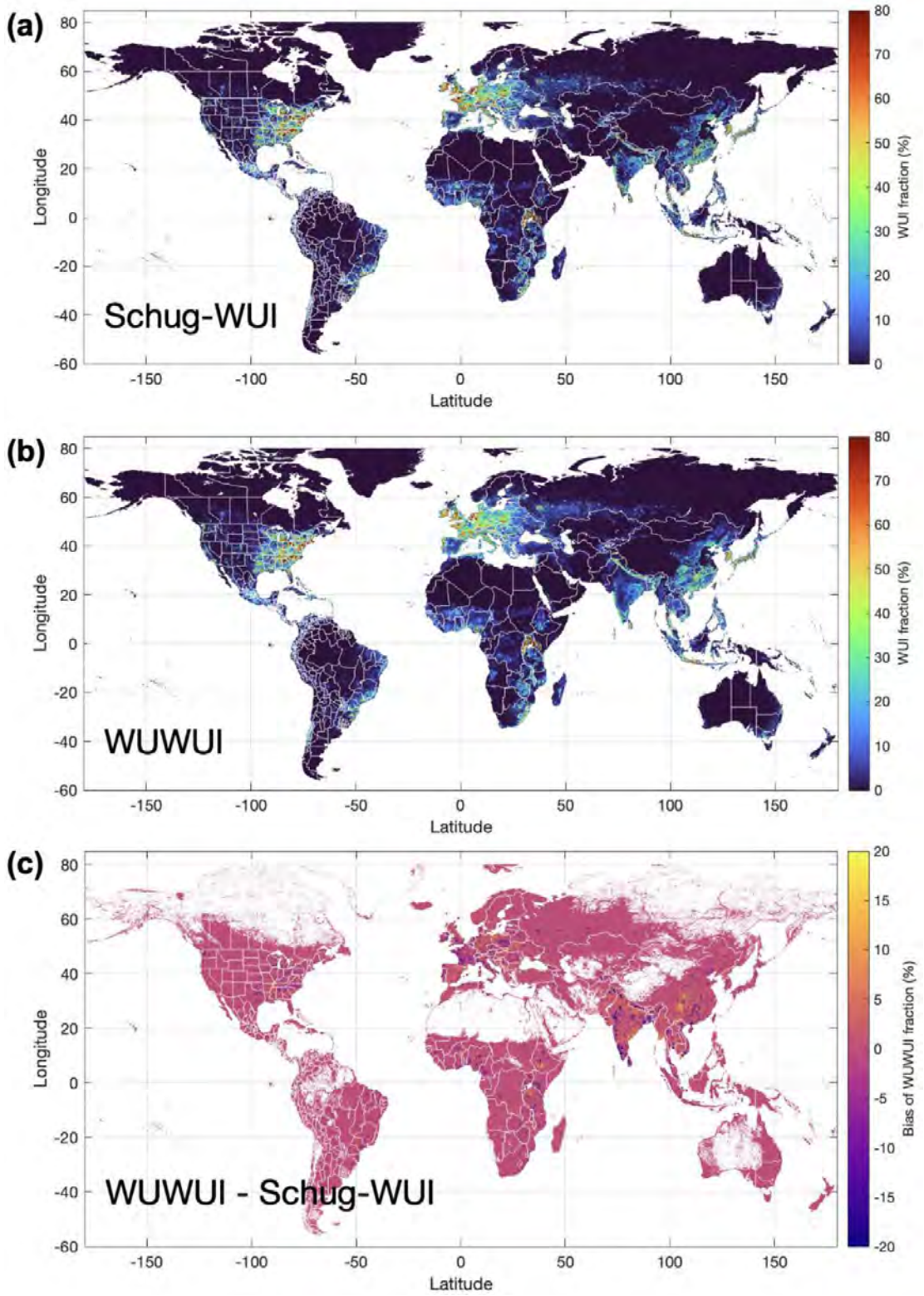


Figure 1. (a) Wildland-urban interface (WUI) fraction (%) in 2020 from the Schug-WUI map for 2020 (Schug *et al* 2023b) and (b) worldwide unified wildland-urban interface (WUWUI) data. (c) Difference (%) between (a) and (b) calculated by WUI fraction from WUWUI minus WUI fraction from the Schug-WUI map. Grids in which WUI fraction is extremely low (<0.01%) in both WUWUI and Schug-WUI map are not shown.

these parameters are 100, 44, and 3, respectively. The performance of the Random Forest models can be found in table S1. A comparison between WUWUI and Schug-WUI maps in 2020 is shown in figure 1. Overall, the Random Forest models perform well in all the six continents and the WUWUI and Schug-WUI maps agree well for the year 2020. We then use the models to predict WUI area fraction for the years of 2001, 2005, 2010, 2015, and 2020. The developed WUWUI maps are shown in figures 1 and 2.

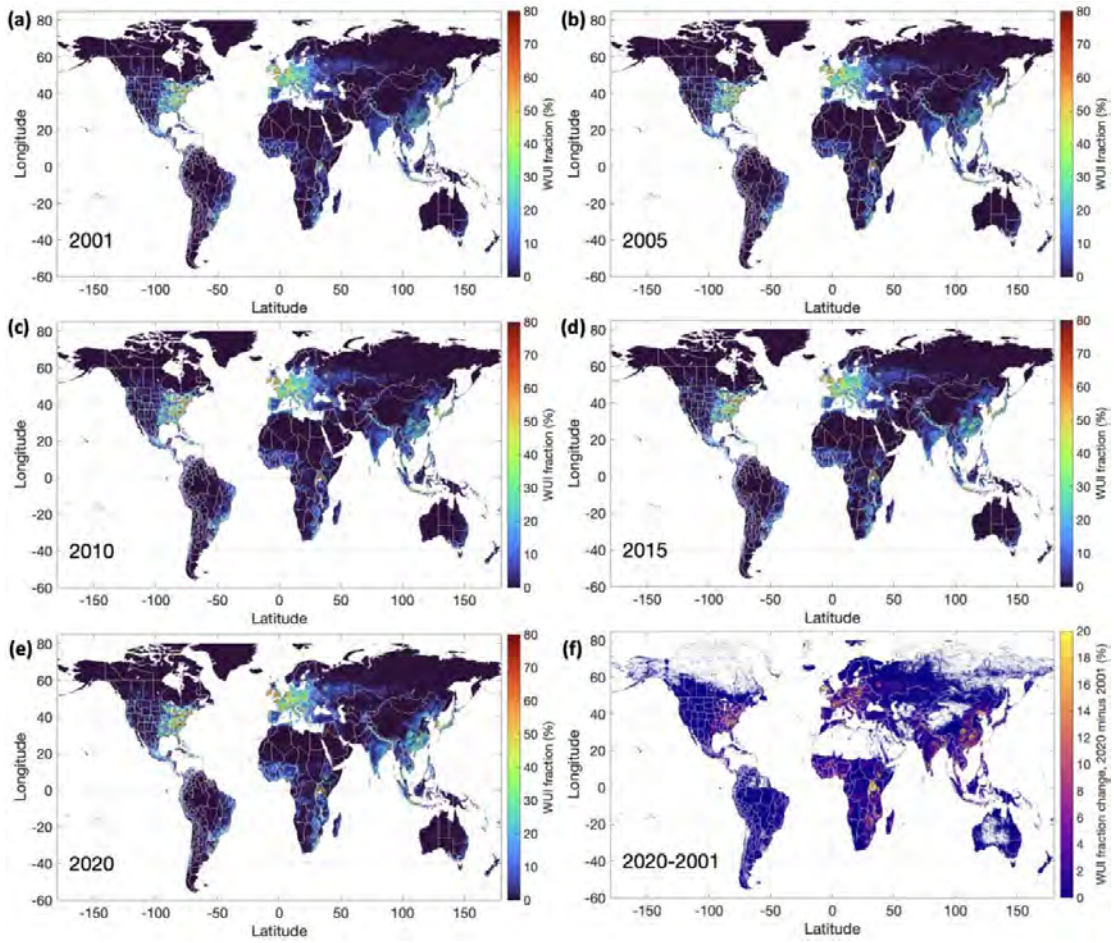


Figure 2. Wildland-urban interface (WUI) fraction (%) in (a) 2001, (b) 2005, (c) 2010, (d) 2015, and (e) 2020 from WUWUI data. (f) Wildland-urban interface (WUI) fractional (%) change from 2001 to 2020, calculated by WUI fraction in 2020 minus WUI fraction in 2001. Grids in which WUI fraction is extremely low (<0.01%) in both 2001 and 2020 are not shown.

2.3. Fire count and burned area data from MODIS

We compare the 2005, 2010, 2015, and 2020 WUWUI maps with MODIS active fire count products (NASA/University of Maryland 2002, Davies *et al* 2009) and burned area products (MODIS/Terra + Aqua Burned Area Monthly L3 Global 500 m; MCD64A1 v061; Giglio *et al* 2021) to quantify the evolution of WUI fires. Unlike WUI, fire detections and burned area have large interannual variability (e.g. Tang *et al* 2023). To address interannual variability and emphasize the trends, we use 3 year averages centered on the years of WUI data for fire counts and burned area to represent the mean fire activity. 2001 is not included due to MODIS data availability. Total fire count and burned area are calculated for each 9 km × 9 km grid. The fire counts (burned area) within WUI for a given grid is calculated by multiplying the total fire counts (burned area) within the entire grid by the WUI fraction of that grid. This calculation implicitly assumes the distribution of fire count and burned area within a grid is independent from the WUI distribution in the grid. This method is adequately accurate at 9 km based on our sensitivity analysis (see the discussion and figure S2 in the supplement for details).

2.4. Future projection of fire burned area in CESM2

The SSPs were established to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation (O'Neill *et al* 2017, Riahi *et al* 2017), which has been used in the IPCC-6 report. SSP1-2.6 (sustainable development) is the low end of the range of future forcing pathways in SSP. SSP2-4.5 is a scenario that represents the middle part of the range of future forcing pathways. SSP5-8.5 is the unmitigated baseline scenario, representing the high end of the range of future pathways.

CESM2 is a widely-used state-of-the-art community Earth system model that has components of ocean, atmosphere, land, sea-ice, land-ice, river, and wave models (Danabasoglu *et al* 2020). The fire scheme in CESM2 provides estimates of fire burned area. The modeled burned area in CESM2 is affected by climate and weather conditions, vegetation composition and structure, and human activities. In general, burned area estimation in fire models is subject

to uncertainties such as uncertainties from population density and land use and land cover change (Li *et al* 2019). Nevertheless, fire simulation in CESM2 still outperforms several other fire models in a previous comparison (Li *et al* 2019). The fire simulation in CESM2 falls in the range of observation-based fire emission inventories (Tang *et al* 2023).

The horizontal resolution for modeled burned area is 1.25° × 0.9° (longitude × latitude). The burned area data from CESM2 under the scenarios SSP1-2.6, SSP2-4.5, and SSP5-8.5 for 2020, 2030, and 2040 are used. More details on these simulations can be found in Tang *et al* (2023). Following the analyses with burned area data from MODIS, we use 3 year averages centered on the years of WUI data of fire counts and burned area.

2.5. Future projection of WUI

The WUI changes at continental scale fit well with linear trends from 2001 to 2020 (R^2 for the linear regressions vary from 0.97 to 0.99; figure S3). Therefore, we use the linear trends to project WUI fractions for 2030 and 2040 by continent. We first show the linear-projection-based results as a possible scenario for the future, assuming the WUI fractions will grow at the same rate from 2020 to 2040 as it was in the past 20 years.

Even though the WUI change in the past 20 years follows very well the linear trends, the WUI change in the future is still uncertain. To address this uncertainty, we assess 3 WUI change scenarios: (1) the WUI fraction is projected to increase from 2020 to 2040 following the same linear trend as 2001–2020; (2) the WUI fraction is projected to increase from 2020 to 2030 following the same trend as 2001–2020, and then stay at the 2030 level; (3) the WUI fraction at 2030 and 2040 will be the same as 2020. These three WUI change scenarios cover a range of possible different WUI conditions in the near future.

After projecting WUI to 2030 and 2040, we then calculate the projected fraction of burned area within WUI. The WUI fraction of burned area is calculated by multiplying the projected total burned area within a grid with the projected WUI fraction of the grid at the resolution of 1.25° × 0.9°. To reduce the uncertainty from the coarse spatial resolution of CESM model results, we apply scaling factors to correct the systematic bias due to coarse resolution (See Supplement for details).

3. Evaluation of WUWUI

We evaluate the WUWUI map against the Schug-WUI map for the year 2020, which shows very high spatial consistency (figure 1). The 2001–2020 WUI data for the conterminous United States (CONUS) downloaded from the Forest Service Research Data Archive, United States Department of Agriculture (Radeloff *et al* 2023) (hereafter USDA WUI for short) was developed following the Federal Register definition of WUI (USDA and USDI 2001), which is also used for the Schug-WUI and WUWUI maps. Therefore, here we compare WUWUI with USDA WUI map over CONUS at 9 km × 9 km resolution (figures 3 and S4). The spatial patterns of WUWUI and USDA WUI maps agree well for the years 2010 and 2020 (figure 3), given that the USDA WUI map and WUWUI were developed via different methods. USDA WUI was developed through integrating U.S. Census and USGS National Land Cover Data with geographic information systems, while the Schug-WUI map (basis for WUWUI) uses European Space Agency World Cover dataset (Zanaga *et al* 2021) for land cover and the GHS-POP dataset (Schiavina *et al* 2022) for population. The WUWUI map also agrees well with another global WUI dataset developed in Chen *et al* (2022) for the year 2020 (figure S5).

4. Change of global WUI from 2001 to 2020

The most noticeable increase in the WUI fraction from 2001 to 2020 is seen in the East Africa (figure 2(f)). The global average fraction (excluding the Antarctic and oceans) of WUI increases from 3.9% to 4.8% during 2001–2020 (figure 4(a)). The continental mean fraction of WUI is the largest in Europe (increasing from 12.4% in 2001 to 14% in 2020), followed by North America (increasing from 5.9% in 2001 to 6.5% in 2020). As for the WUI area (figure S6), North America and Asia has the largest WUI area in 2020 (1.43×10^{12} m^2 and 1.43×10^{12} m^2, respectively), followed by Europe (1.37×10^{12} m^2). In 2001, continental averaged fraction of WUI is the lowest in Africa (2.2%), but in 2020, South America has the lowest WUI fraction (2.6%). WUI has been increasing in all continents from 2001 to 2020 with different increase rates (figure 4(a)). The largest absolute increase of the WUI fraction from 2001 to 2020 occurs over Europe (0.08%/year) and Africa (0.07%/year) (figure 4(a)). In terms of the relative change (i.e. difference in the WUI fraction between 2020 and 2001 divided by the WUI fraction in 2001), Africa and Asia have the most significant increase. From 2001 to 2020, the WUI fraction in Africa has increased by 59% compared to the 2001 value.

The rapid increase in the WUI fraction combined with the large area of the Africa continent points toward an urgent need to understand and address WUI expansion and associated issues (e.g. WUI fires) in Africa. Similarly, the WUI fraction (and area) in Asia has increased by 33% in the past 20 years compared to the 2001 value. The lowest relative increase from 2001 to 2020 is seen in North America (∼11%) where the WUI fraction is already relatively high.

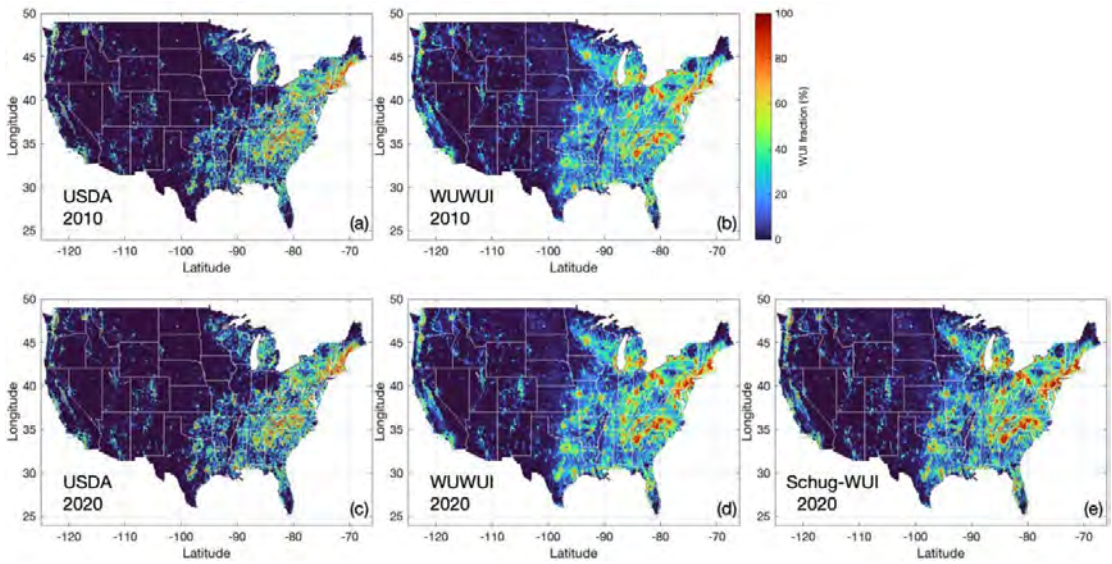


Figure 3. Wildland-urban interface (WUI) fraction (%) in 2010 from (a) USDA WUI map and (b) WUWUI database. Wildland-urban interface (WUI) fraction (%) in 2020 from (c) USDA WUI map (Radeloff *et al* 2022), (d) WUWUI database, and (e) the Schug-WUI map (Schug *et al* 2023b).

5. Changes of global WUI fires from 2005 to 2020

Globally, the WUI fraction of fire counts (figure 4(b); defined as fire counts within WUI divided by total fire counts) and the WUI fraction of burned area (figure 4(c); defined as burned area within WUI divided by total burned area) increase from 2005 to 2020. The global total fire counts and burned area decreased from 2005 to 2020 (figure S7) mainly driven by the decreased wildland fire counts and burned area (figure S9). Similar to the overall global trend, fire count and burned area per unit WUI area also decreased (figure S8), even though the total WUI fire counts and burned area increased (figure S9). Therefore, the increase of WUI fractions of fire counts and burnt area is driven by the expansion of WUI area in the past 20 years.

Specifically, the global total fire counts decrease by 10% from 2005 to 2020, whereas the WUI fraction of fire counts from 2005 to 2020 increases from 3.5% to 4.3% (i.e. relative increase of 23%). The global total burned area decreases by 22% from 2005 to 2020, whereas the WUI fraction of burned area from 2005 to 2020 increases from 1.7% to 2.3% (i.e. relative increase of 35%). The global increase of the relative importance/fraction of WUI fires (in terms of both fire count and burned area) suggests an urgent need to understand and quantify WUI fires and their impacts globally, especially in those understudied regions such as Africa.

Over Africa, the WUI fractions of both fire counts and burned area increase from 2005 to 2020 with absolute increases of 1.1% and 0.65% and relative increases of 41% and 36%, respectively, even though the total fire counts and burned area in Africa decrease from 2005 to 2020 (figure S7). The relative increase of WUI fractions of both fire counts (41%) and burned area (36%) are close to the relative increase of WUI fraction itself (46%) in Africa during 2005–2020. This suggests that the increased WUI fraction of fire activities may be mainly driven by the increase of WUI areas. The fire trends in Africa largely contribute to the global trends as Africa has the highest fire count and burned area (figure S7). Over Europe, the WUI fractions of both fire counts and burned area also increase from 2005 to 2020 with absolute increases of 2.6% and 1.5% and relative increases of 25% and 29%, respectively, even though the total fire counts and burned area in Europe decreased from 2005 to 2020 (figure S7). In Asia and South America, however, the WUI fractions of fire counts and burned area increase from 2005 to 2015 but decrease from 2015 to 2020. The overall trends are still positive. In Oceania, there is no clear trend in either the WUI fractions of fire counts or burned area from 2005 to 2020 (figure S7).

In North America, the WUI fraction of fire counts (8%–9%) is higher than the WUI area fraction (∼6%). This implies that fire risk is relatively high in WUI regions compared to non-WUI regions over North America as fire counts represents fire occurrence. The WUI fraction of fire counts increase from 2005 (8.2%) to 2010 (9.2%) and stays almost constant from 2010 (9.2%) to 2020 (9.1%). However, the WUI fraction of burned area increases during 2010–2020. In 2015, the WUI fraction of burned area is 4.5%, whereas it is 4.9% in 2020. These changes of fire counts and burned area indicate that the WUI fires in North America may become larger and more destructive from 2015 to 2020.

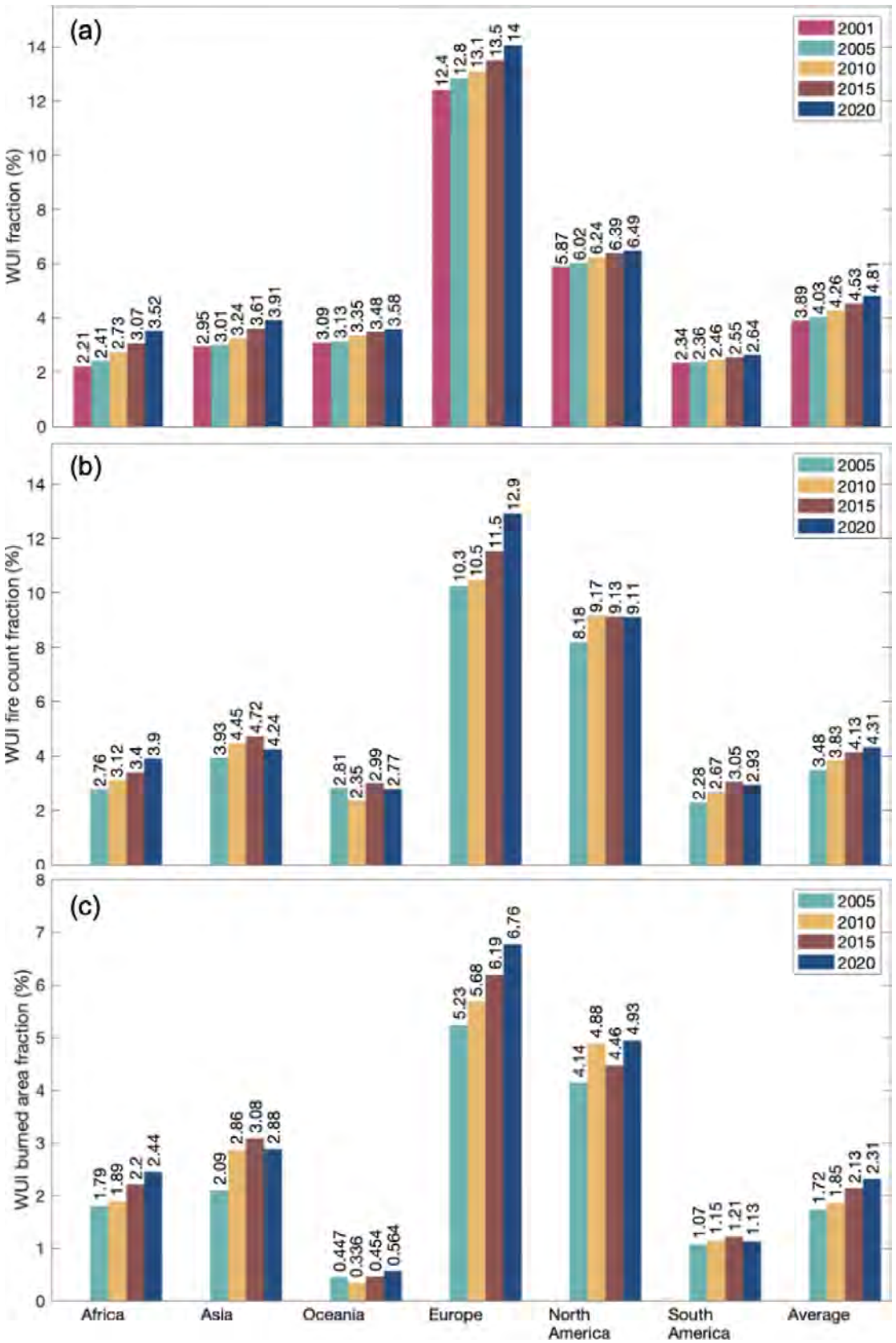


Figure 4. (a) Wildland-urban interface (WUI) fraction (%) in 2001, 2005, 2010, 2015, and 2020 by continents. (b) Fraction of fire counts within WUI (%) in 2005, 2010, 2015, and 2020 by continents. (c) Fraction of burned area within WUI (%) in 2005, 2010, 2015, and 2020 by continents. 2001 is not included in (b) and (c) due to data availability.

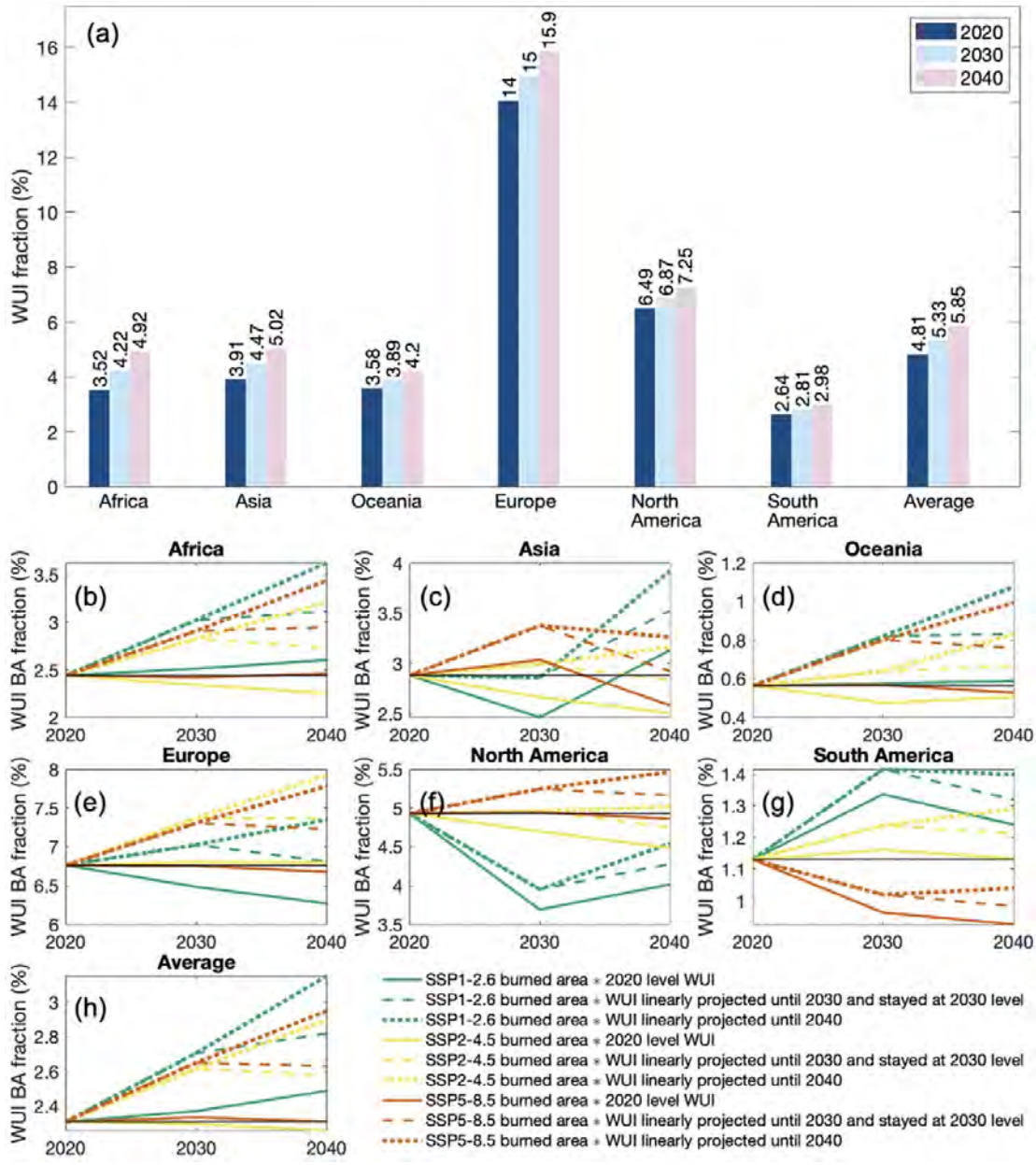


Figure 5. (a) Wildland-urban interface (WUI) fraction (%) in 2020, 2030, and 2040 by continents. (b)–(h) Fraction of burned area within WUI (%) in 2020, 2030, and 2040 under different scenarios. The fraction of burned area within WUI (%) calculated with CESM2 burned area is normalized to the fraction of burned area within WUI (%) in 2020 calculated with MODIS burned area observations (shown in figure 4). An unnormalized version is shown in figure S11.

In all six continents, the WUI fraction of fire counts is higher than that of burned area. Globally, the WUI fraction of burned area (~2%) is smaller than that of fire count (3%–4%), implying that WUI fires tend to have smaller sizes than wildland fires. This is reasonable as fire management and fire suppression activities can be different in WUI versus wildland (e.g. Stewart *et al* 2007, Jaffe *et al* 2020). WUI fires could also have different duration due to fire management (e.g. Masoudvaziri *et al* 2021) which impacts MODIS detection of active fire counts. The different changes in WUI fractions of fire counts and burned area can reflect changes in human activities and practice. In terms of the WUI fire trends, the relative increase of the WUI fraction of burned area (35%) is larger than that of fire counts (24%) globally, indicating WUI fires may become larger in size in global average sense.

6. Trends of future WUI and WUI fires at continental scale

Following the linear trends, the global average WUI fraction is projected to be 5.3% (5.9%) in 2030 (2040) if the WUI expansion follows the historical trend (figure 5(a)). Europe and North America are projected to still have the highest WUI fractions (15.9% and 7.3% in 2040, respectively). In 2040, the WUI fraction

in Africa (4.9%) is projected to be higher than that in Oceania (4.2%) and close to that in Asia (5.0%).

We combine the three future WUI scenarios with the three future burned area scenarios. The projected burned area is shown in figure S10. Globally (figure 5(h)), the only scenario under which the WUI fraction of burned area is projected to slightly decrease (2.26% in 2040) is the one with future WUI staying at the 2020 level combined with SSP2-4.5 burned area as burned area is projected to decrease under SSP2-4.5 (figure S10). Under all the scenarios with the WUI fraction linearly increasing from 2020 to 2030 or 2040, the WUI fraction of burned area will increase (2.58%–3.15% in 2040). This suggests that WUI fires will likely become more significant in the future. The trends under different scenarios vary across individual continents. In Africa, Europe, and Oceania, the WUI changes tend to play a more important role in determining the trends of future WUI fractions of burned area, whereas in Asia, North America, and South America, the future changes of burned area appear to play a more important role.

7. Conclusions

We developed a 9 km WUWUI database for 2001–2020. We then analyzed the WUI area fraction from WUWUI together with MODIS fire counts and burned area to understand the change of WUI fires. In addition, we analyzed projected changes of WUI fraction and WUI fires in 2030 and 2040. The main conclusions are as follows:

- The global average fraction (excluding the Antarctic and oceans) of WUI is 4%–5% during 2001–2020. The continental average fraction of WUI is the largest in Europe (12%–14%) and the lowest in Oceania (2%–3%).
- WUI area fraction has been increasing in all populated continents from 2001 to 2020 and the global relative increase is 24% (increased from 3.9% in 2001 to 4.8% in 2020). The largest relative increase of WUI from 2001 to 2020 occurs over Africa (59%). The lowest relative increase occurs in North America (11%), where the WUI fraction is already relatively high.
- Global total fire counts and burned area decrease by 10% and 22% from 2005 to 2020, respectively, whereas the WUI fractions of fire counts and burned area increase by 23% and 35%, respectively, mainly due to the WUI area expansion.
- Globally, the WUI fraction is projected to increase from now (4.8%) to 2040 (5.9%). The global WUI fraction of burned area is projected to increase from now to 2040 under most scenarios analyzed in this study. This indicates that WUI and WUI fires would become more important in the future. More research is needed on WUI fires and their impacts on air quality and climate.

This study is a first step to quantify the changes of WUI fires at the global scale, which paves the road for future studies of their impacts on air quality and climate. WUI fires can interact with many key elements such as air quality, urban meteorology, and health/property exposure. Given the global expansion of WUI areas and the increasing importance of WUI fires, understanding WUI fires is becoming crucial in quantifying fire characteristics in the Earth system, interactions between fires and human activities, and fire impacts on air quality and health.

Data availability statement

The WUWUI dataset can be accessed through https://zenodo.org/records/10703310 (Accessed 12 March 2023). The MCD12Q1 data is available at https://lpdaac.usgs.gov/products/mcd12q1v061/ (Accessed 16 November 2023). The MCD43A3 data is available at https://lpdaac.usgs.gov/products/mcd43a3v061/ (Accessed 17 November 2023). The MOD13Q1 data is available at https://lpdaac.usgs.gov/products/mod13q1v061/ (Accessed 17 November 2023). The MOD44B data is available at https://lpdaac.usgs.gov/products/mod44bv061/ (Accessed 31 May 2023). The GHS Population Grid Multitemporal (1975–2030)—OBSOLETE RELEASE data can be accessed through https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/GHSL/GHS_POP_GLOBE_R2022A/ (Accessed 17 November 2023). The MCD64A1 data is available at https://lpdaac.usgs.gov/products/mcd64a1v061/ (Accessed 17 November 2023). The FIRMS fire count data is available at https://firms.modaps.eosdis.nasa.gov/active_fire/ (Accessed 17 November 2023). CESM2 model results can be accessed at https://esgf-node.llnl.gov/projects/cmip6/ (Accessed 17 November 2023).

Acknowledgments

This project is supported by NOAA Atmospheric Chemistry, Carbon Cycle and Climate (AC4) Program (Award Number: NA22OAR4310204). Cenlin He was partially supported by NOAA's Climate Program Office's Modeling, Analysis, Predictions, and Projections Program (MAPP), Grant# NA20OAR4310421. This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977. We thank Schug *et al* for their global WUI map for 2020. We thank Radeloff *et al* for the WUI dataset of conterminous United States (CONUS) downloaded from the Forest Service Research Data Archive, United States Department of Agriculture. We thank the MODIS MCD12Q1, MCD43A3, MOD13Q1, MOD44B, MCD64A1, and active fire teams for the satellite data. We thank GHS-POP team for the population data.

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References

Abatzoglou J T, Williams A P and Barbero R 2019 Global emergence of anthropogenic climate change in fire weather indices *Geophys. Res. Lett.* **46** 326–36
Bento-Gonçalves A and Vieira A 2020 Wildfires in the wildland-urban interface: key concepts and evaluation methodologies *Sci. Total Environ.* **707** 135592
chAs-Amil M L, Touza J and García-Martínez E 2013 Forest fires in the wildland–urban interface: a spatial analysis of forest fragmentation and human impacts *Appl. Geogr.* **43** 127–37
Chen B, Wu S, Jin Y, Song Y, Wu C, Venevsky S, Xu B, Webster C and Gong P 2022 Wildfire risk for global wildland–urban interface (WUI) areas (https://doi.org/10.21203/rs.3.rs-2147308/v1)
Danabasoglu G *et al* 2020 The community earth system model version 2 (CESM2) *J. Adv. Model. Earth Syst.* **12** 1–35
Davies D K, Ilavajhala S, Wong M M and Justice C O 2009 Fire information for resource management system: archiving and distributing MODIS active fire data *IEEE Trans. Geosci. Remote Sens.* **47** 72–79
Davis J B 1990 The wildland-urban interface: paradise or battleground? *J. For.* **88** 26–31
Di Virgilio G, Evans J P, Blake S A P, Armstrong M, Dowdy A J, Sharples J and McRae R 2019 Climate change increases the potential for extreme wildfires *Geophys. Res. Lett.* **46** 8517–26
Didan K 2015 MOD13Q1 MODIS/terra vegetation indices 16-day L3 global 250m SIN grid V006 *NASA EOSDIS Land Processes DAAC* (available at: https://doi.org/10.5067/MODIS/MOD13Q1.006) (Accessed 05 February 2023)
DiMiceli C, Carroll M, Sohlberg R, Kim D, Kelly M and Townshend J 2015 MOD44B MODIS/terra vegetation continuous fields yearly L3 global 250m SIN grid V006 *NASA EOSDIS Land Processes DAAC* (available at: https://doi.org/10.5067/MODIS/MOD44B.006) (Accessed 05 February 2023)
Ewert A W 1993 The wildland-urban interface: introduction and overview *J. Leis. Res.* **25** 1–5
Flannigan M, Cantin A S, De Groot W J, Wotton M, Newbery A and Gowman L M 2013 Global wildland fire season severity in the 21st century *For. Ecol. Manage.* **294** 54–61
Friedl M and Sulla-Menashe D 2019 MCD12Q1 MODIS/terra+aqua land cover type yearly L3 global 500m SIN grid V006 *NASA EOSDIS Land Processes DAAC* (available at: https://doi.org/10.5067/MODIS/MCD12Q1.006) (Accessed 05 February 2023)
Galiana-Martin L, Herrero G and Solana J 2011 A wildland–urban interface typology for forest fire risk management in Mediterranean areas *Landsc. Res.* **36** 151–71
Giglio L, Justice C, Boschetti L and Roy D 2021 MODIS/terra+aqua burned area monthly L3 global 500m SIN grid V061 *NASA EOSDIS Land Processes DAAC* (available at: https://doi.org/10.5067/MODIS/MCD64A1.061) (Accessed 05 August 2023)
Herrero-Corral G, Jappiot M, Bouillon C and Long-Fournel M 2012 Application of a geographical assessment method for the characterization of wildland–urban interfaces in the context of wildfire prevention: a case study in western Madrid *Appl. Geogr.* **35** 60–70
Holder A L, Ahmed A, Vukovich J M, Rao V and Amon C H 2023 Hazardous air pollutant emissions estimates from wildfires in the wildland urban interface *PNAS Nexus* **2** pgad186
Jaffe D A, O'Neill S M, Larkin N K, Holder A L, Peterson D L, Halofsky J E and Rappold A G 2020 Wildfire and prescribed burning impacts on air quality in the United States *J. Air Waste Manage. Assoc.* **70** 583–615
Johnston L M and Flannigan M D 2017 Mapping Canadian wildland fire interface areas *Int. J. Wildland Fire* **27** 1–14
Li F *et al* 2019 Historical (1700–2012) global multi-model estimates of the fire emissions from the Fire Modeling Intercomparison Project (FireMIP) *Atmos. Chem. Phys.* **19** 12545–67
Liu Z, Wimberly M C, Lamsal A, Sohl T L and Hawbaker T J 2015 Climate change and wildfire risk in an expanding wildland–urban interface: a case study from the Colorado front range corridor *Landsc. Ecol.* **30** 1943–57
Manzello S L 2014 Special issue on wildland–urban interface (WUI) fires *Fire Technol.* **50** 7–8
Masoudvaziri N, Bardales F S, Keskin O K, Sarreshtehdari A, Sun K and Elhami-Khorasani N 2021 Streamlined wildland-urban interface fire tracing (SWUIFT): modeling wildfire spread in communities *Environ. Modell. Softw.* **143** 105097
Mell W E, Manzello S L, Maranghides A, Butry D and Rehm R G 2010 The wildland–urban interface fire problem–current approaches and research needs *Int. J. Wildland Fire* **19** 238–51
Miranda A, Carrasco J, González M, Pais C, Lara A, Altamirano A, Weintraub A and Syphard A D 2020 Evidence-based mapping of the wildland-urban interface to better identify human communities threatened by wildfires *Environ. Res. Lett.* **15** 094069
Modugno S, Balzter H, Cole B and Borrelli P 2016 Mapping regional patterns of large forest fires in wildland–urban interface areas in Europe *J. Environ. Manage.* **172** 112–26
NASA/University of Maryland 2002 MODIS hotspot/active fire detections, data set, MODIS rapid response project *NASA/GSFC (producer)* (University of Maryland, Fire Information for Resource Management System (distributors)) (available at: http://maps.geog.umd.edu,)
O'Neill B C *et al* 2017 The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century *Glob. Environ. Change* **42** 169–80
Pechony O and Shindell D 2010 Driving forces of global wildfires over the past millennium and the forthcoming century *Proc. Natl Acad. Sci. USA* **107** 19167–70
Pesaresi M and Politis P 2022 *GHS Built-up Surface Grid, Derived From Sentinel2 and Landsat, Multitemporal (1975–2030)* (European Commission, Joint Research Center)
Platt R V 2010 The wildland–urban interface: evaluating the definition effect *J. For.* **108** 9–15
Price O and Bradstock R 2014 Countervailing effects of urbanization and vegetation extent on fire frequency on the wildland urban interface: disentangling fuel and ignition effects *Landsc. Urban Plan.* **130** 81–88
Radeloff V C *et al* 2018 Rapid growth of the US wildland-urban interface raises wildfire risk *Proc. Natl Acad. Sci.* **115** 3314–9
Radeloff V C, Helmers D P, Mockrin M H, Carlson A R, Hawbaker T J and Martinuzzi S 2022 *The 1990-2020 Wildland-Urban Interface of the Conterminous United States - Geospatial Data* 3rd edn (Forest Service Research Data Archive) (https://doi.org/10.2737/RDS-2015-0012-3)
Radeloff V C, Helmers D P, Mockrin M H, Carlson A R, Hawbaker T J and Martinuzzi S 2023 *The 1990–2020 Wildland-urban Interface of the Conterminous United States–Geospatial Data* 4th edn (Forest Service Research Data Archive) (https://doi.org/10.2737/RDS-2015-0012-4)
Riahi K *et al* 2017 The shared socioeconomic path ways and their energy, land use, and greenhouse gas emissions implications: an overview *Glob. Environ. Change* **42** 153–68

Sarricolea P, Serrano-Notivoli R, Fuentealba M, Hernández-Mora M, De la Barrera F, Smith P and Meseguer-Ruiz Ó 2020 Recent wildfires in Central Chile: detecting links between burned areas and population exposure in the wildland urban interface *Sci. Total Environ.* **706** 135894

Schaaf C and Wang Z 2015 MCD43A3 MODIS/terra+aqua BRDF/albedo daily L3 global—500m V006 *NASA EOSDIS Land Processes DAAC* (available at: https://doi.org/10.5067/MODIS/MCD43A3.006) (Accessed 05 February 2023)

Schiavina M, Freire S and MacManus K 2022 GHS-POP R2022A—GHS population grid multitemporal (1975–2030)—obsolete release (European Commission, Joint Research Centre)

Schug F *et al* 2023a The global wildland–urban interface *Nature* **621** 94–99

Schug F *et al* 2023b Map of the global wildland-urban interface (1.1) *Zenodo* (https://doi.org/10.5281/zenodo.7941460)

Stewart S I, Radeloff V C, Hammer R B and Hawbaker T J 2007 Defining the wildland–urban interface *J. For.* **105** 201–7

Stewart S I, Wilmer B, Hammer R B, Aplet G H, Hawbaker T J, Miller C and Radeloff V C 2009 Wildland-urban interface maps vary with purpose and context *J. For.* **107** 78–83 (available at: www.fs.usda.gov/research/treesearch/34152)

Tang W 2024 Worldwide Unified Wildland-Urban Interface (WUWUI) database (Version v2) *Zenodo* (https://doi.org/10.5281/zenodo.10703310)

Tang W, Tilmes S, Lawrence D M, Li F, He C, Emmons L K, Buchholz R R and Xia L 2023 Impact of solar geoengineering on wildfires in the 21st century in CESM2/WACCM6 *Atmos. Chem. Phys.* **23** 5467–86

Theobald D M and Romme W H 2007 Expansion of the US wildland–urban interface *Landsc. Urban Plan.* **83** 340–54

Thomas D S and Butry D T 2014 Areas of the US wildland–urban interface threatened by wildfire during the 2001–2010 decade *Nat. Hazards* **71** 1561–85

USDA and USDI 2001 Urban wildland interface communities within the vicinity of federal lands that are at high risk from wildfire *Fed. Regist.* **66** 751–77

Veira A, Lasslop G and Kloster S 2016 Wildfires in a warmer climate: emission fluxes, emission heights, and black carbon concentrations in 2090–2099 *J. Geophys. Res. Atmos.* **121** 3195–223

Zanaga D *et al* 2021 ESA WorldCover 10 m 2020 v100 *Zenodo* (available at: https://zenodo.org/record/5571936)

EXHIBIT H

Rapid growth of the US wildland-urban interface raises wildfire risk

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Edited by Janet Franklin, University of California, Riverside, CA, and approved February 6, 2018 (received for review October 28, 2017)

The wildland-urban interface (WUI) is the area where houses and wildland vegetation meet or intermingle, and where wildfire problems are most pronounced. Here we report that the WUI in the United States grew rapidly from 1990 to 2010 in terms of both number of new houses (from 30.8 to 43.4 million; 41% growth) and land area (from 581,000 to 770,000 km^2; 33% growth), making it the fastest-growing land use type in the conterminous United States. The vast majority of new WUI areas were the result of new housing (97%), not related to an increase in wildland vegetation. Within the perimeter of recent wildfires (1990–2015), there were 286,000 houses in 2010, compared with 177,000 in 1990. Furthermore, WUI growth often results in more wildfire ignitions, putting more lives and houses at risk. Wildfire problems will not abate if recent housing growth trends continue.

wildfires | housing growth | sprawl | development | fragmentation

The wildland-urban interface (WUI), defined as the area where houses are in or near wildland vegetation, is the area where wildfires pose the greatest risk to people due to the proximity of flammable vegetation (1). Wildfires frequently burn houses in the WUI (2, 3), and are most difficult to fight there. Furthermore, the WUI is where people often ignite wildfires (4), and the vast majority of fires are human-caused (5). While fires are an integral part of many ecosystems and the Earth system as a whole (6), humans have changed fire regimes globally (7) and throughout the United States (5), and climate change will increase fire frequency in the future, including in the WUI (8).

The close proximity of houses and wildland vegetation does more than increase fire risk (9). As houses are built in the WUI, native vegetation is lost and fragmented (10); landscaping introduces nonnative species and soils are disturbed, causing nonnatives to spread (11); pets kill large quantities of wildlife (12); and zoonotic disease, such as Lyme disease, are transmitted (13). Thus, understanding WUI patterns and WUI growth is important with respect to wildfires and many other environmental problems.

The WUI is widespread in the United States (1, 14) and in many other parts of the world (15, 16), including Argentina (17), Australia (18), France (19), and South Africa (20). Furthermore, both the annual area burned (8, 21, 22) and fire suppression costs (23) have rapidly increased in the United States. The area burned annually nearly doubled, from an average of 18,000 km^2/y in 1985–94 to 33,000 km^2 in 2005–14 (22). Concomitantly, federal wildfire suppression expenditures tripled from $0.4 billion/y to $1.4 billion/y (23), and exceeded $2 billion in 2017.

While there is ample evidence that houses in the WUI pose problems, it is not clear how fast the WUI is growing. Overall, the US population grew by 60 million people and 29.2 million homes from 1990 to 2010, but how much of that growth occurred in the WUI is uncertain. Previous assessments of WUI growth (24, 25) analyzed only housing data up to 2000, and did not account for changes in wildland vegetation. Post-2000 housing data are important, because the United States entered a recession after 2008, accompanied by a strong downturn in the housing market. Similarly, without data on vegetation change, the major cause of WUI growth is unclear. Areas where forests are regrowing on abandoned farmland, such as in the New England states (26), could see WUI growth without any additional houses. Fundamentally, two processes can create new WUI: construction of new homes in or near existing wildland vegetation, and an increase in wildland vegetation within and near previously developed areas. The prevalence of each process is unclear.

Knowing how the WUI is growing, and why, is essential when evaluating management and policy responses (3, 8). In the United States, federal wildfire management policy prioritizes fuel treatments and the promotion of fire-adapted communities in the WUI. Local jurisdictions use a variety of land use planning tools to limit the environmental impacts of housing growth in the WUI. The importance of the WUI for the environment and for national policy, accompanied by the lack of information about WUI growth in the most recent decade, highlight the need to both assess WUI growth and identify its causes. Thus, we addressed three major questions: (*i*) how much has the WUI in the conterminous United States grown from 1990 to 2010; (*ii*) whether WUI growth is caused mainly by housing growth or by vegetation growth; and (*iii*) how much WUI growth has occurred within recent wildfire perimeters.

The lack of consistent, fine-resolution longitudinal housing data has been the biggest impediment to a nationwide assessment

Significance

When houses are built close to forests or other types of natural vegetation, they pose two problems related to wildfires. First, there will be more wildfires due to human ignitions. Second, wildfires that occur will pose a greater risk to lives and homes, they will be hard to fight, and letting natural fires burn becomes impossible. We examined the number of houses that have been built since 1990 in the United States in or near natural vegetation, in an area known as the wildland-urban interface (WUI), and found that a large number of houses have been built there. Approximately one in three houses and one in ten hectares are now in the WUI. These WUI growth trends will exacerbate wildfire problems in the future.

Author contributions: V.C.R., M.H.M., P.M.A., A.B.-M., V.B., T.J.H., S.M., A.D.S., and S.I.S. designed research; V.C.R., D.P.H., and H.A.K. performed research; V.C.R., D.P.H., H.A.K., V.B., T.J.H., and S.M. analyzed data; and V.C.R., H.A.K., M.H.M., P.M.A., A.B.-M., T.J.H., S.M., A.D.S., and S.I.S. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1718850115/-/DCSupplemental.

Published online March 12, 2018.

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of WUI growth. The decennial US Census provides fine-resolution housing data for 1990, 2000, and 2010, but the boundaries of the smallest units for which housing units are reported (i.e., census blocks) often shift between decades, precluding direct change analyses (27). We have developed algorithms to convert the decennial Census data at census block resolution into a consistent dataset on housing growth across the conterminous United States (*Methods*), which we combined with 1992, 2001, and 2011 National Land Cover Data (NLCD) on wildland vegetation: forests (classes 41–43), shrublands (classes 51 and 52), grasslands (class 71), and woody wetlands (class 90). We mapped decadal WUI change from 1990 to 2010 within 2010 census block boundaries, based on the WUI definitions in the *Federal Register* and our previously developed WUI mapping algorithms (1, 14), and conducted several robustness checks of our new dataset (*Supporting Information*). Because of concerns about housing growth and wildfire management, we calculated housing growth for 1990–2010 within WUI burned areas identified in Landsat imagery between 1990 and 2015 (22).

We found that the WUI was widespread in 2010, covering 9.5% of the conterminous United States (Fig. 1), and that the WUI grew rapidly from 1990 to 2010 in all its aspects (Fig. 2).

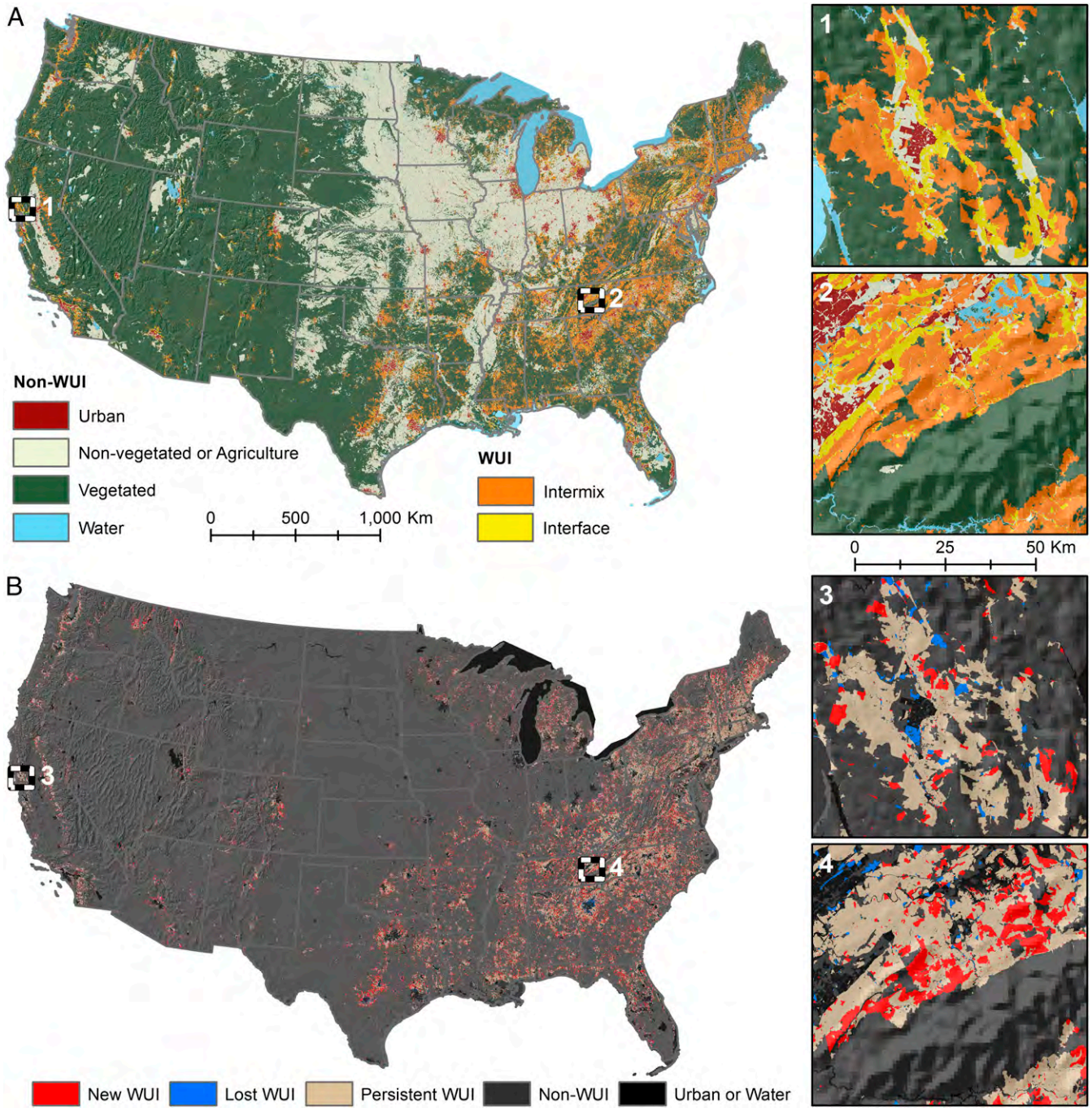


Fig. 1. The WUI in the United States was widespread in 2010 (*A*), as were changes in WUI area (*B*), for example, in and around Santa Rosa, California (1, 3), and Gatlinburg, Tennessee (2, 4), areas where wildfires destroyed many homes in 2017 and 2016, respectively.

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The number of housing units ("houses" hereinafter) in the WUI grew fastest, followed by the number of people in the WUI and then WUI area (Fig. 2*B* and Table S1). New WUI area totaled 189,000 km^2, an area larger than Washington State. At 33%, WUI area growth is faster than that of any of the level I land cover categories included in the NLCD (28). Increases in houses and people were also strong, with 12.7 million more houses and 25 million more people in the WUI in 2010 compared with 1990. The overall combination of more WUI area (7.2% of the conterminous United States in 1990 vs. 9.5% in 2010; Fig. 2*C*) and higher growth rates for both houses and people in the WUI, compared with the nationwide averages (Table S1), increased the percentage of houses (from 30.3% to 33.2%) and people (from 29.4% to 31.9%) in the WUI from 1990 to 2010 (Fig. 2*C*). Even though the WUI occupies less than one tenth of the land area of the conterminous United States, 43% of all new houses were built there, and 61% of all new WUI homes were built in areas that were already in the WUI in 1990 (and remained in the WUI in 2010) (Tables S1 and S2).

There are two main types of WUI: intermix WUI, the area where houses and wildland vegetation directly intermingle, and interface WUI, where settled areas abut wildland vegetation (1). We found that intermix WUI was both more extensive and expanded much more rapidly in area (from 5.6% to 7.5% of the conterminous United States from 1990 to 2010) than interface WUI (from 1.6% to 2.0%). However, interface WUI had higher housing growth rates (43% from 1990 to 2010) than intermix WUI (38%) and non-WUI areas (23%; Table S1). In absolute numbers, there were 4.7 million more houses in the intermix WUI and 8.0 million more in the interface WUI in 2010 than in 1990.

Regional differences in WUI growth were striking (Fig. 3). The highest absolute gains in WUI area occurred in the East, whereas high gains in houses and people in the WUI were most common in the South and Southwest. Absolute gains are most relevant for management agencies, because they indicate how much area and how many people and houses may require management actions; however, rapid growth often garners the most attention. Across the United States there is an interesting dichotomy in that states in the East had large absolute gains, but relatively low WUI growth rates, largely because WUI was already so widespread in 1990. In contrast, states in the northern Rockies saw much smaller absolute gains in WUI area and houses, but rapid WUI growth rates.

New WUI areas arise either when new houses are built in or near wildland vegetation or when wildland vegetation regrows in or near settled areas. Between these two possible causes, housing growth was unambiguously the main cause for new WUI areas, with increases in vegetation contributing minimally. Of all new WUI areas, 97% were caused by housing growth in sparsely settled areas, pushing these areas over the threshold of 1 house per 40 acres (6.17 homes/km^2). Only 2% of new WUI area was due to vegetation growth alone, and 1% was due to the combination of both housing and vegetation growth (Table S2). Similarly, new houses were the cause of >80% of WUI growth in all states except Delaware, the District of Columbia, Maryland, and New Jersey (Fig. S1).

Among areas that were WUI in 1990, the vast majority were still WUI in 2010, and both homes and population increased in those areas over that time (Table S2). A small proportion (6%) of the 1990 WUI areas dropped out of the WUI by 2010. Among all WUI changes (i.e., gains and losses combined), 13% of the changes in WUI area and 23% of the changes in WUI houses from 1990 to 2010 were losses. In terms of the causes of WUI area loss, reduced housing density was the most important (65.0%), whereas the loss of vegetation accounted for 32.6%. Housing density may have declined due to actual removal of housing units, or possibly due to enumeration errors in the Census data. Loss of vegetation was the dominant driver of loss of homes from the WUI (65.0%), which occurred largely in densely settled areas where additional housing development, deforestation, or fuel management may have removed wildland vegetation.

The number of houses within burned areas in the different decades is a strong indication of how much WUI growth can exacerbate wildfire problems. In 1990, there were 177,000 houses within the perimeters of the fires that occurred in the subsequent 25 y. By 2010, there were 286,000 housing units in the same fire perimeters, i.e., 109,000 more, which corresponds to 62% growth (far outpacing the average US housing growth rate of 29%). Of these new houses, those built before the wildfires occurred complicated firefighting because more houses had to be protected and more residents had to be evacuated. Similarly, houses built after fires occurred are of concern because new development in areas that burned recently, and thus are known to have a high fire risk, suggests that there is little adaptation to fire risk (2).

Our results provide compelling evidence that the WUI in the United States has grown rapidly, despite the risks that wildfires pose to homes and lives (3) and despite the other environmental problems caused by housing development in or near wildland vegetation (9). Our findings are generally in alignment with previous studies that found rapid previous WUI growth (24) and widespread potential for future WUI growth (25, 29), even though absolute numbers are not comparable because of differences in WUI definitions, datasets, and time periods (30). Furthermore, the WUI is not unique to the United States, but is widespread in many other countries as well (15, 16, 18–20). Rampant WUI growth demonstrates that the social and economic factors that together propel WUI growth are strong. WUI areas are attractive places to live because of affordability and ready access to natural settings and recreation (31). As WUI areas attract new residents, the number of houses per capita often increases as well, due to increasing rates of seasonal homeownership and declining family size (32). Indeed, despite the economic downturn after 2008, the absolute number of

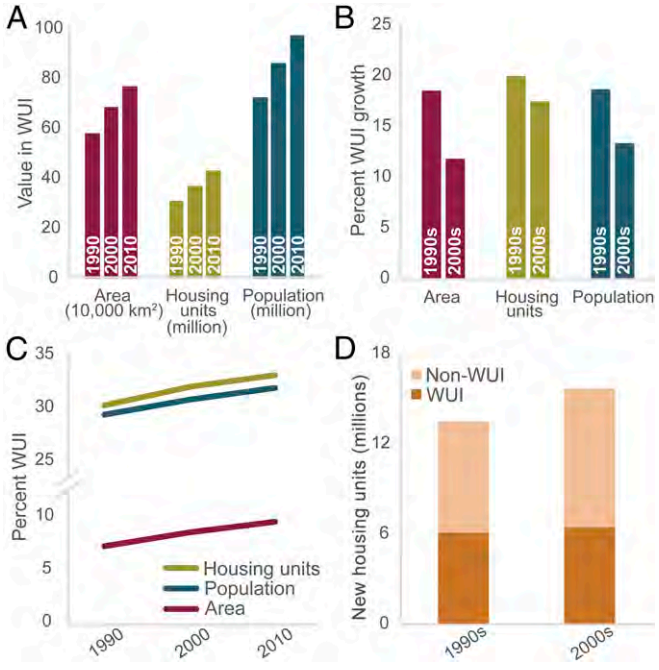


Fig. 2. WUI growth was rapid in terms of the absolute numbers of the area, houses, and people in the WUI in 1990, 2000, and 2010 (*A*); WUI growth rates during the 1990s and the 2000s (*B*); the proportion of all houses and people, as well as the land area in the WUI in 1990, 2000, and 2010 (*C*); and the absolute number of all new housing units within and outside the WUI during the 1990s and 2000s (*D*).

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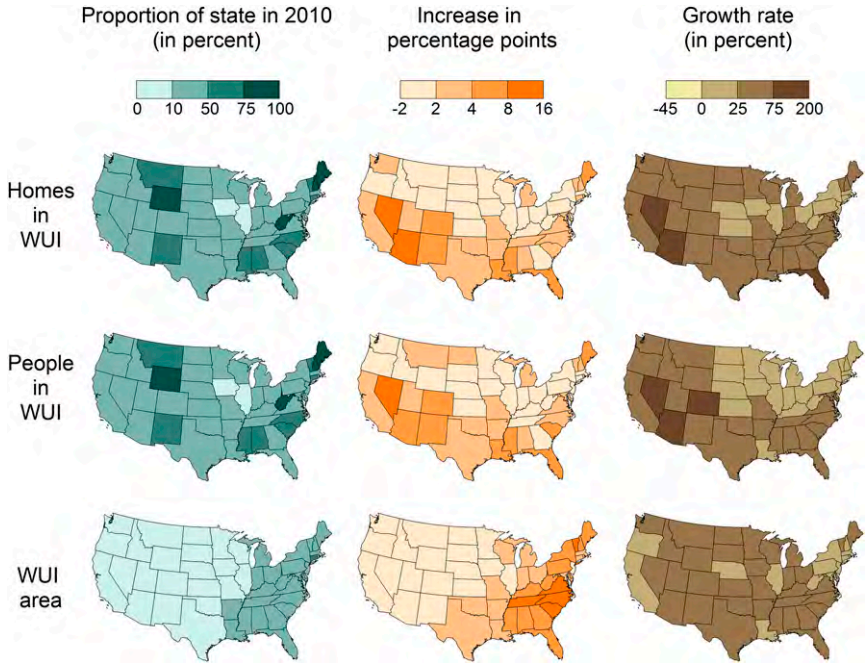


Fig. 3. WUI growth differed greatly among states, especially in the Southwest versus the Southeast, in terms of houses in the WUI, people in the WUI, and WUI area, calculated as the percentage of the state total in 2010, change in the WUI percentage from 1990 to 2010, and the growth rate (in percent) of the WUI from 1990 to 2010. Only the District of Columbia had negative absolute growth in the WUI (homes, people, and area). Fig. S2 summarizes these metrics at the county level.

houses built in the WUI, and in the United States as a whole, was higher between 2000 and 2010 than between 1990 and 2000 (Table S1). Demographic trends do not suggest slower future WUI growth. Furthermore, climate change projections indicate that conditions favorable for wildfires will occur more frequently in the future (8). Thus, increased wildfire ignition rates due to WUI expansion will initiate more wildfires in vegetation that is more susceptible to fire spread, leading to more widespread fires and possibly more severe fire behavior (33). This suggests that WUI growth and climate change together will compound the existing problems with wildfires in the WUI.

As WUI growth continues, there are many management options and policy tools to consider for addressing both wildfire and other environmental problems. Just as WUI-related problems involve actors (e.g., homeowners, community leaders) at many levels, so too must their solutions involve actors at multiple levels (i.e., local, regional, state, and national) (3, 8). Homeowners can reduce their individual fire risk by removing vegetation directly adjacent to their house (i.e., the home ignition zone; refs. 3 and 34), changing roofing and building materials, and following additional Firewise recommendations (35). To limit some of the other environmental problems associated with living in the WUI, homeowners can keep cats inside and dogs on a leash, limit fertilizer and pesticide use, and landscape with native plants (9). To reduce wildfire impacts, communities can coordinate fuel reduction efforts, educate homeowners, train firefighters, and establish wildfire management plans. Insurance companies can offer reduced premiums for communities taking mitigation action to incentivize community-level efforts to reduce wildfire losses. Communities and local jurisdictions could anticipate wildfires and environmental impacts more explicitly when planning future land use to avoid housing expansion in high-risk wildfire areas and other environmentally sensitive areas (36). State and federal agencies typically do not regulate development directly, but can allocate resources to areas experiencing rapid WUI growth, support local and regional planning efforts, and provide important research data and information to help communities adapt to fire-prone environments. Agencies managing public lands could consider targeted purchases of private inholdings to limit future housing growth within the administrative boundaries of public lands, which has been particularly rapid (37). In summary, there are many concrete management actions and policy responses that can limit the negative effects of WUI growth on wildfire risk and other environmental problems, but changes will require efforts at all levels by homeowners and community leaders, local and county governments, and state and federal agencies.

Housing development in the WUI greatly exacerbates wildfire problems and other environmental issues in the United States (1, 5, 8), and globally (16, 18–20). Our results highlight the magnitude and rapid rates of WUI growth in the US, underscoring the urgency of identifying what can be done to address WUI growth and its associated wildfire challenges (3). Past federal fire policy has focused largely on fighting and preventing wildfires and on fuel reduction, public outreach campaigns, and other actions (38). Although laudable, such efforts are unlikely to be successful by themselves, because housing growth is clearly the dominant cause of WUI growth, as well as a major factor contributing to wildfire occurrence and cost. As long as WUI growth is unchecked, wildfire problems will likely worsen. On a more hopeful note, to the extent that WUI growth reflects an affinity for nature, the evident consequences and costs of growth could prompt discussions on how to sustain those highly valued ecosystems in which so many people have chosen to live.

Materials and Methods

Our WUI definition is based on the definition published by the US government in the *Federal Register* (39) and that has been widely used for WUI assessments in the past (1, 14, 40). It specifies two types of WUI, intermix and interface. Intermix WUI is where houses and wildland vegetation intermingle, with both a housing density of >1 house per 40 acres (6.17 houses/km^2) and >50% of the area in wildland vegetation. Interface WUI represents settled areas that have <50% vegetation, but lie within

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1.5 miles (2.4 km) of a densely vegetated area (at least 75% wildland vegetation) that is at least 5 km^2 in size (so that settlements near small urban parks are not included in the WUI).

Our WUI assessment was based on two main datasets: US Census data, which provided housing data (TIGER shape files for block boundaries, plus Census summary files for attribute data), and the US Geologic Survey's NLCD, which provided information on wildland vegetation. We derived housing data from the US Decennial Censuses for 1990, 2000, and 2010 at its finest resolution, the census block level. However, a major obstacle to conducting change analyses is that census block boundaries frequently change from one decade to the next, preventing direct change analyses (27). Indeed, 62% of all blocks changed their boundaries from 1990 to 2000, and 56% changed from 2000 to 2010, invalidating any housing density change analysis that does not account for these boundary changes. We used additional information available from the US Census Bureau as relationship files that details for each decade which blocks of the starting date were at least partly contained by which block in the second decade, and vice versa, to calculate the number of 1990 and 2000 housing units for the boundaries for each 2010 census block.

Based on the Census Bureau relationship files, we first allocated 1990 housing units to 2000 block boundaries by identifying the type of relationship for each 1990 block to 2000 block(s), classifying the relationship as one-to-one, one-to-many, many-to-one, or many-to-many. For one-to-one and many-to-one relationships, 1990 housing units were allocated directly to corresponding 2000 blocks. For one-to-many relationships, 1990 housing units were allocated proportionally based on the number of housing units in the 2000 blocks. For many-to-many relationships, we identified the least common denominator of polygons that fully contained groups of both 1990 and 2000 blocks. For each least common denominator polygon, we then summed the 1990 housing units and allocated them based on the proportion of the 2000 housing units. To minimize instances of many-to-many relationships and maximize direct relationships, we removed blocks that were classified as water in 1990 and as vacant in 2000, as well as all 1990 and 2000 blocks that intersected by <1% of their area. Once 1990 housing units were allocated to 2000 census block geometry, we repeated the process using the 2000–2010 relationship files to allocate 2000 housing units to 2010 block boundaries. We then joined the 1990 housing units allocated to 2000 block boundaries with the 2000–2010 relationship files, and repeated the process to allocate 1990 housing units to 2010 block boundaries. The end result of our algorithms are 1990 and 2000 housing units allocated to the 2010 block geometry across the conterminous United States, i.e., a dataset that permits valid analyses of housing growth across the United States at fine spatial resolution and that minimizes erroneous changes due to changing census block boundaries.

We further refined census block boundaries by integrating them with information on the boundaries of protected areas. The boundaries of protected areas were provided by the Protected Area Database, version 2. Where protected areas intersected census block boundaries, we assumed that the houses in that block were located in nonprotected areas only. However, where census blocks with houses were entirely within a protected area, we made no changes, and assumed a uniform housing density throughout the block.

The 30-m resolution NLCD provided us with data on wildland vegetation. We analyzed both the 1992/93–2001 and the 2001–2011 land cover change products and calculated the percentage of each NLCD land cover class within each census block after refinement by the protected area boundaries. We included forest and grass/shrub land cover classes as wildland vegetation and excluded open water, urban, barren, wetlands, and ice/snow.

For each decade, we mapped the WUI separately, by combining 1990 Census data with 1992/93 data from the 1992/93–2001 land cover change product, and 2000 and 2010 Census data with 2001 and 2011 data from the 2001–2011 land cover change product. We first identified all intermix WUI areas based on the housing and vegetation thresholds. We then identified contiguous vegetation areas that were at least 5 km^2 in size and had >75% wildland vegetation, selecting areas within 2.4 km that were above the housing threshold (but below the 50% vegetation threshold), and labeling these as interface WUI. When census blocks were only partly within this distance, we split them.

The NLCD change products are not fully consistent, in that the 2001 land cover in the 1992/93–2001 change product differs from the 2001 land cover in the 2001–2011 change product. Thus, we conducted a sensitivity analysis and mapped the 2001 WUI twice, based on the two representations, and then compared the resulting WUI maps. The differences between the two WUI maps were very minor.

To calculate the number of homes within fire perimeters over time, we analyzed all fire perimeters of fires that burned between 1990 and 2015 according to the Monitoring Trends in Burn Severity (MTBS) dataset, which includes all fires >404 ha (1,000 ac) in the West and 202 ha (500 ac) in the East. We then assessed which census blocks were at least partially within these fire perimeters and calculated an area-weighted estimate of the number of housing units within the fire perimeters in 1990 (177,000), 2000 (210,000), and 2010 (286,000). We note that this is a conservative estimate of the number of houses affected by wildfires because the MTBS dataset does not include small fires.

ACKNOWLEDGMENTS. We thank J. Diffendorfer and J. Slate for providing valuable feedback on an earlier version of this manuscript. Support for this research was provided by the US Forest Service Northern Research Station, the interagency Joint Fire Sciences program, the Land Change Science Program in the US Geological Survey Climate and Land Use Mission Area, and PhD fellowships from the Fulbright Exchange program and the Foundation for Science and Technology of Portugal (to P.M.A.).

1. Radeloff VC, et al. (2005) The wildland-urban interface in the United States. *Ecol Appl* 15:799–805.
2. Alexandre PM, Mockrin MH, Stewart SI, Hammer RB, Radeloff VC (2015) Rebuilding and new housing development after wildfire. *Int J Wildland Fire* 24:138–149.
3. Calkin DE, Cohen JD, Finney MA, Thompson MP (2014) How risk management can prevent future wildfire disasters in the wildland-urban interface. *Proc Natl Acad Sci USA* 111:746–751.
4. Syphard AD, et al. (2007) Human influence on California fire regimes. *Ecol Appl* 17: 1388–1402.
5. Balch JK, et al. (2017) Human-started wildfires expand the fire niche across the United States. *Proc Natl Acad Sci USA* 114:2946–2951.
6. Bowman DM, et al. (2009) Fire in the earth system. *Science* 324:481–484.
7. Bowman DM, et al. (2011) The human dimension of fire regimes on Earth. *J Biogeogr* 38:2223–2236.
8. Schoennagel T, et al. (2017) Adapt to more wildfire in western North American forests as climate changes. *Proc Natl Acad Sci USA* 114:4582–4590.
9. Bar Massada A, Radeloff VC, Stewart SI (2014) Biotic and abiotic effects of human settlement in the wildland-urban interface. *Bioscience* 64:429–437.
10. Gonzalez-Abraham CE, et al. (2007) Patterns of houses and habitat loss from 1937 to 1999 in northern Wisconsin, USA. *Ecol Appl* 17:2011–2023.
11. Gavier-Pizarro GI, Radeloff VC, Stewart SI, Huebner CD, Keuler NS (2010) Housing is positively associated with invasive exotic plant species richness in New England, USA. *Ecol Appl* 20:1913–1925.
12. Loss SR, Will T, Marra PP (2013) The impact of free-ranging domestic cats on wildlife of the United States. *Nat Commun* 4:1396.
13. Larsen AE, MacDonald AJ, Plantinga AJ (2014) Lyme disease risk influences human settlement in the wildland-urban interface: Evidence from a longitudinal analysis of counties in the northeastern United States. *Am J Trop Med Hyg* 91:747–755.
14. Martinuzzi S, et al. (2015) *The 2010 Wildland-Urban Interface of the Conterminous United States* (US Forest Service, Newtown Square, PA), p 123.
15. Syphard AD, Radeloff VC, Hawbaker TJ, Stewart SI (2009) Conservation threats due to human-caused increases in fire frequency in Mediterranean-climate ecosystems. *Conserv Biol* 23:758–769.
16. Modugno S, Balzter H, Cole B, Borrelli P (2016) Mapping regional patterns of large forest fires in wildland-urban interface areas in Europe. *J Environ Manage* 172: 112–126.
17. Argañaraz JP, et al. (2017) Assessing wildfire exposure in the wildland-urban interface area of the mountains of central Argentina. *J Environ Manage* 196:499–510.
18. Buxton M, Haynes R, Mercer D, Butt A (2011) Vulnerability to bushfire risk at Melbourne's urban fringe: The failure of regulatory land use planning. *Geogr Res* 49: 1–12.
19. Lampin-Maillet C, et al. (2010) Mapping wildland-urban interfaces at large scales integrating housing density and vegetation aggregation for fire prevention in the south of France. *J Environ Manage* 91:732–741.
20. van Wilgen BW, Forsyth GG, Prins P (2012) The management of fire-adapted ecosystems in an urban setting: The case of Table Mountain National Park, South Africa. *Ecol Soc* 17:8.
21. Abatzoglou JT, Williams AP (2016) Impact of anthropogenic climate change on wildfire across western US forests. *Proc Natl Acad Sci USA* 113:11770–11775.
22. Hawbaker TJ, et al. (2017) Mapping burned areas using dense time-series of Landsat data. *Remote Sens Environ* 198:504–522.
23. National Interagency Fire Center (2017) Historical wildland fire information: suppression costs, 1985-2016. Available at https://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf. Accessed February 16, 2018.
24. Hammer RB, Radeloff VC, Fried JS, Stewart SI (2007) Wildland-urban interface housing growth during the 1990s in California, Oregon, and Washington. *Int J Wildland Fire* 16:255–265.
25. Theobald DM, Romme WH (2007) Expansion of the US wildland-urban interface. *Landsc Urban Plan* 83:340–354.
26. Drummond MA, Loveland TR (2010) Land-use pressure and a transition to forest-cover loss in the eastern United States. *Bioscience* 60:286–298.

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27. Syphard AD, et al. (2009) Assessing housing growth when census boundaries change. *Int J Geogr Inf Sci* 23:859–876.
28. Homer C, et al. (2015) Completion of the 2011 National Land Cover Database for the conterminous United States: Representing a decade of land cover change information. *Photogramm Eng Remote Sens* 81:345–354.
29. Gude P, Rasker R, van den Noort J (2008) Potential for future development on fire-prone lands. *J For* 106:198–205.
30. Stewart SI, et al. (2009) Wildland-urban interface maps vary with purpose and context. *J For* 107:78–83.
31. Abrams JB, Gosnell H, Gill NJ, Klepeis PJ (2012) Re-creating the rural, reconstructing nature: An international literature review of the environmental implications of amenity migration. *Conserv Soc* 10:270–284.
32. Bradbury M, Peterson MN, Liu JG (2014) Long-term dynamics of household size and their environmental implications. *Popul Environ* 36:73–84.
33. Flannigan MD, Krawchuk MA, de Groot WJ, Wotton BM, Gowman LM (2009) Implications of changing climate for global wildland fire. *Int J Wildland Fire* 18:483–507.
34. Cohen JD (2000) Preventing disaster: Home ignitability in the wildland-urban interface. *J For* 98:15–21.
35. Syphard AD, Brennan TJ, Keeley JE (2014) The role of defensible space for residential structure protection during wildfires. *Int J Wildland Fire* 23:1165–1175.
36. Syphard AD, Bar Massada A, Butsic V, Keeley JE (2013) Land use planning and wildfire: Development policies influence future probability of housing loss. *PLoS One* 8: e71708.
37. Radeloff VC, et al. (2010) Housing growth in and near United States protected areas limits their conservation value. *Proc Natl Acad Sci USA* 107:940–945.
38. Schoennagel T, Nelson CR, Theobald DM, Carnwath GC, Chapman TB (2009) Implementation of National Fire Plan treatments near the wildland-urban interface in the western United States. *Proc Natl Acad Sci USA* 106:10706–10711.
39. USDA; USDI (2001) Urban wildland interface communities within vicinity of federal lands that are at high risk from wildfire. *Fed Regist* 66:751–777.
40. Bar-Massada A, Stewart SI, Hammer RB, Mockrin MH, Radeloff VC (2013) Using structure locations as a basis for mapping the wildland urban interface. *J Environ Manage* 128:540–547.

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EXHIBIT I

VOL. 47, NO.2 MARCH 2020

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JOURNAL OF THE CALIFORNIA NATIVE PLANT SOCIETY



CALIFORNIA FIRES: Challenges and Proposed Solutions

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California Native Plant Society
ISSN 0092-1793 (print)
ISSN 2572-6870 (online)

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FREMONTIA

VOL. 47, NO. 2, MARCH 2020

FROM THE EDITORS

Perhaps you are one of thousands of California residents who have recently become intimately acquainted with Public Safety Power Shutoffs. Even those of us who haven't found ourselves in the path of recent wildfires have had to navigate dramatic interruptions to our daily lives, including smoke-filled air and increases in the cost of fire insurance (if we can still get it). It is becoming abundantly clear that living in California means living with wildfire.

Of course, fire has always been integral to California's diverse ecosystems. Many people choose to live here because of the state's natural beauty. But proximity to that natural beauty comes with the responsibility to respect and understand the forces that created it, including fire.

Over the past 20 years, a dramatic increase in large, deadly wildfires has transformed California's environmental politics, with unprecedented impacts on our communities. We're living through a time of remarkable change, and the need for solutions is urgent. Often missing in the midst of crisis, however, is a science-based, historical perspective which would help inform our search for effective responses to this "new normal."

The diversity of California's ecosystems means that we can't treat wildfire the same way throughout the state. Instead, we need rigorous science and regional expertise to inform how we deal with fire, from Sierra Nevada forests, to the chaparral of Southern California.

Providing such scientific expertise and local input is CNPS's role and the purpose of this special issue of *Fremontia*. In it, you'll find commentary from ecologists, foresters, sociologists, and others dedicated to understanding fire in California, as well as science-based recommendations for more fire-resilient homes, gardens, and communities.

Of course, even a special expanded issue of *Fremontia* is too small to contain all that must be said about fire in California. Native perspectives—and in particular, traditional practices developed by indigenous Californians over many centuries—are notably missing from this issue. For thousands of years, California's tribal communities have applied fire to steward landscapes and the critical resources they sustain. This tradition of caring for the land must be brought to the table as we seek more sustainable ways of living in this beautiful and diverse state. Generations of learning cannot be squeezed into a single article, and CNPS looks forward to devoting an upcoming issue to "Traditional Ecological Knowledge," encompassing (but not limited to) Native Californians' relationship with fire.

– Emily Underwood & David Loeb, *Guest Editors*

Cover: The 2017 Thomas Fire near Santa Barbara.
(Photograph by Stuart Palley/U.S. Forest Service)





CONTENTS

REESTABLISHING BALANCE BETWEEN PEOPLE, PLANTS, AND FIRE IN CALIFORNIA 2
Greg Suba

NEXUS BETWEEN WILDFIRE, CLIMATE CHANGE, AND POPULATION GROWTH IN CALIFORNIA 4
Jon E. Keeley and Alexandra D. Syphard

WHY ARE SO MANY STRUCTURES BURNING IN CALIFORNIA? 14
Alexandra D. Syphard and Jon E. Keeley

WILDFIRES AND FOREST RESILIENCE: THE CASE FOR ECOLOGICAL FORESTRY IN THE SIERRA NEVADA 22
Rodd Kelsey

FIRE IN CALIFORNIA: THE LONG ROAD TO RECOVERY 32
Craig Thomas

DEVELOPING THE INFRASTRUCTURE NEEDED TO RESTORE FOREST HEALTH 36
Jonathan Kusel

LOOKING FOR MULTI-BENEFIT SOLUTIONS: AN INTERVIEW WITH CAITLIN CORNWALL 38
David Loeb

CNPS FELLOWS: CELEBRATING THOSE WHO SPEAK FOR NATIVE PLANTS 44

IN MEMORIAM:

Celia Kutcher: A Guiding Light in Orange County 60
Dan Songster

Watson McMillian "Mac" Laetsch 61
John Taylor

Steve McLaughlin 62
Stephen Ingram

Lester Bradford Rowntree 63
David Loeb



REESTABLISHING BALANCE BETWEEN PEOPLE, PLANTS, AND FIRE IN CALIFORNIA

Greg Suba

For millennia, fire has been a part of California. Our native flora evolved with fire and exists in part because of it. California's original people harnessed its forces to their advantage and continue to integrate fire successfully into their land management practices today. But over the last century, California's relationship with fire has changed.

While wildfire certainly brings great danger and tragedy to human communities, it remains fundamental to how California naturally functions. Nevertheless, most Californians have developed a misunderstanding of, and antagonism to, fire. This issue of *Fremontia* addresses how we got into our current wildfire situation, tracing the more than 100-year history of fire suppression in California. It describes how our penchant for harvesting the biggest trees has contributed to fire-starved, overgrown forests, and shows how an increasing population in chaparral and coastal sage scrub habitats is generating more problems with fire, suggesting that we must invest in more than vegetation management to develop resilience to wildfire.

The California Native Plant Society (CNPS) has long held a realistic view of the necessity of living with fire, communicated through policies, publications, and advocacy. We continue that dialog in this issue of *Fremontia*, which brings together a selection of research, personal stories, and expert opinion to explore our broken relationship with fire and what we can do to fix it.

Providing an historical perspective, Craig Thomas leads us along the path we've taken away from fire, describing the forest choices and actions that shape our current relationship with forest fire. Jon Keeley and Alexandra Syphard summarize research and data related to recent increases in wildfire extent, intensity, and damage. Caitlin

Above: The 2014 Happy Camp Complex Fire. *[Photograph courtesy of U.S. Forest Service]*

"The need for vigorous participation in the discourse underscores the fundamental importance of preserving a process whereby the public—all sides—can provide meaningful input that guides policy and action."

Cornwall and Jason Mills provide examples of how one post-fire community is learning from their tragedy to balance rebuilding with conservation, keeping resilience in mind.



[Photograph by Cecilio Ricardo/U.S. Forest Service]

Many voices, including those of CNPS members, have long advocated that—rather than focus almost exclusively on vegetation management—California's leaders should make a greater commitment to hardening homes against ember ignitions, maintaining defensible space, and favoring more fire-safe land use decisions. These are priorities reinforced by stories and findings presented by contributing authors in this issue.

Our members have advocated ardently and at length for appropriate vegetation management when and where it is needed. Rather than resist all vegetation management, CNPS has supported the thinning of some understory forest vegetation in order to restore greater forest structural heterogeneity, along with an increase in the pace and scale of prescribed and managed forest fire. At the same time, CNPS continues to dispel damaging misconceptions about the relationship between fire and chaparral and coastal sage scrub landscapes (see *Fremontia* Vol. 35, No. 4, Fall 2007 - Special Issue: Chaparral). In this issue, Rodd Kelsey makes the case for ecological thinning and increased burning in the Sierra Nevada's mixed conifer forests. Achieving this presents social, economic, and ecological challenges as well as opportunities. Jonathan Kusel describes the potential for community-based biomass energy and alternative wood products to provide solutions to these obstacles.

Our imperative to build a fire-resilient California faces unprecedented opposing forces: rapidly changing climate, fire-prone landscapes, having to unlearn a century of wildfire bias, and a growing population of fire-starting humans. We've built ourselves into a problem. Solving it responsibly must include keeping lives and property safe without forsaking the beauty and wildlife (plants and animals) we experience today, nor our ability to pass it on to those who follow us.

Under these conditions, especially within our forested lands, the no-action alternative is hardly an option. The pace and scale of intervention on natural lands has begun to increase, spurring a concurrent increase in the scales of environmental decision making and management actions. Finding a sustainable path through this uncharted territory requires an all-lands, all-voices approach. Success will require using the best science, continued research, letting go of "No" at times, and acknowledging we're going to make mistakes. Our ability to monitor our successes and failures effectively, to learn from them, and to improve on them will be all-important.

There will always be, and ought to be, tension around how much intervention is enough and how much is too much. Though frustrating at times, open debate is essential to successful natural lands management and conservation. The need for vigorous participation in the discourse underscores the fundamental importance of preserving a process whereby the public—all sides—can provide meaningful input that guides policy and action.

"The West is burning, but mostly not in the way it should be," as Craig Thomas sums it up. This winter we sat in his home in the Sierra foothills, where he has lived since the 1970s, and I listened to him recount the years of effort he and many others have dedicated to reestablishing fire as an ecological tool in the Sierra Nevada. Their journey is a saga about people living through something new, and working together to establish a path forward. I find myself invested in a central theme of their story, one which I hope readers will take away from this issue: Challenges are neither always bad nor insurmountable.

–Greg Suba is Conservation Biologist for Sierra Forest Legacy. He served as CNPS Conservation Program Director from 2009-2019.



NEXUS BETWEEN WILDFIRE, CLIMATE CHANGE, AND POPULATION GROWTH IN CALIFORNIA

Jon E. Keeley and Alexandra D. Syphard

Since the year 2000 California has experienced a remarkable upsurge in wildfires. Over five million hectares have burned in the last 20 years, which is double the area burned in the previous two decades. Much of this increase has been driven by large fires of more than 50,000 hectares that cause catastrophic losses of lives and property (Keeley and Syphard 2019). This increased fire activity has been correlated with an increase in average temperature over this same period, leading many observers to assert that global climate change must be playing a major role. Climate models forecast continued warming and thus some have suggested these catastrophic fires are the "new normal" or the "new *ab*normal," (Birnbaum 2018). In contrast, others have declared that these fires are the result of "forest mismanagement" (Cranley 2018) and this has stimulated renewed interest in fuel reduction (Office of Governor 2019). It's almost as though these opinions aren't even in reference to the same fires, and as described below, there is some validity to this assertion.

Sorting out the factors driving this rise in fire activity requires an appreciation for the diversity of landscapes and fire regimes in the state. After all, California has the largest latitudinal range of any western state, comparable to that from southern New Mexico to Wyoming, and the largest altitudinal range (containing both the lowest and highest points in the lower 48 states). California also is the most populous state in the union: One out of eight Americans live here. And most live within dense metropolitan areas juxtaposed with fire-prone wildlands, while a great many more live widely dispersed in rural settings.

A key to sorting out the factors behind increased fire activity is understanding that we are looking at two very different types of fires: fuel-dominated vs. wind-dominated fires. And each of these is controlled by different environmental and historical factors (Table 1). Understanding the differences between these two types of wildfires is helpful for navigating the confusing array of opinions expressed in the media as well as determining the appropriate management responses to reduce future fire impacts.

Above: **Aerial retardant drop on a chaparral wildfire in coastal Southern California, taken July 5, 2008, in the foothills of the Los Padres National Forest.** *[Photograph by Dan Lindsay]*

FUEL-DOMINATED FIRES

Many of the forest fires of the past two decades have grown out of control due to anomalous fuel loads resulting from 20th century management practices. In the early 1900s increasing state and federal interest in timber resources led to vigorous suppression of natural fires in forests that historically had burned at decadal frequency (McKelvey and Busse 1996) (Fig. 1). In the moderately productive mid-elevation conifer forests of the Sierra Nevada there is typically a vertical separation between dead branches and other litter on the ground and the living tree canopies above, and thus frequent lightning-ignited fires were commonly restricted to low intensity surface fires (Fig. 2). As a result such fires were relatively easy to extinguish and thus many forests in the western U.S. have experienced over a century of near total fire exclusion.



Figure 1. Cross section of ponderosa pine, upper edge is the outer bark, pith is toward the bottom. Dates indicate previous fires and none since active fire suppression in the early 1900s *(Section from Bruce Kilgore, photograph by Jon Keeley, USGS)*

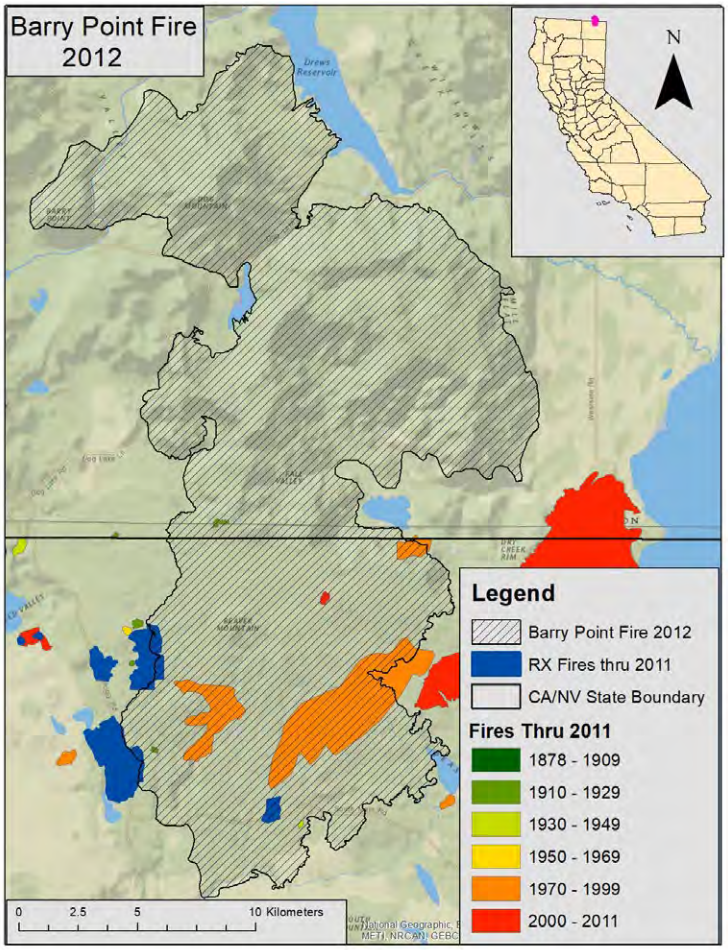
Figure 2. Low intensity surface fire typical of historical fires in many western forests *(Rim Fire burning in Yosemite National Park, photograph by Jon Keeley, USGS)*

Figure 3. Fire perimeter for the 2012 Barry Point Fire. Hatched area indicates no previous recorded fire from 1910 to 2012, roughly 90% of area burned in 2012. Legend indicates other historical fire dates *(Data from the State of California Fire and Resource Assessment Program, FRAP Fire History Database, https://frap.fire.ca.gov/mapping/gis-data/; accessed Jan. 2020).*



One consequence is that some of these forests have accumulated understory surface fuels that represent fuel loads an order of magnitude greater than historical levels (Keifer et al. 2006), made even worse by the massive ingrowth of new saplings that not only further increase the fuel load but also act as ladder fuels carrying fire from the surface to the canopy. A century without fire has made these forests susceptible to high-intensity crown fires, a fire pattern evident in many recent Sierra Nevada fires (Fig. 3). These types of fires are best described as fuel-dominated fires (Table 1).

To be sure, some fuel-dominated fires can produce their own extreme winds (e.g., the 2010 Station Fire in Los Angeles County or the 2018 Carr Fire in Shasta County), resulting from the high-intensity burning of heavy fuel loads. The extreme heat produces pyrocumulonimbus clouds and are often described as plume-driven fires that can collapse, producing extreme wind events (Clements et al. 2018). However, such winds are internally generated, a phenomenon that could be altered by undertaking fuel treatments prior to fire events.



WIND-DOMINATED FIRES

On the other hand, wind-dominated fires are those controlled by external weather events. This is an important distinction, as we have no ability to alter such weather-driven wind events. Our most catastrophic fires of the past few decades have been just such wind-dominated fires. They typically occur in the western portions of California and burn over non-forested landscapes of shrubs, grasses, and woodlands. These fires grow rapidly due to extreme wind events and, as a result, pose severe challenges to fire suppression efforts. Readers will be familiar with several of these recent "firestorms," including the 2017 Napa-Sonoma Wine Country fires and the 2018 Camp Fire driven by North winds in Northern California. (Historically this is the appropriate term; however, such winds are sometimes referred to as Diablo winds, a term spawned by a newspaper reporter who noted that the 1991 Oakland Hills Tunnel Fire was driven by winds coming from the direction of Mount Diablo; thus the term is less appropriate for wind-driven fires throughout the region.) Other such "firestorms" include the 2017 Thomas Fire and the 2018 Woolsey Fire driven by Santa Ana winds in Southern California. While these winds may occur in both the spring and autumn (Fig.5a) they are most problematic in the autumn, following the three to six months of drought typical of our Mediterranean climate (Fig. 5b), leaving natural vegetation at its lowest moisture level. It is these autumn Santa Ana wind and North wind fires that account for the most catastrophic fires in the state (Table 1).

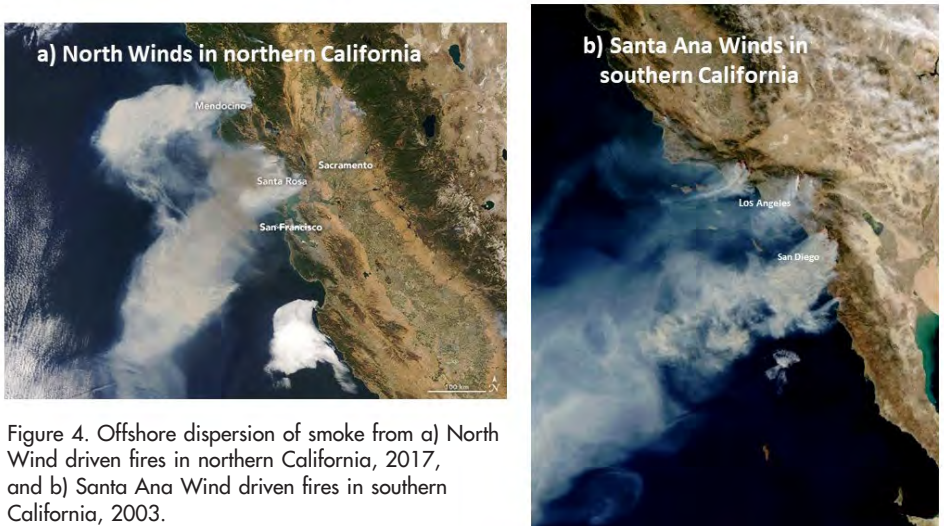


Figure 4. Offshore dispersion of smoke from a) North Wind driven fires in northern California, 2017, and b) Santa Ana Wind driven fires in southern California, 2003.

TABLE 1. Selected fires representing fuel-dominated and wind-dominated fires.

Year	Fire	County	Mon. (days)*	Hectares	Cause	Lives	Structures
Fuel-Dominated Fires:							
2007	Marble C	Monterey	July -	71,980	Lightning	0	0
2012	Barry Point	Modoc	Aug -	37,630	Lightning	0	3
2012	Rush	Lassen	Aug -	110,080	Lightning	0	1
2013	Rim	Stanislaus	Aug -	104,220	Campfire	0	112
2014	King	El Dorado	Sept -	39,260	Arson	0	80
2015	Rough	Fresno	July -	61,360	Lightning	0	4
Wind-Dominated Fires:							
1889	Santiago	Orange	Sept (3)	125,000	Campfire	0	0
1970	Laguna	San Diego	Sept (3)	70,500	Powerline	5	382
2003	Cedar	San Diego	Oct (3)	109,500	Flares	15	2,820
2007	Witch	San Diego	Oct (2)	80,200	Powerline	2	1,265
2017	Tubbs	Sonoma	Oct (2)	14,900	Powerline	22	5,643
2017	Thomas	Ventura	Dec (10)	114,080	Powerline	2	1,063
2018	Camp	Butte	Nov (2)	62,060	Powerline	88	18,804
2018	Woolsey	Ventura	Nov (3)	39,335	Powerline	3	1,643
2019	Kincade	Sonoma	Nov (5)	31,470	Powerline	0	374

*Indicates days of Santa Ana or North winds *[Data from the State of California Fire and Resource Assessment Program, FRAP Fire History Database, https://frap.fire.ca.gov/mapping/gis-data/; accessed Jan 2020].*

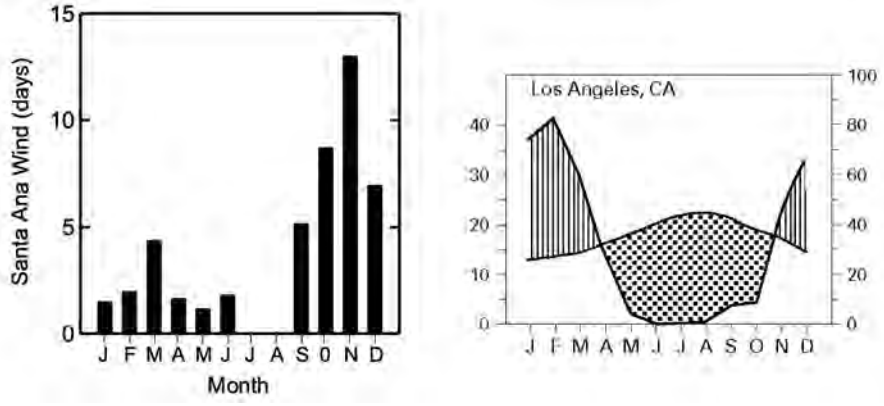


Figure 5. Days of Santa Ana winds (left) and (right) temperature and precipitation in Los Angeles illustrating typical Mediterranean climate of winter rains and summer droughts *(from Keeley et al. 2012).*

Historically these landscapes have not experienced the fire exclusion seen in many Sierra Nevada landscapes, despite being managed by the same fire suppression policy (Fig. 6). This is due to the fact that essentially all are caused by human ignitions, which are relatively common due to the high population density in the western portion of California (Keeley and Syphard 2018). As a consequence, there has not been any lack of fire and most large fire events burn across landscapes with an extensive fire history and no anomalous fuel accumulation. Indeed, some of these large fires—e.g., the Thomas Fire (Keeley and Syphard 2019)—have burned across areas where extensive prescription burning had occurred in recent years, pointing to the conclusion that prior fuel treatments are having limited effect on the spread of these fires. Even landscapes not experiencing high fire frequencies, such as the San Francisco Bay Area, are not outside their range of natural fire frequencies and so fuels have not accumulated due to fire suppression (Keeley 2005). To be sure, some communities in this region have dangerous fuels but these are often the result of urban plantings of *Acacia, Eucalyptus* and *Pinus* and not so much due to accumulation of wildland fuels from elimination of natural fires.

Every year there are many Santa Ana wind events but most years we don't see major wind-driven fires because they are entirely dependent on a human ignition happening during an extreme wind event. Indeed, only about five percent of the Santa Ana wind days are accompanied by a large fire event (Rolinski et al. 2019). Some have suggested that these Santa Ana winds are increasing in frequency, duration, and intensity, but records do not show a change in the character of these winds since the mid-1900s (Williams et al. 2019). Rolinksi et al. (2016) found that fires during extreme weather events are larger than ones in less extreme Santa Ana conditions, and some have interpreted this to mean that fires are becoming worse because Santa Ana winds are becoming more extreme. However, this study only considered Santa Ana winds after an ignition had occurred, thus ignition sources are critically important. It is important to recognize that Rolinksi's Santa Ana Wind Threat Index is not an indication of when an extreme fire will occur but only how bad the fire will be once ignited. What determines an extreme fire year is the untimely human ignition during an extreme wind event. This is illustrated by the fact that the frequency of these wind events is not correlated with area burned (Keeley and Syphard 2018) and our largest fire years occur in high-as well as low-Santa Ana wind intensity years

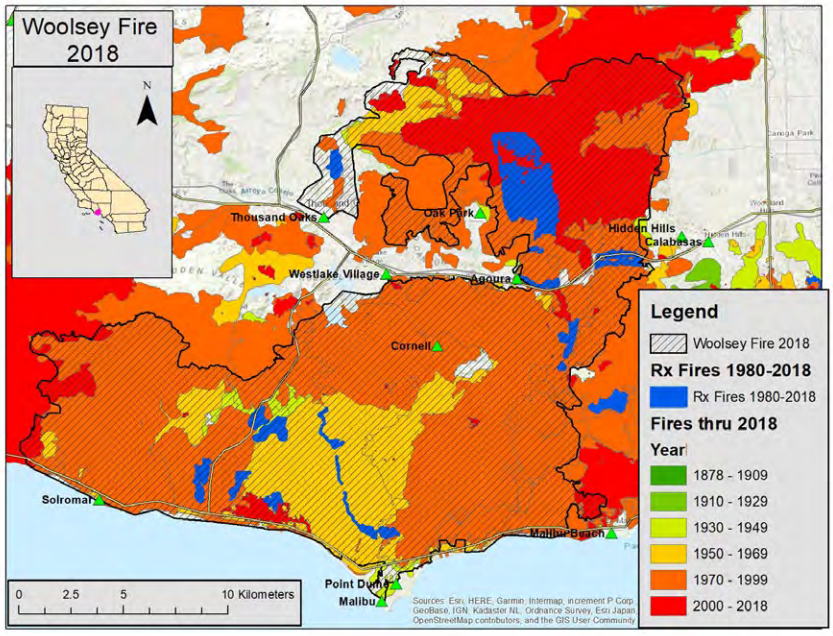


Figure 6. Fire history within the perimeter of the 2018 Woolsey Fire. Hatched area indicates less than 1% of the area unburned prior to 2018. Legend indicates other fire dates *(Data from the State of California Fire and Resource Assessment Program, FRAP Fire History Database, https://frap.fire.ca.gov/mapping/gis-data/; accessed Jan. 2020).*

(Fig. 7). Ultimately it is all determined by an untimely human ignition event. Of course climate is peripherally related as it has been found that these fires are less likely to occur when relative humidity is high (Jin et al. 2014) and this most certainly is tied to decreased probability of such fires after early autumn precipitation (Keeley and Syphard 2017).

Indeed, Santa Ana wind events occur multiple times every year, yet during most such wind events there is no human ignition and thus no fire (Keeley and Syphard 2017). There is little evidence that the increase in the number of catastrophic fires is the result of increased intensity of Santa Ana wind events. For example Guzman-Morales et al. (2016) mapped the annual intensity of Santa Ana wind events (Fig. 7) yet when we overlaid extreme fire years of over 100,000 hectares burned in Southern California (Fig. 7), we find that such extreme fire years are associated with low as well as high intensity Santa Ana wind years; e.g., the catastrophic 2003 Cedar Fire (Table 1) occurred during a year with low-intensity Santa Ana winds.

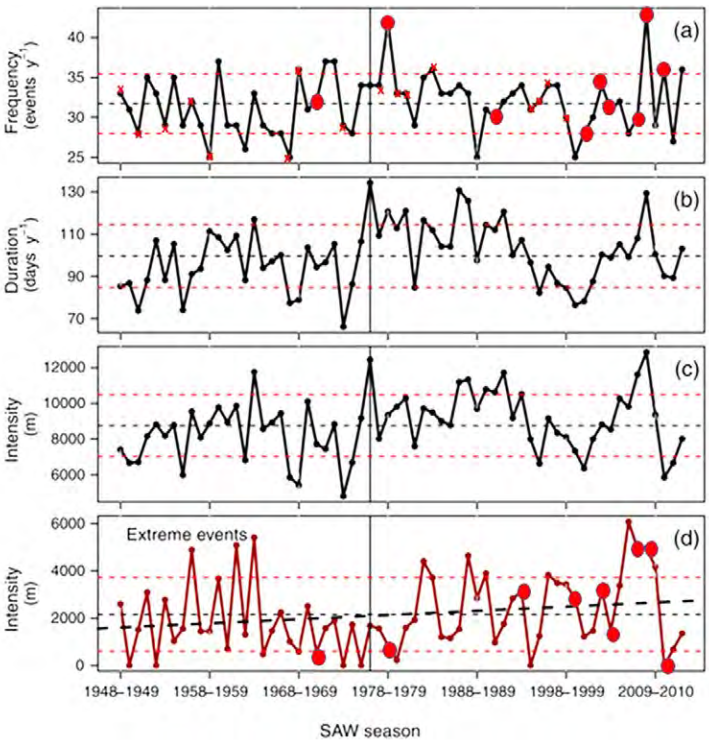


Figure 7. Pattern of Santa Ana wind (SAW) characteristics from Guzman-Morales et al. 2017 and with red dots indicating very high fire years exceeding a hundred thousand hectares burned *(from Keeley and Syphard 2017)*. Correlation analysis between frequency of Santa Ana wind events or the intensity of extreme Santa Ana wind events with area burned suggests there is no significant relationship in Southern California (R2=0.01 and R2=0.00, respectively).

CHANGING IGNITION SOURCES

Lightning is a common ignition source in forests of the Sierra Nevada and northeastern California and thus accounts for many fuel-dominated fires (Table 1). However, lightning is relatively uncommon in coastal regions (Keeley and Syphard 2018) and does not occur under the synoptic conditions that create extreme Santa Ana and North wind events. Thus, these wind-dominated fires are ~ 100 percent human-ignited fires (either from intentional causes, such as arson, or accidental causes, such as sparks from equipment).

In the last decade, the majority of these large fires—including some of the biggest fires in 2017, 2018, and 2019—have been ignited by powerline failures during extreme wind events. Indeed, since the year 2000, over half a million acres have burned due to powerline failures, which is five times more than in the prior two decades (Keeley unpublished data). The increased impact of powerline-ignited fires is not the result of increased frequency or intensity of extreme wind events. There are two likely explanations for this increase in powerline-ignited fires: 1) expansion of the electrical grid due to increased development, which provides more opportunities for powerline ignited fires, and/or 2) deteriorating powerline equipment resulting from age and inadequate maintenance (one California regulator contends that electrical grid equipment is being run to the point of failure (Penn et al. 2019)).

GLOBAL CLIMATE CHANGE

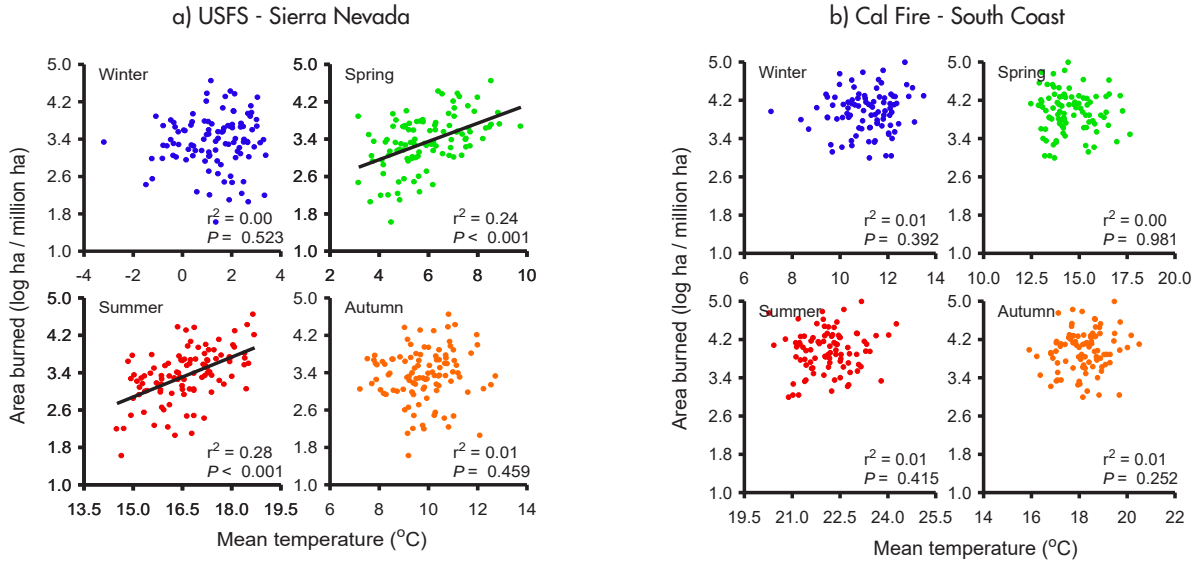
Some forecasts of future fire regimes based on different climate change simulations predict huge increases in California wildfires (Westerling 2018). These models need to be viewed in light of the fact that they are driven by untested assumptions. They don't adequately account for the complexity of fire-driven changes in vegetation (Syphard et al. 2018b), and they don't consider changes in fire–climate relationships over time, as well as changes in human-ignition patterns.

An alternative approach to future modeling is retrospective studies. Confucius stated, "If one wants to define the future, they must study the past" (Castro 2012). We recently conducted a study that took an empirical approach and asked how seasonal variation in temperature and precipitation has correlated with area burned, year to year, in the past. This investigation, which differs from those using algorithms of future fire–climate relationships, covered much of the last 100 years and separated out the effect of different seasonal temperatures (Keeley and Syphard 2017).

One interesting finding is that in no region of the state did winter temperature play a role in determining subsequent fire activity. This may be important since some climate models predict the greatest global warming to occur in the winter in the northern hemisphere. So perhaps this type of warming might not translate into changes in fire severity and frequency in California.

We can summarize our findings by contrasting U.S. Forest Service lands in the Sierra Nevada (Fig. 8a) with the lower elevation California Department of Forestry and Fire Protection (Cal Fire) responsibility lands in Southern California (Fig. 8b). In Sierra Nevada forests there is a significant relationship between higher spring and summer temperatures and area burned; indeed, in the last 50 years, the combination of these two climate variables (spring and summer temperature) could explain over 50 percent of the year-to-year variation in area burned (Keeley and Syphard 2017). This is consistent with claims that global warming has played a role in increased burning in western forests in recent decades (Abatzoglou and Williams 2016).

In contrast, on non-forested landscapes in Southern California we found little correlation between seasonal temperatures and area burned (Fig. 8b), a pattern consistent with other recent studies (Williams et al. 2019). We surmise that this is likely due to the fact that in Southern California it is hot and dry enough every year to support large fires. (Note that maximum summer temperatures in the Sierra Nevada, when fires are most extensive, are similar to the lowest temperatures observed in Southern California in the summer, Fig. 8a&b). The lack of a strong annual climate relationship with fires in Southern California is due to climate being overridden by other factors, such as extreme wind events, increasing human ignitions during severe wind events, and long-term drought. Interestingly, while there has been an effect in the last 50 years of prior year precipitation on fires in Southern California, this effect is well known in grasslands and savannas throughout the southwest and is tied to elevated grass fuel loads following high rainfall years (Keeley and Syphard 2017). We believe this relationship showed up for Southern California in the last half of the long-term record (Fig. 8b) because of the the well-documented increase in type conversion from shrublands to grasslands in the region (Syphard et al. 2018a).



Akaike IC regression models

Sierra Nevada (USFS)	r2	
1910 - 2013	0.39	Temp spr+Temp sum-Ppt spr
1910 – 1959	0.42	- Ppt spr - Ppt win
1960 - 2013	0.52	Temp spr + Temp sum

South Coast (Cal Fire)	r2	
1919 - 2013	0.00	
1919 - 1959	0.00	
1960 - 2013	0.25	Prior ppt-Ppt aut -Ppt sum

Figure 8. a) Annual area burned from 1910–2013 for USFS lands in the Sierra Nevada plotted against winter, spring, summer, autumn temperatures and multiple regression models using all temperature and precipitation data for these four seasons, and b) annual area burned from 1919 – 2013 on Cal Fire lands in Southern California and multiple regression analysis *(from Keeley and Syphard 2017).*

One climate factor not considered when investigating annual climates is the impact of long-term droughts; i.e., those that last for multiple years. Recently California experienced an intense drought that began in 2012 and lasted for three years in the Sierra Nevada and eight years in Southern California (Jacobsen and Pratt 2018). It was accompanied by an immense dieback of trees in the Sierra Nevada (Stephens et al. 2018) and of shrublands in Southern California (Keeley and Syphard 2019). This creation of massive dead fuel loads represents a legacy on the landscape that may persist through subsequent years of higher rainfall. If drought-induced dieback proves to have been a critical factor in making the 2017 and 2018 fire years so extreme, it raises doubts as to whether these fire years represent a new normal for California, since although droughts are expected to be more severe under climate change, there is no evidence that such extreme droughts will be a normal feature going forward.

What can we conclude about how climate change may impact these coastal wind-driven fires? Global warming may reduce grass growth leading to reduced fire frequency in these grass-dominated landscapes. On the other hand, higher temperatures have the potential for increasing the intensity of plant stress during droughts, perhaps elevating dieback of woody plants that would exacerbate fire spread and intensity; a study by Williams et al. (2015) concluded that the last severe drought in the Sierra Nevada increased the stress by ~10-15 percent. A further likely impact of global warming is that it will alter postfire recovery of shrublands by changing the competitive balance to favor alien grasses, increasing type conversion to highly flammable herbaceous fuels, and leading perhaps to increased fire frequency (Syphard et al. 2018a, 2019, Park et al. 2018).

In summary, there is good reason to conclude that global warming is affecting Sierra Nevada forest fires. In montane forests with fuel-dominated fires, summer temperatures—although fluctuating greatly from year to year—have been on an upward trajectory for many decades and it is reasonable to assume a causal relationship between increased fire activity and global warming. However, over this same period there has been a steady increase in understory fuels. This raises an interesting question: Would the strength of the observed climate impact (Fig. 8a) have been as strong in the absence of this anomalous fuel accumulation due to fire suppression? In contrast, in the coastal regions there is limited evidence that climate change is impacting wind-dominated fires (Fig. 8b). However, global warming has the potential for a number of indirect impacts on vegetation that may alter fire regimes.

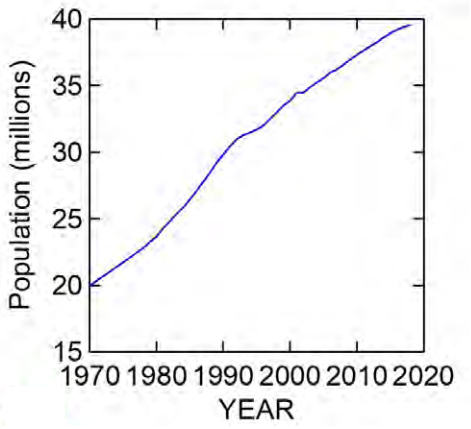


Figure 9. California population from Census Bureau *(www.census.gov; accessed June 2019)*

POPULATION GROWTH

Roger Kennedy, a former National Park Service director, was one of the first to bring attention to the role of population growth in raising the threat of wildfire (Kennedy 2006). It is true that since 2000 California has experienced a highly variable and subtle rise in temperature. However, less noticed is that there has also been a steep rise in population, adding about six million people (Fig. 9) over the last two decades. Since ~100 percent of the wind-dominated fires are ignited by humans or human infrastructure, there is likely a causal relationship between this population growth and the increased incidence of catastrophic wind-dominated wildfires.

Although local, state, and federal agencies have made significant progress in reducing the overall number of fires in the state over the last several decades (Keeley and Syphard 2018), there has been an increase in ignitions during extreme wind events. Thus, the real driver of wind-dominated fires is not the extreme wind events per se, but rather untimely human ignitions during such extreme wind events. And, of course, the addition of 300,000 more people every year in the state increases the probability of such an ignition event; moreover, urban sprawl into wildland areas increases the probability of losses of lives and property. An illustration of this is the 2017 Tubbs Fire that roared through sections of Santa Rosa, Sonoma County (Fig. 10b) causing the deaths of 22 people and destroying more than 5500 structures. Fifty years earlier the Hanly Fire had burned through much of the same landscape during a North wind event (Fig. 10a), yet no one died and only about

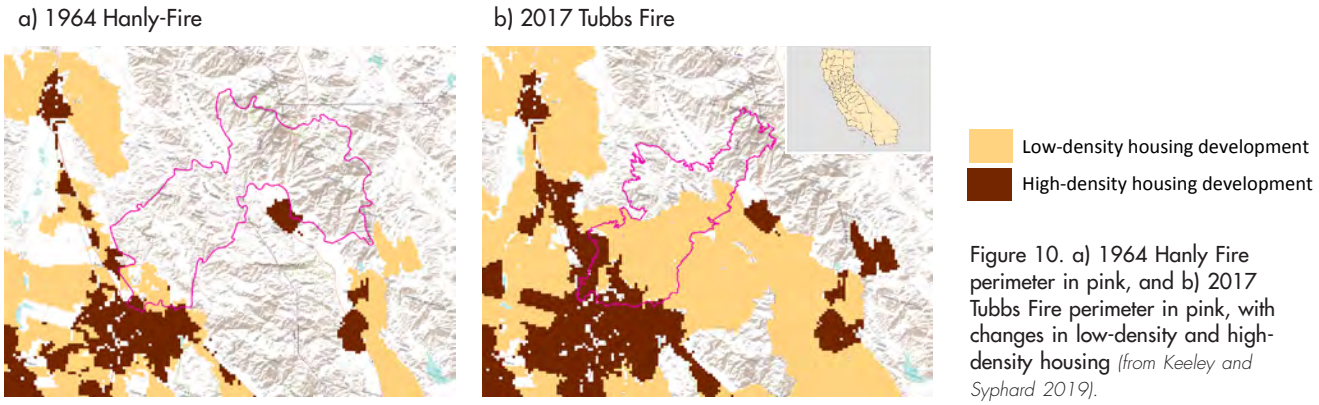


Figure 10. a) 1964 Hanly Fire perimeter in pink, and b) 2017 Tubbs Fire perimeter in pink, with changes in low-density and high-density housing *(from Keeley and Syphard 2019).*

100 structures were lost. Some researchers have discounted this comparison because the Hanly Fire burned over a longer period of time and therefore it is assumed it was not driven by severe winds. However, that fire burned for a longer duration because it was nearly three times the size of the Tubbs Fire and when it made its run toward Santa Rosa (overlapping with the perimeter of the much later Tubbs Fire) it was driven by extreme dry winds (*The Press Democrat*, September 26, 1964, front page), suggesting fire behavior similar to the 2017 Tubbs Fire. The difference in impact of these two fires is likely due to the fact that during this 50-year period Santa Rosa's population grew from 30,000 to 170,000 people and the urban footprint had expanded such that in 2017 development had expanded so that two-thirds of the area burned by the Tubbs Fire was low-density housing (Fig. 10b). This urban expansion was accompanied by expansion of the electric power grid, increasing the chances of a powerline failure during North wind events that drove both the Hanly and Tubbs fires.

MANAGEMENT CONSIDERATIONS

Fuel-dominated and wind-dominated fires exhibit important differences (Table 1) that inform how to manage these events. First, the fuel-dominated fires are largely forest fires in lightly populated regions such as the Sierra Nevada. In contrast, most wind-dominated fires occur in non-forested ecosystems in the western half of the state, though they may also occasionally occur in more interior sites, such as the 2018 Camp Fire that burned in Paradise. Wind-dominated fires occur in densely populated landscapes, and these fires are responsible for the greatest loss of lives and property.

MANAGEMENT CONSIDERATIONS—FUEL-DOMINATED FIRES

Montane forests have an anomalous accumulation of fuels due to more than a century of fire suppression and logging and therefore require concerted efforts at reducing the present fuel load (North et al. 2012). In the late 1960s, staff at Sequoia National Park began prescription (Rx) burning and soon after the other national parks in the Sierra Nevada followed suit (Keeley and Syphard 2019). Over time these parks greatly exceeded the area burned by adjacent forests. In recent years the USFS lands have accelerated the amount of Rx burning. However, all Sierra Nevada lands are a long way from burning at a rate sufficient to restore natural historical fire frequencies. There are many limitations, including funding, air quality restrictions, diversion of personnel from Rx burns due to wildfires, among others.

MANAGEMENT CONSIDERATIONS—WIND-DOMINATED FIRES: THE 5 P'S

The distinction between fuel-dominated and wind-dominated fires is similar to the dichotomy between katabatic and non-katabatic wind-driven fires made by Kolden and Abatzoglou (2018). They point out that in Southern California there are summer "fuel-dominated fires" and autumn "wind-dominated fires." While both types of fires occur in the region, it is the latter type that account for the vast amount of acreage burned, loss of lives and destruction of property. While management needs to be cognizant of both types of fire, it also needs to appreciate that summer fires are the least threatening fires and we should put our greatest effort toward autumn wind-dominated fires. Although all fires are a threat if fuels around homes have not been reduced, there are five points to consider with respect to the catastrophic wind-dominated fires:

1) ***People:*** On these landscapes, fire is more of a people problem than a fuel problem. More people translates into a greater probability of an ignition during a severe wind event, and more development in highly fire-prone landscapes inevitably results in greater losses of lives and homes.

2) ***Prevention:*** Rather than focusing on fuel treatments the scientific evidence clearly points to a need for a much greater emphasis on fire prevention. Although progress has been made in reducing the number of fires, the area burned has increased (Keeley and Syphard 2018). Powerline failures are a major cause of large fires and solutions to this increasing threat remain elusive. As widely reported in the media, three major utility companies in the state have implemented plans to monitor winds and shut down the power grid during extreme wind events. Such so-called Public Safety Power Shutoffs (PSPS) have the potential to decrease fire starts and limit damage (and, as a by-product, raise public awareness of fire threats). But there are many accompanying problems, as became evident during the recent Kincade Fire (Table 1) in October 2019, which was started by an electric failure, despite widespread power outages at the time. Such shutdowns impacted a multitude of vital services, including medical equipment, water pumps, traffic signals, communication equipment etc. One solution might be undergrounding the power lines in areas known to be corridors for extreme winds (Keeley et al. 2009). However, this would be much more expensive for the utilities to install and maintain. In addition, in areas where sensitive natural resources are present, overhead power lines may be less destructive. Nonetheless, San Diego Gas & Electric, which has led the way with responding to powerline-ignited wildfires, reports that 60 percent of its distribution lines are currently underground (Joe Vaccaro, Fire Mitigation & Climate Adaptation Manager, San Diego Gas & Electric Company, personal communication, 5 Dec 2019).

3) ***Planning:*** Community planning needs to devote similar attention and resources to fire as to other hazards. Since we have limited ability to control earthquakes and floods, some urban planners have utilized zoning restrictions to reduce impacts of these hazards. Yet, zoning restrictions are largely lacking when it comes to fire hazards, in large part because fires have been perceived as controllable. However it is increasingly obvious that this is not always the case and many communities are currently very vulnerable. Fire zoning (Kennedy 2006) needs to be given more consideration as well as urban planning that insures adequate ingress for fire fighters and egress for residents during extreme fire events. Perhaps replacing community planning with a more regional approach might contribute to these efforts.

4) ***Protection:*** High-intensity fires generally do not directly ignite homes when separated from vegetation by 30 meters (Cohen 2000). Home ignitions are usually the result of embers blown onto the structure, and this is particularly true under extreme wind conditions. Ember-cast firebrands often travel over a distance of half a mile or more. Embers ignite only under specific circumstances and this is most likely when they land on dead fuels (Zhou et al. 2019). Homeowners can diminish the probability of damage by addressing those factors that affect embers igniting their home, such as reducing plant litter on roofs and gutters, enclosing eves so that vent orientation is less susceptible to ember entry, closing open eves, placing fine-mesh screens on vents, and installing double-pane windows and appropriate siding (Syphard and Keeley 2019). Well-watered trees with significant foliage can provide protection from ember cast onto a home (Keeley and Syphard 2019). In fact, watered trees with green foliage may not be susceptible to ignitions by embers, but rather could serve to extinguish them and deprive them of dry fuels. While the notion of trees as "ember catchers" is appealing, it is a largely untested idea.

   Rooftop sprinklers may provide an added measure of protection and may be justified by the observation that trees adjacent to destroyed homes often survive because their foliage is moist, whereas combustible materials in homes represent dead fuels that are likely at equilibrium with ambient relative humidity of 10 percent or less. However, such sprinklers would need to address a number of issues. For example, metropolitan water lines and water supplies are sometimes compromised during fire events and thus there would need to be a stand-alone water tank. Also, shutting down the power grid is happening more often and thus solar or other alternative power would need to be available to pump water. In addition, there is the need for further research on how to engineer such a system in order to prevent the water spray from being dissipated to the atmosphere due to the high winds. Incorporating a system like this would likely be a significant expenditure that may not be possible for many home owners.

   Fuel treatment around homes is critical but needs to be focused on the "house out," i.e., putting the greatest effort into the area nearest the home and less as one moves further into the wildlands. Reducing fuels within 30 meters of the house is generally sufficient and further clearance beyond that is of doubtful value (Syphard et al. 2012).

5) ***Prediction:*** There is an urgent need for improved meteorological and fire behavior models that can provide real-time prediction of wind patterns and

fire spread during these extreme events, coupled with improvements in communication systems for providing that information to agencies and homeowners.

Acknowledgments

We thank Marti Witter and David Loeb for very constructive suggestions on this manuscript and Anne Pfaff for preparing the fire history maps. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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REFERENCES

Abatzoglou J. T., and A. P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences* 113: 11770-11775.

Birnbaum, E. 2018. California governor on wildfires: 'This is the new abnormal.' The Hill 11/11/18, https://thehill.com/homenews/state-watch/416167-california-governor-on-wildfires-this-is-the-new-abnormal.

Castro, J.A. 2012. What does 'Study the past if you define fhte future' mean? http://wiki.answers.com/Q/What_does_'Study_the_past_if_you_would_define_the_future'_mean

Clements, C.B., N.P. Lareau, D.E. Kingsmill, C.L. Bowers, C.P. Camacho, R.Bagley, and B. Davis. 2018. The rapid deployments to wildfires experiment (RaDFIRE): Observations from the fire zone. Bulletin of the American Meterological Society *https://doi.org/10.1175/BAMS-D-17-0230.1*.

Cranley, E. 2018. Trump continues to blame fires on forest mismanagement even while traveling to California. Business Insider 11/17/18, https://www.businessinsider.com/trump-continues-to-blame-wildfires-on-forest-mismanagement-2018-11.

Deser, C., A. Phillips, V. Bourdette, and H. Teng. 2012. Uncertainty in climate change projections: the role of internal variability. *Climate Dynamics* 38: 527-546.

Jacobsen, A. L., and R. B. Pratt. 2018. Extensive drought-associated plant mortality as an agent of type-conversion in chaparral shrublands. *New Phytologist* 219: 498-504.

Jin Y, J. T. Randerson, N. Faivre, S. Capps, A. Hall, and M. L. Goulden. 2014. Contrasting controls on wildland fires in Southern California during periods with and without Santa Ana winds. Journal of Geophysical Research, *Biogesciences* 119: doi:10.1002/2013/G002541.

Keeley, J. E., H. Safford, C. J. Fotheringham, J. Franklin, and M. Moritz. 2009. The 2007 southern California wildfires: Lessons in complexity. *Journal of Forestry* 107: 287-296.

Keeley, J. E., and A. D. Syphard. 2017. Different historical fire-climate relationships in California. *International Journal of Wildland Fire* 26: 253-268.

Keeley, J. E., and A. D. Syphard. 2018. Historical patterns of wildfire ignition sources in California ecosystems. *International Journal of Wildland Fire* 27: 781-799.

Keeley, J. E., and S. D. Syphard. 2019. Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. *Fire Ecology* 15: 24 doi.org/10.1186/s42408-019-0041-0.

Keifer, M. B. 2006. Long-term surface fuel accumulation in burned and unburned mixed-conifer forests of the Central and Southern Sierra Nevada, CA (USA). *Fire Ecology* 2: 53-72.

Kennedy, R. G. 2006. Wildfire and Americans. How to save lives, property, and your tax dollars. Hill and Wang, New York.

Kolden, C. A., and J. T. Abatzoglou. 2018. Spatial distribution of wildfires ignited under katabatic versus non-katabatic winds in Mediterranean Southern California USA. *Fire* 1:19, doi: 10.3390/fire1020019.

McKelvey, K.S. and K.K. Busse. 1996. Twentieth-century fire patterns on forest service lands. In Sierra Nevada Ecosystem Project: Final report to Congress, vol II, Centers for Water and Wildland Resources, University of California, Davis, pp1119-1138.

North, M., B. M. Collins, and S. Stephens. 2012. Using fire to increase the scale, benefits, and future maintenance of fuels treatments. *Journal of Forestry* 110: 392-401.

Office of Governor 2019. Governor Newsom signs bills to enhance wildfire mitigation, preparedness and response effors. 10/2/2019, https://www.gov.ca.gov/2019/10/02/governor-newsom-signs-bills-to-enhance-wildfire-mitigation-preparedness-and-response-efforts/

Park, I. W., J. Hooper, J. M. Flegal, and G. D. Jenerette. 2018. Impacts of climate disturbance and topography on distribution of herbaceous cover in Southern California chaparral: insights from a remote-sensing method. *Diversity and Distributions* 24: 497-508.

Penn, I., P. Eavis, and J. Glanz. 2019. How PG&E ignore fire risks in favor of profits. New York Times 03/18/2019, https://www.nytimes.com/interactive/2019/03/18/business/pge-california-wildfires.html

Rolinski, T., S. B. Capps, R. G. Fovell, Y. Cao, B. J. D'Agostino, and S. Vanderburg. 2016. The Santa Ana wildfire threat index: Methodology and operational implementation. *Weather and Forecasting* 31: 1881-1897.

Rolinski, T., S. B. Capps, and W. Zhuang. 2019. Santa Ana Winds: A descriptive climatology. *Weather and Forecasting* 34: 257-275.

Stephens, S. L., B. M. Collins, C. J. Fettig, M. A. Finney, C. M. Hoffman, E. E. Knapp, M. P. North, H. Safford, and R. B. Wayman. 2018. Drought, tree mortality, and wildfire in forests adapted to frequent fire. *BioScience* 68: 77-88.

Syphard, A. D., T. J. Brennan, and J. E. Keeley. 2018a. Chaparral landscape conversion in Southern California, pp. 311-334. In E. C. Underwood, H. D. Safford, J. E. Keeley, N. Molinari, and J. J. Hooper (eds), *Valuing Chaparral. Ecological, Socio-Economic, and Management Perspectives.* Springer, New York.

Syphard, A. D., T. Sheehan, H. Rustigian-Romsos, K. Ferschweller. 2018b. Mapping future fire probability under climate change: Does vegetation matter? *PLOS ONE* 10.1371/journal.pone.0201680.

Westerling, A. L. 2018. Wildfire simulations for California's fourth climate change assessment: projecting changes in extreme wildfire events with a warming climate. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CED-2018-014.

Williams, A. P., R. Seager, J. T. Abatzoglou, B. I. Cook, J. E. Smardon, and E. R. Cook. 2015. Contribution of anthropogenic warming to California drought during 2012-2014. *Geophysical Research Letters* 10.1002/2015GL064924.

Williams, A. P., J. T. Abatzoglou, A. Gershunov, J. Guzman-Morales, D. A. Bishop, J. K. Balch, and D. P. Lettenmaier. 2019. Observed impacts of anthropogenic climate change on wildfire in California. *Earth's Future* 7: 892-910.



WHY ARE SO MANY STRUCTURES BURNING IN CALIFORNIA?

Alexandra D. Syphard and Jon E. Keeley

California has earned a reputation for wildfires that inflict serious damage on human infrastructure, dating back to images of Richard Nixon hosing down the roof of his house in the 1961 Bel-Air fire, and of the famous "fireproof" home of grocery store entrepreneur Fred Roberts burning to the ground in 1982. In recent years, this notoriety has been transformed into public alarm, reflected in the apocalyptic headlines of recent newspaper articles suggesting the "end of California" (*New York Times*, 30 October 2019) and that "California is becoming unlivable" (*The Atlantic,* 30 October 2019). Now the phrase "the new normal" has worked its way into the lexicon, sustained by record-breaking structure loss numbers in 2017 and 2018 despite significantly lower structure losses in 2019.

It remains to be seen whether or not those two recent years were back-to-back, once in a century events, or if the trend has crossed some kind of tipping point, but data does show a long-term trend of significant increase in structures lost to wildfires since the beginning of the 20th century (Fig. 1). What was an average of ~500 homes lost per year in Southern California from about 1950–2000 (Cal Fire 2000) has recently climbed to ~2700 structures per year statewide from 2000–2018 (Syphard and Keeley 2019). California is not alone in the U.S., or in the world, in suffering increasing impacts from wildfires (e.g., Blanchi et al. 2012, Haynes 2015, Viegas 2018). Impacts so far in the recent Australian bushfire season have been record-breaking, with several thousand structures lost, more than 25 fatalities, and unthinkable losses to wildlife. The question that follows, then, is why?

Although trends vary from region to region, one clear reason for increasing wildfire-related losses is

Above: A home burned by the Thomas Fire in 2017. *[Photograph by Master Sgt. Brian Ferguson/U.S. Air Force]*

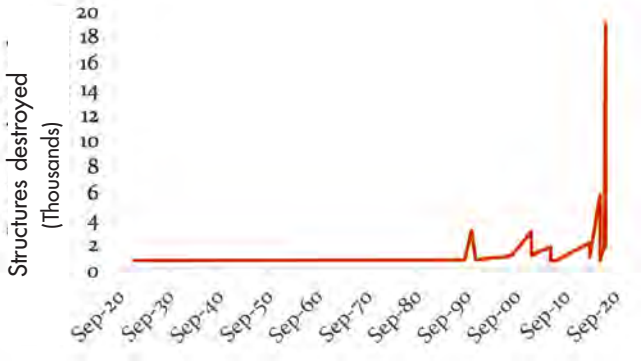


Figure 1. Annual number of structures destroyed in wildfires in California from 1920 to 2018. *[Source: California Department of Forestry & Fire Protection]*

the overall increase in wildfire activity. Although, counter to intuition, the number of wildfires has declined in the last several decades, area burned has either remained constant or increased, with substantially higher frequency of large wildfires (Keeley and Syphard 2018)(Discussed further in Keeley and Syphard, pg. 4 of this issue.) Perhaps an even stronger explanation for increased wildfire-related structure loss is the rapid development of the wildland–urban interface (WUI), which not only exposes more structures to wildland fire, but also increases the likelihood for more human-ignited fires (Radeloff et al. 2018). Despite these trends, however, not all fires result in structure loss, and not all structures are impacted by wildfires they are exposed to. Thus, it is essential to study the factors that are most strongly related to structure exposure and resilience to wildfire, which could then lead to better adaptation and coexistence with wildfire in this era of the "new normal."

In response to this need, a growing number of scientists are conducting empirical research studies to answer the question of why some structures are lost in wildfires and others aren't. Results so far show that the answer to that question is complicated. That is, structure loss results from the confluence of multiple interacting factors across different temporal and spatial scales, which all vary by ecosystem. Given this complexity, misunderstandings and disagreements have arisen over the cause and direction of trends in wildfire activity (Doerr and Santín 2016), fire risk and structure loss (Mccaffrey et al. 2019), and thus, the most effective approach for prioritizing fire management decisions (Moritz et al. 2014). In fact, management techniques appropriate for one region are commonly applied inappropriately to other regions (Noss et al. 2006).

One way that this conflict over priorities can be reduced is through better information and understanding of the similarities and differences that contribute to structure loss among wildfire ecoregions. As data accumulate about the range of conditions under which losses occur, it will be increasingly possible to sort out which risk management techniques are most appropriate for different regions. Wildfire structure losses in the last several decades have already provided a wealth of data for studies comparing factors associated with structures that survived or were destroyed. Most of this work has been done in California (Maranghides and Mell 2009, Syphard et al. 2012a, 2014, 2017, 2019c, Miner 2014, Alexandre et al. 2015, Kramer et al. 2019, Syphard and Keeley 2019) and Australia (Leonard 2009, Blanchi et al. 2010, 2012, Gibbons et al. 2012, 2018, Price and Bradstock 2013, Penman et al. 2019); but some work has also been done in other parts of the continental United States (Alexandre et al. 2016, Kramer et al. 2019).

Combined, the results of this research show clear roles for both local, house-level factors (e.g., structural characteristics of a particular house and property-level landscaping) and broader, landscape-level factors (e.g., housing pattern and location, topography, fuel, and fire characteristics) in explaining why some structures survive wildfires and others don't. This is consistent with the natural hazards literature that theoretically places vulnerability within the intersection of "exposure," that is, potential contact with a hazard; and "sensitivity," or the degree to which the hazard can cause harm (Birkmann 2006). Vulnerability to wildfire is a combination of exposure and sensitivity such that vulnerability results in loss when sensitive characteristics of structures are exposed to hazard events (e.g., the wildfire) (Cutter 1996, Schumann et al. 2019). Thus, exposure is the part of vulnerability related to characteristics of a location, and sensitivity is the risk of loss due to intrinsic physical or social characteristics.

EXPOSURE

Coincidence of fires and houses

A structure's wildfire hazard exposure ultimately lies at the spatial intersection of a wildfire event and the location of the property. The probability of structure loss thus depends on the relative likelihood that a fire ignition results in a fire within the geographical range of structures in the WUI. In turn, this depends on the location and timing of a fire ignition, which varies depending on cause and biophysical characteristics (Syphard and Keeley 2015) relative to other determinants of fire size, including topographic con-



Most homes don't burn from direct contact with flame. Here, a wind-driven fire carried embers over cement and ice plant to the house, reinforcing the importance of reducing the flammability of the home—focusing fire risk reduction from the "house outward." *[Photograph by Rick Halsey]*

ditions; fuel amount, moisture, and spatial continuity; and weather (Faivre et al. 2016). Large fires tend to be either primarily fuel-dominated or wind-dominated (Keeley and Syphard 2019), with most damage and economic loss occurring from wind-driven fire events (Jin et al. 2015, Keeley and Syphard this issue).

Large fire probability increases with the co-occurrence of human-caused ignitions and severe wind conditions (Abatzoglou et al. 2018). This means that, as population increases and development further encroaches into wildland vegetation, there is an increased risk that a human-caused ignition will coincide in place and time with hot, dry weather; flammable vegetation; and severe wind conditions. Data show that fires tend to be most frequent at low to intermediate housing and population densities (Syphard et al. 2009, Bistinas et al. 2013). Thus, the rapid increase in the spread of exurban development like that occurring now in California (Radeloff et al. 2018), has the potential to both increase the number of ignitions and decrease the overall distance between wildlands and housing.

As the distance between wildland vegetation and housing development decreases across a landscape, the overall exposure of houses to wildfire increases. This helps to explain research that shows the arrangement and location of housing development to be a top-ranked predictor of whether a structure survives or is destroyed by wildfire (e.g., Syphard et al. 2012b, Alexandre et al. 2016, Kramer et al. 2019). In terms of arrangement, data consistently shows that loss to wildfire is highest at relatively low housing density (Kramer et al. 2018, Syphard et al. 2019c) and at the interface between wildlands and development (Kramer et al. 2019), regardless of the geographic region in which a structure is located.

Other housing patterns, such as the way housing is dispersed, or the size of housing clusters, are also influential, although their relative importance in explaining structure loss varies from region to region (Alexandre et al. 2015, 2016). Topography is an additional exposure-related factor significantly related to structure loss, as fire tends to spread quickly upslope, meaning that houses on ridgetops are particularly vulnerable. An important caveat to the relationship between low structure density and structure loss is that, once a fire reaches a development, structure-to-structure spread is possible if adjacent houses are highly flammable and spaced within at least 50 meters of one another (Price and Bradstock (2013). In these circumstances, high housing density can be a significant risk factor (Maranghides and Mell 2009).

Fire patterns, altered fire regimes, and vegetation management

In addition to housing arrangement, housing location affects the potential exposure of a structure to wildfire because some areas are inherently more fire-prone than others (Syphard et al. 2012b). Certain parts of the landscape tend to burn repeatedly while others do not, and this reflects the wide variation in fire regimes across California (Syphard and Keeley in press). During the last century, fire regimes in California have been altered due to a range of factors including climate change, land use change, and legacies of fire management. However, the cause of fire regime changes, and their relative effects, have been nearly opposite in the northern and southern coastal parts of the state (Safford and Water 2014). As described in Keeley and Syphard (this issue), a history of successful fire exclusion in dry, mixed-conifer forests contributed to an alteration of what had been a low-intensity surface fire regime that typically burned back the understory plants without reaching into the canopy and burning

the large trees. The subsequent increase in the density of surface litter and the unchecked ingrowth of young trees that serve as ladder fuels now facilitate uncharacteristically severe crown fires. In contrast, in the native shrublands of southern and central coastal California, increased human-caused ignitions have resulted in unnaturally high fire frequency, with increases in wildfire further promoted by ongoing conversion of shrublands to more flammable invasive grasses (Fusco et al. 2019, Syphard et al. 2019b, 2019a).

These differences in the two fire regimes, and how they have been altered, have led to substantial controversy regarding wildfire exposure and the effects and effectiveness of vegetation management (Keeley et al. 2009, Halsey and Syphard 2015). In both northern and southern California, changes in fire regimes could lead to more dangerous or frequent wildfires, thereby increasing structure exposure to hazard. Mechanical treatments and prescribed fire in dry, mixed-conifer forests that reduce the understory and decrease small diameter tree density may help return these forests to a more resilient condition, and thereby potentially reduce exposure of structures to high fire hazard (Knapp et al. 2017).

On the other hand, in the non-forested landscapes that dominate the coastal central and southern parts of the state, vegetation management is primarily focused on reducing the extent of woody vegetation. That is, mechanical treatments are typically designed to remove and reduce the cover of native shrublands and increase the cover of herbaceous vegetation. Prescribed fire in this region *increases* the amount of uncharacteristically frequent fire, putting additional stress on native chaparral and shrublands. Therefore, in non-forested ecosystems vegetation management is inconsistent with ecological integrity and, in addition, has minimal efficacy in the wind-driven fires that result in the most structure loss (Keeley and Syphard this issue).

Access as a risk factor

While vegetation management may control fire behavior by slowing wildfire spread, wildfires during extreme wind conditions typically generate embers and burning debris that can fly kilometers ahead of the fire front. Therefore, fuels management in remote landscapes, even if it does alter fire behavior, has little possibility of preventing wind-driven fires from spreading and expanding if there are no firefighters present to control the fire. This is the likely explanation for why Penman et al. (2014) found that fire size and exposure of property to wildfire in Southern California are primarily controlled by fire weather and characteristics of the built environment, with fuel treatments or fuel load management having minimal influence. Fuel load is less likely to be limiting during wind-driven wildfires and reduction of fuel load in remote areas is unlikely to affect fire outcomes (Keeley et al. 2004, Schoennagel et al. 2004).

On the other hand, strategic placement of fuel breaks near communities may be more effective at reducing exposure because firefighters can use these for safe access to perform suppression activities (Syphard et al. 2011). In addition to strategically placed fuel breaks near communities, the road network surrounding a structure is also important for minimizing exposure from an access perspective. Wide roads and multiple access points can facilitate the transport of firefighting resources to properties within a community; in addition, a good road network provides faster and more efficient evacuation alternatives (Mangan 2000).

SENSITIVITY

Community sensitivity to wildfire, and the capacity to recover from wildfire losses, is related to the social and demographic characteristics of a region (Schumann et al. 2019). In terms of the physical nature of structure loss, however, the primary determinants of sensitivity include defensible space and home structure characteristics as well as firefighter accessibility.

Defensible space

There is certainly a degree of confusion regarding defensible space. A common sentiment is that the larger the defensible space, the better protected the home.

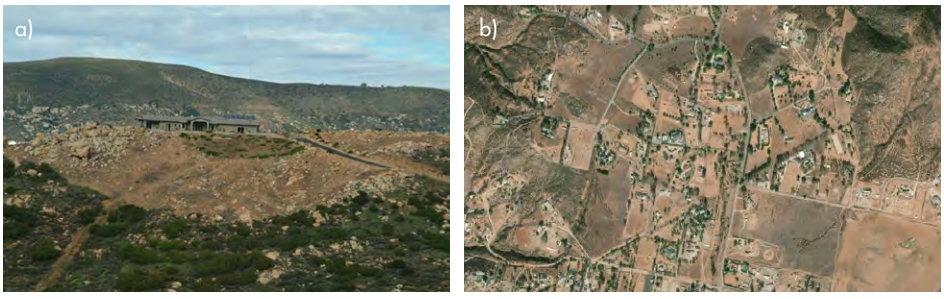


Figure 3. Local (a) and landscape-scale (b) examples of defensible space being performed beyond legal requirements or scientific evidence for protection. *[Images courtesy of Alexandra Syphard]*

Thus, clearance far in excess of legal requirements is increasingly being carried out (Fig. 3a), sometimes at a broad scale (Fig 3b). This is not necessarily helpful or effective. At the same time, many homeowners fail to create sufficient defensible space to improve structure survival.

What does the evidence show about the effectiveness of defensible space? The state of California requires homeowners in state-defined hazardous areas to provide 30 meters (100 feet) of defensible space around their home, which involves the maintenance of specific horizontal and vertical distances of spacing between patches of woody vegetation. Empirical studies in two Southern California areas found that defensible space of approximately 5-20 meters (16-66 feet) provided significant protection, with additional distance providing little or no significant benefit, even on steep slopes (Miner 2014, Syphard et al. 2014). Empirical research looking at structure loss in Australia also found that vegetation reduction and defensible space were most effective at close proximity to the structure (Gibbons et al. 2012, Penman et al. 2019), and that regular irrigation and proper spacing could be as just as effective as clearing woody vegetation (Gibbons et al. 2018).

The largest empirical study of home survival published to date, which included more than 40,000 structures subjected to wildfires over a five year period (Syphard and Keeley 2019), showed that defensible space distance explained little or none of the variance in structure survival. Instead, characteristics of the structure itself were far more significant (Fig. 4). These results should not be interpreted to mean defensible space is not important. But they do suggest that the most important component of defensible space may be the characteristics of vegetation closest to the house. For example, vegetation touching the structure and trees overhanging the roof were highly significant in the two empirical examples from Southern California.

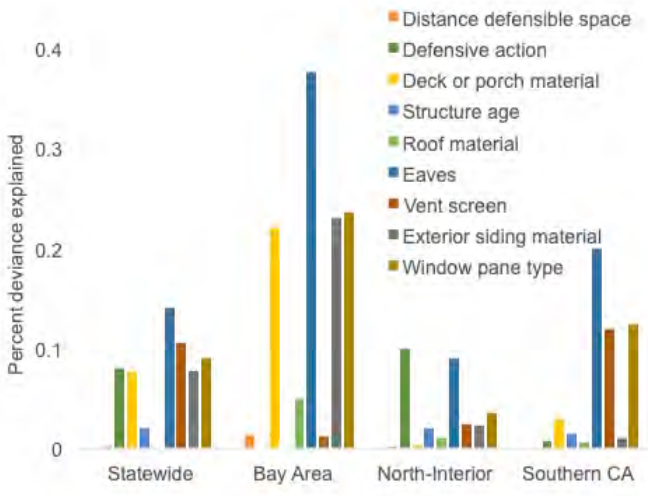


Figure 4. Relative importance (percent deviance explained) of defensible space distance and structural characteristics explaining structure loss to California wildfires from 2013–2018 for the entire state and broken into three broad regions. *[Figure modified from Syphard and Keeley 2019]*



Figure 5. Image of flammable debris on a roof that could ignite from wind-blown embers, reflecting how vegetation near or overhanging structures could increase the likelihood of structure loss.

Ember cast

It needs to be appreciated that, particularly during extreme wind-driven fires, most homes do not burn from direct flame contact, but rather from embers blown from the fire front, even from a kilometer or more away. Thus, the material that embers land on, be it vegetation or the structure itself, is key to whether the structure ignites or not. In some cases, the effect of overhanging trees or nearby vegetation is mostly related to the dead plant material or debris that is close to the structure (Fig.5). Likewise, many of the structural characteristics found to be most important in this recent study (Syphard and Keeley 2019) were related to the prevention of ember penetration, such as vent screens and eaves. Open eaves (Fig. 6a) are much more vulnerable to fires than closed eves (Fig. 6b). Open eaves have vents that are arranged perpendicular to the ground and thus in direct line of oncoming wind-driven ember cast. Closed eaves have vents facing down towards the ground and perhaps less prone to embers entering the vents.



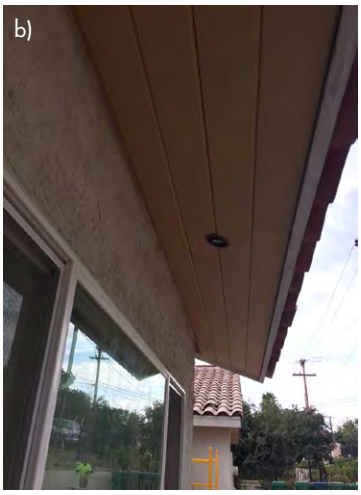


Figure 6. Images of a) open eave design that may allow ember penetration into the structure more readily than b) closed eave design that has been significantly associated with structure survival in California wildfires. *[Photographs here and above courtesy of Alexandra Syphard and Jon Keeley]*

CONCLUSION

The studies described above illustrate that some structures are destroyed in wildfires and others are not because of multiple, often interacting, factors that variably influence the exposure and sensitivity of a property to wildfire. In an ideal world, strategies to increase community resilience to wildfire would be ranked and prioritized according to their relative potential for success in preventing structure loss in any given ecosystem. Of course, an ideal world would also not have to account for factors such as cost, effort, and feasibility, which add to the complexity of decision-making in the real world.

While most empirical research on structure loss has so far focused on either exposure or sensitivity factors independently, an integrated analysis in Southern California provided a comparison of the relative importance of different exposure-related and sensitivity-related variables (Syphard et al. 2017, Fig. 7) in distinguishing destroyed from surviving structures. Study results suggested that exposure (when measured by structure density) was the most important factor overall that distinguished destroyed from surviving structures. The relative importance of different sensitivity variables (e.g., structure age or landscaping characteristics) varied depending upon whether the structure was highly exposed (i.e., at low housing density) or less exposed (i.e., at high housing density) (Fig. 7).

These results suggest that, in an ideal world, the most effective strategy at reducing future structure loss would focus on reducing the extent of low-density housing via careful land planning decisions. This conclusion is rather obvious given that reducing exposure reduces the chance that a wildfire could reach a structure in the first place. In the real world, regardless of land use planning decisions for future development, there is extensive existing development that may be exposed to future wildfires. Therefore, strategies like ignition prevention and strategic vegetation management could potentially reduce the exposure of these houses by focusing on the initiation or spread of the wildfire.

Once a fire reaches a property, structure sensitivity then becomes the key determinant for survival. In many areas, effective efforts to minimize sensitivity to wildfire include education and increased awareness of appropriate defensible space practices, development of Firewise Communities (Jakes et al. 2007), and improvement in building codes. Nonetheless, some communities underinvest in defensible space (Taylor et al. 2019), while in others, homeowners create excessive clearance (Fig. 3) that may increase the extent of invasive grass on the property. Conversion of native woody vegetation into grass in the non-forested landscapes of Southern California, for example, could increase the flammability of the property (Fusco et al. 2019), particularly if the grass is not irrigated regularly (Gibbons et al. 2018).

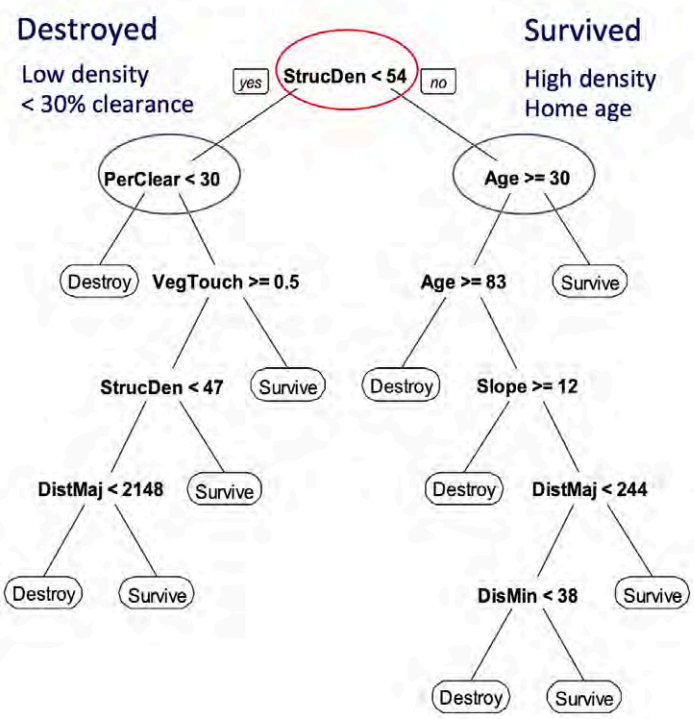


Figure 7. Classification tree showing the hierarchy of factors that best distinguished destroyed from survived structures in Southern California wildfires. Abbreviations are: StrucDen = structure density; PerClear = percentage woody vegetation clearance on property; Age = age of structure; VegTouch = number of sides of structure with vegetation touching; Slope = percentage slope on property; DistMaj = distance in meters to a major road; DisMin = distance in meters to a minor road. *Modified from Syphard et al. 2017.*

Given the importance of structural characteristics in home survival in recent California wildfires (Syphard and Keeley 2019), the improvement of building codes has been a positive development overall. However, there is already extensive existing residential development in fire-prone areas that was built prior to the adoption of new building codes. Reducing the fire sensitivity of these homes generally entails retrofits and modifications, which can be expensive (Quarles and Pohl 2018). However, some of the most effective actions, such as eave coverings and vent screens, are generally less expensive than replacing roofing or exterior siding, although window replacement can also be expensive (Quarles and Pohl 2018).



The 2017 Thomas Fire. *[Photograph courtesy of Stuart Palley/ U.S. Forest Service]*

It would appear, given recent improvements in adapting structures to withstand fire, that the increase in the numbers of houses burned in wildfire is not a matter of increased sensitivity. Instead, the answer lies somewhere in the combination of factors that govern exposure, including changes to wildfire behavior and activity, as well as exurban development that places structures in the path of these wildfires. Climate and vegetation change may increase the probability of large wildfires in some regions, such as the northern parts of California (Syphard et al. 2019c); but in other regions, like Southern California, climate change is likely to manifest differently, most likely indirectly, via factors such as long-term drought and vegetation change.

While the effects of climate change on wildfire vary from region to region, housing pattern variables have consistently been the most important factors explaining structure loss across California and elsewhere. This suggests that much of the increase in structure loss in California may be attributable to increases in this type of exposure—and that planning decisions could have broad-scale benefits in the future. Also consistent across regions is the potential for homeowner mitigation measures to provide significant improvement in structure survival probability. Those measures that focus on reduction of ember impact and penetration are most important.

Despite these overall consistencies, there is variation in the nature and strength of relationships in all of these factors. Wildfire frequency and behavior, and fuel characteristics, vary widely by ecosystem; thus, vegetation management efforts differ greatly in effects and effectiveness and should be implemented appropriately. Regardless of regional variations, everyone, from the individual homeowner, to local planning and permitting officials, to state and federal government authorities, will need to be involved in instituting preventive measures. Management appropriately informed by science and data analysis can reduce future structure losses and minimize ecological impacts to assure a more sustainable future. While these efforts may seem expensive in the present, it is much less expensive than paying for losses in the future.

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REFERENCES

Abatzoglou, J. T., J. K. Balch, B. A. Bradley, and C. A. Kolden. 2018. Human-related ignitions concurrent with high winds promote large wildfires across the USA. *International Journal of Wildland Fire* 27:377–386.

Alexandre, P. M., S. I. Stewart, N. S. Keuler, M. K. Clayton, M. H. Mockrin, A. Bar-Massada, A. D. Syphard, and V. C. Radeloff. 2016. Factors related to building loss due to wildfires in the conterminous United States. *Ecological Applications* 26.

Alexandre, P. M., S. I. Stewart, M. H. Mockrin, N. S. Keuler, A. D. Syphard, A. Bar-Massada, M. K. Clayton, and V. C. Radeloff. 2015. The relative impacts of vegetation, topography and spatial arrangement on building loss to wildfires in case studies of California and Colorado. *Landscape Ecology* 31:415–430.

Birkmann, J. 2006. Measuring vulnerability to natural hazards: towards disaster resilient societies. United Nations University Press, Tokyo.

Bistinas, I., D. Oom, A. C. L. Sá, S. P. Harrison, I. C. Prentice, and J. M. C. Pereira. 2013. Relationships between human population density and burned area at continental and global scales. *PLOS ONE* 8:e81188.

Blanchi, R., J. Leonard, K. Haynes, K. Opie, M. James, M. Kilinc, F. D. De Oliveira, and R. Van den Honert. 2012. Life and house loss database description and analysis. CSIRO.

Blanchi, R., C. Lucas, J. Leonard, and K. Finkele. 2010. Meteorological conditions and wildfire-related houseloss in Australia. *International Journal of Wildland Fire* 19:914–926.

Cal Fire. 2000. Wildland Fire Hazard Assessment. California Division of Forestry and Fire Protection, Sacramento, CA.

Cutter, S. L. 1996. Vulnerability to environmental hazards. *Progress in Human Geography* 20:529–539.

Doerr, S. H., and C. Santín. 2016. Global trends in wildfire and its impacts: Perceptions versus realities in a changing world. Philosophical Transactions of the Royal Society B: *Biological Sciences* 371.

Faivre, N. R., Y. Jin, M. L. Goulden, and J. T. Randerson. 2016. Spatial patterns and controls on burned area for two contrasting fire regimes in Southern California. *Ecosphere* 7:e01210.

Fusco, E. J., J. T. Finn, J. K. Balch, R. C. Nagy, and B. A. Bradley. 2019. Invasive grasses increase fire occurrence and frequency across US ecoregions. *Proceedings of the National Academy of Sciences*: 1–6.

Gibbons, P., L. van Bommel, A. Gill, G. J. Cary, D. A. Driscoll, R. A. Bradstock, E. Knight, M. A. Moritz, S. L. Stephens, and D. B. Lindenmayer. 2012. Land management practices associated with house loss in wildfires. *PLOS ONE* 7:e29212.

Gibbons, P., A. M. Gill, N. Shore, M. A. Moritz, S. Dovers, and G. J. Cary. 2018. Options for reducing house-losses during wildfires without clearing trees and shrubs. *Landscape and urban planning* 174:10–17.

Halsey, R. W., and A. D. Syphard. 2015. High-Severity Fire in Chaparral: Cognitive Dissonance in the Shrublands. The Ecological Importance of Mixed-Severity Fires: Nature's Phoenix.

Haynes, H. J. G. 2015. *Fire loss in the United States during 2014.* National Fire Protection Association, Fire Analysis and Research Division.

Jakes, P., L. Kruger, M. Monroe, K. Nelson, and V. Sturtevant. 2007. Improving wildfire preparedness: lessons from communities across the US. *Human Ecology Review*:188–197.

Jin, Y., M. Goulden, S. Faivre, V. Veraverbeke, A. Hall, M. Hand, S. Hook, and J. Randerson. 2015. Identification of two distinct fire regimes in southern California: implications for economic impact and future change. *Environmental Research Letters* 10:094005.

Keeley, J. E., C. J. Fotheringham, and M. A. Moritz. 2004. Lessons from the October 2003 Wildfires in Southern California. *Journal of Forestry*: 102: 26-31.

Keeley, J. E., H. D. Safford, C. J. Fotheringham, J. Franklin, and M. A. Moritz. 2009. The 2007 southern California wildfires: Lessons in complexity. *Journal of Forestry* 107:287–296.

Keeley, J. E., and A. D. Syphard. 2018. Historical patterns of wildfire ignition sources in California ecosystems. *International Journal of Wildland Fire* 27:781–799.

Keeley, J. E., and A. D. Syphard. 2019. Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. *Fire Ecology* 15:24.

Knapp, E. E., J. M. Lydersen, M. P. North, and B. M. Collins. 2017. Efficacy of variable density thinning and prescribed fire for restoring forest heterogeneity to mixed-conifer forest in the central Sierra Nevada, CA. *Forest Ecology and Management* 406:228–241.

Kramer, H. A., M. H. Mockrin, P. M. Alexandre, and V. C. Radeloff. 2019. High wildfire damage in interface communities in California. *International Journal of Wildland Fire* 28:641.

Kramer, H. A., M. H. Mockrin, P. M. Alexandre, S. I. Stewart, and V. C. Radeloff. 2018. Where wildfires destroy buildings in the US relative to the wildland–urban interface and national fire outreach programs. *International Journal of Wildland Fire* 27:329–341.

Leonard, J. 2009. Report to the 2009 Victorian Bushfires Royal Commission. Building performance in bushfires. Highett, Victoria, Australia: CSIRO Sustainable Ecosystems.

Mangan, R. J. 2000. Improving firefighter safety in the wildland-urban intermix. USDA Forest Service, Technology and Development Program.

Maranghides, A., and W. Mell. 2009. A Case Study of a Community Affected by the Witch and Guejito Fires.

Mccaffrey, S. M., G. L. Duffner, and L. M. Decker. 2019. Chapter Twenty-Seven. Social Dynamics of Wildland Fire in California. *Fire in California's Ecosystems:* 507–516.

Miner, A. 2014. Defensible space optimization for preventing wildfire Structure loss in the Santa Monica Mountains. Johns Hopkins University.

Moritz, M. A., E. Batllori, R. A. Bradstock, A. M. Gill, J. Handmer, P. F. Hessburg, J. Leonard, S. McCaffrey, D. C. Odion, T. Schoennagel, and *Nature*: 515 (6):58-66.

Noss, R. F., J. F. Franklin, W. L. Baker, T. Schoennagel, and P. B. Moyle. 2006. Managing fire-prone forests in the western United States. *Frontiers In Ecology And The Environment* 4:481–487.

Penman, S. H., O. F. Price, T. D. Penman, and R. A. Bradstock. 2019. The role of defensible space on the likelihood of house impact from wildfires in forested landscapes of south eastern Australia. *International Journal of Wildland Fire* 28:4–14.

Penman, T. D., L. Collins, A. D. Syphard, J. E. Keeley, and R. A. Bradstock. 2014. Influence of fuels, weather and the built environment on the exposure of property to wildfire. *PLOS ONE* 9(10): e111414.

Price, O., and R. Bradstock. 2013. Landscape scale influences of forest area and housing density on house loss in the 2009 Victorian bushfires. *PLOS ONE* 8:e73421.

Quarles, S., and K. Pohl. 2018. Building a Wildfire-Resistant Home: Codes and Costs. Bozeman, MT.

Radeloff, V. C., D. P. Helmers, H. Anu Kramer, M. H. Mockrin, P. M. Alexandre, A. Bar-Massada, V. Butsic, T. J. Hawbaker, S. Martinuzzi, A. D. Syphard, and S. I. Stewart. 2018. Rapid growth of the US wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences* 115:3314–3319.

Safford, H., and K. Van de Water. 2014. Using fire return interval departure (FRID) analysis to map spatial and temporal changes in fire frequency on national forest lands in California.

Schoennagel, T., T. T. Veblen, and W. H. Romme. 2004. The interaction of fire, fuels, and climate across rocky mountain forests. *Bioscience* 54:661–676.

Schumann, R. L., M. Mockrin, A. D. Syphard, J. Whittaker, O. Price, C. Johnson, C. T. Emrich, and V. Butsic. 2019. International Journal of Disaster Risk Reduction Wildfire recovery as a " hot moment " for creating fire-adapted communities. *International Journal of Disaster Risk Reduction:* 101354.

Syphard, A. D., T. J. Brennan, and J. E. Keeley. 2014. The role of defensible space for residential structure protection during wildfires. *International Journal of Wildland Fire* 23:1165–1175.

Syphard, A. D., T. J. Brennan, and J. E. Keeley. 2017. The importance of building construction materials relative to other factors affecting structure survival during wildfire. *International Journal of Disaster Risk Reduction* 21:140-147.

Syphard, A. D., T. J. Brennan, and J. E. Keeley. 2019a. Extent and drivers of vegetation type conversion in Southern California chaparral. *Ecosphere* 10:e02808.

Syphard, A. D., T. J. Brennan, J. E. Keeley, and T. Vaclavik. 2019b. Drivers of chaparral type conversion to herbaceous vegetation in coastal Southern California. *Diversity and Distributions* 10: 90-101.

Syphard, A. D., and J. E. Keeley. 2015. Location, timing, and extent of wildfire varies by cause of ignition. *International Journal of Wildland Fire* 24:37–47.

Syphard, A. D., and J. E. Keeley. 2019. Factors associated with structure loss in the 2013 - 2018 California wildfires. *Fire* 2:49.

Syphard, A. D., J. E. Keeley, and T. J. Brennan. 2011. Comparing the role of fuel breaks across southern California national forests. *Forest Ecology and Management* 261:2038–2048.

Syphard, A. D., J. E. Keeley, A. B. Massada, T. J. Brennan, and V. C. Radeloff. 2012a. Housing arrangement and location determine the likelihood of housing loss due to wildfire. *PLOS ONE* 14(2): e0211454.

Syphard, A. D., J. E. Keeley, A. B. Massada, T. J. Brennan, and V. C. Radeloff. 2012b. Housing arrangement and location determine the likelihood of housing loss due to wildfire. *PLOS ONE* 7:1–13.

Syphard, A. D., V. C. Radeloff, T. J. Hawbaker, and S. I. Stewart. 2009. Conservation Threats Due to Human-Caused Increases in Fire Frequency in Mediterranean-Climate Ecosystems. *Conservation Biology* 23:758–769.

Syphard, A. D., H. Rustigian-Romsos, M. Mann, E. Conlisk, M. A. Moritz, and D. Ackerly. 2019c. The relative influence of climate and housing development on current and projected future fire patterns and structure loss across three California landscapes. *Global Environmental Change* 56:41–55.

Taylor, M. H., L. Christman, and K. Rollins. 2019. Targeting policy to promote defensible space in the wildland-urban interface: evidence from homeowners in Nevada. *Land Economics* 95:531–556.

Viegas, D. X. 2018. Wildfires in Portugal. *Fire Research.*



WILDFIRES AND FOREST RESILIENCE: THE CASE FOR ECOLOGICAL FORESTRY IN THE SIERRA NEVADA

Rodd Kelsey

INTRODUCTION

Forests of the Sierra Nevada and across the western U.S. are experiencing an unprecedented increase in the size and severity of wildfires,[1-6] along with widespread tree mortality due to drought and insect outbreaks.[7-9] Over the last six years alone, five separate wildfires in the Sierra Nevada have burned 100,000 acres or more with unusually large patches of forest burned at high severity, with greater than 75 percent tree mortality.

Several of these fires behaved in ways unlike any experienced in recorded memory and were uncharacteristic of the way that the forests burned before Euro-American arrival in California. These developments are detrimental to forest sustainability as the climate continues to warm,[10-13] not only threatening lives and communities but seriously compromising forest health and resilience, degrading many of the important benefits forests provide to people.

The forested watersheds of the Sierra Nevada provide clean water for over 25 million people[14], support rural economies and tourism[15], and play a critical role in carbon storage and climate control.[16-18] Healthy Sierra forests are also home to abundant and diverse wildlife, with over 500 vertebrate species (24 of which occur nowhere else) and 3,500 plant species (400 of which occur nowhere else).[19]

Above: **Example of ecological thinning on lands owned by the American River Conservancy.** *[Photograph by David Edelson/ The Nature Conservancy]*

This paper focuses on fire in the forests of the Sierra Nevada. Importantly, the causes and consequences of a changing fire regime vary among the different kinds of ecosystems in California. The now more frequent and devastating fires of coastal and inland shrub communities are driven by different factors and, thus, require different solutions.

We know how to manage forests so that they are less prone to megafires and drought and how to decrease the likelihood of large tree mortality events from insect and disease outbreaks.[9,10,20,21] Through targeted ecological thinning, prescribed fire, and managed wildfire we can reduce high fuel loads, promote more resilient forests, reduce the risk of large, high-severity wildfires, and protect sensitive species. Unfortunately, the current pace and scale of these activities is inadequate given the widespread scope and long-term consequences of the problem.

An important obstacle to increasing the pace and scale of ecologically sound forest management in the Sierra Nevada is widespread misunderstanding among policy makers and the public of the two important approaches required to restore our forests: thinning trees to reduce fuels and using fire as a natural restorative process. In this article, we explain how our forests became overgrown and at risk from uncharacteristic, high-severity wildfire and tree mortality. Then, we make the scientific case for ecological forestry—a combination of strategic thinning, prescribed fire, and managed wildfire—as the best solution to the challenges our forests face.

A LEGACY OF LOGGING AND FIRE SUPPRESSION HAS CREATED FORESTS PRONE TO SEVERE WILDFIRES

Why do California's fires burn differently than they did 200 years ago? One critical factor is that, despite the large and destructive wildfires of recent years, many of the forests of the Sierra Nevada are fire-starved.

Prior to the 20th century, wildfires roamed over large areas in the Sierra Nevada every year.[22-25] These were both naturally caused by lightning and intentionally set by Native Americans for the many benefits fire can create, like regenerating valuable food and textile plants. Prior to European settlement, 400,000 to 500,000 acres burned each year on what are now National Forest lands of the Sierra Nevada.[3,26]

Most of these fires were of low or moderate severity. (Low severity generally means less than 25 percent tree mortality, while moderate severity refers to a mortality rate of 25-75 percent.) The majority of trees survived them, except for patches that created openings in the forest.[13,23,27] This patchy mosaic created a wide array of forest conditions, including open, shrubby patches, pocket meadows, and shady stands of large, fire-resistant trees.[27-32] This maintained the health and resilience of the forest and the biota that depend on it. Frequent low-to-moderate intensity fires also reduced the likelihood of megafires in some forests, by removing surface fuels and keeping the shrubs and understory trees that fuel intense fires in check.[27,29-33] The fires also regenerated and increased the variety of understory plants.[134,135] In contrast, today's high intensity fires tend to favor mostly shrubby species over uncharacteristically large patches, in some cases lowering diversity indefinitely.[136]

California's lack of ecologically appropriate fire is the result of the aggressive elimination of fire, beginning in the mid-19th century when Native American burning was drastically reduced. Widespread fire suppression followed in the 20th century, based on the well-intentioned but now disproved assumption that all fire is bad.[13,34-38]

Another important contributor, also beginning in the mid-1800s, was logging—specifically, timber management practices that removed most of the large, fire-resistant trees in old-growth forests and favored uniform "plantations" of trees of the same age and species. These practices removed trees that provide habitat for sensitive species like the California spotted owl and made many forests in the Sierra Nevada highly homogenous and—combined with fire suppression—overly dense with small trees and shrubs.

Today, many of California's forests are dominated by fire-intolerant species, like firs, where there were once mixed conifer forests. The resulting forests have few large fire-resistant trees, continuous canopy cover, and heavy understory fuel loading from litter and woody debris.[13,31,36,37,39-43] Many private timberlands also have relatively homogenous, even-aged stands of trees. Overall, these uncharacteristically uniform, dense, young forests are more prone to high-severity fire.

As a consequence, while the overall frequency of fires remains lower than it once was, in recent decades we have experienced a rapid increase in the area burned by fires.[5,44] There's also strong evidence for an increase in the severity of fires (as measured by trends in fire-driven tree mortality)[1,3,11,34,45] and area burned at high severity.[1,3,34,46] At high elevations, where fire was historically infrequent, the number of fires burning and the annual area burned also appear to be increasing.[3,47] Of particular concern is the potential for more of the largest, most severe fires, like several experienced within the last five years.[48] One recent example of such a "megafire" is the 2014 King Fire, in which half of the 97,000 acres affected burned so severely that it formed a few very large contiguous patches of mostly dead trees. This reflects the change in forests over the



A California spotted owl parent and its chick, recently out of the nest. Most of the large, old trees that spotted owls need for nesting were removed by early logging efforts; those that remain are at risk from high-severity fires. *[Photograph by Danny Hofstadter]*

last hundred years.[49] Based on the best available evidence on historical fire regimes, in contrast to what we witnessed with the King Fire, high-severity burn areas would have been fewer and distributed across many smaller patches.[2,3,27]

The King Fire also burned 30 spotted owl breeding territories where pairs nest and hunt. About half of each of these owl territories was severely burned, on average. In 14 of the territories, the high-severity burn area averaged 89 percent (Gavin Jones, personal communication). The result was a sevenfold higher incidence of abandonment of territories compared to that found in unburned and low-severity burned territories.[50]

The intensity of the King Fire precipitated massive erosion events that caused millions of dollars in damage and maintenance costs for the Placer County Water Agency. It can take decades, if not hundreds of years, for large patches of severely burned forests to recover; some of the forests may be permanently converted to shrub fields if the high-severity patches are very large (like in the King Fire) or if they repeatedly burn during the warmest, driest periods of subsequent years.[51-54]

Even more concerning are the observed and potential long-term effects of a warming climate. California is on track to exceed a 2°C increase in average temperature by 2050 and to experience more intense droughts.[44,55,56] This may push many forests into a climate regime they have not experienced for millenia, or ever,[57] and intensify fire and tree mortality in Sierra forests.[10,12] Increasingly early snowmelt is likely to increase fire frequency and lengthen the fire season.[5] Overall, burned area is expected to increase with a drier and warmer future: By the end of century, we can expect a roughly 50 percent increase in the frequency of extreme wildfires that burn more than 25,000 acres.[58,59]

Dense and young forests are also more prone to the impacts of drought,[60,61] including water stress, insect outbreaks, and some diseases.[9,20,21,62–65] During the 2012-2016 drought, for example, an estimated 130 million trees died in the Sierra, including up to 50 percent of pines in lower and middle elevation watersheds in the central and southern Sierra.[66,67] These conditions can lead to high-intensity fires that endanger human communities and forests.[21]

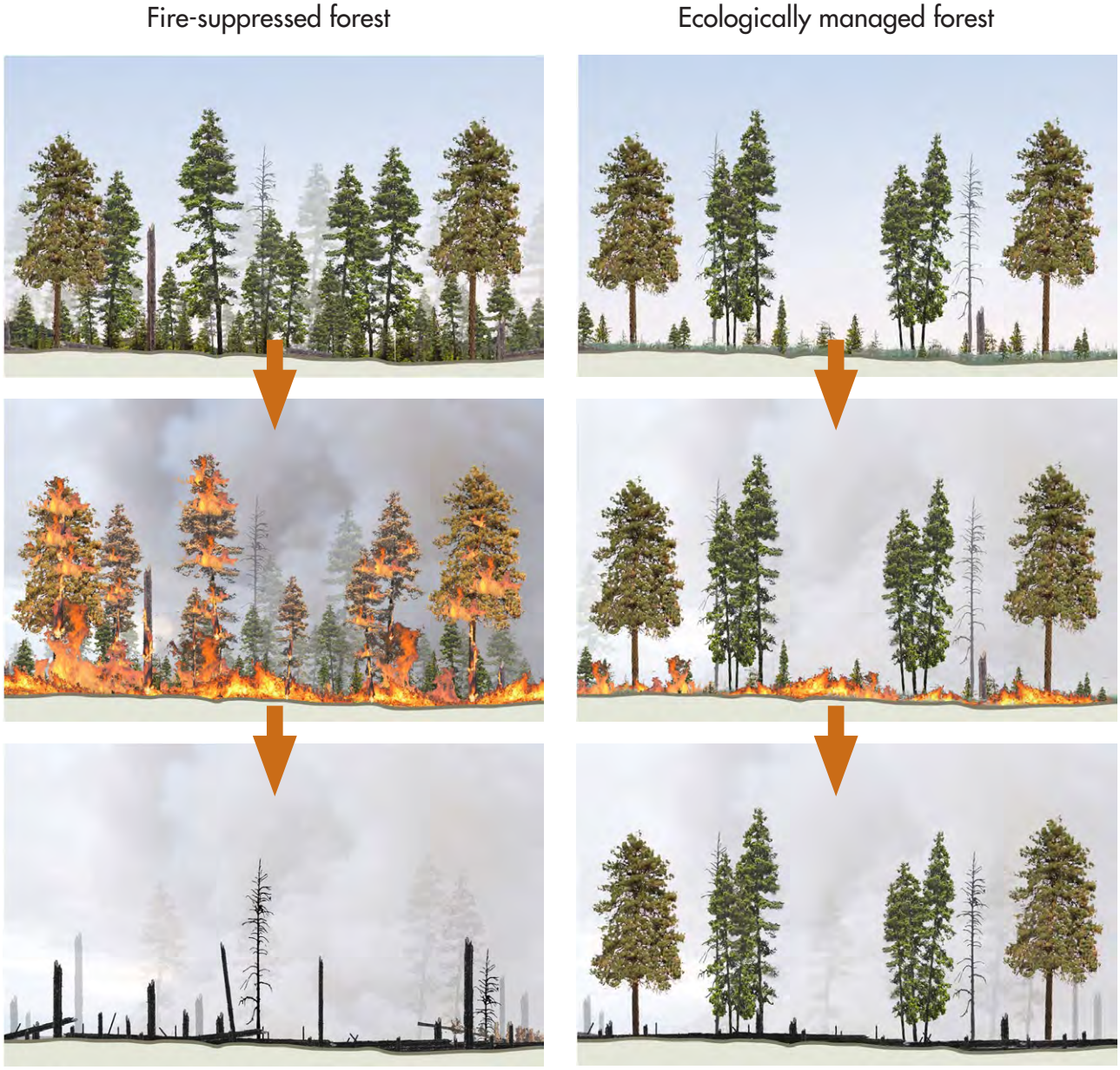
CURRENT FOREST CONDITIONS ARE BAD FOR PEOPLE AND NATURE

Not only do severe fires near communities threaten lives and properties, they can lead to erosion and mudslides that damage homes and water supplies.[68-71] The effects of severe wildfires also go well beyond the forest. Large, intense wildfires degrade air quality around the state and even across the country.[72-74] This increases the duration of smoke exposure,[75] leading to acute and chronic human health impacts such as increased asthma-related hospital visits, respiratory disease, and cardiovascular disease.[76-78]

Forests are a significant source of carbon storage in terrestrial ecosystems, but the value of Sierra Nevada forests as a vital carbon sink is in jeopardy.[12,16,18] Further, the many imperiled species that depend on older, closed-canopy forests and suffer from the legacy of past logging—including California spotted owls[79]—are increasingly threatened by the impact severe fires can have on the little remaining old-growth forest they occupy.[50,80-83]

Many more people live in the forest now than did a century ago. This has intensified the challenges of managing fire, especially at the wildland-urban interface.[84] But eliminating wildfire is not a practical, affordable, or ecologically desirable solution. As recent events have demonstrated, it is also impossible.

In sum, our fire-adapted forests need more of the right kind of fire, yet existing conditions and a warming climate make it unsafe for people and nature to allow all fires to burn under unmanaged conditions. So what is the solution?



Fire-starved forests that have not experienced fire in many decades are prone to high-severity fires that burn very hot and kill 75% or more of trees, including large, fire-resistant trees.

By carefully thinning the understory of some forests to reduce fuel load, we can safely reintroduce fire as a restorative process.
[Graphics courtesy of The Nature Conservancy]

ECOLOGICAL FORESTRY

Forests are diverse and complex, as are the changes they have experienced. There is not a one-size-fits-all answer to restoring their resilience, diversity, and safety.[85-88] The good news is that we largely know what needs to be done. There's robust science showing what the forests used to look like, and how to reduce high-severity fire risk while protecting forests in a changing climate.

Many low- and mid-elevation forests of the Sierra Nevada need to be restored to a more open, patchy, and diverse structure, in order to make them more resilient to drought and a warming climate.[87,89] This will require increasing the scale of ecological forestry: targeted thinning of smaller trees and shrubs where it is needed most combined with more frequent low- and moderate-severity fire. Reducing the impacts of fire on people will also require fire-hardening communities and reducing development in fire prone areas. All three measures will be necessary, and none of them will be sufficient on its own.



California spotted owl nesting and roosting habitat.
[Photograph by David Edelson/The Nature Conservancy]

Ecological forestry will also need to include proactive measures to ensure the resilience and adaptive capacity of the forests to a changing environment over the long term. This may include active replanting of seeds from drought tolerant populations or facilitating the expansion of tree and shrub genotypes that are better adapted to future climates and disturbance regimes.[90,91]

ECOLOGICAL THINNING

As counter-intuitive as it may seem, given that historical logging created some of the challenges our forests face, cutting some trees is now a necessary part of the solution.[28,92-96] Under current conditions, healthy fire cannot be safely reintroduced to some forested areas without some preliminary fuel reduction. This is particularly important in areas that are closest to homes and communities and in areas that can transport high-intensity fire to the wildland-urban interface, as happened in the 2018 Camp Fire. Targeted and ecologically based thinning in accessible areas is needed to open up the forest where it is unnaturally dense. Done well, this kind of thinning can recreate a diverse forest structure that protects wildlife and plant diversity and facilitates the reintroduction of fire where it would currently be unsafe to do so.[95-97]

Ecological forestry has little in common with historical logging practices. Ecological thinning does not mean clearcutting, old-growth forest logging, or extensive salvage logging after fires. It is explicitly focused on protecting the oldest trees and creating a diverse mosaic of natural features that are essential for forest diversity and regeneration.[96,98]

Intensive logging can negatively affect sensitive wildlife and the diversity and function of the forests, so this must be done carefully to balance the trade-offs between short-term impact and long-term benefits. That means prioritizing the removal of the surface and ladder fuels that contribute most to wildfire hazard[99], while minimizing ground disturbance and impacts to those trees and shrubs that will not be removed. It also means maintaining higher canopy cover in some locations and protecting stands of large trees in high quality habitat of sensitive species, such as the California spotted owl and Pacific fisher.

There remains some uncertainty about how sensitive species respond to severe wildfire compared to ecological thinning. For example, further research is needed to compare how ecological thinning affects spotted owls compared to varying amounts and severities of fire. However, it is clear that some thinning in strategic areas will be needed to reduce the risks that high-severity wildfire poses to these species.[50,101] Otherwise, the benefits of avoiding near-term impacts from ecological thinning will be overwhelmed by the devastating loss of habitat due to high-severity wildfires.[50] Ongoing and future research will build on our understanding of how species respond to forest management and megafires, and we will be able to adapt our forest management strategies in response.

PRESCRIBED FIRE AND MANAGED WILDFIRE

Reintroducing fire to many of our forested watersheds is the second key ingredient in ecological forestry, and ultimately will be the most important contributor to restoring forest health and resilience. Both prescribed and managed wildfires will be important. Prescribed fires are intentionally planned, ignited, and managed fires targeted to specific places and often preceded by thinning of small trees and shrubs where needed. Managed wildfires are those that are unintentionally started by natural causes like lightning, but then allowed to burn where weather conditions permit and managed for resource benefits and human safety. Managed wildfires require advanced planning so that when fires start the appropriate measures can be taken to manage them.

Reestablishing more frequent fires of relatively low severity in places where this was once the natural regime will keep the most flammable fuels in check, protect the larger trees, and recycle nutrients in the forest to develop a healthier canopy and a less flammable and more diverse understory. It also means allowing and managing smaller patches of moderately and severely burned forest where safe and appropriate. Such patchiness moderates the intensity of future fires[30,103-105] and is essential for supporting the full diversity of plants and wildlife that are unique to the Sierra Nevada, including those that are adapted to and benefit from severely burned forest patches.[83,102,106-110]

There is now ample evidence that thinning, combined with prescribed fire, works best to restore Sierra Nevada forests. Areas treated with both approaches have more species diversity, and the reduction in potential fire severity lasts longer than if thinning or fire are implemented alone.[11,26,28,89,113-117] In fact, following thinning with fire may be essential in many areas, because forests can grow back quickly after a single thinning treatment.[99,116-119]

As a practical matter, given the many constraints on applying prescribed and managed wildfire, ecological thinning will be an important part of the solution, at least in the near to mid term. Management guidelines for federal and state lands often encourage wildfire suppression, regardless of the potential to safely manage them for resource benefits, and fewer than 1 percent of Forest Service lands are currently being managed with fire each year,[26] which likely reflects the scale across other federal and state lands. It will take years to build the capacity and social will to manage fire for resource benefits at large scales, and some areas (e.g. near communities) may never be suitable for fire, even in the long term.

ECOLOGICAL FORESTRY WILL PROVIDE MANY BENEFITS

While it is a daunting challenge, implementing ecological forestry broadly across Sierra Nevada forests will help ensure that we are able to protect the natural diversity and beauty of California's fire-prone forests. Done thoughtfully, it will protect habitat for, and mitigate high-severity fire risks to, the imperiled species that have been pushed to the brink. It will also help to protect California's largest supply of clean water, the Sierra snowpack and runoff,[120-125] and make forests more resilient to drought.[10,60,126,127] Further, protecting our forests from the most extreme fire and tree mortality events will protect the forests against more extreme losses of carbon storage that would come with widespread and severe wildfires, as well as help stabilize carbon stores in these forests over the long term.[44,128-132]

Taking a large scale, ecologically based approach to forest management is also important for human safety. Focusing California's forest management resources exclusively on defensible space around communities and fire hardening homes may not be enough. These defenses can be overwhelmed by an intense and fast-moving fire coming out of the forest, as recent fires like the 2018 Camp Fire have demonstrated. Late season fires of this intensity, fueled by large fuel loads, dry weather, and high winds, can quickly move out of the wildlands and send embers flying miles to land on homes in the middle of densely populated communities. Instances like these are becoming more frequent in California and forcing the state to rethink how it maps fire hazard zones.

There could also be important indirect benefits of ecological forestry to public health and the economy. Lower-severity fires (including prescribed fires and managed wildfires) can have lower emissions per fire event, and thus may reduce the potential human health impacts and costs over time compared to unplanned megafires.[72,75]

California also has the opportunity to lead in the development of a forest restoration economy. At present, there are few innovative uses for the small wood material that will be removed and not enough facilities to process the material. There are also far too few trained personnel in ecological forestry and the application of prescribed fire. Those that are trained can

barely keep up with managing the dangerous wildfires that need to be contained. Ramping up investments and training in ecological forestry, bio-energy, and small diameter wood products (e.g. cross-laminated timber, a product made from gluing layers of lumber together) could create new jobs and revitalize struggling rural communities (see Kusel, page 36).[133]

California's fire-prone forests are unhealthy and at serious risk of uncharacteristic, high-severity wildfire, drought, and insect outbreaks. There is compelling evidence that ecological forestry—ecological thinning, prescribed burning, and managed wildfire—can reduce these risks and promote healthier, more resilient forests. We urge policymakers to maintain and increase funding for ecological thinning and prescribed fire and to take steps to address the policy and practical barriers to implementing ecological forestry at a scale and pace appropriate to the challenge at hand.

Acknowledgements

This paper benefitted from thorough review, edits, and comments from the following experts: John Battles, PhD, Sue Britting, PhD, Dick Cameron, David Edelson, Matthew Hurteau, PhD, Gavin Jones, PhD, Jon Keeley, PhD, Pat Manley, PhD, Kerry Metlen, PhD, Malcolm North, PhD, Zach Peery, PhD, Hugh D. Safford, PhD, Edward Smith, MFS, and Scott L. Stephens, PhD.

–Rodd Kelsey, PhD, is lead scientist at The Nature Conservancy's California Chapter

REFERENCES

1. Miller, J. D., Safford, H. D., Crimmins, M. & Thode, A. E. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. *Ecosystems* 12, 16–32 (2009).
2. Miller, J. D. & Safford, H. Trends in wildfire severity: 1984-2010 in the Sierra Nevada, Modoc Plateau, and southern Cascades, California USA. *Fire Ecology* 8, 41-57 (2012).
3. Mallek, C., Safford, H., Viers, J. & Miller, J. Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA. *Ecosphere* 4, art153 (2013).
4. Singleton, M. P., Thode, A. E., Sánchez Meador, A. J. & Iniguez, J. M. Increasing trends in high-severity fire in the southwestern USA from 1984 to 2015. *Forest Ecology and Management* 433, 709–719 (2019).
5. Westerling, A. L. Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. *Philosophical Transactions of the Royal Society, London B* 371, 20150178 (2016).
6. Collins, B. M., Miller, J. D., Knapp, E. E. & Sapsis, D. B. A quantitative comparison of forest fires in central and northern California under early (1911–1924) and contemporary (2002–2015) fire suppression. *International Journal of Wildland Fire* (2019).
7. Marlon, J. R. et al. Long-term perspective on wildfires in the western USA. *Proceedings of the National Academy of Sciences* 109, E535–E543 (2012).
8. Preisler, H. K., Grulke, N. E., Heath, Z. & Smith, S. L. Analysis and out-year forecast of beetle, borer, and drought-induced tree mortality in California. *Forest Ecology and Management* 399, 166–178 (2017).
9. Kolb, T. E. et al. Observed and anticipated impacts of drought on forest insects and diseases in the United States. *Forest Ecology and Management* 380, 321–334 (2016).
10. Restaino, C. M. & Safford, H. D. *Fire and climate change, in Fire in California's Ecosystems* (eds. Van Wagtendonk, J. W. et al.) 493–505 (University of California Press, 2018).
11. Miller, J. D. & Safford, H. D. Corroborating evidence of a pre-Euro-American low- to moderate-severity fire regime in yellow pine-mixed conifer forests of the Sierra Nevada, California, USA. *Fire Ecology* 13, 58–90 (2017).
12. Dettinger, M. D. *et al.* Sierra Nevada summary report. California's Fourth Climate Change Assessment. (California Energy Commission/Natural Resources Agency, 2018).
13. Safford, H. D. & Stevens, J. T. Natural Range of Variation (NRV) for yellow pine and mixed conifer forests in the Sierra Nevada, southern Cascades, and Modoc and Inyo National Forests, California, USA. Gen.Tech. Rep. PSW-GTR-256. (USDA Forest Service, Pacific Southwest Region, 2017).
14. Klausmeyer, K. R. & Fitzgerald, K. Where Does California's Water Come From? Land conservation and the watersheds that provide California's drinking water. (The Nature Conservancy, 2012).
15. Case, D., Fowler, D., Morgan, H., Schwellenbach, S. & Culbertson, K. Moving to the Mountains: Amenity migration in the Sierra and southern Appalachian mountains, in *Political Economies of Landscape Change: Places of Integrative Power* (eds. Wescoat, J. L. & Johnston, D. M.) 77–88 (Springer Netherlands, 2008).
16. Gonzalez, P., Battles, J. J., Collins, B. M., Robards, T. & Saah, David, S. Aboveground live carbon stock changes of California wildland ecosystems, 2001-2010. *Forest Ecology and Management* 348, 68–77 (2015).
17. Hurteau, M. D. & Brooks, M. L. Short- and long-term effects of fire on carbon in US dry temperate forest systems. *BioScience* 61, 139–146 (2011).
18. Hurteau, M. D., Bradford, J. B., Fulé, P. Z., Taylor, A. H. & Martin, K. L. Climate change, fire management, and ecological services in the southwestern US. *Forest Ecology and Management* 327, 280–289 (2014).
19. Manley, P. N. The Future of Biodiversity in the Sierra Nevada through the Lake Tahoe Basin Looking Glass 1, in *Proceedings of the Sierra Nevada Science Symposium*, October 7-10, 2002.
20. Guarín, A. & Taylor, A. H. Drought triggered tree mortality in mixed conifer forests in Yosemite National Park, California, USA. *Forest Ecology and Management* (2005).
21. Stephens, S. L. et al. Drought, Tree Mortality, and Wildfire in Forests Adapted to Frequent Fire. *BioScience* (2018).
22. Agee, J. K. Fire ecology of Pacific Northwest forest. *International Journal of Wildland Fire* 4, 493 (1993).
23. McKelvey, K. S. et al. An Overview of Fire in the Sierra Nevada, in Sierra Nevada Ecosystem Project (SNEP)-*Final Report to Congress (Vol. II): Assessments and scientific basis for management options* 1033–1040 (University of California, Davis, Centers for Water and Wildland Resources, 1996).
24. Van De Water, K. M. & Safford, H. D. A summary of fire frequency estimates for California vegetation before Euro-American settlement. *Fire Ecology* 7, 26–58 (2011).
25. Safford, H. D. & Van De Water, K. M. Using fire return interval departure (FRID) analysis to map spatial and temporal changes in fire frequency on national forest lands in California. Research Paper PSW-RP-266. (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 2014).

26. North, M. P., Collins, B. M. & Stephens, S. L. Using fire to increase the scale, benefits, and future maintenance of fuels treatments. *Journal of Forestry* 110, 392–401 (2012).
27. van Wagtendonk, J. W. *et al.* Fire in California's ecosystems. (University of California Press, 2018).
28. Hessburg, P. F. et al. Tamm Review: Management of mixed-severity fire regime forests in Oregon, Washington, and Northern California. *Forest Ecology and Management* 366, (2016).
29. Hessburg, P. F., Agee, J. K. & Franklin, J. F. Dry forests and wildland fires of the inland Northwest USA: Contrasting the landscape ecology of the pre-settlement and modern eras. *Forest Ecology and Management* 211, 117–139 (2005).
30. Perry, D. A. et al. The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. *Forest Ecology and Management* 262, 703–717 (2011).
31. Beaty, R. M. & Taylor, A. H. Fire history and the structure and dynamics of a mixed conifer forest landscape in the northern Sierra Nevada, Lake Tahoe Basin, California, USA. *Forest Ecology and Management* 255, 707–719 (2008).
32. Beaty, R. M. & Taylor, A. H. Fire disturbance and forest structure in old-growth mixed conifer forests in the northern Sierra Nevada, California. *Journal of Vegetation Science* (2007).
33. Hessburg, P. F. & Agee, J. K. An environmental narrative of Inland Northwest United States forests, 1800–2000. *Forest Ecology and Management* 178, 23–59 (2003).
34. Steel, Z. L., Safford, H. D. & Viers, J. H. The fire frequency-severity relationship and the legacy of fire suppression in California forests. *Ecosphere* 6, art8 (2015).
35. Lydersen, J. M., North, M. P., Knapp, E. E. & Collins, B. M. Quantifying spatial patterns of tree groups and gaps in mixed-conifer forests: reference conditions and long-term changes following fire suppression and logging. *Forest Ecology and Management* 304, 370–382 (2013).
36. Parsons, D. J. & DeBenedetti, S. H. Impact of fire suppression on a mixed-conifer forest. *Forest Ecology and Management* 2, 21–33 (1979).
37. North, M., Hurteau, M. & Innes, J. Fire suppression and fuels treatment effects on mixed-conifer carbon stocks and emissions. *Ecological Applications* 19, 1385–1396 (2009).
38. Calkin, D. E., Gebert, K. M., Jones, J. G. & Neilson, R. P. Forest Service large fire area burned and suppression. *Journal of Forestry* 103, 179–183 (2005).
39. Knapp, E. E., Skinner, C. N., North, M. P. & Estes, B. L. Long-term overstory and understory change following logging and fire exclusion in a Sierra Nevada mixed-conifer forest. *Forest Ecology and Management* 310, 903–914 (2013).
40. Lutz, J. A., van Wagtendonk, J. W. & Franklin, J. F. Twentieth-century decline of large-diameter trees in Yosemite National Park, California, USA. *Forest Ecology and Management* 257, 2296–2307 (2009).
41. Dolanc, C. R., Safford, H. D., Dobrowski, S. Z. & Thorne, J. H. Twentieth century shifts in abundance and composition of vegetation types of the Sierra Nevada, CA, US. *Appl. Veg. Sci.* 17, 442–455 (2014).
42. Bouldin, J. Twentieth-century changes in forests of the Sierra Nevada, California (Doctoral dissertation). (University of California, Davis, 1999).
43. Stephens, S. L., Lydersen, J. M., Collins, B. M., Fry, D. L. & Meyer, M. D. Historical and current landscape-scale ponderosa pine and mixed conifer forest structure in the Southern Sierra Nevada. *Ecosphere* 6, 1–63 (2015).
44. Bedsworth, L., Cayan, D., Franco, G., Fisher, L. & Ziaja, S. California's Fourth Climate Change Assessment: Statewide summary report. Publication number: SUM- CCCA4-2018-013. (2018).
45. Steel, Z. L., Koontz, M. J. & Safford, H. D. The changing landscape of wildfire: burn pattern trends and implications for California's yellow pine and mixed conifer forests. *Landscape Ecology* 33, 1159–1176 (2018).
46. Keyser, A. R. & Westerling, A. L. Predicting increasing high severity area burned for three forested regions in the western United States using extreme value theory. *Forest Ecology and Management* 432, 694–706 (2019).
47. Schwartz, M. W. et al. Increasing elevation of fire in the Sierra Nevada and implications for forest change. *Ecosphere* 6, 121 (2015).
48. Stephens, S. L. et al. Temperate and boreal forest mega-fires: characteristics and challenges. *Front. Ecol. Environ.* 12, 115–122 (2014).
49. Stephens, S. L., Stevens, J. T., Collins, B. M., York, R. A. & Lydersen, J. M. Historical and modern landscape forest structure in fir (Abies)-dominated mixed conifer forests in the northern Sierra Nevada, USA. *Fire Ecology* 14, (2018).
50. Jones, G. M. et al. Megafires: an emerging threat to old-forest species. *Frontiers in Ecology and Environment* 14, 300–306 (2016).
51. Stevens, J. T., Collins, B. M., Miller, J. D., North, M. P. & Stephens, S. L. Changing spatial patterns of stand-replacing fire in California conifer forests. *Forest Ecology and Management* 406, (2017).
52. Welch, K. R., Safford, H. D. & Young, T. P. Predicting conifer establishment post wildfire in mixed conifer forests of the North American Mediterranean-climate zone. *Ecosphere* 7, e01609 (2016).
53. Walker, R. B., Coop, J. D., Parks, S. A. & Trader, L. Fire regimes approaching historic norms reduce wildfire-facilitated conversion from forest to non-forest. *Ecosphere* 9, e02182 (2018).
54. Coppoletta, M., Merriam, K. E. & Collins, B. M. Post-fire vegetation and fuel development influences fire severity patterns in reburns. *Ecological Applications* 26, (2016).
55. He, M., Schwarz, A., Lynn, E. & Anderson, M. Projected Changes in Precipitation, Temperature, and Drought across California's Hydrologic Regions in the 21st Century. *Climate* 6, 31 (2018).
56. Diffenbaugh, N. S., Swain, D. L. & Touma, D. Anthropogenic warming has increased drought risk in California. *Proceedings of the National Academy of Sciences* 112, 3931–3936 (2015).
57. Thorne, J. H. et al. The impact of climate change uncertainty on California's vegetation and adaptation management. *Ecosphere* 8, (2017).
58. Westerling, A. L. et al. Climate change and growth scenarios for California wildfire. *Clim. Change* 109, 445–463 (2011).
59. Westerling, A. L. *Wildfire simulations for California's Fourth Climate Change Assessment: projecting changes in extreme wildfire events with a warming climate.* 57 (California Energy Commission, 2018).
60. Young, D. J. N. et al. Long-term climate and competition explain forest mortality patterns under extreme drought. *Ecol. Lett.* 20, 78–86 (2017).
61. Voelker, S. L. et al. Fire deficits have increased drought sensitivity in dry conifer forests: Fire frequency and tree-ring carbon isotope evidence from Central Oregon. *Global Change Biology* 00, 1–17 (2019).
62. Williams, A. P. et al. Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Climate Change* 3, 292–297 (2013).
63. Allen, C. D., Breshears, D. D. & McDowell, N. G. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. *Ecosphere* 6, art129 (2015).

64. Allen, C. D. et al. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management* 259, 660–684 (2010).

65. Carnicer, J. et al. Widespread crown condition decline, food web disruption, and amplified tree mortality with increased climate change-type drought. *Proceedings of the National Academy of Sciences* 108, 1474-1478 (2011).

66. Fettig, C. J., Mortenson, L. A., Bulaon, B. M. & Foulk, P. B. Tree mortality following drought in the central and southern Sierra Nevada, California, U.S. *Forest Ecology and Management* (2019).

67. Buluç, L., Fischer, C., Ko, J., Balachowski, J. & Ostoja, S. Drought and tree mortality in the Pacific Southwest Region: a synopsis of presentations and work group sessions from the science and management symposium - lessons learned from extreme drought and tree mortality in the Sierra Nevada. (U.S. Department of Agriculture, California Climate Hub, 2017).

68. Larsen, I. J. et al. Causes of Post-Fire Runoff and Erosion: Water Repellency, Cover, or Soil Sealing? *Soil Science Society of America Journal* 73, 1393-1407 (2009).

69. Moody, J. A. & Ebel, B. A. Hyper-dry conditions provide new insights into the cause of extreme floods after wildfire. *Catena* 93, 58–63 (2012).

70. Moody, J. A., Shakesby, R. A., Robichaud, P. R., Cannon, S. H. & Martin, D. A. Current research issues related to post-wildfire runoff and erosion processes. *Earth-Science Reviews* 122, 10–37 (2013).

71. Aha, N., Boorman, M., Leidman, S. & Perry, S. The Effect of sediment deposition on Sierra riverine ecosystems following high-intensity fires. (2014).

72. Schweizer, D. Fine particulate matter and wildland fire smoke: integrating air quality, fire management, and policy in the California Sierra Nevada. (University of California, Merced, 2016).

73. Preisler, H. K. et al. Estimating contribution of wildland fires to ambient ozone levels in National Parks in the Sierra Nevada, California. *Environmental Pollution* 158, 778–787 (2010).

74. Preisler, H. K. et al. A statistical model for determining impact of wildland fires on particulate matter (PM 2.5) in central California aided by satellite imagery of smoke. *Environmental Pollution* 205, 340–349 (2015).

75. Long, J. W., Tarnay, L. W. & North, M. P. Aligning smoke management with ecological and public health goals. *Journal of Forestry* 116, 76–86 (2017).

76. Reid, C. E. et al. Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives* (2016).

77. Reid, C. E., Jerrett, M., Tager, I. B., Petersen, M. L., Mann, J. K., Balmes J. R. Differential respiratory health effects from the 2008 northern California wildfires: A spatiotemporal approach. *Environmental Research* (2016).

78. Liu, J. C., Pereira, G., Uhl, S. A., Bravo, M. A. & Bell, M. L. A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental Research* (2015).

79. Jones, G. M., Keane, J. J., Gutiérrez, R. J. & Peery, M. Z. Declining old-forest species as a legacy of large trees lost. *Diversity and Distributions* 24, 341-351 (2017).

80. Jones, G. M., Gutiérrez, R. J., Tempel, D. J., Zuckerberg, B. and Peery, M. Z. Using dynamic occupancy model to inform climate change adaptation strategies for California spotted owls. *Journal of Applied Ecology* 53, 895-905 (2016).

81. Tempel, D. J. et al. Evaluating short- and long-term impacts of fuels treatments and simulated wildfire on an old-forest species. *Ecosphere* 6, 1–19 (2015).

82. Tempel, D. J. et al. Effects of forest management on California spotted owls: Implications for reducing wildfire risk in fire-prone forests. *Ecological Applications* 24, 2089–2106 (2014).

83. Miller, J. E. D., Root, H. T. & Safford, H. D. Altered fire regimes cause long-term lichen diversity losses. *Global Change Biology* 24, 4909–4918 (2018).

84. Dombeck, M. P., Williams, J. E. & Wood, C. A. Wildfire policy and public lands: integrating scientific understanding with social concerns across landscapes. *Conservation Biology* 18, 883–889 (2004).

85. Schoennagel, T., Veblen, T. T. & Romme, W. H. The Interaction of fire, fuels, and climate across Rocky Mountain forests. *BioScience* 54, 661–677 (2004).

86. Moritz, M. A. *et al.* Learning to coexist with fire. Nature 515, 58–66 (2014).

87. Schoennagel, T. *et al.* Adapt to more wildfire in western North American forests as climate changes. *Proceedings of the National Academy of Sciences* 114, (2017).

88. Stephens, S. L. et al. Managing Forests and Fire in Changing Climates. *Science* 342, 41–42 (2013).

89. Stevens, J. T., Safford, H. D. & Latimer, A. M. Wildfire-contingent effects of fuel treatments can promote ecological resilience in seasonally dry conifer forests. *Can. J. For. Res.* 44, 843–854 (2014).

90. North, M. P. et al. Tamm Review: Reforestation for resilience in dry western U.S. forests. *Forest Ecology and Management* 432, 209–224 (2019).

91. Stevens, J. T., Safford, H. D., Harrison, S. & Latimer, A. M. Forest disturbance accelerates thermophilization of understory plant communities. *J. Ecol.* 103, 1253–1263 (2015).

92. North, M. P. *et al.* Constraints on Mechanized Treatment Significantly Limit Mechanical Fuels Reduction Extent in the Sierra Nevada. J. For. 40–48 (2014). doi:http://dx.doi.org/10.5849/jof.14-058

93. Agee, J. K. & Skinner, C. N. Basic principles of forest fuel reduction treatments. *Forest Ecology and Management* 211, 83–96 (2005).

94. Noss, R. F., Franklin, J. F., Baker, W. L., Schoennagel, T. & Moyle, P. B. Managing fire-prone forests in the western United States In a nutshell : *Front. Ecol. Environ.* 4, 481–487 (2006).

95. Fulé, P. Z., Crouse, J. E., Roccaforte, J. P. & Kalies, E. L. Do thinning and/or burning treatments in western USA ponderosa or Jeffrey pine-dominated forests help restore natural fire behavior? *Forest Ecology and Management* 269, 68–81 (2012).

96. North, M. P., Stine, P., Hara, K. O., Zielinski, W. & Stephens, S. L. An ecosystem management strategy for Sierran mixed- conifer forests, Gen. Tech. Rep. PSW-GTR-220. (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 2009).

97. Krofcheck, D. J., Hurteau, M. D., Scheller, R. M. & Loudermilk, E. L. Prioritizing forest fuels treatments based on the probability of high-severity fire restores adaptive capacity in Sierran forests. *Global Change Biology* 24, 729–737 (2018).

98. North, M. P. (ed). *Managing Sierra Nevada forests.* (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 2012).

99. Stephens, S. L. et al. Fire treatment effects on vegetation structure, fuels, and potential fire severity in western U.S. forests. *Ecological Applications* 19, 305–320 (2009).

100. Chiono, L. A., Fry, D. L., Collins, B. M., Chatfield, A. H. & Stephens, S. L. Landscape-scale fuel treatment and wildfire impacts on carbon stocks and fire hazard in California spotted owl habitat. *Ecosphere* 8, e01648 (2017).

101. Ganey, J. L., Wan, H. Y., Cushman, S. A. & Vojta, C. D. Conflicting perspectives on spotted owls, wildfire, and forest restoration. *Fire Ecology* 13, 1–20 (2017).

102. Stephens, S. L. et al. California spotted owl, songbird, and small mammal responses to landscape fuel treatments. *BioScience* 64, 893–906 (2014).
103. Finney, M. A. Design of Regular Landscape Fuel Treatment Patterns for Modifying Fire Growth and Behavior. *Forest Science* 47, (2001).
104. Ager, A. A., Vaillant, N. M. & Finney, M. A. A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure. *Forest Ecology and Management* 259, 1556–1570 (2010).
105. Finney, M. A. et al. Simulation of long - term landscape - level fuel treatment effects on large wildfires. *Int. Journal of Wildland Fire* 16, 712–727 (2007).
106. Ponisio, L. C. et al. Pyrodiversity begets plant-pollinator community diversity. *Global Change Biology* 22, 1794–1808 (2016).
107. Tingley, M. W., Ruiz-Gutiérrez, V., Wilkerson, R. L., Howell, C. A. & Siegel, R. B. Pyrodiversity promotes avian diversity over the decade following forest fire. *Proceedings of the Royal Society of London, B* 283, 1–9 (2016).
108. Converse, S. J., White, G. C., Farris, K. L. & Zack, S. Small mammals and forest fuel reduction: national-scale responses to fire and fire surrogates. *Ecological Applications* 16, 1717–1729 (2006).
109. Meyer, M. D., North, M. P. & Kelt, D. A. Short-term effects of fire and forest thinning on truffle abundance and consumption by Neotamias speciosus in the Sierra Nevada of California. *Canadian Journal of Forest Research* 35, 1061–1070 (2005).
110. DellaSala, D. A. & Hanson, C. T. *The ecological importance of mixed-severity fires : nature's Phoenix.* (Elsevier, 2015).
111. Converse, S. J., White, G. C. & Block, W. M. Small mammal responses to thinning and wildfire in ponderosa pine–dominated forests of the southwestern United States. 70, 1711–1722 (2006).
112. DellaSala, D. A., Bond, M. L., Hanson, C. T., Hutto, R. L. & Odion, D. C. Complex early seral forests of the Sierra Nevada: what are they and how can they be managed for ecological integrity? *Natural Areas Journal* 34, 310–324 (2014).
113. Graham, R. T., Harvey, A. E., Jain, T. B. & Tonn, J. R. Effects of thinning and similar stand treatments on fire behavior in western forests, General Technical Report, PNW-GTR463. (USDA Forest Service, Pacific Northwest Research Station, 1999).
114. Safford, H. D., Stevens, J. T., Merriam, K., Meyer, M. D. & Latimer, A. M. Fuel treatment effectiveness in California yellow pine and mixed conifer forests. *Forest Ecology and Management* 274, 17–28 (2012).
115. Clyatt, K. A., Keyes, C. R. & Hood, S. M. Long-term effects of fuel treatments on aboveground biomass accumulation in ponderosa pine forests of the northern Rocky Mountains. *Forest Ecology and Management* 400, 587–599 (2017).
116. Stephens, S. L., Collins, B. M. & Roller, G. Fuel treatment longevity in a Sierra Nevada mixed conifer forest. *Forest Ecology and Management* 285, 204–212 (2012).
117. Stephens, S. L. et al. The effects of forest fuel-reduction treatments in the United States. *Bioscience* 62, 549–560 (2012).
118. Krofcheck, D. J., Hurteau, M. D., Scheller, R. M. & Loudermilk, E. L. Restoring surface fire stabilizes forest carbon under extreme fire weather in the Sierra Nevada. *Ecosphere* 8, e01663 (2017).
119. Stephens, S. L. & Moghaddas, J. J. Experimental fuel treatment impacts on forest structure , potential fire behavior , and predicted tree mortality in a California mixed conifer forest. *Forest Ecology and Management* 215, 21–36 (2005).
120. Boisramé, G., Thompson, S., Collins, B. & Stephens, S. Managed wildfire effects on forest resilience and water in the Sierra Nevada. *Ecosystems* 20, 717-732 (2017).
121. Smith, H. G., Sheridan, G. J., Lane, P. N. J., Nyman, P. & Haydon, S. Wildfire effects on water quality in forest catchments: a review with implications for water supply. *Journal of Hydrology* 396, 170–192 (2011).
122. Buckley, M. *et al.* Mokelumne watershed avoided cost analysis: why Sierra fuel treatments make economic sense: A report prepared for the Sierra Nevada Conservancy, The Nature Conservancy, and U.S. Department of Agriculture, Forest Service. (Sierra Nevada Conservancy, 2014).
123. Elliot, W. J., Miller, M. E. & Enstice, N. Targeting forest management through fire and erosion modelling. *International Journal of Wildland Fire* 25, 876–887 (2016).
124. Ellison, D. et al. Trees, forests and water: Cool insights for a hot world. *Global Environmental Change* 43, 51–61 (2017).
125. Ellis, C. R., Pomeroy, J. W., Link, T. E. & Rivers, M. Modeling increases in snowmelt yield and desynchronization resulting from forest gap-thinning treatments in a northern mountain headwater basin. *Water Resource Research* 49, 1–14 (2013).
126. D'amato, A. W., Bradford, J. B., Fraver, S. & Palik, B. J. Effects of thinning on drought vulnerability and climate response in north temperate forest ecosystems. *Ecological Applications* 23, 1735–1742 (2013).
127. Kerhoulas, L. P., Kolb, T. E., Hurteau, M. D. & Koch, G. W. Managing climate change adaptation in forests: a case study from the U.S. Southwest. *Journal of Applied Ecology* 50, 1311–1320 (2013).
128. Collins, B. M. et al. Beyond Reducing Fire Hazard. *Ecological Applications* 23, 515–522 (2013).
129. Hurteau, M. D. & North, M. Carbon recovery rates following different wildfire risk mitigation treatments. *Forest Ecology and Management* 260, 930–937 (2010).
130. Hurteau, M. D. Quantifying the carbon balance of forest restoration and wildfire under projected climate in the fire-prone southwestern U.S. *PLOS ONE* 12, e0169275 (2017).
131. Loudermilk, E. L., Scheller, R. M., Weisberg, P. J. & Kretchun, A. Bending the carbon curve: fire management for carbon resilience under climate change. *Landscape Ecology* (2017).
132. Liang, S., Hurteau, M. D. & Westerling, A. L. Large-scale restoration increases carbon stability under projected climate and wildfire regimes. *Frontiers in Ecology and Environment* 16, 207–212 (2018).
133. Wu, T., Kim, Y.-S. & Hurteau, M. D. Investing in natural capital: using economic incentives to overcome barriers to forest restoration. *Restoration Ecology.* 19, 441–445 (2011).
134. Wayman, R. B., and M. North. 2007. Initial response of a mixed-conifer understory plant community to burning and thinning restoration treatments. *Forest Ecology and Management* 239:32–44.
135. Webster, K. M., and C. B. Halpern. 2010. Long-term vegetation responses to reintroduction and repeated use of fire in mixed-conifer forests of the Sierra Nevada. *Ecosphere* 1:1–27.
136. Richter, C., M. Rejmanek, J. E. D. Miller, K. R. Welch, J. Weeks, and H. Safford. 2019. The species diversity and fire severity relationship is hump-shaped in semiarid yellow pine and mixed conifer forests. *Ecosphere* 10(10):e02882. 10.1002/ecs2.2882
137. Lake, F.K., Giardina, C., Parrotta, J.A., and Davidson-Hunt, I. 2018. Considering diverse knowledge systems in forest landscape restoration-Chapter 3. In: Forest Landscape Restoration: Integrated Approaches to Support Effective Implementation. S. Mansourian and J. Parrotta (eds), Routledge Press:37-46, ISBN: 978-1-315-11187-2 (ebk).



FIRE IN CALIFORNIA: THE LONG ROAD TO RECOVERY

Craig Thomas

California has one of the most fire-prone climates on the planet, with mild, wet winters and long, dry summers. We share this adventure with only a handful of other places on Earth, among them Portugal, central Chile, and South Africa. We hear about these places regularly in the news, most recently, with the deadly bushfires in Australia.

There's nothing new about California's tendency to burn. Before the 1800s, wildfires ignited by lightning and deliberately set by Native Americans burned 4.5 million acres each year, according to research on early California fire patterns by UC Berkeley fire scientist Scott Stephens (Stephens et al. 2007). Fire scientists now call that early 1800s condition a "reference" condition that we can consider in many ways to be a reasonable landscape restoration goal for much (but not all) of California's remaining wildlands. Well-founded science tells us what we must do to restore Sierra Nevada forest heterogeneity and health (see Kelsey, page 22 of this issue).

If fire is a constant in California, why is it taking so long for us to adapt to living with it? It has much to do with cultural history and misunderstanding of the landscape in which we live. In this article, I will lay out the history of our aversion to fire, and signs that we're moving toward a healthier relationship with the fires that sustain California's landscapes.

IN THE BEGINNING

A fundamental misunderstanding of our relationship with fire is deeply rooted in our culture. As a first step, with all due respect to the authors, we would do well

Above: **Caples Creek prescribed fire, June 2018.** *[Photograph by Craig Thomas]*

to reinterpret the marching orders "...fill the earth and subdue it. Rule over the fish in the sea and the birds in the sky and over every living creature that moves on the ground" (Genesis 1:28). Compared to other traditions that include more nature-centered worldviews, "ruling over" and "subduing" are taking a heavy toll on the Garden of Eden.

In California, trouble began during the Mission period in the late 1700s (Taylor 2016). The establishment and expansion of agrarian-based Spanish missions led to the removal of, and disease outbreaks in, the Native American population, putting an end to their frequent use of fire to increase food supplies and weaving materials.

In 1904, a program of active fire suppression on federal lands led to the lowest level of average fire activity in the past 400 years. Most of the lower montane forests of the Sierra Nevada have not burned in more than a century (Steel et al. 2015) because of effective early detection and initial attack efforts in this era.

Smokey Bear's arrival on the scene 75 years ago fostered a new awareness of fire threat (for an historical perspective, read *The Big Burn* by Timothy Egan). In the 1970s, well-meaning environmental policies began to take hold in natural resource management decisions and carried an anti-fire bias into the current era.

In 1976 the U.S. Forest Service was governed by the National Forest Management Act (NMFA), a positive move forward that helped the agency improve its natural resource management planning process. This began an era of science-based consideration and management of multiple resources. Yet fire is mentioned only three times in the text of NFMA, and all in the context of a catastrophe. The goal was to grow lots of trees and put all fires out.

AN ERA OF SCIENCE-BASED MANAGEMENT

In the 1980s, the effectiveness of fire suppression began to unravel due to increased climate warming, extended fire seasons, and early snowmelt, along with higher levels of forest fuels due to the absence of natural fire. In recent years, fire science has been pushing fire policy into a new and deeper understanding of fire's role in ecosystem resilience and diversity.

The 2009 Guidance for Implementation of Federal Wildfire Management Policy and the 2014 National Cohesive Wildland Fire Management Strategy supported management of planned and unplanned ignitions for multiple resource benefits, such as wildlife habitat, fuels reduction, and watershed protection. These federal policies allow for the management of multiple objectives—which can change during a wildfire's progression—and recognize the science and professionalism of the modern federal fire cadre, fostering a major step forward and bringing Smokey Bear in to the modern fire management arena.

CHANGING FIRE'S PUBLIC IMAGE

Fire is regenerative, reduces fuels, enhances biodiversity, and creates resilience. But it can also burn down entire towns when we mistakenly assume we can control nature and eliminate a natural ecological process.

In the past most Californians rarely saw fire in action, on the rare occasion when a wildfire made the evening news. But over the last 20 years the situation has changed dramatically in California, and increasingly large and severe wildfires have begun to dominate the news locally and nationally.

Our culture has evolved very different attitudes about fire and rain, though both are critically important ecological processes in our California landscape. Fire has gotten a century of bad press (Schweizer and Cisneros 2018) even though rainfall can be equally destructive. One need only recall recent floods and the eroded dam spillway in Oroville to be reminded of the high costs associated with rain, yet we tend to look forward to rain and fear fire. Many media outlets reinforce that attitude.

Beneficial aspects of fire, such as fire's role in habitat enhancement, nutrient recycling, and soil health, as well as the lower smoke emissions outputs from strategically planned fire, are rarely part of the public discourse. Yet they need to be if we are to reestablish a positive relationship with fire and value its nurturing role in our landscapes. Efforts to change public attitudes took a major step forward in the California Legislature in 2018 with the signing of SB 1260 (Jackson 2018) at the end of the Brown Administration. Also positive were the 2017 California Biodiversity Initiative and the 2018 Little Hoover Commission Report, "Fire on the Mountain," which pointed toward fire's benefits in California. While prescribed fire is not a cure-all and can't be guaranteed to halt all incoming wildfires, resilient landscapes that include frequent fire applications are a much better choice for our ecosystems, community protection, and public health.

Fire that benefits nature and humans has been operating alongside precipitation for tens of thousands of years. Scientists from California and throughout the

West have been calling for the reestablishment of fire as a critical ecological process for 30 years, and warning of some dire consequences if we don't heed their warning. It is now clear that those dire consequences have arrived. The West is burning, but mostly not in the way it should be.

GOING FORWARD

Have we reached a critical point in our shared cultural history to embrace a positive relationship with fire? The answer is yes. Our forests, watersheds, carbon sequestration goals, safety, and health all require that we embrace active fire use if we want to maintain a California landscape that is recognizable, productive, and resilient. While scientists warn of increasingly large, high-intensity fires, increased release of forest carbon into the atmosphere, and increased mega-emission events causing massive public health and economic impacts, there is one consistent recommendation stated in most of the published science pertaining to forest resilience, climate change and public health: to reestablish fire's role as a key part of natural resource management.

Multiple efforts are underway throughout the state to reintroduce fire into fire-excluded forests at appropriate scale, intensity, and timing. One example of a collaborative, landscape-level effort to restore natural fire in California is the expansion of prescribed burn programs across the Forest Service and National Park Service, such as the Fire MOU Partnership, and the State Forest Management Task Force and its Prescribed Fire Working Group.

With astronomical fire suppression costs, growing public health impacts and resource damage from mega-emission wildfires, and the state's forest carbon sequestration goals, these groups are forging a new path forward. Their recommendations are key to overcoming barriers to burning (Schultz et al. 2018) and restoring ecologically significant fire in California.

Calculate the avoided costs and co-benefits of a resilient California landscape

How do we balance what we take from our forests with what we restore, maintain, and rebuild, and how does achieving such balance pencil out economically? First and foremost, we must place real value in the avoided costs and co-benefits associated with a resilient and fire-restored California landscape. Real value means an honest accounting of the costs of restoring landscapes in the economic and political equation, including all major categories of avoided costs.

One example is the $300 million estimate of the cost to remove the carcinogen benzene from the Paradise, Calif. water supply (Bizjak, Tony. "Rare toxic cocktail from Camp Fire is poisoning Paradise water," *The Sacramento Bee*, April 2019.) Another example is the carbon emissions from large fires that will eventually happen in the absence of treatment, and the health impacts and cost of hospital admissions from such events.

Also important to consider are co-benefits created when forest landscapes are maintained with ecologically appropriate fire. For example, fire reduces use of toxic herbicides on forest landscapes, which pollute our air, water supplies, forest workers, and native food sources. Another co-benefit occurs from stabilization or realignment of carbon stocks in larger, fire resilient trees, which is a more secure way to store forest carbon in our highly fire-associated landscapes.

Expand fire manager–air regulator collaborations throughout the state

Since the initiation of the California Clean Air Act in the 1970s, the state has made major improvements in air quality. After the act was passed, the state began to regulate emissions of six primary pollutants, including carbon monoxide (CO), lead (Pb), particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2, and sulphur dioxide (SO_2).

There is no question that we need the Clean Air Act statutes, nationally and in their strengthened form in California. But there is one enormous problem with the National Ambient Air Quality Standards (NAAQS) regulating pollution outputs in the state: They are too aggressive in limiting ecologically necessary fire. Fire has been interacting with vegetation as a regulating natural and critical ecological process for tens of thousands of years in California, along with rainfall, snow, wind, floods, and other natural disturbances. Unfortunately, when the new Clean Air Act regulations were drafted in the 1970s, much less was known about fire science or what a natural fire regime was, what it would mean to sustain aggressive fire suppression, or the mega-emissions that would result.

While the California Clean Air Act has made significant improvements in automobile and industrial pollution reductions since its inception, uncharacteristically frequent and intense wildfires and resulting smoke emissions have risen to hazardous levels in multiple events across the state. Recently, several air quality scientists, along with air quality regulators, medical doctors, and policy makers have taken a second look at

the harm to public health from denying fire its appropriate role in building resilience in California's forests and wildlands.

The California Air Resources Board, local air districts, the California Air Pollution Control Officers Association, federal air quality experts, and atmospheric scientists have also joined with fire managers in California (Forest Service, Bureau of Land Management, National Park Service, and the state fire agency, Cal Fire) to expand planned burning, and at the same time support the best smoke management and public health protection efforts in the country. This is a positive trend that needs to continue.

Capacity, capacity, capacity

If we had all the necessary plans and permits in place to increase prescribed and managed burning today, there still wouldn't be enough trained people to do the work. We must increase our prescribed fire workforce. Ideas on the table today include expanded prescribed fire training, support for multi-partner cross-jurisdictional burning, and increased logistical support of larger landscape burning. There is also discussion of setting up permanent, flexible wildfire crews capable of carrying out complicated burns across the state. Other issues include expanded burn windows for larger landscape fire restoration efforts, the need to resolve liability protection for prescription burning, and establishing Prescribed Burn Associations to bring private rural landowners into the restoration and maintenance fire culture.

Finally, it is critical to sustain public education and outreach regarding the need for fire restoration in California. Where there's fire, there's smoke, and we will all be affected by it. We need to include media, policy makers, and the public health community in conversations about fire and emissions tradeoffs, air quality monitoring, and fire prevention at the individual and collective scales.

The goal should be a state in which natural levels of smoke from science-based fire restoration efforts are considered normal background conditions (Schweizer and Cisneros 2016) and are exempted from regulatory limitations. Prescribed fire and smoke management collaboration efforts are expanding. When we reach meaningful ecological scales of fire restoration, we will have reached the best ecological and social outcome possible for our fire-prone landscape.

–Craig Thomas is co-founder of Sierra Forest Legacy and founder of the Fire Restoration Group.

REFERENCES

Cisneros, R., Schweizer, D. 2018. The efficacy of news releases, news reports, and public nuisance complaints for determining smoke impacts to air quality from wildland fire *Air Quality, Atmosphere & Health.* 11(4):423–429.

Egan, Timothy. *The Big Burn.* 2009.

Fire MOU Partnership. Accessed Jan. 29, 2020. https://www.sierraforestlegacy.org/CF_ManagingFire/FireMOU.php

Hurteau, M.D., Westerling, A.L., Wiedinmyer, C., Bryant, B.P. 2014. Projected Effects of Climate and Development on California Wildfire Emissions through 2100. *Environmental Science & Technology* 48 (4): 2298-2304

Liu, X., et al. 2017. Airborne measurements of western U.S. wildfire emissions: Comparison with prescribed burning and air quality implications, *J. Geophys. Res. Atmos.* 122: 6108– 6129.

Long, J.W., Tarnay, L.W., North, M.P. 2018. Aligning Smoke Management with Ecological and Public Health Goals. *Journal of Forestry* 116 (1): 76–86.

North, M., Collins, B.M., Stephens, S. 2012. Using Fire to Increase the Scale, Benefits, and Future Maintenance of Fuels Treatments. *Journal of Forestry* 110 (7): 392-401.

Prescribed Fire Working Group. Accessed Jan. 2020: https://fmtf.fire.ca.gov/working-groups/prescribed-fire/

Schultz, C., Huber-Stearns, H., McCaffrey, S., Quirke, D., Ricco, G., Moseley, C. 2018. Prescribed Fire Policy Barriers and Opportunities: A Diversity of Challenges and Strategies Across the West.

Sally Jewell, Secretary of the Interior, Thomas J. Vilsack, Secretary of Agriculture. 2014: The National Strategy: The Final Phase of the Development of the National Cohesive Wildland Fire Management Strategy.

Schweizer. D., Cisneros, R. 2017. Forest fire policy: Change conventional thinking of smoke management to prioritize long term air quality and public health. *Air Quality, Atmosphere & Health.* 10 (1): 33-36.

Schweizer, D., Cisneros, R., Traina, S., Ghezzehei, T. A., Shaw, G. 2017. Using National Ambient Air Quality Standards for fine particulate matter to assess regional wildland fire smoke and air quality management. *Journal of Environmental Management* 201: 345-356.

Steel, Z.L., Safford, H.D., Viers, J.H. 2015. The fire frequency-severity relationship and the legacy of fire suppression in California forests. *Ecosphere* 6 (1): 1-23.

Stephens, S. L., Martin, R. E., Clinton, N. E. 2007. Prehistoric fire area and emissions from California's forests, woodlands, shrublands, and grasslands. *Forest Ecology and Management* 251: 205-216.

Taylor, A.H., Trouet, V., Skinner, C.N., Stephens, S. 2016. Socioecological transitions trigger fire regime shifts and modulate fire-climate interactions in the Sierra Nevada, USA, 1600-2015 CE. Proceedings of the National Academy of Sciences 113 (48) 13684-13689.

U.S. Dept of the Interior, U.S. Dept of Agriculture. *Guidance for Implementation of Federal Wildland Fire Management Policy,* 2009.





DEVELOPING THE INFRASTRUCTURE NEEDED TO RESTORE FOREST HEALTH: TURNING WOODY BIOMASS INTO ENERGY IN THE NORTHERN SIERRA

Jonathan Kusel

In September 2007, the Moonlight Fire burned 65,000 acres of forest land in the northern Sierra, emitting the annual carbon equivalent of 750,000 gasoline-powered cars. The fire also ravaged habitat for several sensitive species, including nesting habitat for spotted owls and goshawks. The U.S. Forest Service reported that 38,000 acres had burned at high severity.

Six years later, in 2013, an agency survey of the area found that shrubs now occupied 29 percent of the landscape, compared to only three percent before the fire. Sierra mixed conifer, true fir, and yellow pine forest types all gave way to the shrub encroachment (USDA Forest Service, 2013). Researchers from the University of California at Davis examined large fires that burned between 1999 and 2008, including the Moonlight Fire, and reported in the October 2019 issue of *Ecosphere* that high severity fires not only destroy forests but lead to reduced plant diversity. Other researchers have found that the shrub fields emerging five to ten years after high severity wildfires have more limited plant diversity than the forests that preceded them (Richter, 2019). What can be done to reduce this type of risk in our subalpine forests, where a legacy of fire suppression has led to dangerously high levels of forest biomass that contribute to the severity of these modern wildfires?

The nonprofit Sierra Institute for Community and Environment has been working for more than 10 years to improve forest and watershed health while also revitalizing rural economies and reducing the risk of catastrophic wildfire by increasing the utilization of low-value wood from forests of the Upper Feather River Watershed. In our rural Plumas County home in the northern Sierra, we are advancing community-scale wood utilization projects that create a market for woody biomass: the small diameter trees and other woody material that need to be removed from the forest to reduce fire risk and restore forest health.

To advance this vision, in 2018 the Institute completed installation of a small-scale, biomass-fired combined heat and power boiler system in Quincy, California. The system, one of the first of its kind in the state, generates both heat and electric power for the Plumas County Health and Human Services Center (HHSC), one of the largest buildings in the county, and one that has historically had high heating costs.

Wood chips derived from material removed as part of forest restoration projects fuel the boiler, which uses up to 400 tons a year of this fuel-reduction wood product (to produce 800 kW of heat). The boiler system burns the chips to heat water that is circulated throughout the building to provide heat. The heated

Above L-R: Biomass boiler burning inside the novel cross-laminated timber building; cross-laminated wood wall panels lowered into place; roof panel being lowered onto the structure. *[Photos courtesy of the Sierra Institute for Community and Environment]*

water is also used to heat an organic thermal oil to produce electricity through an Organic Rankine Cycle (ORC) power generator. The ORC generator converts thermal energy into mechanical power. As the thermal oil vaporizes, it creates pressure that spins a turbine that makes the power for electricity (up to 35 kW), which has the added advantage of being a closed system: As the organic fluid cools, it is condensed and reused. Another advantage is that, unlike water, the organic fluid does not corrode metal parts of the turbine. Together, the boiler and ORC unit are called a combined heat and power (CHP) system.

The boiler uses wood removed from nearby forest restoration projects, and in so doing creates value for this material that would otherwise be disposed of through burning. Compared to open pile burning in the woods, the most economical disposal method, burning forest biomass in a boiler results in a 98 to 99 percent reduction in emissions of fine particulate matter, carbon monoxide, non-methane organic compounds, methane, and black carbon, among other pollutants.

Like in many rural counties across California, inexpensive natural gas is unavailable in Plumas County, and most public facilities rely on expensive fossil fuels transported from afar for heating. Biomass fuel, on the other hand, is locally derived and relatively inexpensive, with prices more stable than those of fossil fuels. This helps counties avoid scrambling to meet costs when fossil fuel prices spike. Using biomass for heat and power can therefore reduce energy costs, fossil fuel use, and harmful emissions, at the same time that it supports essential fuels reduction work to lessen the risk of high severity wildfire and associated emissions. The biomass per boiler installed at the HHSC saves the county $30,000 year in heating costs over a standard electric boiler for heat, and further reduces GHG emissions by securing fuel locally.

This project is also innovative in another way: The HHSC biomass system is housed in a full cross-laminated timber (CLT) building, the first of its kind in California. CLT is made out of multiple layers of solid lumber that are laid flat against one another, with each layer of lumber lying at 90 degrees to the layers above and below it. Layers are glued together, creating a strong, durable panel of wood. The walls of the HHSB boiler building are five layers thick and the roof is seven layers thick. Because CLT panels are multi-layered with no air space between layers, they have proven to be extremely fire resistant and seismically sound, as compared to the two-by-four lumber that is used in standard stud and fiberboard home construction. Use of CLT in buildings also offers a tremendous opportunity to have carbon sequestered in a durable building product.



Right: **Moonlight Fire, 2007.** *[Photograph courtesy of Wikimedia Commons]*

Construction of the CLT building was completed in two days. Use of local contractors for construction of the CLT building and biomass facility resulted in nearly $1 million being pumped into the local economy. The project was made possible by a $2.3 million California Energy Commission grant to fund development of the combined heat and power system; Plumas County contributed another $400,000 for the building, with the remaining funds donated by the U.S. Forest Service, Sierra Nevada Conservancy, and the Barrett Foundation.

This biomass system and its CLT building at the HHSC are an example of how locally-sourced and abundant biomass material can be used to benefit both forests and local communities. Sierra Institute is working with the county school district and sheriff's department to install biomass boilers at a local high school and a new jail, respectively. A similar system based on the HHSC boiler is under development at a Lake Tahoe ski resort.

Of course, one or two or three such HHSC boilers can only make a limited dent in the abundant biomass that needs to be cleared from the currently overstocked forests of the northern Sierra. But as philosopher Lao Tzu said, "The journey of a thousand miles begins with one step." The HHSC biomass system in a CLT building is a first step and an important example of the wood utilization infrastructure needed to successfully reduce risks of catastrophic wildfire, restore forest health, and sustain the diversity of animal and plant species on which we depend, while also supporting rural communities.

–Jonathan Kusel, PhD, is the founder and executive director of the Sierra Institute for Community and Environment

REFERENCES

Richter et al, 2019. The species diversity × fire severity relationship is hump-shaped in semiarid yellow pine and mixed conifer forests. *Ecosphere.* 10: 2150-8925

USDA Forest Service, 2013. Moonlight Fire Restoration Strategy Forest Service, Plumas National Forest, Mt. Hough Ranger District.



LOOKING FOR MULTI-BENEFIT SOLUTIONS: RESPONDING TO FIRE IN THE SONOMA VALLEY

CONVERSATION WITH CAITLIN CORNWALL OF THE SONOMA ECOLOGY CENTER

David Loeb

In October 2017, Sonoma and Napa counties were hit almost simultaneously by three separate wildfires (Tubbs, Nuns, and Atlas) that are collectively referred to as the Wine Country Fires. At the time, the Tubbs Fire was the most destructive wildfire in California history (a title it held for only a year, when it was surpassed by the November 2018 Camp Fire). These fires burned over 210,000 acres, claimed 44 lives, destroyed some 7,800 homes and other structures, and introduced a new narrative about the capacity of wind-driven wildland fires to cause significant damage in urbanized areas.

The Sonoma Ecology Center is a nonprofit organization that has been advocating for the environmental health of the land and people of the Sonoma Valley since 1990, and will celebrate its 30th anniversary on Earth Day, 2020. In response to the burning of more than one quarter of the landscape of the Sonoma Valley in the Nuns Fire, the Center's staff quickly rolled out a number of programs to help the community respond to the fire and heal from it. Soon thereafter, the work shifted to advocacy for initiatives and practices to make the valley's human and natural communities more resilient to future fires.

In October 2019, as the smoke from the Kincade Fire in northern Sonoma County was still impacting air quality in the county, I traveled to the modest offices of the Sonoma Ecology Center in portable trailers along the banks of Sonoma Creek to talk to Caitlin Cornwall, who directs planning and partnerships for the Center, and Restoration Manager Jason Mills. We discussed the Center's perspectives on living with and responding to fire in Sonoma County.

DL – Your organization's website talks about a three-part response to the 2017 fires: education, active response, and prevention. Is that still a good way to frame your response to wildfire in Sonoma Valley?

CC – You know, I don't think these are the right categories now. The one that's not working for me is "prevention." There's no such thing as preventing fire in California. Collectively we could do a much better job of preventing harm to people and their stuff from fire, but it would be impossible and counterproductive to try to prevent fire.

The categories that I thought you were going to ask about are the three that we use to talk to people about

Above: After the 2017 fires, the Sonoma Ecology Center led "fire recovery walks" through the burned areas of Sugarloaf Ridge State Park, to demonstrate the resilience of the native landscape. *[Photograph courtesy of Sonoma Ecology Center]*

fire in its causes and appropriate responses. Those categories still ring true: One is the direct effects of fire on people. Second is how fire behaves in a healthy natural setting. And the third is what fire means in places that are already disturbed.

We devised those categories because what people should do is really different in those different categories. Impacts on people is all about emergency response, fire prevention, defensible space, fire-ready houses; land use, that is, where we put houses; electrical infrastructure; human caused ignitions; and social services.

The second category is wild places; that's where we talk about the incredibly extensive pattern of fire during Indian times, fire adaptations of all of the native flora and fauna, the potential benefits of prescribed fire (if it's done right), how fire rejuvenates plant communities (if it's on the right return interval). That's a huge topic.

And then the third category includes things like erosion, invasive plants, biodiversity, those parts of the landscape that need a lot of stewarding and active work that they aren't currently getting—invaded grasslands, areas near roads. By the way, there was a scientific study that came out the other day that showed how invasive plants have increased the risk of fire as much as climate change.

DL – Let's go back to the question of the Ecology Center's response to the October 2017 fires. What were some of the programs you developed to deal with the fires and their aftermath?

CC – One of the very first things we did right after the fire was respond to the crisis posed by the number of charred wrecks of houses with the rains coming on. These were essentially piles of toxic ash and debris. If you think about it, most of what's in a house, if it burns, is toxic. It was going to start raining soon, and all of this toxic stuff was going to wash into our creeks. And that was especially a problem here in the Sonoma Valley because we weren't going to be first on the EPA's list for containment work, because our population density here is much less than Santa Rosa's.

So we had no idea when they [EPA] would get here, they were so completely overwhelmed by the scale of the problem—the number of houses—that required containment. So we came up with this emergency program, with volunteer crews and emergency funding from the State Water Board, to map out the location of burned structures in Sonoma Valley, and where they were in relation to steelhead streams. Then we located



Caitlin Cornwall leading a spring hike at Van Hoosear Preserve, a privately protected grassland preserve in Sonoma Valley managed by the Sonoma Ecology Center. *[Photograph by David Loeb]*

nearby staging areas, and got truckloads of straw wattles and sand bags, and trained volunteers to install them. And more important than the materials was our experience in this area. We do a lot of erosion control in normal times, so we have the experience of thinking like water, putting the wattles in the right place, etc. So our restoration staff already had a background for this task. The hardest part about this project was reaching the residents [of the burned homes] to get permission to work on their properties. So many of them had left the area.

DL – What was the scale?

CC – Oh, hundreds of houses. And we just did it in Sonoma Valley.

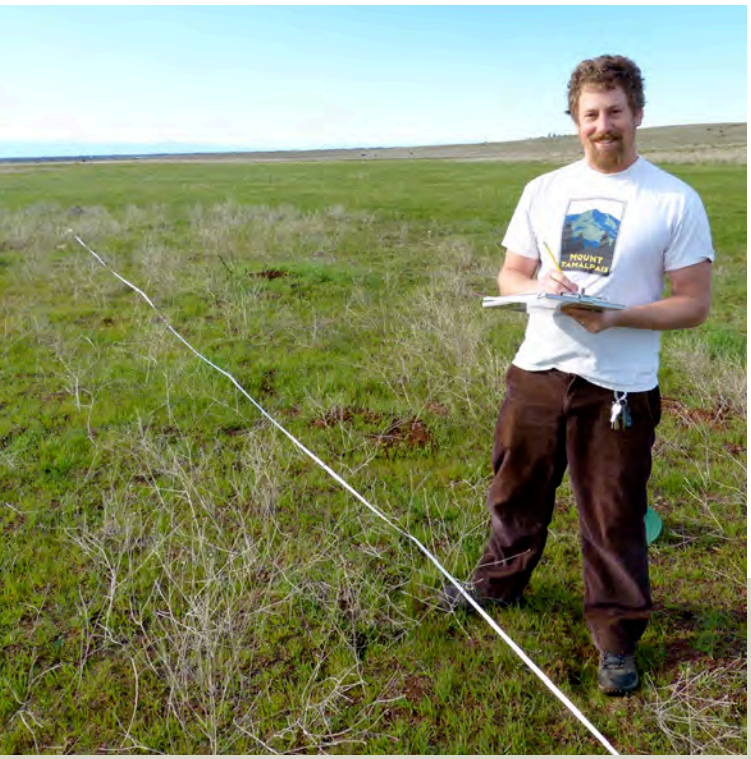
DL – What other programs did you institute in response to the fires?

CC – Immediately following the fires we created pop-up day camps, to address the unbelievable level of chaos and disruption that happens when the schools are shut down. Children are so stressed out by the uncertainty; when they see that adults are uncertain about what's going to happen next, they can get really upset. When we do stuff with kids, we talk about the fires, about climate change, about why this is happening.

Then after the immediate emergency of the fires had passed, we took hundreds of people on fire recovery walks, primarily at Sugarloaf Ridge State Park, but other places around the Valley as well. We worked hard to craft the messages we wanted to get across. We wanted to address people's emotional trauma as well as educate them about the resilience of the landscape and the benefits of fire. No one on those walks had ever really touched these topics in this fashion. It felt really revelatory. Both to deliver this content and for people to receive it. It was pretty emotional. People were in a very ripped-open state emotionally, and we

wanted to be with them in that state, to acknowledge it, and at the same time let the vitality of the land help them be healed. And that's what happened. For most people, those topics were utterly novel, and we felt it was important to experientially convey to people—not just with words, but by walking and touching and smelling—that the land knows fire and was not harmed by it.

There were people on some of the earlier walks who work in the healing professions, who ended up bringing whole groups of their peers on later walks, because they needed the sort of metaphorical language of the land healing to help other people heal.



DL – And you also did other kinds of education about fire ecology?

CC – Yes, we integrated fire ecology into our existing environmental education curriculum that we do in all the schools in the Valley, including field trips. We do these programs for the 2nd, 4th, 5th, and 6th grades.

But beyond that, one of our biggest concerns was that people would take their fear of fire and use it to rationalize cutting down everything that grows on their property. For most people living in California now, fire is a new topic. Or at least it's newly relevant, and it's complicated. People usually get confused or overwhelmed or they apply a fact they've heard about fire to a situation that's not appropriate.

The biggest misapplication of fire facts that we see all over California is the belief that fire suppression is a major reason that we have these dangerous fires. That may be true in some plant communities, but it's not in others. Fire suppression in the forests in the Sierra, yes. But fire suppression in chaparral is not a reason we have lots of fire in chaparral. So when people misapply some of the facts, it can lead them to support problematic solutions.

So one of our projects was to produce a brochure putting out the message that your property can be

Left: Jason Mills doing post-fire transect monitoring at Upper Bidwell Park outside Chico as part of a study on the effects of prescribed burning on species composition in California grasslands. *[Photograph by Ayla Joy Mills]*

Jason Mills: Fire Resilience for Homeowners

Jason Mills is the Restoration Manager and Fire Ecologist for the Sonoma Ecology Center. One of his roles is to respond to requests for advice from local landowners who want to make their properties more fire resilient.

We have a program where we advise landowners in the Valley on what's happening on their properties and how to manage them to be more fire resilient. People don't have the time with their busy lives to understand this on their own. We go out and take a look at what's going on and provide an assessment. And I'll probably say that you don't want any vegetation within that first five feet from your house. Pathways, hardscaping, whatever it is, could be used, but you might have to sacrifice whatever you have growing there.

Then in the next 30 feet out, that's generally where people have their ornamental, irrigated, maintained landscape. That's a really sensitive subject, because these are the plants that people paid for, cared for, feel connected with. We don't get involved with clearing those plants, though we might point out that this is a woody plant full of oils that is more flammable than that plant. But we're not going to recommend decimating people's ornamental landscapes. And it's been shown that if these areas are receiving irrigation and are maintained and limbed and properly attended to, it lowers their flammability. Also, rather than take all the trees out, let's preserve them, so you can have shade and allow for herbaceous, rhizomatous, low-growing native plants to get established as ground cover. The more shade you have, the more you can do your irises, your blue-eyed grass, heuchera, carex, juncus, all of these low-growing natives. And that's going to be your best planting option within

made ready for fire *and* be wildlife friendly *and* water conserving. You don't have to choose. There are design and maintenance practices that can achieve all three objectives.

And now we're following up the brochure with workshops in neighborhoods that are at high risk of fire. The challenge for landowners is that they're receiving all these different messages that tend to be driven by just one issue at a time, and it's our job to integrate all of these admirable objectives—being ready for fire, being good wildlife habitat stewards, using less water, and being climate smart—into a unified set of practices.

Our society has a whole set of complicated problems right now in relation to the planet, and the right course of action isn't to try to solve these problems as if they are separate. That's just playing whack-a-mole. The right solution is to paint a picture of a better way of living on Planet Earth that addresses all these problems at once.

Yet it's important not to present all these problems as a horde of ten thousand, because that just paralyzes people. But it turns out that the solutions *do* reinforce each other and make for a better life overall. So if people can do their defensible space in a way that maintains their tree canopy and that focuses on long-lived native plants, they really will be conserving water, providing habitat, and making their house safer. Whereas if they do it in a scorched earth way, and open up their yard to too much sun, and disturb the soil, they're going to invite in a whole crop of invasive, short-lived grasses, and make their property less safe. *And* require a ton of maintenance. *And* be ugly!

DL – I've heard you talk about the tension between the need to get people back into their homes as soon as possible, and the need to have those homes rebuilt in a more sustainable way.

CC – Unfortunately, land use policies and construction standards have not really changed. Polling shows that people think that housing should not be allowed in high fire risk areas, but they don't think that they themselves are in such an area. And of course, California *as a whole* is a high-risk area, so we can't eliminate all risks. But every new house in California is required to be built earthquake-ready, so why on earth don't we require houses to be fire-ready? And on the land use question, there are so many reasons to prioritize compact development and avoid isolated houses out in the woods. We're not the frontier anymore!

So the right community response to the belated realization that we live in a fire-prone place would be things like compact development, distributed power generation, renewable energy, electrification of things previously powered by combustion, microgrids. And having healthier land would help too, dealing with invasive plants, getting fire back to being a beneficial tool instead of a demon of chaos and destruction.

30 feet of the home. But if you cut everything down, and get all this sun in there, it's going to be harder to keep all of this wet and happy through the fire season.

Once you get outside that 30 feet, that's generally where you encounter wild vegetation. In that area, we advise and do active management to protect those resources. People really want to be proactive, anything that's burned they want it gone. Like, they want to take down burned trees, and yet that costs a lot. And when you bring in the tree companies, they may not be looking at this from an ecological perspective. So we're seeing a lot of damage being done to native trees that might have recovered if left alone. So when we come in, we can look at the trees for canopy damage, cambium damage, fungus and insect infestation. And come up with the likelihood of specific trees making it. UC Extension has a recent paper on recovery and mortality of burned oaks, and the US Forest Service has a paper on burned conifers, and those are great. But it would be really nice to have species-specific protocols for assessing post-fire tree mortality for hardwoods, such as madrone and buckeyes.

And then out there in the wildland, we prioritize removing the invasive weeds. Because the most aggressive plants are going to be your fuels. All this new growth in the spring is going to be flashy, flammable fuel in the peak fire season. And if you wait too long, until it starts turning brown, in late May, and the seeds are already forming, then you hire landscapers to go mow it all, and they're spreading the seed all around. But if you can get in there on those annuals in March, start mowing early, you could actually knock back the seed trajectory and start transforming the landscape back into an area that has more native beneficial habitat. And then if you shift to establishing native perennial grasses, they'll stay green longer going in to fire season.

DL – Is there funding for instituting any of these practices?

CC – There's funding for cutting down vegetation, which if done badly, is more of a harm than a benefit. Well, I shouldn't be so glib. The state as a whole is groping toward a long-term response to the problem. But just throwing money at people with chainsaws is not helpful.

There is a new initiative called Taking Action that's still in the discussion stage. It comes out of a realization that there are millions of acres of land in private hands that aren't being taken care of very well. People just don't have the knowledge or resources to do it right. This is everything from managing invasives to managing erosion; thinning forests where that's called for; etc. The basic concept of Taking Action is to create a self-financing mechanism for getting that work done. Not just for fire resilience, but for healthier lands overall. There are so many benefits that could come from this—water availability, biodiversity, jobs, etc., on top of reduced fire risk. So there ought to be a way to monetize these benefits of healthier wildlands. It would use science and mapping to figure out priority areas for which kinds of treatments; it would have its own equipment and crews, sort of like a utility. The way it is now, the agencies fund individual projects, but it's opportunistic instead of being systematic.



Sonoma Ecology Center staff and volunteers install fiber wattles to prevent toxic materials and erosion from burned homesites reaching local creeks.
[Photograph courtesy of the Sonoma Ecology Center]

DL – What about the Sonoma Valley Wildlands Collaborative? Is that a step toward a regional response?

CC – It's a start. The collaborative is made up of six large conservation landowners—public and private—in the valley [California State Parks; Sonoma County Regional Parks; Sonoma Land Trust; Audubon Canyon Ranch (Bouverie Preserve); Sonoma County Ag & Open Space; Sonoma Mountain Ranch Preservation Foundation] who are banding together to develop permitted plans for vegetation management. The permits would come from Cal Fire. They're hoping that they can save time and money by doing it all as one entity, because their lands are almost contiguous. The Collaborative has been granted about $1 million so far by Cal Fire, which basically just covers the cost of CEQA analysis for the work they want to do, not the work itself. But the work has already started on a small scale: County Parks has done some small prescribed burns; Bouverie did a burn. State Parks is by far the biggest player. The Ecology Center isn't officially part of the Collaborative because we don't own land, but we do work very closely with State Parks because we operate Sugarloaf Ridge State Park for them. We've already done some post-fire work for them on weed mapping there, and also mapping areas of burned Douglas fir forest, because they have Doug fir invasion issues—like many other landowners here—and the fire was actually positive on that front because it took out a lot of Doug fir, which had been part of their management plans even before the fire.

DL – Is it the objective of the Collaborative to make their conservation lands more fire resilient?

CC – There's some subtlety here. The money that was made available after the fires is coming from fire people, fire-*fighting* people. So that funding tends to be all about reducing fuels. But the mission of these landowners in the Collaborative is about biodiversity and conservation. So they want to use vegetation management as a tool for increasing the health of their lands. And of course that could also have the effect of reducing the risk of loss of life and property from fire. "Fuel reduction" can mean very different things. It can look like clear-cutting, or it can look like restoration. How much you cut, what you cut, when you cut, and how often you cut.

DL – It seems that a lot of fire science and fire management practices have been developed around forests in the Sierra Nevada, or Southern California chaparral. But might we need a different set of practices here in the northern and central California coast ranges?

CC – Yes, as I said before, people can misapply facts from other parts of the state to areas where they're not relevant. Unlike in the Sierra, there's very little natural lightning in coastal California, for example. So fires on the coast have mostly been caused by people, intentionally or not. And so the natural return interval of fire is different than it is in the lightning-prone mountains. And the concept that fires are now more severe due to fire suppression in the past, is not as relevant. Here, we have some plant communities that are vulnerable to too-frequent fires. Chaparral is a poster child for that; the natural fire return interval for chaparral is long, very long. We don't need to be doing prescribed fire in chaparral. If we do, we're in danger of losing it. While in other areas, prescribed burning is useful. In the coast ranges, we humans need to decide what we want these lands to support and then we need to work toward a fire regime that supports them.

DL – But it's my understanding that chaparral IS fire-adapted.

CC – Everything here is fire adapted, including oaks and redwoods; look at their bark. But fire in chaparral needs to be pretty rare. Otherwise, there's not enough time for it to regrow—chaparral grows really slowly.

DL – But in oak woodland, my understanding is that there *was* frequent low-intensity burning under Native Californian stewardship.

CC – Yes, that's right. But then you have to deal with the fact that many of our oak woodlands are completely infested with nonnative grasses, and when you burn them, these grasses do really well. So if I were designing a fire regime for oak woodland, I would design it around what's left of the native understory. Burn at the time of year that's good for those natives. The oaks are fine with a cool fire. But the timing and frequency can have a real impact on the understory plants. And so you want the timing to benefit those long-lived natives instead of the short-lived invasives.

DL – Do you think the response, both public and private, to this year's fires was improved by what was learned in 2017?



The Nuns Fire burns in the near distance in Sonoma Valley during the North Bay wildfires of October 2017. *[Photograph courtesy of the Sonoma Ecology Center]*

CC – Definitely. In 2017 we didn't have the content yet. Now we have this brochure. And we have developed workshops for both residents and agency personnel that focus on fire-wise, wildlife-friendly landscaping.

One thing going on now that wasn't happening in 2017 is that there are all these forces in the county working to get homeowners to implement defensible space. The county has an ordinance with inspectors going out; insurance companies are asking people to clear stuff. And PG&E is out clearing much more than it has before. And so our messaging, via the brochure and the workshops, is really important now that those programs are rolling. Because people are getting these messages to cut cut cut, but without a lot of nuance.

So it's very easy for people to believe that cutting more is going to make them safer. Some of the guidelines can be interpreted in problematic ways. For instance, there are horizontal and vertical spacing guidelines and nobody really knows where they came from. And if you followed all of them, you could do a lot of damage and make yourself less safe. So we're working actively with the county, with the fire chief, to make sure that we can be on the same page, that we figure out what people really need to know. They want to do a better job training their inspectors; they're really glad we're doing these workshops.

And again, problems arise when you look at the land through a single lens. The most fire-resistant thing you can have on your land is a paved parking lot and nothing else. So if you just pursue one objective, you won't get a desirable result. We all want to be safe, and to live in a beautiful place, in a functioning community. Generally people live here in Sonoma because they love the beauty of the land, they like being close to wildlife. So we're trying to help people see how then can have all of those values through multi-benefit solutions.



CNPS FELLOWS

CELEBRATING THOSE WHO SPEAK FOR NATIVE PLANTS

[Photograph by Catherine Traub]

Early in my tenure at CNPS, I was struck by a simple but profound statement I heard volunteers and staff repeat: ***"We are the voice for plants."***

For those sensitive enough to hear, our native plants have something to say.

The people working to protect,study, and nurture California's native plants are connected by the common understanding that native plants are the foundation of this place we call home. When we save these plants, we save everything else.

CNPS Fellow Ileene Anderson, the Center for Biological Diversity's public desert lands director and former CNPS Sourthern California conservation botanist, once said, "If the bug has bitten you or the cactus has stuck you, and you're hooked on plants, keep that alive! I do believe that the plants choose you."

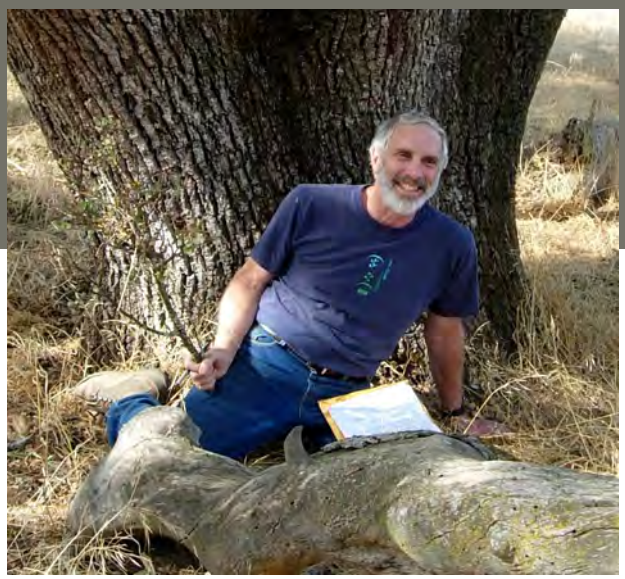
On the following pages, we celebrate an extraordinary group of people who heard that call of the green world and gave it voice—the 2016–2019 CNPS Fellows. To be named a CNPS Fellow is the highest honor given to members of the California Native Plant Society.

With this issue of *Fremontia*, we've got quite a few people to recognize. Please join us in thanking each of them for their service and contributions to California's native plants.

In that same spirit of gratitude, we have four incredible lives to remember: Celia Kutcher, Les Rowntree, Steve McLaughlin, and Mac Laetsch, the first president of CNPS. While we mourn their loss, we celebrate their memories and their lasting contributions to California.

Together, these voices have made the voice for plants a cause for all Californians, and we are indebted.

~ Liv O'Keeffe is the CNPS senior director of communications and engagement



Michael Barbour is a national leader in vegetation conservation who guided the publication of the first CNPS *Manual of California Vegetation in 1995*. *[Photograph by Jennifer Buck Diaz/CNPS]*

CNPS FELLOW
Michael Barbour

To be respected in the scholarly world as well as the practical, boots-in-the-dirt plant world takes a special person. Michael Barbour is one of those rare individuals who moves freely between both realms, earning plaudits on all sides. A longtime leader for CNPS in vegetation conservation, he is also a widely published author and researcher, cherished educator, and a passionate spokesman for plants. As his Fellow nomination letter notes, he is one of California's most influential plant ecologists.

Michael graduated magna cum laude from Michigan State University, was a Fulbright Fellow in Australia, then received his doctorate in botany from Duke University in 1967. He then joined the faculty of the University of California, Davis, becoming a professor of botany and environmental horticulture. At Davis he earned a reputation for finely tuning his lectures for his audience, whether they were laypeople or graduate students. Since his retirement from UC Davis in 2008, he has remained actively involved in CNPS on many fronts, including his most recent publication through CNPS, the beautiful *California's Botanical Landscapes* (2016).

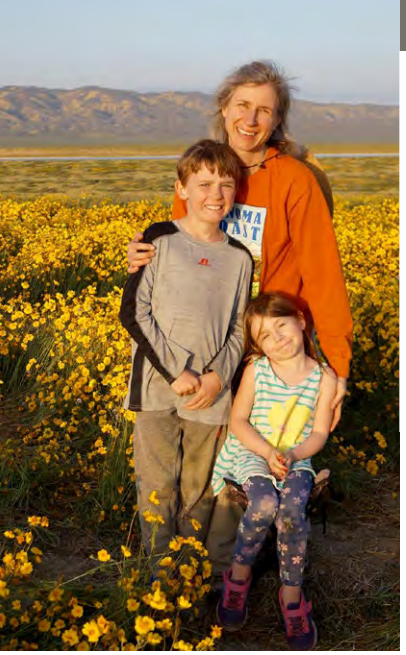
Michael has been the author or co-author of textbooks on botany, plant ecology, landscape ecology, and vegetation. He co-wrote one of the most widely used texts on plant ecology, *North American Terrestrial Vegetation*, with his major professor at Duke University, W.D. Billings. Along with his UC Davis friend and mentor Jack Major, Michael also edited and wrote portions of the first two editions of the extensive compendium on California vegetation ecology, the *Terrestrial Vegetation of California*, the second edition of which was published by CNPS in 1988. These books have set the stage for many developments in the study of Californian and western North American vegetation. His research work into plant ecology has taken him to many countries across the globe, including Argentina, Spain, Israel, Australia, and South Africa. He also welcomed European vegetation scientists to work with him on refining California's vegetation classification. He has published more than 50 books, book chapters, and papers, including several articles in *Fremontia*.

Michael has been involved in a number of conservation issues, demonstrating the power of conservation through scientifically defensible means. This includes the conservation and understanding of California's vernal pools. He and his co-authors developed a quantifiable approach to vernal pool classification that led to a means for putting metrics on vernal pool restoration by quantifying the deviance between created vernal pool communities and naturally occurring ones. The Environmental Protection Agency and other regulatory agencies have adopted this same methodology.

His efforts for CNPS have been as far-reaching as his academic work. In 1989 he was chosen to lead the new Plant Communities Committee, now known as the Vegetation Committee. He and his group established a sampling protocol for vegetation throughout the state, developed a database to contain collected vegetation transect and plot data, and trained many CNPS chapter members on the selection of rare communities and their sampling. Most important, his committee guided the development and writing of the first *Manual of California Vegetation* published by CNPS in 1995.

Michael not only has been a state leader in vegetation conservation, but also a national leader. He was the first chair of the Ecological Society of America's Vegetation Committee, which published the first U.S. National Vegetation Classification in 1998. And throughout his distinguished career, Michael has been a congenial, even-handed, and humorous member of the plant ecology community. As his nominators note, "CNPS and the conservation world has been extremely fortunate to have him in 'our corner.'"

–Kathy Morrison





Under Julie Evens' leadership, the CNPS Vegetation Program became an important partner for county, state, and national agencies. (Left) Julie with her children Leo and Daphne Cox at Carrizo Plain National Monument. *[Photographs by Jeffrey Cox]*

CNPS FELLOW

Julie Evens

Being the first of anything can be tough, especially when expectations are high. That was the situation Julie Evens faced when she became the first full-time CNPS vegetation ecologist in 2001. Thanks to her efforts, the CNPS Vegetation Program has since grown in size and prominence, earning state and national respect as a leading force in ecosystem classification and conservation. CNPS recently recognized Julie Evens for her dedicated advocacy and support of the program with its highest honor, the title of Fellow.

Julie grew up in the Midwest and arrived in California to attend the University of California Santa Cruz (UCSC). As a horticulture intern at the UC Santa Cruz Arboretum, Julie assisted in the California collections, especially Channel Islands endemic plants. She graduated in 1995 with two BA degrees in environmental studies and biology/botany with honors.

Fresh out of college, Julie worked as a scientific aide with the Natural Diversity Database Natural Communities Program, where she helped inventory valley oak riparian forest in the Sacramento and San Joaquin valleys. She went on to be a field team leader in the joint State and Federal Mojave Desert Ecosystem Program, Central Mojave Vegetation Database Project. She and others collected more than 1,200 relevés throughout the central Mojave. This information formed the basis of the Mojave Desert Ecoregional vegetation classification, which was used to make a map of approximately 12 million acres of desert.

As a Humboldt State graduate student, Julie decided to explore the ecological intricacies of desert wash systems and spent two field seasons collecting relevé samples in the Sweeney Granite Mountains Reserve. Her master's thesis was an analysis and definition of the Eastern Mojave wash vegetation. It remains the authoritative work on the subject.

As a field team leader for two seasons in the Vegetation Classification project for Sequoia and Kings Canyon National Parks, Julie grew interested in CNPS' work. Allen Barnes had recently become the organization's first executive director, and CNPS was searching for its first full-time vegetation ecologist. Julie was selected for the position over stiff competition. Her goals for the Vegetation Program included increasing chapter involvement, and improving methods in data collection and description of vegetation. She also helped drive active conservation planning of natural communities through development of new vegetation information for key areas.

These goals took root in a project with the Santa Clara Valley Chapter, which resulted in a detailed report on the classification of Coyote Ridge, one of the premier serpentine grassland landscapes in California. To help raise awareness of vegetation conservation—a goal of the CNPS Vegetation Committee—Julie and her growing program delved into immensely detailed regional projects, such as the classification of the vegetation of Western Riverside County Multiple Species Habitat Conservation Plan (MSHCP).

To accomplish these increasingly complex tasks, Julie became a diligent and creative grant writer and project manager. She received a competitive National Fish and Wildlife Foundation grant to test and develop efficiency and effectiveness of field data collection (Peoria Wildlife Area). Since then, she and her staff have won many contracts and grants with the California Division of Fish and Wildlife, NatureServe, National Parks Service, and others. Funding stability has allowed her program to address goals such as the writing of the second edition of the *Manual of California Vegetation*, and development of the online MCV and the MCV database.

On a more personal level, Julie has two young children and is active in the Sacramento Valley Chapter, showing off her native-plant-filled front yard during garden tours. Above all, as her Fellow nomination letter notes, "It has been Julie's strong sense of passion for her work, belief in the power of grass-roots involvement, and familial loyalty to her staff and her cooperators that has brought such statewide recognition to Vegetation Conservation."

–Kathy Morrison



Brett Hall and Tori Bauman with *Arctostaphylos montereyensis* in the Maritime Chaparral section of the California Conservation Gardens at UCSC Arboretum. *[Photograph courtesy of Brett Hall]*

CNPS FELLOW
Brett Hall

Educator, advocate, enthusiast— all are characteristics that describe Brett Hall and his invaluable contributions to the California native plant community. As California Native Plant Program director of the UC Santa Cruz Arboretum, he has been deeply involved in teaching about and conserving native plants. Having served as president of the state CNPS board as well as the Santa Cruz and Tahoe chapters, he has spread the mission of CNPS and worked tirelessly on projects such as the new Important Plant Area (IPA) initiative. His botanical pursuits cover everything from plant sales to seed banks.

This dynamo of native plant advocacy was born in Carmel and grew up exploring the flora of the Santa Lucia Range. After working in his family's landscaping and garden design business, he enrolled in UC Santa Cruz and received a bachelor's in natural history and biology. Ken Norris and Ray Collett were among his instructors; their legendary Natural History Field Quarter courses launched many environmental careers. While at UCSC, Brett worked at the Arboretum, which was still in its early days, and his senior project was a study of the rare plants of Santa Cruz County.

In 1975, Brett became an official staff member of the Arboretum, and two years later was promoted to botanical garden manager. About this time, he joined the Santa Cruz Chapter of CNPS and became one of its great champions. His nominator, colleague and fellow CNPS member Dylan Neubauer, says, "Indeed, a more exemplary advocate for the organization would be hard to find."

The Santa Cruz Chapter, though small in those days, was able to preserve several special botanical areas in the county, including the Bonny Doon sandhills and the Glenwood grasslands, both home to federally and state-listed taxa. "Brett's earnest and hands-on style (never one to wear a suit to a meeting or hearing!) was invaluable during those early efforts as well as later ones," recalls botanist Laurie Kiguchi. "His trustworthiness and dedication were apparent, and he always came across as calm, thoughtful, and open."

Brett became director of horticulture at the UCSC Arboretum in 1985 and worked to expand its holdings, traveling and bringing in many ornamental plants that then were new to California horticulture but became popular in the nursery trade. He was director of collections and conservation in 2014-15 before assuming his current position as California Native Plant Program director. The Arboretum now is well known for its collections of Mediterranean-climate plants, including California natives. One of Brett's long-term projects, the California Conservation Garden, houses a large collection of rare manzanitas, a favorite genus of his.

Brett's passion for native plants is a common thread of his Arboretum work and his efforts for CNPS. For many years he served as coordinator of the semiannual CNPS plant sales, which were held alongside the spring and fall Arboretum sales. The venue for CNPS meetings for many years, the Arboretum also hosted chapter council meetings in 2009 and 2013 while Brett was chapter president. He joined the CNPS state board of directors in 2007, served as state president from 2009-13, then rejoined the board in 2016. He added numerous roles to his Santa Cruz Chapter activities, then helped revive the Tahoe Chapter in his "second home," becoming its president in 2014.

Brett has been deeply involved in the California Rare Plant (CaPR) initiative, seedbanking of rare and locally rare plants, and CNPS' Vegetation Program and new Important Plant Area initiative. His students benefit from his knowledge and enthusiasm for all these projects. As Neubauer notes in his nominating letter, "A true educator, Brett knows how to convey his expertise about California places and plants in a way that gets people turned on—for life."

–Kathy Morrison





Dave Imper, also known as "Mr. Lily," has worked across government agencies to establish protections for rare plants. *[Photographs courtesy of Dave Imper]*

CNPS FELLOW
Dave "Kim" Imper

David Kimberly Imper answers to both "Dave" and "Kim" but plant folks like to call him "Mr. Lily," for his work with the endangered Western lily (*Lilium occidentale*). Now retired from his position as a U.S. Fish and Wildlife (USFWS) biologist, Imper is respected in the North Coast region for his academic and professional knowledge, as well as his willingness to stand up for the plants, even putting his job on the line when necessary.

Dave earned a BS degree in botany from Cal Poly San Luis Obispo and a master's in botany and plant pathology from Oregon State. His professional career included time with the U.S. Forest Service, LACO Engineering Consultants, SHN Engineers & Geologists Inc., and finally USFWS, where the service hired three botanists to replace him after his retirement. His professional ethics always were foremost, say the writers of his Fellow nomination. They offer these examples:

"He reported a timber company to the Army Corps for illegally filling part of Crescent City Marsh. When Pacific Lumber Co. demanded that a section on obligate wetland plants be removed from a report on a timber harvest survey, Dave said, 'Why don't we call the Army Corps and see what they think?' You can guess how that debate ended! He did wait until he retired to confront the Six Rivers National Forest on their lack of stewardship of the Lassics Lupine and then to proceed with the listing petition."

Dave did not shy away from working with other agencies to protect rare plants. His partnerships ranged from the Bureau of Land Management to the Humboldt County Roads Department, from the California Department of Fish and Wildlife to cannabis farmers. Through these efforts, projects such as the Two-Flower Pea Reserve became reality, and the Crescent City Marsh drainage issue was fixed for the benefit of the Western lily. Drivers along Highway 101 appreciate his work with Caltrans to establish a "botanical management area" where a large, gorgeous array of native Columbia lily (*Lilium columbianum*) blooms annually.

He also was an early and dedicated supporter of the concept that loss and alteration of natural ecological disturbance is as much a threat to rare plants and natural communities as the other more typical threats. Dave helped local conservationists understand that conservation is more than just roping off land and not touching it. Many rare plant populations need a certain fire, flooding, or grazing regime, or they will not persist.

As a botanist, Dave's experience includes botanical surveys, protection measures, conservation and recovery plans, habitat restoration and purchase, monitoring, status reviews, listing petitions, genetic studies, publications, lectures, and field trips. So it's no surprise he has been a cherished resource for the CNPS North Coast Chapter, which he joined in 1981. He has taken on many board roles, including chapter president in 1987. He has also led field trips, served as speaker at CNPS programs, written articles for *Darlingtonia*, and built an educational booth for use at fairs and other occasions. He was an important organizer of the 2002 Rare Plant Symposium, one of the chapter's most ambitious projects, and developed an Adopt-a-Rare Plant program for the chapter. He was also the first recipient of the chapter's highest award, the Gilded Darlingtonia.

For the last word on the invaluable contributions of Dave "Kim" Imper, here is James P. Smith, one of the founders of the North Coast Chapter: "Few indeed have been the combination of a person with such a strong professional background, active field experience, dedication to the cause of rare plant studies and conservation, and willingness to devote his time, knowledge, energy, and personal resources to the cause."

–Kathy Morrison



Four taxa have been named in Dave Keil's honor, pictured here receiving his Fellow award. *[Photograph by Melissa Mooney]*

CNPS FELLOW
David Keil

Was David Keil born with a plant key in his hand? At the very least, he carries one around in his head. Now retired from Cal Poly San Luis Obispo, where he taught for 37 years, Dave influenced generations of botany and biology students through his classes, field trips, and research. He continues to inspire and influence his fellow members of CNPS, and especially the San Luis Obispo Chapter, as a CNPS Fellow.

Dave attended Arizona State University, earning both a bachelor's and master's of science. In 1973, he completed his PhD at Ohio State University. He joined the faculty at California Polytechnic State University in 1976, and two years later was appointed director of the Robert F. Hoover Herbarium. Students have described his field botany course as both the hardest and best of their college careers. Not surprisingly, Dave is an avid plant collector; over the years, many of his more than 30,000 specimens became part of the herbarium's collection. He received the university's Distinguished Teaching Award in 1980.

Not long after his arrival in SLO, Dave joined the CNPS San Luis Obispo Chapter. In 1978, he served as the chapter president, and has since filled many other roles, including vice president. He has regularly presented chapter meeting programs and workshops that were fun and surprising, including new discoveries and unusual findings, members say.

CNPS members have also benefited from Dave's knowledge on chapter field trips, including for the chapter's annual Wildflower Weekend event; Sierra Madre and Mt. Pinos weekend ventures; trips to the Carrizo Plains; and trips focusing on coastal, riparian and serpentine endemic plants. Some trips were spur of the moment, such as an evening trip to the Irish Hills for grass identification, or a quick trip to West Cuesta Ridge.

Another example of Dave's dedication is related in his Fellow nomination letter: In 2009, he volunteered for a "quick" CNPS committee to develop a guide to common plants, for distribution by the city of San Luis Obispo, and the effort turned into a multi-month project. Dave later became editor of the 86-page guide, *Wildflowers of San Luis Obispo, California*, of which an expanded second edition was recently published. In recognition of his generous contributions to the SLO Chapter, Dave was given the 1989 Hoover Award, the chapter's greatest honor.

Dave also has been active and influential at the state level of CNPS, serving on numerous committees and boards, including the Rare Plant Scientific Advisory Committee and the *Fremontia* Editorial Advisory Board. He most recently sat on the 2019-20 Education Grants Committee, a roll he also volunteered for from 2014 through 2016. He also has conducted multiday workshops on California flora for the State Education Program.

Beyond CNPS, Dave has lent his expertise to the California botanical community through his contributions to *The Jepson Manual* Project. He wrote the "Key to California Plant Families" and served as the editor and primary author of the *Asteraceae* for both editions of *The Jepson Manual*. Key writing has always been one of his strengths, colleagues say, and it is a major part of his legacy. Fittingly, four taxa have been named in this plant expert's honor: Santa Ynez groundstar (*Ancistrocarphus keilii*); Keil's daisy (*Erigeron inornatus* var. *keilii*); *Wedelia keilii* B.L. Turner, and *Chrysanthellum keilii* B.L. Turner.

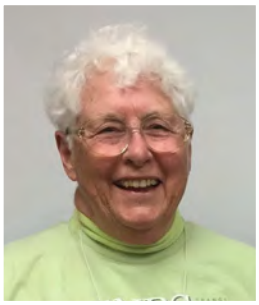
–Kathy Morrison

A NEW FELLOW REMEMBERED

Celia Kutcher

(December 1938 – November 2019)





Members of the CNPS Orange County Chapter celebrate Celia's Fellow recognition last spring. Celia at center in green. *[Photographs courtesy of the CNPS Orange County Chapter]*

California native plants have lost one of their greatest champions. Last spring, CNPS awarded Celia Kutcher its highest honor of CNPS Fellow, recognizing Celia for four decades of native plant conservation advocacy and service to the organization. Now, we honor her passing.

In reviewing the nomination packet submitted by members of the CNPS Orange County Chapter, one is struck by one theme more than any other: the powerful example Celia set for others. Whether drafting meticulous comment letters in defense of endangered species, creating native gardens, or cleaning up after events, Celia did it all. Her nominators say the other chapter volunteers couldn't help "but follow her lead." Celia's example was an inspiration, and for so many reasons.

Celia is perhaps best known for her steadfast conservation work at the local level, where she served as the CNPS Orange County Conservation chair for 25 years, and statewide, as a member of the Conservation Program, Litigation, and Policy Committees. In 1997, she formed and chaired the Dana Point Headlands Action Coalition, taking on powerful interests to protect the last undeveloped headland in Orange County. The group's partial victory saved two federally endangered species and set aside a large Environmentally Sensitive Habitat Area for rare native plants.

Celia was an expert across many of California's most complex environmental issues, providing valuable input on behalf of her chapter and the statewide organization. "Whether on realistic fire/fuel management strategies, watershed issues, toll road proposals, legislative attacks on CEQA and many other CEQA-related issues, DEIR and EIR biological resources reviews, invasive plant topics, or NCCP actions, her detailed language is accurate and well supported, her tone is never strident or accusatory, always courteous and professional," said her nominators.

Celia held degrees in both botany and plant ecology and a master's in environmental studies from California State University Fullerton, where she served as the Fullerton Arboretum's curator of plant collections for 22 years. During that time, she directed the planting of Chaparral Hill, a native plant collection with trails and interpretive signage spanning more than an acre. She also designed the native landscape around the Oak Hall complex and organized CNPS Orange County Chapter members to install the garden. Both Fullerton landscapes were the first public native gardens in Orange County. Later, Celia organized a similar effort for the UC Irvine Arboretum, leading the chapter's creation of three California Gardens.

Celia directed her chapter's early efforts at controlling invasive weeds in county wildlands and served as an active member of the Orange County Chapter's award-winning Invasive Plant Program's Early Detection/Rapid Response Group. A founding member of the Orange County Chapter, Celia filled nearly every volunteer leadership role at one time or another, from vice president and historian to plant sales chair. Not surprisingly, her fellow volunteers awarded her the chapter's "Native Perennial Award" in 2008 and Board Member of the Year in 1999.

It is with much admiration and gratitude that we honor Celia Kutcher's contributions and life. A remembrance by her fellow Orange County Chapter member and friend Dan Songster appears on page 60.

–Liv O'Keeffe



CNPS Fellow Dianne Lake was one of the first advocates for the concept of "locally rare" plants. She continues her work monitoring locally rare plants today and has authored a guide to helped other chapters do the same.
[Photograph courtesy of CNPS East Bay Chapter]

CNPS FELLOW
Dianne Lake

Dianne Lake discovered botany during summers spent eating blackberries and caring for her grandmother's garden in St. Charles, Illinois. These childhood pleasures formed an early stewardship ethic, which Dianne has enacted through decades of observation, advocacy, and leadership on behalf of California's native flora.

A self-taught botanist, Dianne gained her knowledge of the flora of the East Bay by joining CNPS hikes, taking courses at Peralta and Merritt College, "pestering" the former director of the Tilden Botanic Garden, as she puts it, and hiking in the wilds of the East Bay with her kids.

While on East Bay Chapter outings in the 1980s, Dianne noticed that certain native plants were present all the time, while others could be found only occasionally, and some very rarely. She concluded that a list of East Bay plants with five or fewer known locations should be compiled. In this way, Dianne became an early advocate for the concept of "locally rare" plants that scientists consider sensitive or unique in a specific region.

Dianne's observations kicked off a collaborative search for botanical information, including chapter and East Bay Regional Park District plant lists, conversations with other botanists, herbarium vouchers, field notes, and Environmental Impact Reports. The resulting list included 861 plants, and prompted Dianne to develop criteria for listing and ranking each plant.

In the years since, Dianne and her partners have produced eight hardcopy editions of the *Unusual and Significant Plants of Alameda and Contra Costa Counties*, which they converted to an online database in 2010. In all, they've tracked more than 1,000 plant taxa and compiled 18,000 observation records from 1,050 people. Dianne herself has personally reported 4,993 observations.

Dianne has been a member of CNPS for decades. She served on the board of the East Bay Chapter for approximately 28 years, continuing as a board member today. When Franklin Canyon in Contra Costs County was slated for development in 2004, Dianne went from door to door, collecting signatures to support the *Protect Franklin Canyon Area Initiative*.

Her efforts helped get the initiative on the ballot, ultimately saving Franklin Canyon and the nine locally rare plants that live there. In addition, Diane participated in the efforts to get Richmond to include protection of locally rare plant species as a priority in its general plan.

Since Dianne started her work, many others have been inspired to develop lists for their chapters and counties—helped in no small part by Dianne's how-to guide, *Establishing a Locally Rare Plants Program for Your Chapter*, which can be found online at cnps.org/locally-rare-chapter-program-guide.

Not one to slow down, Dianne continues her work alongside other chapter volunteers to continually monitor plants and update their knowledge of the East Bay flora. Dianne's energy, conservation ethic, and steadfast study of the East Bay flora are an inspiration to all.

–Adapted by CNPS staff from text by Heath A. Bartosh

CNPS FELLOWS

Carol LeNeve and Brian LeNeve



Carol LaNeve has been a driving force behind seminal Monterey County botanical texts, including *The Plants of Monterey County*. *[Photograph by Michael Mitchell]*

Working both together and separately, Brian and Carol LeNeve have dedicated decades to California native plants and habitats, and to CNPS. Their story starts with Carol, "the glue that has held together the Monterey Bay Chapter," as her Fellow nomination letter puts it. She joined the chapter in 1980 and quickly became involved in the annual plant sale. At that time the sale was held on the lawn of Carmel High School. By the late 1980s, Carol was in charge of the event, raising its profile so it became the primary fundraising source for the chapter.

The sale moved to the Monterey Peninsula College parking lot by the early 1990s, where high-quality plants chosen from local wholesalers drew a growing clientele of native plant gardening lovers. Carol developed sales aids, too, including cards for each species with color photographs and informative labels. The sale has since moved to the Hilton Bialek habitat area at Carmel Middle School, and Carol retired from sole management of the event in 2012, but she set the standard and helped establish stability for the Monterey Bay Chapter.

On the statewide level, Carol served as editor of the CNPS state bulletin from 1988 to 1994 and sat on the state book publication committee. She selected titles to be offered at the plant sale and chapter meetings. Proceeds from those book sales went into a special educational fund. In 1997 "a longtime goal was realized" with the publication of (Corky) Matthews' *Illustrated Field Key to the Flowering Plants of Monterey County,* note Chris Hauser and Peggy Grier in their nominating letter. Corky Matthews "was the first to say that the project would not have succeeded without Carol's management," they add.

The book has subsequently been revised, each time with Carol's careful oversight. In 2012, a revision of *The Jepson Manual* in turn required an update on Monterey flora. So in 2015 a new third edition was published, written by Michael Mitchell and retitled *The Plants of Monterey County*. Carol again had a hand in the work: She enabled Mitchell to get started by taking on the huge project of creating a "crosswalk" database of old and new plant names.

Early on she joined the weekly day trips of Matthews, Vern Yadon, and Ron Branson, seeking out rare or unusual plants in the little-traveled areas of the county. (Interestingly, some of these trips wound up at the LeNeves' ranch in Priest Valley, in the southeast corner of Monterey County.) She assisted Matthews and Yadon in the long-term project of updating the herbarium of the Pacific Grove Museum of Natural History, where Yadon was the director. She also compiled a display of the Ten Most Wanted (weeds) of Monterey County, which she toted to any and all meetings of environmental groups. Her dedication, knowledge, and attention to detail—not to mention her famous chocolate chip cookies—have made her an invaluable member of the chapter and the Monterey region plant community. At present she serves on the chapter board.

With Carol deeply involved in CNPS, it was bound to rub off on Brian. It took a while, but he became so interested in native plants and conservation that he's now known as "Mr. Clarkia." Brian grew up in the Carmel area, following in his father's footsteps as a painting contractor. At first he was just an occasional driver on those plant-hunting drives around the county. As Carol took on more responsibility with the chapter plant sales, Brian became her go-to delivery man, banner installer, and general laborer. The couple



An expert in riparian habitat and clarkia, Brian LeNeve has been an adviser on the project to remove the San Clemente dam and redirect the headwaters of the Carmel River. *[Photograph courtesy of CNPS]*

developed a tight organization behind the scenes that became their trademark.

Brian eventually expanded his involvement to the Pacific Grove Wildflower Show, which Yadon and Beatrice Howitt founded at the Pacific Grove Museum. This annual event, now in its 59th year, requires a huge amount of legwork from CNPS members and other plant lovers. In his Fellow nomination letter, Grier and Hauser describe how Brian sets up tables and collection lists for the show, handles all coordination with museum staff, then oversees set-up day when the work crew transforms a sea of plant specimens in buckets in to a highly organized show that attracts many hundreds of plant lovers."

A few years ago Brian finally was joined by a CNPS co-chairman to relieve him of some of the duties of the wildflower show. Since retiring from his painting business, he also has served three terms as president of the CNPS chapter, as well as serving on the state board of directors and the chapter council.

So how did he become Mr. Clarkia? About 15 years ago, Brian took on a year-long study of species occurring in a quadrant at the Church Creek divide, near Chews Ridge and China Camp, and later presented a program on the area at a chapter meeting. His long-term interest in clarkias took him to the Jepson Herbarium at UC Berkeley to review clarkia species across California, and he decided to track them all down, as well as species in neighboring states. Corky Matthews, herself a CNPS Fellow, now calls him a leading authority on the genus.

The longtime hunter-fisherman also jumped into helping with the problems of steelhead in the Carmel River, eventually becoming president of the Steelhead Association. In the course of his steelhead involvement he developed expertise on riparian habitats, and now serves as consultant and adviser on the monster project of removing the San Clemente dam and redirecting the very headwaters of the Carmel River. (In winter months he takes time for multiple trips to fish the streams of Northern California.)

Brian's newest role is chapter representative to the BLM monitoring of the Clear Creek area in the interior of Monterey County. The mission is protecting rare plant species in a serpentine area frequented by off-road vehicles, a mission with its share of risks. "Brian has been our chapter's lead person in the filing of litigation against BLM, and the result has been to ensure enforcement of their management plans," Grieg and Hauser note.

By the way, that ranch in Priest Valley, which the LeNeves bought originally so Brian could pursue his love of hunting, is now leased to neighbors for grazing. Carol and Brian have their own "plant preserve"—they are valuable stewards of the Monterey County flora and invaluable members of CNPS and the plant community.

–Kathy Morrison



For more than four decades, Larry Levine has quietly helped lead CNPS efforts like the CNPS Phytophthora policy, chapter council, and technology innovation. *[Photograph courtesy of CNPS North Coast Chapter]*

CNPS FELLOW
Larry Levine

CNPS is an organization dedicated to plants, but its success relies on tending to the human side of the operation. Not many people understand this more than North Coast Chapter member Larry Levine, whose peers named him a CNPS Fellow in 2018.

Larry balances his scientific savvy with social acumen, excelling not only in rare plant research but hospitality and communications. He has conducted research into rare plants like Bensoniella (*Bensoniella oregona*) and Howell's alkali grass (*Puccinellia howellii*), and was also the first in his chapter to point out the need to serve refreshments at chapter meetings.

He instituted accessible, two-hour plant walks for his community, organizing 18 consecutive walks in one year, and was also an early technology pioneer, advocating for putting the CNPS Rare Plant Inventory online in the early 1990s.

"Larry is a solid scientific thinker and an experienced, ace botanist who has both a deep and a broad knowledge of the California flora, natural history, and ecological principles," said North Coast chapter leaders Carol Ralph and Gordon Leppig in their nomination letter.

Larry also knows how to grow an organization and its mission. As co-organizer of the North Coast chapter's wildflower show, he developed a teacher's guide for the show, managed the database and species identification cards, and supervised the plant identification crew. In his respective roles as publicity chair and webmaster, he overhauled his chapter's website and provided website mentorship to other chapters. He also wrote, edited, and compiled hundreds of public service announcements, articles, and news releases.

Not limited to the chapter level, Larry's efforts extend to the entire organization. Over 30 years of service to CNPS, he served as CNPS chapter council vice chair for 10 years and, since 2003, has served as a chapter delegate.

As vice chair, he initiated the round table approach to facilitate discussion at meetings, and took an active role in developing and organizing CNPS policies across a wide range of complex issues. He was the Phytophthora Subcommittee chair and a major contributor to the development of the CNPS policy of preventing the spread of harmful pathogens via native plant nursery and plant sale stock.

"Larry always strives for thoughtful, effective engagement that focuses on active listening, finding common ground, seeking consensus, deescalating tensions, conflict resolution, facilitating creative solutions, and diminishing interpersonal issues while focusing instead on the substance of the issue," said Larry's nominators of his ability to bring people together—a much-needed gift in today's deeply polarized world.

–Liv O'Keeffe



Award-winning horticulturalist, author, and former *Fremontia* editor Bart O'Brien helped write the book(s) on native plant gardening. *[Photograph by Ashika Narayan]*

CNPS FELLOW
Bart O'Brien

One of California's leading experts in native plant horticulture, Bart O'Brien's impact is felt statewide. A long time member and former president of the Santa Clara Valley Chapter of CNPS, he is the current director of the Regional Parks Botanic Garden in Tilden Regional Park in the Berkeley hills. Before that, from 1990 to 2013, he worked at the Rancho Santa Ana Botanic Garden in Southern California. In 2005, the Southern California Horticultural Society named him Horticulturist of the Year.

A fifth-generation California native from Hollister, Bart received his BA in Environmental Planning at U.C. Davis and then an MA in Landscape Architecture from the Harvard School of Design. In 1981, he returned to the Bay Area to pursue a career in landscape design, eventually becoming manager of Yerba Buena Nursery, the pioneering native plant nursery in the South Bay, from 1988–1990. He credits Gerda Isenberg, the visionary founder of the nursery, with stimulating his lifelong passion for native plants.

In 1982, Bart joined the Santa Clara Valley chapter of CNPS, becoming an active member right away. He served as chapter vice president in 1983–1984 and then as president in 1985–1986, increasing public awareness of native plants through field trips, lectures, and plant sales. In 1987, Bart became editor of the chapter newsletter, starting his career as a prolific writer about native plants. He also chaired the Edgewood Park Committee, which worked to keep this botanically important open space in San Mateo County from being developed as a golf course. This resulted in the permanent protection of important serpentine grasslands and the creation of Edgewood County Park and Natural Preserve in 1993.

In 1990, Bart was lured away from the South Bay to become director of horticulture at the Rancho Santa Ana Botanic Garden (RSABG). In his 24 years at this revered Southern California institution, he introduced generations of homeowners—and water agency officials—to the beauty of native plants adapted to the region's dry climate. His years of experience and knowledge in cultivating native plants for California gardens resulted in the authoritative *California Native Plants for the Garden* (Cachuma Press, 2005), which he co-authored with David Fross and Carol Bornstein, and which won the American Horticultural Society's annual Book Award.

Bart then shifted to the role of director of special projects, giving lectures on the benefits of native plant gardening and pursuing his research into the flora of Baja California. This latter area of interest has continued even after his subsequent move back north, as Bart continues to serve on the board of Terra Peninsular, a Mexican nonprofit dedicated to the preservation of the native flora of northern Baja.

One of Bart's greatest contributions to California horticulture has been his concentration on native cultivars, reflected in the new cultivar garden he created at RSABG and an accompanying guide. Bart also served CNPS as editor of *Fremontia* from 2006 through 2009, and he remains a member of the *Fremontia* Advisory Board. He has been active in the Education Committee's Horticultural Program and continues to serve on CNPS' Horticultural Experts Committee.

In 2013, Bart returned to Northern California when he was hired to take over the position of manager of the Regional Parks Botanic Garden from retiring longtime director Steve Edwards. There, at one of the most significant collections of California native plants in the world, he has continued as a leading advocate for the use of native plants in home gardens, while expanding the garden's dedicated community of volunteers and supporters. And he has worked to deepen the garden's partnership with California Plant Rescue, an ambitious effort to create a seed bank of all of California's native plants as a hedge against extinction.

–David Loeb



One of California's most influential botanists, Dieter Wilken managed the first edition of *The Jepson Manual*. *[Photograph courtesy of Santa Barbara Botanic Garden]*

CNPS FELLOW

Dieter Wilken

Dr. Dieter Wilken has been a pillar of California botany since he was a graduate student in the late 1960s, and has made tremendous contributions toward the appreciation and conservation of California Flora throughout his long career. His pioneering work in systematizing the identification and classification of rare native plants has set the gold standard in that field. As the lead manager of the first edition of *The Jepson Manual* (1993) and the lead editor of the second edition (2012), Dieter has provided resources of incalculable value to those working with native plants. He continues to serve the broad community of native plant adherents in his position as Director of Conservation at the Santa Barbara Botanic Garden (SBBG), an institution he has worked for since his return to California in 1993.

Like the plants that he knows so well, Dieter Wilken is himself a California native, born in East Los Angeles in 1944. Since graduating from UC Santa Barbara with his PhD in 1971, Dieter has worked tirelessly to support the understanding and conservation of native plants in western North America, including California. He is a broadly trained systematist and a world expert on several plant groups, including the charismatic California lilacs (*Ceanothus*, Rhamnaceae), showy *Ipomopsis* (Polemoniaceae), and the genus *Hulsea* (Asteraceae). Dieter was also a trailblazer in specimen digitization, and thanks to his guidance, the herbarium at SBBG is now nearly completely digitized.

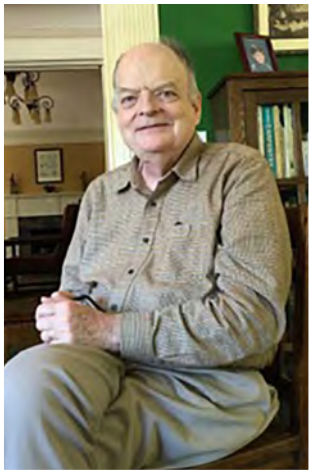
Toward the end of his two decades teaching at Colorado State University, Dieter was hired to serve as Project Manager for the ambitious *Jepson Manual* project. At the time, the project was behind schedule, over budget, and at risk of total collapse. Dieter was able to right the ship, and the first edition of the *Manual* immediately became an invaluable resource for learning about and identifying California native plants. It would later form the basis for *The Jepson Desert Manual* (2002} and the second edition of *The Jepson Manual* (2012), on both of which Dieter served as a primary editor. Dieter also published two other important books: *Ceanothus* (2006}, and the complete flora of the plants of Santa Cruz Island (1995). He completed these important books while leading applied rare plant conservation on the Central Coast through SBBG and the California Native Plant Society.

Following publication of the *Manual*, Dieter returned to California to become Director of Research at SBBG. There, Dieter founded and ran all aspects of the Garden's rare plant program from 1993 to 2013. For the Central Coast and Channel Islands, there is no one more knowledgeable or passionate about regionally important rare plants; his work with many regional stakeholders has translated into direct conservation action on behalf of native plants and habitats in the region. In 2008, Dieter received the Center for Plant Conservation's Star Award for his work in protecting rare plants.

Dieter has also provided his expertise and knowledge as a contributor to the CNPS Rare Plant Forum, the primary vehicle for soliciting information from experts for decision making pertaining to the CNPS Rare Plant Inventory (e.g., listing and delisting of taxa). From 2008 until 2017, Dieter served as a founding member of the CNPS Rare Plant Program Committee. Through this committee, Dieter evaluated hundreds of plants for CNPS listing and worked with Jim Andre and other members to standardize and formally describe the process for listing a plant through CNPS. Andre describes Dieter as "our most experienced advisor on California's rare plants."

Finally, Dieter is a prolific contributor to CNPS's very active Facebook page, where he provides patient, thorough answers to posted queries from amateurs and professionals alike. In what other venue could one receive direct feedback from the Project Manager of the first edition of *The Jepson Manual* and one of the godfathers of specimen digitization?

–David Loeb



As a landscaper, Joe Willingham was an early advocate for native plant landscaping back in the 1970s. He's since served his chapter in myriad ways, from conservation and rare plant advocacy to website development. *[Photograph courtesy of CNPS East Bay Chapter]*

CNPS FELLOW

Joe Willingham

Most people know Joe Willingham as the indefatigable editor of the *Bay Leaf* newsletter and the computer-savvy manager of the East Bay Chapter's website. Joe's decades of service to CNPS began in 1977, after he took a landscaping course at UC Extension on California native plants taught by the legendary David Bigham. Already employed as a landscaper, Joe quickly started using California natives on his clients' properties, and has continued to use them throughout his career.

Joe joined the East Bay Chapter board of directors in 1989. He has since held more than a dozen chapter board positions, including rare plant chair, chair of local conservation issues, and several years as chapter president and vice president.

As the rare plant chair, Joe participated in scouting expeditions, wrote monthly articles and led field trips. As local conservation issues chair, he kept abreast of the issues and wrote articles to keep the membership informed. He also served many years as one of the "plant experts" available to shoppers at the yearly plant sales at Merritt College and the chapter's Native Here Nursery.

In 2003, Joe became the editor of the East Bay Chapter newsletter, the *Bay Leaf*, learning the printing business from Phoebe Watts and Brett Boltz. Joe and his wife, Doris, hosted monthly mailing parties too numerous to count, and were always generous with wine and snacks.

In 2005, he created the chapter's website and later a website for the chapter's Native Here Nursery. Joe continues to work as *Bay Leaf* editor, coordinating capable proofreading by David Margolies, Holly Forbes, and Doris Willingham.

Joe served on the chapter council from 2004–2005, following state legislation. In that capacity, he played a key role in hiring now-retired CNPS lobbyist Vern Goering, serving as Vern's liaison to the CNPS board of directors. "Joe has indeed made so many outstanding contributions to our chapter and CNPS and continues to do so," say his nominators. Those of us fortunate enough to know him will agree that Joe Willingham deserves the Society's highest honor.

–Adapted by CNPS staff from text by Delia Taylor



See a listing of all CNPS Fellows dating back to 1973 at cnps.org/fellows.

Photograph by Ger Ericson



Vern Yadon on the trail named after him in gratitude for his decades of service on behalf of Monterey County flora.
[Photograph by Lynn Bomberger]

CNPS FELLOW
Vern Yadon

The Monterey area, and particularly Pacific Grove, owes many of its nature traditions and resources to Vern Yadon, the "grand old man of the plant community," as his nominators for Fellow dubbed him. Yadon was the first director and curator of the Pacific Grove Museum of Natural History and was instrumental in starting the Pacific Grove Wildflower Show, now in its 59th year. He also was a founding member of the Monterey Bay Chapter of CNPS in 1966.

"I can't overestimate his value to our chapter," says Brian LeNeve, chapter president and, like Vern, a CNPS Fellow. "He's the go-to person for questions about local botany, and is well thought of in the statewide botany community."

Vern Yadon might be considered a well-adapted transplant. He grew up in the San Joaquin Valley, and went on to study biology at Oregon State University. Hired in 1957 at the Pacific Grove Museum, which has a history dating to the 1880s, he dove into establishing the museum's plant collection. He assisted Beatrice Howitt and John Thomas Howell in gathering information for the original edition of *Vascular Plants of Monterey County, California* (1964).

In 1961, Yadon and Howitt founded the Pacific Grove Wildflower Show with about 100 species that he and a few others had collected. The show grew into an important tradition under the CNPS banner, and now includes 600-700 species on display over a three-day weekend.

No corner of Monterey County has gone unexplored by Vern, who early in his career made it his business to learn all the plants in Howitt and Howell's book. This plant bible became a detective story for the intrepid plant lover, who took weekly car trips on his day off to obscure sites such as Fort Hunter Liggett, Salmon Creek, Burro Creek and Clear Creek, and Fort Ord. Fellow plant fans Corky Matthews, Ron Branson, and Carol LeNeve (also a CNPS Fellow) often joined him; Branson estimates they put 20,000 miles on his VW bus.

Vern is at his most cheerful out in the field, friends say. He's been known to smell a *Malacothamnus* 100 yards away. In the process of tracking down the known plants, he found new treasures: Several species are named for him, including Vern's rein-orchid (*Piperia yadonii*), Santa Lucia horkelia (*Horkelia yadonii*) and Menzies' wallflower (*Erysimum menziesii* ssp. *yadonii*). He always had his plant press with him, and his collections now grace the Pacific Grove Museum's herbarium, which he refined and expanded. He retired from the museum in 1992 but still serves as curator emeritus.

Vern has shared his knowledge of the area's botany with fellow Monterey Bay Chapter CNPS members, leading countless field trips. He trained and mentored several generations of local botanists, including Bruce Delgado of the Bureau of Land Management. "I learned so much so fast with Vern," says Delgado, who is based at Fort Ord National Monument. In addition to serving as the CNPS chapter president, over the years Vern has been a Pacific Grove City Council member and a leader in the Sierra Club. He also was on the Del Monte Forest Open Space Advisory Committee. And he's still always available to identify a mystery plant, no matter who's asking.

Now 85, Vern Yadon is seen around town on regular walks with Farley, his Dalmatian. He's also an artist, and his watercolors of local plants and animals have graced the walls of the Carmel Art Association for more than 40 years. His other areas of expertise include ornithology, carpentry, horticulture, and local Native American culture. Monterey County is richer for the myriad contributions of this renaissance man.

–Kathy Morrison



Native plant nursery expert Betty Young is a leader in phytophthora best management practices and Sonoma County Re-Oak efforts. *[Photograph courtesy of Betty Young]*

CNPS FELLOW
Betty Young

Betty Young's extensive knowledge of and experience in nursery management and native plant propagation have helped protect and beautify California landscapes throughout her career, most recently through two important CNPS initiatives: the Re-Oak California effort and the establishment of best management practices to prevent Phytophthora in CNPS chapter-sold plants.

After studying nursery management and plant science at UC Davis, Young went to work in 1985 at Filoli Garden, an historic estate in Woodside. The site is registered with the National Trust for Historic Preservation, and its extensive gardens change with the season. Young left Filoli in 1989 for a stint with the Peace Corps in Thailand, focusing on soil conservation. Returning to the U.S. in 1990, she moved to Sonoma County to work at Skylark, a wholesale nursery. Next she joined Circuit Riders, a revegetation nursery, where she gathered seeds of local natives and grew plants for use in Sonoma County revegetation projects.

In 1997, Young joined the staff of the Golden Gate National Recreation Area (GGNRA) as the director of native plant nurseries, managing six greenhouses and producing 175,000 plants annually for GGNRA revegetation efforts. While at the GGNRA, she was responsible for the recording and sharing of propagation information into a publicly available online database. She also presented on, and taught classes in, nursery management throughout California. Young worked at GGNRA until she retired in 2015, after which she moved back to Santa Rosa.

Young had joined the CNPS Milo Baker Chapter when she first lived in Sonoma County, serving as president from 1993-1997. The chapter at that time began managing Cunningham Marsh, a state Department of Fish and Game easement on private property. Young worked with the owners of the property that surrounded the marsh, winning a grant that paid for a local expert to draw up a plan for the active management of the rare plant on the property: the endangered Pitkin Marsh lily (*Lilium pardalinum* ssp. *pitkenense*). Continued maintenance of Cunningham Marsh remains an important chapter activity.

In her retirement, Young supported the CNPS Milo Baker Chapter as field trip chair, then chaired a group interested in organizing a garden tour. The chapter partnered with the Sonoma County Water Agency in its Eco-Friendly Garden Tour, held each spring.

A key initiative for Young, at both the state and local CNPS level, is putting in place best management practices (BMP) for plants grown for or sold at CNPS plant sales, to prevent the introduction and spread of *Phytophthora* root rot. This is a serious issue for nursery-grown plants, and Young has traveled around the state to assess nursery practices and help local chapters. Closer to home, she has been instrumental in getting the Milo Baker Chapter's nursery shade house built, in order for plants for its annual sale to be grown in a *Phytophthora*-free environment. In addition to working out all the details for the project, she was the main fundraiser, bringing in more than $25,000 from grants and donations. The shade house, at the Laguna Foundation site in Santa Rosa, was completed in time for the 2019 sale.

Recently, Young has been the leader in the Re-Oak Sonoma effort, a CNPS-led initiative following the huge wine country fires in the fall of 2017. She organized volunteers to gather tens of thousands of acorns from all over the region, and taught members how to evaluate, clean, store, and germinate the oak seedlings. Her work inspired a similar, statewide CNPS effort for all of California's oak woodlands. In Sonoma County the young oak trees are now being used to revegetate burned areas on public and private lands. It's safe to say that Californians, and Sonoma County residents in particular, owe much to Betty Young's continuing efforts for native plants.

–Kathy Morrison

IN MEMORIAM

CELIA KUTCHER

A GUIDING LIGHT IN ORANGE COUNTY

By Dan Songster





Celia enjoying California's botanical wonders as a child and from the trail. *[Photographs courtesy of the Kutcher family]*

With great sadness we report the passing of Celia Kutcher, a vital and much loved member of the Orange County Chapter of CNPS since its founding. She was a mother, grandmother, and friend to many. She cherished her family and good company. Celia was a botanist, naturalist, and horticulturalist all rolled into one. She enjoyed the fragrance of coastal sage, the sound of its birds, the smell of winter rains, the shade of an oak woodland, and the discovery of a rare plant. She loved all of California's wildlands but Orange County was her home and we were lucky to have her. We will miss her in so many ways.

An environmental pioneer, Celia's passion for native plants and her growing awareness of conservation challenges emerged in the late 1960s and early 1970s. Even as she raised her two young sons, she resolved to return to school and pursue an education and career that would enable her to effectively work for the preservation of natural habitats. We can imagine her, having lived most of her life in Orange County, seeing the encroaching homes and roads fragmenting the lands she loved and resolving to do something about it.

It was only natural that Celia and CNPS would get together, but at the time there was no chapter here in Orange County. Celia was there in the late 1970s and early 1980s as the Chapter waxed and waned until 1982, when Celia and several other native plant lovers held a formal organizational meeting to assign roles and choose officers and in general ensure that meetings became more regular. Celia was in the heart of things then as she was throughout her life. And what a productive and fulfilling life.

She set a sterling example, serving enthusiastically and efficiently in nearly every chapter office and committee while attending almost every board and membership meeting for over 35 years. There were no "little" jobs for Celia, and her involvement extended from outreach events to chapter planning sessions and native habitat advocacy and so much more. Her practical advice on a broad range of chapter issues came with a seasoned historical perspective. Her steady commitment to the needs of the chapter, accompanied by a wry sense of humor, was inspirational to all of us who worked with her.

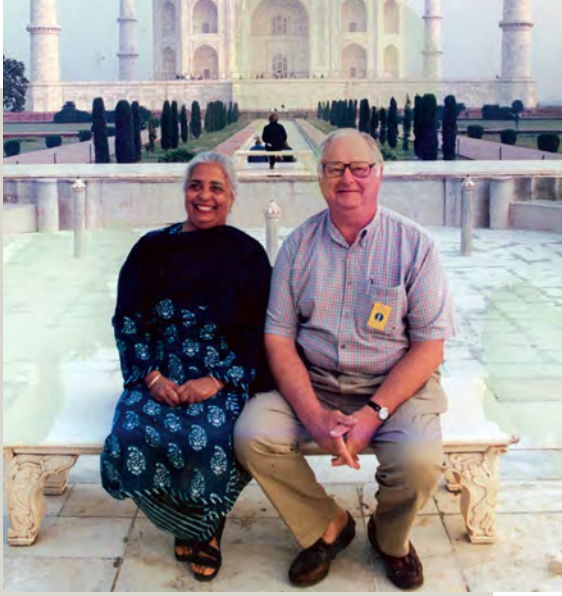
Above all else, Celia was the guiding light of our Conservation program, directing efforts to protect our county's wildlands. No matter the complexity of the situations or the applicable laws, Celia was always well prepared with a thorough understanding of the issues. Her comments, whether verbal or written, on behalf of CNPS were always succinct and clear, and in a tone that was always courteous and professional, never strident or accusatory. Celia is rightly known and applauded for her dedication over many decades to saving native habitat, rare plants, intact plant communities, and to upholding the laws that protect them. Her loss will be keenly felt for years to come in southern California conservation circles.

Her family requests that donations in Celia's honor be made to the California Native Plant Society, Orange County Chapter, with a note in the MEMO field indicating the gift is honor of Celia Kutcher. Please mail to: P.O. Box 54891, Irvine, CA 92619-4891.

IN MEMORIAM

WATSON MCMILLIAN "MAC" LAETSCH

By John Taylor



Mac and Sita Priyadarshini (Capildeo) Laetsch, his wife of 61 years. *[Photograph courtesy of the Laetsch family]*

Watson McMillan "Mac" Laetsch, a distinguished professor emeritus of plant biology and former vice chancellor of undergraduate affairs and development at the University of California at Berkeley, passed away at his home on January 5, 2020. He was 86.

Mac helped to found the California Native Plant Society and served as its first president. CNPS grew out of an ad hoc effort to save the Regional Parks Botanic Garden in Tilden Park in 1965. When the garden was saved, Mac asked, "Well, why don't we form a society to protect native plants?" Mary Wohlers, Helen-Mar Beard, and Leonora Strohmaier were also key players in starting CNPS, along with Jim Roof, then director of the Garden, and Jepson Herbarium staff members Remo Bacigalupi and Larry Heckard. The first meetings were in Mac's and Helen-Mar's homes, and the group persuaded Mac to become the first president.

Mac was born in Bellingham, Washington in 1933. His father was a Protestant minister and his mother an avid reader. Ministers and their families travel, so Mac spent his high school years in Indiana. He was an outstanding athlete and scholar in high school, earning multiple college offers, and ultimately chose to attend Wabash College, where he majored in botany, zoology, and history. At graduation, in 1956, he won a Fulbright scholarship to study in India, where he met his future wife, Sita Priyadarshini Capildeo. Sita was the daughter in a prominent Indian family in Trinidad and Tobago, and her parents had sent her to India to find a suitable Brahman husband. After a first kiss at the Taj Mahal, Mac and Sita eloped to Canada to get married.

Mac earned his PhD at Stanford in 1961, won a National Science Foundation Senior Fellowship to do postdoctoral studies at University College London, and taught briefly at SUNY Stony Brook before joining the botany department at UC Berkeley in 1963. Mac and Sita settled in Berkeley and raised a family there, while Mac became a lifelong member of the East Bay Chapter of CNPS.

As a scientist, Mac made seminal contributions to the understanding of C4 photosynthesis. His studies of leaf anatomy and chloroplast ultrastructure rounded out the biochemical studies of two Australian plant physiologists. In 1968 he wrote, "A hypothesis is presented stating that the unique morphological and biochemical characters of these plants represent adaptations for efficient and rapid carbon fixation in environments where water stress frequently limits photosynthesis." Mac's hypothesis was spot-on, and C4 grasses such as sorghum have since become the subjects of intense study owing to their ability to withstand drought.

Mac excelled as a leader, a rare quality at any university. He led the UC Botanical Garden and the Lawrence Hall of Science, and was vice chancellor for undergraduates and then vice chancellor for development. His colleague in botany, mycologist Ralph Emerson, wrote to a committee considering Mac's promotion that "Mac Laetsch walks with ease in the halls of wealth and power." Mac worked with Chancellor Ira Michael Heyman to lead the record-setting "Keeping the Promise" campaign, and later, as an emeritus professor, he worked with Heyman again to raise more than $30 million to rebuild the Bancroft Library.

Mac is survived by his elder brother, Bruce Laetsch of Indianapolis, sons Krishen and John Laetsch, daughter-in-law Jenny Hanson, and his grandson Charlie Hanson. Mac's wife, Sita, preceded him in death in 2019, after 61 years of marriage.

Donations in the professor's name may be made to the Friends of the Bancroft Library or the UC Berkeley Botanical Garden.

Thanks to the CNPS East Bay Chapter for permission to reprint this article, which appeared in March 2020 issue of The Bay Leaf *newsletter.*

The scientific publication quoted above is: Laetsch, W. M. (1968). Chloroplast specialization in dicotyledons possessing the C4-dicarboxylic acid pathway of photosynthetic CO2 fixation. *American Journal of Botany,* 55(8), 875-883.

IN MEMORIAM

STEVE MCLAUGHLIN

By Stephen Ingram

Steve McLaughlin, former president of the Bristlecone Chapter of CNPS, died on December 29, 2019 at the age of 71 at his home in Santa Fe, New Mexico. Steve and his wife, author and botanist Janice Bowers, moved from Tucson to Birch Creek, southwest of Big Pine in the Eastern Sierra, in 2007 to enjoy their retirement.

Steve's knowledge of botany was broad and deep. He earned his PhD at the University of Arizona in 1978, where he taught courses in plant systematics, economic botany, and arid crops ecology. A professor of Arid Lands Resource Sciences and herbarium curator at UA, Steve studied the ecophysiology of arid lands crops, such as *Hesperaloe funifera* (giant hesperaloe) and *Grindelia camporum* (Great Valley gumweed). He also worked on the discovery and development of anti-cancer agents in plants, and on the analyses of floristic areas in the western U.S. He also named one new species, *Phacelia sonoitensis*, from southern Arizona.

In 2004 Steve received the Anson Ellis Thompson Career Service Award from the Association for the Advancement of Industrial Crops, and in 2006 was recognized by the Arizona Botanists Symposium with a Lifetime Achievement Award. Steve was sole author or co-author on more than a hundred scientific publications and presentations.

When Steve and Jan moved to the Eastern Sierra in 2007, it was inevitable that they would become involved with the Bristlecone Chapter of CNPS. Steve and Jan had joined our chapter back in 1999, but after moving here Steve wasted no time and became president within a year.

Steve was thoughtful, gentle, and generous. Michele Slaton, current vice president of the Bristlecone Chapter and an ecologist with the Inyo National Forest was asked by Steve to join the board in 2008. She says, "He made it clear this work was not about chores and busywork … but that there is important progress to be made to protect our land and native plants. He was a real mentor, and helped me with botanical writing, with forest planning, and urged me to pursue tasks and skills that felt like a good match... I will truly miss him."

Steve strengthened ties between CNPS and other conservation organizations throughout the Eastern Sierra. He served on the Owens Lake Master Project Committee, where he was in many ways, the conscience of the working groups, according to Pete Pumphrey, Steve's friend and colleague with Eastern Sierra Audubon. Steve also contributed to the GLORIA (Global Observation Research Initiative in Alpine Environments) plant surveys in the White Mountains. Jim Bishop from the Mount Lassen Chapter recalls how Steve freely shared his expertise in the surveys: "He was always very helpful and an all-around nice guy."



Steve McLaughlin on a field trip to McGee Creek for Friends of the Inyo, June 2013. *[Photograph by Maggie Wolfe Riley]*

Steve was a popular field trip leader, organizing trips for the Bristlecone Chapter, Friends of the Inyo, and the Mono Basin Bird Chautauqua. He always refused the honorarium offered to trip leaders, and had "the patience of a saint" when teaching others about plants, according to his friend and neighbor Sydney Quinn. Steve will be missed by everyone in the Eastern Sierra who cares about conservation, as well as those who value learning about plants and birds from a consummate teacher.

An excerpt from Steve's first President's Message from the January/February 2008 Bristlecone newsletter:

> *During my academic career I was fortunate to be able to travel and work many places on this earth, but I have never been anywhere as breathtaking and fascinating as the Eastern Sierra. There are many ways to enjoy and learn more about this great area in which we are privileged to live, and one important way is to take advantage of opportunities provided by the Bristlecone Chapter. I urge you all to come to our Wednesday evening programs and participate in our field trips. Enjoy exceptional places, beautiful plants, and interesting people.*

IN MEMORIAM

LESTER BRADFORD ROWNTREE

By David Loeb



Lester Rowntree in Charleston Slough in the South Bay, in June 2004. *[Photograph by Allison Kidder]*

On August 30, 2019 the California Native Plant Society lost a good friend and California lost a dedicated teacher of environmental science. Dr. Lester B. Rowntree passed away at his home in the Berkeley hills after a protracted battle with cancer. Dr. Rowntree (or Les, as he preferred to be called) was a long-time professor for the pioneering Department of Environmental Studies at San Jose State University, which he joined in the early 1970s. He would eventually serve the department as program director and chair prior to his retirement in 2005.

Dr. Les was an integrative and open-minded scientist who sought to understand, and then educate others about, the elemental forces that shape the physical world. Nothing gave him greater pleasure than inspiring curious young students to become scientists dedicated to understanding the world and making it a better place.

In "retirement" Les dedicated himself to updating the widely-adopted environmental studies and geography course textbook, *Diversity Amid Globalization: World Regions, Environment, Development* (Pearson), of which he was the lead and coordinating author. Initially published in 2000, the textbook is now in its sixth edition.

If you were to visit Les' website, the first words you'd encounter would be "Actually there are two of us." Of course, he was referring to his more well-known grandmother, Lester Rowntree, née Gertrude Ellen Lester, the famous "California Native Plant Woman" who traveled around the state in a jerry-rigged station wagon to study the state's native flora. She was the author of *Hardy Californians* (1935) and *The Flowering Shrubs of California* (1936), and lifetime honorary president of the California Native Plant Society at its founding in 1965. Grandson Les enjoyed being able to say that he was the "other Lester Rowntree." But Les was a formidable contributor to our knowledge of California (and world) ecosystems in his own right.

Lester Bradford Rowntree was born and raised in Carmel. His interest in the natural world of California derived in part from the time he spent with his grandmother at her hillside home in Carmel Highlands. He always considered the rugged coastline of Big Sur to be his spiritual home, even after his immediate family moved to Berkeley in the late 1940s.

I got to know Les through my work for *Bay Nature* magazine, accompanying him on a field trip to the Big Sur coast in April 2009 as he was researching an article on the 2008 wildfires there. It was the height of wildflower season, but to my surprise (and mild annoyance) he wasn't able to help me identify the less common wildflowers we were seeing, and didn't seem particularly interested in doing so. Instead, Les was a big picture, macro level scientist, attuned to how vegetation patterns had shifted in response to the fires. He was able to contrast what we were seeing with his prodigious memory of the area, developing a clearer picture of how fire had shaped—and continues to shape—this region.

Another of Les's post retirement projects was the re publication of his grandmother's classic work, *Hardy Californians*, which includes additional chapters about his grandmother's life and impact. The publication of this new edition in 2006 (University of California Press) gave Les the opportunity to travel up and down the state with a slide show reintroducing Lester—in all her idiosyncratic, convention-defying glory—to a new generation of native plant lovers.

In his talk, Les related a story from a day late in Lester's life when she was in both physical and mental decline (she lived to be 100). He searched for her in the house to no avail, and finally found her lying under some bushes in the chaparral outside. "Leave me alone," she said, "Can't you see I'm trying to die."

Les the grandson was considerably less prickly than his famous grandmother. But he was similarly clear-eyed about his approaching death. He chose to die at home, surrounded by his family, right next to an open door that looked out onto a backyard garden filled with some of his favorite California native plants.

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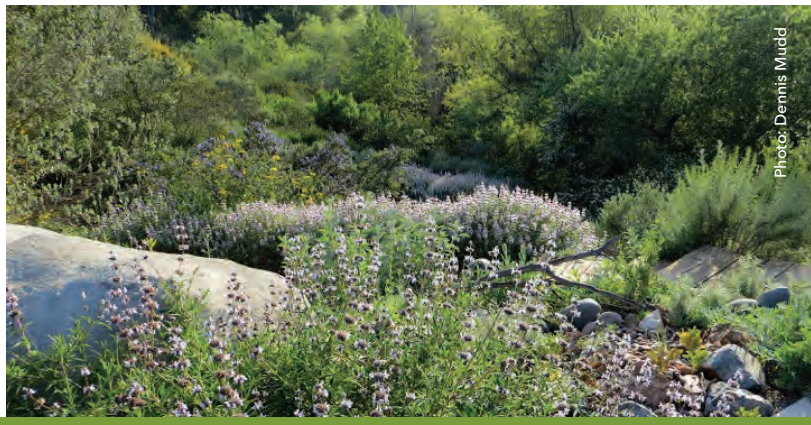


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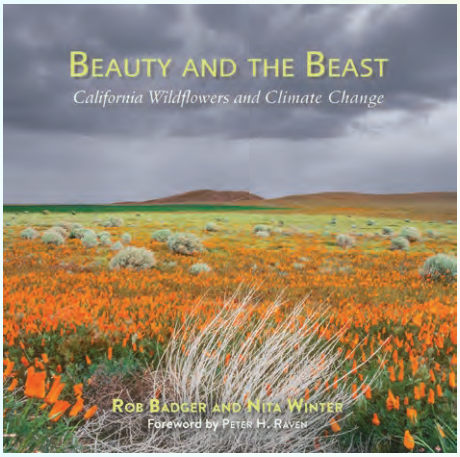
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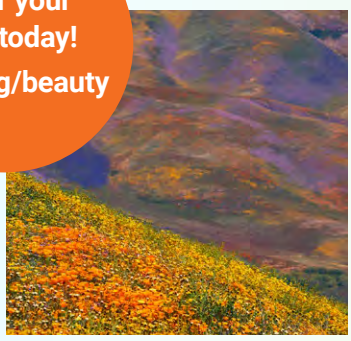


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Rob Badger and Nita Winter
Hardcover $60
ISBN: 978-1-7331044-0-1

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In 1992, Rob Badger and Nita Winter discovered and fell in love with California's spectacular Wildflower blooms in the Mojave Desert's Antelope Valley California Poppy Preserve. This inspired a 27-year journey photographing wildflowers throughout the West, and, in 2011, their documentary art project, *Beauty and the Beast: Wildflowers and Climate Change,* a project sponsored by Blue Earth Alliance. In 2016, they created their first joint exhibit on California's wildflowers. The beautiful book, published in conjunction with the California Native Plant Society, is a companion to the traveling exhibit.

California Native Plant Society
Winter Badger Press

EXHIBIT J

Union of Concerned Scientists

REPORTS & MULTIMEDIA / FEATURE

Infographic: Wildfires and Climate Change

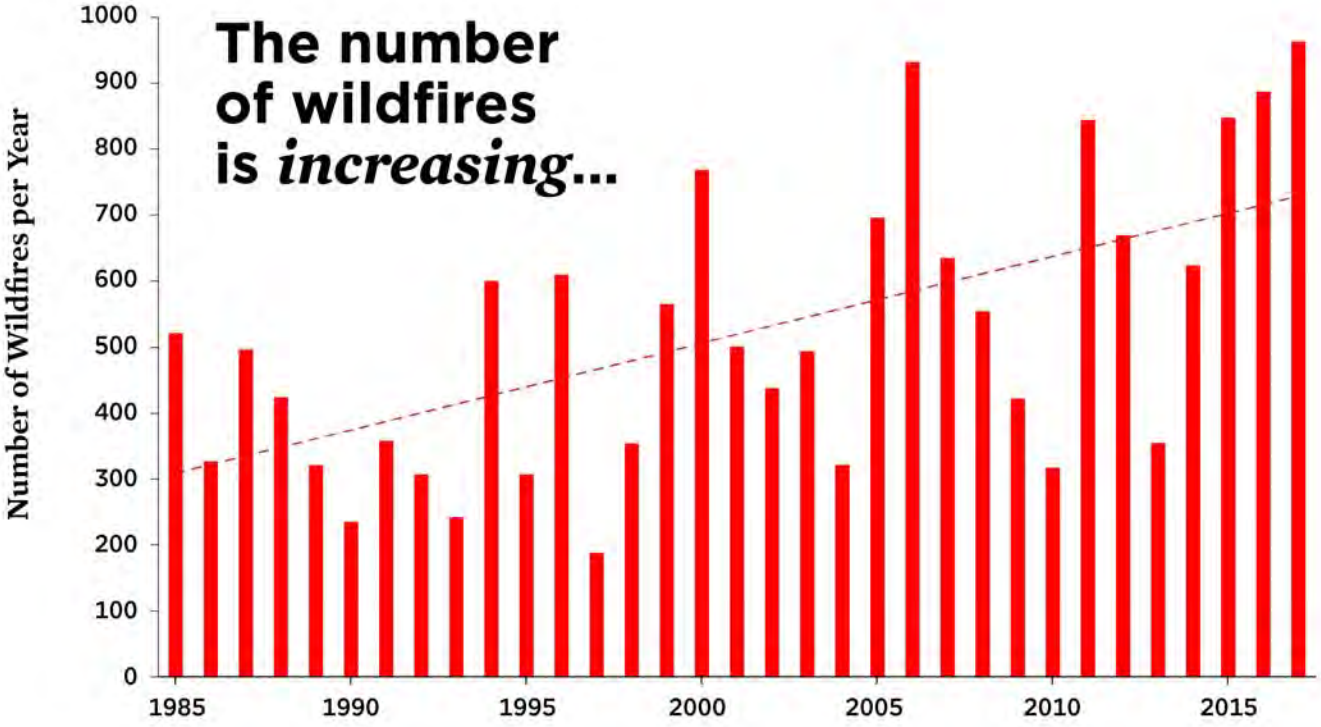
Visualizing the Connection in Five Sets of Photos and Charts

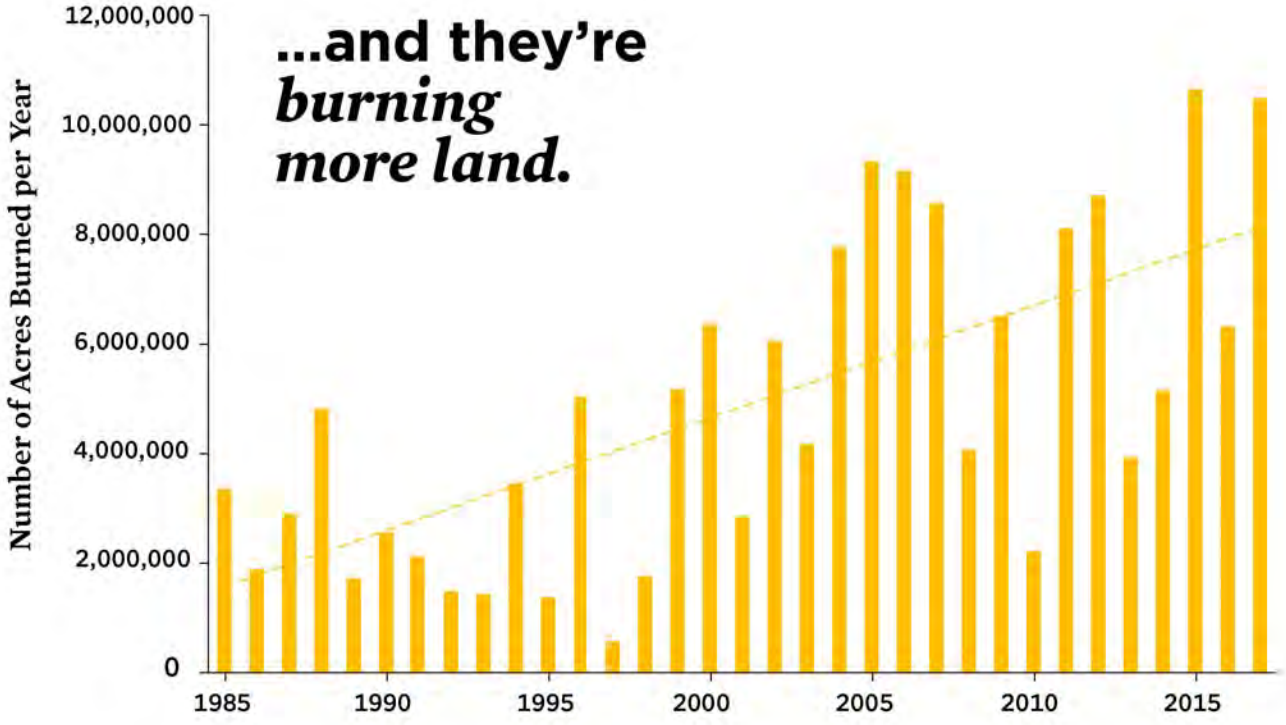
Published Sep 8, 2020 | Updated May 9, 2022

TABLE OF CONTENTS

Every year, millions of acres of land are consumed by fire in the United States. By raising temperatures, melting snow sooner, and drying soils and forests, climate change is fueling the problem. Here's what we know.

#1: Wildfires are getting worse

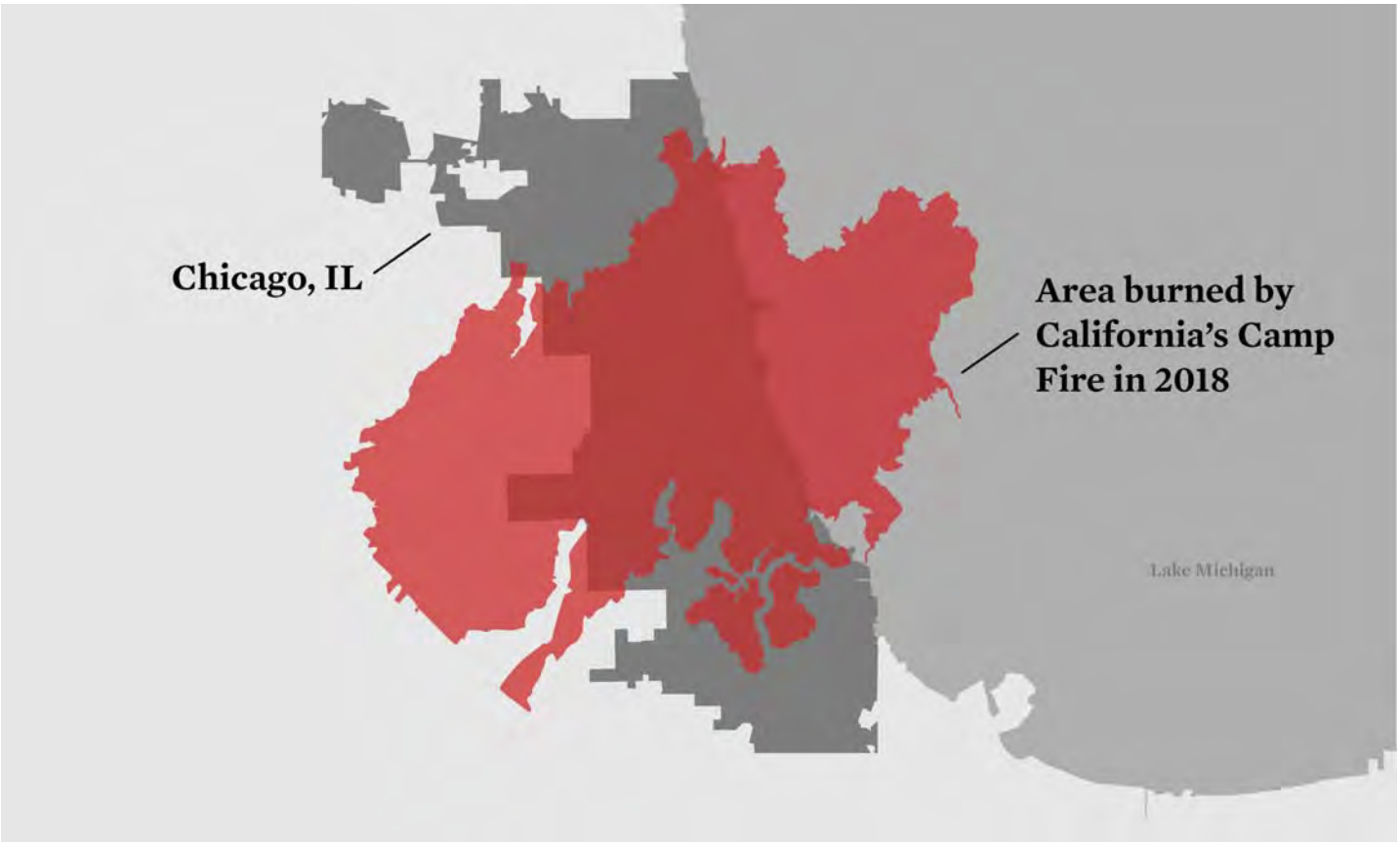

The number of wildfires is *increasing*...
Number of Wildfires per Year
1000
900
800
700
600
500
400
300
200
100
0
1985
1990
1995
2000
2005
2010
2015

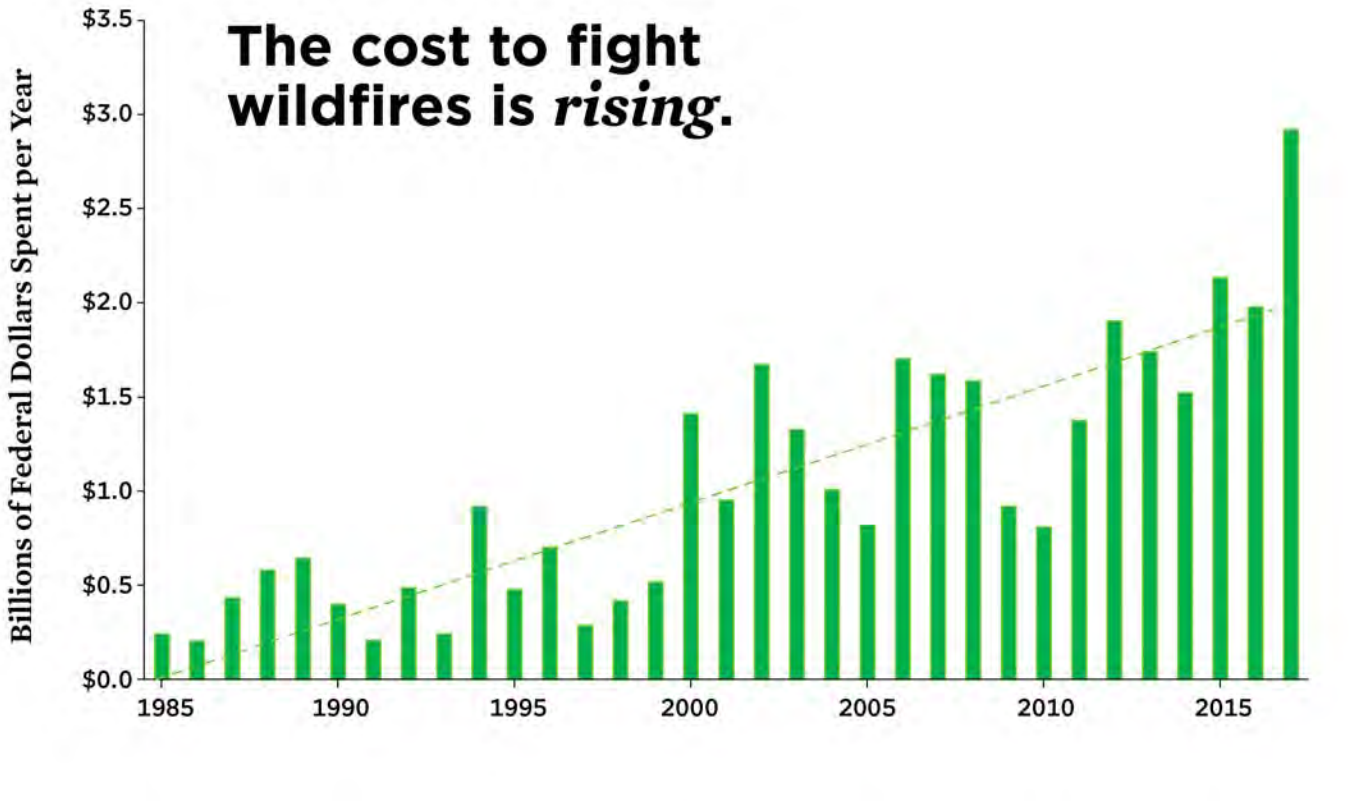

...and they're *burning more land.*
Number of Acres Burned per Year
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1985
1990
1995
2000
2005
2010
2015

Data from the Monitoring Trends in Burn Severity program. MTBS only includes large fires in the United States (>500 acres for the eastern US, >1000 acres for the west). Prescribed fires removed.

Since 2015, the United States has experienced, on average, roughly 100 more large wildfires every year than the year before. This changes region by region, and year to year, but generally we're seeing more wildfires, more acres burned, and longer, more intense fire seasons.

#2 Wildfires are causing more harm





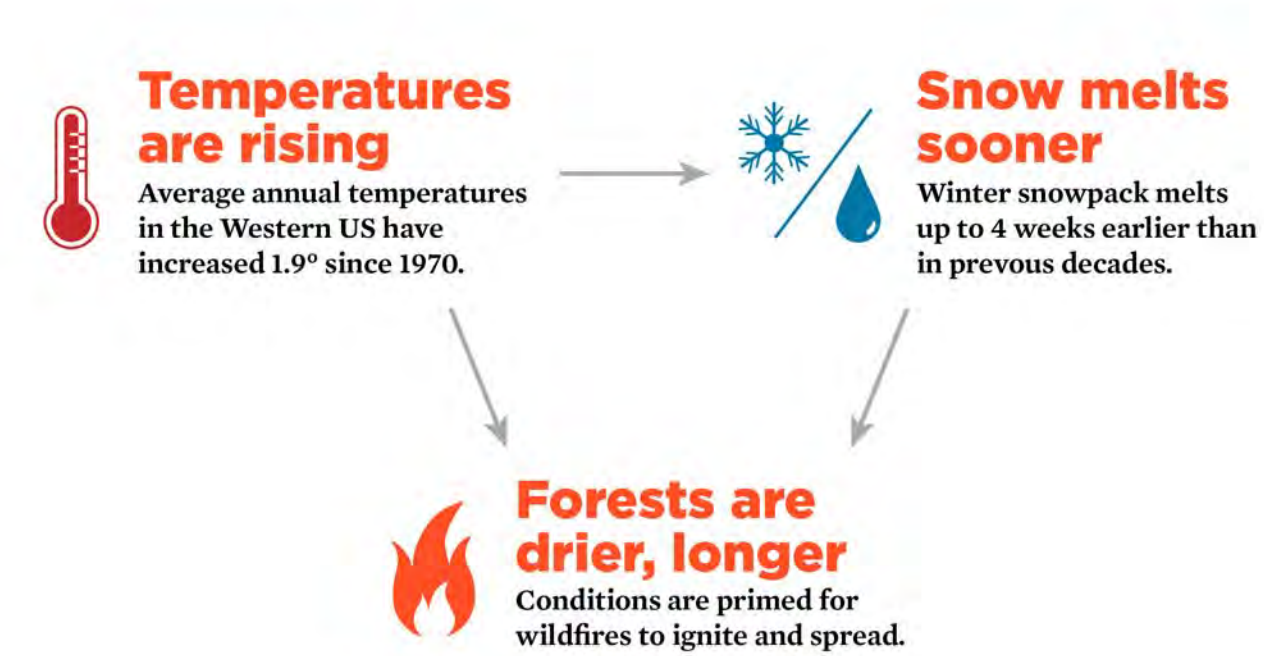
On left, the perimeter of the massive Camp Fire is overlayed on Chicago. Federal suppression costs from the National Interagency Fire Center.

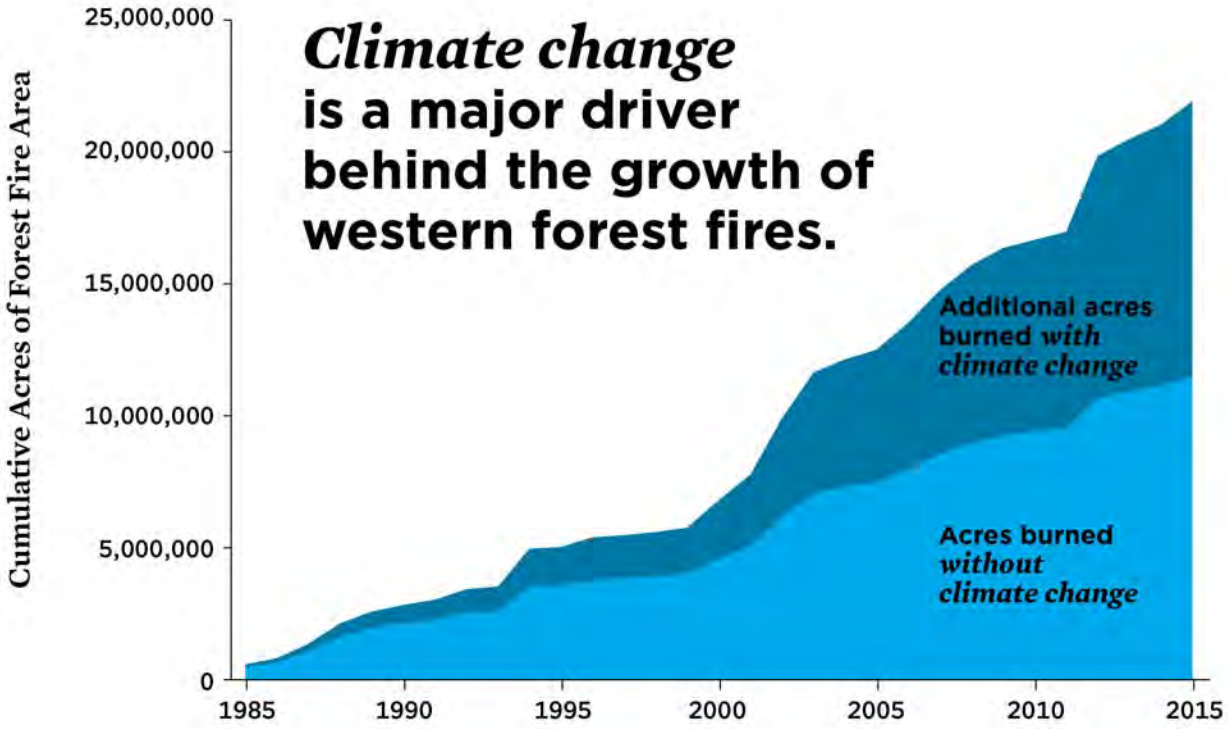
Wildfires are dangerous and destructive. The historically large Camp Fire of 2018 caused at least ninety deaths, destroyed more than 18,000 structures, and covered an area roughly the same size as the Chicago metropolitan area.

They're also expensive. Between 2014 and 2018, the federal government spent an average of *2.4 billion dollars* fighting wildfires every year. Even when adjusted for inflation, that's more than twice what we spent 20 years earlier (1994-1998).

And as the forests burn, they release carbon dioxide and other global warming gases, worsening climate change. As wildfires burn more land, emissions go up.

#3: Climate change is a key driver





Data shown are from John T. Abatzoglou and A. Park Williams, Impact of anthropogenic climate change on wildfire across western US forests, which models forest fire area as a function of fuel dryness both with and without climate change.

Fire has historically been a natural part of many wild landscapes. But global warming has changed some of the underlying variables that make wildfires more or less likely to occur every year.

Warmer temperatures increase the likelihood that fires will burn more intensely. They also cause snow to melt sooner, and lead to drier soils, forests, and plants, which act as kindling. Increased droughts, unusual rain patterns, and insect outbreaks that lead to large stands of dead trees are also connected with climate change—and they all make wildfires more likely.

#4 Management matters

Other factors also influence wildfire risk—especially management and development decisions in fire-prone areas near forests.

In the western United States, forests historically evolved with frequent, low-intensity fires that removed underbrush, debris, and fallen timber. This allowed for larger trees and made massive fires much less common.

But for the past century, almost all fires have been suppressed, even small ones. This has allowed forests to maintain denser growth and more potential fuel, leading to larger and more intense wildfires.

In addition, development near and into previously wild areas has increased fire risk and made fire-fighting more costly, challenging, and dangerous.

Government agencies have tried to lower forest density through prescribed burning (purposefully lit, low-intensity fires) and thinning (the physical removal of brush, vegetation and dead trees), but have struggled to do so at scale.

On smaller landscapes in the southeast, land managers conduct far more frequent prescribed burns. These fires bring their own risks, including poor air quality, and the chance of growing to be a damaging wildfire. But by mimicking smaller ″natural″ fires, prescribed burns can benefit forest ecology, and help mitigate at least some of the increased wildfire risk presented by climate change.

#5 Action is possible

In the near term, ecologically-sound forest and fire management could help limit fire risks.

But in the long-term, *climate action* is the best tool we have. When we reduce global warming emissions, we slow the growth of climate risks, including wildfire. Until then, summers will continue getting hotter, forests will get drier, and more and more people will face the threat of wildfire.

INFOGRAPHIC



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EXPLAINER



Water, Wildfire, and Climate Change

Fires across the West, and particularly in California, are threatening the availability and quality of water for millions of people.

PODCAST



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GRAPHIC



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Photo credits: Burning car and home, and burnt neighborhood by Josh Edelson/Getty. Smoke plume by David McNew/Getty. Firefighter carrying drip torch courtesy of the National Park Service. Protesters by Leonhard Foeger/Reuters.

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EXHIBIT K

12. M. Gustafsson, L. Frommhold, *Astron. Astrophys.* **400**, 1161 (2003).
13. H. C. Harris *et al.*, *Astrophys. J.* **524**, 1000 (1999).
14. S. T. Hodgkin *et al.*, *Nature* **403**, 57 (2000).
15. B. R. Oppenheimer *et al.*, *Astrophys. J.* **550**, 448 (2001).
16. L. R. Bedin *et al.*, *Astrophys. J.* **624**, L45 (2005).
17. B. M. S. Hansen, *Phys. Rep.* **399**, 1 (2004).
18. I. N. Reid, J. E. Gizis, *Astron. J.* **116**, 2929 (1998).
19. R. G. Gratton *et al.*, *Astron. Astrophys.* **408**, 529 (2003).
20. S. K. Leggett, F. Allard, P. H. Hauschildt, *Astrophys. J.* **509**, 836 (1998).
21. S. Lepine, M. M. Shara, R. M. Rich, *Astrophys. J.* **602**, L125 (2004).
22. I. R. King, J. Anderson, A. M. Cool, G. Piotto, *Astrophys. J.* **492**, L37 (1998).
23. I. Baraffe, G. Chabrier, F. Allard, P. H. Hauschildt, *Astron. Astrophys.* **327**, 1054 (1997).
24. The models in (*23*) have been updated (available at http://perso.ens-lyon.fr/isabelle.baraffe).
25. G. Chabrier, I. Baraffe, *Annu. Rev. Astron. Astrophys.* **38**, 337 (2000).
26. Supported by NASA/HST grant GO-10424 (J.A., B.M.S.H., I.R.K., J.S.K., R.M.R., M.M.S.), a NASA Hubble Fellowship (J.S.K.), the U.S.-Canada Fulbright Fellowship Committee (H.B.R.), the Natural Sciences and Engineering Research Council of Canada (H.B.R.), and the University of British Columbia. H.B.R. thanks I. Ozier for fruitful discussions on CIA, as well as UCLA for support during his extended visit during which most of this paper was written. This research is based on NASA/ESA Hubble Space Telescope observations obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy Inc. under NASA contract NAS5-26555. These observations are associated with proposal GO-10424.

31 May 2006; accepted 18 July 2006
10.1126/science.1130691

Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity

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Western United States forest wildfire activity is widely thought to have increased in recent decades, yet neither the extent of recent changes nor the degree to which climate may be driving regional changes in wildfire has been systematically documented. Much of the public and scientific discussion of changes in western United States wildfire has focused instead on the effects of 19th- and 20th-century land-use history. We compiled a comprehensive database of large wildfires in western United States forests since 1970 and compared it with hydroclimatic and land-surface data. Here, we show that large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.

Wildfires have consumed increasing areas of western U.S. forests in recent years, and fire-fighting expenditures by federal land-management agencies now regularly exceed US$1 billion/year (*1*). Hundreds of homes are burned annually by wildfires, and damages to natural resources are sometimes extreme and irreversible. Media reports of recent, very large wildfires (>100,000 ha) burning in western forests have garnered widespread public attention, and a recurrent perception of crisis has galvanized legislative and administrative action (*1*–*3*).

Extensive discussions within the fire-management and scientific communities and the media seek to explain these phenomena, focusing on either land-use history or climate as primary causes. If increased wildfire risks are driven primarily by land-use history, then ecological restoration and fuels management are potential solutions. However, if increased risks are largely due to changes in climate during recent decades, then restoration and fuels treatments may be relatively ineffective in reversing current wildfire trends (*4*, *5*). We investigated 34 years of western U.S. (hereafter, "western") wildfire history together with hydroclimatic data to determine where the largest increases in wildfire have occurred and to evaluate how recent climatic trends may have been important causal factors.

Competing explanations: Climate versus management. Land-use explanations for increased western wildfire note that extensive livestock grazing and increasingly effective fire suppression began in the late 19th and early 20th centuries, reducing the frequency of large surface fires (*6*–*8*). Forest regrowth after extensive logging beginning in the late 19th century, combined with an absence of extensive fires, promoted forest structure changes and biomass accumulation, which now reduce the effectiveness of fire suppression and increase the size of wildfires and total area burned (*3*, *5*, *9*). The effects of land-use history on forest structure and biomass accumulation are, however, highly dependent upon the "natural fire regime" for any particular forest type. For example, the effects of fire exclusion are thought to be profound in forests that previously sustained frequent, low-intensity surface fires [such as Southwestern ponderosa pine and Sierra Nevada mixed conifer (*2*, *3*, *10*, *11*)], but of little or no consequence in forests that previously sustained only very infrequent, high-severity crown fires (such as Northern Rockies lodgepole pine or spruce-fir (*1*, *5*, *12*)].

In contrast, climatic explanations posit that increasing variability in moisture conditions (wet/dry oscillations promoting biomass growth, then burning), and/or a trend of increasing drought frequency, and/or warming temperatures have led to increased wildfire activity (*13*, *14*). Documentary records and proxy reconstructions (primarily from tree rings) of fire history and climate provide evidence that western forest wildfire risks are strongly positively associated with drought concurrent with the summer fire season and (particularly in ponderosa pine–dominant forests) positively associated to a lesser extent with moist conditions in antecedent years (*13*–*18*). Variability in western climate related to the Pacific Decadal Oscillation and intense El Niño/La Niña events in recent decades along with severe droughts in 2000 and 2002 may have promoted greater forest wildfire risks in areas such as the Southwest, where precipitation anomalies are significantly influenced by patterns in Pacific sea surface temperature (*19*–*22*). Although corresponding decadal-scale variations and trends in climate and wildfire have been identified in paleo studies, there is a paucity of evidence for such associations in the 20th century.

We describe land-use history versus climate as competing explanations, but they may be complementary in some ways. In some forest types, past land uses have probably increased the sensitivity of current forest wildfire regimes to climatic variability through effects on the quantity, arrangement, and continuity of fuels. Hence, an increased incidence of large, high-severity fires may be due to a combination of extreme droughts and overabundant fuels in some forests. Climate, however, may still be the primary driver of forest wildfire risks on interannual to decadal scales. On decadal scales, climatic means and variability shape the character of the vegetation [e.g., species populations and their drought tolerance (*23*) and biomass (fuel) continuity (*24*), thus also affecting fire regime responses to shorter term climate variability]. On interannual and shorter time scales, climate variability affects the flammability of live and dead forest vegetation (*13*–*19*, *25*).

High-quality time series are essential for evaluating wildfire risks, but for various reasons (*26*), previous works have not rigorously documented changes in large-wildfire frequency for

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western forests. Likewise, detailed fire-climate analyses for the region have not been conducted to evaluate what hydroclimatic variations may be associated with recent increased wildfire activity, and the spatial variations in these patterns.

We compiled a comprehensive time series of 1166 large (>400 ha) forest wildfires for 1970 to 2003 from federal land-management units containing 61% of western forested areas (and 80% above 1370 m) (*26*) (fig. S1). We compared these data with corresponding hydroclimatic and land surface variables (*26–34*) to address where and why the frequency of large forest wildfire has changed.

Increased forest wildfire activity. We found that the incidence of large wildfires in western forests increased in the mid-1980s (Fig. 1) [hereafter, "wildfires" refers to large-fire events (>400 ha) within forested areas only (*26*)]. Subsequently, wildfire frequency was nearly four times the average of 1970 to 1986, and the total area burned by these fires was more than six and a half times its previous level. Interannual variability in wildfire frequency is strongly associated with regional spring and summer temperature (Spearman's correlation of 0.76, $P < 0.001$, $n = 34$). A second-order polynomial fit to the regional temperature signal alone explains 66% of the variance in the annual incidence of these fires, with many more wildfires burning in hotter than in cooler years.

The length of the wildfire season also increased in the 1980s (Fig. 1). The average season length (the time between the reported first wildfire discovery date and the last wildfire control date) increased by 78 days (64%), comparing 1970 to 1986 with 1987 to 2003. Roughly half of that increase was due to earlier ignitions, and half to later control (48% versus 52%, respectively). Later control dates were no doubt partly due to later ignition dates, given that the date of the last reported wildfire ignition increased by 15 days, but a substantial increase in the length of time the average wildfire burned also played a role. The average time between discovery and control for a wildfire increased from 7.5 days from 1970 to 1986 to 37.1 days from 1987 to 2003. The annual length of the fire season and the average time each fire burned were also moderately correlated with the regional spring and summer temperature (Spearman's correlations of 0.61 ($P < 0.001$) and 0.55 ($P < 0.001$), respectively.

The greatest increase in wildfire frequency has been in the Northern Rockies, which account for 60% of the increase in large fires. Much of the remaining increase (18%) occurred in the Sierra Nevada, southern Cascades, and Coast Ranges of northern California and southern Oregon ("Northern California," in fig. S2). The Pacific Southwest; the Southern Rockies; the Northwest; coastal, central, and southern California; and the Black Hills each account for 11%, 5%, 5%, <1%, and <1%, respectively. Interestingly, the Northern Rockies and the Southwest show the same trend in wildfire frequency relative to their respective forested areas. However, the Southwest's absolute contribution to the western regional total is limited by its smaller forested area relative to higher latitudes.

Increased wildfire frequency since the mid-1980s has been concentrated between 1680 and 2590 m in elevation, with the greatest increase centered around 2130 m. Wildfire activity at these elevations has been episodic, coming in pulses during warm years, with relatively little activity in cool years, and is strongly associated with changes in spring snowmelt timing, which in turn is sensitive to changes in temperature.

Fire activity and the timing of the spring snowmelt. As a proxy for the timing of the spring snowmelt, we used Stewart and colleagues' dates of the center of mass of annual flow (CT) for snowmelt-dominated streamflow gauge records in western North America (*32–34*). The annual wildfire frequency for the region is highly correlated (inversely) with CT at gauges across the U.S. Pacific Northwest and interior West, indicating a coherent regional signal of wildfire sensitivity to snowmelt timing (Fig. 2).

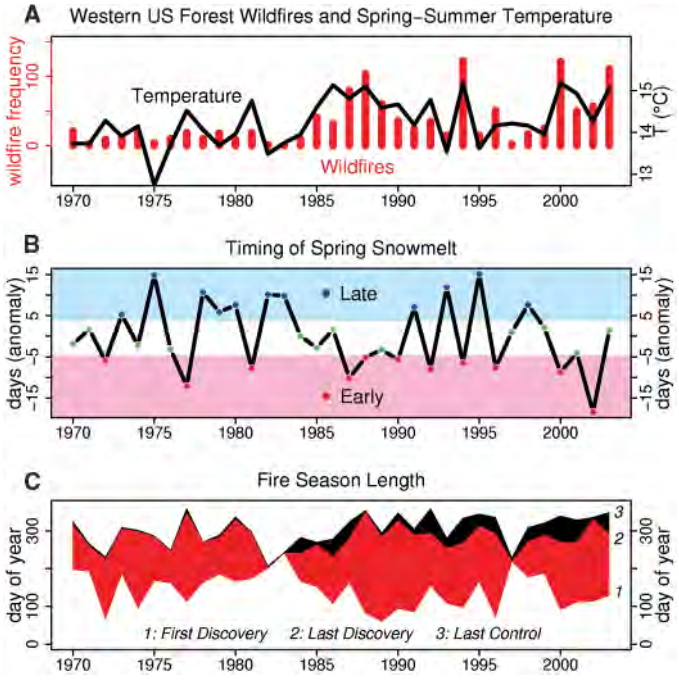


Fig. 1. (**A**) Annual frequency of large (>400 ha) western U.S. forest wildfires (bars) and mean March through August temperature for the western United States (line) (*26*, *30*). Spearman's rank correlation between the two series is 0.76 ($P < 0.001$). Wilcoxon test for change in mean large–forest fire frequency after 1987 was significant ($W = 42$; $P < 0.001$). (**B**) First principle component of center timing of streamflow in snowmelt dominated streams (line). Low (pink shading), middle (no shading), and high (light blue shading) tercile values indicate early, mid-, and late timing of spring snowmelt, respectively. (**C**) Annual time between first and last large-fire ignition, and last large-fire control.

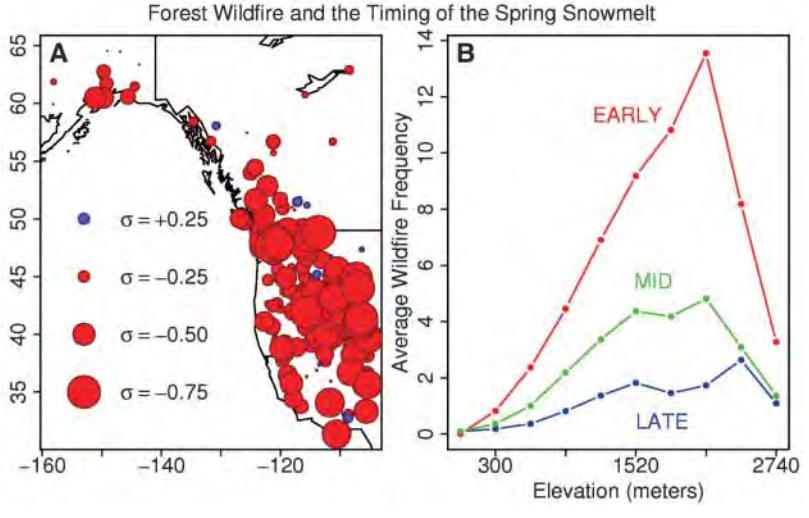


Fig. 2. (**A**) Pearson's rank correlation between annual western U.S. large (>400 ha) forest wildfire frequency and streamflow center timing. *x* axis, longitude; *y* axis, latitude. (**B**) Average frequency of western U.S. forest wildfire by elevation and early, mid-, and late snowmelt years from 1970 to 2002. See Fig. 1B for a definition of early, mid-, and late snowmelt years.

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The negative sign of these correlations indicates that earlier snowmelt dates correspond to increased wildfire frequency. Following Stewart *et al*., we used the first principal component (CT1) of CT at western U.S. streamflow gauges as a regional proxy for interannual variability in the arrival of the spring snowmelt (Fig. 1) (*26*, *32*). This signal had its greatest impact on wildfire frequency between elevations of 1680 and 2590 m (Fig. 2), with a nonlinear response at these elevations to variability in snowmelt timing. Overall, 56% of wildfires and 72% of area burned in wildfires occurred in early (i.e., lower tercile CT1) snowmelt years, whereas only 11% of wildfires and 4% of area burned occurred in late (i.e., upper tercile CT1) snowmelt years.

Temperature affects summer drought, and thus flammability of live and dead fuels in forests through its effect on evapotranspiration and, at higher elevations, on snow. Additionally, warm spring and summer temperatures were strongly associated with reduced winter precipitation over much of the western United States (Fig. 3). The arrival of spring snowmelt in the mountains of the western United States, represented here by CT1, is strongly associated with spring temperature (*26*). Average spring and summer temperatures throughout the entire region are significantly higher in early than in late years (Fig. 3), peaking in April. The average difference between early and late April mean monthly temperatures in forested areas was just over 2°C, and it increased with elevation.

Snow carries over a substantial portion of the winter precipitation that falls in western mountains, releasing it more gradually in late spring and early summer, providing an important contribution to spring and summer soil moisture (*35*). An earlier snowmelt can lead to an earlier, longer dry season, providing greater opportunities for large fires due both to the longer period in which ignitions could potentially occur and to the greater drying of soils and vegetation. Consequently, it is not surprising that the incidence of wildfires is strongly associated with snowmelt timing.

Changes in spring and summer temperatures associated with an early spring snowmelt come in the context of a marked trend over the period of analysis. Regionally averaged spring and summer temperatures for 1987 to 2003 were 0.87°C higher than those for 1970 to 1986. Spring and summer temperatures for 1987 to 2003 were the warmest since the start of the record in 1895, with 6 years in the 90th percentile—the most for any 17-year period since the start of the record in 1895 through 2003—whereas only 1 year in the preceding 17 years ranked in the 90th percentile. Likewise, 73% of early years since 1970 occurred in 1987 to 2003 (Fig. 1).

Spatial variability in the wildfire response to an earlier spring. Vulnerability of western U.S. forests to more frequent wildfires due to warmer temperatures is a function of the spatial distribution of forest area and the sensitivity of the local water balance to changes in the timing of spring. We measured this sensitivity using the October-to-September moisture deficit—the cumulative difference between the potential evapotranspiration due to temperature and the actual evapotranspiration constrained by available moisture—which is an important indicator of drought stress in plants (*24*). We used the percentage difference in the moisture deficit for early versus late snowmelt years scaled by the fraction of forest cover in each grid cell to map forests' vulnerability to changes in the timing of spring (Fig. 4) (*26*). The Northern Rockies and Northern California display the greatest vulnerability by this measure—the same forests accounting for more than three-quarters of increased wildfire frequency since the mid-1980s. Although the trend in temperature over the Northern Rockies increases with elevation, vulnerability in the Northern Rockies is highest around 2130 m, where the greatest increase in fires has occurred. At lower elevations, the moisture deficit in early years is increasing from a high average value (i.e., summer drought tends to be longer and more intense at lower elevations), whereas at higher elevations the longer dry season in early years is still relatively short, and vegetation is somewhat buffered from the effects of higher temperatures by the available moisture.

Discussion. Robust statistical associations between wildfire and hydroclimate in western forests indicate that increased wildfire activity over recent decades reflects sub-regional responses to changes in climate. Historical wildfire observations exhibit an abrupt transition in the mid-1980s from a regime of infrequent large wildfires of short (average of 1 week) duration to one with much more frequent and longer burning (5 weeks) fires. This transition was

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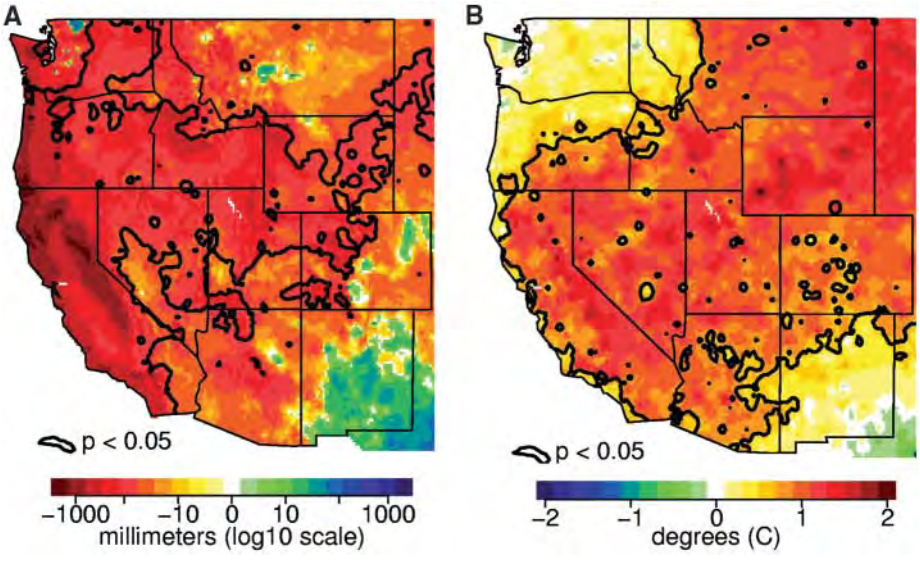


Fig. 3. Average difference between early and late snowmelt years in average precipitation from October through May (**A**) and average temperature from March through August (**B**). Contours enclose regions in which a *t* test for the difference in mean between 11 early and 11 late years was significant ($P < 0.05$). The null hypothesis that precipitation from October through May is normally distributed could not be rejected using the Shapiro-Wilk test for normality ($P > 0.05$ for more than 95% of 24,170 grid cells, $n = 49$ for precipitation; $P > 0.05$ for more than 95% of 24,170 grid cells, $n = 50$ for temperature). See Fig. 1B for a definition of early, mid-, and late snowmelt years.

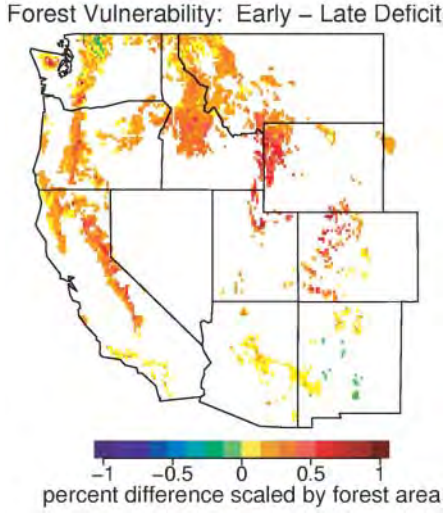


Fig. 4. Index of forest vulnerability to changes in the timing of spring: the percentage difference in cumulative moisture deficit from October to August at each grid point in early versus late snowmelt years, scaled by the forest-type vegetation fraction at each grid point, for 1970 to 1999 (*26*). See fig. S3 for a map of forest vulnerability for 1970 to 2003 over a smaller spatial domain. See Fig. 1B for a definition of early, mid-, and late snowmelt years.

marked by a shift toward unusually warm springs, longer summer dry seasons, drier vegetation (which provoked more and longer burning large wildfires), and longer fire seasons. Reduced winter precipitation and an early spring snowmelt played a role in this shift. Increases in wildfire were particularly strong in mid-elevation forests.

The greatest absolute increase in large wildfires occurred in Northern Rockies forests. This sub-region harbors a relatively large area of mesic, middle and high elevation forest types (such as lodgepole pine and spruce-fir) where fire exclusion has had little impact on natural fire regimes (*1*, *5*), but where we found that an advance in spring produces a relatively large percentage increase in cumulative moisture deficit by midsummer. In contrast, changes in Northern California forests may involve both climate and land-use effects. In these forests, large percentage changes in moisture deficits were strongly associated with advances in the timing of spring, and this area also includes substantial forested area where fire exclusion, timber harvesting, and succession after mining activities have led to increased forest densities and fire risks (*10*, *11*). Northern California forests have had substantially increased wildfire activity, with most wildfires occurring in early years. Southwest forests, where fire exclusion has had the greatest effect on fire risks (*2*, *3*), have also experienced increased numbers of large wildfires, but the relatively small forest area there limits the impact on the regional total, and the trend appears to be less affected by changes in the timing of spring. Most wildfires in the Southern Rockies and Southern California have also occurred in early snowmelt years, but again forest area there is small relative to the Northern Rockies and Northern California. Thus, although land-use history is an important factor for wildfire risks in specific forest types (such as some ponderosa pine and mixed conifer forests), the broad-scale increase in wildfire frequency across the western United States has been driven primarily by sensitivity of fire regimes to recent changes in climate over a relatively large area.

The overall importance of climate in wildfire activity underscores the urgency of ecological restoration and fuels management to reduce wildfire hazards to human communities and to mitigate ecological impacts of climate change in forests that have undergone substantial alterations due to past land uses. At the same time, however, large increases in wildfire driven by increased temperatures and earlier spring snowmelts in forests where land-use history had little impact on fire risks indicates that ecological restoration and fuels management alone will not be sufficient to reverse current wildfire trends.

These results have important regional and global implications. Whether the changes observed in western hydroclimate and wildfire are the result of greenhouse gas–induced global warming or only an unusual natural fluctuation is beyond the scope of this work. Regardless of past trends, virtually all climate-model projections indicate that warmer springs and summers will occur over the region in coming decades. These trends will reinforce the tendency toward early spring snowmelt (*36*, *37*) and longer fire seasons. This will accentuate conditions favorable to the occurrence of large wildfires, amplifying the vulnerability the region has experienced since the mid-1980s. The Intergovernmental Panel on Climate Change's consensus range of 1.5° to 5.8°C projected global surface temperature warming by the end of the 21st century is considerably larger than the recent warming of less than 0.9°C observed in spring and summer during recent decades over the western region (*37*).

If the average length and intensity of summer drought increases in the Northern Rockies and mountains elsewhere in the western United States, an increased frequency of large wildfires will lead to changes in forest composition and reduced tree densities, thus affecting carbon pools. Current estimates indicate that western U.S. forests are responsible for 20 to 40% of total U.S. carbon sequestration (*38*, *39*). If wildfire trends continue, at least initially, this biomass burning will result in carbon release, suggesting that the forests of the western United States may become a source of increased atmospheric carbon dioxide rather than a sink, even under a relatively modest temperature-increase scenario (*38*, *39*). Moreover, a recent study has shown that warmer, longer growing seasons lead to reduced CO_2 uptake in high-elevation forests, particularly during droughts (*40*). Hence, the projected regional warming and consequent increase in wildfire activity in the western United States is likely to magnify the threats to human communities and ecosystems, and substantially increase the management challenges in restoring forests and reducing greenhouse gas emissions.

References and Notes

1. C. Whitlock, *Nature* **432**, 28 (2004).
2. W. W. Covington, *Nature* **408**, 135 (2000).
3. C. D. Allen *et al.*, *Ecol. Appl.* **12**, 1418 (2002).
4. J. L. Pierce, G. A. Meyer, A. J. T. Jull, *Nature* **432**, 87 (2004).
5. T. Schoennagel, T. T. Veblen, W. H. Romme, *BioScience* **54**, 661 (2004).
6. M. Savage, T. W. Swetnam, *Ecology* **71**, 2374 (1990).
7. A. J. Belsky, D. M. Blumenthal, *Conserv. Biol.* **11**, 315 (1997).
8. S. J. Pyne, P. L. Andrews, R. D. Laven, *Introduction to Wildland Fire* (Wiley, New York, 1996).
9. W. W. Covington, M. M. Moore, *J. For.* **92**, 39 (1994).
10. K. S. McKelvey *et al.*, in *Sierra Nevada Ecosystems Project: Final Report to Congress* (Univ. of California, Davis, CA, 1996), vol. 2, chap. 37.
11. G. E. Gruell, *Fire in Sierra Nevada Forests: A Photographic Interpretation of Ecological Change Since 1849* (Mountain Press, Missoula, MT, 2001).
12. T. Schoennagel, T. T. Veblen, W. H. Romme, J. S. Sibold, E. R. Cook, *Ecol. Appl.* **15**, 2000 (2005).
13. R. C. Balling, G. A. Meyer, S. G. Wells, *Agric. For. Meteorol.* **60**, 285 (1992).
14. E. K. Heyerdahl, L. B. Brubaker, J. K. Agee, *Holocene* **12**, 597 (2002).
15. K. F. Kipfmueller, T. W. Swetnam, in *Wilderness Ecosystems, Threats, and Management*, D. N. Cole, S. F. McCool, W. T. Borrie, J. O'Loughlin, Eds. (U.S. Forest Service, RMRS-P-15, Fort Collins, CO, 2000), vol. 5, pp. 270–275.
16. T. W. Swetnam, J. L. Betancourt, *J. Clim.* **11**, 3128 (1998).
17. T. T. Veblen, T. Kitzberger, J. Donnegan, *Ecol. Appl.* **10**, 1178 (2000).
18. A. L. Westerling, T. J. Brown, A. Gershunov, D. R. Cayan, M. D. Dettinger, *Bull. Am. Meteorol. Soc.* **84**, 595 (2003).
19. T. W. Swetnam, J. L. Betancourt, *Science* **249**, 1017 (1990).
20. A. Gershunov, T. P. Barnett, *J. Clim.* **11**, 1575 (1998).
21. A. Gershunov, T. P. Barnett, D. R. Cayan, *Eos* **80**, 25 (1999).
22. A. L. Westerling, T. W. Swetnam, *Eos* **84**, 545 (2003).
23. N. L. Stephenson, *Am. Nat.* **135**, 649 (1990).
24. N. L. Stephenson, *J. Biogeogr.* **25**, 855 (1998).
25. T. W. Swetnam, *Science* **262**, 885 (1993).
26. Materials and methods are available as supporting material on *Science* Online.
27. K. E. Mitchell *et al.*, *J. Geophys. Res.* **109**, D07S90 (2004).
28. E. P. Maurer, A. W. Wood, J. C. Adam, D. P. Lettenmaier, B. Nijssen, *J. Clim.* **15**, 3237 (2002).
29. A. F. Hamlet, D. P. Lettenmaier, *J. Hydrometeor.* **6**, 330 (2005).
30. NCDC, "Time bias corrected divisional temperature-precipitation-drought index," documentation for data set TD-9640 (DBMB, NCDC, NOAA, Asheville, NC, 1994); available online (www.ncdc.noaa.gov/oa/climate/onlineprod/drought/readme.html).
31. X. Liang, D. P. Lettenmaier, E. F. Wood, S. J. Burges, *J. Geophys. Res.* **99**, 14415 (1994).
32. I. T. Stewart, D. R. Cayan, M. D. Dettinger, *J. Clim.* **18**, 1136 (2005).
33. D. R. Cayan, S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio, D. H. Peterson, *Bull. Am. Meteorol. Soc.* **82**, 399 (2001).
34. J. R. Slack, J. M. Landwehr, *U.S. Geol. Surv. Open-File Rep. 92–129* (1992).
35. J. Sheffield, G. Goteti, F. H. Wen, E. F. Wood, *J. Geophys. Res.* **109**, D24108 (2004).
36. National Assessment Synthesis Team, *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change* (U.S. Global Change Research Program, Washington, DC, 2000).
37. J. T. Houghton *et al.*, Eds., *IPCC Climate Change 2001: The Scientific Basis* (Cambridge Univ. Press, Cambridge and New York, 2001).
38. S. W. Pacala *et al.*, *Science* **292**, 2316 (2001).
39. D. Schimel, B. H. Braswell, in *Global Change and Mountain Regions: An Overview of Current Knowledge*, U. M. Huber, H. K. M. Bugmann, M. A. Reasoner, Eds., vol. 23 of *Advances in Global Change Research* (Springer, Dordrecht, Netherlands, 2005), pp. 449–456.
40. W. Sacks, D. Schimel, R. Monson, *Oecologia,* in press.

41. We thank M. Dettinger and D. Schimel for help. This work was supported by grants from the National Oceanographic and Atmospheric Administration's Office of Global Programs, the National Fire Plan by means of the U.S. Forest Service's Southern Research Station, and the California Energy Commission.

Supporting Online Material

www.sciencemag.org/cgi/content/full/1128834/DC1
Materials and Methods
Figs. S1 to S3
References

17 April 2006; accepted 28 June 2006
Published online 6 July 2006;
10.1126/science.1128834
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Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity

A. L. Westerling, H. G. Hidalgo, D. R. Cayan and T. W. Swetnam

Science **313** (5789), 940-943.
DOI: 10.1126/science.1128834originally published online July 6, 2006

ARTICLE TOOLS http://science.sciencemag.org/content/313/5789/940

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EXHIBIT L

SCENARIOS OF CLIMATE CHANGE IN CALIFORNIA: AN OVERVIEW

WHITE PAPER

A Report From:
California Climate Change Center

Prepared By:
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Arnold Schwarzenegger, *Governor*

February 2006
CEC-500-2005-186-SF

Acknowledgements

The authors would like to acknowledge the contributions from each one of the researchers that prepared the papers from which this overview is based. Without their valiant efforts this paper would not have been possible. We also thank Mary Tyree, of Scripps Institution of Oceanography for very rapidly and pleasantly archiving, processing, and dispensing data; and Edward Vine, with the University of California Office of the President, for managing the peer review process. Funding for the research and preparation of this report was provided by the California Environmental Protection Agency (Cal/EPA), the California Energy Commission (Energy Commission), California Air Resources Board, California Integrated Waste Management Board, and State Water Resources Control Board. In addition, Amy Luers wishes to express her appreciation for a grant received from the Robert & Patricia Switzer Foundation, which made her contribution possible.

We acknowledge the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving the model data, the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) and their Coupled Model Intercomparison Project (CMIP) and Climate Simulation Panel for organizing the model data analysis activity, and the IPCC WG1 TSU for technical support. The IPCC Data Archive at Lawrence Livermore National Laboratory is supported by the Office of Science, U.S. Department of Energy. In particular, we thank the NOAA Geophysical Fluids Dynamics Laboratory global modeling group, the NCAR/DOE Parallel Climate Modeling group, and the U.K. Met Office Climate Impacts LINK Project for very responsive model output and consultation

We are grateful to Chris Field, of the Carnegie Institution of Washington; Peter Frumhoff, of Union of Concerned Scientists; and Stephen Schneider from Stanford University for their review of a draft version of this paper. We thank the reviewers for their extremely valuable comments; however, we remain responsible for the content of this paper and for any errors or omissions that may have escaped our attention.

Finally, we would like to express our appreciation to California Environmental Protection Agency (Cal/EPA) and the California Energy Commission (Energy Commission) for their leadership on climate change issues; and to Eileen Tutt, Assistant Secretary for Climate Change Activities, in particular, for entrusting the research group with this study. In the California Energy Commission, we wish to express our thanks to Kelly Birkinshaw and Martha Krebs for supporting our activities and allowing one of the authors, Guido Franco, to focus most of his energy on the work that has culminated with this paper.

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, these reports receive minimal editing, and the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contact the Energy Commission at (916) 654-5164.

Table of Contents

Preface ii
1.0 Summary of Key Findings and Recommendations 1
2.0 Motivation and Overview of The Scenarios Project 2
3.0 Core Research Papers 3
4.0 Introduction 4
5.0 Climate Change Scenarios 5
5.1. Emission Scenarios 5
5.2. Climate Projections 7
5.2.1. Temperature 7
5.2.2. Precipitation 8
6.0 Coastal Sea Level 10
7.0 Water Resources 14
7.1. Snowpack 14
7.2. Water Supply 15
7.3. Winter Recreation 16
8.0 Agriculture 19
8.1. Temperature 19
8.2. Carbon Dioxide (CO_2) 20
8.3. Pests and Weeds 20
8.4. Potential Strategies for Reducing the Impact on Agriculture 20
9.0 Forests and Natural Landscapes 22
9.1. Natural Landscapes 22
9.2. Wildfires 22
9.3. Pests and Pathogens 24
9.4. Forest Productivity 25
9.5. Potential Strategies for Reducing Impacts on Wildfire Risk and Forestry 25
10.0 Public Health 26
10.1. Heat-related Deaths 26
10.2. Air Pollution-related Death and Disease 27
10.2.1. Wildfires 30
10.3. Asthma 30
10.4. Infectious Disease 31
10.5. Potential Strategies for Reducing Public Health Impacts 31
11.0 Electricity Generation and Demand 32

11.1. Electricity Generation: Hydropower 32
11.2. Electricity Demand 34
11.3. Potential Strategies for Reducing Impacts on Electricity Sector 37
12.0 Implications for Mitigation and Adaptation 38
13.0 The Need for Climate Change Information for California 41
14.0 References 42

List of Figures

Figure 1. IPCC SRES Emission Scenarios 5

Figure 2. Change in California annual mean temperature 8

Figure 3. Observed change in sea level rise in San Francisco and projections of global mean sea level rise 10

Figure 4. Projected number of hours per year, when San Francisco sea level height (SLH) exceeds 99.99% of its historical threshold 12

Figure 5. Projected total exceedances of San Francisco hourly sea level height 13

Figure 6. April 1 snow water equivalent 2070–2090 fraction of 1961–1990. 14

Figure 7. Exceedance probability plot for Central Valley Project and the State Water Project 17

Figure 8. Cotton/pink bollworm (PBW): Predicting areas of favorableness 21

Figure 9. Vegetation distribution under historical conditions and multiple climate change scenarios at end of century 23

Figure 10. Percent change in the expected minimum number of large fires per year in California 24

Figure 11. Projected increase in the number of extreme heat days relative to 1961–1990. *Extreme heat* is defined as the average temperature that is exceeded less than 10% of the days during the historical period (1961–1990), or approximately 36 days a year. 26

Figure 12. Summary of pollutant response to meteorological perturbations when background ozone concentrations are doubled to 60 ppb during pollution episodes that occurred in: (a) Southern California on September 9, 1993; (b) Southern California on September 25, 1996; and (c) the San Joaquin Valley on January 6, 1996. The bars represent the range of concentration change at any location in the modeling domain in response to the indicated perturbation. The circles represent the concentration change at the location of the maximum concentration for each pollutant. 29

Figure 13. Projected days at Riverside meteorologically conducive to exceedances of the 1-hour California ambient air quality standard for ozone of 0.09 ppm. 30

Figure 14. Probability of producing at a minimum level of generation in a year in major water supply reservoirs modeled in CALVIN: period centered in 2050. 33

Figure 15. Electricity demand in the CalISO area as function of average temperatures: 2004 35

Figure 16. Peak electricity demand in the CalISO area as a function of maximum daily temperature: June-September 2004 36

Figure 17. Projected impacts[1] end of 21st century.[2] Impacts presented relative to 1971–2000. 39

List of Tables

Table 1. Potential warming ranges for California 9

Table 2. Estimated incremental changes in annual electricity and peak load demands for lower, higher, and medium range of projected warming relative to 1961 to 1990 base period 36

1.0 Summary of Key Findings and Recommendations

- Climate change impacts will affect all of the sectors considered in this report: sea-level rise, agriculture, snowpack and water supply, forestry, wildfire risk, public health, and electricity demand and supply.
- The more that greenhouse gases (GHGs) accumulate in the Earth's atmosphere over the next century, the greater the warming and the more severe and costly the impacts will be. This study considered three future GHG emissions scenarios—low, medium high, and high emissions—and explored associated climate changes through three modern climate models of differing sensitivity to GHG concentrations.
- Although climate model results are inconclusive as to whether California's precipitation will change over the next century, all climate models show increases in temperature, with the aggregate of several model runs containing a range of warming from 2000 to 2100 from about +2°C to about +6°C (+3.6°F to about +10.8 °F). Increases in temperature alone would impact the California hydrological cycle, with consequences upon the state's water supply, hydroelectric power supply, agriculture, recreation, and ecosystems.
- Climate change could produce compounding impacts—for instance, in the San Francisco Bay Delta, heightened sea levels and high river inflows from warmer storms would place levee systems in greater jeopardy of flooding.
- Some of the most dramatic climate change impacts will be experienced as increased frequency and severity of extreme events, such as heat waves, wildfires, flooding, and conditions conducive to air pollution formation.
- Even under lower GHG emissions scenarios, some impacts of climate change are inevitable. As a result, although adaptation is not the solution to climate change, it is a necessary complementary strategy to manage some of the projected impacts.
- Although there are many opportunities for California to increase its capacity to cope with many climate change impacts, these can be costly, and they require time and planning.
- More analysis—and in some cases, more information—is needed to better understand the vulnerability of California's health, economy, and environment to climate change. In particular, greater attention must focus on social dimensions of climate change for both assessing and implementing the state's mitigative and adaptive potential. Critical to this work will be evaluating and addressing the distributional and equity implications of climate changes in California.

2.0 Motivation and Overview of The Scenarios Project

Governor Arnold Schwarzenegger's Executive Order S-3-05 of June 1, 2005, called for specific emission reductions and a periodic update on the state of climate change science and the emerging understanding of potential impacts on climate-sensitive sectors such as the state's water supply, public health, agriculture, coastal areas, and forestry. In response to this Executive Order, the California Energy Commission (Energy Commission) and the California Environmental Protection Agency (Cal/EPA) commissioned an assessment of the potential impacts of climate change on key state resources ("the Scenarios Project").

The Scenarios Project was conducted under the direction of the California Climate Change Center ("the Center"), which has engaged in a long-term, California-specific climate research program. The assessment builds on earlier work that came out of the Center and other previous studies. In particular, it extends the work of a recent study that compared the projected impact of climate change in California under differing emissions scenarios (Hayhoe et al. 2004). This assessment draws upon experts within and outside of the Center to produce a collection of separate research reports on the projected impacts of climate change under multiple scenarios across six different sectors: coasts, water resources, agriculture, public health, forestry, and electricity production and demand.

This report summarizes the findings from the individual research reports and compares them with the earlier findings from the Hayhoe et al. (2004) study. This summary report compares the impacts on key sectors under multiple future scenarios of temperature changes and links these impacts to GHG emission trajectories, assuming different climate sensitivities.

3.0 Core Research Papers

This document summarizes and integrates the results of several studies listed in the following table. The California Institute for Energy and Environment (CIEE, associated with the Office of the President, University of California) is conducting an external review on all the papers listed in this table. Dr. Edward Vine is managing the peer review process. These papers are available at www.climatechange.ca.gov/.

Research Papers	
Dan Cayan et al.	Climate Scenarios for California
Dan Cayan et al.	Projecting Future Sea Level
Dennis Baldocchi et al.	An Assessment of Impacts of Future CO_2 and Climate on Agriculture
Brian Joyce et al.	Climate Change Impacts on Water for Agriculture in California: A Case Study in the Sacramento Valley
Josue Medellin et al.	Climate Warming and Water Supply Management in California
Department of Water Resources	Progress on Incorporating Climate Change into Management of California's Water Resources*
Andrew Paul Gutierrez	Analysis of Climate Effects on Agricultural Systems
Timothy Cavagnaro et al.	Climate Change: Challenges and Solutions for California Agricultural Landscapes
James Lenihan et al.	The Response of Vegetation Distribution, Ecosystem Productivity, and Fire in California to Future Climate Scenarios Simulated by the MC1 Dynamic Vegetation Model
Anthony Westerling and Benjamin Bryant	Climate Change and Wildfire in and Around California: Fire Modeling and Loss Modeling
Jeremy Fried et al.	Predicting the Effect of Climate Change on Wildfire Severity and Outcomes in California: A Preliminary Analysis
Max Moritz and Scott Stephens	Fire and Sustainability: Considerations for California's Altered Future Climate
John Battles et al.	Climate Change Impact on Forest Resources
Deborah Drechsler et al.	Public Health-Related Impacts of Climate Change for California
Amy Lynd Luers and Suzanne Moser	Preparing for the Impacts of Climate Change in California: Opportunities and Constraints for Adaptation
Technical Notes	
Sebastian Vicuña et al.	Climate Change Impacts on High Elevation Hydropower Generation in California's Sierra Nevada: A Case Study in the Upper American River
Guido Franco and Alan Sanstad	Climate Change and Electricity Demand in California
Sebastian Vicuña	Predictions of Climate Change Impacts on California Water Resources Using CalSim-II: A Technical Note

* The Department of Water Resources (DWR) coordinated the peer-review process for this paper. It will be available from DWR.

4.0 Introduction

It is now apparent that the increasing atmospheric concentration of GHGs, resulting from human activities, is changing the climate in ways that pose serious risks to California's health, economy, and environment. However, the most severe impacts that are expected with greater temperature rises could be avoided if the rate of GHG emissions is reduced. To help identify the potentially avoidable climate impacts in California, this paper summarizes some of the impacts expected under lower, medium, and higher ranges of projected warmings, as determined by different GHG emissions scenarios and different global climate models.

Linking temperature changes with particular levels of GHG emissions is a useful way to gauge the level of emissions reductions needed to avoid serious climate change impacts. However, current understanding of the climate system permits only limited precision in linking specific temperature changes to specific emission scenarios. Among a collection of more than a dozen national and international global climate models, *all* project increased temperatures as a result of higher emissions of GHG. However, the models differ in their sensitivity to changes in atmospheric GHG concentrations. For example, temperature rises between 1.5°C to 4.5°C (2.7°F to 8.1°F) have been projected for a doubling of CO_2 concentration above pre-industrial levels (IPCC 2001). The range in temperature response is the result of differences in the way that the models represent certain processes of the climate system, such as the way that they simulate clouds and radiation (Stephens 2005).

Society can neither control, nor at present precisely determine, the sensitivity of the earth's climate system to rising GHG concentrations. As a result, society must consider the implications of a range of climate sensitivities when evaluating the risks of climate change and devising policies to manage the one factor we can control: our own GHG emissions.

This paper summarizes the findings of the California Climate Change Center Scenarios Project ("the Project") and compares these new projections with those reported in an earlier study produced by many of the same researchers (Hayhoe et al. 2004). The projections in this summary are based upon three GHG scenarios—a lower emissions, medium-high emissions, and higher emissions scenario. The effect of different estimates of the sensitivity of the climate system to GHG forcing is explored by comparing the temperature projections from three different global climate models—each containing somewhat different representations of some crucial physical processes that result in different levels of climate sensitivity.

The following sections describe the emission scenarios and climate projections, and report on the projected impacts of the specific climate projections across six sectors: coasts, water resources, agriculture, forests/fire, public health, and electricity. The paper concludes with a discussion of the implications of these projections for mitigation and adaptation, and points out some outstanding problems that require further information or research.

5.0 Climate Change Scenarios

5.1. Emission Scenarios

The Intergovernmental Panel on Climate Change's (IPCC's) *Special Report on Emissions Scenarios* (SRES) developed a set of possible future emissions scenarios based on different assumptions about global development paths (Nakicenovic et al. 2000). This report contrasts the results from recent analyses for California of three SRES emissions scenarios—a lower emissions scenario (B1), a medium-high emissions scenario (A2), and a higher emissions scenario (A1fi) (Figure 1):

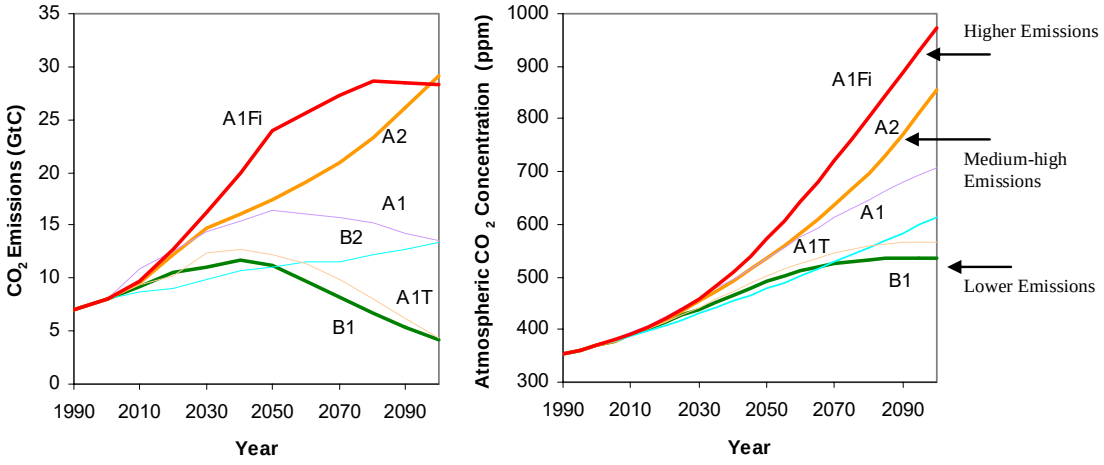


Figure 1. IPCC SRES Emission Scenarios

Six IPCC SRES Emissions Scenarios are presented here. The bold lines represent the three scenarios used in the analysis presented here (B1, A2, A1fi), the other lines represent IPCC scenarios not used in this study, yet presented here to illustrate how the trajectories selected for this study fit within the family of curves developed by the IPCC (Nakicenovic et al. 2000). The trajectories in this figure do not exactly match those in official IPCC documents (Nakicenovic et al. 2000) because the results we report here are based on revised emissions projections subsequently made available by IPCC; these are available at http://sres.ciesin.columbia.edu/. In addition, the authors used a new version of MAGICC available from www.cgd.ucar.edu/cas/wigley/magicc/index.html. However, the differences between this figure and similar figures provided by the IPCC are minor, and do not affect the discussion in this paper.

- The lower emissions scenario (B1) characterizes a world with population growth similar to the highest emissions scenarios, but with rapid changes toward a service and information economy and with the introduction of clean and resource-efficient technologies. The B1 scenario has CO_2 emissions peaking just below 10 gigatonnes per year (Gt/yr) in mid-century before dropping below the current-day level of 7 Gt/yr by 2100. Under the B1 scenario, the CO_2 concentration would double, relative to its pre-industrial level, by the end of this century.
- The medium-high emissions scenario (A2) projects continuous population growth, with slower economic growth and technological change than in the other scenarios. For the medium-high emissions scenario (A2), CO_2 emissions continue to climb throughout the century, reaching almost 30 Gt/yr, about four times the present rate of emissions. By the end of the century CO_2 concentration would reach more than triple its pre-industrial level.
- The higher emissions scenario (A1fi) represents a world of rapid fossil-fuel-intensive economic growth, global population that peaks mid-century then declines, and the introduction of new and more efficient technologies towards the end of the century. The higher emissions scenario (A1fi) rises faster than the A2 scenario, reaching about 25 Gt/yr, more than three times the present rate of emissions, by 2050. The A1fi scenario concludes the century with approximately the same annual emissions as the A2 scenario. However, the A2 and A1fi scenarios differ in two ways that have important implications for the projected changes. First, the emissions pathways of A1fi and A2 diverge by mid-century, with A1fi rising rapidly and then flattening out toward the end of the century. Second, the total cumulative emissions in the A1fi scenario are almost 20% higher at the end of century than in the A2 scenario.

To capture a range of uncertainty among climate models, this chapter reports on projections from three state-of-the-art global climate models (GCMs) that capture a range of climate sensitivities:

- The Parallel Climate Model (PCM1) from the National Center for Atmospheric Research (NCAR) and the U.S. Department of Energy (DOE) groups (Washington et al. 2000), a low-sensitivity model, with a climate sensitivity of approximately 1.8°C (3.2°F)[1]
- The Geophysical Fluids Dynamic Laboratory (GFDL) CM2.1 (NOAA Geophysical Dynamics Laboratory, Princeton New Jersey) model (Delworth et al. 2005), a medium-sensitivity model with climate sensitivity of approximately 3°C (5.4°F)
- The U.K. Met Office Hadley Centre Climate Model, version 3 (HadCM3) (Pope et al. 2000), with a slightly higher climate sensitivity of 3.3°C (5.9°F)

Each of the three GCMs produced a reasonably good simulation of key features of California's observed climate and representations of tropical Pacific ENSO variability.

[1] *Climate sensitivity* is defined as the change in temperature resulting from a doubling of CO_2 concentration above pre-industrial levels.

The models were also chosen for having available simulation datasets at monthly and daily time scales in order to carry out the impact studies undertaken in the scenarios analysis.

Global climate models calculate weather, ocean, and land surface variables over a discrete global grid too coarse to adequately depict the complex structure of temperature and precipitation that characterizes the California setting. The results presented here rely principally on a statistical technique using properties of observed data (Wood et al. 2002), that was employed to correct model biases and "downscale" the model data to a finer level of detail—a grid of approximately 12 kilometers (km) (7 miles). This downscaling technique, which was employed in previous climate change assessments, was used to satisfy study requirements for impact studies, including modeling the water and energy balance. To derive land surface hydrological variables consistent with the downscaled forcing data, a macroscale, distributed, physically based hydrologic model—the variable infiltration capacity (VIC) model (Liang et al. 1994; Liang et al. 1996)—was used.

5.2. Climate Projections

5.2.1. Temperature

Temperatures in California are projected to rise significantly over the twenty-first century. As shown in Table 1 and Figure 2, magnitudes of the warming vary because of the uncertainties in the climate sensitivity, as expressed by differences between models and in the emission scenarios. The rises (2000 to 2100) vary from approximately 1.7°C–3.0°C (3.0°F–5.4°F) in the lower range of projected warming, 3.1°C–4.3°C (5.5°F–7.8°F) in the medium range, and 4.4°C–5.8°C (8.0°F–10.4°F) in the higher range (Cayan et al. 2006a). To comprehend the magnitude of these projected temperature changes, over the next century the lower range of projected temperature rise is slightly larger than the difference in annual mean temperature between Monterey and Salinas, and the upper range of project warming is greater than the temperature difference between San Francisco and San Jose, respectively.[2]

[2] The difference in annual mean temperatures between Monterey (65.3ºF or 18.5ºC) and Salinas (67.8ºF or 19.9ºC) is 2.5ºF (1.4ºC) and the difference between San Francisco Mission Dolores (63.6ºF or 17.6ºC) and San Jose (71.0ºF or 22ºC) is 7.4ºF (4.4ºC).

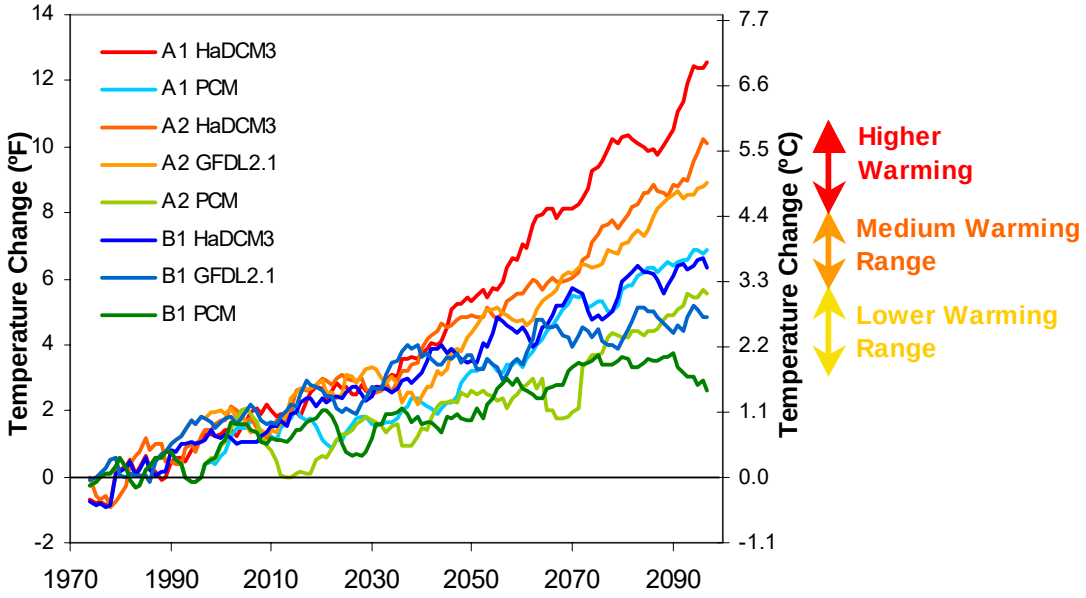


Figure 2. Change in California annual mean temperature

Change in California annual mean temperature (7-year running mean) (°F/°C) by year, from 1970–2099, relative to 1961–1990 average.

An important aspect of the model results is that all of the GHG scenario simulation, (except the low-emission scenario simulated by the low response model) exhibit higher warming in summer than in winter. In the medium-high emission (A2) scenario with the low sensitivity and medium sensitivity models, temperature increases by the end of the twenty-first century are 1.5°C–3.5°C (2.7°F–6.3°F), greater in summer than in winter (Cayan et al. 2006a). This result has important implications for impacts such as ecosystems, agriculture, water and energy demand, and the occurrence of heat waves, which have public health consequences.

5.2.2. Precipitation

There is no clear trend in precipitation projections for California over the next century. However, from the recent IPCC model projections—including several models that were not selected for the present study—there are considerable differences, from wetter to drier, between models and between emissions scenarios. The center of this distribution of simulations yields relatively little change, with a tendency for a slight decrease in precipitation, as is the case for the GFDL and the HadCM3 simulations (Cayan et al. 2006a).

Table 1. Potential warming ranges for California

	GCMs	Lower °C (°F)	Medium °C (°F)	Higher °C (°F)
Projected End of Century Range of Warming*		1.7°C–3°C (3.0°F–5.4°F)	3.1°C–4.4°C (5.5°F–7.8°F)	4.4°C–5.8°C (8.0°F–10.4°F)
Lower GHG Emissions B1	PCM	1.7 (3.0)		
	GFDL	2.2 (4.0)		
	HadCM3		3.1 (5.6)	
Medium-High GHG Emissions A2	PCM	2.6 (4.7)		
	GFDL		3.9 (7.0)	
	HadCM3			4.5 (8.1)
Higher GHG Emissions A1fi	PCM		3.3 (6.0)	
	HadCM3			5.8 (10.4)

*The temperature ranges were defined here for illustration only. The division was made simply by dividing evenly (low, medium, high) range of change in California's average annual temperatures as projected by the three GCM and emissions scenarios reported on in this summary (1.7°C–5.8°C **(**3.0°F–10.4°F**)**). The projected warming ranges presented here are for 2070–2099 relative to 1971–2000. However, some of the impacts summarized in this report used a different historical climatological baseline of 1961–1990. The difference between the 1961–1990 and 1971–2000 baselines leads to a small difference in projected temperature rise for the different scenarios and models. The difference in baselines amounts to approximately a 0.2°C (0.36°F) difference in the full range of projected end-of-century temperature rise.

There is no evidence from the projections indicating that the Mediterranean seasonal precipitation regime in California will change. All of the simulations examined here indicate that the very dominant portion of precipitation continues to be derived during winter from North Pacific storms. Summer precipitation changes only incrementally, and actually decreases in some of the simulations, so there is little evidence for a stronger monsoon influence. For the scenarios reported here, each of the model runs is characterized by large interannual to decadal fluctuations of precipitation, but not much change in annual precipitation over the 2000–2100 period. Little change in variability over the period of the model runs is evident in the simulations. The frequency of warm tropical events (El Niños) remains about the same as was exhibited in the historical simulations. As in observations, GCM El Niño events are related to anomalous precipitation patterns near the California region (Cayan et al. 2006a).

6.0 Coastal Sea Level

Coastal observations and global model projections indicate that California's open coast and estuaries will experience rising sea levels during the next century. Sea level rise already has affected much of the coast in Southern California, Central California, and the San Francisco Bay and estuary. These historical trends, quantified from a small set of California tide gages, have approached 2 mm/year (0.08 in/yr), which are rates very similar to those estimated for global mean sea level. So far, there is little evidence that the rate of rise has accelerated, and indeed the rate of rise at California tide gages has actually flattened since about 1980. However, projections indicate that substantial sea level rise, even faster than the historical rates, could occur during the next century.

As discussed in Cayan et al. (2006b), recent climate change simulations project significant global sea level rise during the next century, as the result of thermal expansion as the oceans warm and as runoff from melting land-based snow and ice accelerates. Sea level rise projected from the models increases in proportion to the amount of global warming. By the 2070–2099 period, sea level rise projections range from 13–62 cm (5.1–24.4 in) higher than the 2000 level for simulations following the lower emissions scenario (B1), from 18–76 cm (7.1–29.9 in) for the medium-high emission scenario (A2), and from 21–89 cm (8.5–35.2 in) for the higher emissions scenario(A1fi). These are illustrated in Figure 3, together with the last century of observed sea level at the San Francisco tide gage.

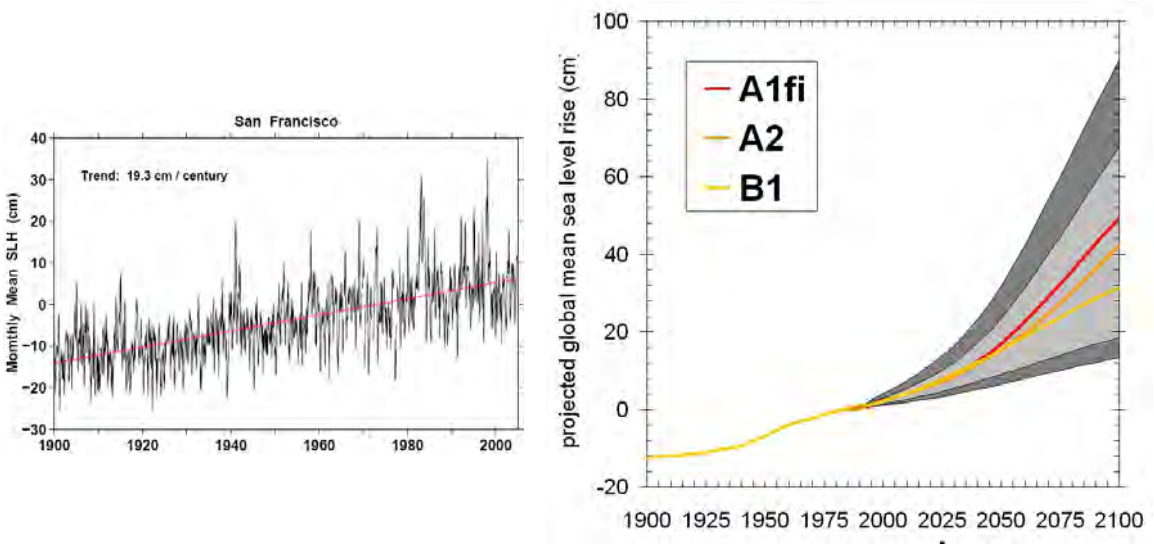


Figure 3. Observed change in sea level rise in San Francisco and projections of global mean sea level rise

Projected sea level rise from climate model estimates for three GHG emissions scenarios, A1fi (higher emissions), A2 (medium-high emissions), and B1 (lower emissions). San Francisco observed sea level, with trend of 19.3 cm/century (7.6 in/century), is shown for comparison. (Cayan et al. 2006b). In the graph on the right, light gray and dark gray represent uncertainty from thermal expansion and ice melt, respectively.

In addition to relatively steady long-term trends and astronomical tides, sea levels along the California coast undergo inter-annual and weather scale fluctuations that carry sea level elevations above and below the predicted tides and trends. These slower sea level rises are crucial because they boost the sea level excursions associated with the shorter term tidal, weather, and climate fluctuations. The most impressive examples of high sea level episodes in recent decades occurred during the winters of the massive El Niño events of 1982–1983 and 1997–1998 (Flick 1998). Thus, much of the potential damage from rising sea levels will occur during the occasions when high water stands due to tides, weather and climate anomalies are made higher (or more frequent) by the gradually rising mean sea levels. Importantly, GCMs include El Niños and La Niñas, as well as longer-lasting Pacific decadal variability, both in historical simulations as well as in projections that are being used to investigate twenty-first century climate changes.

Cayan et al. (2006b) considered two climate models and three emission scenarios to provide a set of future weather and short-period climate fluctuations, and a range of potential long-term sea level rises. Moderate to very large sea level rises were projected. The middle to higher end of this range would substantially exceed the historical rate of sea level rise (15–20 cm (5.9–7.8 in) per century) observed at San Francisco and San Diego during the past 100 years. Using a model of the combined contributions of tides, weather, climate, and long-term global warming on hourly sea levels, the potential for sea level rise impacts was assessed from the occurrence of hourly extremes. Considering a range of scenarios, and a range of possible sea level trends (Figure 4), Cayan et al. (2006b) find that, if warming is near the low end of the temperature range of projections so that sea level rise trends are also near the low end, then the occurrence of extremely high sea level events will increase, but not greatly, and sea level extremes under the various emissions scenarios (B1, A2, A1fi) are not much different from each other. On the other hand, if warming is greater, then sea level rise trends are at the higher end in each scenario, causing extreme events and their duration to increase markedly, especially for the medium-high and higher GHG emissions scenarios (A2, A1fi). Because of uncertainties in the climate sensitivity, it is not clear how rapidly sea levels will rise, even under the lowest emission scenarios. However, the California coast has already experienced rises of sea level that approach 15–20 cm (6–8 in) over the last century, so it seems prudent to consider scenarios where projected rise rates equal or exceed these historical sea level rise rates.

Coastal sea level extremes are also exacerbated by other processes, such as heavy surf from wind-driven waves, and these effects tend to be active during the same storms that causing anomalously high sea levels. Near San Francisco and Crescent City, when sea level fluctuations, above tide predicted levels, reach anomalies that exceed the 99th percentile of their measurements, the average in peak wave height at nearby wave-measuring buoys maintained by NOAA climbs to about double its ambient level. Because wave energy is proportional to the *square* of the wave height, the wave height increase during anomalous sea level episodes is equivalent to a coincident increase in wave energy by a factor of four. This observational evidence indicates that when anomalous sea level is highest, wave energy has an increased likelihood of reaching very high levels. When waves and anomalously high sea level coincide with high tides, the

chances for coastal damage are heightened. Continuing increases in mean sea level due to global change makes this problem even more severe.

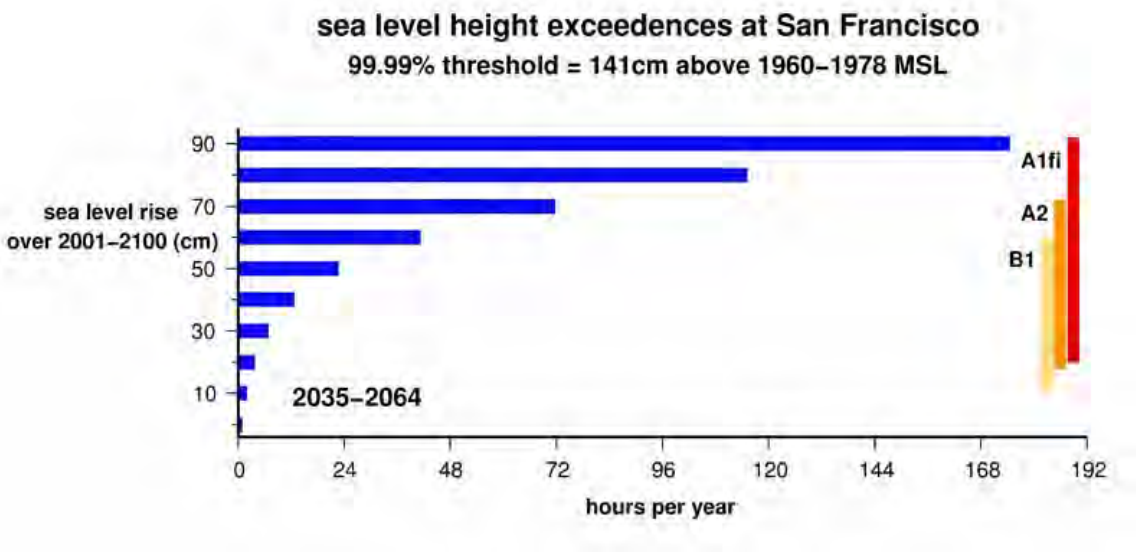


Figure 4. Projected number of hours per year, when San Francisco sea level height (SLH) exceeds 99.99% of its historical threshold

Projected number of hours per year, averaged over 2035–2064, when San Francisco sea level height exceeds historical (1960–19780 99.99 percentile observed threshold. Estimates are calculated from GFDL model weather and ENSO variability superimposed on predicted tides and a range of long term sea level rise as approximated by linear trends, from 0 to 90 cm over 2000–2100. Range of trends that have been estimated from climate models is indicated for three different GHG emission scenarios (Cayan et al. 2006b).

Sea level rise also threatens the Sacramento/San Joaquin Delta of the San Francisco Bay estuary. Historically, major floods have produced breaches in levees that protect low-lying, subsiding island tracts in the Delta and riverine and estuarine margins elsewhere, despite many engineered changes to the rivers. As sea levels rise, flood stages in the Delta would be expected to rise also, putting increasingly more pressure on Delta levees. The threats from sea level rise are particularly significant, because as Mount and Twiss (2005) have noted, the forces that rising sea/river levels bring to Delta levees increase as the *square* of the rises, rather than "just" linearly with the rises. Furthermore, the combination of flood and high sea-level stands are particularly dangerous in the Delta, where it is the combination of sea level and river stages that determine the water height. Storms are primary causes of the highest water levels both from barometric and wind effects on the sea levels and from the (freshwater) floods that they can generate. A count of the number of projected extremely high sea level episodes at San Francisco that coincide with potential storm/flood episodes is depicted in Figure 5 by cases when sea level is unusually high and atmospheric surface pressure is unusually low. This simulation indicates that, at least during the earlier decades of the next century, the largest increases in the frequency of extremely high sea level episodes as sea levels rise will coincide with periods of enhanced storm-flood risks.

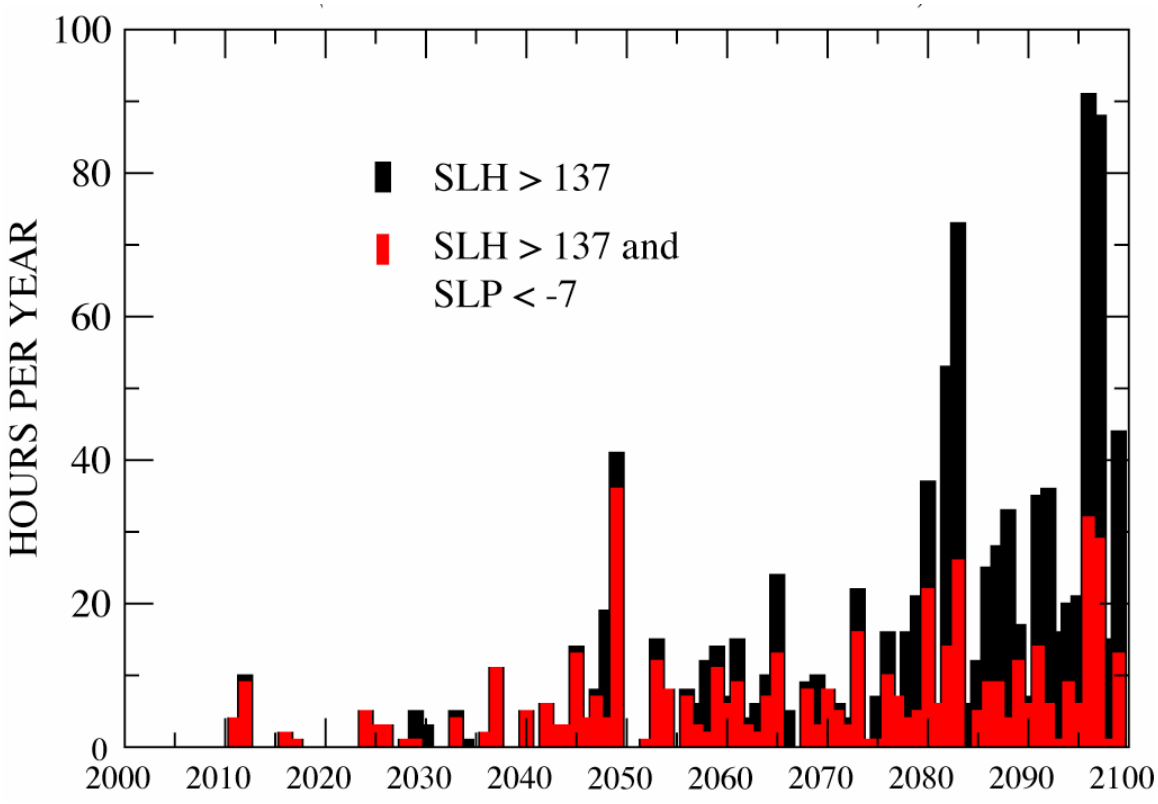


Figure 5. Projected total exceedances of San Francisco hourly sea level height

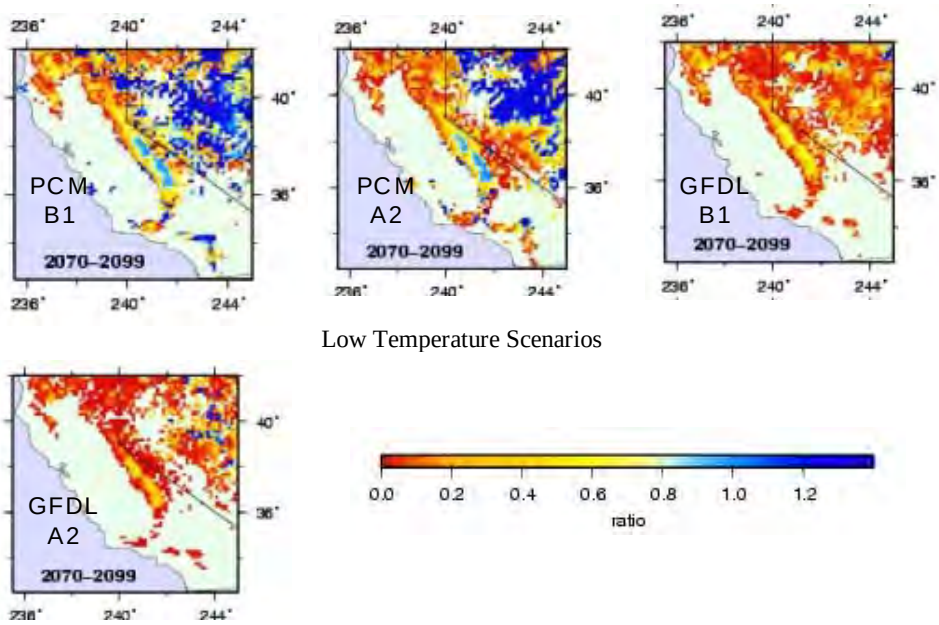
Projected total exceedances of San Francisco hourly sea level height above historical 99.99 percentile (black), and number that are coincident with sea level pressure (SLP) anomalies less than -7 mb. This figure was generated using projected sea level from GFDL model weather and Nino3.4 SST with a linear trend of 30 cm over 2000–2100 (Cayan et al. 2006b).

7.0 Water Resources

Although most climate model simulations project relatively moderate changes in precipitation over this century, rising temperatures are expected to lead to diminishing snow accumulation in mountainous watersheds, including the Sierra Nevada. Warmer conditions during the last few decades across the western United States have already produced a shift toward more precipitation falling as rain instead of snow (Knowles et al. 2005), and snowpacks over the region have been melting earlier in the spring (Mote et al. 2005; Stewart et al. 2005). Delays in snow accumulation and earlier snowmelt will have cascading affects on water supplies, natural ecosystems, and winter recreation.

7.1. Snowpack

The Variable Infiltration Capacity (VIC) distributed land surface hydrology model was used to simulate snowpack throughout the century (Cayan et al. 2006a). Projected reductions in snowpack increase with temperature, with the larger losses of spring snowpack in the higher range of projected warming (Figure 6). Each of the simulations shows losses of spring snow accumulation, largely over the Sierra Nevada, become progressively larger over the twenty-first century. In the Sierra Nevada by the 2035–2064 period, snowpack could decrease 12% to 47% from historical levels under the lower range of projected warming, and decrease 26% to 40% in the higher range of projected warming, with precipitation changes playing a partial role in the reductions for the lower temperature cases. By the end of century, snowpack could decrease by as much as 90% in the higher amount of warming—almost double the losses expected under the lower warming cases.



Low Temperature Scenarios

Medium Temperature Scenario

Source (Cayan et al. 2006a)

Figure 6. April 1 snow water equivalent 2070–2090 fraction of 1961–1990.

7.2. Water Supply

Declining snowpack will aggravate the already overstretched water resources in California. The snowpack in the Sierra Nevada provides natural water storage, equal to about half the storage capacity in California's major human-made reservoirs, holding the winter precipitation in the form of snow and releasing it in the spring and early summer as the snow melts. This loss in storage could mean more water shortages in the futures. However, the full effect of this storage loss will depend in part on whether reservoirs can be managed to capture the earlier snowmelt while not losing flood control capacity or, at the higher elevations, hydropower generation capacity.

Two different methods were used to project the effects of the alternative climate scenarios on water supply. One approach used the VIC model to simulate inflows into major reservoirs in the Sacramento Valley as drivers for their respective water resource management models, CALSIM and CALVIN[3] (Chung et al. 2006; Medellin et al. 2006; Vicuña et al. 2006; Vicuña 2006). The second approach used the Water Evaluation and Planning (WEAP) system (Joyce et al. 2006).

These two approaches differ in how they process the climate change scenarios.[4] Under most scenarios, both modeling approaches project streamflows to decrease slightly by mid-century, with more dramatic changes by the end of the century. Flows into the major Sierra Nevada reservoirs could decline between 25%–30% under the medium range of projected warming and the simulated decline in precipitation—almost double the decrease projected under the lower range of projected warming. However one model run produces a slight increase in precipitation and a corresponding rise in projected streamflows.

The Sacramento Four River Index (also called the *Sacramento 40-30-30 Index*) was used to classify the probability of water year types under the different climate change scenarios.[5]

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[3] CALSIM was used to assess hydrologic impacts in the Central Valley; CALVIN also covers the portions of the state outside the Central Valley

[4] CALSIM and CALVIN require as input a given time series of monthly stream flows—both use a modified version of the historical stream flow over the period 1922–1994. Climate change is incorporated into the given historical series by the "perturbation ratio" method: for a given time period of interest (2035–2064 or 2070–2099), a given stream location, and a particular month, one computes the average ratio of the VIC streamflow in that month over the period of interest to the VIC streamflow for the corresponding month over a base period (1961–1990). The monthly ratios are then used to adjust, or "perturb," the monthly stream flows in the historical series 1922–1994. In contrast, the WEAP approach uses raw time series of precipitation and temperature in a watershed hydrology model and directly generates a time series of streamflows. The perturbation approach is tied more closely than the WEAP approach to the historic inter-annual pattern of year-to-year variation in drought and wetness, although both approaches can generate changes in drought persistence.

[5] The Sacramento River Index was developed by the State Water Resources Control Board for regulatory purposes, and requires the forecasting by May of each year of the current year's April–July unimpaired runoff in the Sacramento Valley. When a retrospective analysis is conducted using the historical hydrology, as here, the actual April–July runoff is known, but not the prospective forecast, and therefore the index cannot be calculated in exactly the same way. The research here uses the Brekke et al. (2004) retrospective approximation for calculating the index.

This river index classifies the years into five categories: Wet, Above Normal, Below Normal, Dry, and Critical. Because the River Index pays greater attention to the aggregate stream flow then the timing of flow, it is more influenced by changes in precipitation then temperature. The projections for the less dry model (PCM) indicate that toward the end of the century, under the higher-emissions scenario, up to 50% of the years between 2070–2099 could be critically dry years, as compared to 18% in the historical period (Vicuña 2006; Hayhoe et al. 2004). Under the lower-emissions scenario in the less-dry model, little or no change in the frequency of critically dry years is expected. In contrast, from the projections using the drier models (HadCM3 and GFDL), even under the lower-emissions scenarios the frequency of critically dry years would increase, up to twice as often as historical conditions.

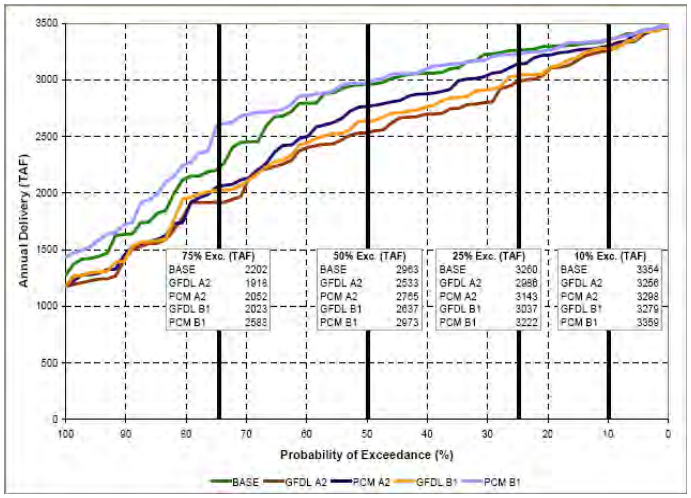
CALSIM was used to assess the consequences of the climate change scenarios on carryover storage at CVP and SWP reservoirs and for deliveries to CVP and SWP (Chung et al. 2006; Vicuña 2006). Toward the end of the century, the change in the volume and timing of runoff reduce the ability of the major projects to deliver water to agricultural users south of the Delta. These deliveries fall by 15%–30% under the lower range of projected warming, and 40%–50% under the medium and higher ranges of projected warming (Vicuña 2006) (Figure 7), with the drier model simulations showing the largest decreases. The projected changes in water supply would be further exacerbated by increased demand due to warmer temperatures. By the end of century, warmer temperatures are expected to increase the crop demand between 2% and 13%, in the lower and medium warming cases, respectively; there could be a similar effect on urban demand for outdoor lawn watering (Baldocchi et al. 2006).

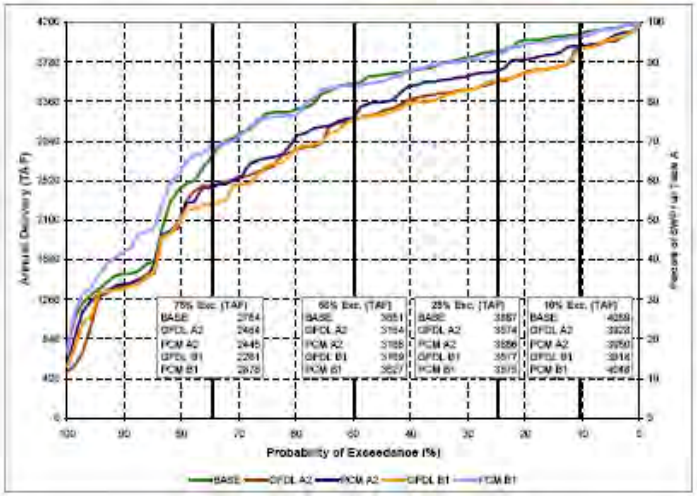
7.3. Winter Recreation

Declines in Sierra snowpack will also have widespread implications for winter tourism. Warming could affect the starting and closing dates of the ski season. Toward the end of the century, in lower temperature scenarios, the ski season at lower and middle elevation settings could shorten by as much as a month, while projected climatic changes under the higher temperature scenario suggest that the minimum snow conditions for ski resort operation might never occur, and resorts would be forced to rely entirely on snowmaking or move their operations (Hayhoe et al. 2004).

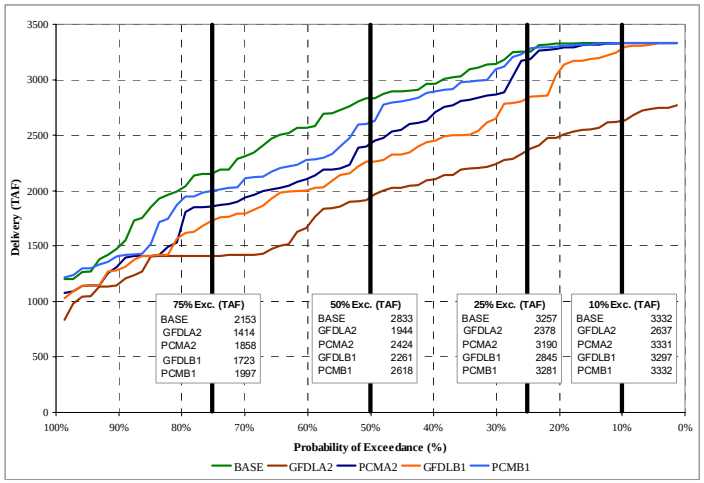
CVP **SPW**

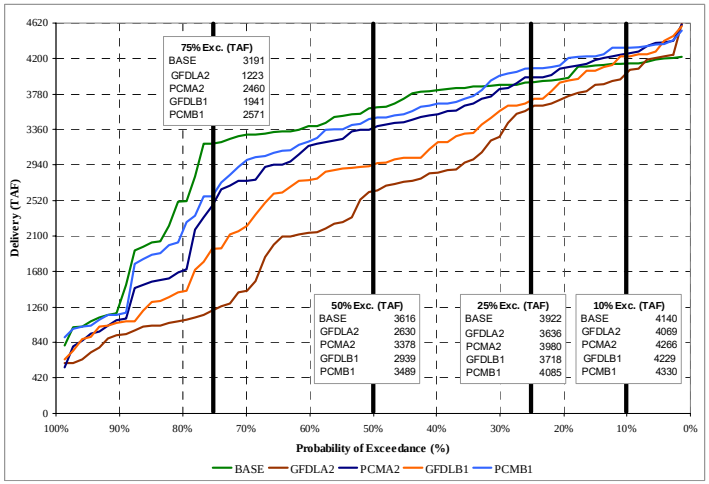
2035-2064





2070-2099





(Chung et al. 2006; Vicuña 2006)

Figure 7. Exceedance probability plot for Central Valley Project and the State Water Project

7.4 Potential Strategies for Reducing the Impacts on Water Resources

To compensate for the loss of natural storage in the snowpack, the existing man-made storage capacity will have to be managed more effectively, and also augmented. Modern probabilistic seasonal and short-term hydrology forecasting methods and more sophisticated decision algorithms could help reservoir managers better balance the competing demands of storage for water supply, hydropower, and flood control (Yao and Georgakakos 2001).[6] Besides this, it is likely that some form of additional storage will eventually be needed, whether above ground or below ground in the form of enhanced conjunctive use. More generally, it is likely that a portfolio of adaptation responses will be needed, including more conservation and increased efficiency in water use. The transmission systems for moving water around the state will also need to be both firmed up (to protect against seismic risks in the Delta, for example) and also enhanced to provide greater flexibility and connectivity in meeting water users' demands.

[6] A demonstration project is underway with funding from the CALFED Bay-Delta Program, the National Oceanic Atmospheric Administration (NOAA), and the Public Interest Energy Research Program (PIER). If that project is successful, it will pave the way for the operational use of these new management tools.

8.0 Agriculture

Agriculture, along with forestry, is the sector of the California economy that is most likely to be affected by a change in climate. California agriculture is a $68 billion industry.[7] California is the largest agricultural producer in the nation and accounts for 13% of all U.S. agricultural sales, including half of the nation's total fruits and vegetables. Regional analyses of climate trends over agricultural regions of California suggest that climate change is already in motion. Over the period 1951 to 2000, the growing season has lengthened by about a day per decade, and warming temperatures have resulted in an increase of 30 to 70 growing degree days per decade, with much of the increase occurring in the spring (Feng and Hu (2004). Climate change affects agriculture directly through increasing temperatures and rising CO_2 concentrations, and indirectly through changes in water availability and pests.

8.1. Temperature

Temperature influences crop growth through its impact on photosynthesis and respiration, as well as on growing season length and water use. Temperature also serves as a controlling factor for developmental processes, such as flowering and fruit maturation, which may be threatened if lengthening of the growing season introduces asynchrony between the timing of flowering and the life cycle of important insect pollinators.

Crop growth models show that a warming from a low to a higher temperature generally raises yield at first, but then becomes harmful (Doering et al. 2002). Possible effects of excessively high temperature include: decreased fruit size and quality for stone fruits, premature ripening and possible quality reduction for grapes, reduced fruit yield for tomatoes, increased incidence of tipburn for lettuce, and similar forms of burn for other crops. For example, rising temperatures are likely to produce adverse effects on quantity and quality for a number of California's agricultural products. For example, milk production has been found to decline when temperatures rise above 25°C (77°F), and Hayhoe et al. (2004) projected that in California milk production could decline up to 20% if temperatures rise to the higher warming range. Hayhoe et al. (2004) also projected a decline in wine grape quality as a result of increasing temperatures, where grapes in the major wine growing regions were expected to shift from optimal quality to marginal or impaired as temperatures rise to the higher warming range. Similarly, Baldocchi and Wong (2006) found that as temperatures rise from to the lower and medium warming ranges the number of chill hours declines, threatening the future viability of many species of fruit trees in the state.[8]

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[7] This is the 1998 figure for the total sales of agricultural and processing products in California (Kuminoff et al. 2001).

[8] Tree crops have become an increasingly prominent part of Central Valley agriculture over the three decades; the economic cost associated with the loss of a tree crop due to extreme weather conditions is likely to be significantly larger than that associated with the loss an annual field crop.

8.2. Carbon Dioxide (CO_2)

From a variety of studies in the literature, photosynthesis increases when a plant is exposed to a doubling of CO_2. However, whether this translates into increased yield of economically valuable plant product is uncertain and highly variable. Also, elevated CO_2 levels are associated with decreased concentrations of mineral nutrients in plant tissues, especially a decrease in plant nitrogen, which plays a central role in plant metabolism. Some crops may benefit in quality from an increase in CO_2; for example the fruit flavor of strawberries improves. Some crops are harmed by an increase in CO_2— for example grain protein in crops decreases and, in the case of wheat, breadmaking quality decreases (Cavagnaro et al. 2006).

8.3. Pests and Weeds

Growth rates of weeds, insect pests, and pathogens are also likely to increase with elevated temperatures, and their ranges may expand. A relatively new area of research involves the use of physiologically based dynamic models to fully understand the effects of weather (e.g., temperature, rainfall, solar radiation) on species dynamics. Gutierrez et al. (2006) used a dynamic model to estimate the potential impacts of a pest (pink bollworm, PBW) on cotton cultivation in the state. At the present time this pest is of importance only in the southern desert valleys (e.g., the Imperial and Coachella valleys), because winter frost restricts PBW's invasion to the million acres of cotton grown in the San Joaquin Valley. However, if winter temperatures rise by 2°C to 2.5°C (3.6°F to 4.5°F), as projected under the medium- to higher ranges of projected warming, the distribution of PBW would likely expand northward (Figure 8).

8.4. Potential Strategies for Reducing the Impact on Agriculture

Because of the greater priority being given to urban users in the event of water shortage, the agricultural sector is likely to bear a disproportionate share of water scarcity due to any climate-induced reduction in surface water supply. Farmers will likely respond by increasing their pumping of groundwater where this is available, shifting to higher value/less water-using crops, adopting higher efficiency methods of irrigation, and fallowing some farmland. Over time, new seed varieties could be developed that are better adapted to the changed climate and pest conditions, and entirely new crops may be found to meet pharmaceutical or energy supply needs. However, some of these adaptations may require publicly supported research and development if they are to materialize.

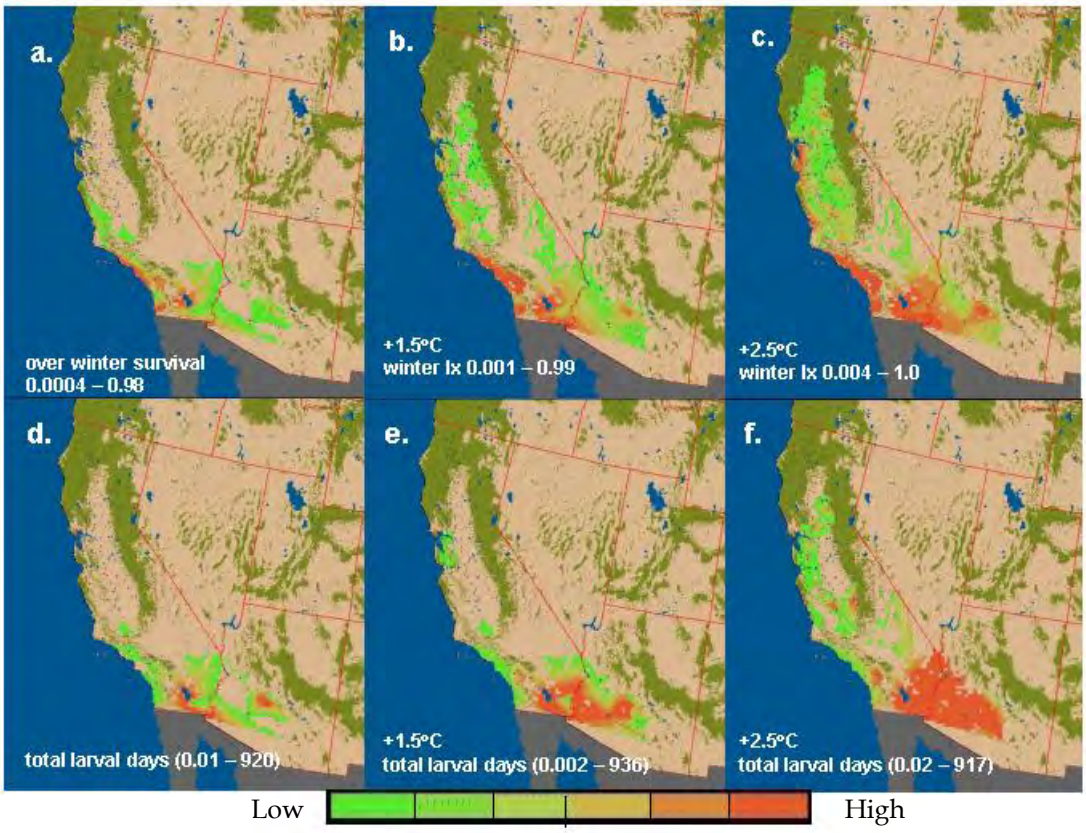


Figure 8. Cotton/pink bollworm (PBW): Predicting areas of favorableness

The effects on winter survival (a-c) and total seasonal pest PBW larval densities (larval days, d-e) under current weather (a,d) and with 1.5°C (2.7°F) (b,e) and 2.5°C (4.5°F) (c,f) increases in daily temperatures respectively (Gutierrez et al. 2006).

9.0 Forests and Natural Landscapes

Climate changes and increased CO_2 concentrations are expected to alter the extent and character of forests and other ecosystems (Field et al. 1999; McCarty et al. 2001; Aber et al. 2001). The distribution of species is expected to shift; the risk of climate-related disturbance such as wildfires, disease, and drought is expected to rise; and forest productivity is projected to increase or decrease—depending on species and region. In California, these ecological changes could have significant implications for both market (e.g., timber industry, fire suppression and damages costs, public health) and non-market (e.g., ecosystem services) values.

9.1. Natural Landscapes

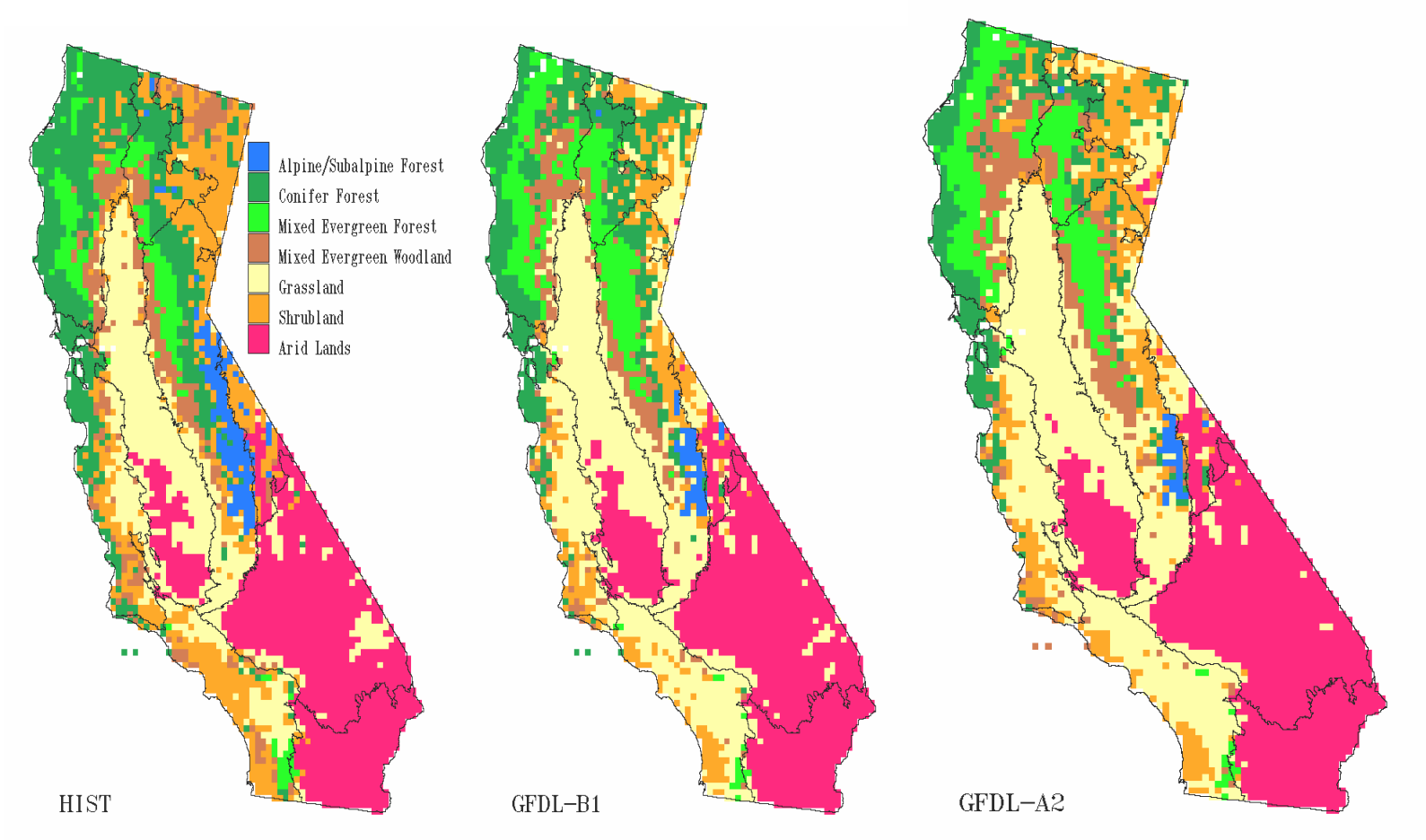
Lenihan et al. (2006) used the MC1 Dynamic Vegetation Model to simulate the response of vegetation distribution and ecosystem productivity to observed historical climate and to project the response to several scenarios of potential future climate change for California (Lenihan et al. 2006; Hayhoe et al. 2004). MC1 simulates lifeform mixtures and vegetation types; ecosystem fluxes of carbon, nitrogen, and water; and fire disturbance. The MC1 projections indicate that the ecosystems most susceptible to temperature rise are the alpine and subalpine forest cover. In addition, changes in fire frequency are expected to contribute to an increase in the expanse of grasslands, largely at the expense of woodland and shrubland ecosystems (Figure 9).

9.2. Wildfires

Fire is an important natural disturbance within many California ecosystems that promotes vegetation and wildlife diversity, releases nutrients and eliminates heavy fuel accumulations that can lead to catastrophic burns. The changing climate could alter fire regimes in ways that could have social, economic, and ecological consequences (McKenzie et al. 2004; Fried et al. 2004; Brown et al. 2004).

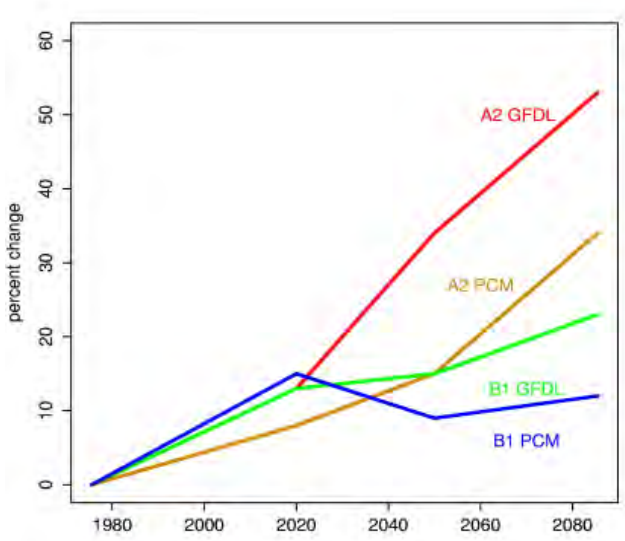
Westerling and Bryant (2006) estimated future statewide wildfire risk from a statistical model based on temperature, precipitation, and simulated hydrologic variables. These are conservative estimates because they do not include effects of extreme fire weather, but implications are nonetheless quite alarming. Projections made for the probabilities of "large fires"—defined as fires that exceed an arbitrary threshold of 200 hectares (approximately 500 acres)—indicate that the risk of large wildfires statewide would rise almost 35% by mid-century and 55% by the end of the century under a medium-high emissions scenario, almost twice that expected under lower emissions scenarios (Figure 10). Estimates of increased damage costs from the increases in fire season severity (Westerling and Bryant 2006) are on the order of 30% above current average annual damage costs.

A second study explored, through a case study in Amador and El Dorado Counties, the effects of projected climate change on fire behavior, fire suppression effort, and wildfire outcomes (Fried et al. 2006). Climate and site-specific data were used in California Department of Forestry and Fire Protection (CDF) standard models to predict wildfire behavior attributes such as rate of spread and burning intensity. The predicted wildfire



(Lenihan et al. 2006)

Figure 9. Vegetation distribution under historical conditions and multiple climate change scenarios at end of century



(Source: Westerling and Bryant 2006)

Figure 10. Percent change in the expected minimum number of large fires per year in California

outcomes were aggregated using the California Fire Economics Simulator version 2 (Fried and Gilless 1999), a stochastic computer model developed for CDF's fire protection planning program. The study found an increase in the projected area burned (10%–20%) and number of escaped fires (10%–40%) by the end of century, under the drier climate scenarios (GFDL). However, the less dry model showed little change.

Neither of these approaches for modeling the effects of climate change on wildfires considers the effects of the potential changes in wind conditions that may result from a changing climate, because the winds produced by GCMs are too coarse to be useful over most of the complex terrain in the California region. However, the strength and direction of winds can greatly influence fire behavior (Fried et al. 2004). Although initial studies suggest that future climate change may decrease early fall Santa Ana Wind conditions in some regions (Miller and Schlegel 2006), further research is needed to more thoroughly characterize potential changes in wind conditions and their possible effects on wildfires in the state.

9.3. Pests and Pathogens

Pests and disease have historically had a significant effect on California forests. The changing climate may exacerbate these effects, by expanding the range and frequency of pest outbreaks. For example, the introduced pathogen, pine pitch canker (*Fusarium subglutinans* f. sp. *pini*), once limited to coastal areas of California has expanded to the El Dorado National Forest in the Sierra Nevada. Rising winter temperature in the Sierra Nevada would make conditions more favorable for pitch canker, and could result in increased disease severity and economic loss (Battles et al. 2006).

9.4. Forest Productivity

Past studies project increases in forest productivity with continued climatic change (Mendelsohn 2003; Lenihan et al. 2003). However increasing evidence suggests that given the uncertainties concerning how trees will respond to elevated CO_2 concentrations (Körner et al. 2006), and the increased risk and susceptibility to catastrophic loss, the implications for the forest productivity and the timber industry may be less optimistic.

The recent assessment by Battles et al. (2006) of the expected impacts of climate change on the California forest sector used an industry standard planning tool to forecast 30-year tree growth and timber yields for forest stands in El Dorado County under a high and medium level of projected warming. Conifer tree growth was reduced under all climate change scenarios. In the medium level of projected warming, productivity in mature mixed-species stands was reduced by 20% by the end of the century. The reductions in yield were more severe (30%) for pine plantations.[9] Projections further indicate that the reduced growth rates could lead to substantial decreases in tree survival rates.

9.5. Potential Strategies for Reducing Impacts on Wildfire Risk and Forestry

Existing fire management strategies will be severely challenged by the interacting effects of expected changes in population and land use, and the projected changes in wildfire frequency and severity resulting from climate change. However, there are actions that can be taken in the near-term to improve our ability to live within California's fire-prone landscapes, while maintaining the functioning and structure of the ecosystems upon which we depend. For example, Moritz and Stephens (2006) suggest: (1) the adoption of a risk-based framework for fire management; (2) the reintroduction of fire to fire-prone ecosystems; (3) the creation of flexible policies that differentiate between the diverse ecosystems in California; and (4) a reevaluation of building and land use planning in the wildland-urban interface.

Battles et al. (2006) point to a number of strategies to offset declining forest yields. For example, silvicultural treatments could be designed to compensate growth losses to climate change with improvements in stand conditions. Planting mixtures of species, maintaining several age classes, reducing tree density, and pruning trees at strategic intervals are examples of cultural practices that could improve timber yields. Retaining a mixture of species and ages in the mixed conifer forests may alleviate some of the risks associated with the projected climatic changes. Single-species stands are at most risk. Spatially mixed forests limit the spread of both pathogens and insects. Decreasing tree densities reduce fuel loads and competition, and promote structures that are more resilient to catastrophic events like fire and epidemics.

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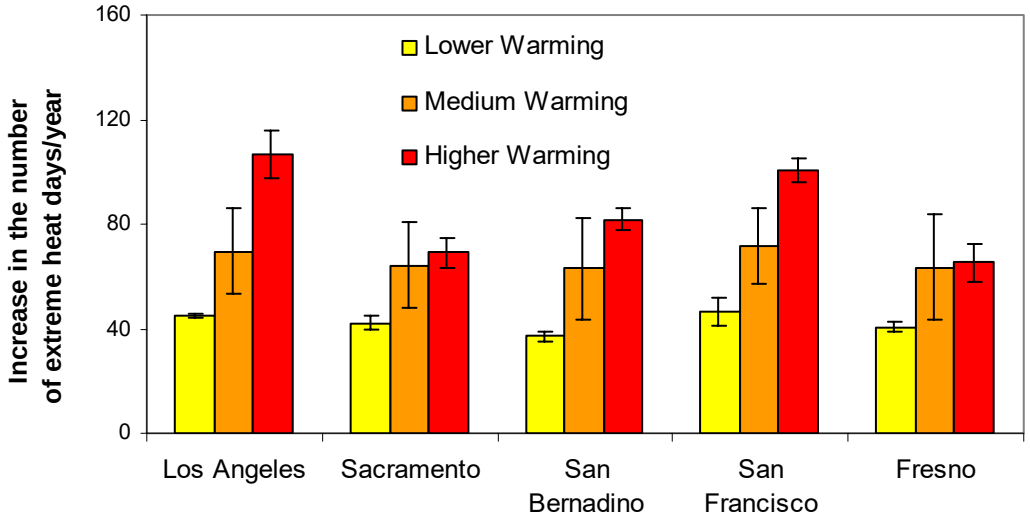
[9] The projections do not consider possible changes in vegetation distribution over the time period. However, Lenihan et al. (2006) analysis suggests that the composition for the study site considered in this study is expected to change very little over the next century.

10.0 Public Health

Climate change will affect the health of Californians by increasing the frequency, duration, and intensity of conditions conducive to air pollution formation, oppressive heat, and wildfires. The primary concern is not the change in average climate, but rather the projected increase in extreme conditions that are responsible for the most serious health consequences. In addition, climate change has the potential to influence asthma symptoms and the incidence of infectious disease.

10.1. Heat-related Deaths

Analyses of various climate change scenarios indicate that the future will have a greater number of extremely hot days and fewer extremely cold days, which may lead to two to six times as many heat-related deaths for the five cities studied (Drechsler et al. 2006). For the higher range of projected warming, the number of days over 31˚C (90˚F) in Los Angeles and over 35˚C (95˚F) in Sacramento will increase by up to 100 days by the end of the century—a striking increase over historical rates of occurrence, and almost twice the increase projected under the low-temperature path (Drechsler et al. 2006) (Figure 11).



(Source: Drechsler et al. 2006)

Figure 11. Projected increase in the number of extreme heat days relative to 1961–1990. *Extreme heat* is defined as the average temperature that is exceeded less than 10% of the days during the historical period (1961–1990), or approximately 36 days a year.

Individuals likely to be most affected include the elderly, the already ill, and the economically disadvantaged (CDC 2005a,b; Kilbourne 2002; Kaiser et al. 2001). Other identified risk factors for temperature-related health effects include social isolation, not leaving the home daily, and for heat-related death, living on the upper floors of multi-story buildings (Naughton et al. 2002). The number of deaths attributed to heat have declined over the past 30 years in the United States, primarily due to the increasing

number of households with central air conditioning, which appears to be the strongest protective factor (Davis et al. 2003; Donaldson et al. 2003). Kilbourne (2002) suggested that municipal housing codes be modified to require functional air conditioners in rental housing, in addition to existing requirements for heat. The U.S. Department of Commerce expects that air conditioning will be universal in the United States by 2050 (McGheehin and Mirabelli 2001), which will increase demand for electricity for residential cooling—especially on peak demand summer days in the future. In 2100, California will need at least 10% more electricity, compared to today's total generation capacity, for air conditioning alone on peak demand summer days (Miller et al. 2005). Ongoing studies are investigating the contribution of air pollution increases to deaths attributed to heat and refining the air conditioning demand estimates.

10.2. Air Pollution-related Death and Disease

Californians experience the worst air quality in the nation, with over 90% living in areas that violate either the state ambient air quality standard for ozone or particulate matter (PM) (CARB 2005a). The annual health impacts of these standard violations include 8800 premature deaths (3000–15,000 probable range), or 4% of all death; 9500 (4600–14,000) hospitalizations and emergency room visits; 2,800,000 (2,400,000–3,200,000) lost work days; and 4,700,000 (1,200,000–8,600,000) school absence days (CARB and OEHHA 2002, 2005; CARB 2005b). An annual value of $2.2 billion ($1.5–2.8 billion) is associated with hospitalizations and the treatment of major and minor illnesses related to air pollution exposure in California (CARB 2005b). In addition, the value of premature deaths resulting from exposure to air pollution in excess of the state's PM and ozone standards is $69 billion ($34–133 billion) (CARB 2005b). Current motor vehicle and industry control programs cost about $10 billion per year.[10] Ozone (from the precursors methane and nitrogen oxides, NO_X) and PM (especially elemental carbon), and to a lesser extent carbon monoxide and volatile organic compounds (VOCs), contribute to climate change (IPCC 2001).

Two recent reports from the National Research Council of the National Academies note that higher temperatures lead to increased emissions and formation of air pollution (NRC 2001, 2004). Maximum ozone levels are about double the current air quality standards and climate change will slow progress toward attainment by increasing emissions, accelerating chemical processes, and increasing summertime stagnation episodes. Model estimates of the effect of altered climate applied to current (2005) pollutant emission patterns show that temperature alone may alter emissions. For the medium-high emissions scenario, summer-time on-road VOC emissions from motor vehicles for the 2005 baseline are estimated to increase by 4% to 5% using temperature

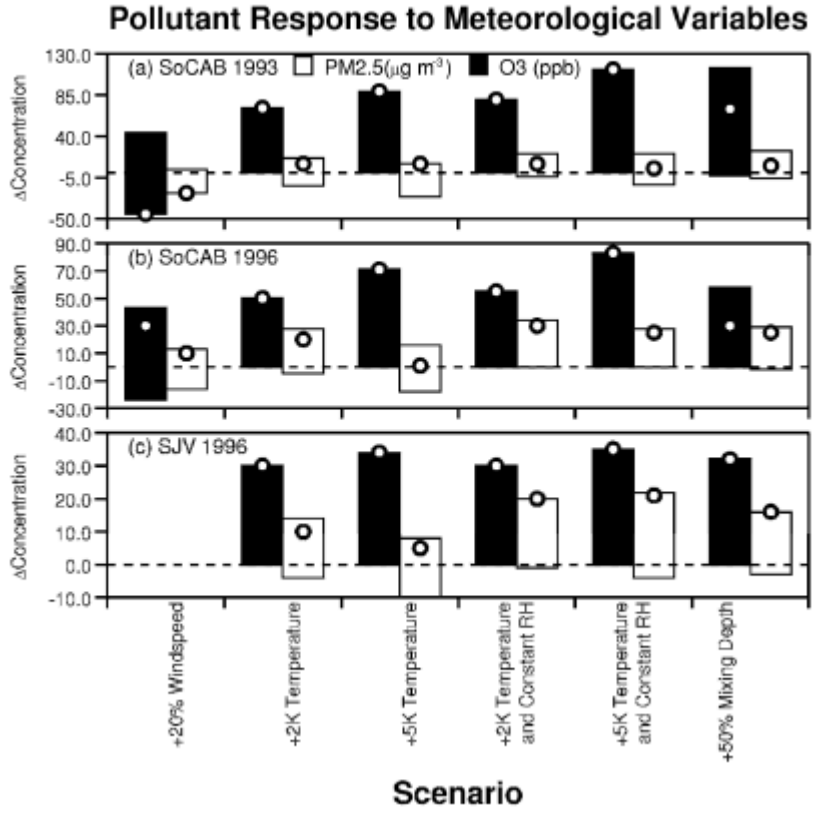
[10] The nationwide annual cost for air pollution control in 2000 was estimated to be $44 billion in 1986 dollars (USEPA 1991). Between 1986 and 2000, nationwide control costs grew about 3.85% annually. Assuming that control costs continued to grow at the same rate from 2000 to 2004, the annual control cost in 2004 is estimated to be about $53 billion in 1986 dollars. Using the Consumer Price Index (CPI), the nationwide annual cost of air pollution control is estimated to be $88 billion in 2004 dollars (the 2005 CPI is not yet available). Assuming California accounts for 12% of this expenditure (proportional to its population), the annual cost of air pollution control for California is about $10 billion.

projections for mid-century and by 13% to 16% for end-of-century temperature projections (Drechsler et al. 2006). These estimates also suggest small decreases in NO_X (Drechsler et al. 2006). Estimates for the low-emissions scenario are similar for mid-century and less than half for 2100. The medium-high emissions scenario results in a positive feedback loop for GHG emissions from on-road motor vehicles, with 4% to 5% increase in methane and 8% to 9% increases in CO_2 by 2100. These emissions estimates are strictly a test of sensitivity to temperature, as they do not take into account future changes in motorist behavior (e.g., increased air conditioning usage or increased miles driven), future growth in the number of vehicles or changes in the fleet mix, future emission controls, or possible technological advances in vehicle design. Constable et al. (1999) estimate that a doubled CO_2 atmosphere will result in a doubling of national biogenic VOC emissions. While California power plants are well controlled, higher temperatures lead to increased NO_X emissions (3% per °F, or 1.8% per °C) due to increased air conditioning usage (Drechsler et al. 2006).

A sensitivity study of three air pollution episodes in the South Coast Air Basin and San Joaquin Valley (Kleeman and Cayan 2006) found that increased temperatures favor the formation of ozone but discourage the formation of ammonium nitrate (a major component of PM). The decrease in PM caused by increased temperatures will be offset by other factors, most notably the increase in background ozone concentrations. The IPCC (2001) estimates that global background ozone concentrations could increase to 40–80 ppb by the year 2100 (up to double the current background value), largely due to emissions outside of California. Background ozone strongly contributes to the nighttime formation of particulate nitrate through the production of N_2O_5 in the upper atmosphere during the evening hours. A preliminary study by Kleeman and Cayan (2006) suggests that if global background ozone levels double, there would be an increase in $PM_{2.5}$ concentrations in California (Figure 12), despite the corresponding increase in temperature. Increased humidity also favors the formation of ozone and ammonium nitrate. Increased wind speed reduces ozone and PM concentrations by enhancing dilution of precursor emissions. Increased mixing depth also reduces PM concentrations, but leads to an increase in surface ozone concentrations because less NO_X is available to titrate the ozone that is produced aloft and mixed to the surface. The converse would be true for lowered wind speeds and mixing heights.

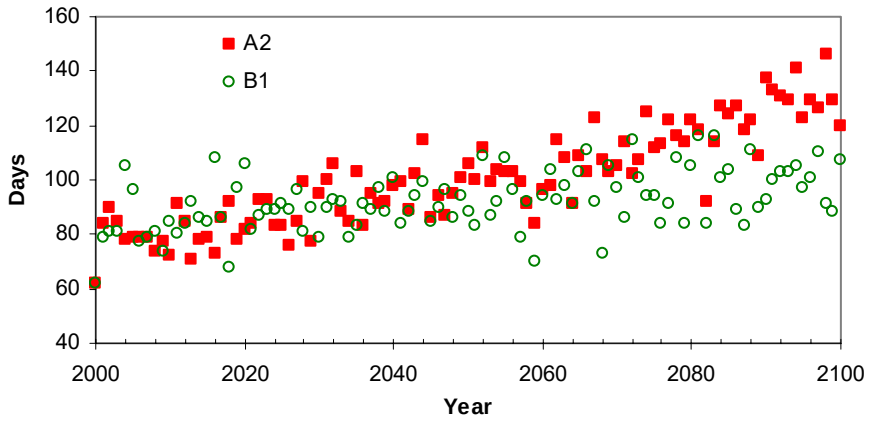
Statistically downscaled climate data from two simulations of one global climate model (GFDL) using two global emissions scenarios (a medium-high (A2) and a lower (B1) scenario), indicates that the number of days meteorologically conducive to pollutant formation could rise by 75% to 85% in the high ozone areas of Los Angeles (Riverside) (Figure 13) and the San Joaquin Valley (Visalia, the high ozone area downwind of Fresno) by the end of the century under a medium-high emissions scenario, but only 25% to 35% under the lower emissions path (Kleeman and Cayan 2006). In addition, global background ozone (primarily formed from the GHG methane and NO_X from fuel combustion) is projected to increase by 4-10 ppb (low scenario) to more than 20 ppb (high scenario) at 2100 (Prather et al. 2003). If background ozone increases by the amount projected for the high scenario, the state 8-hour-average ozone air quality standard of 70 ppb would be impossible to attain in much of California, even with near-zero local emissions. The future trend for PM is not as clear, because increasing

temperatures reduce some particle types while others show no change or increase slightly. Rainy days, wildfires, global dust storms, humidity, and other factors also affect PM, and are the subject of ongoing study (Kleeman and Cayan 2006).



(Source: Kleeman and Cayan 2006)

Figure 12. Summary of pollutant response to meteorological perturbations when background ozone concentrations are doubled to 60 ppb during pollution episodes that occurred in: (a) Southern California on September 9, 1993; (b) Southern California on September 25, 1996; and (c) the San Joaquin Valley on January 6, 1996. The bars represent the range of concentration change at any location in the modeling domain in response to the indicated perturbation. The circles represent the concentration change at the location of the maximum concentration for each pollutant.



(Source: Kleeman and Cayan 2006)

Figure 13. Projected days at Riverside meteorologically conducive to exceedances of the 1-hour California ambient air quality standard for ozone of 0.09 ppm.

10.2.1. Wildfires

Wildfires affect public safety and have the potential to significantly impact public health through their smoke. For example, a survey of 26% of all tribal households on the Hoopa Valley National Indian Reservation in northern California showed a 52% increase in medical visits for respiratory problems during a large fire in 1999, compared to the same period of 1998. More than 60% of those surveyed reported an increase in respiratory symptoms during the smoke episode, and 20% continued to report increased respiratory symptoms two weeks after the smoke cleared (Mott et al. 2002). The projected increases in fire season severity could lead (Westerling and Bryant 2006) to more "bad air" days. However, quantitative estimation of the impacts of future wildfire events is extremely difficult. The impacts of any fire are unique to that event, and are influenced not only by the magnitude, intensity, and duration of the fire, but also the proximity of the smoke plume to a population.

10.3. Asthma

Another concern of climate change is the effect on asthma prevalence and attacks. This impact is difficult to predict for several reasons. The most common asthma triggers are dust mites and molds, both of which are higher indoors than outdoors. Both require a relatively humid environment for survival. Consequently, if the climate becomes drier, or drought periods increase, these triggers will become less important. However, both will respond to higher humidity with increased growth, and these triggers may become more significant. Many asthmatics are allergic to various plant pollens. Plants and trees typically have pollination seasons that last a few weeks per year. To the extent that pollen seasons lengthen or become more intense in response to climate change, increased asthma exacerbation could result.

10.4. Infectious Disease

Climate change also has the potential to influence the incidence of infectious disease spread by mosquitoes, ticks, fleas, rodents, and food (Colwell and Patz 1998). More study is needed, because research to date has focused on short-term changes in weather patterns (primarily in ambient temperature and rainfall), rather than long-term changes.

10.5. Potential Strategies for Reducing Public Health Impacts

Some of the public health impacts can be reduced through adaptation measures, but costs are significant and special attention will need to be given to those most vulnerable to the health effects. For example, building climate change considerations into efforts to attain the health-based air quality standards will be necessary in the long-term if the standards are to be met. In addition, heat emergency action plans can help reduce those affected by extreme heat waves (Bernard and McGeehin 2004). Chicago and Milwaukee have developed effective heat emergency plans that could serve as models for California. In both cities, heat-related death rates were considerably lower during the 1999 heat wave, during which the action plans developed in response to the 1995 heat wave were activated (Naughton et al. 2002; Weisskopf et al. 2002). However, Bernard and McGeehin (2004) reviewed heat emergency plans from 18 cities, and found that many plans were inadequate, and that many other at-risk cities had no heat emergency action plans. These findings point to the urgency of developing heat emergency action plans for California before the need arises, and the inclusion of objective criteria for assessing the effectiveness of the plans.

11.0 Electricity Generation and Demand

Changes in temperature and other meteorological variables will affect both the generation of and demand for electricity. The demand for natural gas to warm our homes and buildings will also be affected, most likely resulting in reduced demand in the winter. This section summarizes what is known about the potential effects of climate change on electricity in California and presents some new results for the climate scenarios discussed in previous sections.

11.1. Electricity Generation: Hydropower

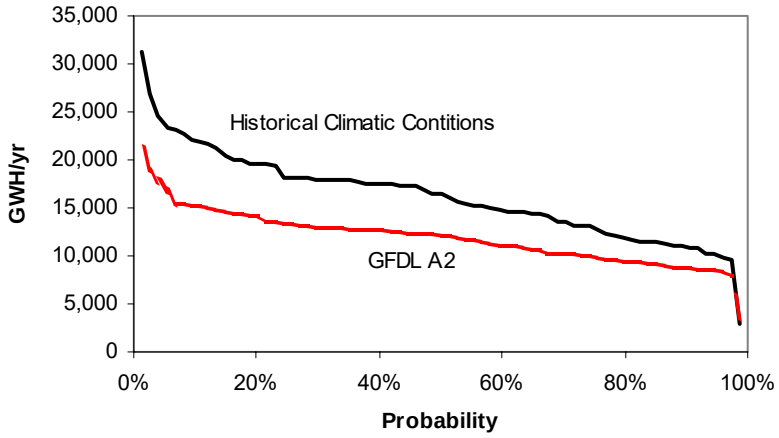
Changes in precipitation levels, should they occur, and changes in the patterns and timing of snowmelt would alter the amount of electricity that hydroelectric facilities could generate. It would also affect seasonal availability, with less water available for hydroelectric generation in the late spring and summer months, when demand is the highest. In addition, there is a high likelihood that changes in precipitation and runoff patterns would lead to changes in broader water policies and end-use priorities, such as water supply and flood control, which could place further limitations on hydroelectric production. Currently, hydropower generation contributes about 15% of California's in-state electricity production, with a range from 9% to 30%, due to variations in climatic conditions. Because it is used predominantly during on-peak periods, hydropower's value outweighs its simple energy contribution. In addition, the state also receives a significant amount of surplus power hydroelectric facilities from the Pacific Northwest, which will also be affected by climate change.

Two recent studies project losses in annual hydropower generation on the order of 10% to 30% by the end of this century, if precipitation levels in California decline (Lund et al. 2003; Vanrheenen et al. 2004). An important caveat about these studies is that they only addressed generation associated with relatively low elevation units, representing about 44% of the total generation capacity from hydropower facilities in the state.

For this study an economic-engineering optimization model of the state water system (CALVIN) was run to estimate the potential impacts of climate change on water resources assuming hypothesized year 2050 level of development with the climate conditions estimated for the end of the century (2070–2099) by the GFDL model for the A2 emissions scenario. As with previous studies, this study indicates that reductions of hydropower generation for relatively low elevation units on the order of 30% would occur, which is a response to a reduction of about 28% in streamflows. Figure 14 presents the frequency distribution of hydropower generation from the major water supply reservoirs modeled in CALVIN. As a point of reference, in the 1990 to 2002 period, California generated from 20,000 gigawatt-hours (GWh) to 51,000 GWh in a given year (Medellin et al. 2006).

Another recent study prepared by the California Department of Water Resources (DWR) used climate projections for the middle of this century (Chung et al. 2006). The DWR modeled the State Water and Central Valley Projects which, as indicated above, represent about 27% of the state's hydroelectric capacity. This study indicates that reductions in electricity generation of approximately 7% would occur for most of lower

and medium range of projected warming. However, for the PCM B1 scenario, the least dry scenario, DWR estimated an increase in generation on the order of 4%.



(Source: Medellin et al. 2006)

Figure 14. Probability of producing at a minimum level of generation in a year in major water supply reservoirs modeled in CALVIN: period centered in 2050.

All the studies reported so far address potential impacts on hydropower units that are located in relatively low elevations and served by a large reservoir storage capacity. These can be used to partially offset the trend to an early melting of the snow stored in the Sierra Nevada. Hydropower units in relatively medium and low elevations have little reservoir storage capacity and rely more heavily on the accumulated snow as a natural reservoir. A substantial fraction of the mountain snowpack that supplies water to these units in the spring and summer is located above 1200 meters (3900 feet). This zone is the most vulnerable area to higher temperatures and is expected to experience the most dramatic spring snow losses (Knowles and Cayan 2004). At the present time, the quantitative evaluation of the potential impacts on the medium and high elevation units remains is an unexplored area of study. However, a recent exploratory study of a system owned and operated by the Sacramento Municipal Utility District (SMUD) in the Upper American River Watershed indicates that, as with lower elevation hydro units, electricity generation would go down in response to lower precipitation levels but the existing reservoir system would be able to store enough water to allow generation of electricity in the hot summer months when it is most needed (Vicuña et al. 2006). This occurs despite earlier streamflow runoff caused by climate change. It is unclear how this and other similar systems would respond under scenarios with increased precipitation levels. The most important variables that will determine impacts are storage capacity of the system relative to the volume of stream inflows and the timing of runoff as it compares to the pattern and timing of energy demand.

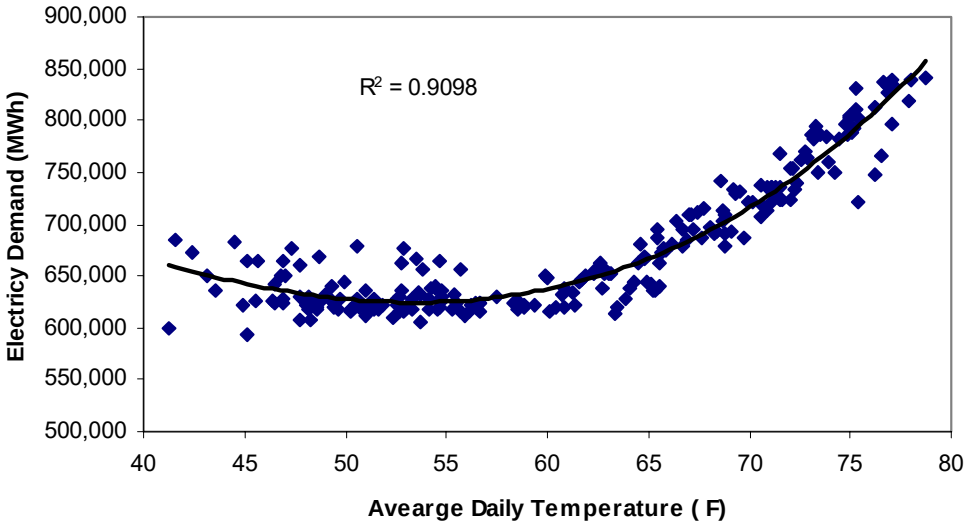
It is important to emphasize that even relatively small changes in in-state hydropower generation result in substantial extra expenditures for energy generation, because this "free" generation must be purchased from other sources. For example, assuming a decrease of 10% from the current average in-state generation level from this renewable energy source, and assuming a price of about 10 cents per kilowatt-hour, this decrease would result in an additional $350 million per year in net expenditures to purchase sufficient electricity to replace the electricity that otherwise would be generated using hydroelectric resources.

11.2. Electricity Demand

One of the few papers that have been published on the potential effect of climate change on electricity demand in California, (Baxter and Calandri 1992) indicates significant increases in electricity requirements. This study was guided by energy forecast models that were developed for or by the Energy Commission to estimate electricity demand taking into account increased population and economic activity. Under their worst-case scenario (a 1.9ºC (3.4ºF) increase), electricity requirements in 2010 would increase by about 7,500 GWh, and would require an additional peak capacity of 2,400 MW. This trend would represent an increase of about 2.6% and 3.7% in energy and peak generation capacity, respectively, from their 2010 base case.

Since it is impossible to know how the energy system and socioeconomic conditions in the state will evolve in the next 100 years, the study described below investigates how future climate projections would affect electricity demand assuming the current infrastructure and demographics. In practice, higher temperatures will increase the penetration of air conditioning units for cooling, but, more important, this approach fails to consider the trend toward more development in the interior parts of California that experience higher temperatures. For these reasons, actual impacts could be higher than what is reported in this section.

Figure 15 shows daily demand of electricity for the area serviced by the California Independent System Operator (CalISO) in 2004 as a function of the simple average of daily temperatures in San Jose, Sacramento, Fresno, and Los Angeles. Figure 15 only includes demand during weekdays, and excludes holidays.

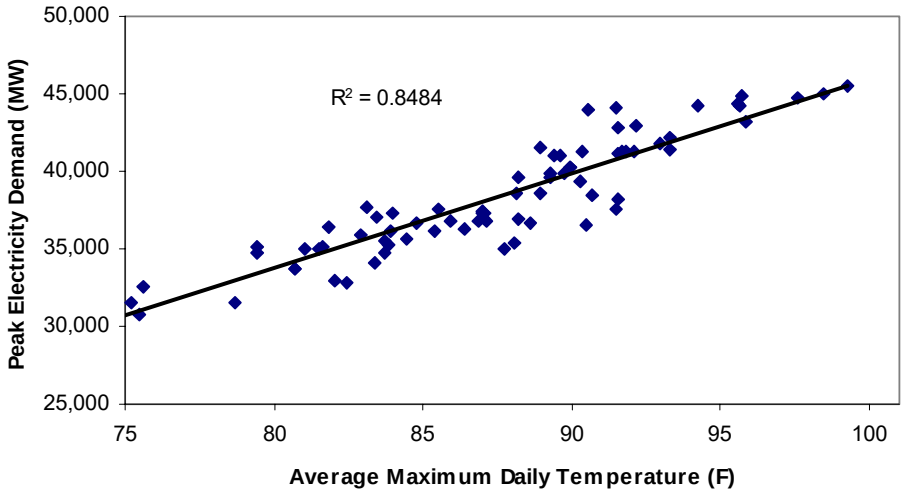


(Source: Franco and Sanstad 2006)

Figure 15. Electricity demand in the CalISO area as function of average temperatures: 2004

Peak electricity demand occurs mostly in the summer months, and it is a strong function of maximum daily temperatures. Figure 16 presents the daily peak energy demand in the CalISO region as function of the average daily maximum temperature measured in San Jose, Sacramento, Fresno, and Los Angeles. It only includes non-holiday weekdays. Electricity consumption during weekends and holidays tends to be lower.

Franco and Sanstad (2006) used these relationships between demand and temperature, to estimate the impact of higher temperatures on annual electricity and peak summer demands (see Table 2). Estimated changes in electricity demand were determined from multiple temperature projections as reported by Cayan et al. (2006a) for grid points close in the cities listed in the previous paragraphs. To calculate changes in peak demand, they used averaged maximum annual temperatures for the periods listed in Table 2.



(Source: Franco and Sanstad 2006)

Figure 16. Peak electricity demand in the CalISO area as a function of maximum daily temperature: June-September 2004

Table 2. Estimated incremental changes in annual electricity and peak load demands for lower, higher, and medium range of projected warming relative to 1961 to 1990 base period

Time Period	Projected Warming Range	Change in Annual Electricity Demand (%)	Change in Peak Demand (%)	Climate Model	Emission Scenario
2005–2034	Low	0.9	1.4	PCM	Low (B1)
		2.5	1.5	GFDL	Low (B1)
		1.2	1.0	PCM	Medium-High (A2)
	Medium	2.9	3.6	GFDL	Medium-High (A2)
	High	3.4	4.8	HadCM3	Higher (A1fI)
2070–2099	Low	3.1	4.1	PCM	Low (B1)
		5.8	7.3	GFDL	Low (B1)
		5.3	5.6	PCM	Medium-High (A2)
	Medium	11.0	12.1	GFDL	Medium-High (A2)
	High	20.3	19.3	HadCM3	Higher (A1fI)

Annual expenditures of electricity demand in California represent about $28 billion (U.S. EIA 2005). Therefore, even the relatively small increases in energy demand shown in Table 2 would result in substantial extra financial expenditures for energy services in the state. For example, assuming a linear increase in electricity expenditures from the recent

historical period, a 3% increase in electricity demand by 2020 would translate to about $1.2 billion nominal dollars a year in additional electricity expenditures.

11.3. Potential Strategies for Reducing Impacts on Electricity Sector

The impacts of climate change on the electricity system will depend in part on how the electricity system evolves in the future. For example, an increased penetration of photovoltaic (PV) systems would reduce the impacts of peak demand because this energy source closely matches the diurnal demand for electricity (Borenstein 2005), but other technologies could also be used to satisfy an increased demand. Energy efficiency programs will reduce electricity demand counteracting some of the negative effects of increased ambient air temperatures. Finally, reducing the heat island effect with the use of more reflective surfaces (e.g., for roofs and pavement) and planting trees that provide shade to homes and buildings will also allow the state to better cope with the expected temperature increases.

12.0 Implications for Mitigation and Adaptation

Continued climate change would have widespread impacts on California's economy, ecosystems, and the health of its citizens. The analyses summarized in Figure 17, however, suggest that many of the more severe impacts projected under the medium and higher warming ranges could be avoided by following the lower emissions pathway. However, if the actual climate sensitivity to GHGs reaches the level of the more sensitive global climate models employed here, an even lower emissions path than the B1 scenario may be required to avoid the medium warming range. How much would GHG emissions have to be reduced to stay below the lower emissions pathway (B1) and insure against temperatures rising to the medium and higher warming ranges presented in this study? The Governor's Executive Order #S-3-05 calls for an 80% reduction in GHG emissions below 1990 levels by 2050. If the industrialized world were to follow California's lead, and assuming the industrializing nations followed the B1 pathway, global emissions would remain below the lower emissions scenario (B1),[11] increasing the likelihood that California and the world would be on track to avoid the more severe impacts by preventing temperatures from rising to the medium warming range.[12] This estimate of the impact of an 80% reduction by the industrialized world has on global emissions depends crucially on the development patterns of the developing world. The SRES B1 scenario assumes development proceeds with a "high level of environmental and social consciousness" with a transition to "alternative energy systems" (Nakicenovic et al. 2000). Emission reductions targets such as the one set by the Governor's Executive Order could spur the innovation necessary to lead the world to a transition to alternative energy systems.

However, even if global emissions stay below the lower emissions scenario (B1), some impacts from climate change are inevitable. Evidence indicates that even if actions could be taken to immediately curtail GHG emissions, the potency of GHGs that have already built up, their long atmospheric lifetimes, and the inertia of the Earth's climate system could result in average global temperatures rising an additional 0.6°C (1.1°F) (Wigley 2005; Meehl et al. 2005). As a result, some impacts from climate change, in California and across the globe, are now unavoidable. Consequently, although it is not the solution to global warming, it is becoming clear that adaptation is an essential complementary strategy to manage some of the projected impacts of climate change.

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[11]This was calculated as follows: (1) Organisation for Economic Co-operation and Development (OECD) population and total emissions were based on SRES B1 IMAGINE runs (Nakicenovic et al. 2000). OECD total emission in 1990 were 2.83 GtC; (2) Eighty percent below this value is 566 MtC; (3) Total global emissions was calculated by adding the 566 MtC to the total emissions for non-OECD countries, as projected by SRES B1. This value is approximately 10 GtC; (4) This 10 GtC/yr was compared to the global emission projected in the B1 scenario (approximately 11 GtC/yr).

[12] As illustrated in Figure 1, beyond 2050, global emissions will need to decrease substantially below 10 GtC/yr to stay on the B1 pathway out to the end of the century. The SRES B1 pathway assumes global emissions decrease to 4.23 GtC/yr by 2100. However, stabilizing atmospheric concentrations will require even lower emissions as natural uptake is estimated between 0.7–2.9 GtC/yr (IPCC 2001).

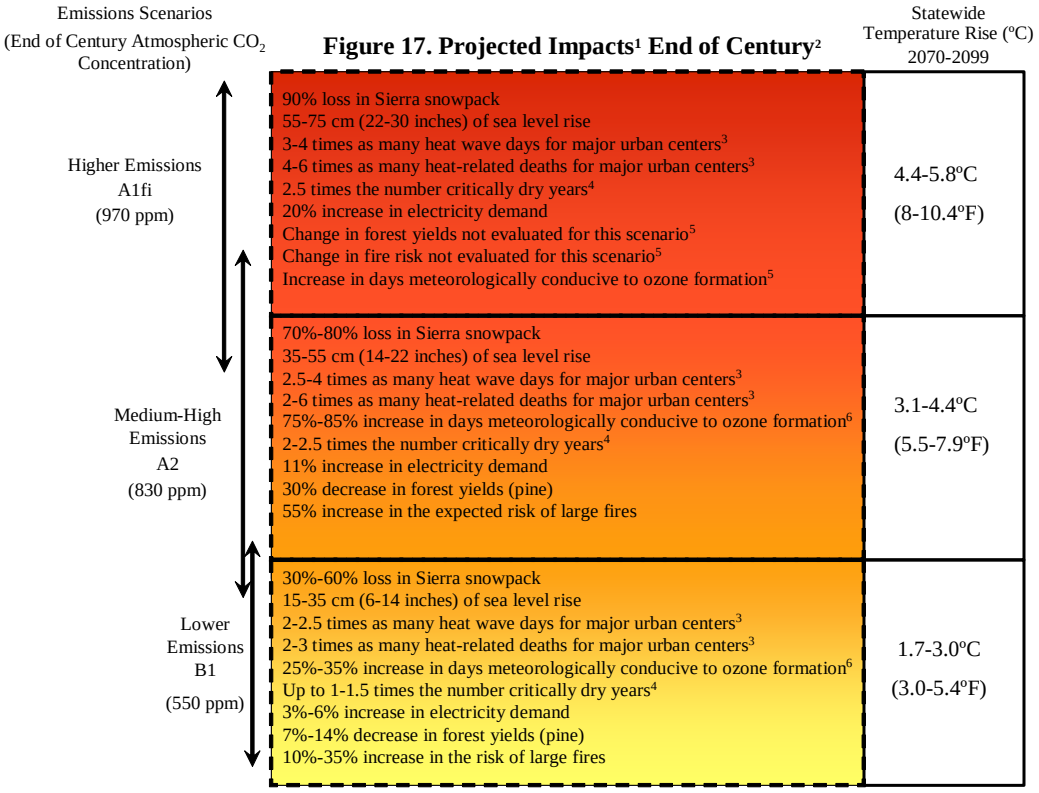


Figure 17. Projected impacts[1] end of 21st century.[2] Impacts presented relative to 1971–2000.

[1] The impacts summarized in this figure reflect projections from different models, based on the current scientific understanding of the relevant social and biophysical processes. Because our scientific understanding is still developing in some key processes that would affect the sectors studied, we provide here some guidance to our levels of confidence of these projections. We assign high confidence to the direction of change in all of impacts described in Figure 17. However, in some sectors we have less confidence in the magnitude of change, because the projections are based on specific assumptions about future development patterns or societal response to projected changes. For example, changes in the number of heat-related deaths could decrease if different assumptions were made about the effectiveness of adaptation measures such as air conditioner use. Furthermore, neither the projection for heat-related deaths nor the projected increases in energy demand take into account population growth, and thus the magnitude of the impact may be significantly higher than the projections presented here. Similarly, the projections for wildfire risk may be conservative, in that they assume constant population and existing vegetation, land-use, and management patterns.

[2] The projected warming ranges presented here are for 2070–2099, relative to 1971–2000. However, some of the impacts summarized in this report used a different historical climatological baseline of 1961–1990. The difference between the 1961–1990 and 1971–2000 baselines leads to a small difference in projected temperature rise for the different scenarios and models. The difference in baselines amounts to approximately a 0.2°C (0.36°F) difference in the full range of projected end-of-century temperature rise.

[3] Los Angeles, San Bernardino/Riverside, San Francisco, Sacramento, and Fresno.

[4] Measures for the San Joaquin and Sacramento basins.

[5] Impacts expected to be more severe as temperatures rise. However, the higher range of projected warming was not assessed for the project.

[6] For high ozone locations in Los Angeles (Riverside) and the San Joaquin Valley (Visalia).

While there are many opportunities for California to increase its capacity to cope with the projected changes, these often can be costly and require time and planning. Furthermore, there are critical limits to adaptation, especially in addressing the threats of abrupt climate changes or in dealing with those impacts on natural, unmanaged species and ecosystems, which may not be able to keep up with the increasingly rapid and severe climate changes expected if emissions go unabated. In addition, managing the impacts of climate change may be particularly challenging when different kinds of changes are experienced together. For example, how would California manage in years where it was subjected simultaneously to an extreme heat wave, an energy blackout, and widespread wildfires, during an extended drought? While at present we are unable to predict the probability and all of the consequences of such an event, in preparing for change we must consider the potential compounding effects of multiple impacts.

Finally, the ability to cope and adapt is differentiated across populations, economic sectors, and regions within the state. As a result, without appropriate mitigating actions, climate change will likely aggravate existing equity issues within California and the rest of the United States. For example, the most vulnerable populations to the health impacts of climate change are children, elderly people, and the poor—the same groups that already face the greatest health and environmental risks.

In order to realize the state's adaptive and mitigative response potential, the state will need to continue to generate public discussion, build awareness, and foster the political will necessary to manage climate change.

13.0 The Need for Climate Change Information for California

There are key unknowns in the cascade of effects of climate change that inhibit better planning and policy actions. For example, better monitoring is needed of California's climate and climate-sensitive sectors to detect and understand a complex chain of impacts. In particular, more work is needed on ecological impacts both in terrestrial and aquatic systems, in the development of more detailed, probabilistic climate projections for the state, and to determine how climate changes and environmentally related policies might impact the California economy, recreation, and tourism. A more comprehensive analysis of the effects of climate change on energy supply and demand, within and outside of California, is needed. The effect of climate change on water resources, including more quantitative understanding of water supply and water demand for the rich complex of agricultural and natural ecosystems in the state is still not well understood. A geographically detailed analysis of the impacts of sea level rise on the California coast and the San Francisco Bay and Delta will be needed to assess potential impacts and conduct planning on local and regional scales. The impact of climate and climate change on temperature-related deaths, air pollutant emissions and quality impacts, and other aspects of human health will require more data and further study. Population growth, urbanization, and technological innovation are among a number of important factors that directly affect these areas. Given the serious potential consequences of climate change on the state's resources, the research community should continue to produce the tools, methods, and information that will be needed to develop robust coping or adaptation strategies in California.

Moreover, additional information is needed to help identify and understand the social and institutional constraints to managing climate change. The international and some national research efforts increasingly have turned away from simple impact assessments towards a "vulnerability" assessment approach that focus on identifying what makes certain populations and sectors susceptible to impacts of climate change. The vulnerability framework considers climate change within the context of multiple interacting stresses—such as population growth, land-use change, and institutional change. California's climate research should begin to include this research framework to identify the most vulnerable populations and regions of the sate, and develop strategies to build their resilience to climate variability and change, and related stresses.

14.0 References

Aber, J., R. P. Neilson, et al. 2001. "Forest processes and global environmental change: Predicting the effects of individual and multiple stressors." *BioScience* 51(9): 735–751.

Baxter, Lester W., and Kevin Calandri. 1992. "Global warming and electricity demand: A study of California." *Energy Policy* March: 233–244.

Baldocchi, D., A. Gutierrez, M. Hanemann, L. Dale, and W. Schlenker. 2006. An assessment of impacts of future CO_2 and climate on agriculture. (www.climatechange.ca.gov/).

Battles, J., T. Robards, A. Das, K. Waring, J. K. Gilles, F. Schurr, J. LeBlanc, G. Biging, and C. Simon. 2006. Climate change impact on forest resources. (www.climatechange.ca.gov/).

Bernard, S., and M. McGeehan. 2004. "Municipal heat wave response plans." *American Journal of Public Health* 94: 1520–1522.

Brekke, L. D., N. L. Miller, K. E. Bashford, N. W. T. Quinn, and J. A. Dracup. 2004. "Climate change impacts uncertainty for water resources in the San Joaquin River Basin, California." *J. American Water Resources Association* 40(1): 149–164.

Brown, S., T. Pearson, et al. 2004. Baseline Greenhouse Gas Emissions for Forest, Range, and Agricultural Lands In California. Sacramento, California Energy Commission: 1–91.

Borenstein, S. 2005. "Valuing the Time-Varying Electricity Production of Solar Photovoltaic Cells." CSEM Working Papers. The University of California Energy Institute (UCEI). March.

CARB (California Air Resources Board). 2005a. *The California Almanac of Emissions and Air Quality: 2005 Edition.* www.arb.ca.gov/aqd/almanac/almanac05/almanac05.htm.

CARB (California Air Resources Board). 2005b. *Draft Emission Reduction Plan for Ports and International Goods Movement in California.* www.arb.ca.gov/planning/gmerp/gmerp.htm. December 1.

CARB and OEHHA.(California Air Resources Board and Office of Environmental Health Hazard Assessment. 2002. *Staff Report: Public Hearing to Consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates.* www.arb.ca.gov/research/aaqs/std-rs/pm-final/pm-final.htm. May 3.

CARB and OEHHA (California Air Resources Board and Office of Environmental Health Hazard Assessment). 2005. *Revised Staff Report: Public Hearing to Consider Amendments to the Ambient Air Quality Standards for Ozone.* www.arb.ca.gov/research/aaqs/ozone-rs/rev-staff/rev-staff.htm. October.

Cavagnaro, T., L. Jackson, and K. Scow. 2006. *Climate change: Challenges and solutions for California agricultural landscapes.* (www.climatechange.ca.gov/).

Cayan, D., E. Maurer, M. Dettinger, M. Tyree, K. Hayhoe, C. Bonfils, P. Duffy, and B. Santer. 2006a. *Climate scenarios for California.* (www.climatechange.ca.gov/).

Cayan. D., P. Bromirski, K. Hayhoe, M. Tyree, M. Dettinger, and R. Flick. 2006b. *Projecting future sea level.* (www.climatechange.ca.gov/).

CDC (Centers for Disease Control and Protection). 2005a. "Hypothermia-related deaths – United States, 2003–2004." *Morbidity and Mortality Weekly Report* 54: 173–175.

CDC. 2005b. "Heat-related mortality–Arizona, 1993–2002, and United States, 1979–2002." *Morbidity and Mortality Weekly Report* 54: 628–630.

Chung et al. 2006. *Progress on Incorporating Climate Change into Management of California's Water Resources.* California Department of Water Resources.

Colwell, R., and J. Patz. 1998. *Climate, Infectious Disease and Health: An Interdisciplinary Perspective.* American Academy of Microbiology.

Constable, J., A. Guenther, D. Schimel, and R. Monson. 1999. "Modeling changes in VOC emission in response to climate change in the continental United States." *Global Change Biology* 5: 791–806.

Davis, R., P. Knappenberger, P. Michaels, and W. Novicoff. 2003. "Changing heat-related mortality in the United States." *Environmental Health Perspectives* 111: 1712–1718.

Delworth, T. et al. 2005. "GFDL's CM2 global coupled climate models - Part 1: Formulation and simulation characteristics." Accepted for publication in the *Journal of Climate,* April 2005.

Doering, O. C. et al. 2002. *Effects of Climate Change and Variability on Agricultural Production Systems.* Kluwer Academic Publishers. Boston.

Donaldson, G., W. Keatinge, and S. Nayha. 2003. "Changes in summer temperature and heat-related mortality since 1971 in North Carolina, South Finland, and Southern England." *Environmental Research* 91: 1–7.

Dreschler, D. M., N. Motallebi, M. Kleeman, D. Cayan, K. Hayhoe, L. S. Kalkstein, N. Miller, S. Sheridan, and J. Jin. 2006. *Public health-related impacts of climate change.* (www.climatechange.ca.gov/).

Feng S., and Q. Hu. 2004. "Changes in agro-meteorological indicators in the contiguous United States: 1951–2000." *Theoretical and Applied Climatology* 78: 247–264.

Field, C., G. C. Daily, et al. 1999. *Confronting Climate Change in California Ecological Impacts on the Golden State.* The Union of Concerned Scientists and The Ecological Society of America.

Flick, R. E. 1998. "Comparison of California tides, storm surges, and mean sea level during the El Niño winters of 1982–1983 and 1997–1998." *Shore and Beach* 66(3):7–11.

Franco, G., and A. Sanstad. 2006. *Electricity Demand and Climate Change in California.* (www.climatechange.ca.gov/).

Fried, J. S., M. S. Torn, et al. 2004. "The impact of climate change on wildfire severity: A regional forecast for Northern California." *Climatic Change* 64: 169–191.

Fried et al. 2006. *Predicting the effect of climate change on wildfire severity and outcomes in California: A preliminary analysis.* (www.climatechange.ca.gov/).

Fried, J. S., and J. K. Gilless. 1999. *CFES2: The California Fire Economics Simulator Version 2 User's Guide*. University of California, Division of Agriculture and Natural Resources Publication 21580. 92 pp.

Gutierrez, A. P. 2006. *Analysis of climate effects on agricultural systems.* (www.climatechange.ca.gov/).

Hayhoe, K., D. Cayan, et al. 2004. "Emissions pathways, climate change, and impacts on California." *PNAS* 101(34): 12422–12427.

IPCC. 2001. *IPCC Third Assessment Report, Climate Change 2001: The Scientific Basis.* Intergovernmental Panel on Climate Change.

Joyce, B., et al. 2006. *Climate change impacts on water for agriculture in California: A case study in the Sacramento Valley.* (www.climatechange.ca.gov/).

Kaiser, R., C. Rubin, A. Henderson, M. Wolfe, S. Kieszak, C. Parrott, and M. Adcock. 2001. "Heat-related death and mental illness during the 1999 Cincinnati heat wave." *The American Journal of Forensic Medicine and Pathology* 22: 303–307.

Kilbourne E. M. 2002. "Heat-related illness: Current status of prevention efforts." *American Journal of Preventative Medicine* 22: 328–329.

Kleeman, M., and Dan Cayan. 2006. *Impact of Climate Change on Meteorology and Regional Air Quality In California.* Interim Report to ARB. January

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2005. "Trends in Snowfall versus Rainfall in the Western United States." *J. Climate,* in review.

Knowles, N., and D. R. Cayan. 2004. "Elevational dependence of projected hydrologic changes in the San Francisco estuary and watershed." *Climatic Change* 62: 319–336.

Körner, C., R. Asshoff, O. Bignucolo, S. Hättenschwiler, S. G. Keel, S. Peláez-Riedl, S. Pepin, R. Siegwolf, and G. Zotz. 2005. "Carbon Flux and Growth in Mature Deciduous Forest Trees Exposed to Elevated CO_2." *Science* 309:1360–1362.

Kuminoff, N. V., A. D. Sokolow and D. A. Sumner. 2001. Farmland Conversion: Perceptions and Realities. Agricultural Issues Center, Issues Brief No 16.

Lenihan, J. M., R. Drapek, et al. 2003. "Climate change effects on vegetation distribution, Carbon, and Fire in California." *Ecological Applications* 13(6): 1667–1681.

Lenihan et al. 2006. *The response of vegetation distribution, ecosystem productivity, and fire in California to future climate scenarios simulated by the MC1 dynamic vegetation model.* (www.climatechange.ca.gov/).

Liang, X., D. P. Lettenmaier, E. Wood, and S. J. Burges. 1994. "A simple hydrologically based model of land surface water and energy fluxes for general circulation models." *Journal of Geophysical Research* 99: 14,415–414,428.

Liang, X., D. P. Lettenmaier, and E. F. Wood. 1996. "One-dimensional statistical dynamic representation of subgrid spatial variability of precipitation in the two-layer variable infiltration capacity model." *Journal of Geophysical Research* 101: 21,403–421,422.

Lund, J. R., et al. Climate Warming & California's Water Future. 2003. California Energy Commission: Sacramento. 1–251. This is appendix VII in www.energy.ca.gov/pier/final_project_reports/500-03-058cf.html.

McCarty, J. P. 2001. "Ecological Consequences of Recent Climate Change." *Conservation Biology* 15: 320–331.

McGeehin, M. A., and M. Mirabelli. 2001. "The Potential Impacts of Climate Variability and Change on Temperature-Related Morbidity and Mortality in the United States." *Environmental Health Perspectives* 109 (Supplement 2): 185–189.

McKenzie, D., Z. Gedalof, D. L. Peterson, P. Mote. 2004. "Climatic change, wildfire, and conservation." *Conservation Biology* 18: 890–902.

Medellin, J., J. Harou, M. Olivares, J. Lund, R. Howitt, S. Tanaka, M. Jenkins, and T. Zhu. 2006. *Climate warming and water supply management in California.* (www.climatechange.ca.gov/).

Meehl, G. A. et al. 2005. "How much more Global Warming and Sea Level Rise." *Science* 307: 1769–1772.

Mendelsohn, R. 2003. A California model of climate change impacts on timber markets. Appendix XII in *Global climate change and California: Potential implications for ecosystems, health, and the economy.* www.energy.ca.gov/pier/final_project_reports/500-03-058cf.html. 26 pages.

Miller, N. L., J. Jin, K. Hayhoe, M. Auffhammer, and A. Sanstad. 2005. *Heat Extremes and Energy Demand.* Presented at Second Annual Climate Change Research Conference, Sacramento, California. September 15.

Miller, N. L., and N. J. Schlegel. 2006. *Climate Change Science Report to the Governor: Climate Change Projected Santa Ana Fire Weather Occurrence.* (www.climatechange.ca.gov/).

Moritz, M., and S. Stephens. 2006. *Fire and Sustainability: Considerations for California's Altered Future Climate.* (www.climatechange.ca.gov/).

Mote P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. "Declining snowpack in western North America." *Bulletin of the American Meteorological Society* 86: 39–49.

Mott, J., P. Meyer, D. Mannino, S. Redd, E. Smith, C. Gotway-Crawford, and E. Chase. 2002. "Wildland forest fire smoke: Health effects and intervention evaluation, Hoopa, California, 1999." *Western Journal of Medicine* 176: 157–165.

Mount, J., and R. Twiss. 2005. "Subsidence, sea level rise, and seismicity in the Sacramento-San Joaquin Delta." *San Francisco Estuary and Watershed Science* 3(1): 1–18.

Nakicenovic, N. et al. 2000. *Special Report on Emissions Scenarios.* Intergovernmental Panel on Climate Change.

Naughton, M., A. Henderson, M. Mirabelli, R. Kaiser, J. Wilhelm, S. Kieszak, C. Rubin, and M. McGeehin. 2002. "Heat-related mortality during a 1999 heat wave in Chicago." *American Journal of Preventive Medicine* 22: 221–227.

NRC (National Research Council of the National Academies). 2001. *Global Air Quality: An Imperative for Long-Term Observational Strategies.* National Academy Press, Washington, D.C., pp. 10–13. www.nap.edu/books/0309074142/html/.

NRC (National Research Council of the National Academies). 2004. *Air Quality Management in the United States.* National Academy Press, Washington, D.C. pp. 16, 277–278. www.nap.edu/books/0309089328/html.

Pope, V. D., M. L. Gallani, P. R. Rowntree, and R. A. Stratton. 2000. "The impact of new physical parametrizations in the Hadley Centre climate model: HadAM3. *Climate Dynamics* 16: 123–146.

Prather, M. et al. 2003. "Fresh air in the 21st century?" *Geophys. Res. Lett.* 30(2): 1100. doi:10.1029/2002GL016285.

Stephens, G. L. 2005. "Cloud Feedbacks in the Climate System: A Critical Review." *Journal of Climate* American Meteorological Society. 18: 237–273.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2005. "Changes toward earlier streamflow timing across Western North America." *Journal of Climate* 18: 1136–1155.

U. S. Energy Information Administration, U. S. Dept. of Energy, State Energy Price and Expenditure Series. 2005.

USEPA (U.S. Environmental Protection Agency). 1991. *Environmental Investments: The Cost of a Clean Environment: A Summary, Report of the Administrator.* Island Press, Washington, D.C. December.

Vanrheenen, N. T. et al. "Potential implications of PCM climate change scenarios for Sacramento-San Joaquin river basin hydrology and water resources." *Climatic Change* 2004. 62: 257–281.

Vicuña 2006. *Predictions of Climate Change Impacts on California Water Resources Using CalSim-II: A Technical Note.* (www.climatechange.ca.gov/).

Vicuña et al. 2006. *Climate change impacts on high elevation hydropower generation in California's Sierra Nevada: A case study in the Upper American River.* (www.climatechange.ca.gov/).

Washington, W. M., J. W. Weatherly, G. A. Meehl, A. J. Semtner, T. W. Bettge, A. P. Craig, W. G. Strand, J. Arblaster, V. B. Wayland, R. James, and Y. Zhang. 2000. "Parallel climate model (PCM) control and 1% per year CO_2 simulations with a 2/3 degree ocean model and a 27 km dynamical sea ice model." *Clim. Dyn.* 16: 755–774.

Weiskopf, M., H. Anderson, S. Foldy, L. Hanrahan, K. Blair, T. Torok, and P. Rumm. 2002. "Heat wave morbidity and mortality, Milwaukee, Wis. 1999 vs 1995: An improved response?" *American Journal of Public Health* 92: 830–833.

Westerling, A., and B. Bryant. 2006. *Climate change and wildfire in and around California: Fire modeling and loss modeling.* (www.climatechange.ca.gov/).

Wigley, T. M. L. 2005. "The Climate Change Commitment." *Science* 307: 1766–1769.

Wood, A. W., E. P. Maurer, et al. 2002. "Long-range experimental hydrologic forecasting for the eastern United States." *Journal of Geophysical Research-Atmospheres* 107(D20): 4429.

Yao, H., and A. Georgakakos. 2001. "Assessment of Folsom Lake response to historical and potential future climate scenarios 2. Reservoir management." *Journal of Hydrology* 249(1–4): 176–196.

EXHIBIT M

State of California
Office of the Attorney General

ROB BONTA
ATTORNEY GENERAL

Best Practices for Analyzing and Mitigating Wildfire Impacts of Development Projects Under the California Environmental Quality Act

I. Introduction

Wildfires are part of California's present, and with the effects of climate change, an increasing part of our future. Development in fire-prone areas increases the likelihood that more destructive fires will ignite, fire-fighting resources will be taxed, more habitat and people will be put in harm's way or displaced, and more structures will burn. It is therefore imperative that local jurisdictions making decisions to approve new developments carefully consider wildfire impacts as part of the environmental review process, plan where best to place new development, and mitigate wildfire impacts to the extent feasible.

This guidance is designed to help lead agencies[1] comply with the California Environmental Quality Act, Public Resources Code, section 21000 et seq. (CEQA), when considering whether to approve projects in wildfire-prone areas. These areas are often in the wildland-urban interface, generally defined as the area where the built environment meets or intermingles with the natural environment.[2] The California Department of Forestry and Fire Protection (CAL FIRE) has classified lands based on fire risk, the highest being those classified as high or very high fire hazard severity zones. It has also identified areas where the State (as opposed to a local agency) has responsibility for fire-fighting.[3] Particularly in these high-risk areas, but also throughout the

[1] Lead agencies are any public agencies with "principal responsibility for carrying out or approving a project which may have a significant effect upon the environment." (Pub. Resources Code, § 21067.)

[2] CAL FIRE has published an instructive map on the wildland-urban interface in California: https://frap.fire.ca.gov/media/10300/wui_19_ada.pdf. The wildland-urban interface is defined differently by different agencies for different purposes, but the most widely used definition for wildfire purposes include the intermix and interface areas mapped by Radeloff et al. 2005, 2018. See Volker C. Radeloff, et al., *Rapid Growth of the US Wildland-Urban Interface Raises Wildfire Risk.* PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA, 115(13):3314-3319 (2018), available at https://www.pnas.org/doi/10.1073/pnas.1718850115.

[3] See https://osfm.fire.ca.gov/divisions/community-wildfire-preparedness-and-mitigation/wildland-hazards-building-codes/fire-hazard-severity-zones-maps/. Note that areas mapped by CAL FIRE as high or very high fire risk are not always coextensive with the wildland-urban interface. In addition, CAL FIRE's maps are currently in the process of being updated and lead agencies should consult with CAL

wildland-urban interface, wildfire risks must be considered during the environmental review process for individual development projects.

This guidance provides suggestions for how best to comply with CEQA when analyzing and mitigating a proposed project's impacts on wildfire ignition risk, emergency access, and evacuation.[4] This guidance is aimed at proposed development projects, such as residential, recreational, or commercial developments.[5] The extent to which it applies will inherently vary by project, based on project design and location. This document does not impose additional requirements on local governments or alter any applicable laws or regulations. Rather, it is intended to provide guidance on some of the issues, alternatives, and mitigation measures that should be considered during the environmental review process. This guidance is based on the Office of the Attorney General's experience reviewing, commenting on, and litigating CEQA documents for projects in high wildfire prone areas, and is intended to assist lead agencies with their planning and approval of future projects. The guidance reflects current requirements and conditions and may need to be updated as changes occur.

II. Background

Although wildfires are and have been an important natural process throughout California's history, recent changes in fire frequency, intensity, and location are posing increasing threats to the residents and environment of California. More acres of California have burned in the past decade than in the previous 90 years[6] and eight of the State's ten largest fires since 1932 have occurred in the last decade.[7] While lightning is a common cause of some of the State's largest

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FIRE before relying on the classifications listed on this map. CAL FIRE's list of state responsibility areas (defined as areas where the State of California, as opposed to a local agency, is financially responsible for prevention and suppression of wildfires) can be found at: https://calfire-forestry.maps.arcgis.com/apps/webappviewer/index.html?id=468717e399fa4238ad86861638765ce1. Each county should have a map of the very high or high fire hazard severity zones in its jurisdiction, and they are also included on the CAL FIRE zone map: https://egis.fire.ca.gov/FHSZ/.

[4] Readers who want to determine their legal obligations under CEQA should consult their own attorney for legal advice.

[5] This guidance is not intended to apply to state and local agency fire management activities, such as prescribed burns, approval of vegetation management plans to reduce wildfire risk, and review of timber harvesting plans.

[6] CAL FIRE, Top 20 Largest California Wildfires (Jan. 13, 2022), available at https://www.fire.ca.gov/media/4jandlhh/top20_acres.pdf. See also Hugh D. Safford et al., *The 2020 California Fire Season: A Year Like No Other, a Return to the Past or a Harbinger of the Future?* (Apr. 17, 2022) GLOBAL ECOLOGY AND BIOGEOGRAPHY, available at https://onlinelibrary.wiley.com/doi/10.1111/geb.13498?af=R.

[7] Paul Rogers, *Map: 1 of Every 8 acres in California has Burned in the Last 10 Years. Here's Where the Biggest Fires Spread—and are Burning Now*, Mercury News (Sept. 29, 2021), available at https://www.mercurynews.com/2021/09/29/top-10-california-wildfires-megafires-map/. Notably, the large fires of late are not unprecedented in the State's history with similarly large fires occurring specifically during the 1920s. See Jon E. Keeley & Alexandra D. Syphard, *Large California Wildfires: 2020*

fires, in recent years, many of the State's most destructive fires have been caused by human activity, such as downed powerlines or electrical sources associated with residential development or industrial facilities.[8]

Wildfires can have dramatic, adverse ecological impacts. Frequent wildfires can result in habitat loss and fragmentation, shifts in vegetative compositions, reductions in small mammal populations, and accelerated loss of predatory species.[9] Wildfire can also have adverse impacts on erosion and water quality. During active burning, ash and associated contaminants can enter water supplies. Later, after large burns, rainstorms can flush vast amounts of sediment from exposed soils into those same water supplies.[10]

Wildfires also have tragic consequences for California's residents. Since 2010, wildfires have killed nearly 150 people in California[11] and, since 2005, wildfires have destroyed over 97,000 structures,[12] requiring mass evacuations and exacerbating the State's already-pressing need for more housing. In addition, wildfire smoke is unhealthy to breathe and is a public health concern.[13] Further, wildfire losses are not experienced equally. Lower-income households are more likely to lose all of their assets and less likely to have adequate insurance to cover their losses.[14] Meanwhile, the costs of wildfire suppression and resiliency have become significant. In

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Fires in Historical Context (Aug. 25, 2021) FIRE ECOLOGY, available at https://fireecology.springeropen.com/articles/10.1186/s42408-021-00110-7.

[8] See CAL FIRE, Top 20 Largest California Wildfires (Jan. 13, 2022), available at https://www.fire.ca.gov/media/4jandlhh/top20_acres.pdf; CalFire, Top 20 Most Destructive California Wildfires (Jan. 13, 2022), available at https://www.fire.ca.gov/media/t1rdhizr/top20_destruction.pdf.

[9] See Alexandra D. Syphard, et al., *Human Influence on California Fire Regimes.* ECOLOGICAL APPLICATION 17:1388-1402 (2007).

[10] United States Environmental Protection Agency, Wildfires: How do They Affect Our Water Supplies? (Aug. 13, 2019), available at https://www.epa.gov/sciencematters/wildfires-how-do-they-affect-our-water-supplies#:~:text=Vegetation%20that%20holds%20soil%20in,%2C%20rivers%2C%20and%20downstream%20reservoirs.

[11] CAL FIRE, Top Deadliest California Wildfires (Oct. 22, 2021), available at https://www.fire.ca.gov/media/lbfd0m2f/top20_deadliest.pdf.

[12] Headwaters Economics, Wildfires Destroy thousands of structures each year (Nov. 2020, updated Aug. 2022), available at https://headwaterseconomics.org/natural-hazards/structures-destroyed-by-wildfire/.

[13] See Kurtis Alexander, *California Ranks Worst in Nation for Air Pollution Because of Wildfire Smoke*, S.F. Chronicle (June 23, 2022), available at https://www.sfchronicle.com/bayarea/article/california-air-quality-17259687.php. See also Lora Kolodny, *The West Coast Is Suffering from Some of the Worst Air in the World — These Apps Show How Bad it Is*, CNBC (Sept. 13, 2020), available at https://www.cnbc.com/2020/09/12/air-quality-apps-purpleair-airnow-iqair-essential-in-western-us.html; and California Air Resources Board, *Protecting Yourself from Wildfire Smoke*, available at https://ww2.arb.ca.gov/protecting-yourself-wildfire-smoke.

[14] California Council on Science and Technology, The Costs of Wildfire in California (Oct. 2020), at p. 69, available at https://ccst.us/reports/the-costs-of-wildfire-in-california/.

2021, the State invested $1.5 billion in wildfire resiliency efforts, and the 2022-2023 budget includes an additional $1.2 billion to support wildfire and forest resilience.[15] The changing nature of wildfires, under various metrics—frequency, area burned, adverse ecological impacts, the number of Californians displaced—is a worsening crisis that will unfortunately be part of California's future.[16]

As of 2010, about one-third of California's housing units were located within the wildland-urban interface.[17] Residential developments in the wildland-urban interface and other wildfire prone areas can significantly increase the risks of wildfires and the risk to public safety for several reasons. First, introducing more people—via additional development—into a flammable landscape increases the likelihood of: (1) a wildfire igniting due to the increased presence of people; and (2) the ignition becoming a wildfire because of the placement of homes amongst the flammable vegetation.[18] Second, building housing units in the wildland-urban interface puts more people in harm's way.[19] Wildfires, particularly those that impact developments in relatively remote locations, may impede the evacuation of communities and emergency access, making it more difficult to ensure public safety and to limit, control, or extinguish wildfires. Finally, fires in remote locations require significant fire-fighting resources and mobilization of fire-fighters from all over the State—putting a major strain on the State's fire-fighters and the State's budget. Put simply, bringing more people into or near flammable wildlands leads to more frequent, intense, destructive, costly, and dangerous wildfires.[20]

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[15] Gavin Newsom, California State Budget (2022-2023), at p. 61, available at https://www.ebudget.ca.gov/FullBudgetSummary.pdf; California State Budget, Budget Addendum (2021-2022), at p. 3, available at https://www.ebudget.ca.gov/BudgetAddendum.pdf.

[16] See California Council on Science and Technology, *The Costs of Wildfire in California* (Oct. 2020), at p. 17, available at https://ccst.us/reports/the-costs-of-wildfire-in-california/.

[17] Community Wildfire Planning Center, Land Use Planning Approaches in the Wildland-Urban Interface (Feb. 2021), at p. 7, available at https://www.communitywildfire.org/wp-content/uploads/2021/02/CWPC_Land-Use-WUI-Report_Final_2021.pdf; see also Heather Anu Kramer, et al., *High Wildfire Damage in Interface Communities in California* (2019) INTERNATIONAL JOURNAL OF WILDLAND FIRE, available at https://www.fs.usda.gov/nrs/pubs/jrnl/2019/nrs_2019_kramer_001.pdf. At the current rate of growth and under current growth patterns, it is anticipated that an additional 645,000 housing units will be developed in areas designated by CAL FIRE as very high fire hazard severity zones by 2050. Next 10, Rebuilding for a Resilient Recovery: Planning in California's Wildland Urban Interface (June 2021), at p. 9, available at https://www.next10.org/publications/rebuilding-resilient.

[18] See Alexandra D. Syphard, *Why Are so Many Structures Burning in California?* (2020) Fremontia, *47*(2), at p. 29; Volker C. Radeloff, et al., *Rapid Growth of the US Wildland-Urban Interface Raises Wildfire Risk.* PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA, 115(13):3314-3319 (2018).

[19] See Heather Anu Kramer, et al., *High Wildfire Damage in Interface Communities in California* (2019) International Journal of Wildland Fire, available at https://www.fs.usda.gov/nrs/pubs/jrnl/2019/nrs_2019_kramer_001.pdf; Volker C. Radeloff, et al., *Rapid growth of the US wildland-Urban interface raises wildfire risk.* PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA, 115(13):3314-3319 (2018).

[20] See Michael L. Mann, et al., *Incorporating Anthropogenic Influences into Fire Probability Models: Effects of Human Activity and Climate Change on Fire Activity in California* (Apr. 28, 2016) PLOS ONE

III. Wildfire and Land Use Planning

While this guidance is focused on best practices to disclose, analyze, and mitigate wildfire impacts in compliance with CEQA, it is important to note that general planning also provides a critical opportunity for local jurisdictions to think proactively about how to accommodate their housing and development needs while reducing the risks of wildfire.[21] In the last ten years, new legislation has passed requiring local jurisdictions to consider wildfire risks in their general planning processes.[22] The Governor's Office of Planning and Research (OPR) recently published comprehensive guidance to help local agencies comply with these requirements.[23] We encourage local jurisdictions to consult this guidance and to thoughtfully plan for new development given the increasing risk of wildfires throughout the state.[24]

11(4), available at https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0153589; Alexandra D. Syphard, *Why Are so Many Structures Burning in California?* (2020) FREMONTIA, *47*(2), at pp. 28-35, available at https://pubs.er.usgs.gov/publication/70215982; Alexandra D. Syphard, et al., *Land Use Planning and Wildfire: Development Policies Influence Future Probability of Housing Loss* (2013) PLOS ONE, available at https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0071708&type=printable; see also Final Statement of Reasons for Regulatory Action re Amendments to the State CEQA Guidelines OAL Notice File No. Z-2018-0116-12 ("Statement of Reasons"), at p. 87, available at https://resources.ca.gov/CNRALegacyFiles/ceqa/docs/2018_CEQA_Final_Statement_of%20Reasons_111218.pdf.

[21] See Alexandra D. Syphard, *Why Are so Many Structures Burning in California?* (2020) FREMONTIA, *47*(2), at p. 33, available at https://pubs.er.usgs.gov/publication/70215982 [concluding that "the most effective strategy at reducing future structure loss would focus on reducing the extent of low-density housing via careful land planning decisions"].

[22] See Sen Bill No. 1241 (2011-2012 Reg. Sess.), amending and/or adding Gov. Code, §§ 65302, subd. (g)(3), 65302.5, subd. (b), and 66474.02) [requiring local jurisdictions within state responsibility areas or very high fire hazard severity zones to address wildfire risk when updating their safety elements and to submit their draft updates to the State Board of Forestry and Fire Protection for review]; Sen. Bill No. 99 (2019-2020 Reg. Sess.), amending Gov. Code, § 65302, subd. (g)(5) [requiring updated safety elements to identify residential developments within hazard areas that do not have at least two evacuation routes]; Assem. Bill No. 747 (2019-2020 Reg. Sess.), adding Gov. Code, § 65302.15 [requiring local jurisdictions to update their safety element to address the capacity of evacuation routes under a range of various emergency scenarios]; Assem. Bill No. 1409 (2020-2021 Reg. Sess.), amending Gov. Code, § 65302.15 [requiring that safety elements identify locations where people can evacuate to].

[23] Governor's Office of Planning and Research, Fire Hazard Planning Technical Advisory, 2022 Update (Aug. 2022), available at https://opr.ca.gov/docs/20220817-Fire_Hazard_Planning_TA.pdf; and Wildland-Urban Interface Planning Guide: Examples and Best Practices for California Communities (Aug. 2022), available at https://opr.ca.gov/docs/20220817-Complete_WUI_Planning_Guide.pdf.

[24] Local jurisdictions that have complied with their general planning obligations, including incorporating wildfire and evacuation planning considerations into their general plans, may benefit from streamlined CEQA requirements at the project approval level. If a development project is consistent with an updated general plan and an environmental impact report (EIR) was prepared for that plan, the CEQA review for the project may be limited to the parcel-specific impacts of the project or impacts that new information,

IV. Analyzing and Mitigating Wildfire Risk Impacts Under CEQA

A. CEQA's requirements for analyzing wildfire risks

CEQA requires local jurisdictions considering development projects to prepare an environmental impact report (EIR) or a mitigated negative declaration[25] if the project may potentially have a significant impact on the environment and is not otherwise exempt from CEQA.[26] Under CEQA, local jurisdictions may act as lead agencies with responsibility for preparing the EIR (or other CEQA document), or as responsible agencies relying on an EIR prepared by a lead agency. CEQA provides a critical process for local jurisdictions to understand how new developments will exacerbate existing wildfire risks, allowing them to consider project design features, alternatives, and mitigation measures that provide for smarter development and the protection of existing communities.

The CEQA Guidelines[27] require that an EIR include a description of the physical environmental conditions in the vicinity of the project, at the time the notice of preparation is published, or if no notice of preparation is published, at the time environmental analysis is commenced.[28] This "baseline" of existing environmental conditions is generally used to determine the significance of project-related impacts. In the EIR's discussion of the existing environmental conditions, lead agencies should include information about open space areas and habitats within the project area that may be fire prone, as well as a discussion of fire history and fuels on the project site. Including a discussion of existing available water supplies for fire-fighting is also critical. Providing detail about existing environmental conditions at the project site that may exacerbate or minimize wildfire impacts will help ensure that the EIR fully considers the project's impacts on wildfire risk.

The CEQA Guidelines require an analysis of "any significant environmental effects the project might cause or risk exacerbating by bringing development and people into the area affected," including by locating development in wildfire risk areas.[29] The "environmental checklist form" in Appendix G of the CEQA Guidelines, Section XX, directs lead agencies to assess whether

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arising since adoption of the general plan, shows will be more significant than described in the prior EIR. (Pub. Resources Code, § 21083.3; CEQA Guidelines, § 15193).

[25] Where "EIR" is used in this guidance it should also be considered to refer to a mitigated negative declaration.

[26] Pub. Resources Code, § 21067; CEQA Guidelines, §§ 15050 and 15367.

[27] The CEQA Guidelines are found at California Code of Regulations, title 14, section 15000, et seq.

[28] CEQA Guidelines, § 15125.

[29] CEQA Guidelines, § 15126.2.

projects located *in or near* state responsibility areas or lands classified as very high fire hazard severity zones,[30] would:

a) Substantially impair an adopted emergency response plan or emergency evacuation plan;
b) Due to slope, prevailing winds, and other factors, exacerbate wildfire risks, and thereby expose project occupants to pollutant concentrations from a wildfire or the uncontrolled spread of a wildfire;
c) Require the installation or maintenance of associated infrastructure (such as roads, fuel breaks, emergency water sources, power lines or other utilities) that may exacerbate fire risk or that may result in temporary or ongoing impacts to the environment; or
d) Expose people or structures to significant risks, including downslope or downstream flooding or landslides, as a result of runoff, post-fire slope instability, or drainage changes.[31]

In addition to the four questions above, Section IX(g) of the checklist broadly directs lead agencies to consider whether a project will "expose people or structures, either directly or indirectly, to a significant risk of loss, injury or death involving wildland fires."[32] In answering these questions, lead agencies must consider both on- and off-site impacts.[33]

B. Analyzing a project's impact on wildfire risks

Several variables should be considered in analyzing a project's impact on wildfire risk, including:

- **Project Density:** Project density influences how likely a fire is to start or spread, and how likely it is that the development and its occupants will be in danger when a fire starts. Fire spread and structure loss is more likely to occur in low- to intermediate-density developments.[34] This is because there are more people present to ignite a fire (as compared to undeveloped land), and the development is not concentrated enough

[30] See footnote 1 for more information on state responsibility areas and very high fire hazard severity zones.

[31] CEQA Guidelines, Appendix G, XX.

[32] CEQA Guidelines, Appendix G, IX(g). This Guidance focuses on these key wildfire-related questions in Sections IX(g) and XX of the checklist, but in conducting environmental review, lead agencies must continue to thoroughly address the other questions identified in Section XX and the checklist more generally.

[33] CEQA Guidelines, § 15360 [defining the environment to be considered as "the area in which significant effects would occur either directly or indirectly as a result of the project"].

[34] Alexandra D. Syphard, *The Relative Influence of Climate and Housing Development on Current and Projected Future Fire Patterns and Structure Loss Across Three California Landscapes* (2019) GLOBAL ENVIRONMENTAL CHANGE; Alexandra D. Syphard, et al., *Housing Arrangement and Location Determine the Likelihood of Housing Loss Due to Wildfire* (Mar. 28, 2012) PLOS ONE, available at https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0033954.

(as compared to high-density developments) to disrupt fire spread by removing or substantially fragmenting wildland vegetation.[35] "Isolated clusters of development and low housing density mean that homes are embedded within, and more exposed to, a matrix of wildland vegetation."[36] Moreover, fire-fighters may have difficulty accessing more remote and disconnected developments.[37]

- **Project Location in the Landscape:** Project placement in the landscape relative to fire history, topography and wind patterns also influences wildfire risk. Although wildfire ignitions are primarily human-caused in California, wildfire behavior is largely driven by topography, fuel, climatic conditions, and fire weather (such as low humidity and high winds). How a development project is planned within the landscape determines to what extent it will influence fire risk.[38] For example, if a project site is located in a wind corridor, above-ground power lines may become a source of ignition. Similarly, siting residential structures in rugged terrain or on the top of steep hills may increase the wildfire risk. By contrast, if a project site includes landscape features that could prevent or slow the spread of fire, such as a lake or an irrigated golf course, the development may be strategically located so as to capitalize on that feature as a natural fuel break.[39]

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[35] See generally Alexandra D. Syphard, et. al., *Multiple-Scale Relationships between Vegetation, the Wildland-Urban Interface, and Structure Loss to Wildfire in California* (Mar. 12, 2021) MDPI FIRE 2021.

[36] Max A. Moritz, et al., *Learning to Coexist with Wildfire* (2014) NATURE 515(7525), at p. 64; see also Alexandra D. Syphard, et. Al., *Multiple-Scale Relationships between Vegetation, the Wildland-Urban Interface, and Structure Loss to Wildfire in California* (March 12, 2021) MDPI FIRE 2021.

[37] See Alexandra D. Syphard, *Why Are so Many Structures Burning in California?* (2020) FREMONTIA, *47*(2), at p. 31.

[38] See generally Max Moritz, et al., *Building to Coexist with Fire: Community Risk Reduction Measures for New Development in California* (Apr. 2020) University of California Agriculture and Natural Resources, Publication 8680, available at https://escholarship.org/uc/item/6n12m6pn; Alexandra D. Syphard, *Why Are so Many Structures Burning in California?* (2020) FREMONTIA, *47*(2), at pp. 28-35, available at https://pubs.er.usgs.gov/publication/70215982.

[39] See Max Moritz, et al., *Building to Coexist with Fire: Community Risk Reduction Measures for New Development in California* (Apr. 2020) University of California Agriculture and Natural Resources, Publication 8680, at p. 10, available at https://escholarship.org/uc/item/6n12m6pn; see also Conservation Biology Institute, *Paradise Nature-Based Fire Resilience Project Final Report* (June 2020), available at https://d2k78bk4kdhbpr.cloudfront.net/media/reports/files/CBI_Paradise_Final_Report_for_Posting_Online.pdf [An examination of how siting and greenbelts may have protected homes during the Paradise fire]. Siting of a new fire-resistant development between wildlands and existing development may even serve as a protective barrier for the existing development. But there can still be some risk of ember spread if the new development succumbs to fire. See Alexandra D. Syphard, *Why Are so Many Structures Burning in California?* (2020) FREMONTIA, *47*(2), at pp. 28-35, available at https://pubs.er.usgs.gov/publication/70215982; California Council on Science and Technology, The Costs of Wildfire in California (Oct. 2020), at p. 67, available at https://ccst.us/reports/the-costs-of-wildfire-in-california/.

- **Water Supply and Infrastructure**: As part of evaluating a project's wildfire risk impacts, an EIR should analyze the adequacy of water supplies and infrastructure to address fire-fighting within the project site.[40] This analysis should consider the potential loss of water pressure during a fire, which may decrease available water supply[41] and the potential loss of power, which may eliminate the supply.[42]

To understand how a project may exacerbate the risk of wildfire, an EIR should qualitatively assess these variables and also use fire modeling and other spatial and statistical analyses to quantify the risks to the extent feasible. Experts should utilize fire models to account for various siting and design elements, as well as a variety of different fire scenarios. The modeling should include scenarios for fires that start in, near, and far from the project site, as well as extreme weather conditions that exacerbate fire spread.

Lead agencies are encouraged to develop thresholds of significance that either identify an increase in wildfire risk as a significant impact or determine, based on substantial evidence, that some increase in the risk of wildfires is not considered a significant impact. Relevant factors should include the project's impact on ignition risk, the likelihood of fire spread, and the extent of exposure for existing and new residents based on various fire scenarios. Modeling the various scenarios enables local agencies to quantify increased wildfire risks resulting from a project adding more people to wildfire prone areas and to assess the risks according to the threshold of significance.

Some EIRs have concluded that the conversion of some wildland vegetation into paved development reduces or does not increase wildfire risk. This conclusion is contrary to existing evidence and the well-accepted understanding that the fundamental driver of increased wildfire risk is the introduction of people into a flammable landscape.[43] Accordingly, the conversion of vegetation into developed land does not obviate the need for lead agencies to carefully consider and model how the addition of development into wildfire prone areas contributes to the risk of wildfire.

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[40] See Max Moritz, et al., *Building to Coexist with Fire: Community Risk Reduction Measures for New Development in California* (Apr. 2020) University of California Agriculture and Natural Resources, Publication 8680, at p. 19 and Appendix B, available at https://escholarship.org/uc/item/6n12m6pn.

[41] See Max Moritz, et al., *Building to Coexist with Fire: Community Risk Reduction Measures for New Development in California* (Apr. 2020), at p. 19, University of California Agriculture and Natural Resources, Publication 8680, available at https://escholarship.org/uc/item/6n12m6pn.

[42] See Alexandra D. Syphard, *Nexus Between Wildfire, Climate Change and Population Growth in California* (2020) FREMONTIA, *47*(2), at p. 26.

[43] See Heather Anu Kramer, et al., *High Wildfire Damage in Interface Communities in California* (2019) INTERNATIONAL JOURNAL OF WILDLAND FIRE, available at https://www.fs.usda.gov/nrs/pubs/jrnl/2019/nrs_2019_kramer_001.pdf; see also Exhibit A to the Final Statement of Reasons for Regulatory Action re Amendments to the State CEQA Guidelines, OAL Notice File No. Z-2018-0116-12, at p. 212, available at https://resources.ca.gov/CNRALegacyFiles/ceqa/docs/2018_CEQA_ExA_FSOR.pdf.

C. Analyzing the project's impact on evacuation and emergency access

The addition of new development into high wildfire risk or adjacent areas may impact the evacuation of project residents, as well as the existing population (e.g., residents, workers, students, visitors, and possibly livestock) in the area and the ability of emergency responders to simultaneously access the area to fight wildfire. This can, in turn, impact the risk and extent of large-scale fire spread and community safety within and around the new development. The EIR should evaluate these impacts both during construction and over the life of the project. The required analysis is relative to a project's impacts and risks; e.g., a higher density infill project within an already developed area would likely not require the same level of analysis as a new low-density development within the wildland-urban interface and surrounded largely by open space.[44]

For projects located in high wildfire risk areas that present an increased risk of ignition and/or evacuation impacts, evacuation modeling and planning should be considered and developed at the time of project review and approval—when there is greater flexibility to modify a project's design, density, siting, and configuration to address wildfire considerations—rather than deferred to a later stage of the development process. Lead agencies will be best-positioned to ensure proposed development projects facilitate emergency access and ease constraints on evacuation with this information in hand prior to project approval. The ultimate objective is to allow for informed decision-making that minimizes the environmental and public safety hazards associated with new developments that increase the risk of ignition and impede evacuation in high wildfire prone areas.

Evacuation modeling and analysis should include the following:

- Evaluation of the capacity of roadways to accommodate project and community evacuation and simultaneous emergency access.
- Assessment of the timing for evacuation.
- Identification of alternative plans for evacuation depending upon the location and dynamics of the emergency.
- Evaluation of the project's impacts on existing evacuation plans.
- Consideration of the adequacy of emergency access, including the project's proximity to existing fire services and the capacity of existing services.
- Traffic modeling to quantify travel times under various likely scenarios.

[44] See Max Moritz, et al., *Building to Coexist with Fire: Community Risk Reduction Measures for New Development in California* (Apr. 2020), University of California Agriculture and Natural Resources, Publication 8680, at p. 5, available at https://escholarship.org/uc/item/6n12m6pn [describing the benefits of infill development].

In considering these evacuation and emergency access impacts, lead agencies may use existing resources and analyses, but such resources and analyses should be augmented when necessary. For example, agencies should:

- Utilize information from the EIR's analysis of traffic/transportation impacts, but they should not limit themselves to that information, which may not reflect the impact of emergency conditions on travel times.
- Consult with local fire officials and ensure that assumptions and conclusions regarding evacuation risk are substantiated with sound facts. Emergency conditions may not allow for ideal evacuation scenarios—staggered, staged, or targeted evacuation in response to a wildfire may sometimes be possible, but human behavior is difficult to predict and wildfires can be erratic, unpredictable, and fast-moving.[45]
- Consider impacts to existing evacuation plans, but recognize that, depending on the scope of an existing evacuation plan, additional analyses or project-specific plans may be needed. Community evacuation plans often identify roles and responsibilities for emergency personnel and evacuation routes, but do not necessarily consider the capacity of roadways, assess the timing for community evacuation, or identify alternative plans for evacuation depending upon the location and dynamics of the emergency.
- Avoid overreliance on community evacuation plans identifying shelter-in-place locations. Sheltering in place, particularly when considered at the community planning stage,[46] can serve as a valuable contingency, but it should not be relied upon in lieu of analyzing and mitigating a project's evacuation impacts.[47]

Local jurisdictions are encouraged to develop thresholds of significance for evacuation times. These thresholds should reflect any existing planning objectives for evacuation, as well as

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[45] See FEMA and U.S. Fire Administration, *Wildland Urban Interface: A Look at Issues and Resolutions* (June 2022), available at https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf.

[46] FEMA, *Planning Considerations: Evacuation and Shelter-in-Place* (July 2019), available at https://www.fema.gov/sites/default/files/2020-07/planning -considerations-evacuation-and-shelter-in-place.pdf. The distinction between temporary shelter-in-place locations and buildings designed or retrofitted for longer term shelter-in-place should also be considered. See Max Moritz, et al., *Building to Coexist with Fire: Community Risk Reduction Measures for New Development in California* (Apr. 2020) University of California Agriculture and Natural Resources, Publication 8680, at p. 17, available at https://escholarship.org/uc/item/6n12m6pn [discussing the difference between "safety zones"—areas with little flammable vegetations, such as golf courses—versus buildings that are designed to provide protection from heat and embers while the front of a fire passes, typically for a duration of at least 30-60 minutes].

[47] See Mejia, *Pepperdine University Defends 'Shelter in Place' Decision During Woolsey Fire*, Los Angeles Times (Nov. 13, 2018), available at https://www.latimes.com/local/lanow/la-me-ln-pepperdine-shelter-20181113-story.html; Chandler, *Am I Going to Stay in the Parking Lot . . . While the Fires Burn Around Me?*, Record Searchlight (Dec. 12, 2019), available at https://www.redding.com/in-depth/news/2019/04/25/california-wildfire-shelter-place-plans-questioned-evacuation-preparation/3427075002/.

informed expert analysis of safe and reasonable evacuation times given the existing and proposed development. Local jurisdictions should consider whether any increase in evacuation times for the local community would be a significant impact. A conclusion that an increase in evacuation times is a less than significant impact should be based on a threshold of significance that reflects community-wide goals and standards.

In establishing thresholds, local jurisdictions should consider referring to successful evacuations from prior emergencies within their community or similarly situated communities. The thresholds should include, but not be limited to, whether the project creates an inconsistency with: (1) an adopted emergency operations or evacuation plan; (2) a safety element that has been updated per the requirements in Government Code sections 65302(g)(5) and 65302.15 to integrate wildfire and evacuation concerns; or (3) recommendations developed by the California Board of Forestry and Fire Protection regarding the safety of subdivisions pursuant to Public Resources Code section 4290.5.

D. Mitigating wildfire risk, evacuation, and emergency access impacts

If a project presents significant increased wildfire risks and/or evacuation and access impacts, CEQA requires the lead agency to consider and adopt feasible alternatives and mitigation measures to avoid or reduce the project's impacts (or make a finding of overriding consideration).[48] Not all project design features or mitigation measures will achieve the same reduction in impacts for every project—the effects and effectiveness of measures will vary geographically and by project. An EIR that baldly concludes that certain project design features or mitigation measures will reduce or eliminate all potential wildfire risks, without first describing those risks, fails to fully analyze the project's impacts. Compressing the analysis of impacts and mitigation deprives decision makers of a full description of the project's adverse impacts and, therefore, fails to equip the decision makers with the necessary information to properly address the impacts by adopting project design features, mitigation measures, or alternatives. To avoid this error and provide for better project design, the project EIR should first analyze the increased wildfire risks and evacuation impacts, and then consider feasible mitigation and alternatives to avoid or reduce those impacts.

Set forth below are some examples of potential mitigation measures and design alternatives that may reduce wildfire risk impacts. This list is not exclusive and a lead agency's adoption of some or all of these mitigation measures for a particular project may not be sufficient to comply with CEQA's requirement to adopt all feasible mitigation measures.

- Increasing housing density and consolidated design, relying on higher density infill developments as much as possible.
- Avoidance and minimization of low-density exurban development patterns or leapfrog-type developments (i.e., those with undeveloped wildland between developed areas).

[48] Pub. Resources Code, § 21081.

- Decreasing the extent and amount of "edge," or interface area, where development is adjacent to undeveloped wildlands.
- Creation of buffer zones and defensible space within and adjacent to the development, with particular attention to ensuring that vegetation will not touch structures or overhang roofs.[49] It is also important that legal obligations are structured so that defensible space measures are retained over time.[50]
- Siting projects to maximize the role of low-flammability landscape features that may buffer the development from fire spread.
- Undergrounding power lines.
- Limiting development along steep slopes and amidst rugged terrain, so as to decrease exposure to rapid fire spread and increase accessibility for fire-fighting.
- Placement of development close to existing or planned ingress/egress and designated evacuation routes to efficiently evacuate the project population and the existing community population, consistent with evacuation plans, while simultaneously allowing emergency access.
- Placement of projects close to adequate emergency services.
- Construction of additional points of ingress and egress and modification of evacuation routes to minimize or avoid increasing evacuation times or emergency access response times.
- Fire hardening structures and homes—upgrading the building materials and installation techniques to increase the structure's resistance to heat, flames, and embers—beyond what is required in applicable building codes, both for new structures and existing structures in proximity to the new development.
- Requiring fire-hardened communication to the project site including high-speed internet service.
- Enhanced communication to the project population about emergency evacuation plans and evacuation zones.
- Parking limitations to ensure access roads are not clogged with parked vehicles.
- On-site water supply/storage to augment ordinary supplies that may be lost during a wildfire.

In all situations, mitigation measures should be combined and tailored to the specifics of the project, the surrounding landscape, and nearby existing uses. In some contexts, the mitigation measure itself may have an adverse impact that should be evaluated in an EIR. In addition,

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[49] Note, however, that defensible space around homes does not alone tend to account for structural survival. See Alexandra D. Syphard, *Why Are so Many Structures Burning in California?* (2020) FREMONTIA, *47*(2), at p. 32, available at https://pubs.er.usgs.gov/publication/70215982; Alexandra D. Syphard et al., *The Role of Defensible Space for Residential Structure Protection During Wildfires* (Oct. 14, 2014) INTERNATIONAL JOURNAL OF WILDLAND FIRE, available at http://dx.doi.org/10.1071/WF13158.

[50] See Max Moritz, et al., *Building to Coexist with Fire: Community Risk Reduction Measures for New Development in California* (Apr. 2020), at p. 12, University of California Agriculture and Natural Resources, Publication 8680, available at https://escholarship.org/uc/item/6n12m6pn.

mitigation measures may not provide the same level of protection or mitigation in all scenarios.[51] For example, home hardening has been shown to be an extremely effective measure for preventing structure loss during a wildfire. The California Building Code was updated in 2008 to require more advanced fire hardening and homes built to the revised standards were shown to be 40 percent less likely to be destroyed by a wildfire than similarly situated homes built prior to the update.[52] However, home hardening by itself may not be an adequate mitigation measure in all situations. During the Camp Fire, which swept through Paradise in 2018, homes built before and after the 2008 Building Code update were destroyed at roughly equal rates.[53] Home hardening in conformance with the 2008 Building Code alone did not meaningfully effect survivability; rather, proximity to other destroyed structures, the extent of vegetative overstory, and defensive space around homes was more relevant to whether or not a home survived.[54] While home hardening may be a worthy measure, this highlights the importance of combining measures, with an awareness to overall landscape conditions, to maximize public safety and minimize wildfire-related losses. It also demonstrates that defensive measures can improve but do not guarantee survivability, which highlights the continued importance of planning for evacuation and emergency access.

VII. Conclusion

As climate change and housing pressure continue to impact the State's landscape, wildfire risks, and development needs, local agencies need to thoroughly evaluate where and how new development is planned and constructed. With careful forethought during the various planning processes and thoughtful environmental review at the individual project development stage, new development can be designed and positioned to minimize future wildfire risks, enhance fire resiliency of our communities, and protect the health and safety of California's residents and natural resources. While the applicable rules, requirements, and analytical tools to reduce wildfire risk are evolving, this guidance is intended to provide suggestions for how best to comply with CEQA when analyzing and mitigating the wildfire risks of development projects in the wildland-urban interface and other fire prone areas.

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[51] See Alexandra D. Syphard, et. al., *Multiple-Scale Relationships between Vegetation, the Wildland-Urban Interface, and Structure Loss to Wildfire in California* (Mar. 12, 2021), at p. 13, MDPI FIRE 2021 [noting that "the most effective fire risk reduction approach will account for multiple factors at multiple scales and will incorporate simultaneous strategies"].

[52] Patrick W Baylis, et al., *Mandated vs. Voluntary Adaptation to Natural Disasters: the Case of U.S. Wildfires* (Dec. 2021), National Bureau of Economic Research, available at https://www.nber.org/papers/w29621.

[53] Eric E. Knapp, et al., *Housing Arrangement and Vegetation Factors Associated with Single-Family Home Survival in the 2018 Camp Fire, California* (2021) FIRE ECOLOGY 17:25, available at https://fireecology.springeropen.com/track/pdf/10.1186/s42408-021-00117-0.pdf [37 percent of homes built between 1997 and 2008 survived, while 44 percent of homes built between 2008 and 2018 survived].

[54] Eric E. Knapp, et al., *Housing Arrangement and Vegetation Factors Associated with Single-Family Home Survival in the 2018 Camp Fire, California* (2021) FIRE ECOLOGY 17:25, available at https://fireecology.springeropen.com/track/pdf/10.1186/s42408-021-00117-0.pdf.

EXHIBIT N

SAN BERNARDINO COUNTY

MULTI-JURISDICTIONAL HAZARD MITIGATION PLAN

FEMA Approved: July 13, 2017

San Bernardino County Unincorporated Area
San Bernardino County Fire Protection District
San Bernardino County Flood Control District
San Bernardino County Special Districts Department



This document was supported by HSGP Grant No. 2015-0078 awarded by the U.S. Department of Homeland Security (DHS) Federal Emergency Management Agency (FEMA). Points of view, opinions, findings, and conclusions expressed in this document are those of the authors and do not necessarily represent the official position of policies of FEMA or DHS. DHS/FEMA reserves a royalty-free, non-exclusive, and irrevocable license to reproduce, publish, and use these materials and to authorize others to do so.

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Table of Contents

Section 1. Introduction 1
1.1 San Bernardino County Unincorporated Area 2
1.1.1 San Bernardino County Fire Protection District 3
1.1.2 San Bernardino County Flood Control District 4
1.1.3 Special Districts Department 6
1.2 Purpose of the Plan 11
1.3 Authority 12
1.4 What's New 12
1.4.1 Updates to the Current Plan 13
1.4.2 New Jurisdictional Annexes 13
1.4.3 New Risk Assessment 14
1.4.4 Successful Wildfire Mitigation Implementation 15
1.4.5 Flood Hazard Mitigation Success 18
1.4.6 Geologic Hazard Mitigation Success 21
1.5 Community Profile 23
1.5.1 Physical Setting 23
1.5.2 History 26
1.5.3 Climate 27
1.5.4 Demographics 28
1.5.5 Existing Land Use 30
1.5.6 Development Trends 32
Section 2. Plan Adoption 35
2.1 Adoption by Local Governing Body 35
2.2 Promulgation Authority 35
Section 3. Planning Process 37
3.1 Preparing the Plan 37
3.1.1 Project Prioritization Involved Comprehensive Consideration of Criteria/Factors 39
3.1.2 Planning Team 39
3.2 Coordination with Other External Jurisdictions, Agencies and Organizations 44
3.2.1 Internal Coordination 44
3.2.2 External Coordination 47
3.3 Public Involvement/Outreach 48
3.3.1 Public Meetings 48
3.3.2 Ready SB County Preparedness App Message/Web Postings 50
3.3.3 CERT Teams 50
3.3.4 Public Hearing Process (to be completed upon FEMA Approval) 51
3.4 Planning Process 51
3.4.1 Hazard Screening 52
3.4.2 Set Goals 53
3.4.3 Review and Propose Mitigation Measures 54
3.4.4 Draft the Multi-Jurisdictional Hazard Mitigation Plan 56

3.4.5 Adopt the Plan 56
Section 4. Risk Assessment 59
4.1 Hazard Identification 59
4.1.1 Hazard Screening Criteria 59
4.1.2 Hazard Prioritization 63
4.2 Hazard Profiles 63
4.3 Earthquake Geologic Hazards 65
4.3.1 Regulatory Environment 65
4.3.2 Past Occurrences 66
4.3.3 Location/Geographic Extent 66
4.3.4 Magnitude/Severity 68
4.3.5 Frequency and Probability of Occurrence 69
4.4 Wildfire 73
4.4.1 Regulatory Environment 73
4.4.2 Past Occurrences 74
4.4.3 Location/Geographic Extent 77
4.4.4 Magnitude/Severity 78
4.4.5 Frequency/Probability of Future Occurrences 78
4.5 Flood 83
4.5.1 Regulatory Environmental 84
4.5.2 Past Occurrences 85
4.5.3 Location/Geographic Extent 86
4.5.4 Magnitude/Severity 88
4.5.5 Frequency/Probability of Future Occurrences 89
4.6 Drought 91
4.6.1 Regulatory Environment 92
4.6.2 Past Occurrences 92
4.6.3 Location/Geographic Extent 93
4.6.4 Magnitude/Severity 93
4.6.5 Frequency/Probability of Future Occurrences 97
4.7 Terrorism 99
4.7.1 Antiterrorism Regulatory Environment 99
4.7.2 Counterterrorism Regulatory Environment 100
4.7.3 Past Occurrences 100
4.7.4 Location/Geographic Extent 103
4.7.5 Magnitude/Severity 104
4.7.6 Frequency/Probability of Future Occurrences 107
4.8 Climate Change 109
4.8.1 Regulatory Environment 109
4.8.2 Past Occurrences 111
4.8.3 Location/Geographic Extent 112
4.8.4 Magnitude/Severity 114
4.8.5 Frequency/Probability of Future Occurrences 114
4.8.6 El Niño Effect 115
4.8.7 Extreme Weather 116

4.9 Other Hazards 117
4.10 Vulnerability Assessment 118
4.10.1 Methodology 118
4.10.2 Hazus MH Inputs 120
4.11 Population and Assets 123
4.11.1 Population 123
4.12 Hazard Specific Vulnerabilities 131
4.13 Earthquake 133
4.13.1 Population at Risk 133
4.13.2 Improved Parcel Value at Risk 134
4.13.3 Critical Facilities with Damage Potential 135
4.13.4 Loss Estimation Results 137
4.14 Wildfire 141
4.14.1 Population at Risk 142
4.14.2 Improved Parcel Value at Risk 143
4.14.3 Critical Facilities at Risk 143
4.14.4 Loss Estimation Results 145
4.15 Flooding 148
4.15.1 Population at Risk 149
4.15.2 Residential Parcel Value with Flood Risk 149
4.15.3 Critical Facilities Exposure 151
4.15.4 Loss Estimation Results 153
4.16 Drought 158
4.16.1 Loss Estimation Results 158
4.16.2 Statewide Mandatory Water Reductions 158
4.17 Terrorism 160
4.17.1 Population at Risk 160
4.17.2 Critical Facilities Exposure 160
4.18 Climate Change 162
4.18.1 Population at Risk 163
Section 5. Community Capability Assessment 164
5.1 Existing Plans, Policies and Programs 164
5.1.1 San Bernardino County General Plan 164
5.1.2 Regulations, Code, Policies and Ordinances 165
5.1.3 Local Programs for Mitigation Implementation 165
5.2 Fiscal Resources 174
5.2.1 The Budget in Brief 174
5.2.2 Budget Highlights (2016 – 2017) 176
Section 6. Mitigation Strategy 184
6.1 Mitigation Goals and Objectives 184
6.1.1 All Hazard (AH) 184
6.1.2 Wildfire (WF) 186
6.1.3 Earthquake/Geologic Hazards (EQ) 188
6.1.4 Flood (FL) 189

6.1.5 Drought (DR) 190
6.1.6 Anti-Terrorism (AT) 191
6.1.7 Climate Change (CC) 192
6.2 Mitigation Strategy 192
6.2.1 Mitigation Action Plan 194
Section 7. Plan Maintenance 209
7.1 Monitoring Evaluating and Updating the HMP 209
7.1.1 Plan Adoption 210
7.1.2 Implementation 210
7.1.3 Continued Public Involvement 226
Section 8. Works Cited 227
Appendix A. Outreach Documentation 229
A.1 Ready SB County Preparedness App Message 229
A.2. San Bernardino County Fire Public Input Requested 229
A.3. MJHMP PowerPoint Presentation 231
Annex A. Fire Protection District 233
A.1 Introduction 233
A.2 Fire District Profile 233
A.3 Planning Process 234
A.4 Hazard Identification and Prioritization 234
A.5 Coordination with existing Fire District Mechanisms 235
A.5.1 Critical Route Planning Committee 235
A.5.2 Public Alert and Education Programs 236
A.5.3 OES Volunteer Programs 237
A.5.4 ROPE Plan (Responders Organized For Pass Emergencies) 239
A.5.5 Great ShakeOut County Drill in all Disciplines (held annually) 240
A.5.6 “Ready SB” Smart Phone App for Disaster Preparedness Program 2016 240
A.5.7 Cal Fire 240
A.5.8 Organized Group Volunteer Activities 241
A.6 Fire Protection District Mitigation Project Prioritizing 241
A.7 Fire Protection District Mitigation Project Actions 243
Annex B. Flood Control District 249
B.1 Introduction 249
B.2 Flood District Profile 249
B.3 Planning Process 249
B.4 Hazard Identification and Prioritization 250
B.5 Coordination with Existing Flood District Mechanisms 251
B.5.1 Flood Area Safety Taskforce (FAST) 251
B.5.2 Alluvial Fan Task Force 253
B.5.3 StormReady 256
B.6 Mitigation Project Prioritization and Implementation 257
B.7 Flood Project Prioritization and Implementation 259
B.7.1 Priority Project Descriptions 260
B.7.2 Projects with Mitigation Benefits 266
B.7.3 Future Year Projects 267

Annex C. Special Districts Department 277
C.1 Introduction 277
C.2 Special Districts Profile 277
C.3 Planning Process 278
C.4 Hazard Identification and Prioritization 279
C.5 Coordination with County Planning Efforts 279
C.5.1 3.2 Water Systems (Distribution Systems): 280
C.5.2 3.3 Sewer Systems (Collection Systems): 281
C.5.3 3.4 Wastewater Treatment Plant 282
C.5.4 3.5 Roads 282
C.5.5 3.6 Television Translator Districts 283
C.5.6 3.7 Parks Districts 283
C.6 Special Districts Mitigation Project Prioritizing 284
C.7 Special Districts Mitigation Actions 285

List of Figures

Figure 1-1: Organizational Chart for San Bernardino County 2
Figure 1-2: San Bernardino County Fire Protection District 4
Figure 1-3: Map of San Bernardino County Flood Control District 5
Figure 1-4: Map of Special District Department Districts 9
Figure 1-5: Special Districts Valley/Mountain Region 10
Figure 1-6: Morongo Basin/Twentynine Palms Region 10
Figure 1-7: Special Districts Victor Valley/Barstow Region 11
Figure 1-8: Unincorporated and Corporate Areas in San Bernardino County 25
Figure 1-9: Topographic Features in San Bernardino County 25
Figure 1-10: San Bernardino County Unincorporated Area Population Changes 2011 - 2016 28
Figure 1-11: San Bernardino County Unincorporated Area 2014 Population by Ethnicity 29
Figure 1-12: San Bernardino County Land Use 31
Figure 1-13: San Bernardino County Land Use Map 32
Figure 4-1: Major California Faults 67
Figure 4-5: USGS Liquefaction Susceptibility Zone 68
Figure 4-2: California Faults Probability of ≥ M 6.7 Earthquake 70
Figure 4-3: California Area Earthquake Probabilities by Magnitude 71
Figure 4-4: Earthquake Fault Zone 72
Figure 4-6: Wildfire History 1900 – 2016 (CalFire and USFS Data 2010) 75
Figure 4-7: San Bernardino National Forest – Vegetation Mortality 77
Figure 4-8: Fire Hazard Severity Zone 79
Figure 4-9: USGS Mean Fire Return Interval Map 80
Figure 4-10: Flood Hazard Severity Zone Map 87
Figure 4-11: US Drought Monitor Map for the State of California on August 23, 2016 94
Figure 4-12: USSDO Drought Tendency Map (Valid August 18-November 30, 2016 95

Figure 4-13: Month SPI through the end of August 2016 for San Bernardino County 96
Figure 4-14: Vegetation Drought Response Index – California Region 4 for August 21, 2016 97
Figure 4-15: Types of Terrorist Attacks in California from 1970-Present 101
Figure 4-16: Total and Fatal Terrorist Attacks in the United States by Year 102
Figure 4-17: International Terrorist Attacks Against the United States 103
Figure 4-18: Climate Impact Regions 111
Figure 4-19: July Decadal Average High Temperature Map; 2010 113
Figure 4-20: July Decadal Average High Temperature Map; 2090 113
Figure 4-21: California Historical and Projected Temperature increases 1961-2099 114
Figure 4-22: Data Source and Methodology 119
Figure 4-23: Census Block Building and Content Exposure Values 121
Figure 4-24: Census Tract Building and Content Exposure Values 122
Figure 4-25: Median Household Income Distribution Maps 125
Figure 4-26: Population Under Age 18 126
Figure 4-27: Population Over Age 65 127
Figure 4-28: Population Exposure to the Great Shakeout EQ Shake Severity Zone 134
Figure 4-29: Great Shakeout Scenario MMI Classes 139
Figure 4-30: Population at Risk from Wildfire Hazards 142
Figure 4-31: Population Exposed to NFIP Flood Zones 149
Figure 4-32: Total Building and Content Loss by Occupancy Type for 100 Year Flood 155
Figure 4-33: Total Building and Content Loss by Occupancy Type for 500 Year Flood 156
Figure 4-34: Decadal Snowpack Averages 1960-2090 163

List of Tables

Table 1-1: Special Districts Department District Listing 7
Table 1-2: Hazardous Tree Removal Project and Fuel Modification Projects 16
Table 1-3: Completed Flood Control Projects 19
Table 3-1: Proposed Project Timeline 38
Table 3-2: Multi-Jurisdictional Planning Team 40
Table 3-3: Stakeholder List 41
Table 3-4: Planning Team Meetings 43
Table 4-1: Document Review Crosswalk 60
Table 4-2: Federal, State and County Declared Disasters 61
Table 4-3: Prioritized Hazard Assessment Matrix 63
Table 4-4: Earthquakes: 2010-2015 San Bernardino County 66
Table 4-5: MMI Scale 69
Table 4-6: Wildfire Occurrences 2010-2016 74
Table 4-7: Severe Weather Events 2010-Present 86
Table 4-8: San Bernardino County Flood Hazard Area 86
Table 4-9: Land Use Compatibility Chart for 100 Year Flood Plains (General Plan Table S-1) 88
Table 4-10: Terrorist Attacks in San Bernardino County 100
Table 4-11: Event Profiles for Terrorism and Technological Hazards 104

Table 4-12: Hazus Flood Census Block Input Values 121
Table 4-13: Hazus Earthquake Census Tract Input Values 122
Table 4-14: Critical Facility Points 128
Table 4-15: Linear Utilities 129
Table 4-16: Improved Parcel Value Exposure from Southern California Great ShakeOut 134
Table 4-17: Critical Facilities with Earthquake Risk Southern California Great ShakeOut 135
Table 4-18: Lifeline with Earthquake Risk Southern California Great ShakeOut 137
Table 4-19: Estimated Building and Content Loss Great ShakeOut Scenario Earthquake 138
Table 4-20: Residential Buildings and Content at Risk from Wildfire 143
Table 4-21: Critical Facilities at Risk from Wildfire 144
Table 4-22: Lifelines with Wildfire Risk 145
Table 4-23: Parcels Exposed to NFIP Flood Zones 151
Table 4-24: Critical Facility Exposed to NFIP Flood Zones 152
Table 4-25: Lifelines Exposure to NFIP Flood Zones 152
Table 4-26: Flood Loss Estimation (Based on Depth) in NFIP Flood Zones 153
Table 4-27: 100 Year Flood Los Estimation (Based on Depth) in NFIP Flood Zones by Occupancy Type 154
Table 4-28: 500 Year Flood Loss Estimation (Based on Depth) In NFIP Flood Zones by Occupancy Type 156
Table 5-1: County Development Code Hazard Crosswalk 165
Table 5-2: Planning and Regulatory Mitigation Capabilities Summary 166
Table 5-3: Public Education and Alert Programs 166
Table 5-4: Wildfire Mitigation Programs 169
Table 5-5: Spending Authority for San Bernardino County 175
Table 5-6: 2015-2017 Staffing Budget 176
Table 6-1: Mitigation Alternative Summary 193
Table 6-2: Mitigation Action Descriptions 196
Table 7-1: Wildfire Mitigation Implementation Methods 218
Table 7-2: General Plan Geologic Hazard Overlay Maps 219
Table 7-3: Tentative Schedule for the LGA Grant 225
Table A-1: Fire District Planning Team 234
Table A-2: Fire District Hazard Priority Matrix 235
Table A-3: Mitigation Project Prioritization and Implementation 243
Table B-4: Flood Control District Hazard Mitigation Planning Team 250
Table B-5: Prioritized Hazard Assessment Matrix 250
Table B-6: Priority Flood Control Projects 259
Table B-7: In Progress Flood Control Mitigation Projects 266
Table B-8: Future Year Projects 267
Table C-9: Special District Hazard Mitigation Planning Team 278
Table C-10: Mitigation Project Prioritization and Implementation 285

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RESOLUTION NO. 2017-_____

A RESOLUTION OF THE BOARD OF SUPERVISORS OF THE COUNTY OF SAN BERNARDINO, STATE OF CALIFORNIA, ADOPTING THE SAN BERNARDINO COUNTY UNINCORPORATED AREA MULTI-JURISDICTIONAL HAZARD MITIGATION PLAN DATED MARCH 2017, AND AUTHORIZING FUTURE NON-SUBSTANTIVE AMENDMENTS TO THE PLAN

On Tuesday, _____, 2017, on motion of Supervisor _____, duly seconded by Supervisor _____ and carried, the following resolution is adopted by the Board of Supervisors of San Bernardino County, State of California.

WHEREAS, the preservation of life and property is an inherent responsibility of local, state and federal government, including the County of San Bernardino, and the San Bernardino County Office of Emergency Services, to prepare a local Multi-Jurisdictional Hazard Mitigation Plan (HMP) for the unincorporated area of San Bernardino County to define hazard mitigation measures to reduce or eliminate loss of life and/or property; and

WHEREAS, this HMP represents a comprehensive description of the County's commitment to reducing, preventing or eliminating potential impacts of disasters caused by natural hazards; and

WHEREAS, the HMP is a Federal requirement under the Disaster Mitigation Act of 2000 for the County to be eligible to apply for federal funds for disaster recovery and mitigation assistance; and

WHEREAS, the HMP established a coordinated effort to support mitigation activities, identifies measures to combat natural hazards within our County; and

WHEREAS, the HMP is an extension of the State of California Multi-Hazard Mitigation Plan, and will be reviewed periodically and revised as necessary to meet changing conditions; and

WHEREAS, the Board of Supervisors agrees to adopt this HMP and urges all officials, employees, public and private organizations, and citizens, individually and collectively, to do their share in furthering the preparation of hazard mitigation within the County of San Bernardino;

NOW, THEREFORE, BE IT RESOLVED THAT:

The Board of Supervisors of the County of San Bernardino, a public entity established under the laws of the State of California, hereby authorizes this HMP to be adopted, that the San Bernardino County Fire Protection District Office of Emergency Services Division Manager is hereby authorized to implement future non-substantive amendments, recommended by the Federal Emergency Management Agency upon their review, to the HMP, that a copy of the Board of Supervisors' approved San Bernardino County Unincorporated Area Hazard Mitigation Plan be forwarded to the Federal Emergency Management Agency and CalOES, that once approved the HMP will be considered to be incorporated into the County's General Plan, and this plan become effective immediately.

PASSED AND ADOPTED by the Board of Supervisors of the County of San Bernardino, State of California, by the following vote:

AYES: SUPERVISORS:

NOES: SUPERVISORS:

ABSENT: SUPERVISORS:

* * * * *

STATE OF CALIFORNIA)
) ss.
COUNTY OF SAN BERNARDINO)

I, **LAURA H. WELCH,** Clerk of the Board of Supervisors of the County of San Bernardino, State of California, hereby certify the foregoing to be a full, true and correct copy of the record of the action taken by the Board of Supervisors, by vote of the members present, as the same appears in the Official Minutes of said Board at its meeting of _____, 2017.

LAURA H. WELCH
Clerk of the Board of Supervisors

By _____
Deputy

RESOLUTION NO. 2017-_____

A RESOLUTION OF THE BOARD OF SUPERVISORS OF THE SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT, STATE OF CALIFORNIA, ADOPTING THE SAN BERNARDINO COUNTY UNINCORPORATED AREA MULTI-JURISDICTIONAL HAZARD MITIGATION PLAN DATED MARCH 2017, AND AUTHORIZING FUTURE NON-SUBSTANTIVE AMENDMENTS TO THE PLAN

On Tuesday, _____, 2017, on motion of Supervisor _____, duly seconded by Supervisor _____ and carried, the following resolution is adopted by the Board of Supervisors of the San Bernardino County Flood Control District, State of California.

WHEREAS, the preservation of life and property is an inherent responsibility of local, state and federal government, including the County of San Bernardino, and the San Bernardino County Office of Emergency Services, to prepare a local Multi-Jurisdictional Hazard Mitigation Plan (HMP) for the unincorporated area of San Bernardino County to define hazard mitigation measures to reduce or eliminate loss of life and/or property; and

WHEREAS, this HMP represents a comprehensive description of the County's commitment to reducing, preventing or eliminating potential impacts of disasters caused by natural hazards; and

WHEREAS, the HMP is a Federal requirement under the Disaster Mitigation Act of 2000 for the County to be eligible to apply for federal funds for disaster recovery and mitigation assistance; and

WHEREAS, the HMP established a coordinated effort to support mitigation activities, identifies measures to combat natural hazards within our County; and

WHEREAS, the HMP is an extension of the State of California Multi-Hazard Mitigation Plan, and will be reviewed periodically and revised as necessary to meet changing conditions; and

WHEREAS, the Board of Supervisors agrees to adopt this HMP and urges all officials, employees, public and private organizations, and citizens, individually and collectively, to do their share in furthering the preparation of hazard mitigation within the County of San Bernardino

NOW, THEREFORE, BE IT RESOLVED THAT:

The Board of Supervisors of the San Bernardino County Flood Control District, a public entity established under the laws of the State of California, hereby authorizes this HMP to be adopted, that the San Bernardino County Fire Protection District Office of Emergency Services Division Manager is hereby authorized to implement future non-substantive amendments, recommended by the Federal Emergency Management Agency upon their review, to the HMP, that a copy of the Board of Supervisors' approved San Bernardino County Unincorporated Area Hazard Mitigation Plan be forwarded to the Federal Emergency Management Agency and the CalOES, that once

approved the HMP will be considered to be incorporated into the County's General Plan, and this plan become effective immediately.

PASSED AND ADOPTED by the Board of Supervisors of the San Bernardino County Flood Control District, State of California, by the following vote:

AYES: SUPERVISORS:

NOES: SUPERVISORS:

ABSENT: SUPERVISORS:

* * * * *

STATE OF CALIFORNIA)
) ss.
COUNTY OF SAN BERNARDINO)

I, **LAURA H. WELCH,** Clerk of the Board of Supervisors of the San Bernardino County Flood Control District, State of California, hereby certify the foregoing to be a full, true and correct copy of the record of the action taken by the Board of Supervisors, by vote of the members present, as the same appears in the Official Minutes of said Board at its meeting of _____, 2017.

LAURA H. WELCH
Clerk

By _____
Deputy

RESOLUTION NO. 2017-

A RESOLUTION OF THE BOARD OF DIRECTORS OF THE BOARD GOVERNED COUNTY SERVICE AREAS ADOPTING THE SAN BERNARDINO COUNTY UNINCORPORATED AREA MULTI-JURISDICTIONAL HAZARD MITIGATION PLAN DATED MARCH 2017, AND AUTHORIZING FUTURE NON-SUBSTANTIVE AMENDMENTS TO THE PLAN

On Tuesday, , 2017, on motion of Director , duly seconded by Director and carried, the following resolution is adopted by the Board of Directors of the Board Governed County Service Areas and their Zones.

WHEREAS, the preservation of life and property is an inherent responsibility of local, state and federal government, including the County of San Bernardino, and the San Bernardino County Office of Emergency Services, to prepare a local Multi-Jurisdictional Hazard Mitigation Plan (HMP) for the unincorporated area of San Bernardino County to define hazard mitigation measures to reduce or eliminate loss of life and/or property; and

WHEREAS, this HMP represents a comprehensive description of the County's commitment to reducing, preventing or eliminating potential impacts of disasters caused by natural hazards; and

WHEREAS, the HMP is a Federal requirement under the Disaster Mitigation Act of 2000 for the County to be eligible to apply for federal funds for disaster recovery and mitigation assistance; and

WHEREAS, the HMP established a coordinated effort to support mitigation activities, identifies measures to combat natural hazards within our County; and

WHEREAS, the HMP is an extension of the State of California Multi-Hazard Mitigation Plan, and will be reviewed periodically and revised as necessary to meet changing conditions; and

WHEREAS, the Board of Directors agrees to adopt this HMP and urges all officials, employees, public and private organizations, and citizens, individually and collectively, to do their share in furthering the preparation of hazard mitigation within the County of San Bernardino;

NOW, THEREFORE, BE IT RESOLVED THAT:

The Board of Directors of the Board Governed County Service Areas and their Zones, a public entity established under the laws of the State of California, hereby authorizes this HMP to be adopted, that the San Bernardino County Fire Protection District Office of Emergency Services Division Manager is hereby authorized to implement future non-substantive amendments, recommended by the Federal Emergency Management Agency upon their review, to the HMP, that a copy of the Board of Directors' approved San Bernardino County Unincorporated Area Hazard Mitigation Plan be forwarded to the Federal Emergency Management Agency and CalOES, that

once approved the HMP will be considered to be incorporated into the County's General Plan, and this plan become effective immediately.

PASSED AND ADOPTED by the Board of Directors of the Board Governed County Service Areas and their Zones by the following vote:

AYES: DIRECTORS:

NOES: DIRECTORS:

ABSENT: DIRECTORS:

* * * * *

STATE OF CALIFORNIA)
) ss.
COUNTY OF SAN BERNARDINO)

I, **LAURA H. WELCH,** Secretary of Board of Directors of the Board Governed County Service Areas and their Zones, hereby certify the foregoing to be a full, true and correct copy of the record of the action taken by the Board of Directors, by vote of the members present, as the same appears in the Official Minutes of said Board at its meeting of Tuesday, , 2017.

LAURA H. WELCH
Secretary

By _____
Deputy

RESOLUTION NO. 2017-

A RESOLUTION OF THE BOARD OF DIRECTORS OF THE SAN BERNARDINO COUNTY FIRE PROTECTION DISTRICT ADOPTING THE SAN BERNARDINO COUNTY UNINCORPORATED AREA MULTI-JURISDICTIONAL HAZARD MITIGATION PLAN DATED MARCH 2017, AND AUTHORIZING FUTURE NON-SUBSTANTIVE AMENDMENTS TO THE PLAN

On Tuesday, , 2017, on motion of Director , duly seconded by Director and carried, the following resolution is adopted by the Board of Directors of San Bernardino County Fire Protection District.

WHEREAS, the preservation of life and property is an inherent responsibility of local, state and federal government, including the County of San Bernardino, and the San Bernardino County Office of Emergency Services, to prepare a local Multi-Jurisdictional Hazard Mitigation Plan (HMP) for the unincorporated area of San Bernardino County to define hazard mitigation measures to reduce or eliminate loss of life and/or property; and

WHEREAS, this HMP represents a comprehensive description of the County's commitment to reducing, preventing or eliminating potential impacts of disasters caused by natural hazards; and

WHEREAS, the HMP is a Federal requirement under the Disaster Mitigation Act of 2000 for the County to be eligible to apply for federal funds for disaster recovery and mitigation assistance; and

WHEREAS, the HMP established a coordinated effort to support mitigation activities, identifies measures to combat natural hazards within our County; and

WHEREAS, the HMP is an extension of the State of California Multi-Hazard Mitigation Plan, and will be reviewed periodically and revised as necessary to meet changing conditions; and

WHEREAS, the Board of Directors agrees to adopt this HMP and urges all officials, employees, public and private organizations, and citizens, individually and collectively, to do their share in furthering the preparation of hazard mitigation within the County of San Bernardino;

NOW, THEREFORE, BE IT RESOLVED THAT:

The Board of Directors of the San Bernardino County Fire Protection District, a public entity established under the laws of the State of California, hereby authorizes this HMP to be adopted, that the San Bernardino County Fire Protection District Office of Emergency Services Division Manager is hereby authorized to implement future non-substantive amendments, recommended by the Federal Emergency Management Agency upon their review, to the HMP, that a copy of the Board of Directors' approved San Bernardino County Unincorporated Area Hazard Mitigation Plan be forwarded to the Federal Emergency Management Agency and CalOES, that once approved

the HMP will be considered to be incorporated into the County's General Plan, and this plan become effective immediately.

PASSED AND ADOPTED by the Board of Directors of the San Bernardino County Fire Protection District by the following vote:

AYES: DIRECTORS:

NOES: DIRECTORS:

ABSENT: DIRECTORS:

* * * * *

STATE OF CALIFORNIA)
) ss.
COUNTY OF SAN BERNARDINO)

I, **LAURA H. WELCH,** Secretary of Board of Directors of the San Bernardino County Fire Protection District, hereby certify the foregoing to be a full, true and correct copy of the record of the action taken by the Board of Directors, by vote of the members present, as the same appears in the Official Minutes of said Board at its meeting of Tuesday, , 2017.

LAURA H. WELCH
Secretary

By _____
Deputy

Section 1. Introduction

The Multi-Jurisdictional Hazard Mitigation Plan (MJHMP) update is a “living document” that should be reviewed, monitored, and updated to reflect changing conditions and new information. As required, the MJHMP must be updated every five (5) years to remain in compliance with regulations and Federal mitigation grant conditions. In that spirit, this MJHMP is an update of the San Bernardino County Unincorporated Area MJHMP approved by FEMA on October 11, 2011. This MJHMP presents updated information regarding hazards being faced by the County, the San Bernardino County Fire Protection District, the San Bernardino County Flood Control District, and those Board-governed Special Districts administered by the San Bernardino County Special Districts Department.

These Board-Governed Special Districts were formed by the Board of Supervisors to provide a specific service for a specific area of San Bernardino County. Additionally, these Special Districts are treated as an all-inclusive County Organization, not as separate or independent entities. Each Special District is governed cooperatively by the San Bernardino County Board of Supervisors acting as the Board of Supervisors for each of the individual districts.

The County of San Bernardino is governed by five (5) Supervisors; one for each supervisorial district who collectively make up the County Board of Supervisors. The Board of Supervisors is responsible for the County department and agencies, including Board Governed Special Districts, providing services to the unincorporated area.

The Board of Supervisors acts as the Board of Directors for the County Fire Protection District, the County Flood Control District, and the Special Districts Department as part of their responsibilities as an elected member of the County of San Bernardino Board of Supervisors.

The San Bernardino County Organizational Chart clearly shows the relationships between these Board-governed Special Districts and other County departments as one of equal relationship Departments/Districts. See Figure 1-1.

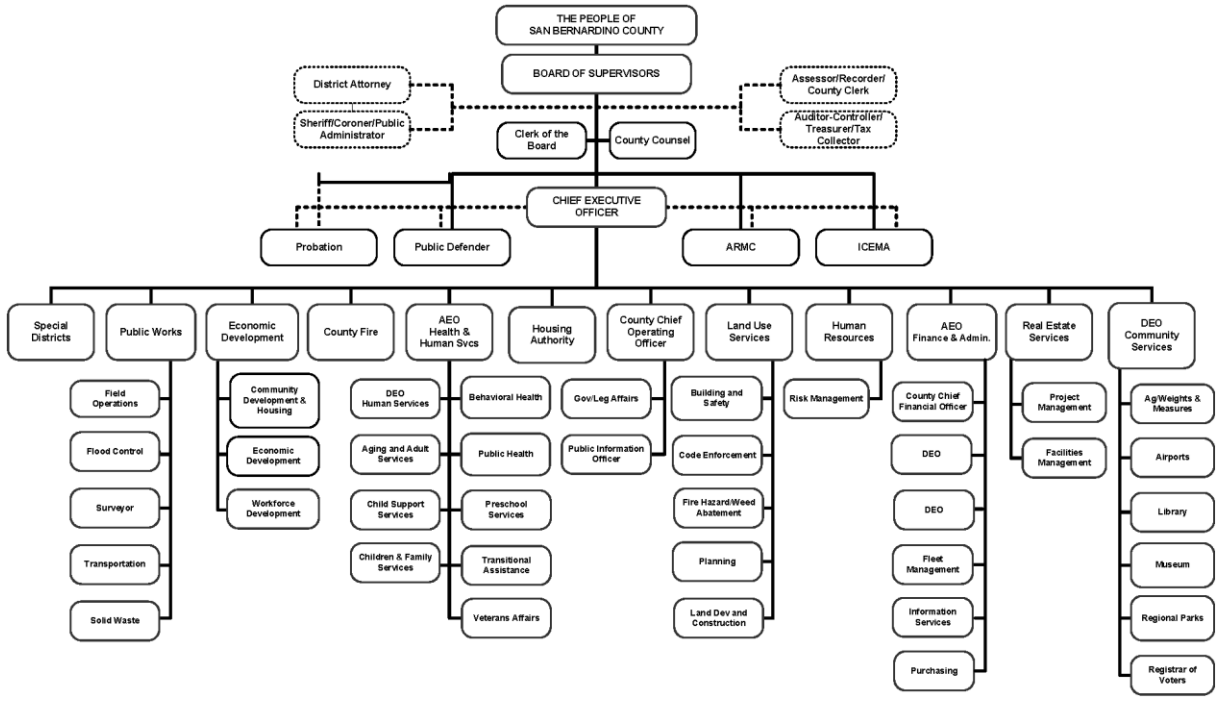


Figure 1-1: Organizational Chart for San Bernardino County

1.1 San Bernardino County Unincorporated Area

The Unincorporated Area of San Bernardino County has a population of 309,759 persons (14.48%) of the entire County Population) and covers 19,233 square miles (95.67% of the entire County land area). There are approximately 61 unincorporated communities within the unincorporated County. San Bernardino County is the largest County in the continental United States. San Bernardino County provides basic services to the residents and citizens of the unincorporated areas. These services include Law Enforcement, Fire Protection, Building and Safety Services, Public Health Services, Library, and Human Services (social services). Five Interstate Highways and four inter-continental railroad lines cross the County, providing vital transportation links from southern California to the remainder of the United States.

1.1.1 San Bernardino County Fire Protection District

San Bernardino County Fire Protection District is a community based all-risk emergency services organization dedicated to the health and well-being of the citizens of San Bernardino County through a balance of regionalized services delivery and accountability to the local community. On July 1, 2008, twenty-seven separate fire districts were merged into one single board governed fire protection district with four regional service zones. The reorganization was not only an administrative advancement but also a significant advancement in operations and delivery of emergency response services.

It has resulted in simplified budgeting and fiscal operations, greater flexibility in the use in the use of department resources and assets and more effective use of day-to-day operations. The reorganization will continue to improve the delivery of fire services and overall operating efficiency.

The San Bernardino County Fire Protection District (County Fire) covers 19,278 square miles, operates 85 fire stations and facilities within 6 Regional Service Zones (Mountain, North Desert, South Desert, High Desert, West Valley and East Valley), and serves 64 unincorporated communities, the City of Grand Terrace, and the Town of Yucca Valley. There are also 6 ambulance enterprise operations that provide service within these Regional Service Zones. In addition, 7 cities are Independent Fire Protection Districts that contract with County Fire: Adelanto, Fontana, Hesperia, Needles, Twentynine Palms, San Bernardino and Victorville. County Fire's executive management is provided by the Fire Chief/County Fire Warden, Deputy Chief, Assistant Chief of Operations as well as Division Managers and Division Chiefs.

County Fire is an all-risk department providing emergency mitigation and management for fire suppression, emergency medical services (paramedic and non-paramedic), ambulance services, HAZMAT response, arson investigation, technical rescue including water borne, flooding and mudslide, winter rescue operations, terrorism and weapons of mass destruction. As part of disaster preparation, response, and mitigation, the department's Office of Emergency Services specifically provides support and assistance to the 24 cities and towns, as well as, all the unincorporated portions of the county. The field functions are supported by a countywide management system that includes organizational business practices, human resources, financial and accounting services, vehicles services and support, and equipment warehousing and distribution. County Fire also provides for the management of community safety services such as: fire prevention, building construction plans and permits, household hazardous waste, Local Oversight Program for hazardous materials, HAZMAT facility inspections, planning and engineering, and public education and outreach.

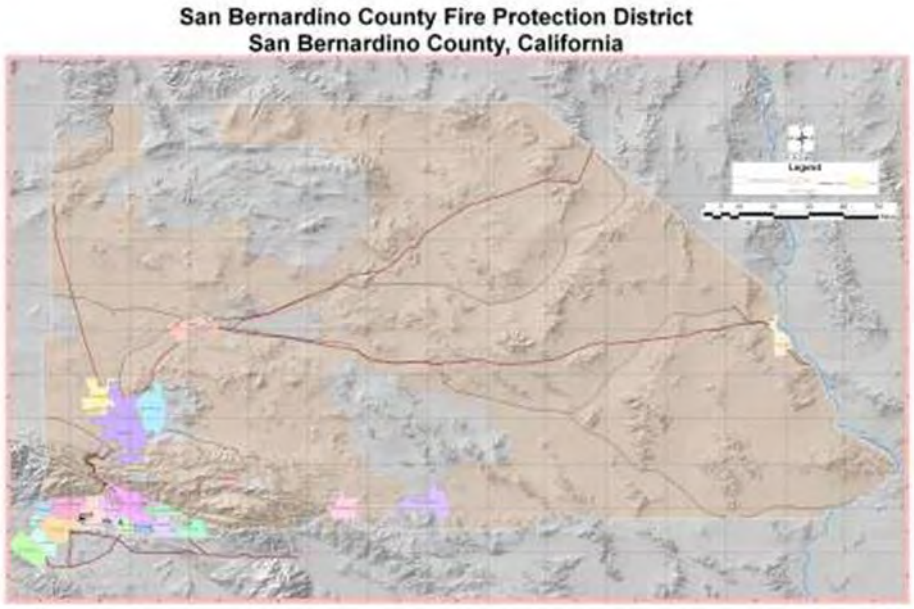


Figure 1-2: San Bernardino County Fire Protection District

1.1.2 San Bernardino County Flood Control District

1.1.2.1 Description of Major Services

The San Bernardino County Flood Control District (District) was created in 1939 under special state legislation. Since its inception, the District has developed a very extensive system of flood control and water conservation facilities, including dams, conservation basins, debris basins, channels and storm drains. The purpose of these facilities is to intercept and convey flood flows through and away from developed areas of the county, as well as to promote water conservation and improved water quality.

The District covers the entire county, including all of the incorporated cities. The District is divided into six geographic flood zones (in recognition of the different characteristics and flood control needs in various areas).

- Zone 1 encompasses the county's West End, from the Los Angeles and Riverside County lines to West Fontana.
- Zone 2 encompasses the central area of the San Bernardino Valley easterly of Zone 1 to approximately the Santa Ana River and City Creek demarcations.
- Zone 3 covers the east end of San Bernardino valley, east of Zone 2.

- Zone 4 covers the Mojave River valley region, from the San Bernardino Mountains to Silver Lakes.
- Zone 5 primarily includes the San Bernardino Mountains.
- Zone 6 encompasses the remainder of the county not covered by other zones.

The District has also established a countywide administrative zone (Zone 7)

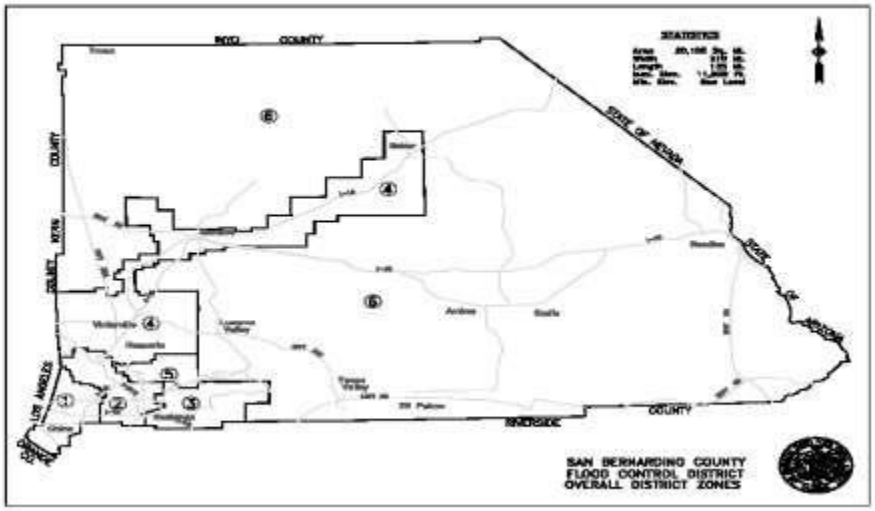


Figure 1-3: Map of San Bernardino County Flood Control District

The District's funding is primarily derived from property taxes, federal and state aid on specific projects, subdivision and permit fees, rents and royalties, and revenue from local water agencies for water spreading services. The District's principal functions are as follows:

- **Flood Protection on Major Streams:** In cooperation with the federal government, the District conducts programs for channel and levee construction, floodwater retention, and debris basin maintenance. Programs or projects are often done in cooperation with the incorporated cities, the U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation.

- **Water Conservation:** The District operates and maintains water conservation basins and spreading grounds. Water from the local mountains and northern California is spread and percolated into the groundwater basins underlying the county. The District has numerous joint use agreements with water districts allowing use of District facilities for groundwater recharge.

- **Storm Drain Construction:** The District is active in comprehensive storm drain master

planning/construction and cooperates with incorporated cities and other agencies in storm drain projects.

- **Facility Maintenance:** The District has a proactive maintenance program for its facilities. Regular inspections of the storm drains, channels, and basins are made as required by various state and federal agencies.

- **National Pollution Discharge Elimination System (NPDES):** The District is the lead permittee in the San Bernardino valley area-wide NPDES permit with 16 cities as co-permittees. The NPDES program, through the State Water Quality Management Board, regulates storm water quality through very detailed and complex permits, which affect everyone within the Santa Ana River Watershed and is expanding into the high desert area of the Victor Valley under Phase II of the permit.

- **State Water Quality Management Board:** regulates storm water quality through very detailed and complex permits, which affect everyone within the Santa Ana River Watershed and is expanding into the high desert area of the Victor Valley under Phase II of the permit.

- **Flood Operations:** During the flood season, the District maintains telemetry systems for monitoring rainfall and runoff and dispatches storm patrols as dictated by the projected severity of a storm. The District has access to a weather satellite data delivery system to provide state-of-the-art weather information. The system provides advance warning of major storm activity.

- **Flood Area Safety Task Force (FAST):** As a result of the October/November fires of 2003, the FAST organization was created. The District is a key component of this task force, which is meant to respond to the elevated flood risk associated with the aftermath of these devastating fires.

1.1.3 Special Districts Department

The Special Districts Department promotes safe, healthy, enjoyable and dynamic communities by providing essential programs and municipal services that meet the current and future needs of the communities served.

The San Bernardino County Board of Supervisors is the governing body for all Board governed Districts, County Service Areas (CSA), and Improvement Zones. The day-to-day management and administration is done through the Special Districts Department. The County Board of Supervisors and the Special Districts Department depend quite heavily on input from the community. The successful operation of a District, CSA and Improvement Zone is a team effort between County staff and property owners. Where needed, the Board of Supervisors will set up a

property owner Advisory Commission or Municipal Advisory Council (MAC) to work with and make recommendations to the Board and County staff.

The formation process begins with a request from property owners and then involves a feasibility study performed by the Special District Department with the assistance of many other County Departments. The final approval of the District, CSA and Improvement Zone is done by the County Board of Supervisors at a public hearing. Depending on the complexity of the issues, the process can take from three (3) months to one (1) year to complete.

There are various forms of financial mechanisms that can be used to fund services such as fees, special taxes, assessments, etc. Prior to a new funding source being implemented, it must receive approval from either the property owners or the registered voters in the area. It is important to understand that all funding is generated through the Districts, CSAs, and Improvement Zones. No County general funds are used or are available.

Special Districts Department is responsible for operating the Board-governed Special Districts within San Bernardino County. There are 102 special districts managed by the Special Districts Department:

Table 1-1: Special Districts Department District Listing

	District Type	Number
1	Special Revenue Districts	11
2	Enterprise Funds (Airport and Refuse)	3
3	Parks Districts	19
4	Road Districts	41
5	Enterprise Funds (Sewer)	9
6	Street Light Districts	11
7	Enterprise Funds (Water)	8
Total Special Districts		102

- **Special Revenue Districts** were created to provide a service to the property owners within the Special Revenue District.
- **Enterprise Funds Districts** derive their funds through fees collected for delivery of a service or good such as water, sewer, refuse or airport fees from the users within the individual District.
- **Parks Districts** derive their funds through property taxes levied on property owners

within the individual Park District.

- **Road Districts** derive their funds through property taxes levied on property owners within the Road District.
- **Street Light Districts** derive their funds through property taxes levied on property owners within the Street Light District.

The two Special Districts listed below were formed differently than the other special districts listed above managed by the Special Districts Department. These two districts were formed with a Board of Directors. (San Bernardino County Board of Supervisors) and are not independently elected. All governance actions are by the elected members of the Board of Supervisors acting as the Board of Directors for the Recreation and Park District.

Big Bear Valley Recreation and Parks District

Big Bear Valley Recreation and Park District currently maintains 6 developed parks, 2 undeveloped parks, several community buildings including the Big Bear Valley Senior Center, 3 ball fields, and a swim beach. Moonridge Animal Park is administered by the Big Bear Valley Recreation and Park District. The Zoo is open year round for visitors to see alpine species on exhibit. The Zoo receives approximately 99,600 visitors annually.

Bloomington Recreation and Parks District

Bloomington Recreation and Park District maintains two community parks, an equestrian arena, sports fields, and a community center.

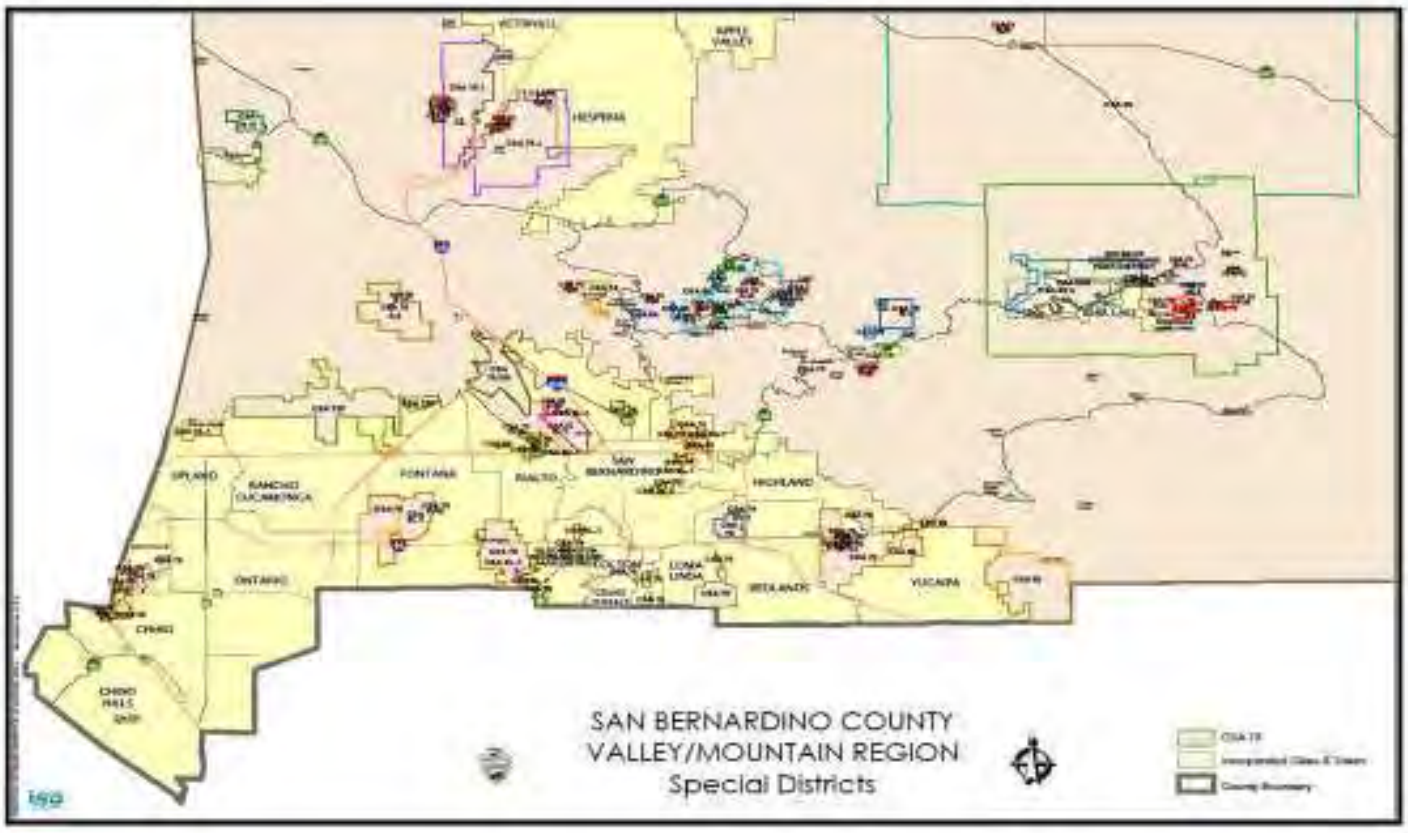


Figure 1-4: Map of Special District Department Districts



Figure 1-5: Special Districts Valley/Mountain Region

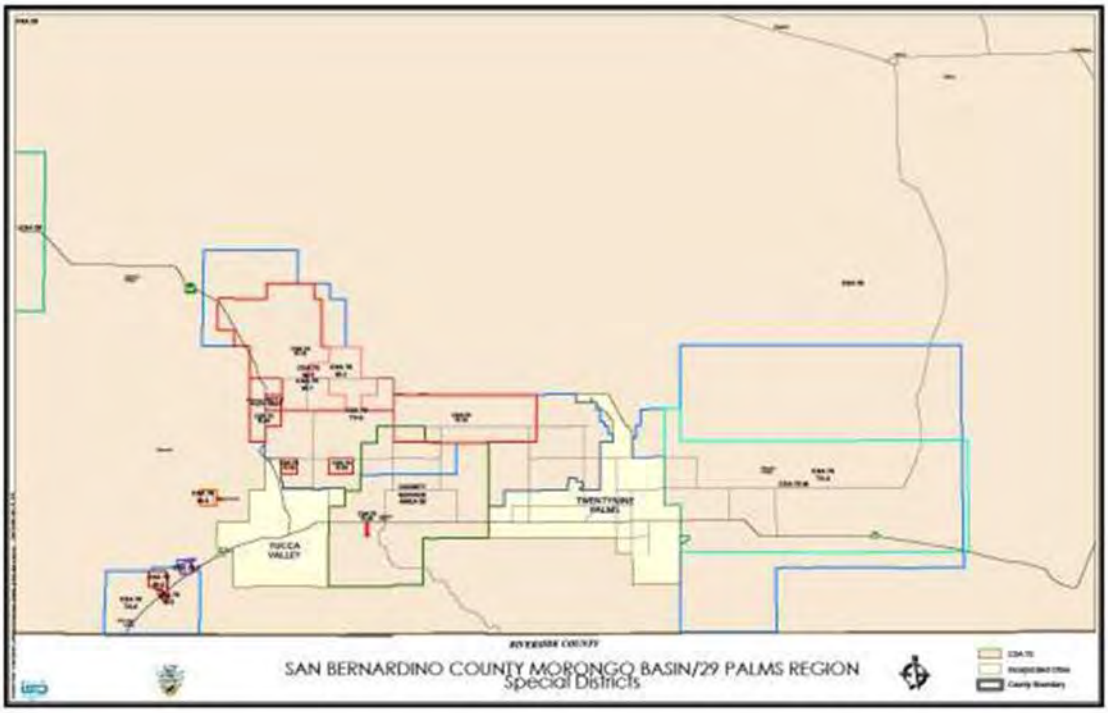


Figure 1-6: Morongo Basin/Twentynine Palms Region

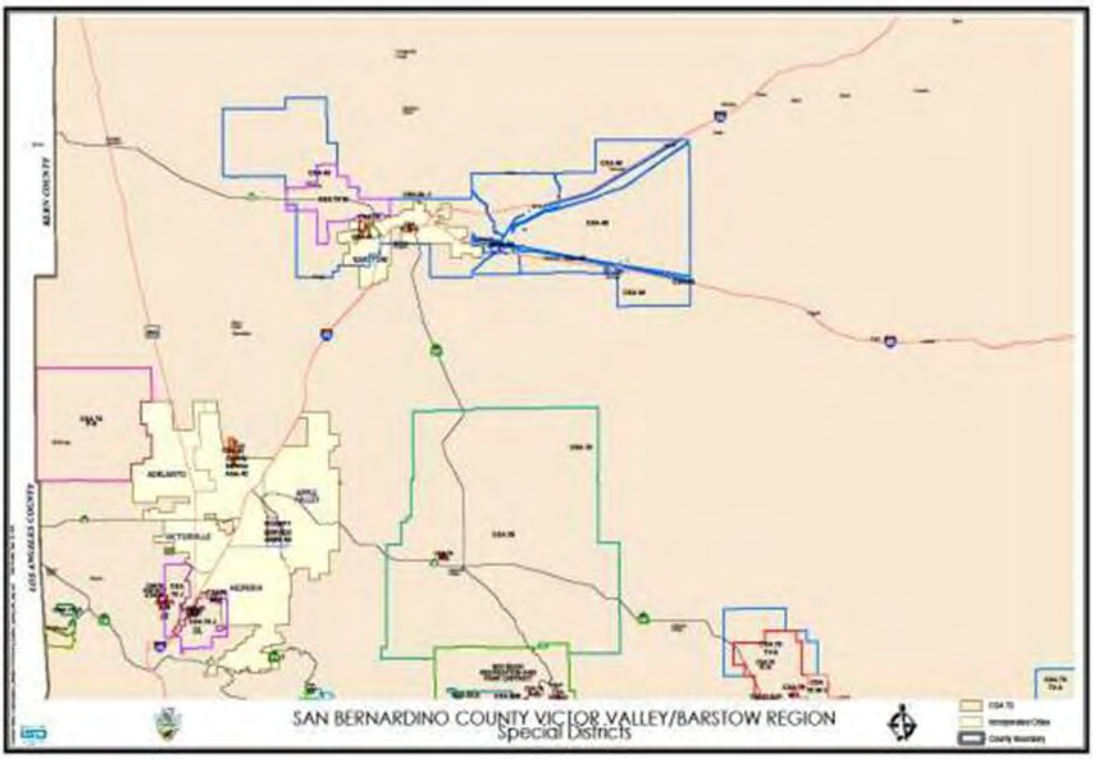


Figure 1-7: Special Districts Victor Valley/Barstow Region

1.2 Purpose of the Plan

The intent of hazard mitigation is to reduce and/or eliminate loss of life and property. Hazard mitigation is defined by FEMA as “any action taken to reduce or eliminate the long-term risk to human life and property from natural hazards.” A “hazard” is defined by FEMA as “any event or condition with the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, environmental damage, business interruption, or other loss.”

The purpose of the Multi-Jurisdictional Hazard Mitigation Plan (MJHMP) is to demonstrate the plan for reducing and/or eliminating risk in the unincorporated area of the County and within areas overseen or managed by the Flood Control District, Fire District and Special Districts Department. The MJHMP process encourages communities within the unincorporated county to develop goals and projects that will reduce risk and build a more disaster resilient community by analyzing potential hazards. By cooperatively and jointly together as a Multi-Jurisdictional Planning team, the partners were able to develop common goals and objectives for mitigation efforts. The individual stakeholders can then take the goals and objectives back to their individual Special Districts for discussion, ranking and project development, and then bring the resulting projects back to the Multi-Jurisdictional Planning Team. The Multi-Jurisdictional Planning Team can then

integrate all projects into the appropriate project listing to be acted upon by the most appropriate managing department or district for the listed projects.

After disasters, repairs and reconstruction are often completed in such a way as to simply restore to pre-disaster conditions. Such efforts expedite a return to normalcy; however, the restoring of things to pre-disaster conditions sometimes result in feeding the disaster cycle; damage, reconstruction, and repeated damage. Mitigation is one of the primary phases of emergency management specifically dedicated to breaking the cycle of damage. Hazard mitigation is distinguished from other disaster management functions by measures that make County development and the natural environment safer and more disaster resilient. Mitigation generally involves alteration of physical environments, significantly reducing risks and vulnerability to hazards by altering the built environment so that life and property losses can be avoided or reduced. Mitigation also makes it easier and less expensive to respond to and recover from disasters.

1.3 Authority

In 2000, FEMA adopted revisions to the Code of Federal Regulations. This revision is known as “Disaster Mitigation Act (DMA).” DMA 2000, Section 322 (a-d) requires that local governments, as a condition of receiving federal disaster mitigation funds, have a Multi-Jurisdictional Hazard Mitigation Plan (MJHMP) that describes the process for assessing hazards, risks and vulnerabilities, identifying and prioritizing mitigation actions, and engaging/soliciting input from the community (public), key stakeholders, and adjacent jurisdictions/agencies.

With an approved (and adopted) MJHMP, the County and participating jurisdictions are eligible for federal disaster mitigation funds/grants (Hazard Mitigation Grant Program, Pre-Disaster Mitigation, and Flood Management Assistance) aimed to reduce and/or eliminate risk.

1.4 What’s New

The 2011 San Bernardino County Multi-Jurisdictional Hazard Mitigation Plan (MJHMP) contained a detailed description of the planning process, a risk assessment of identified hazards for the San Bernardino County Planning Area and an overall mitigation strategy for reducing the risk and vulnerability from these hazards. Since approval of the plan by FEMA, much progress has been made by San Bernardino County and the participating County Districts on implementation of the mitigation strategy. As part of this 2016 MJHMP Update, a thorough review and update of the 2011 plan was conducted to ensure that this update reflects current community conditions and priorities in order to realign the overall mitigation strategy for the next five-year planning period. This section of the plan includes the following:

- **What’s New in the Plan Update** This section provides an overview of the approach to updating the plan and identifies new analyses, data and information included in this Plan Update to reflect current community conditions. This includes a summary of new hazard and risk assessment data as it relates to the San Bernardino Planning Area as well as information on current and future development trends affecting community vulnerability

and related issues. The actual updated data, discussions, and associated analyses are contained in their respected sections within this 2016 MJHMP Update.

- **Summary of Significant Changes to Current Conditions and Hazard Mitigation Program Priorities.** This section provides a summary of significant changes in current conditions, changes in vulnerability, and any resulting modifications to the community's mitigation program priorities.

- **2011 Mitigation Strategy Status and Successes.** This section provides a description of the status of mitigation actions from the 2011 plan and also indicates whether a project is no longer relevant or is recommended for inclusion in the updated 2016 mitigation strategy. This section also highlights key mitigation success stories of the County and participating jurisdictions since the 2011 MJHMP.

This What's New section provides documentation of San Bernardino County Planning Area's progress or changes in their risk and vulnerability to hazards and their overall hazard mitigation program. Completion of this 2016 MJHMP Update further provides documentation of the San Bernardino County community's continued commitment and engagement in the mitigation planning process.

1.4.1 Updates to the Current Plan

This MJHMP update involved a comprehensive review and update of each section of the 2011 plan and includes an assessment of the success of the participating County Districts in evaluating, monitoring and implementing the mitigation strategy outlined in the initial plan. Only the information and data still valid from the 2011 plan was carried forward as applicable into this MJHMP update. In fact, based in part on the issuance of new 2011 and 2013 planning guidance, this 2016 plan has been significantly updated and rewritten.

The San Bernardino County Multi-Jurisdictional Hazard Mitigation Plan (2011) focused on integrating the MJHMP with the County General Plan goals and policies as well as incorporating specific flood mitigation projects that were programmed for completion over the five (5) year period. The Plan did not clearly identify mitigation projects the County would focus on for all priority hazards identified in the plan. However, the County has been very active and engaged in implementing and supporting projects and programs designed to reduce and/or eliminate risk in the County. The list of successful projects in this section represents the activities that the County has undertaken and/or supported to reduce the risks from Wildfire, Earthquake, Flood, Drought, Terrorism, and Climate Change.

1.4.2 New Jurisdictional Annexes

Newly refined and reconfigured Jurisdictional Annexes detail the hazard mitigation planning elements specific to the participating jurisdiction to the San Bernardino County MJHMP Update.

The Annexes are not intended to be a standalone document, but appends to and supplements the information contained in the 2016 base plan document. As such, all sections of the base plan, including the planning process and other procedural requirements apply to and were met by the participating jurisdictions. The newly refined Jurisdictional Annexes provide additional information specific to county participating special district or departments, with a focus on providing additional details on the mitigation strategies for the Fire Protection District, Flood Control District and Special Districts Department. The three annexes provide more detail on mitigation strategies, mitigation projects and existing implementation mechanism for each participating jurisdiction.

The 2011 MJHMP included the Big Bear Valley Recreation and Parks District and Bloomington Recreation and Parks District as standalone jurisdictions. For purposes of this 2016 plan update, Big Bear Valley Recreation and Parks District, and Bloomington Recreation and Parks District hazard mitigation planning efforts are included under the supervision of the Special Districts hazard mitigation planning efforts.

1.4.3 New Risk Assessment

As part of its comprehensive review and update of each section of the plan, San Bernardino County and participating jurisdictions recognized that updated data, if available, would enhance the analysis presented in the risk assessment and utilized in the development of the updated mitigation strategy. Highlights of new data used for this Plan Update is identified below in this Section and is also sourced in context within Chapter 4, Risk Assessment. Specific data used is sourced throughout this plan document. This new data and associated analysis provided valuable input for the development of the mitigation strategy presented in Chapter 5 of this plan. A highlight of new information and analyses contained in this plan update includes the following:

- A new assessment of updated hazards affecting the San Bernardino Planning Area was completed resulting in additional hazards added to planning documents the new hazards include climate change, drought and terrorism.

- The drought hazard was expanded to include water shortage impacts to the County, to better align with the State of California Hazard Mitigation Plan and to reflect the significant issues related to drought conditions resulting from the current and ongoing drought within the County and State of California.

- The climate change hazard was added to include to comply and align with the State of California Hazard Mitigation Plan and to reflect recent SB 379 initiatives. Climate change is affecting and will continue to affect the frequency and severity of natural hazard events, a trend that is of concern across the United States.

- An entire rework of the risk assessment for each identified hazard. This included reworking the hazard profile and adding new hazard event occurrences; redoing the entire vulnerability analysis to add items identified below and updating the vulnerability assessment based on more recent hazard data as well as using the most current parcel and assessor data for the existing built environment.

- An update of the flood hazard analysis to include an updated analysis of the 100-year flood, an analysis of the 500-year flood, including the use the new and updated DFIRMs.
- Utilizing updated critical facility GIS mapping for the Planning Area to provide an updated inventory of critical facilities by jurisdiction (including all municipalities) and a GIS analysis of critical facilities vulnerable to hazards with spatial footprints which include: flood, wildfire, and earthquake.
- An enhanced vulnerability assessment which added a GIS analysis of updated future development areas in the Planning Area and specific to each of the mapped hazards.
- Incorporation and analysis of the new 2010 Census data was utilized for this LHMP update. Census data was used in an intersect analysis to determine how much of the population is exposed to flood, wildfire and earthquake hazards.
- Also, as required by current FEMA planning guidance, an analysis of the County's ongoing and continued compliance with the NFIP is included in the Flood Hazard profile.
- Terrorism is now a reoccurring possibility within the United States, due to the terror attack in San Bernardino County in December of 2015, a hazard profile on this matter has been added to this plan.

1.4.4 Successful Wildfire Mitigation Implementation

1.4.4.1 Fire Safe Councils (FSC) Fuel Reduction Program Success

Fire Safe Councils have received and implemented millions of dollars in grant money for fuels reduction and for public education. Of note recently the Arrowhead Communities FSC developed a grant that did fuels reduction but used the existing staff at the County Tree Removal Program rather than pay additional consultants to do the same work. The benefit of this is that the FSC was able to maximize their expenditure and give the contractor a check upon completion of the project. This way 100% of their grant money went directly to the contractor and none went to administrative overhead.

1.4.4.2 Red Cross Grant Fuel Reduction Success

Although this grant was just recently started, the ARC has successfully removed and reduced fuels on several properties. They have also met with County Roads Sign Division and created the correct number of evacuation directional signs. Fifty signs will be posted in the Moon Ridge area of Big Bear Lake in 2010 and 2011. During an emergency, these directional signs will direct people out of a very confusing network of streets.

1.4.4.3 USFS Grants ARRA and Otherwise and Chipping Program Success

San Bernardino County and its Special Districts were successful in obtaining $3 million in American Recovery and Reinvestment Act funding to support ongoing fuel reduction programs and to create new jobs for the recovering economy. The USFS also funded an additional $13 million to carry on after the NRCS projects were closed out.

Project design, contracting and operations are managed by the County's Public Works Department but the priorities are set by local fire chiefs in monthly MAST Operations Meetings. It is the oldest and most significant program for reducing wildfire threat on a mountain wide basis. Table 1-2 shows current and planned fuels reduction Projects for the San Bernardino County Mountain areas.

Table 1-2: Hazardous Tree Removal Project and Fuel Modification Projects

Project Name	Contract No	Funding	Cost	Project Stage
Mojave view	FM179USFS	USFS	$23,840.00	Complete 2013
Strawberry Lodge	n/a	USFS	n/a	Complete 2013
Harich	n/a	USFS	n/a	Complete 2013
Camp Oaks	n/a	USFS	n/a	Complete 2013
Swinson/Arrowbear	n/a	USFS	n/a	Complete 2013
Osito Rancho/Cedar	n/a	USFS*	n/a	Complete 2013
BBV286SP	n/a	USFS	n/a	Complete 2013
BBV287SP	n/a	USFS	n/a	Complete 2013
BBV280SP	n/a	USFS	n/a	Complete 2013
FF288SP	n/a	USFS	n/a	Complete 2013
LA291SP	n/a	USFS	n/a	Complete 2013
RS292SP	n/a	USFS	n/a	Complete 2013
GVL293SP	n/a	USFS	n/a	Complete 2013
AB294SP	n/a	USFS	n/a	Complete 2013
BBV295SP	n/a	USFS	n/a	Complete 2013
Green Briar	FM100ARRA	ARRA**	$88,000.00	Complete 2013
West Hook Creek	n/a	ARRA	$14,700.00	Complete 2013
Silverwood Lake	n/a	ARRA	$21,000.00	Complete 2013
Weesha	n/a	ARRA	n/a	Complete 2013
Erwin Lake	n/a	ARRA	n/a	Complete 2013
Wrightwood	n/a	ARRA	n/a	Complete 2013
Camp Tahquitz	n/a	ARRA	n/a	Complete 2013

Project Name	Contract No	Funding	Cost	Project Stage
West Cajon	n/a	ARRA	n/a	Complete 2013
LA285SP	n/a	ARRA	n/a	Complete 2013
WW290SP	n/a	ARRA	n/a	Complete 2013
CL289SP	n/a	ARRA	n/a	Complete 2013
Rob Roy	n/a	ARRA	n/a	Complete 2013
Santa's Village	n/a	ARRA	n/a	Complete 2013
Saw Pitt II	n/a	ARRA	n/a	Complete 2013
Oak Hills	n/a	ARRA	n/a	Complete 2013
Fawnskin	n/a	ARRA	n/a	Complete 2013
Heaps Peak	n/a	ARRA	n/a	Complete 2013
Houston	n/a	ARRA	n/a	Complete 2013
Calvary	n/a	ARRA	n/a	Complete 2013
WW298SP	n/a	ARRA	n/a	Complete 2013
LG299SP	n/a	ARRA	n/a	Complete 2013
Project Name	**Contract No**	**Funding**	**Cost**	Complete 2013
Waterman Canyon	n/a	ARRA	n/a	Complete 2013
Willow Creek	FM6501AFSC	ACFSC***	$11,900.00	Complete 2013
LA191EVA	EVA191AFSC	ACFSC	n/a	Complete 2013
NorthBay	FM192AFCS	ACFSC	n/a	Complete 2013
LA215EVA	**n/a**	**ACFSC**	**n/a**	**Complete 2013**

** Funded by United States Forest Service*
*** Funder by American Reinvestment and Recovery Act of 2009*
**** Funded by Arrowhead Communities Fire Safe Council*

1.4.4.4 NRCS Fuel Reduction Project Success

San Bernardino County was the recipient of 72 million dollars that were granted from the National Resource Conservation Service (NRCS) to San Bernardino County Fire Protection District to reduce the amount of fuel and the potential for ignitability. In February of 2010, the grant was successfully closed out one month in advance of the target date. The $72,000,000 provided for almost 1,000 projects substantially reducing heavy fuels on tens of thousands of properties at risk across all mountain communities. Within that grant, $6.7million was provided to the USFS to conduct fuel modifications on Federal land and $7.2 million was provided to Cal Trans to remove fuels along evacuation routes. An additional $2 million was forwarded to San Diego to assist them. The activities funded under this program represent the first of their kind to be accomplished by local/state governments with federal grant funding.

To date the Fuel Management Program has removed over 450,000 trees, improving the overall health of the forested areas in the San Bernardino Mountains and reduced the overall fire threat. On several occasions completed projects have resulted in assisting fire suppression efforts and allowing fire to be contained before it threatens a local community, including Deer Lodge Park in Lake Arrowhead and Nob Hill in Running Springs during the Grass Valley and Slide Fires of 2007.

1.4.5 Flood Hazard Mitigation Success

1.4.5.1 2011 General Plan Amendments

A General Plan Amendment to the Safety Element of the County of San Bernardino 2007 General Plan amended the Flood Plain Overlay District, which became effective on March 11, 2010. The Safety Element includes several layers of hazard overlays that are included in the General Plan mapping system to inform the public of potential hazards to development of property within certain areas of the County and to enable the County to mitigate the risks presented to property owners by these hazards. These overlays include potential flood hazards. Over the past twenty years, certain federal and state agencies have been in the process of digitizing much of this hazard data. The digitization of this data has allowed for greater accuracy as well as more timely updates. In recognition of the new data from various federal and state agencies, the County updated the Flood Hazard Overlay Maps contained within the Safety Element of the General Plan. The Flood Plain Safety Overlay District is amended to incorporate revised FEMA (Federal Emergency Management Agency) Flood Plain data, modifying 47 detail and seven regional General Plan Quad Maps. The FEMA Digital Flood Insurance Rate Map database was adopted in the General Plan Amendment as released by FEMA as it exists as of February 9, 2010 and will updated in the future for the County, by integrating automatic map updates as new data is published by FEMA.

Below is a list of the updated Flood Plain Safety Overlay District Maps effective March 11, 2010.

Map	Quad Name	Map #	Quad Name	Map	Quad Name
DI16B	Baker	FH12B	Telegraph Peak	FH21	Devore
EH07	Hinkley	FH13B	Cajon	FH22	San Bernardino N.
EH14	Wild Crossing	FH14B	Silverwood Lake	FH23	Harrison Mtn.
EH15	Hodge	/FJ B	S Portion of County	FH28	Guasti
EH16	Barstow SE	FH11B	Mt. San Antonio	FH29	Fontana
EH22	Helendale	CK/DK	NE Portion of County	FH30	San Bernardino S.
EH29	Adelanto	EH/FH	SW Portion of County	FH31	Redlands
EH30	Victorville	EI/FI B	S Portion of County	FH32	Yucaipa
EH31	Apple Valley N.	EK/FK B	SW Portion of County	FI09B	Fawnskin
EI01B	Nebo	FH06B	Hesperia	FI10B	Big Bear City
EI02B	Yermo	FH07B	Apple Valley S.	FI17B	Big Bear Lake

Map	Quad Name	Map #	Quad Name	Map	Quad Name
EI03B	Harvard Hill	CH/DH	NW Portion of County	FI18B	Moonridge
EI04B	Manix	CI/DI B	N Portion of County	FH15	Lake Arrowhead
EI09B	Daggett	FH03B	Mescal Creek	FH19	Mt. Baldy
EK03	Needles NW	FH04B	Phelan	FH20	Cucamonga Peak
EK11	Needles SW	FI30B	Joshua Tree S.	FI23B	Sunfair
EK12	Needles	FI32B	Queen Mountain	FI25B	Forest Falls
EK20	**Whale Mountain**	**FI28B**	**Morongo Valley**		

Completed Flood Control Projects with Mitigation Characteristics

Table 1-3: Completed Flood Control Projects

Project Number	Completion Date	Total Cost	Total Funding
F02527	2016	$392,885	$392,885
F00282	2016	$4,100,000	$4,100,000
1-	2010	$7,770,000	$7,700,000
F01761	2016	$4,000,000	$4,000,000
F02234	2016	$1,100,000	$1,100,000
F01767	2014	$3,700,000	$3,700,000
F01389-	2008	$1,300,000	$1,300,000
F01545	2009	$1,500,000	$1,500,000
F01566-	2010	$3,300,000	$3,300,000

1.4.5.2 F02527 29TH Street Basin Levee Certification Restoration Project - Completed

Ensure that the surrounding residential and commercial areas will not be re-mapped as floodplain areas.
Status: Completed
Completion Date: March 2016
Local Priority: High
Total Cost: $392,885
Funding Description: From Flood Control District Budget through Property Tax
Project Selected for: Public safety: history of flood damage at this location
Hazard Mitigated: Potential flooding
Resources to Implement: High

Cost to Implement: High
Time to Implement: High

1.4.5.3 F00282 Alabama at City Creek - Completed

Construct RCB and channel improvements to increase capacity and minimize the possibility of road closures and flood damage.
Status: Completed
Completion Date: January 2016
Local Priority: High
Total Cost: $4.1 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Public safety & convenience
Hazard Mitigated: Flooding, flood damage, road closures and road damage
Resources to Implement: Low
Cost to Implement: High
Time to Implement: Medium

1.4.5.1 F02234 Wilson Creek - Completed

Status: Completed June, 2016
Local Priority: Low
Total Cost: $1.1 million
Funding Description: San Bernardino County Flood Control Property Taxes, City of Yucaipa
Project Selected for: public safety and infrastructure protection
Hazard Mitigated: attenuation of high velocities (50 fps); slope protection
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

1.4.5.2 F01767 Lytle Cajon – Completed

Replacement of damaged concrete invert
Status: completed
Completion Date: 2014
Local Priority: High
Total Cost: $3.7million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety and to prevent additional channel damage
Hazard Mitigated: Additional damage to invert and walls; potential flooding and washouts of nearby area
Resources to Implement: Medium
Cost to Implement: High
Time to Implement: High

1.4.5.3 F01761 Kitchen Wash – Completed

To intercept flows upstream of Rimrock Road to capture headwaters and re-route them to the Mojave River
Status: In preliminary design process
Completion Date: Estimated 2017/2018
Local Priority: Low
Total Cost: $4.0 million
Funding Description: San Bernardino County Flood Control Property Taxes
Project Selected for: Public safety; protection of commercial center
Hazard Mitigated: local flooding, road damage
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

1.4.5.4 Successful "Finalization" of Drainage Feasibility Study Report

The final Drainage Feasibility Study has been completed to evaluate the continuing landslide hazard within Rimforest and the role of concentrated storm runoff in propagating slope failure. The village of Rimforest has eroding cliff-side property and bluff retreat in the Southern part of the village.

This problem is primarily caused by storm runoff from either rainstorms or snowmelt after winter storms. The runoff flows to the south side of Rimforest and is discharged over the cliff at two principal locations. This study report evaluated a number of options to re-direct the majority of the runoff to other discharge locations for the purpose of reducing and mostly eliminating the cliff-side erosion. Two options presented the study appear to be feasible if new conventional storm drain systems are installed. One of the options is now included as potential future mitigation action presented in Section 6 of this plan.

1.4.6 Geologic Hazard Mitigation Success

1.4.6.1 Successful Geologic Hazard Prevention General Plan Amendments

Twenty two overlay maps were completed as part of the 2007 General Plan Amendment which became effective on March 11th, 2010. For more information on the overlay maps, see Section 6.2.2.3.

1.4.6.2 Amendment to Title 6 County Code to Adopt by Reference the 2010 Editions of the California Building Standards Codes

An amendment to Title 6 of the County of San Bernardino Code to adopt by reference the 2010 Editions of the California Building Standards Codes went before the Board of Supervisors on November 2, 2010 and was continued for a second reading on November 16, 2010 and approved unanimously. The amendment became effective on January 1, 2011.

The County of San Bernardino amendment to Title 6 of the County Code to adopt by reference the 2010 Editions of the California Building Standards Codes repealed the current chapters of Division 3 of Title 6 that reflect the 1994/1995 editions of the California Building Standards Codes and adopt the 2010 editions of these codes by reference.

The California Building Standards Commission approved the California Building Standards Code (Code) for a statewide effective date of January 1, 2011 and requires this Code apply in all parts of the state. This Code consists of the California Building, Residential, Plumbing, Mechanical, Electrical, Energy, Historical Buildings, Existing Building (Unreinforced Masonry) and the Green Building Standards Codes. Since this 2010 Edition was adopted by local ordinance, the prior editions of this code will be repealed and the most recent editions of the codes with applicable amendments requiring express findings and certain appendices necessary for the health and safety of the citizens of this County will be in effect within the unincorporated areas of San Bernardino County. The benefit of adopting this Code is that it provides consistency and clarification for the building community as well as building inspectors and plans examiners. State law (Health & Safety Code 18941.5 and 17958.7) requires the local government make express findings in order to amend building standards and the amendments must be necessary due to local climatic, geological, or topographical conditions.

Those amendments and findings are included in the County's ordinance and were filed with the California Building Standards Commission.

The recommended modifications not requiring express findings are administrative or procedural in nature and concern the local implementation issues that are not covered by building standards.

An example of this type of modification is to the California Residential Code, Section R105.3.1.1 which requires the Board of Appeals to confirm substantial valuations in the flood plain. The traditional purpose of the Board of Appeals has been reserved for a contested decision of the Building Official, and it is felt that it should remain as such.

With respect to grading and excavation regulations found in Appendix J of the 2010 State published code, the 2001 California Building Code dealt with grading with more clarity in regards to what activities require a permit and set forth rules to ensure large grading projects are scrutinized in greater detail than smaller projects by requiring more reporting and inspection of such work. The grading chapter in the 2001 Code has been trusted and in use in its primary form for years. The 2010 Appendix J grading chapter needs substantial amendment and modification to address all grading issues and is not recommended for adoption in its present form. The Board adopted the 2001 Appendix Chapter 33 regulations as part of this proposed ordinance. Relocation permit requirements have been moved to a new section of the Code, and it retains specific standards for relocation procedures in details not found in the 2010 State-published code. Clarification of the types of buildings affected by the new regulations has also been made.

Administrative changes to the 2010 California Existing Building Code (Part 10 of Title 24) were approved to outline the procedures required to set allowable time limits for the retrofit and repair

of unreinforced masonry buildings. Staff is also recommending that authorization be given to the Building and Safety Division of the Land Use Services Department to issue Administrative Citations as an alternative means of enforcement of the County Code provisions.

Express findings are made for changes to the California Plumbing Code, Appendix K regarding the soil conditions that exist in this county. These changes are supported by the Environmental Health Division. These express findings are iterated in the ordinance and will be filed with the Building Standards Commission as required by law in order to become effective.

1.5 Community Profile

1.5.1 Physical Setting

The County is bounded by the states of Arizona and Nevada on the east, Inyo County on the north, Kern and Los Angeles Counties on the west, and Orange and Riverside Counties on the south.

San Bernardino County covers 20,102 square miles and is geographically the largest county in the continental United States. The States of Hawaii, Connecticut, Delaware, and Rhode Island and the District of Columbia could all fit inside the County boundary at the same time. The unincorporated area of San Bernardino County covers approximately 19,848 square miles; this is 98.7% of the entire County.

The remaining 1.3% of acreage (254 square miles) is under the jurisdiction of incorporated cities or towns. Figure 7 displays the unincorporated area and the cities/towns. The cities/towns on the map are concentrated in the south/west portion of the county and are color-coded.

San Bernardino County is characterized by three (3) distinct geographic areas: Valley, Mountains, and Desert: the Valley Region contains the majority of the county's incorporated areas and is the most populous region; the

Mountain Region is primarily comprised of public lands owned and managed by federal and state agencies; and, the Desert Region is the largest region (over 93% of the county's land area) and includes parts of the Mojave Desert.4 Aside from open or undeveloped land, the largest land use in the county is for military purposes.

The mountains stretch across the south end of the county. The mountain elevations range from 2,000 feet along the foothills to the 11,502-foot summit of Mount San Gorgonio, the highest peak in Southern California. Figure 8 displays the terrain/topographic features throughout San Bernardino County.

The San Bernardino Mountains feature four (4) large lakes (Big Bear Lake, Silverwood Lake, Lake Arrowhead, and Lake Gregory), and many smaller lakes. The majority of the lakes are the headwaters of the Santa Ana River and the Mojave River.

The Santa Ana River originates in the San Bernardino Mountains and flows southwest to the ocean. The Santa Ana Watershed includes streams flowing south from the San Gabriel Mountains and streams flowing north and west from the San Jacinto Mountains in Riverside County.

The desert area contains low mountains, valleys, and dry lakebeds. The elevations within the valley range of the County is from about 500 feet on the valley floor to 1,700 feet in Live Oak Canyon, and to about 5,400 feet in the hills in Yucaipa. The desert area is an assemblage of mountain ranges interspersed with long, broad valleys that often contain dry lakes. Many of these mountains rise from 1,000 to 4,000 feet above the valleys. Due to the persistent winds that blow throughout the year, large portions of the desert surface have been modified into a mosaic of pebbles and stones known as desert pavement.

A major physical resource of the desert area is the Mojave River, a critical water source for many of its residents. Among the few rivers that both flow north and do not empty into an ocean, the Mojave River travels north and east away from its watershed in the San Bernardino Mountains. The major part of it is over 100-mile length is marked by a dry riverbed that only on occasion reveals the water within it. Except in exceedingly wet years, the Mojave River ends its flow at Soda Dry Lake near Baker. The Colorado River, at the California and Arizona border, borders the County on the east. Streams in the eastern areas of the County area flow into the Colorado River which eventually ends at the Gulf of California.

The densely urban southern part of the County is at the headwaters of the Santa Ana River with its tributaries crossing the valley floor. With the construction of the Seven Oaks Dam the main river source has been controlled. However, Mill Creek, City Creek, Lytle Creek, and Cajon Creek still have the potential to flood areas of the valley if levees fail. A similar potential occurs with the high desert portion of the County with the Mojave River, which is controlled by the Mojave River Falls Dam that flows north from the San Bernardino Mountains to the city of Barstow. The San Antonio Dam on the southwest side of the county provides more than 100-year flood protection to the west end of the San Bernardino Valley. The Colorado River is on the eastern border of the County. The dams along the river have controlled the flow but bank erosion and damage to roads in the area have been experienced during periods of high water.

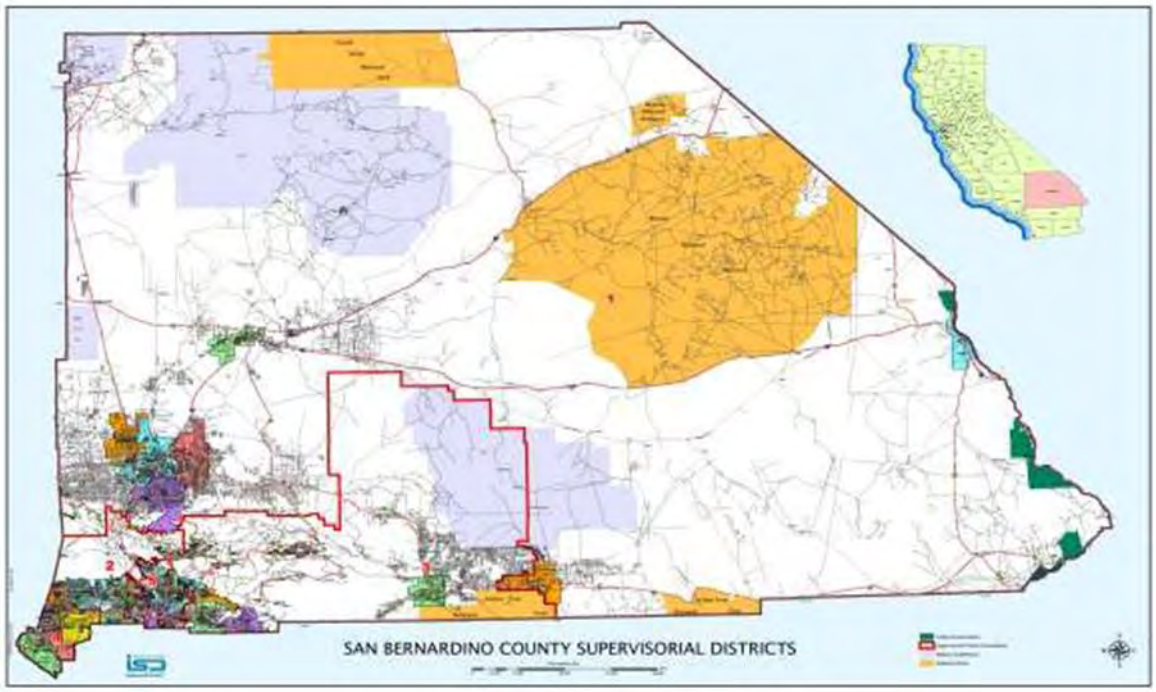


Figure 1-8: Unincorporated and Corporate Areas in San Bernardino County



Figure 1-9: Topographic Features in San Bernardino County

1.5.2 History

Paleo-Indian sites dating from c. 10,000 BC show that the San Bernardino County area has been inhabited for at least 12,000 years. Artifacts in the Calico area suggest much earlier human occupation, but this has not been confirmed. In the past three thousand years, various Indian tribes flourished in the area: the Gabrielenos occupied the West Valley; the Serranos lived in the foothills of the San Bernardino Mountains; the Vanyumes lived along the Mojave River; the Mohave lived along the Colorado River; and the Chemehuevi occupied the Mojave Desert.

The first European explorers to enter the area were Pedro Fages, Military Commander of California, in 1772 and Fr. Francisco Garces, a missionary priest, in 1774. On May 20, 1810, Franciscan missionary Francisco Dumatz, of the San Gabriel Mission, led his company into a valley. In observance of the feast day of St. Bernardine of Siena, Dumatz named the valley San Bernardino. This name was later given to the nearby mountain range, and later the city and county.

In 1842 the Lugo family was granted the Rancho San Bernardino, a holding of 37,700 acres encompassing the entire San Bernardino Valley. Captain Jefferson Hunt, of the Mormon Battalion, led a group of settlers into San Bernardino and founded a Mormon Colony. In 1851 the Mormon Colony purchased the Rancho from the Lugo family.

In 1850 California was admitted into the United States. On April 26, 1853, San Bernardino County was created from parts of Los Angeles, San Diego, and Mariposa Counties. In 1854 the City of San Bernardino was incorporated as the county seat.
In 1857, three orange trees were set out on a farm in Old San Bernardino. By 1882 a rail car load of oranges and lemons grown in the East Valley was shipped to Denver, Colorado. As early as the 1840s, vineyards were planted in the Cucamonga area and in the 1870 census; San Bernardino County was credited with producing 48,720 gallons of wine.

In 1860, gold was discovered in Holcomb and Bear Valleys in the San Bernardino Mountains, and placer mining began in Lytle Creek. Silver was being mined at Ivanpah in 1870, and the rich silver mines of the Calico district were developed in the 1880s. Borax was first discovered in 1761 at Searles Dry Lake near Trona, and transported out by twelve-, eighteen- or twenty-mule team wagons.

As a county, San Bernardino has been uniquely endowed with rich mineral deposits. Large deposits of gold have been mined at Stedman and Vanderbilt, with smaller but still important deposits at Alvord, Oro Grande, Old Dad Mountain, Dale and Nantan, Calico, Ivanpah, Waterman and Providence were the largest silver deposits, with lesser, but important deposits in the Mescal Mountains and at the Death Valley Mine. The most important copper mines are the Copper World and the Bagdad Chase (known usually for its gold production).

Except for a brief period after World War I when silver prices were high, low metal prices and inflation put a damper on mining in the 1920s. However, with the Great Depression of the 1930's

and an increase in the price of gold by nearly $15 an ounce, many small operators reactivated old mines. The region around Barstow, Vanderbilt, Stedman, and Dale were the principal centers of mining activity until World War II.

During World War II, iron was extracted from the Vulcan Mine in the Providence Mountains, and the Bagdad Chase Mine remained active. Since the war, there has been sporadic mining of gold, silver, and tungsten in the county. A major new mine opened during the 1950s, the Mountain Pass rare earth mine. Recently, exploration has outlined potential large tonnage molybdenum properties in the New York and Ord Mountains, copper in the Cooper Basin area of the Whipple Mountains and gold in the Clark Mountains.

After World War II, the citrus industry slowly declined. However, dairies relocating out of Los Angeles County settled in the Chino Valley area, creating a robust dairy industry in San Bernardino County.

Elsewhere in the Valley region, suburbs grew as moderate priced housing developments were built. By the late 1980's, the county had grown into bedroom communities and warehousing for southern California.

1.5.3 Climate

The valleys between mountain ranges experience very high temperatures, while the adjacent mountains often experience much cooler temperatures, particularly at their summits. Rainfall and humidity are low. The annual average precipitation for the area is approximately 30 inches. The differences in elevation and topography are in part responsible for variations in temperature and precipitation from the Valley and Desert areas.

Winter temperatures in some areas of the Desert range near zero, the cold often compounded by the wind-chill factor. In the summer, temperatures can reach as high as 134°F in the lower elevations and along the Colorado River area. Temperatures in the San Bernardino valley area range from an average high of 80ºF and an average low of 53ºF. The record high for the area is 117ºF and the record low is 17ºF. The annual average rainfall for the area is 15.6 inches. During the fall and winter months, strong "Santa Ana" winds blow across the area.

The mountains experience a four-season climate. Temperatures in the Mountain area range from an average high of 62ºF and an average low of 36ºF. The record high for the area is 106ºF and the record low is -25ºF. With the possible exception of some of the higher elevations in the mountains, precipitation throughout the Desert area is less than four inches per year, usually of short duration and high intensity. The resulting flash floods rapidly modify the terrain that is exposed to the erosive surface runoff. Unusually heavy or persistent rains often result in the temporary filling of a number of dry lakes until the surface water evaporates or infiltrates the soil. Persistent winds blow throughout the year

1.5.4 Demographics

The total population of San Bernardino County is approximately 2,139,570 people *(State of California, Department of Finance, E-4 Population Estimates for Cities, Counties, and the State, 2011-2016, with 2010 Census Benchmark. Sacramento, California, May 2016)*. Most of the County's population is in the valley areas located in the south west portion of the County. The County's population has grown by 4.13%, 84,835 people, since 2011 (population in 2011 was 2,054,735 people).

The population of the unincorporated area of the County in 2011 was 294,753 people. In 2016, the population is 309,759; an increase of 14,976 persons (or 1.05%) *(State of California, Department of Finance, E-4 Population Estimates for Cities, Counties, and the State, 2011-2016, with 2010 Census Benchmark. Sacramento, California, May 2016)*

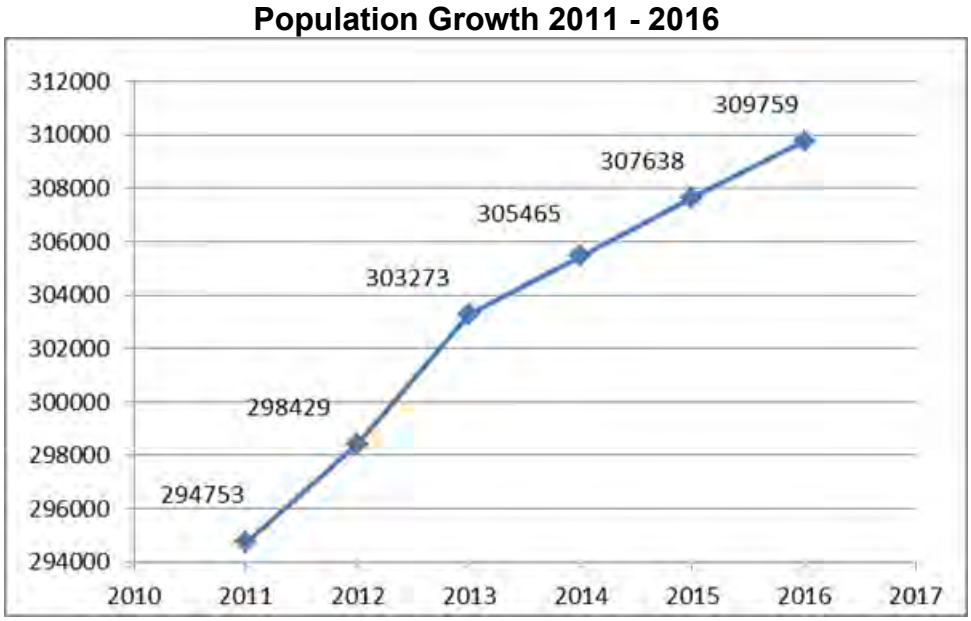


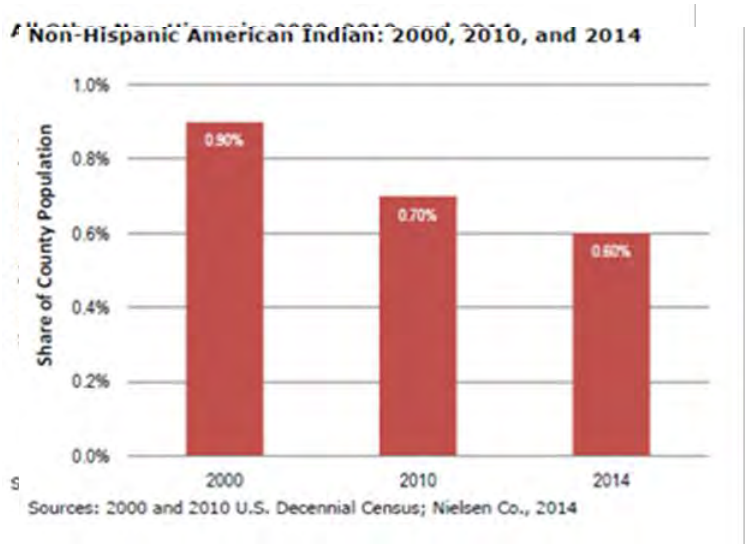
Figure 1-10: San Bernardino County Unincorporated Area Population Changes 2011 - 2016

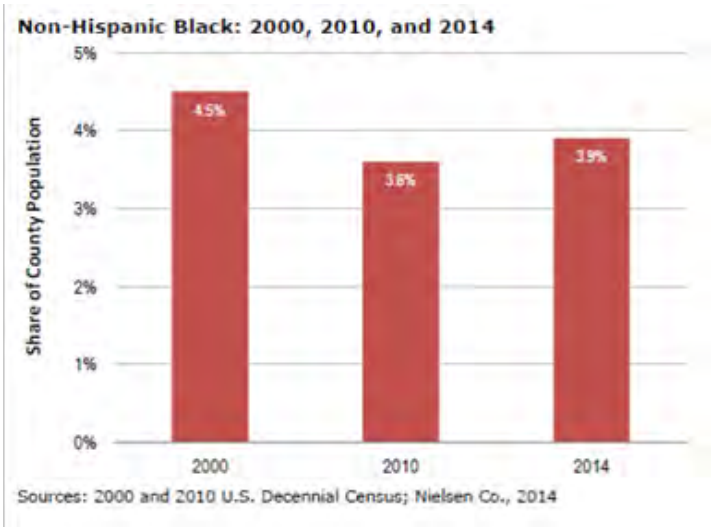
Source: California Department of Finance E-4

Ethnic composition includes Hispanics (48%) who form the largest share of the County's population, followed by Whites (34%). Blacks (9%) and Asians (5%) form a relatively lower share of the total population. It should be noted that the Hispanic population is growing at the fastest rate among all ethnic groups. From 2000 to 2010, the Hispanic population increased by 44%. This trend is consistent with that of the neighboring counties of Riverside and Orange, where the

Latino population grew by 63% and 24%, respectively. During this period, the Asian population grew by 38%, whereas the Black population grew by 15%. The population of Whites declined in

all the six counties in Southern California; San Bernardino County experienced a decline of 7% in its White population. Changes in Ethnicity are from the California Department of Finance, Demographics Unit.





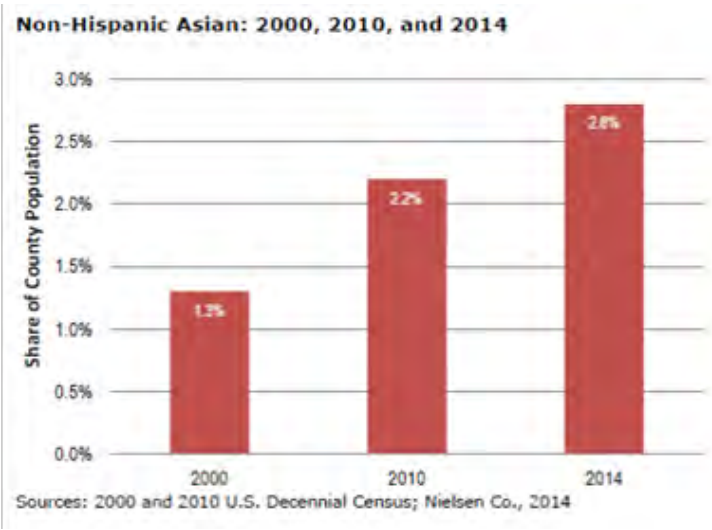


Figure 1-11: San Bernardino County Unincorporated Area 2014 Population by Ethnicity

1.5.5 Existing Land Use

The County has adopted a “one-map approach.” The “one-map approach” permits the use of a single map showing both General Plan land use designations and zoning classifications. The one-map approach assures that there will always be land use consistency between the County's General Plan and its Zoning Code.

There are 18 land use zoning districts that apply only to privately owned lands in the County and not to the lands controlled by other jurisdictions. Lands that are controlled by other jurisdictions, including lands controlled by federal and state agencies as well as incorporated cities, are mapped to identify the public agencies that control them. The 18 land use zoning districts are as follows:

- Resource Conservation (RC)
- Agriculture (AG)
- Rural Living (RL),
- Single Residential (RS),
- Multiple Residential (RM),
- Office Commercial (CO),
- Neighborhood Commercial (CN),
- Rural Commercial (CR),
- Highway Commercial (CH),
- General Commercial (CG),
- Service Commercial (CS),
- Community Industrial (IC),
- Regional Industrial (IR),
- Institutional (IN),
- Special Development (SD),
- Floodway (FW),
- Specific Plan (SP), and
- Open Space (OS).

Resource Conservation (RC) comprises the majority (55.98 percent) of the designated land uses in the County. This land use designation covers over 1 million acres, or about 1,500 square miles of land. Most of the land within this designation is publicly owned (federal and state) and includes national parks, military bases, conservation areas, and lands owned by other federal and state agencies. The County has designated approximately 681,500 acres or 1,065 square miles (37.92 percent) for residential uses. Out of this, about 587,535 acres (32.76 percent of total unincorporated area) are designated Rural Living, 67,691 acres are designated Single Residential, while 4,986 acres are designated Multiple Residential.

Commercial land use zoning districts (Office Commercial, Neighborhood Commercial, Rural Commercial, Highway Commercial, General Commercial, and Service Commercial) occupy a total of 12,177 acres or 0.68 percent of the total unincorporated area. Industrial land use zoning districts (including Community Industrial and Regional Industrial) occupy 21,834 acres or 1.21

percent of the total unincorporated area. Other land use designations include Agriculture occupying 41,793 acres (2.32 percent), Institutional occupying 8,567.51 acres (0.48 percent), Floodway occupying 20,281 acres (1.13 percent), and Specific Plan occupying 4,861.37 acres (0.27 percent).

Because of the size of the County, the San Bernardino County General Plan divides the county into 8 quadrants (Figure 1-12). The "one-map approach" allows the quadrant maps to be used for many different planning and development purposes. Figure 1-13 presents the Land Use Zoning for each quadrant. The Land Use Zoning identifies the type of construction and growth that exists or may occurs in area.

County designated Land Use Zoning Districts do not apply to Federal, State, or incorporated owned property.

The County's General Plan can be found at: http://countywideplan.com/home/about/

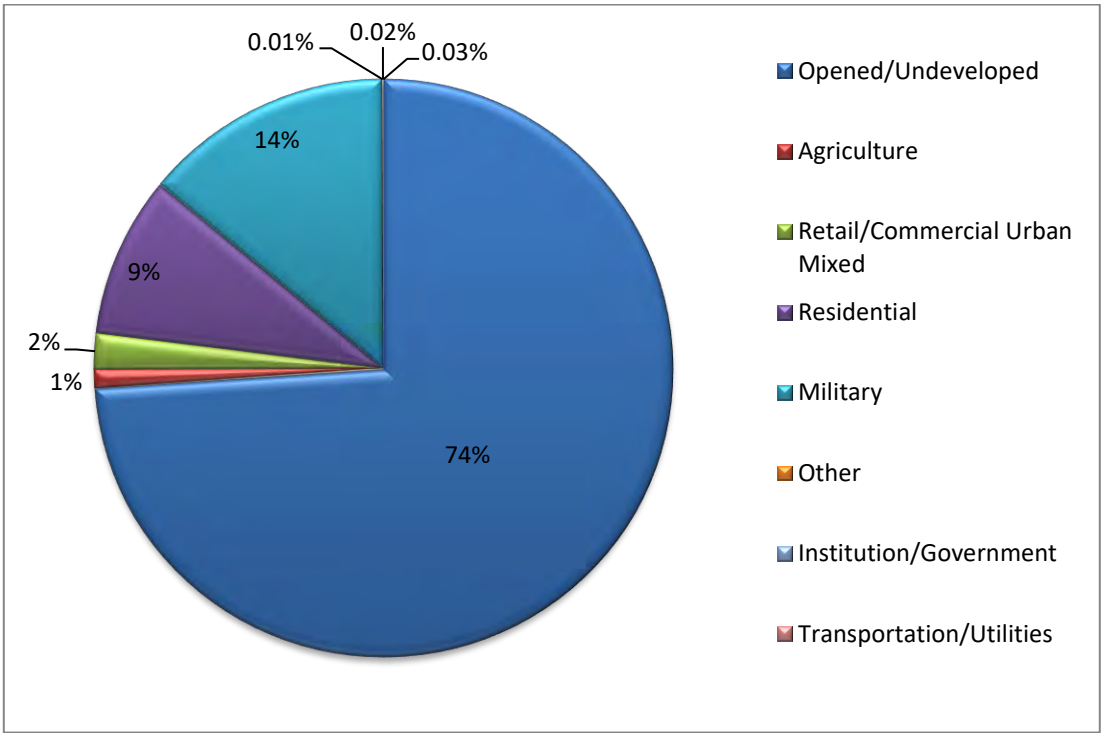


Figure 1-12: San Bernardino County Land Use

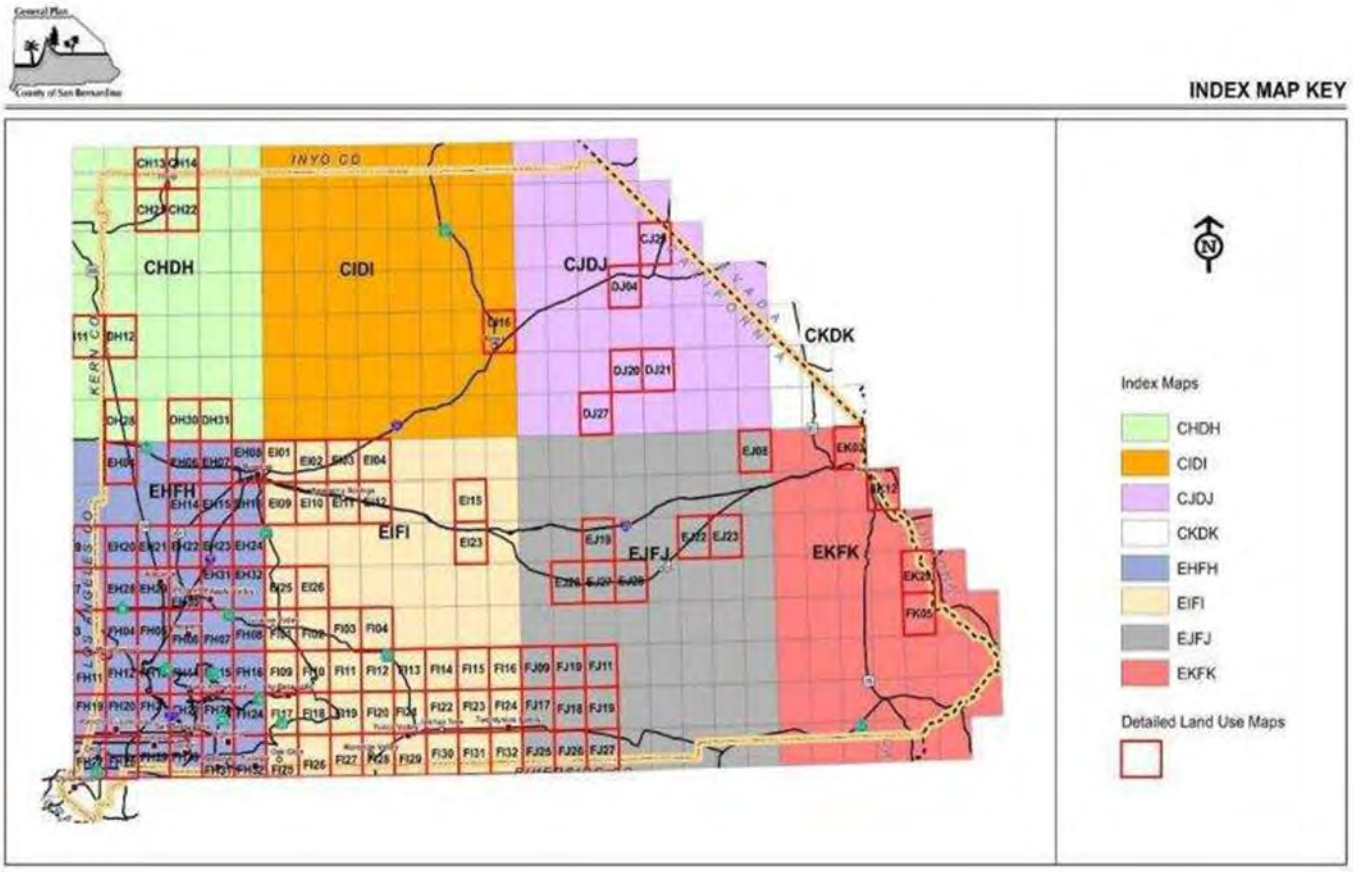


Figure 1-13: San Bernardino County Land Use Map

1.5.6 Development Trends

No major developments occurred in the unincorporated area of the county since the 2010 MJHMP was adopted. The limited development that did occur was scattered throughout the unincorporated area; with no one area being singled out. All development was in accordance with the pre-designated Land Use Zones development zones and complied with all Fire, Flood, and Seismic codes of the County and State at the time of development. This includes commercial, industrial, and residential developments.

The County is optimistic about the potential for future development. The High Desert area of San Bernardino County is one of the best places in the world for solar energy development because of its high altitude, the number of sunny days each year and existing power infrastructure.

- Many large solar energy projects are being proposed in California's desert area on federal Bureau of Land Management (BLM) land. BLM has received right-of-way requests encompassing more than 300,000 acres for the development of approximately 34 large solar thermal power plants totaling approximately 24,000 megawatts. This number of projects has not yet reached the stage of an Application for Certification (AFC) with the California Energy Commission.
- California's electric utility companies are required to use renewable energy to produce 20 percent of their power by 2010 and 33 percent by 2020. A main source of renewable power will be solar energy. Within the County of San Bernardino a Hybrid Power Project has been approved in the Victor Valley area. As of August 2010, three large Solar Projects to be placed in the County are in review by the California Energy Commission.

Once built, these projects will not impact the area to a great extent. Minimal staffing is required to operate these facilities and their very nature places them in remote locations of the County.

Additionally, with the completion of the Alameda Corridor and the emergence of the Ports of Los Angeles and Long Beach as the largest ports in the U.S., shipping trans-Pacific goods from the booming Asian economies, San Bernardino County has evolved as the logistics and distribution hub for the 20 million resident Southern California market and into the rest of the nation. As the international economy recovers amidst tightening land availability for warehousing and transit, San Bernardino County is better positioned than other areas in the region to harness the opportunity to become an even more important logistics hub.

The County has also started development of a bullet train. The bullet train will connect Victorville, CA and Las Vegas NV generally following the I-15 corridor (NOTE: There are discussions of additional bullet trains connecting San Bernardino with Los Angeles and San Diego and San Bernardino County and San Francisco/Sacramento).

While all of these development trends may not be recognized over the next 5 years, all future development that will take place is planned to occur in accordance with the General Plan Land Use Zones and will consider all potential hazards identified within this plan. Additionally, all development will be in compliance with all Fire, Flood, and Seismic codes of the County and State at the time of development.

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Section 2. Plan Adoption

2.1 Adoption by Local Governing Body

The San Bernardino County Board of Supervisors created “districts” to provide a specific service to an area / population of San Bernardino County. These Districts are Board Governed in that the Board of Supervisors has direct control and legislative oversight of the Districts. The Board of Supervisors acts on behalf of each District whenever governance items are necessary. The participating jurisdictions listed in this plan are separate legal entities from the County of San Bernardino. For tax/revenue purposes the Board of Supervisors, acting as the Board of Directors for each participating jurisdiction or “District”, will be adopting the Multi-Jurisdictional Hazard Mitigation Plan on behalf of each District. The Districts are not independent from San Bernardino County but are controlled and administered as any other County Department is administered.

This plan represents mitigation efforts for the unincorporated portions of the County and the efforts of three jurisdictions participating in this Multi-Jurisdictional Hazard Mitigation planning effort. The participating jurisdictional special districts include:

San Bernardino County Fire District
San Bernardino County Flood Control District
San Bernardino County Special Districts Department

San Bernardino County Board of Supervisors is responsible for the review, approval, and adoption of the Multi-Jurisdictional Hazard Mitigation Plan (MJHMP) update for the unincorporated area of San Bernardino County, the San Bernardino County Fire Protection District, the San Bernardino County Flood Control District, and for the County’s Board Governed Special Districts Department. It is also the intent of the San Bernardino County Board of Supervisors to take appropriate actions to incorporate the MJHMP update into the San Bernardino County General Plan.

2.2 Promulgation Authority

The Promulgator Authority for the adoption of the Multi-Jurisdictional Hazard Mitigation Plan by the unincorporated area of San Bernardino County, the San Bernardino County Fire Protection District, the San Bernardino County Flood Control District, and for the County’s Board Governed Special Districts Department and incorporation of the MJHMP into the San Bernardino County General Plan is:

- Chairman Robert A. Lovingood First District
- Janice Rutherford Second District Supervisor
- James Ramos Third District Supervisor
- Vice Chairman Curt Hagman Fourth District Supervisor
- Josie Gonzales Fifth District Supervisor

The Point of Contact for information regarding this MJHMP is:

Michael Antonucci, Emergency Services Manager
San Bernardino County Fire
Office of Emergency Services
1743 Miro Way
Rialto, CA 92376
(909) 356-3998

Section 3. Planning Process

3.1 Preparing the Plan

Multi-Jurisdictional Hazard Mitigation Planning is a process State, Tribal, and local governments use to identify risks and vulnerabilities associated with natural disasters, and to develop long-term strategies for protecting people and property from future hazard events.

Planning creates a way to solicit and consider input from diverse interests. Involving stakeholders is essential to building community-wide support for the plan. In addition to emergency managers, the planning process involves other government agencies (e.g., zoning, floodplain management, public works, community, and economic development), businesses, civic groups, environmental groups, and schools.

To assist with the updating of the Multi-Jurisdictional Hazard Mitigation Plan (MJHMP), a Multi-Jurisdictional Planning Team (Planning Team) was established. The Planning Team was the lynchpin for all activities to update the MJHMP. The Planning Team was established to define and identify the strategies, goals, activities, and development of the MJHMP. The Planning Team represents a comprehensive team of subject matter experts from a range of areas that the team felt was affected by the plan or could provide great benefit to the team. Members of the Planning Team were drawn from San Bernardino County Departments, the San Bernardino County Fire Protection District, the San Bernardino County Flood Control District, and the San Bernardino County Special Districts Department.

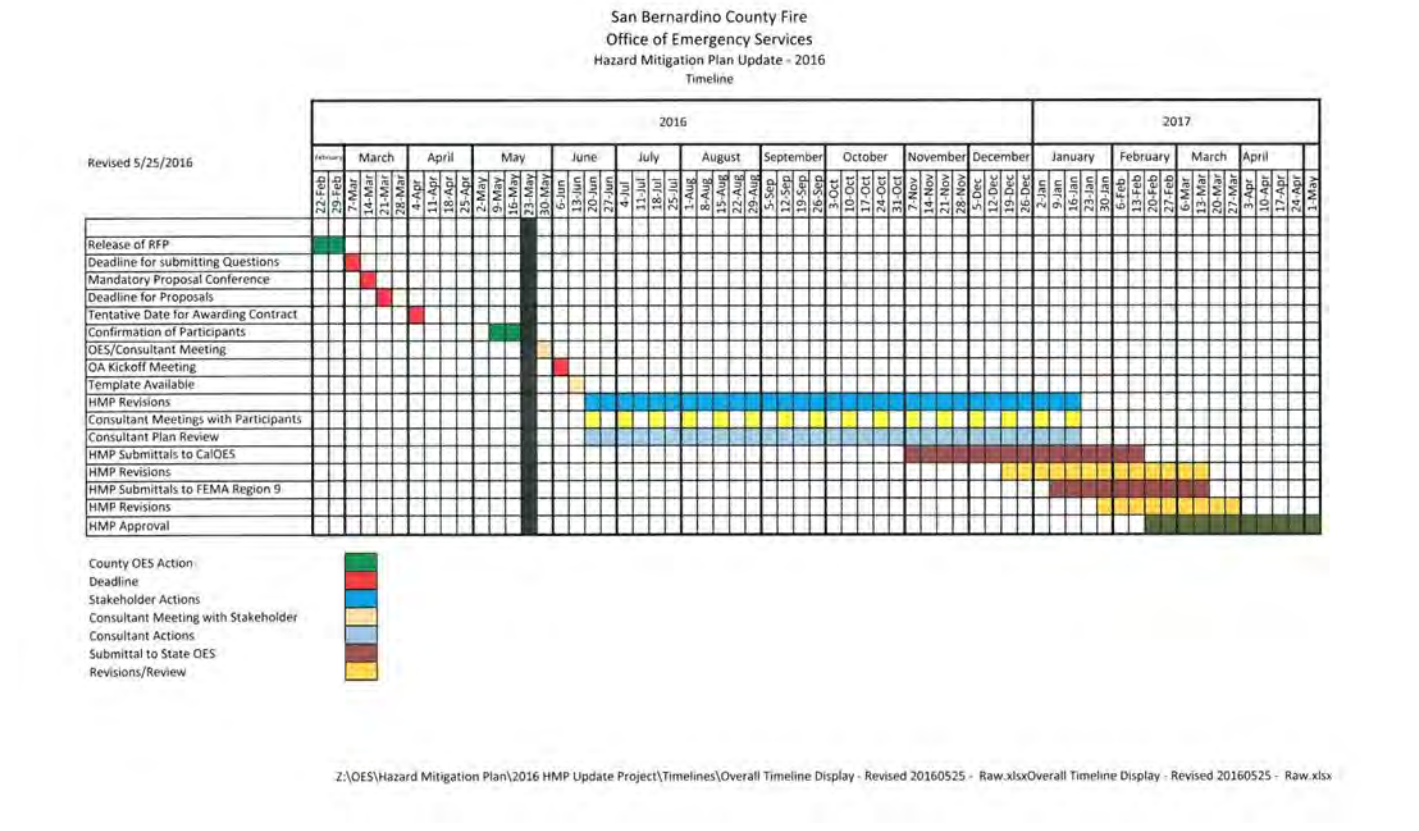
The Multi-Jurisdictional Planning Team members worked together to jointly determine and rank the risks facing the six participating agencies, develop goals and objectives to mitigate the risks, and identify which of the participating jurisdictions would be most appropriate for leading any particular project area identified by the Multi-Jurisdictional Planning Team. The individual Planning Team members then returned to their respective Special Districts where discussions were held, input sought, and potential projects developed and ranked for each of the Planning Team identified risks and projects relevant to the Special District. The Planning Team members then returned to the Multi-Jurisdictional Planning Team and provided the Planning Team with their vetted, prioritized list of potential projects and budgets to include in the Multi-Jurisdictional Hazard Mitigation Plan. These projects and budgets were integrated into the Multi-Jurisdictional Hazard Mitigation Plan. Upon approval, each participating jurisdiction would then be able to apply for grant funding for their prioritized projects without interference from another participating jurisdiction as funding became available.

The Planning Team was led by a representative from the San Bernardino County Fire Protection District-Office of Emergency Service. This representative took on the responsibilities of a Project Manager and facilitated and coordinated activates.

The Project Manager also represented the Unincorporated County at the San Bernardino County Operational Area (OA) Stakeholder meetings. San Bernardino County OES led the effort to coordinate Stakeholder in the Operational Area update their local MJHMP. This effort included: proving technical support, establishing a platform to encourage the exchange of ideas, and help coordination among neighboring stakeholders. The Project Manager was responsible for attending these meetings and incorporating the material into their planning process. One of the resource materials provided through the OA Stakeholder meetings was a suggested Table of Contents (TOC) the purpose of the TOC was to ensure all aspect of the MJHMP requirements were being met and could be found in similar sections in each of the Stakeholders updated MJHMPs.

This sample TOC was reviewed by the Planning Team and incorporated into the unincorporated county's MJHMP update efforts. Using the TOC, the Planning Team decided to conduct a section by section; page by page review of the 2016 MJHMP. To assist with this effort, a proposed project timeline was developed. The proposed Project Timeline illustrates the windows when each section of the 2016 MJHMP will be reviewed and the section revised.

Table 3-1: Proposed Project Timeline



Based on the TOC, the Planning Team divided the update process into seven (7) phases; one for each section of the TOC. This approach allowed for a much focused review of the material and

provided an organized method to introduce new or updated material. The Project Manager led the discussion, solicited comments, took notes, and incorporated results in the MJHMP. Additionally, the Project Manager collected and summarized material provide by Planning Team members. During the Planning Team meetings some members were assigned tasks or action items which were to be completed prior to the next meeting.

Staff assigned to the MJHMP Update reviewed the 2016 MJHMP and provided comments referencing updated information such as current population statistics, new HAZUS-MH MR3 analysis of floods and earthquakes, and provide suggestions for updating the MJHMP. The Planning Team then reviewed the update information and validated/identified Goals, Objectives, and Projects. This step included discussion of how the projects would be prioritized.

3.1.1 Project Prioritization Involved Comprehensive Consideration of Criteria/Factors

While there is not a standard process followed by each of San Bernardino County Departments, and Districts; they all considered social, technological, administrative, political, legal, economic, and environmental factors. The County and each district participated on the Planning Team, and then took the risks, goals, objectives and projects back to their respective jurisdiction for discussion and vetting. After vetting, the individual Planning Team members returned to the Multi-Jurisdictional Planning Team where the individual materials were combined into a single Multi-Jurisdictional Hazard Mitigation Plan. This Multi-Jurisdictional effort resulted in goals, objectives and projects for all participants being listed under the appropriate hazard sections and not by individual participants. This reflects the overall County philosophy of allowing the department/district with the most expertise to suggest and/or manage a project that may affect another participant who does not have expertise in the hazard.

3.1.2 Planning Team

Much of the Planning Team is composed of representatives who were part of the development of the 2010 Unincorporated Area County MJHMP. This provided added value to the team in that they were familiar with the process and provided continuity in the updating of the 2010 MJHMP.

The Planning Team is comprised of representatives from San Bernardino County Departments, the San Bernardino County Fire Protection District, the San Bernardino County Flood Control District, and the San Bernardino County Special Districts Department who specialize in mitigation type activities/planning.

The Planning Team members represented select aspects of the community and were thought of as liaisons to the greater community. Each Planning Team member was responsible for communicating the direction and status of the planning effort to their outside members and in return they are expected to bring to the team outside perspectives. Additionally, the individual Planning Team members acted as liaisons for their respective Special Districts and were responsible for ensuring that the Special Districts provide appropriate input from their respective internal planning processes. Potential projects/budget meetings were held where alternative mitigation actions were discussed and potential mitigation projects were developed and prioritized along with budget development for the individual participating Special Districts and Departments. Additional prioritization after budgets were developed to ensure proper Benefit Cost Analysis (BCA) techniques were applied.

Representation was present on the Multi-Jurisdictional Planning Team from various County Departments and the three participating jurisdictional departments. Planning Team included representatives from all the participating San Bernardino County Special Districts and Departments. See Table 3-2 and Table 3-3.

Table 3-2: Multi-Jurisdictional Planning Team

Multi-Jurisdictional Planning Team Members	Title / Role
Unincorporated County	
Suzanne Peterson	*Countywide Plan Coordinator / Land Use Services / Mitigation Review*
Jerry Blum	*Countywide Plan Coordinator /*
Brent Rolf	*County GIS / Hazus Data Coordinator / Information Services*
Frank Jordan	*Land Use Services / Mitigation Review*
Jim Sowers	*Building and Safety / Risk Assessment Review and Mitigation Action Plan Development*
Patricia Cole	*Economic Development Agency / Implementation and Funding Review*
Carl Alban	*Architecture and Engineering Department*
John Amrhein	*Sherriff's Corner Department Rep. / Mitigation Action Review*
Mazin Kasey	*Public Works Dept. /Transportation Division*
Art Rivera	*Solid Waste Management Division*
Norma Spencer	*Superintendent of Schools*
Fire Protection District	
Michael Antonucci	*OES Director / MJHMP Plan Representative*
Cindy Serrano,	*Project Manager for Planning Process*
Miles Wagner	*Emergency Services Officer, GIS Representative and Stakeholder Coordination.*
David Davis	*Emergency Services Officer / Fire District Representative and Technical Writer*
Mary Barnett	*Technical Writer / Plan Update and Edits*

Multi-Jurisdictional Planning Team Members	Title / Role
Cheryl Nagy	*Emergency Services Officer*
Carrie Cruz	*Emergency Services Officer*
Elli Maldonado	*Elli Maldonado – Office Assistant*
Michael Horton	*Michael Horton – Fire Marshal*
Flood Control District	
Kevin Blakeslee, Deputy Director – Flood Control	*Deputy Director – Flood Control*
Kenneth Eke, Chief, Flood Control Planning/ Water Resources Division	*Chief, Flood Control Planning/ Water Resources Division*
Michael Fam	*Flood Control Planning*
Mona Sadek	*Flood Control Planning*
Marjorie Schrage	*Flood Control Planning*
Special Districts Department	
Jeff Rigney	*Special Districts Dept. Director*
Steve Samaras	*Special Districts Dept. Acting Deputy Director*
Erin Opliger	*Big Bear Valley Recreation and Parks District Rep.*
Erin Opliger	*Bloomington Recreation and Parks District Rep.*

Table 3-3: Stakeholder List

Stakeholder Members	Name	Title / Role
Municipal Partners		
City of Barstow	*Jamie Williams*	*Fire Chief*
City of San Bernardino	*Eric Fyvie*	*Sergeant*
City of Chino	*Chris Wolff*	*Administrative Services Manager*
City of Chino Hills	*Bonnie Michaels*	*Emergency Services Analyst*
City of Colton	*Shannon Kendall*	*Emergency Services Coordinator*
City of Fontana	*Cheryl Nagy/ Mary*	*Emergency Services Officer*
City of Grand Terrace	*Haide Aguirre*	*Management Analyst*
City of Hesperia	*Rachel Molina*	*Public Information Officer*
City of Loma Linda	*Shannon Kendall*	*Emergency Services Coordinator*
City of Montclair	*Angelic Bird*	*Emergency Services Coordinator*
City of Ontario	*Raymond Cheung*	*New Emergency Manager*
City of Rancho Cucamonga	*Breanna Medina/ Denise School*	*Emergency Manager*
City of Redlands	*Fay Glass/ Wanda Viser*	*Emergency Operations Manager*

Stakeholder Members	Name	Title / Role
City of Rialto	*Art Podeska*	*Battalion Chief*
City of Upland	*Angelic Bird*	*Emergency Services Coordinator*
City of Victorville	*Dana Wellborn*	*Emergency Services Manager*
Town of Apple Valley	*Joseph Ramos*	*Emergency Services Officer*
Town of Yucca Valley	*Jessica Rice*	*Management Analyst*
School District Partners		
Apple Valley Unified School District	*Janet Gould*	*Director, Risk Management*
Chino Valley Unified School District	*Dr. Grace Park*	*Assistant Superintendent*
San Bernardino County Superintendent of Schools	*Norma Spencer*	*Risk Management Analyst*
Snowline Joint Unified School District	*Robert Chacon*	*Director of Risk Management*
Special District Partners		
Inland Empire Utilities Agency District Headquarters	*Claudia Neighbors/ Tony Arellano*	*Safety Officer*
Newberry Community Services District	*Stephen Miller*	*Fire Chief- Barstow Fire Protection District*
Omnitrans	*Mark Crosby*	*Security and Emergency Preparedness Coordinator*
Santa Ana Watershed Project Authority	*Richard Haller/ Carlos Quintero*	*Exec. Manager of Engineering and Operations*
Water District Partners		
Crestline Village Water District	*Larrie Ann Davis*	*Office Manager*
Cucamonga Valley Water District	*Rosanna Ammari / Maria Kennedy*	*Maria Kennedy Consultant Representative*
East Valley Water District	*Cecilia Contreras / Gary Sturdivan*	*Administrative Assistant*
Monte Vista Water District	*Jonathon Dizon*	*Engineering Technician*
San Bernardino Valley Municipal Water District	*Dan Borrell/ Brent Adair*	*Project manager- Construction*
Twenty-nine Palms Water District	*Gary Sturdivan*	*Consultant Rep.*
Yucaipa Valley Water District	*John Hull*	*Public Works Management*
CERT Teams		
Wrightwood		*CERT Citizens*
Phelan/Pinion Hills		*CERT Citizens*
Angelus Oaks		*CERT Citizens*
Big Bear Valley		*CERT Citizens*
Helendale		*CERT Citizens*
Lucerne Valley		*CERT Citizens*
Lytle Creek		*CERT Citizens*
Mill Creek Canyon		*CERT Citizens*

Stakeholder Members	Name	Title / Role
Morongo Basin		*CERT Citizens*
Mountain		*CERT Citizens*
Oak Hills		*CERT Citizens*
Rosena Ranch		*CERT Citizens*
San Antonio Heights		*CERT Citizens*
Silver Valley		*CERT Citizens*
Public Representatives		
-	*Destiny Davis*	*Interested Citizen*
-	*John Ferdon*	*Interested Citizen*
Other Partner Agencies		
San Manuel Band of Mission Indians	*Michael Russ*	*Disaster Services Manager*
Arrowhead Regional Medical Center	*Weston Scott Smith*	*Emergency Preparedness*
United States Forest Service	*Marc Stamer*	*San Bernardino National Forest and Angeles National Forest Rep.*
Wrightwood Fire Safe Council	*John Aziz*	*Fire Safe Council*
Rim of the World Mountain Mutual Aid Association	*Aaron Scullin*	*President*

There were a series of meetings held with the Planning Team. Each meeting had a primary focus and provided an opportunity to discuss updates and exchange ideas. Below is a list of the Planning Team meetings:

Table 3-4: Planning Team Meetings

Date	Activity
February 4, 2016	In person meeting to discuss revisions and additions to the Planning Process, Risk Assessment, Community Capability Assessment, Mitigation Strategies, Plan Maintenance, Fiscal Resources, and Public Outreach. Each section was reviewed and discussed by the Team. Additions and corrections will be forwarded to OES for inclusion into the plan.
June 23, 2016	Organizational Meeting for County Unincorporated Area Planning team. Planning Team members were introduced to the project and assigned to review 2016 MJHMP and update risks and mitigation projects as needed.
July 19,2016	Conference Call with participants to discuss revisions and additions to the Planning Process, risk Assessment, Community capability Assessment, Mitigation Strategies, Plan maintenance, fiscal Resources, and Public Outreach. Each section was reviewed and discussed by the Team. Additions and corrections will be forwarded to OES for inclusion into the plan.

August 4, 2010	In person meeting to discuss revisions and additions to the Planning Process, risk Assessment, Community capability Assessment, Mitigation Strategies, Plan maintenance, fiscal Resources, and Public Outreach. Each section was reviewed and discussed by the Team. Additions and corrections will be forwarded to OES for inclusion into the plan
August 30, 2016	In person meeting to discuss revisions and additions to the Planning Process, risk Assessment, Community Capability Assessment, Mitigation Strategies, Plan Maintenance, Fiscal Resources, and Public Outreach. Each section was reviewed and discussed by the Team. Additions and corrections will be forwarded to OES for inclusion in the plan.
September 14, 2016	In Person meeting of the Morongo Basin COAD Community Organizations Active in Disaster. Hazard Mitigations Plan Discussion and outreach for public input on the update of the Hazard Mitigation Plan, and contact information given to the public.
September 20, 2016	In person meeting to discuss changes suggestions with the Fire Safe Council for the following communities: Wrightwood, Phelan, Pinion hills, West Cajon Valley, and Baldy Mesa. The first item on the agenda was the discussion of the LHMP update and explained how to review the current HMP and instructions were given on who and how to contact OES and about 79 persons of the public were present
September 21, 2016	Rim of the World Mountains Mutual Aid Association in Person meeting to discuss Planning Team Goals and Objectives, and any public concerns and contact information was given and it was the first item on the agenda for the meeting. And continuing fire fuel thinning programs (MAST) and Bark Beetle tree removal.
September 24, 2016	In Person meeting of CERT Training on Terrorism, The hazard Mitigation Plan was brought up and discussed and contact information given to the public, a few topics and subjects were brought up.

3.2 Coordination with Other External Jurisdictions, Agencies and Organizations

3.2.1 Internal Coordination

Because of the size and geographical location of Unincorporated County area, there are many jurisdictions, agencies, and organizations that are affected by or have influence on the county and the mitigation planning process. As part of the planning process, the Planning Team, and particularly the Project Manager, took great efforts to engage and include as many members as possible. These members were drawn from San Bernardino County Departments, the San Bernardino County Fire Protection District, the San Bernardino County Flood Control District, and the San Bernardino County Special Districts Department.

One of the first efforts that were made was when the Planning Team was being established. The Planning Team members gave special considerations as to what they thought needed to be in the MJHMP and attempted to identify a person who could representative that area. This consideration went beyond the county departments.

As mentioned above, in addition to being required to participate in the Planning Team meetings, the Planning Team members were also required to liaison with other groups including their own

department/districts planning and project staff and with cooperating agencies to provide updates on the project and to bring to the team the different perspectives and comments. The Planning Team conducted a very extensive outreach effort.

This was done mostly through leveraging of existing meetings and efforts. In this liaison role, the Planning Team members coordinated with CalFire; the United States Forest Service, San Bernardino National Forest and Angeles National Forest; Natural Resource Conservation Service, Special Districts, and the 24 cities and towns within the County. This allowed for the Planning Team to capture a larger perspective; while keeping the Planning Team at a manageable level. The information was then brought back to the Multi-Jurisdictional Planning Team by the individual Planning Team members. At these meeting, potential cooperative projects were discussed, categorized, and prioritized for inclusion in the Multi-Jurisdictional Hazard Mitigation Plan.

As previously mentioned, the Unincorporated County and special districts were also active members of the San Bernardino OA Stakeholder Group meetings. These meetings provided an opportunity to coordinate with all cities/towns and special districts in the county. Through this venue, the Planning Team and the Project Manager reached out to adjacent jurisdictions and associated special districts to ensure that their efforts and findings were not in conflict. Stakeholder Meetings include the primary, alternate, and any consultants for all the participating jurisdictions.

As part of this effort, an OA Stakeholder Web Portal was developed to assist the jurisdictions update their MJHMPs, and encouraged sharing information, resources, and ideas necessary to complete the update process. Meetings, attended by the County Project Manager, were both in person and by conference call; many including a webinar. The Project Manager then brought the materials and discussions held at these meetings back to the Planning Team for review and action wherever applicable to the MJHMP effort. Participating Stakeholders are listed in Annex 5. A list of the OA Stakeholder Meetings is listed below:

- September 21, 2016
  Stakeholders Conference Call/Webinar at OES Headquarters
  1:30 p.m. to 2:30 p.m.

  8 participants in MJHMP Update Project Portal Rollout participated in the Conference Call and Webinar to introduce MJHMP Update Portal. Portal has public and stakeholder sections. During this conference call participants were shown the portal and walked through the log-in process to access the stakeholders' side of the website. Also discussed having weekly and some occasions office calls to update plan progress and needs for information.

- September 28, 2016
  Production team conference call OES Headquarters
  1:30 p.m. to 2:30 p.m.

  This meeting presented the website updates, progress chart and needs from other stakeholder departments to provide data such as proposed, in progress and completed hazard mitigating projects. The MJHMP Resource material was also reviewed. The tentative schedule of Production group meetings was reviewed.

- October 5, 2016
  Production Group Conference Call
  1:30 p.m. to 2:30 a.m.

  Stakeholders discussed MJHMP progress of the MJHMP updates. Revised timelines for updates were presented. New Reference Materials now available on the Web Portal were presented. Questions from the participants were discussed and answered.

- October 12, 2016
  Production team conference call
  OES Headquarters
  1:30 p.m. to 2:30 p.m.

  This meeting presented the website updates, progress chart and needs from other stakeholder departments to provide data such as proposed, in progress and completed hazard mitigating projects. The MJHMP Resource material was also reviewed. The tentative schedule of Production group meetings was reviewed.

- October 19, 2016
  OES Headquarters
  1:30 p.m. to 2:30 p.m.

  This meeting presented the website updates, progress chart and needs from other stakeholder departments to provide data such as proposed, in progress and completed hazard mitigating projects. The MJHMP Resource material was also reviewed. The tentative schedule of Production group meetings was reviewed.

- October 26, CISN
  Project Management Team Meeting
  San Bernardino County Government Center Community Room,
  10:00 a.m. to 12:00 a.m.

  This meeting was with 12 county members and any public to go over changes in the general plan and updates the County Hazard Mitigation plan with current and proposed and approved projects as well as code updates and ordinance changes and draft safety proposals.

- October 26, 2016
  Entire project Teams representatives via in person or video and voice call in
  Video Conference Call
  2 p.m. to 4 p.m.

  All project team stakeholder representatives discussed progress of the MJHMP updates. And timelines were discussed. Questions from the participants were discussed and answered. Also a live meeting in conjunction with Land Use representatives and Fire also consultant staff. 32 in attendance and 108 called in or video linked. Internal and External groups

3.2.2 External Coordination

The unincorporated county also had representation on the OA Working Group team. The Working Group is a small group of OA Stakeholders with experience in developing Multi-Jurisdictional Hazard Mitigation Plans. Members are drawn from the 24 cities/towns, 33 special districts, and the County. The goal of the Working Group is to vet the direction and material being provided to the larger Stakeholder Group such as crosswalk, Web Portal, use of maps, and a method to prioritize and rank the existing and any new hazards. The Working Group also discusses problems and solutions that arise during the MJHMP update process. Meetings were either in person or by conference call.

- June 23, 2016
  Stakeholders Meeting
  San Bernardino Unified School District Community Room, San Bernardino, CA
  2:00 p.m. to 4:00 p.m.

  54 Participants representing 24 cities/towns, 30 special districts, and the unincorporated area of participated. This Stakeholders Meeting introduced the Web Portal and the process to develop a current MJHMP from the 2010 MJHMP. Timelines were presented as well as templates for use in updating the project. Copies of the 2010 MJHMP for the jurisdictions were made available on the Web Portal to use as a starting point in the update process.

- August 30, 2016
  Stakeholders Meeting at OES Headquarters 1:30 p.m. to 2:30 p.m.

  In person meeting to discuss revisions and additions to the Planning Process, risk Assessment, Community capability Assessment, Mitigation Strategies, Plan maintenance, fiscal Resources, and Public Outreach. Each section was reviewed and discussed by the Team. Additions and corrections will be forwarded to OES for inclusion in the plan.

- October 26, 2016
  Entire project Teams representatives via in person, video or voice call in
  Video Conference Call
  2 p.m. to 4 p.m.

  All project team stakeholder representatives discussed progress of the MJHMP updates. Timelines were discussed.
  Questions from the participants were discussed and answered. Also a live meeting in conjunction with Land Use representatives and Fire also consultant staff. 32 in attendance and 108 called in or video linked.

3.3 Public Involvement/Outreach

Public involvement was solicited throughout the process. Since the 2016 MJHMP approval, the County and its special districts have taken several steps to educate the public on the hazards facing the county and had several public forums where mitigation projects were discussed and identified. At all events, public opinion and comments are solicited.

The Planning Team also considered the possibility of including public members on the Planning Team. However, because of the vast size of the county and the volume of possibilities, it was determined that having the Planning Team members liaison with the public would better serve and capture the public interest.

During this process, the County and Special Districts also used several platforms to reach out and inform the public of the MJHMP update. Wherever possible, a joint effort was made by the Planning Team members to include discussion for each participating jurisdictions hazards, goals, and objectives. These joint meetings of the Special Districts and County resulted in joint leverage of the planning effort and a resulting joint benefit of goals/objectives, and project development for the MJHMP development. Public Involvement consisted of meetings for County Departments or Special Districts which gave the public the direct opportunity to comment on the County Unincorporated Area MJHMP, meetings of County Department or Special District advisory committees where hazard specific information and possible projects were discussed, updates on the County website, press releases regarding the MJHMP, and public hearing regarding the MJHMP. All participants collectively supported the following public outreach meetings. Below is a summary list of the public outreach:

3.3.1 Public Meetings

- Wrightwood Fire Safe Council
  Wrightwood Museum, Wrightwood, CA
  July 19, 2016
  7:00 p.m. to 9:00 p.m.

17 community members and 7 Wrightwood Fire Safe Council members attended. A demonstration of Thermo-Gel and various application methods was demonstrated by a private vendor.

Reports of activities were given by the Angeles National Forest and the San Bernardino National Forest.
San Bernardino County Fire Protection District Office of Emergency Services presented a PowerPoint presentation on the effort to update the MJHMP for the unincorporated area of the County. A copy of this PowerPoint is in Annex 9 of the MJHMP.

- Rim of the World Mutual Aid Association
  100 W. Meadow Lane, Big Bear City, CA
  August 21, 2016
  6:00 p.m. to 7:30 a.m.

  24 representatives of local agencies, special districts, utilities, and the public in the Big Bear Valley attended the meeting. The City of Big Bear Lake and the Big Bear City CSD reported on the status of their MJHMP Update efforts. Both are proceeding with the goal of submitting the plan following the Group 1 timelines. Both agencies made presentations to their residents explaining the MJHMP Update Process, public involvement, and timelines.

  San Bernardino County Fire Protection District Office of Emergency Services presented a PowerPoint presentation on the effort to update the MJHMP for the unincorporated area of the County.

- Morongo Basin COAD Community Organizations Active in Disasters
  September 14, 2016
  10:00 a.m. to 12:00 p.m.

  This was a public meeting to discuss volunteers in disasters and the Local Hazard Mitigation Plan and the future of volunteer organizations in active disasters in the areas of Morongo and the entire county of San Bernardino County.

- Wrightwood Fire Safe Council
  Wrightwood Elementary School, Wrightwood, Ca
  September 20, 2016

  Community meeting of the fire safe council for the communities of Wrightwood, Pinion Hills, Phelan, West Cajon Valley, Baldy mesa the meeting covered topics of Emergency Alert System and notifications, repopulation and evacuation pans as well as the Local Hazard Mitigation Plan Update

- Rim of the World Mountain Mutual Aid Association
  September 21, 2016

  Rim of the World Mountains Mutual Aid Association in Person meeting to discuss Planning Team Goals and Objectives, and any public concerns and contact information was given and it was the first item on the agenda for the meeting; continuing on with fire fuel thinning programs (MAST) and Bark Beetle tree removal.

- CERT Terrorism Meeting/Training
  Victoria Gardens Community Center Rancho Cucamonga, CA
  September 24, 2016
  8:00 a.m. to 4:00 p.m.

  This was a CERT Symposium on Terrorism that covered the December 2nd Terror Attack and mass shooting incidents and how to react. An Active Shooter Awareness Course and discussion on the Local Hazard Mitigation Plan Update and Counter Terrorism Awareness courses were all presented to 100 CERT Members and public attendees.

3.3.2 Ready SB County Preparedness App Message/Web Postings

An App message was sent out to alert the public about the hazard mitigation process. The message was sent to over 15,000 people via the SB County Preparedness Mobile App and it is attached to the San Bernardino County Fire Website https://sbcfire.org as referenced in Annex 6. Ready SB County Preparedness Mobile App can be used on either an Android or iPhone. This app provides multiple resources for our residents that will assist them in preparing for a disaster and enhancing the recovery process. Protect yourself and your loved ones before, during and after a disaster.

In addition to hazard mitigation plan updates the public can get the Latest News from SBCounty.gov, CalTrans, National Weather Service, and San Bernardino County Fire Office of Emergency Services. This app provides the public with emergency supply kit lists, grocery lists and checklists tailored to an individual. The public can access and update preparedness plans as needed. Learn all you need to plan for and respond to natural disasters, terrorism and pandemic flu in San Bernardino County.

3.3.3 CERT Teams

The Press Release and Executive Summary were forwarded to the CERT Team leaders for those CERT Teams located in the unincorporated County area. The Team Leaders forwarded the MJHMP Press Release and Executive summary to their team members with the request for comments on the MJHMP. The fourteen (14) CERT Teams within the unincorporated County include:

Angelus Oaks CERT	Big Bear Valley CERT	Helendale CERT
Lucerne Valley CERT	Lytle Creek CERT	Mill Creek Canyon CERT
Morongo Basin CERT	Mountain CERT	Oak Hills CERT
Phelan/Pinon Hills CERT	Rosena Beach CERT	San Antonio Heights CERT
Silver Valley CERT	Wrightwood CERT	

3.3.4 Public Hearing Process (to be completed upon FEMA Approval)

Once FEMA "approval pending adoption" notification is received, the Board of Supervisors reviewed, approved, and adopted the Unincorporated Area Multi-Jurisdictional Hazard Mitigation Plan for the County and its Special Districts at the Public Hearing meeting (**date to be determined**). The Board of Supervisors issued a Letter of Promulgation and Resolution denoting approval of the Multi-Jurisdictional Hazard Mitigation Plan for the County and its special Districts.

Prior to the Public Adoption Hearing Date (date to be determined), the Plan will be posted on the San Bernardino County website as part of the Agenda for the meeting. The Agenda with all attachments is posted the Wednesday prior to the hearing date as a public review requirement. Members of the public were invited to review and make comments at the meeting on (date to be determined). The Multi-Jurisdictional Hazard Mitigation Plan for the County and its Special Districts was on the Board of Supervisors agenda for review and adoption at their regularly scheduled meeting on (date to be determined).Residents of the County were requested to make comments or request information on the Multi-Jurisdictional Hazard Mitigation Plan during the regularly scheduled meeting. After the public had an opportunity to review and comment on the Plan the Board of Supervisors took action on the Board Agenda items.

3.4 Planning Process

As discussed, the planning process followed FEMA How to guides which includes; organizing resources, conducting the risk assessment, developing a capabilities assessment, developing a mitigation strategy and providing implementation measures for continued mitigation success, The Risk Assessment process includes four (4) basic step; 1) hazard identification and screening; 2) hazard profiling; 3) hazard exposure; and, 4) hazard vulnerability. The Project Manager, working with the Planning Team, facilitated discussions around these steps.
The first step in this process was to identify all natural hazards present in the community. The Planning Team started with the 2010 MJHMP and augmented as necessary. This augmentation

considered both adding and removing of hazards to develop a list of potential natural hazards in the community. The Planning Team utilized several sources to ensure they were considering all potential hazards. Material reviewed included the following: 2010 San Bernardino County Operational Area MJHMP, State of California MJHMP, FEMA "How-to Guides," and several surround community MJHMPs. After the list of potential hazards in the community is generated, the hazards were screened. For a full listing of documents see Section 5.1.1

3.4.1 Hazard Screening

The intent of screening hazards is to help prioritize which hazard creates the greatest concern in the community. In 2010, the MJHMP process used Critical Priority Risk Index (CPRI) software to evaluate hazards. In 2016 an alternative approach was implemented. The Planning Team agreed to utilize a non-numerical ranking system for the MJHMP update process. This process consists of generating a qualitative ranking (High, Medium, or Low) rating for: 1) probability; and, 2) impact from each hazard. To further assist with the process, the following definition of "High", "Medium", and "Low" probability and impacts are being provided (NOTE: these definitions we utilized in the 2010 MJHMP process):

Probability
High-Highly Likely/Likely
Medium-Possible
Low-Unlikely
Impact
High-Catastrophic/Critical
Medium-Limited
Low-Negligible

The hazards were then placed into a matrix with the appropriate/corresponding box/cell. The table below is an example of how the process will capture the results.

		Impact		
		High	Medium	Low
Probability	High			
	Medium			
	Low			

After all hazards had been analyzed, the Planning Team then determined which Probability and Impact category (i.e., High Impact; High Probability, Medium Impact) the community will focus on over the next five (5) years. An example of how the hazards may be prioritized is below (Red equaling high priority):

		Impact		
		High	Medium	Low
Probability	High			
	Medium			
	Low			

After identifying the "higher" priority hazards in the community, each of the "high" priority hazards were profiled. The hazard profiling include the incorporation of all new information, material, and reports to better help the Planning Team and the community understand the hazard.

Additionally, for each of the profiled hazards, the Planning Team then analyzed the community's exposure to each hazard (inventory of assets) and the potential impact under scenario events. The Planning Team used HAZUS and hazards intersect analyses recently completed within San Bernardino County to produce this information. See Section 4 for more information.

3.4.2 Set Goals

Goal setting was approached by the Planning Team as a two layered process. The first layer involved the stakeholders acting together as the Planning Team. The second layer involved the individual Special Districts working internally to coordinate those goals identified by the Planning Team with the goals identified internally by the Special Districts. The Planning Team validated and identified new Goals and Objectives for the MJHMP update in 2016. The Planning Team reviewed the hazard exposure and scenario impacts developed during the Risk Assessment portion of the process. With a firm understanding of the risk the community is potentially facing, the Planning Team then re-evaluated the 2010 Multi-Jurisdictional Hazard Mitigation Plan Goals and Objectives; assessed their status and effectiveness in meeting the 2010 Mitigation Measures and identified new Goals and Objectives.

As part of this process, the Planning Team also reviewed the County's General Plan, the State of California MJHMP, Floodplain Management Plans, Task Force After Action, and/or documents, and adjacent local jurisdiction MJHMPs to ensure the Goals and Objectives were comprehensive and compatible with those outlined in this plan.

3.4.3 Review and Propose Mitigation Measures

After the Goals and Objectives were established, the Planning Team then turned to identifying projects under each Goal and Objective that could be implemented to help reduce and/or eliminate the impacts from the priority hazards. As part of this process, the Planning Team reviewed the projects in the 2010 MJHMP to determine which are completed, which are ongoing, and which were deferred. For projects that were not completed the Planning Team validated whether or not the project was necessary.

With a firm understanding of past accomplishments and a good understanding of the potential exposure and scenario impacts from the Risk Assessment section, the Planning Team then started to identify projects that will help reduce and/or eliminate the risk for the high priority hazards. Again, a two-layer approach was used. The Planning Team as a whole identified common projects. These common projects were then coordinated internally by the Special Districts and the County to develop a common list of projects. After a list of all possible projects has been identified, the Planning Team then went through the process of prioritizing the projects.

To assist with this effort the Planning Team adopted the STAPLEE methodology. STAPLEE stands for:

- Social - The public must support the overall implementation strategy and specific mitigation actions. Therefore, the projects will have to be evaluated in terms of community acceptance.
- Technology - It is important to determine if the proposed action is technically feasible, will help to reduce losses in the long term, and has minimal secondary impacts. Determine whether the alternative action is a whole or partial solution, or not a solution at all.
- Administrative - Under this part of the evaluation criteria, examine the anticipated staffing, funding, and maintenance requirements for the mitigation action to determine if the jurisdiction/special district has the personnel and administrative capabilities necessary to implement the action or whether outside help will be needed
- Political - Understanding how your current community and State political leadership feel's about issues related to the environment, economic development, safety, and emergency management. This will provide valuable insight into the level of political support you may have for the mitigation activities and programs. Proposed mitigation objectives sometimes fail because of a lack of political acceptability.
- Legal - Without the appropriate legal authority, the action cannot lawfully be undertaken. When considering this criterion, determine whether your jurisdiction has the legal authority at the State, or local level to implement the action, or whether the jurisdiction must pass new laws or regulations. Each level of government operates under a specific source of delegated authority. As a general rule, most local governments operate under enabling legislation that gives them the power to engage in different activities. Identify the unit of government undertaking the mitigation action, and include an analysis of the interrelationships between local, regional, State, and Federal governments. Legal authority is likely to have a significant role later in the process when your State, or community will

have to determine how mitigation activities can best be carried out, and to what extent mitigation policies and programs can be enforced.

- Economic - Every local government experiences budget constraints at one time or another. Cost effective mitigation actions that can be funded in current or upcoming budget cycles are much more likely to be implemented than mitigation actions requiring general obligation bonds or other instruments that would incur long-term debt to a community. Local communities with tight budgets or budget shortfalls may be more willing to undertake a mitigation initiative if it can be funded, at least in part, by outside sources. “Big ticket” mitigation actions, such as large-scale acquisitions and relocation, are often considered for implementation in a post-disaster scenario when additional Federal and State funding for mitigation is available.
- Environmental - Impact on the environment is an important consideration because of public desire for sustainable and environmentally healthy communities and the many statutory considerations, such as NEPA, to keep in mind when using Federal funds. The Planning Team needed to evaluate whether, when implementing mitigation actions, there would be negative consequences to environmental assets such as threatened and endangered species, wetlands, and other protected natural resources.

In addition to the STAPLEE methodology, the Planning Team incorporated other criteria/factor questions into the process to help engage and solicit input from members. Examples of these criteria/factor questions are:

- Does the Action:
  - Solve the problem?
  - Address Vulnerability Assessment?
  - Reduce the exposure or vulnerability to the highest priority hazard?
  - Address multiple hazards?
  - Address more than one (1) Goal/Objective?
  - Benefits equal or exceed costs?

- Can the Action:
  - Be implemented with existing funds?
  - Be implemented by existing state or federal grant programs?
  - Be completed within the 5-year life cycle of the LMJHMP?
  - Be implemented with currently available technologies?

- Will the Action:
  - Be accepted by the community?
  - Be supported by community leaders?
  - Adversely impact segments of the population or neighborhoods?
  - Require a change in local ordinances or zoning laws?
  - Result in legal action such as a lawsuit?
  - Positively or negatively impact the environment?
  - Comply with all local, state, and federal environmental laws and regulations?

- Is there:
  - Sufficient staffing to undertake the project?
  - Existing authority to undertake the project?

After going through the above mentioned process for each project, the Planning Team identified higher priority projects.

3.4.4 Draft the Multi-Jurisdictional Hazard Mitigation Plan

The Multi-Jurisdictional Hazard Mitigation Plan Update was drafted by the Project Manager, based on input and comments provided by the Planning Team. As indicated previously, the Planning Team used the 2010 MJHMP as a starting point but revised it to reflect updated information). The 2016 MJHMP format and is similar to the 2010 plan with slight heading changes and differences in content. In addition to the heading changes and improved risk assessment information, the Planning Team also uses the FEMA Guidance and materials provided by the consultant hired to coordinate the Operational Area MJHMP and Stakeholder groups. This material aided in the Planning Team's understanding of the level of detail and type of information that is excepting in each section.

This process started with the Special Districts and County providing information to the Planning Team through their liaison on the planning team. After the Planning Team ranked and prioritized the materials, the liaisons returned to their respective Special Districts to vet the Planning Team's work. The Planning Team then worked together with the vetted materials to produce the draft MJHMP. As mentioned earlier, each section was reviewed and updated as necessary. While some Planning Team members are responsible for the updating select sections, all members are responsible for reviewing and commenting on the entire MJHMP. The Planning Team Project Manager was responsible for version control and distribution of the final MJHMP for review.

Once the MJHMP update was drafted, the Planning Team provided opportunities for the public to review and comment on the plan. After the public comment period was closed, the Planning Team finalized the plan and forwarded to Cal EMA and FEMA for approval.

3.4.5 Adopt the Plan

The San Bernardino County Board of Supervisors created each of the Special Districts to provide a specific service to a particular area/population of San Bernardino County. These Special Districts are Board Governed in that the Board of Supervisors has direct control and legislative oversight of the Special Districts. The Board of Supervisors takes action on behalf of each Special District whenever governance items are necessary. As the Five special districts are separate legal entities from the County of San Bernardino for tax/revenue purposes the Board of supervisors, acting as the Board of Directors for each Special District, will be adopting the Multi-

Jurisdictional Hazard Mitigation Plan on behalf of each Special District. The Special Districts are not independent from San Bernardino County but are controlled and administered as any other County Department is administered. In order to comply with legal requirement for each of the five Special Districts, separate resolutions are required. Copies of these resolutions are attached at the front of this MJHMP.

San Bernardino County Board of Supervisors is responsible for the review, approval, and adoption of the Multi-Jurisdictional Hazard Mitigation Plan (MJHMP) update for the unincorporated area of San Bernardino County, the San Bernardino County Fire Protection District, the San Bernardino County Flood Control District, the Big Bear Valley Recreation and Park District, Bloomington Recreation and Park District and for the County's board governed Special Districts Department. It is also the intent of the San Bernardino County Board of Supervisors to take appropriate actions to incorporate the MJHMP update into the San Bernardino County General Plan.

After Cal EMA and FEMA have approved the HMP update, it will be adopted by the San Bernardino County Board of Supervisors. Currently, the adoption process is scheduled for **(date to be determined)**. The item will be part of the consent calendar subject to a public hearing if necessary. The HMP will be listed on the agenda with the plan being made available electronically to the general public for at least three (3) business days prior to the Board of Supervisor's meeting date. Any member of the public can make comments on the Plan during the meeting prior to any action by the Board of Supervisors.

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Section 4. Risk Assessment

The goal of mitigation is to reduce and/or eliminate the future impacts of a hazard including property damage, disruption to local and regional economies, and the amount of public and private funds spent to assist with recovery. However, mitigation should be based on an assessment of the risk.

This Risk Assessment Section evaluates the potential loss from a hazard event by assessing the vulnerability of buildings, infrastructure, and people. It identifies the characteristics and potential consequences of hazards, how much of the unincorporated areas of the County could be affected by a hazard, and the impact on unincorporated County area assets. The Risk Assessment approach consists of three (3) components:

- ***Hazard Identification*** *– Identification and screening of hazards (Section 4.1)*
- ***Hazard Profiles*** *– Review of historic occurrences and assessment of the potential for future events (Section 4.2)*
- ***Vulnerability Assessment*** *– Determination of potential losses or impacts to buildings, infrastructure and population (Section 4.3)*

4.1 Hazard Identification

4.1.1 Hazard Screening Criteria

Per FEMA Guidance, the first step in developing the Risk Assessment is identifying the hazards. The County's HMP Planning Team reviewed a number of previously prepared hazard mitigation plans and other relevant documents to determine the universe of natural hazards that have the potential to affect the County and the nearby region. Table 4-1 provides a crosswalk of hazards identified in the 2010 San Bernardino County Multijurisdictional Hazard Mitigation Plan Update, the County of San Bernardino 2007 General Plan Safety Element, Single Jurisdictional Plans and the 2013 CA State Hazard Mitigation Plan. Seventeen different hazards were identified based on a thorough document review. The crosswalk was used to develop a preliminary hazards list providing a framework for County HMP Planning Team members to evaluate which hazards were truly relevant to the County and which ones are not. For example, volcanic activity was considered to be of little relevance to the County, while earthquake, flooding, and wildfire were indicated in almost all hazard documentation.

Table 4-1: Document Review Crosswalk

Hazards	2010 San Bernardino County Multi-Jurisdictional Hazard Mitigation Plan	County of San Bernardino 2007 General Plan Safety Element	Single Jurisdictional Plans	2013 CA State Hazard Mitigation Plan
Climate Change				■
Dam Inundation			■	■
Drought			■	■
Earthquake/ Geologic Hazards	■	■	■	■
Extreme Heat				■
Extreme Cold				■
Flood	■	■	■	■
Hazardous Waste		■	■	■
High Winds/ Straight Line Winds		■	■	
Hail				
Infestation				
Lightning				
Terrorism			■	■
Tornado				
Volcanic Activity		■		■
Wildfire	■	■	■	■
Winter Storm (Heavy Snowfall)				■

In addition to a document review, previous hazard occurrences were used to identify hazards for this hazard mitigation plan. Previous hazard occurrences provide a historical view of hazards that have affected the County in the past, and thus provide a window into the potential hazards that can affect the County in the future. Information about federal and state disaster declarations in San Bernardino County (declarations are declared by County) was compiled from FEMA and Cal EMA's databases, as shown in Table 4-2. Though not a complete snapshot of hazard incidences in the County (since not all hazard events are federally or state declared), Table 4-2 provided the County HMP Planning Team with solidified accounts of the types and extent of disasters that have affected the County dating back to 1965 when flooding affected entire regions of San Bernardino County. As indicated in Table 4-2 large regional incidents have affected San Bernardino County, including the California Wildfires of 1999. Most recently, disasters for terrorist attacks (2015), flood (2011) and severe storms (2010) were declared in San Bernardino County. The disaster declarations in Table 4-2 provide a baseline for consideration in the hazard prioritization process.

Table 4-2: Federal, State and County Declared Disasters

Disaster Number	Declaration Date	Disaster Type	Incident Type	Title
Federal Declarations				
Major Disaster Declarations				
1952	1/26/2011	DR	Flood	Severe Winter Storms, Flooding, and Debris and Mud Flows
1884	3/8/2010	DR	Severe Storm(s)	Severe Winter Storms, Flooding, and Debris and Mud Flows
1731	10/24/2007	DR	Fire	Wildfires, Flooding, Mud Flows, and Debris Flows
1689	3/13/2007	DR	Freezing	Severe Freeze
1585	4/14/2005	DR	Severe Storm(s)	Severe Storms, Flooding, Landslides, and Mud and Debris Flows
1577	2/4/2005	DR	Severe Storm(s)	Severe Storms, Flooding, Debris Flows, and Mudslides
1498	10/27/2003	DR	Fire	Wildfires, Flooding, Mudflow and Debris Flow Directly Related T
1203	2/9/1998	DR	Severe Storm(s)	Severe Winter Storms and Flooding
1046	3/12/1995	DR	Severe Storm(s)	Severe Winter Storms, Flooding Landslides, Mud Flow
1044	1/10/1995	DR	Severe Storm(s)	Severe Winter Storms, Flooding, Landslides, Mud Flows
1005	10/28/1993	DR	Fire	Fires, Mud/Landslides, Flooding, Soil Erosion
979	2/3/1993	DR	Flood	Severe Winter Storm, Mud & Land Slides, & Flooding
947	7/2/1992	DR	Earthquake	Earthquake & Aftershocks
935	2/25/1992	DR	Flood	Rain/Snow/Wind Storms, Flooding, Mudslides
894	2/11/1991	DR	Freezing	Severe Freeze
872	6/30/1990	DR	Fire	Fires
690	9/22/1983	DR	Flood	Flash Flooding
687	7/1/1983	DR	Flood	Flooding
677	2/9/1983	DR	Coastal Storm	Coastal Storms, Floods, Slides & Tornadoes
635	11/27/1980	DR	Fire	Brush & Timber Fires
615	2/21/1980	DR	Flood	Severe Storms, Mudslides & Flooding
547	2/15/1978	DR	Flood	Coastal Storms, Mudslides & Flooding
521	9/21/1976	DR	Flood	Flooding, Tropical Storm Kathleen
295	9/29/1970	DR	Fire	Forest & Brush Fires
253	1/26/1969	DR	Flood	Severe Storms & Flooding
223	1/2/1967	DR	Flood	Severe Storms & Flooding
211	12/7/1965	DR	Flood	Heavy Rains & Flooding
Fire Management Assistance Declarations				
2955	9/2/2011	FM	Fire	Hill Fire
2841	10/4/2009	FM	Fire	Sheep Fire
2836	9/1/2009	FM	Fire	Pendleton Fire
2833	8/31/2009	FM	Fire	Oak Glen Fire
2792	11/15/2008	FM	Fire	Freeway Fire Complex
3279	10/23/2007	EM	Fire	Wildfires
2738	10/22/2007	FM	Fire	Grass Valley Fire
2728	9/15/2007	FM	Fire	Butler 2 Fire
2653	7/12/2006	FM	Fire	Sawtooth Fire Complex

Disaster Number	Declaration Date	Disaster Type	Incident Type	Title
3248	9/13/2005	EM	Hurricane	Hurricane Katrina Evacuation
2503	10/25/2003	FM	Fire	Old Fire
2501	10/23/2003	FM	Fire	Ca-Grand Prix Fire-10-23-2003
2497	9/6/2003	FM	Fire	Ca-Bridge Fire-09-05-2003
2491	8/19/2003	FM	Fire	Ca-Locust Wildfire-08-19-2003
Emergency Declarations				
3140	9/1/1999	EM	Fire	Ca-Wildfires-08/25/1999
CALOES Emergency and Disaster Proclamations/ Executive Orders				
Other Disasters				
2464	9/24/2002	FS	Fire	Williams Fire
2433	6/27/2002	FS	Fire	Louisiana Fire
2425	6/17/2002	FS	Fire	Blue Cut Fire
###	12/18/2015	EM	Terrorist Attack	Mass Shooting
State Declarations				
145	2/14/1963		Severe Storms	California Severe Storms, Heavy Rains, & Flooding
47	12/22/1955		Flood	California Flood
15	2/5/1954		Flood	California Flood & Erosion
County Declarations				
	3/13/1990		Earthquake	Upland Earthquake
	10/31/1988		Fire	Texas Fire (Watershed Damage)
	9/3/1987		Fire	Wildland Fires
	7/13/1984		Weather	Unstable Weather Conditions (City of Big Bear Lake, CSD, Co. Flood Control, Victor Valley Waste Water Authority, Juniper Riviera County Water District)
	9/29/1979		Gasoline Shortage	Gasoline Shortage Emergency
	6/28/1979		Water Shortage	Water Shortage (Lake Gregory)
	7/22/1960		Fire	Major and Widespread Fires

4.1.2 Hazard Prioritization

The Planning Team determined that the County and its Special Districts should focus over the next five (5) years on hazards that fell within the HIGH and MEDIUM "Probability" and "Impact" categories. While all the hazards present a potential problem in the County, the Planning Team felt that if they were able to reduce or eliminate the risk from these hazards, it would provide a greater service to the people within the jurisdiction. Table 4-3 illustrates how the final prioritization of the hazard; the "Green" colored box represents the highest priority hazards; and the "White" colored boxes represent lower (second and third tier) priority hazards.

		Impact		
		High	Medium	Low
Probability	High	Wildfire Flood Earthquake/ Geologic Hazards	Drought	
	Medium	Terrorism	Climate Change (Extreme Heat and other)	Hail Infestation
	Low		Dam Inundation	Tornado High Winds Winter Storm Lightning Extreme Cold

Table 4-3: Prioritized Hazard Assessment Matrix

4.2 Hazard Profiles

Although the County faces the risk of experiencing many natural and manmade hazards, this section profiles only the County's highest priority natural hazards the unincorporated County areas and Special District areas are expected to experience; earthquake, wildfire, flood, drought, terrorism and climate change. The priority hazards are based on the Calculated Priority Risk Index (CPRI) explained in Section 4.1.2.

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4.3 Earthquake Geologic Hazards



An earthquake is a sudden, rapid shaking of the earth caused by the breaking and shifting of rock beneath the earth's surface. For hundreds of millions of years, the forces of plate tectonics have shaped the earth as the huge plates that form the earth's surface move slowly over, under, and past each other. Sometimes the movement is gradual. At other times, the plates are locked together, unable to release the accumulating energy. When the accumulated energy grows strong enough, the plates break free, causing the ground to shake. Most earthquakes occur at the boundaries where the plates meet; however, some earthquakes occur in the middle of plates.

Ground shaking from earthquakes can collapse buildings and bridges; disrupt gas, electric, and phone service; and sometimes trigger landslides, avalanches, flash floods, fires, and huge, destructive ocean waves (tsunamis). Buildings with foundations resting on unconsolidated landfill and other unstable soil, and trailers and homes not tied to their foundations are at risk because they can be shaken off their mountings during an earthquake. When an earthquake occurs in a populated area, it may cause deaths and injuries and extensive property damage. Earthquakes can strike suddenly, without warning. Earthquakes can occur at any time of the year and at any time of the day or night. On a yearly basis, 70 to 75 damaging earthquakes occur throughout the world.

4.3.1 Regulatory Environment

The Alquist-Priolo Earthquake Fault Zoning (AP) Act was passed into law following the destructive February 9, 1971 San Fernando earthquake. The AP Act provides a mechanism for reducing losses from surface fault rupture on a statewide basis. The intent of the AP Act is to ensure public safety by prohibiting the siting of most structures for human occupancy across traces of active faults that constitute a potential hazard to structures from surface faulting or fault creep.

The 2013 California Building Standards Code (also known as Title 24) became effective for the County on January 1st, 2014. Title 24 includes CBC Section 3417: Earthquake Evaluation and Design for Retrofit of Existing Buildings which can be viewed at http://www.bsc.ca.gov/codes.aspx

Changes or additions to the seismic provisions come from many different sources, including new research results and documentation of performance in past earthquakes. A primary resource is the National Earthquake Hazard Reduction Program (NEHRP) Recommended Seismic Provisions for New Buildings and Other Structures (FEMA P-750: http://www.fema.gov/media-library/assets/documents/18152). FEMA's companion document Earthquake Resistant Design

Concepts (FEMA P-749: http://www.fema.gov/media-library/assets/documents/21866) provides a nontechnical background explanation.

4.3.2 Past Occurrences

Table 4-4 shows earthquakes greater than Magnitude 4.0 that have been felt within the San Bernardino County area in the last five years.

Table 4-4: Earthquakes: 2010-2015 San Bernardino County

Date	Name
9/14/2011	Calimesa 4.1
1/15/2014	Fontana 4.4
7/5/2014	Running Springs 4.6
3/29/2014	Brea 5.1
7/25/2015	Fontana 4.2
9/16/15	Big Bear Lake 4.0
12/30/2015	Muscoy 4.4
1/6/2016	Banning 4.4

There are hundreds more small (M<4.0) earthquakes that have occurred within San Bernardino County during this same time frame. Those with a magnitude of below 4.0 are not listed.

4.3.3 Location/Geographic Extent

Figure 4-1 shows the locations of major faults in California, including the four (4) major faults in Southern California in relation to San Bernardino County. These faults are the Southern San Andreas, the San Jacinto, the Elsinore, and the Garlock Faults. There are also many smaller faults within San Bernardino County capable of producing significant earthquakes. However, these four faults are considered by the United States Geological Survey (USGS) and the California Geological Survey (CGS) to be the most dangerous in the County. (California Geological Survey Special Publication 42, Interim Revision 2007, “Fault-Rupture Hazard Zones in California” - Alquist-Priolo Earthquake Fault Zoning Act). Other geologic hazards include liquefaction and landslides. Both occur during and after earthquakes.

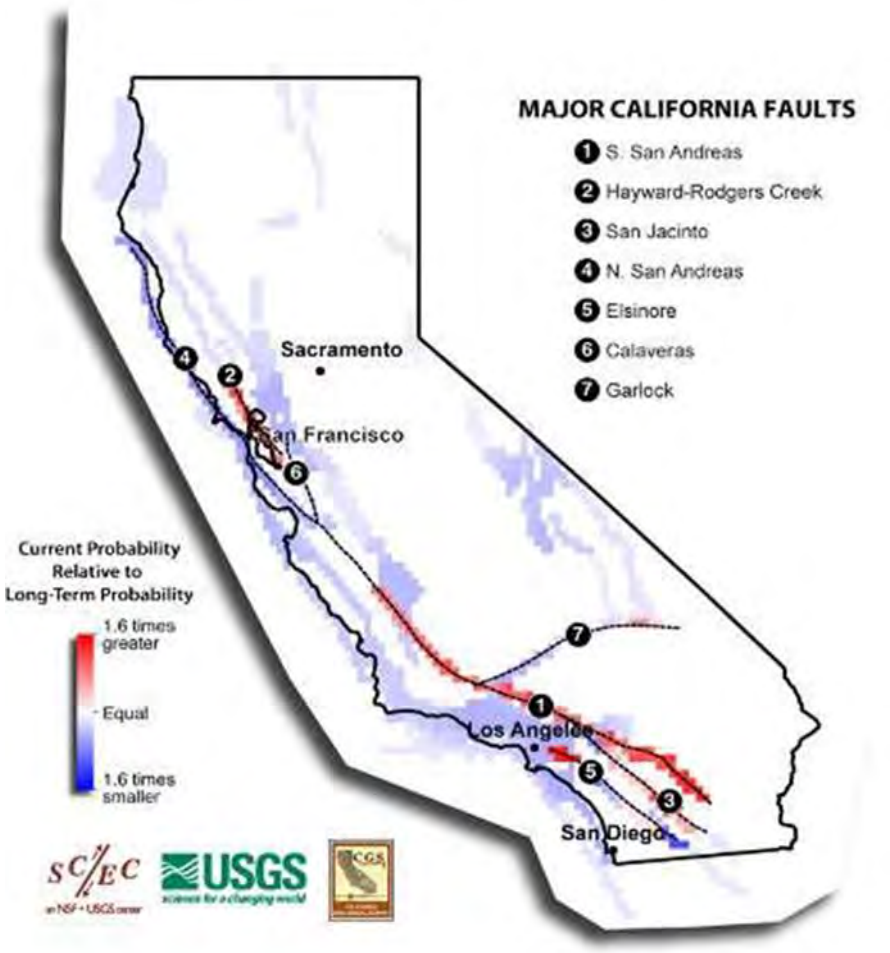


Figure 4-1: Major California Faults

Liquefaction of the ground occurs when the groundwater table is high and soil conditions are favorable. Liquefaction Susceptibility Zones as mapped by the USGS for the 2008 ShakeOut Scenario1 shows areas of the County susceptible to liquefaction during an earthquake. See Figure 4-2

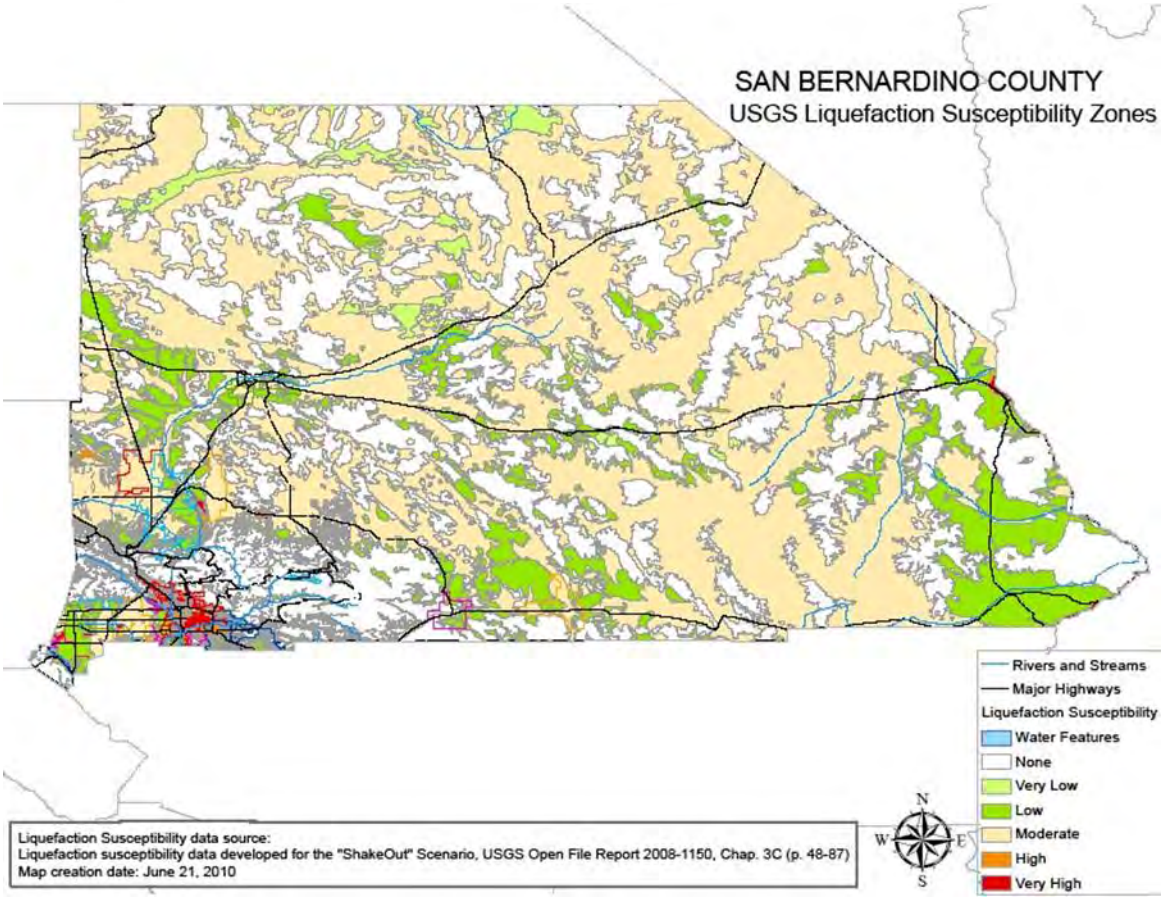


Figure 4-2: USGS Liquefaction Susceptibility Zone

4.3.4 Magnitude/Severity

The MMI Scale measures earthquake intensity as shown in Table 4-5. The MMI Scale has 12 intensity levels. Each level is defined by a group of observable earthquake effects, such as ground shaking and/or damage to infrastructure. Levels I through VI describe what people see and feel during a small to moderate earthquake. Levels VII through XII describe damage to infrastructure during a moderate to catastrophic earthquake.

See Section 4.3.5 to see how magnitude and severity are linked to the probability of earthquake occurrences.

Table 4-5: MMI Scale

Earthquake Magnitude and Intensity		
Magnitude (M_w)	**Intensity (Modified Mercalli Scale)**	**Description**
1.0 – 3.0	I	I. Not felt except by very few people under especially favorable conditions.
3.0 – 3.9	II – III	II. Felt by a few people, especially those on upper floors of buildings. Suspended objects may swing.
		III. Felt quite noticeably indoors. Many do not recognize it as an earthquake. Standing motorcars may rock slightly.
4.0 – 4.9	IV – V	IV. Felt by many who are indoors; felt by a few outdoors. At night, some awakened. Dishes, windows and doors rattle.
		V. Felt by nearly everyone; many awakened. Some dishes and windows broken; some cracked plaster; unstable objects overturned.
5.0 – 5.9	VI – VII	VI. Felt by everyone; many frightened and run outdoors. Some heavy furniture moved; some fallen plaster or damaged chimneys.
		VII. Most people alarmed and run outside. Damage negligible in well-constructed buildings; considerable damage in poorly constructed buildings.
6.0 – 6.9	VII – IX	VIII. Damage slight in special designed structures; considerable in ordinary buildings; great in poorly built structures. Heavy furniture overturned. Chimneys, monuments, etc. may topple.
		IX. Damage considerable in specially designed structures. Buildings shift from foundations and collapse. Ground cracked. Underground pipes broken.
7.0 and Higher	VIII and Higher	X. Some well-built wooden structures destroyed. Most masonry structures destroyed. Ground badly cracked. Landslides on steep slopes.
		XI. Few, if any, masonry structures remain standing. Railroad rails bent; bridges destroyed. Broad fissure in ground.
		XII. Virtually total destruction. Waves seen on ground. Objects thrown into the air.

4.3.5 Frequency and Probability of Occurrence

Several of the major Southern California faults have a high probability of experiencing a Magnitude 6.7 or greater earthquake within the next 30 years (Figure 4-2); 59% probability of a M6.7 or greater on the Southern San Andreas Fault, 31% probability on the San Jacinto Fault, and 11% probability on the Elsinore Fault. These probabilities were determined by the USGS and CGS in a 2008 study (2007 Working Group on California Earthquake Probabilities, 2008, The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2): U.S. Geological Survey Open-File Report 2007-1437 and California Geological Survey Special Report 203 http://pubs.usgs.gov/of/2007/1437/).

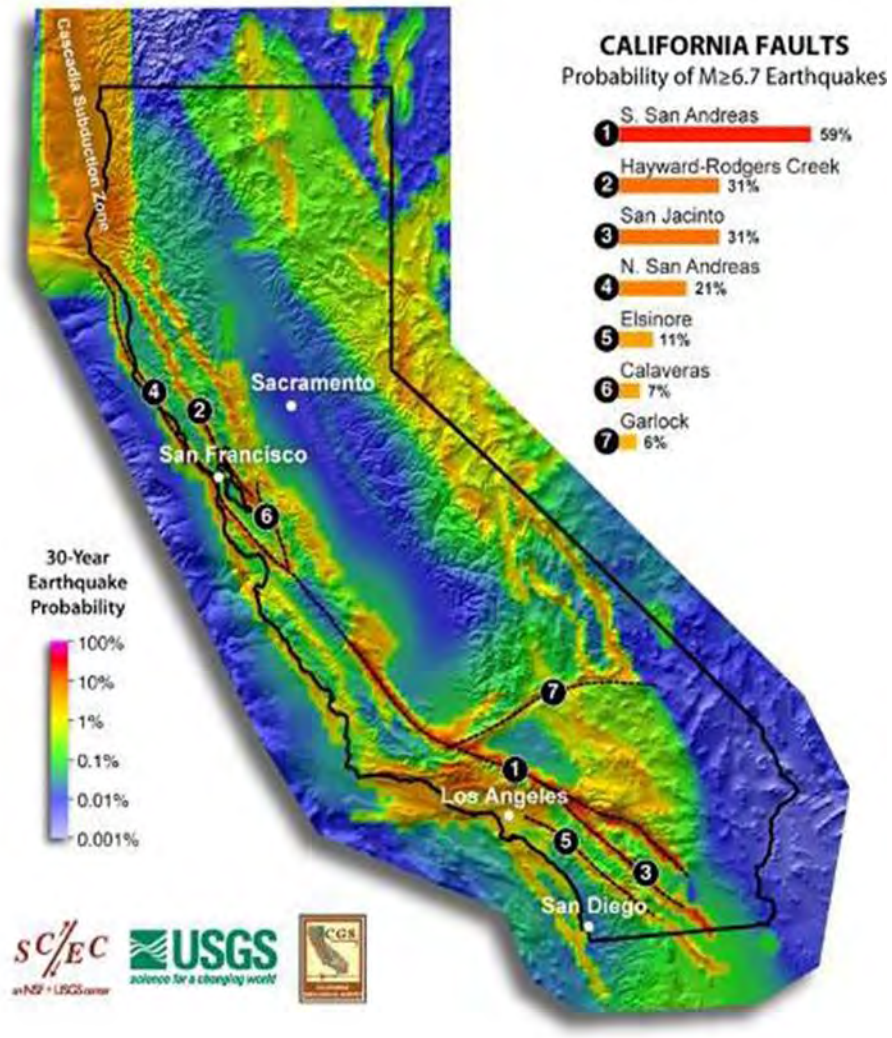


Figure 4-3: California Faults Probability of ≥ M 6.7 Earthquake

As shown in Figure 4-3 the probability of an earthquake with a Magnitude 6.7 or greater occurring somewhere in Southern California within the next 30 years is estimated to be 97% (2007 Working Group on California Earthquake Probabilities, 2008). As can be seen in the table, earthquake probabilities in Southern California are higher than those for Northern California.

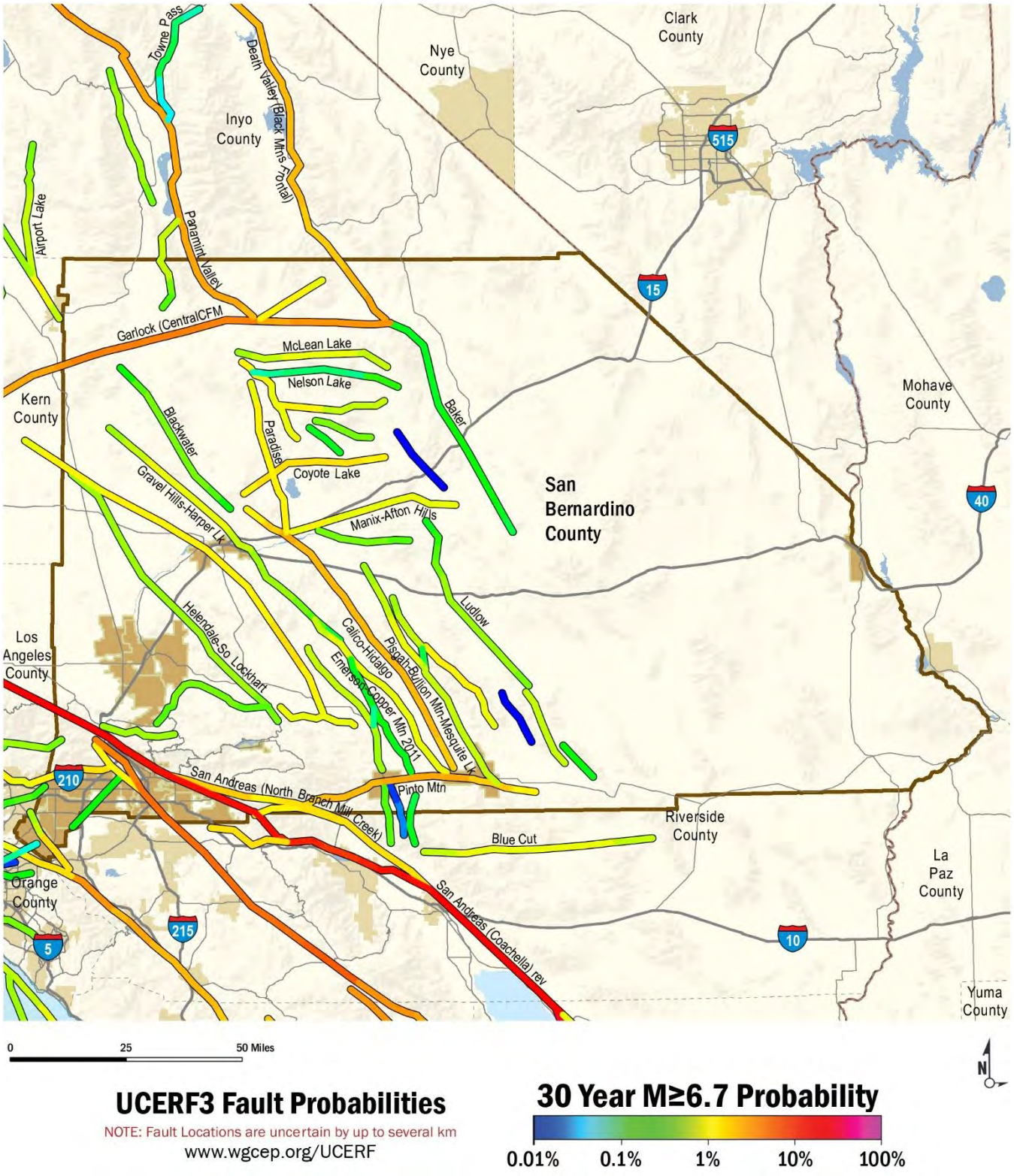


Figure 4-4: California Area Earthquake Probabilities by Magnitude

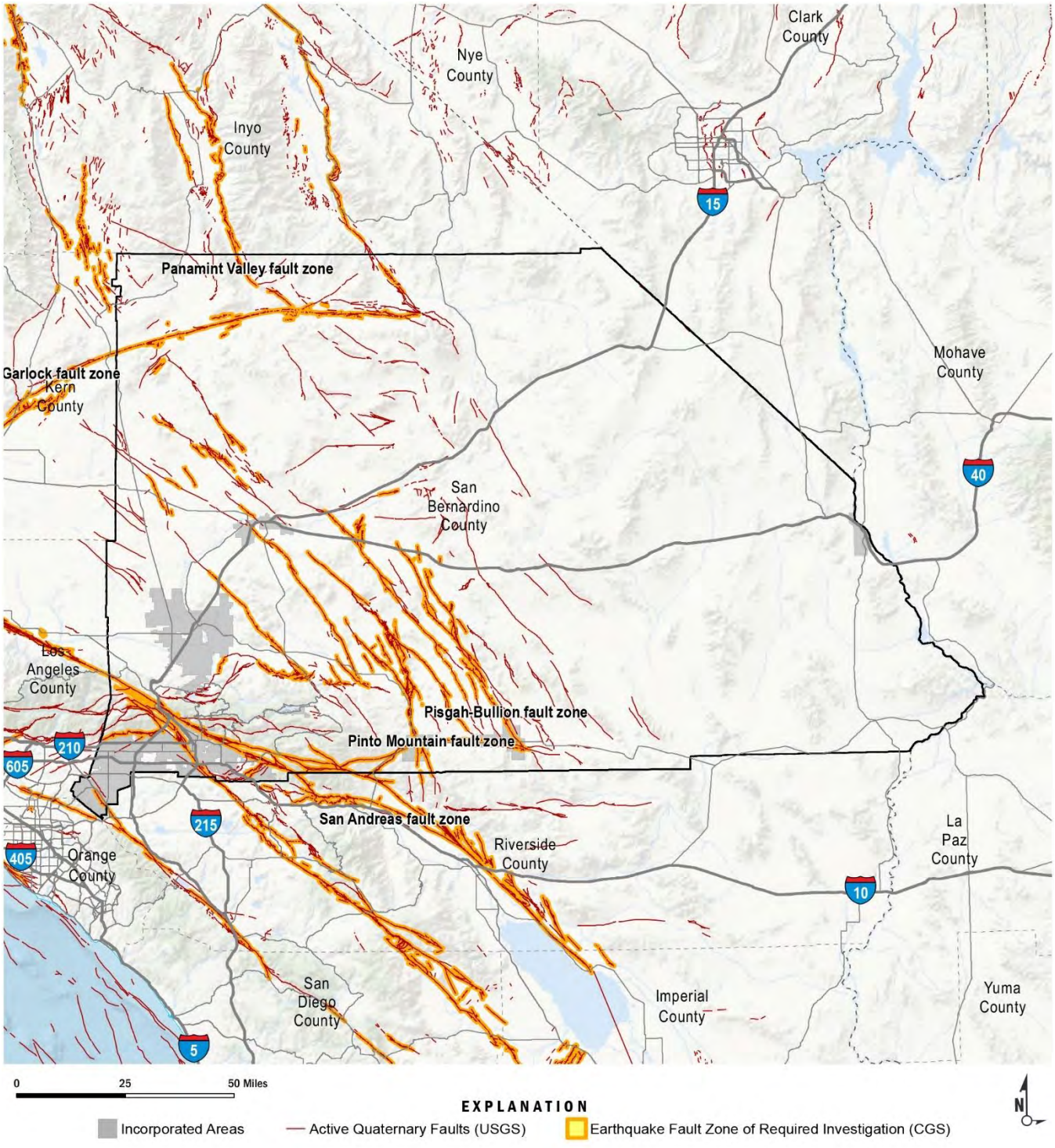


Figure 4-5: Earthquake Fault Zone

4.4 Wildfire



Wildfires present a significant potential for disaster in the County, a region of relatively high temperatures, low humidity, and low precipitation during the summer. This long summer season is followed by a fall season that is famous for high velocity, very dry winds that come out of the desert. The Santa Ana winds very consistently arrive from the middle of October to the end of November. In and of themselves, these weather patterns would be of little significance without the un-naturally dense forest and the dense undergrowth that has been allowed to grow unabated for the last several decades. Compounding the vegetative growth that has occurred is the unchecked development of substantial housing and businesses in mountain communities. This urbanized growth has required parallel growth and sophistication in the fire service that responds to wildfires in the wild land urban interface. With immediate responses to initial fire starts, the vast majority of fires are successfully extinguished in short order. In doing so, this eliminates nature's way of thinning the forest through smaller fires.

Another factor that is a potential for disaster is the number of dead trees in the mountain region. Due to the over densification of the forest combined with drought conditions during the past ten years, trees in the local mountains have become weakened, creating a perfect environment for Bark Beetles to proliferate from 2003 to 2008. Combine these severe burning conditions with people or lightning and the stage is set for the occurrence of large, destructive wildfires. In addition, the forested areas of the County are not only the most popular, with the most visitors in the Nation, but are also the most populated in residences and businesses in the Nation as well. The final element in this catastrophe waiting to happen is that because of the steep mountain terrain, there are only five routes in and out for almost 60,000 residents. On a holiday weekend though, this population can dramatically increase by 50,000 to 100,000 people as weekend vacationers.

4.4.1 Regulatory Environment

4.4.1.1 State

Wildfire State Responsibility Area (SRA) Fire Safe Regulations outline basic wildland fire protection standards for local jurisdictions. SRA Fire Safe Regulations (if policed) can decrease the risk of wildfire events in the wildland interface. SRA Fire Safe Regulations do not supersede local regulations, which equal or exceed minimum state regulations. The State statute for wildfire protection is Public Resources Code, Section 4290. Requirements in the code include information on the following (CA Fire Alliance):

- Road Standards for Fire Equipment Access
- Standards for Signs Identifying Streets, Roads and Buildings
- Minimum Private Water Supply Reserves for Emergency Fire Use
- Fuel Breaks and Greenbelts

4.4.1.2 Local

4.4.1.2.1 Fire Hazard Abatement Program

In an effort to reduce the threat of wild fires, the San Bernardino County Fire Hazard Abatement (FHA) Program enforces the fire hazard requirements outlined in San Bernardino County Code Section 23.0301–23.0319. The primary function of the Fire Hazard Abatement Program is to reduce the risk of fires within communities by pro-actively establishing defensible space and reduction/removal of flammable materials on properties.

The Fire Hazard Abatement Program conducts surveys to identify fire hazards throughout the year. Fire hazards are identified and notices to abate the hazard(s) are mailed to property owners. Property owners are given 30 days to abate the violations. Failure to abate may result in citations, penalties, and/or fees for abatement by the County. The Fire Hazard Abatement Program responds to complaints year round in the unincorporated areas and contracting Cities and Fire Districts.

4.4.2 Past Occurrences

Wildfire locations from 1900 – 2016 are shown in Figure 4-6. In the past five years (since the 2010 MJHMP was approved) there have been 13 significant wildland fires within San Bernardino County. These fires are listed in Table 4-7, and several of the more damaging fires are discussed below.

Table 4-6: Wildfire Occurrences 2010-2016

Number	Date	Name	**Acres**
1.	9/5/2011	Hill Fire	1,158
2.	11/5/2012	Devore Fire	335
3.	6/28/2013	Mill Fire	534
4.	8/8/2013	Sharp Fire	243
5.	9/24/2013	Sierra Fire	200
6.	4/30/2014	Etiwanda Fire	2,143
7.	5/13/2014	Rancho Incident	1,548
8.	3/31/2015	River Bottom Fire	185
9.	6/17/2015	Lake Fire	31,359
10.	7/17/2015	North Fire/ Pines Fire	4,250
11.	8/23/2015	Summit Fire	555
12.	8/7/2016	Pilot Fire	8,110
13.	8/16/2016	Blue Cut Fire	36,274
			86,894

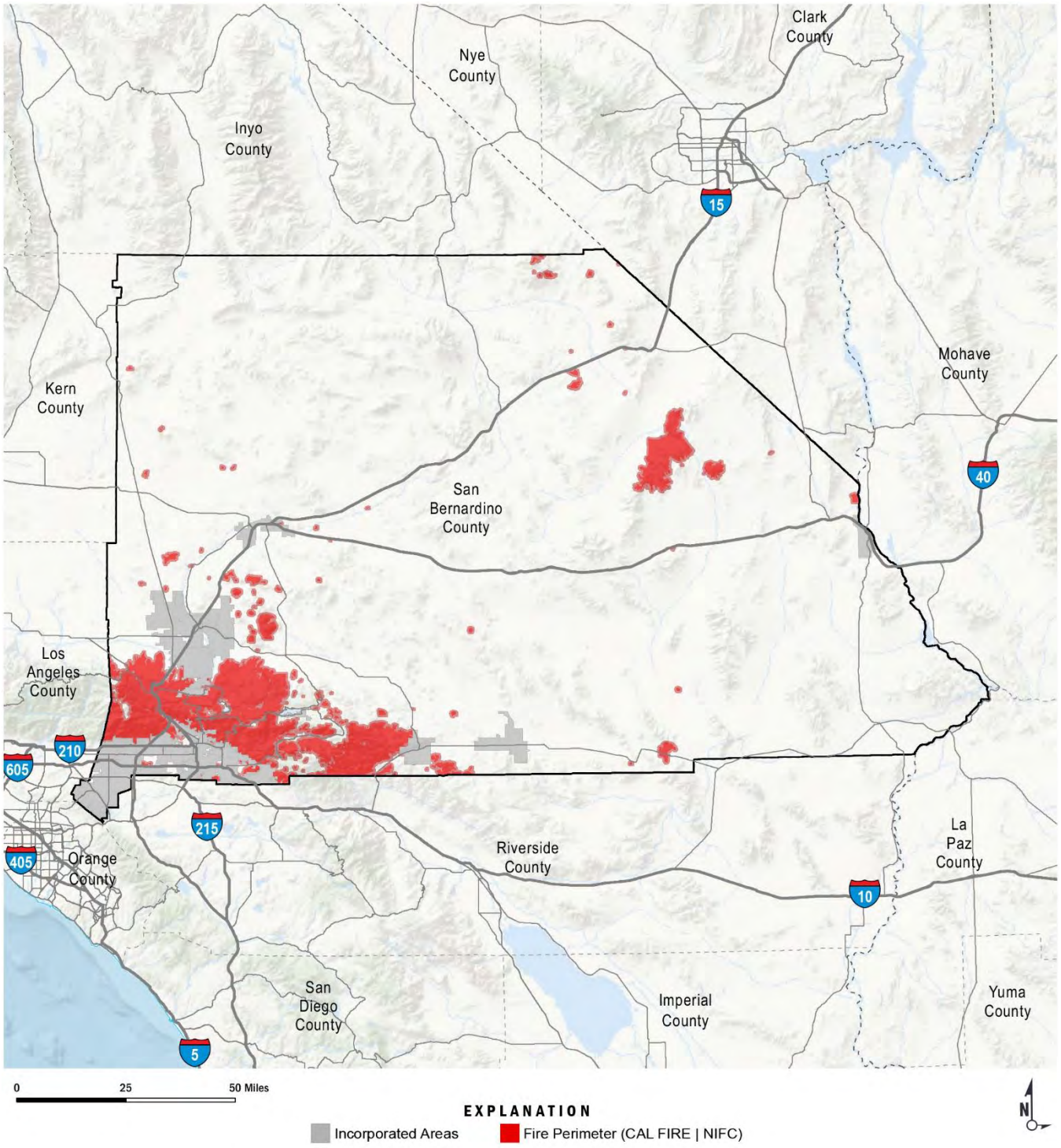


Figure 4-6: Wildfire History 1900 – 2016 (CalFire and USFS Data 2010)

The 2016 Blue Cut Fire was a reminder that wildfires are a significant threat to lives and property in the unincorporated San Bernardino County area. The Blue Cut Fire burned 36,274 acres, destroying an estimated 105 single family residences and 216 outbuildings. In addition, 3 single family residences and 5 other structures were damaged.

In 2015 The Lake Fire burned 31,359 acres and was the cause of 6 minor firefighter injuries and 1 residence and 3 outbuildings were destroyed.

North Fire/Pines Fire in 2015 burned a total of 4,250 acres, destroying 7 homes, 16 outbuildings and 44 vehicles in the community of Baldy Mesa. No injuries were reported.

The Blue Cut Fire, Lake Fire, and North Fire/ Pines Fire all occurred in the County's mapped Very High Fire Severity Zone. Mitigation efforts have reduced but not eliminated the threat from wildfire. The strong fall winds that are capable of creating firestorms cannot be controlled. Drought cannot be controlled. Fuels reduction programs reduce the potential spread of fire, upgraded Building Codes make structures more fire resistant, and public education prepares residents for wildfires. However, the threat of wildfire remains. The continuing goal is to reduce the threat from wildfire wherever possible.

4.4.3 Location/Geographic Extent

Using information from the California Department of Forestry (CAL FIRE) Figure 4-8, illustrates the areas at risk to a wildfire event. The areas with the highest risk of wildfire are the in the southwestern portions of County in the mountainous region.

Figure 4-7 illustrates vegetation mortality due to bark beetle infestation, drought, and other factors in San Bernardino County. These conditions create extreme fire hazards.

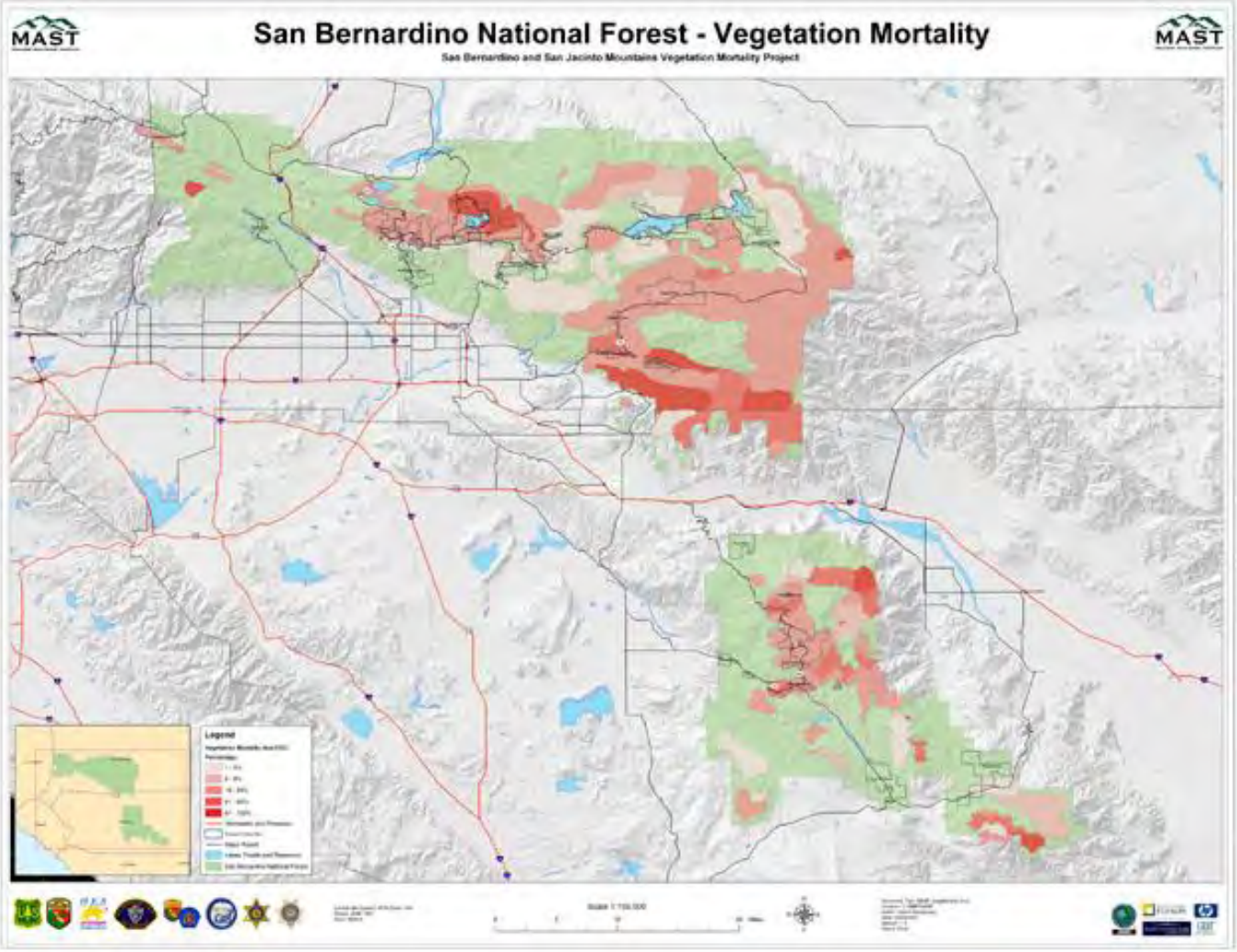


Figure 4-7: San Bernardino National Forest – Vegetation Mortality

4.4.4 Magnitude/Severity

Fire Severity Zones are used in determining additional protective measures required when building new structures or remodeling older structures within the particular zone. Additional measures must be taken on the property around a structure in the higher ranked fire Severity Zones.

CAL FIRE adopted Fire Hazard Severity Zone maps for LRA in June 2008. The Fire Severity Zones for County identifies areas of Very High, High, and Moderate fire hazard severity throughout the County and are mapped in Figure 4-8.

Fire Severity Zones are used in determining additional protective measures required when building new structures or remodeling older structures within the particular zone. Additional measures must be taken on the property around a structure in the higher ranked fire Severity Zones.

Fire hazard mapping is a way to measure the physical fire behavior to predict the damage a fire is likely to cause. Fire hazard measurement includes vegetative fuels, probability of speed at which a wildfire moves the amount of heat the fire produces, and most importantly, the burning fire brands that the fire sends ahead of the flaming front.

The model used to develop the information in accounts for topography, especially the steepness of the slopes (fires burn faster as they burn up-slope.). Weather (temperature, humidity, and wind) also has a significant influence on fire behavior. The areas depicted as moderate and high in are of particular concern and potential fire risk in these are constantly increasing as human development, and the wildland urban interface areas expand.

4.4.5 Frequency/Probability of Future Occurrences

In San Bernardino County, wildfire season commences in the summer when temperatures are high, humidity is low, and conditions remain dry. The season continues into the fall, when the County experiences high velocity, very dry winds coming out of the desert. A statewide drought beginning in 2011 has caused the state to be the driest it's been since record keeping began back in 1895 (California 2016). This has caused extremely dry conditions in unincorporated areas of the County creating plentiful fuel sources for wildfires.

USGS LANDFIRE (Landscape Fire and Resource Management Planning Tools), is a shared program between the wildland fire management programs of the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior, providing landscape scale geo-spatial products to support cross-boundary planning, management, and operations. Historical fire regimes, intervals, and vegetation conditions are mapped using the Vegetation Dynamics Development Tool (VDDT). This USGS data supports fire and landscape management planning goals in the National Cohesive Wildland Fire Management Strategy, the Federal Wildland Fire Management Policy, and the Healthy Forests Restoration Act.

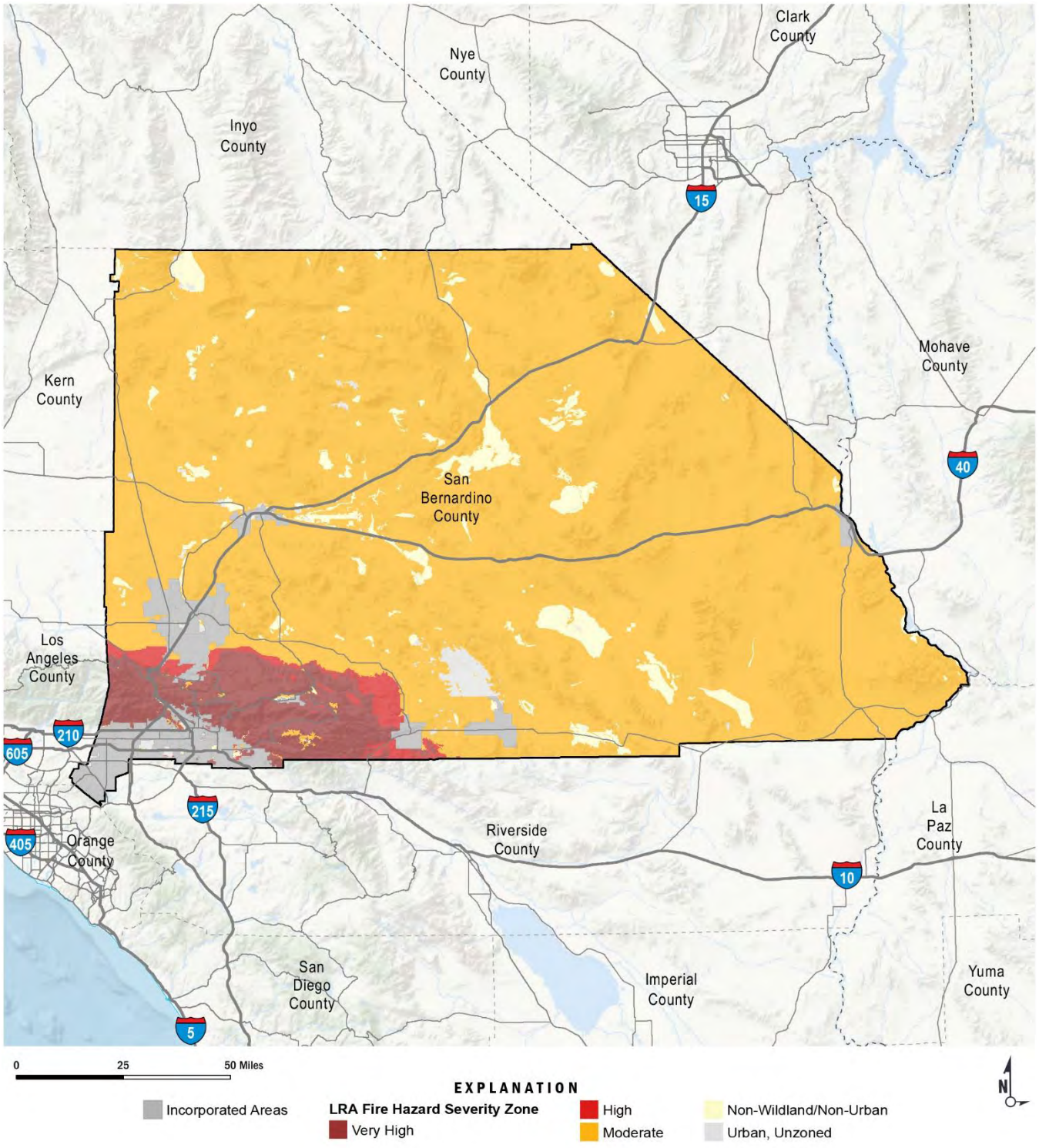


Figure 4-8: Fire Hazard Severity Zone

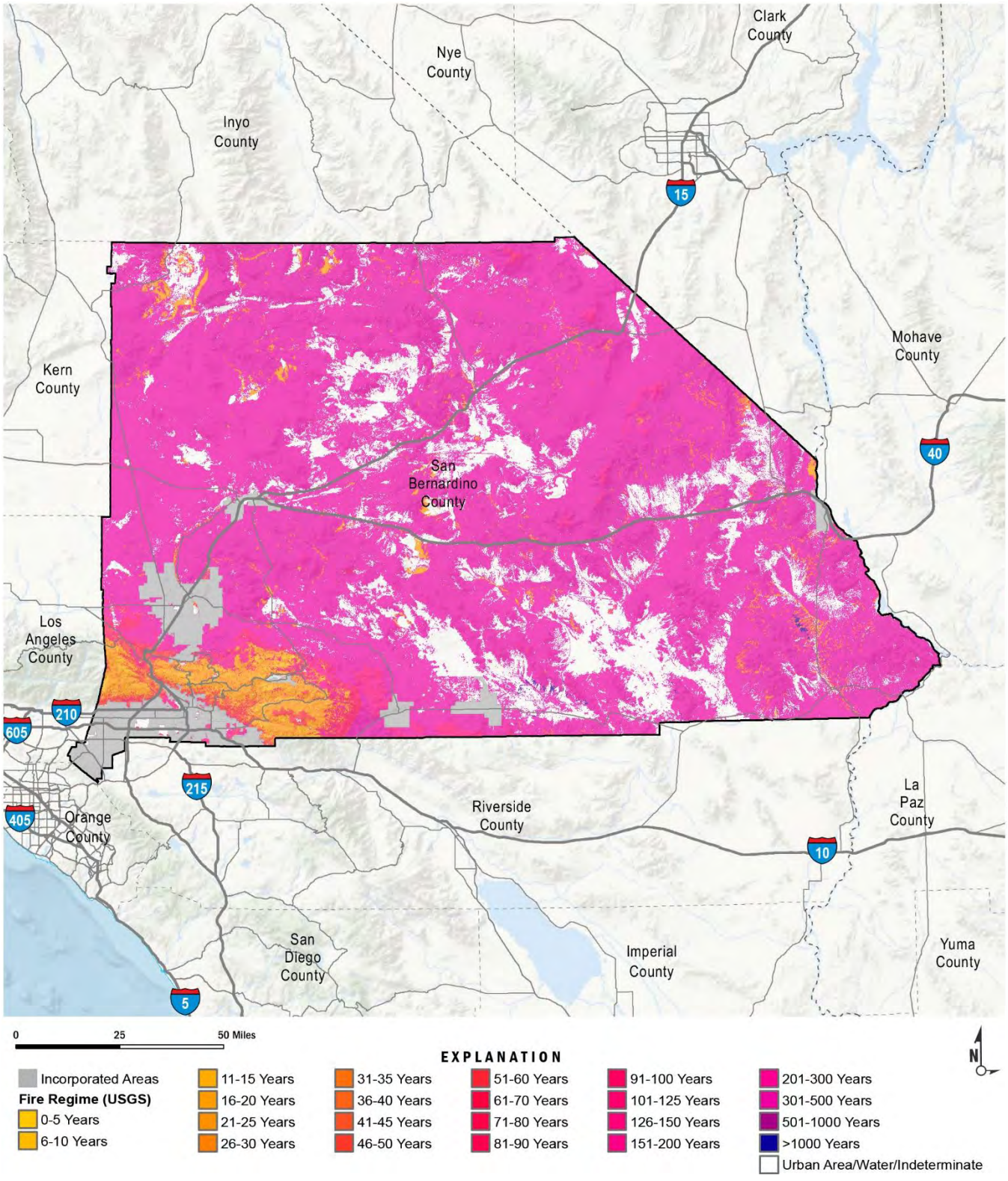


Figure 4-9: USGS Mean Fire Return Interval Map

As part of the USGS Landfire data sets, the Mean Fire Return Interval (MFRI) layer quantifies the average period between fires under the presumed historical fire regime. MFRI is intended to describe one component of historical fire regime characteristics in the context of the broader historical time period represented by the LANDFIRE Biophysical Settings (BPS) layer and BPS Model documentation.

MFRI is derived from the vegetation and disturbance dynamics model VDDT (Vegetation Dynamics Development Tool) (LF_1.0.0 CONUS only used the vegetation and disturbance dynamics model LANDSUM). This layer is created by linking the BpS Group attribute in the BpS layer with the Refresh Model Tracker (RMT) data and assigning the MFRI attribute. This geospatial product should display a reasonable approximation of MFRI, as documented in the RMT. See Figure 4-9 for predicted fire return interval for the jurisdictional area.

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4.5 Flood



Floods are the second most common and widespread of all natural disasters faced by the County and its Special Districts. Most communities in the United States have experienced some kind of flooding during or after spring rains, heavy thunderstorms, winter snow thaws, or summer thunderstorms.

A flood, as defined by the National Flood Insurance Program is: "A general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties (at least one of which is the policyholder's property) from:

- Overflow of inland or tidal waters, or
- Unusual and rapid accumulation or runoff of surface waters from any source, or
- Mudflow, or
- Collapse or subsidence of land along the shore of a lake or similar body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels."

Floods can be slow or fast rising but generally develop over a period of hours or days. Mitigation includes any activities that prevent an emergency, reduce the chance of an emergency happening, or lessen the damaging effects of unavoidable emergencies. Investing in mitigation measures now, such as: engaging in floodplain management activities, constructing barriers such as levees, and purchasing flood insurance will help reduce the amount of structural damage to structures and financial loss from building and crop damage should a flood or flash flood occur.

The standard for flooding is the 1% annual chance flood, commonly called the 100-year flood, the benchmark used by the Federal Emergency Management Agency (FEMA) to establish a standard of flood control in communities throughout the country. The 1% annual chance flood is also referred to as the base flood.

The 1% annual chance flood is the flood that has a 1% chance of being equaled or exceeded in any given year and it could occur more than once in a relatively short period of time. By comparison, the 10% flood (10-year flood) means that there is a 10% chance for a flood of its size to occur in any given year.

4.5.1 Regulatory Environmental

4.5.1.1 County of San Bernardino 2007 Development Code and Zoning Ordinances

One of the purposes of this Development Code is to create a comprehensive and stable pattern of land uses upon which to plan drainage/flood control and other public facilities and utilities. The follow chapters of the development code address floodways, flood control and development near such:

Chapter 82.14 Flood Plain Safety (FP) Overlay
Chapter 85.07 Flood Hazard Development Review
Chapter 86.04 Flood Plain Management Administrator

The County has also adopted Zoning Ordinances that are not part of the County Code but are part of the General Plan. These ordinances regulate land use; map the official land use and hazard overlay districts to include safety hazard and environmental protection areas.

4.5.1.2 National Flood Insurance Program

The National Flood Insurance Program (NFIP) makes federally backed flood insurance available to homeowners, renters, and business owners in participating communities. As a participating member of the NFIP, San Bernardino County is dedicated to protecting homes with more than 1,000 policies currently in force. Like most communities participating in NFIP, FEMA has prepared a detailed Flood Insurance Study (FIS) for areas of San Bernardino County. The study presents water surface elevations for floods of various magnitudes, including the 1-percent annual chance of flood (the 100-year flood) and the 0.2-percent annual chance of flood (the 500-year flood). Base flood elevations and the boundaries of the 100 and 500 year floodplains are shown on the Flood Insurance Rate Maps (FIRM). More information on location and geographic extent of the FIRMs are provided in this section.
The County of San Bernardino entered the regular phase of the NFIP on September 09, 1978; in 2016 the County Floodplain Administrator is Marlene Mioyshi. As a participant in the NFIP, San Bernardino County is dedicated to regulating development in the FEMA regulated floodplain areas in accordance with NFIP criteria. Before a permit to build in a floodplain area is issued, San Bernardino County ensures that two basic criteria are met:

- All new buildings and developments undergoing substantial improvements must, at a minimum, be elevated to protect against damage by the 100-year flood.
- New floodplain developments must not aggravate existing flood problems or increase damage to other properties.

Structures permitted or built in the County/City before the NFIP regulatory requirements were incorporated into the San Bernardino County ordinances (before the effective date of the San Bernardino County FIRM) are called “pre-FIRM” structures. For the San Bernardino County, pre-FIRM structures are those permitted or built before September 09, 1978

Extensive FEMA NFIP databases are used to track claims for every participating community including San Bernardino County. NFIP insurance data provided by FEMA indicates that as of September 02, 2016, there were 1,772 policies in San Bernardino County, resulting in $403,874,500 of insurance in force; this amounts to $1,758,534 in total premiums. Of the 1,772 policies, only 1,070 are for structures located within the 1% annual chance flood zones, while the remaining 701 policies are for structures located outside of the FEMA identified floodplain.

Based on this analysis of insurance coverage, San Bernardino County has significant assets at risk to the 100-year flood. Of the 3,426 improved parcels within the 100-year floodplain, only 1,070 of those parcels maintain flood insurance[1]. That means approximately 2,356 improved parcels are without flood insurance in high risk areas according to FEMA. This condition could exist for a number of different reasons. Ground floor elevations are one foot above the 100-year floodplain and home owners and business that wish not to purchase floodplain insurance (non-federally backed loans, home with no mortgage, homes that are "grandfathered" into the NFIP). The 2,356 uninsured structures located in mapped floodplain areas are especially vulnerable.

Currently, San Bernardino County contains 12 Repetitive Loss (RL) properties under their jurisdictional umbrella. The total dollar amount of claims paid to date by the NFIP is $2,606,098. San Bernardino County also contains zero (0) Severe Repetitive Loss (SRL) structure.

Most of the RL properties that have experienced flooding are in the High Desert and Mountain areas of San Bernardino County are due to debris flow in localized areas. Every loss claim is seasonal in nature as all loss claims have been in December, January or February. Some mitigation on these properties has been conducted and San Bernardino County is currently tracking mitigation actions through standardized forms as required by FEMA.

NOTE: A property does not have to be currently carrying a flood insurance policy to be considered a RL or SRL property. Often homes in communities are not carrying flood insurance but are still on the community's repetitive loss list. The "repetitive loss" designation follows a property from owner to owner; from insurance policy to no insurance policy, and even after the property has been mitigated. Having an insurance policy and making claims that fall into the repetitive loss criteria will put a property on the RL list. Even after the policy on a property has lapsed or been terminated, the property will remain on San Bernardino County RL list.

NOTE: The Privacy Act of 1974 (5 U.S.C. 522a) restricts the release of certain types of data to the public. Flood insurance policy and claims data are included in the list of restricted information. FEMA can only release such data to state and local governments, and only if the data are used for floodplain management, mitigation, or research purposes. Therefore, this plan does not identify the repetitive loss properties or include claims data for any individual property.
For more information on California Regulation and the NFIP, please see California's Department of Water Resources Quick Guide here: http://www.water.ca.gov/floodmgmt/lrafmo/fmb/docs/CAQG-screen.pdf

4.5.2 Past Occurrences

Severe weather events leading to flooding are listed in Table 4-7; several major events are discussed below.

[1] An improved property owner may not carry flood insurance for a number of reasons; not everyone is required to carry flood insurance. Structures carrying federally-backed mortgages that are in a SFHA are required to carry flood insurance in the County of San Bernardino. Owners who have completed the terms of the mortgage or who purchased their property outright may not choose to carry flood insurance and instead bear the costs of recovery on their own.

Table 4-7: Severe Weather Events 2010-Present

Date	Type
1/18/2010	January 2010 Winter Storms
12/17/2010	Highland Flooding Incident
8/25/2013	Flooding- Remnants of Tropical Storm Ivo
11/21/2013	Winter Storms
2/28/2014	Winter Storm
8/3/2014	Thunderstorms, heavy rain, flash flooding, mudslides
7/6/2015	Flash flooding resulting from Lake Fire
7/30/2015	Severe Thunderstorms
1/6/2016	Strong rain, flooding and mudslides
8/22/16	Flash flooding from storm system

4.5.3 Location/Geographic Extent

Table 4-8 shows the number of acres and square miles that lie in flood hazard areas within the County. Figure 4-10 provides flood hazard data for San Bernardino County as mapped in FEMA's National Flood Hazard Layer for California (April, 2010). Mapped areas include areas subject to inundation by the 1% Annual Chance Flood (also referred to as the 100-year flood), and areas subject to inundation in the 0.2% Annual Chance Flood (500-year flood).

Table 4-8: San Bernardino County Flood Hazard Area

Flood Hazard Type	Sum of Acres	Sum of Square Miles
100-Year Flood	65,209	101.89
100-Year, Floodway	13,968	21.83
500-Year Flood	13,838	21.62
500-Year, Protected by Levee	4,336	7
Total	**97,351**	**152.11**

Table 4-9 shows a land use compatibility chart for 100 year flood plains.

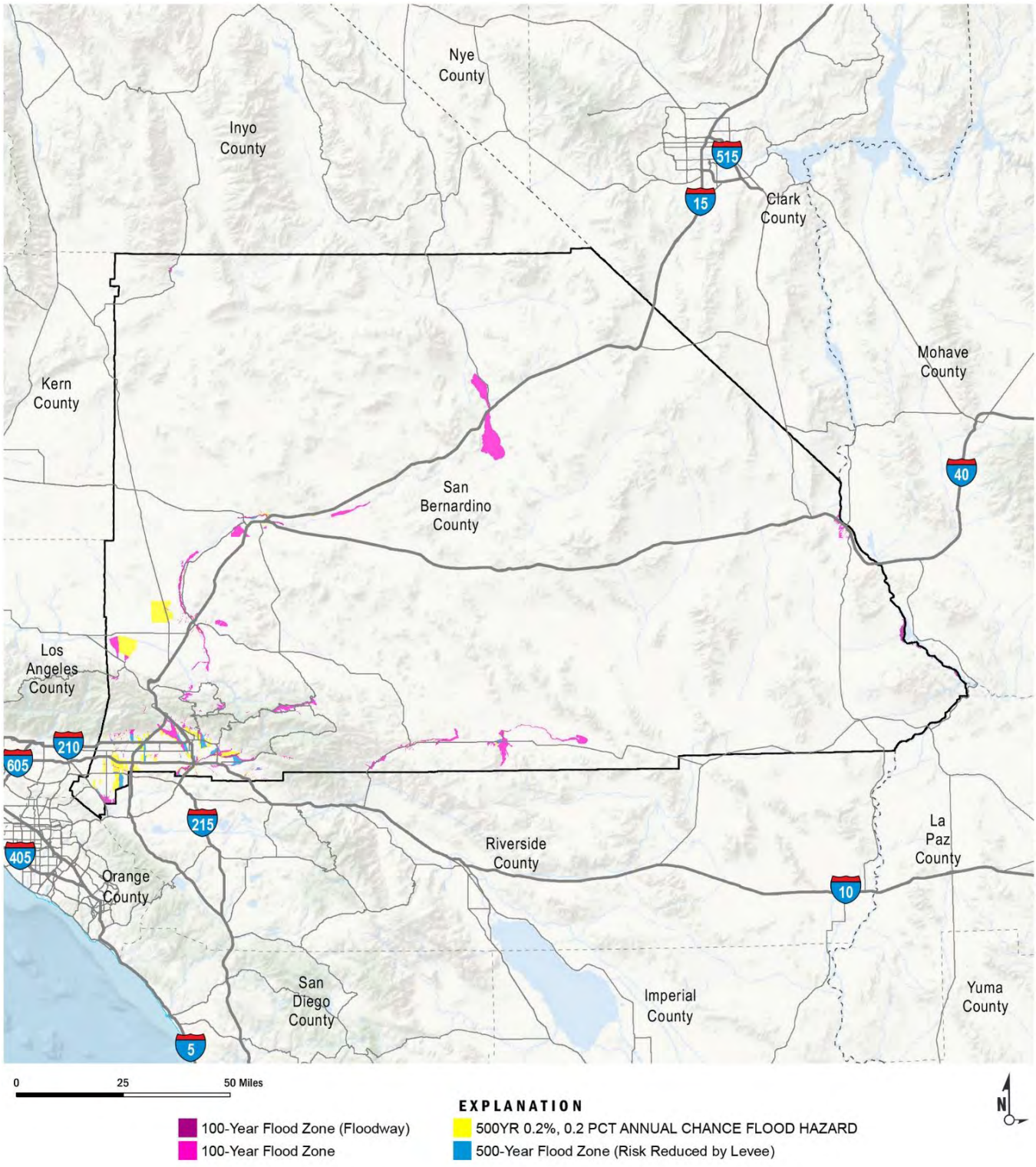


Figure 4-10: Flood Hazard Severity Zone Map

Table 4-9: Land Use Compatibility Chart for 100 Year Flood Plains (General Plan Table S-1)

Land Uses	Compatibility in 100-Year Floodplains
Critical Nuclear related systems; explosives or hazardous materials/ manufacturing, handling or storage; hospitals and other emergency medical facilities.	Restricted
Essential Police, fire and communications systems; Emergency Operations Centers (EOC's); electric power inter-tie systems; power plants; utility substations; sewage treatment plants; water-works; local gas and electric distribution lines; aqueducts; major pipelines; major highways, bridges and tunnels; ambulance services; public assembly sites with 300 or more capacity; schools.	Restricted
High Occupancy Multi-family residential of 20 or more units; major commercial including large shopping centers; office buildings; large hotels; health care clinics and convalescent homes; heavy industry; gas stations.	Generally Incompatible
Normal-Low Risk Single-family and two-family residential; multi-family of less than 20 units; small scale commercial; small hotels, motels; light industry; warehousing.	Generally Incompatible

Restricted unless alternative sites are not available or feasible and it is demonstrated that, although mitigation may be difficult, hazards will be adequately mitigated. Generally Incompatible Restricted unless site investigation demonstrates that site is suitable or that hazards will be adequately mitigated.

4.5.4 Magnitude/Severity

4.5.4.1 Flash Flooding

Flash flooding tends to occur in the summer and early fall because of the monsoon rains and is typified by increased humidity and high summer temperatures.

The desert area contains many mountain ranges that are steep and experience summer thunder storms causing flash floods in many dry washes on the desert floor. The water collects in dry lake beds throughout the desert area.

Environmental permit processing has delayed or prohibited work in the washes to provide flow lines to many bridges on county highways. Many highways do not have bridges but convey water across the road with dip crossings. Flash flooding cause's road and bridge wash outs and erosion of earthen channels and basins when they occur near these facilities.

Cities and towns often experience street closures for several days due to sediment transport and road damage. Because of the sheet flow character of the desert, many private properties experience erosion and sediment deposits. The urban valley also can experience flash flooding in its narrow canyons and within the many unimproved creeks and interim channels feeding the Santa Ana River. The valley floor in many areas is very flat so even minor rain events can produce flooding of roads and private property. In coordination with local jurisdictions, the County of San Bernardino Flood Control District has prepared Master Drainage plans for many cities and towns to provide a plan for reducing flooding due to minor storms. Maps can be found on the County's Department of Public Works website here: http://cms.sbcounty.gov/dpw/FloodControl/Planning/MPD.aspx

However, local resources are not sufficient to cover the cost of the construction of the drainage systems. The densely populated (75% of the county population) urban valley region contains the headwaters of the Santa Ana River. The San Gabriel and San Bernardino Mountains border the North side of the valley are steep reaching 5,000 feet with alluvial fans which are developed and densely populated.

4.5.5 Frequency/Probability of Future Occurrences

The Flood Insurance Rate Map (FIRM) not only identifies the flood hazard zones for insurance and floodplain management purposes, but also provides a statement of probability of future occurrence.

A 500-year flood has a 0.2-percent chance of occurring in any given year; a 100-year flood has a 1-percent chance, a 50-year flood has a 2-percent chance, and a 10-year flood has a 10-percent chance of occurrence. Although the recurrence interval represents the long-term average period between floods of specific magnitude, significant floods could occur at shorter intervals or even within the same year. The FIRM maps typically identify components of the 500-year and 100-year floodplains

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4.6 Drought



Drought is a normal, recurrent feature of climate. It occurs almost everywhere, although its features vary from region to region. Drought severity depends on numerous factors, including duration, intensity, and geographic extent, as well as regional water supply demands by humans and vegetation. The severity of drought can be aggravated by other climatic factors, such as prolonged high winds and low relative humidity.

Drought originates from a deficiency of precipitation over an extended period, usually one or more seasons. Drought can result in a water shortage for some activity, group, or environmental sector. Drought is a complex natural hazard, which is reflected in the following four definitions commonly used to describe it:

- Agricultural – drought is defined principally in terms of naturally occurring soil moisture deficiencies relative to water demands of plant life, usually arid crops.

- Hydrological – drought is related to the effects of precipitation shortfalls on stream flows and reservoir, lake, and groundwater levels.

- Meteorological – drought is defined solely on the degree of dryness, expressed as a departure of actual precipitation from an expected average or normal amount based on monthly, seasonal, or annual time scales.

- Socioeconomic – drought associates the supply and demand of economic goods or services with elements of meteorological, hydrologic, and agricultural drought. Socioeconomic drought occurs when the demand for water exceeds the supply as a result of weather-related supply shortfall. It may also be called a water management drought.

Although climate is a primary contributor to hydrological drought, other factors such as changes in land use (e.g., deforestation), land degradation, and the construction of dams all affect the hydrological characteristics of the basin. Since regions are interconnected by hydrologic systems, the impact of meteorological drought may extend well beyond the borders of the precipitation-deficient area. Similarly, changes in land use upstream may alter hydrologic characteristics such as infiltration and runoff rates, resulting in more variable streamflow and a higher incidence of hydrologic drought downstream. Land use change is one of the ways human actions alter the frequency of water shortage even when no change in the frequency of meteorological drought has been observed.

4.6.1 Regulatory Environment

The County and participating jurisdictions have a number of regulatory requirements and documents to address planning for drought in the County. This includes Watershed Water Quality Management Plans (WQMP) for San Bernardino County and the Mojave and Santa Ana Watersheds. On June 21st, 2013, the Executive Officer approved the revised Technical Guidance Document for Water Quality Management Plan (TGD-WQMP).

The 1972 Federal Water Pollution Control Act, also known as the Clean Water Act (CWA) provides the basis for the protection of all inland surface waters, estuaries, and coastal waters. California's Porter-Cologne Water Quality Control Act of 1970 established the Regional Water Quality Control Board as the agency responsible for implementing the CWA and Porter-Cologne requirements in the Santa Ana Watershed.

In 2006, California State lawmakers adopted AB 1881. This provided guidelines and timelines for the revision of the State's Model Water Efficient Landscape Ordinance (MWELO) and mandated that every city, county or other agency within the State adopt MWELO or be in compliance with it through their own ordinance by January 2010. On January 1, 2010 the San Bernardino County Water Efficient Landscape Ordinance was implemented. It can be obtained on the county website.

4.6.1.1 Watershed Water Quality Management Plan

San Bernardino County's WQMP draft was written in 2013 and final approval was given on June 21, 2013.

4.6.1.2 Technical Guidance Document for Water Quality Management Plan (TGD-WQMP)

Approved on June 21, 2013, this document provides direction to project proponents on the regulatory requirements applicable to a private or public development activity, including public works transportation projects, from project conception to completion.

4.6.2 Past Occurrences

- The 2013 California State MHMP states that from 1950 to 2012, there has been eight-drought State Emergency Proclamations in California. Specifically for San Bernardino County, there have been six drought events since 1896. Previous occurrences of drought are described as follows:

- **1975 to 1977:** California experienced the two driest years (1976 and 1977) in the State's history in 1976 and 1977. The drought was declared an Emergency (FEMA-EM-3023) on January 20, 1977. Total crop damages statewide totaled $2.67 billion dollars for both years ($888.5 million in 1976 and $1.8 billion in 1977).

- **2006 to 2009:** A California State-declared three-year drought of below-average rainfall, low snowmelt runoff, and the largest court-ordered water restricting in state's history. The dry conditions damaged crops, deteriorated water quality, and caused extreme wildfire danger. Approximately $300 million in agricultural revenue loss, and a potential $3 billion in economic losses over time.

- **2012 to 2016:** San Bernardino County first declared a local drought emergency in 2014. As of May 23rd, 2016, San Bernardino County and the City of Rancho Cucamonga had both submitted local Emergency Proclamations. This ongoing drought is the most severe drought in over 100 years. In order to abide by the State Water Resources Control Board's mandatory water reductions, the San Bernardino Municipal Water Department Board of Water Commissioners authorized implementation of Stage IIA of the department's Water Supply Contingency Plan on June 1, 2015. The State Water Board will adjust emergency water conservation regulations through the end of January 2017, in recognition of the differing water supply conditions across the state, and develop proposed emergency water restrictions for 2017 if the drought persists.

Additional information about previous occurrences of droughts in California (in general) can be obtained from the California DWR.

4.6.3 Location/Geographic Extent

Drought can affect the County, region, and the State of California as a whole. The County's primary source of water is imported by the San Bernardino Valley Municipal Water District (http://www.sbvmwd.com/about-us/what-we-do) through participation in the State Water Project (SWP). It is received at the Devil Canyon Power Plant Afterbay. This supply is supplemented by groundwater basins in the County. Drought has no defined geographical boundaries and cannot be depicted in map form. As such, the entire County is subject to drought.

4.6.4 Magnitude/Severity

The magnitude of drought is usually measured in time and the severity of the hydrologic deficit. There are several resources available to evaluate drought status and estimate future expected conditions. The National Integrated Drought Information System (NIDIS) Act of 2006 (Public Law 109-430) prescribes an interagency approach for drought monitoring, forecasting, and early warning. The NIDIS maintains the U.S. Drought Portal (www.drought.gov) which is a web-based

access point to several drought related resources. Resources include the U.S. Drought Monitor (USDM) and the U.S. Seasonal Drought Outlook (USSDO).

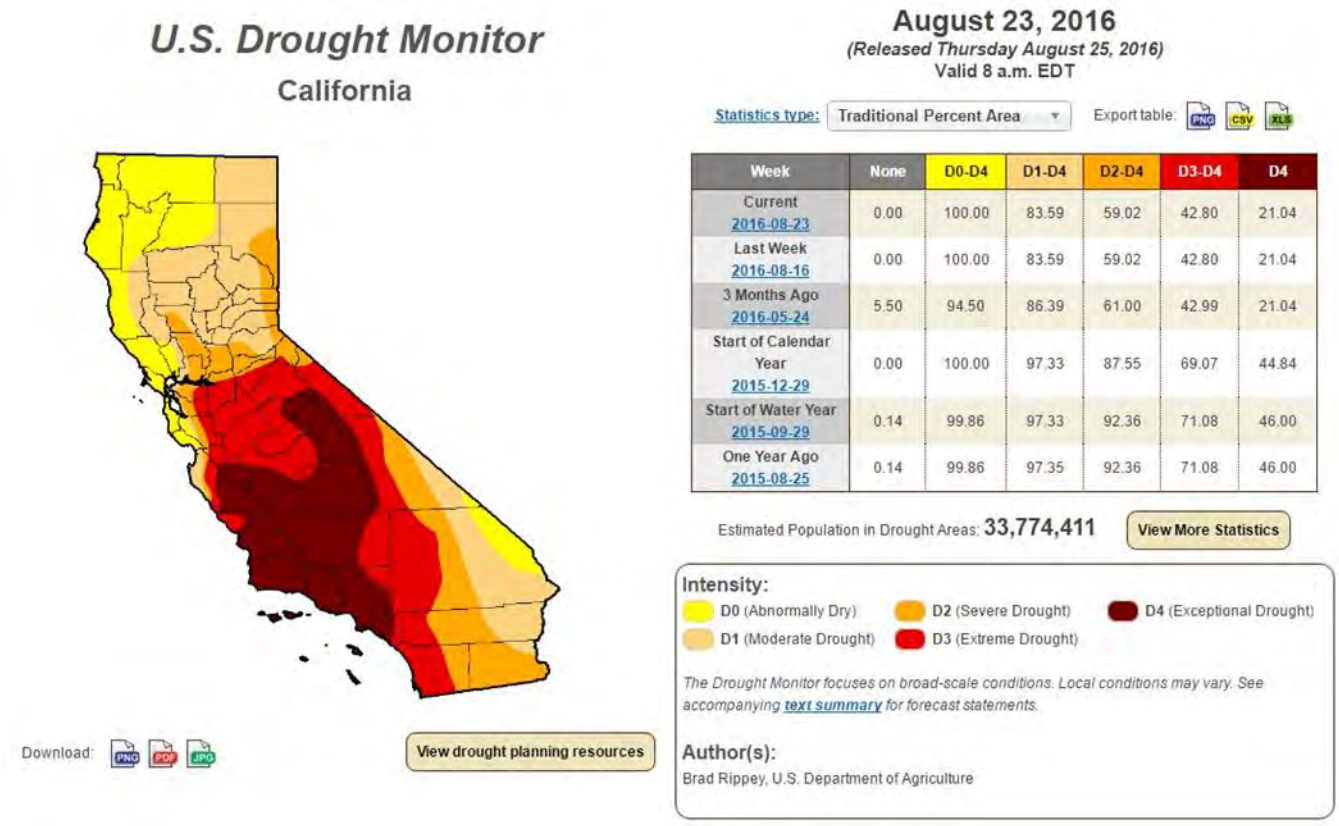


Figure 4-11: US Drought Monitor Map for the State of California on August 23, 2016

The USDM provides a summary of drought conditions across the United States and Puerto Rico and is developed and maintained by the National Drought Mitigation Center (www.drought.unl.edu). USDM includes the U.S. Drought Monitor Map. This map is updated weekly by combining a variety of drought database and indicators, and local expert input into a single composite drought indicator. The map denotes four levels of drought intensity (ranging from D1 - D4) and one level of "abnormal dryness" (D0). In addition, the map depicts areas experiencing agricultural (A) or hydrological (H) drought impacts. These impact indicators help communicate whether short or long-term precipitation deficits are occurring. An example Drought Monitor Map for the State of California for August 23, 2016 is illustrated in Figure 4-11.

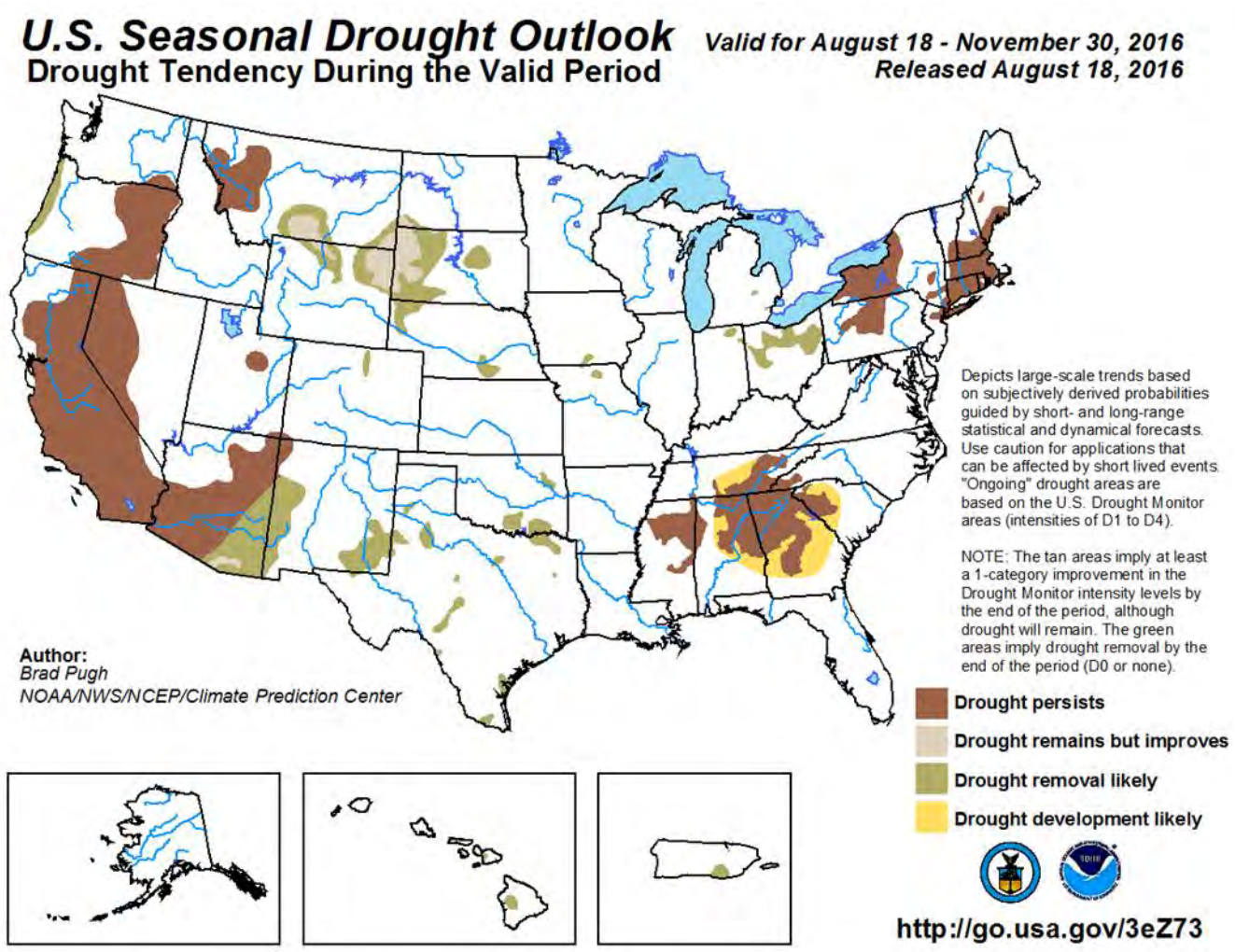


Figure 4-12: USSDO Drought Tendency Map (Valid August 18-November 30, 2016

For western States with mountainous terrain and complex regional microclimates, it is also useful to supplement the PDSI values with other indices such as Surface Water Supply Index and Standardized Precipitation Index (SPI). The Surface Water Supply Index takes snowpack and other unique conditions into account. The National Drought Mitigation Center (NDMC) uses the SPI to identify emerging drought months sooner than the PDSI. It is computed on various time scales to monitor moisture supply conditions. The SPI is the number of standard deviations that precipitation value would deviate from the long-term mean. As shown in Figure 4-13 the 72-month SPI through the end of August 2016 for San Bernardino County is low.

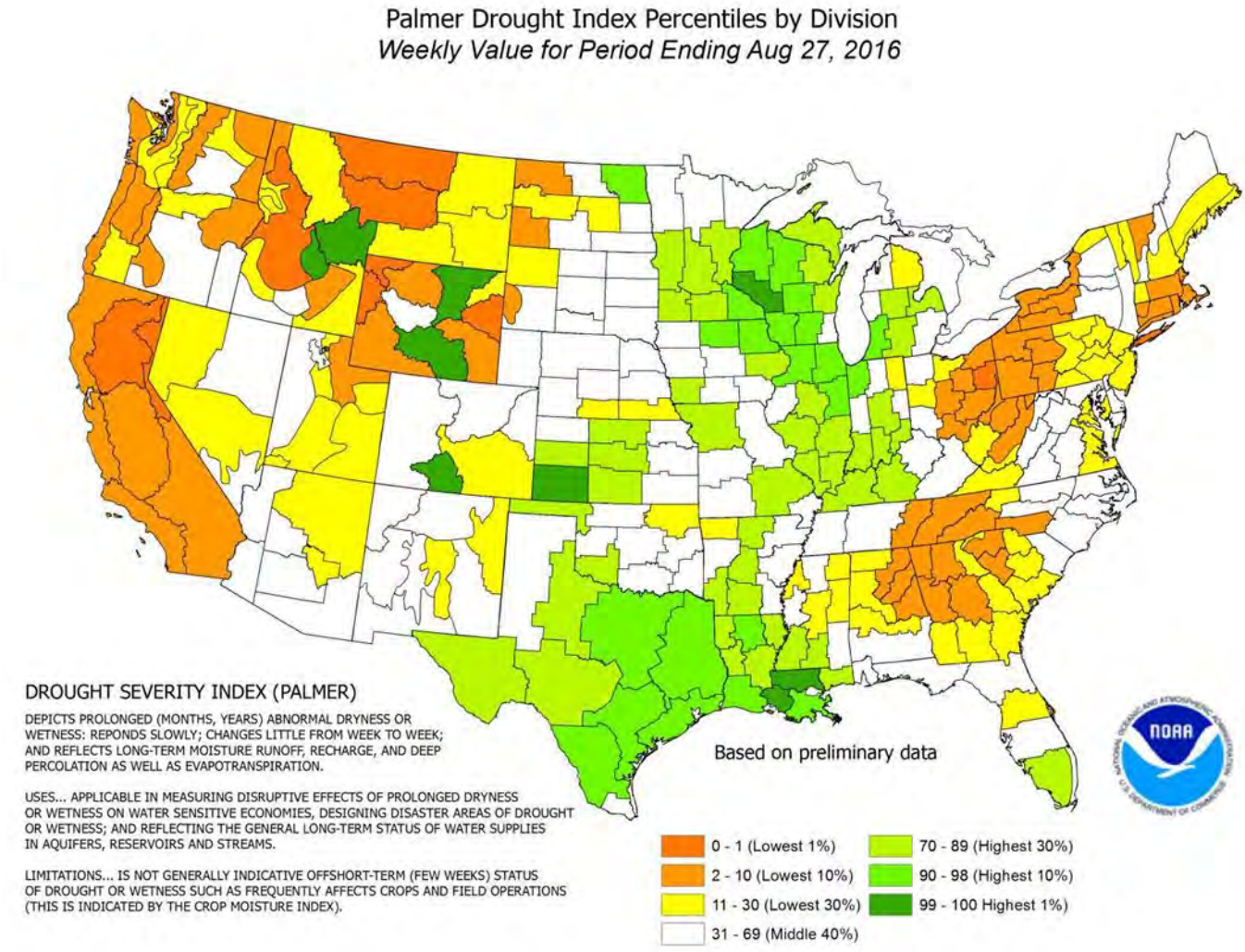


Figure 4-13: Month SPI through the end of August 2016 for San Bernardino County

A number of indices measure how much precipitation for a given period has deviated from historically established norms. The primary indicator for the USDM and USSDO for the western United States is the Palmer Drought Severity Index (PDSI). The PDSI is widely used by the USDA to determine when to grant emergency drought assistance to affected areas. PDSI is a commonly used index that measures the severity of drought for agriculture and water resource management. It is calculated from observed temperature and precipitation values and estimates soil moisture. However, the PDSI is not considered consistent enough to characterize the risk of drought on a nationwide basis (FEMA, 1997) and is not well suited to the dry, mountainous areas in the western U.S.

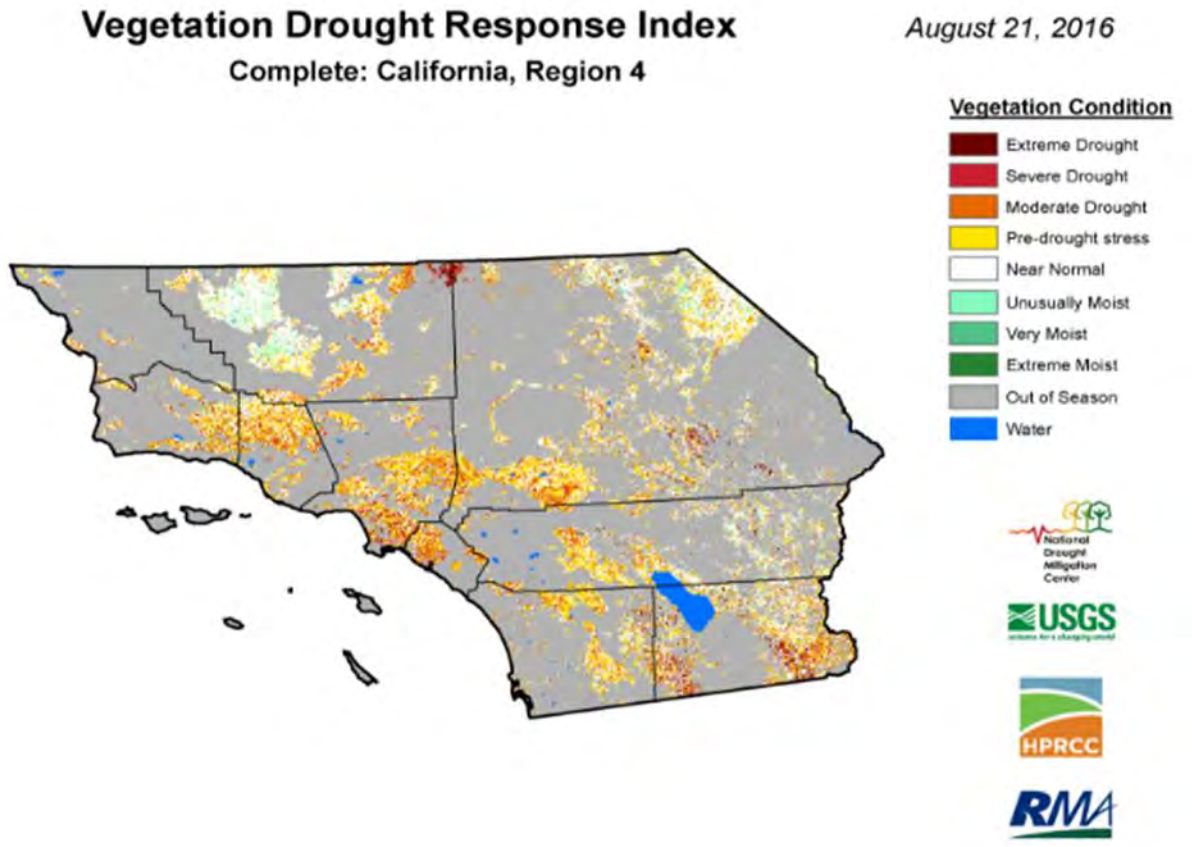


Figure 4-14: Vegetation Drought Response Index – California Region 4 for August 21, 2016

The Vegetation Drought Response Index, or VegDRI, is a bi-weekly depiction of vegetation stress across the contiguous United States. VegDRI is a fine resolution (1-km^2) index based on remote sensing data, and incorporates climate and biophysical data to determine the cause of vegetation stress. Development of the VegDRI map and associated products is a joint effort by the National Drought Mitigation Center (NDMC), the U.S. Geological Survey's (USGS) National Center for Earth Resources Observation and Science (EROS), and the High Plains Regional Climate Center (HPRCC). Figure 4-14 illustrates the VegDRI results for Southern California for August 21, 2016.

4.6.5 Frequency/Probability of Future Occurrences

Currently there is no data on the probability of drought that would be comparable to the USGS effort on earthquakes in the region, or how 100-year flood maps are created.

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4.7 Terrorism



This section was added due to the December 2, 2015 terror attack in San Bernardino County. There is no single, universally accepted definition of terrorism; however, FEMA defines "terrorism" as intentional, criminal, malicious acts. FEMA document 386-7 refers to terrorism specifically as the use of Weapons of Mass Destruction (WMD), including biological, chemical, nuclear, and radiological weapons; arson, incendiary, explosive, and armed attacks; industrial sabotage and intentional hazardous materials releases; and "cyberterrorism."

FEMA developed the Integrated Emergency Management System (IEMS) using an all-hazards approach. While the IEMS was established as an "all-hazard" approach, responding to the threat of terrorism (referred to as counterterrorism) came to be viewed as the responsibility of law enforcement, defense, and intelligence agencies. Furthermore, defensive efforts to protect people and facilities from terrorism (referred to as antiterrorism) were generally limited to the government sector, the military, and some industrial interests.

While the term "mitigation" refers generally to activities that reduce loss of life and property by eliminating or reducing the effects of disasters, in the terrorism context it is often interpreted to include a wide variety of preparedness and response actions. For the purposes of this document, the traditional meaning will be assumed; that mitigation refers to specific actions that can be taken to reduce loss of life and property from manmade hazards by "modifying the built environment" or antiterrorism to reduce the risk and potential consequences of these hazards.

4.7.1 Antiterrorism Regulatory Environment

Adopted on February 9, 2012 and updated on October 1, 2013, United Facilities Criteria (UFC) 4-010-01 defines the United States Department of Defense's (DoD) minimum antiterrorism standards for both new and existing buildings. The document applies to DoD buildings, National Guard buildings, visitor centers and museums, visitor control facilities and expeditionary structures. Historic preservation compliance for implementation of anti-terrorism standards, philosophy, design strategies and assumptions are all taken into account. Site planning, structural design, architectural design, and electrical and mechanical design are discussed in detail in Appendix B.
https://www.fema.gov/news-release/2004/01/13/dhs-announces-new-building-science-guidelines-enhance-terrorism-resistance

4.7.2 Counterterrorism Regulatory Environment

After the 12/2/15 mass shooting, two full time positions with a regional FBI-led terrorist task force (FBI's Joint Terrorism Task Force) were created. These task force officers have the clearance to conduct terrorism investigations in the County. The Task Force includes partners from Homeland Security Investigations (HSI), the San Bernardino Police Department, the San Bernardino County Sheriff's Department, the Riverside County Sheriff's Department, the Ontario Police Department, the Riverside Police Department, the Corona Police Department and the Chino Police Department. For more information regarding the positions, contact the San Bernardino Police Department at (909) 384-5742. Read more here: http://www.pe.com/articles/task-789539-force-san.html

The State of California Department of Justice's Anti-terrorism program works with federal, state and local law enforcement agencies to detect, investigate, prosecute, dismantle, prevent and respond to domestic and international terrorist activities. Read more here: https://oag.ca.gov/bi/atp

The State of California Bureau of Security and Investigative Services' Power to Arrest Course includes a Weapons of Mass Destruction (WMD) & Terrorism Awareness section. Read More Here: http://www.bsis.ca.gov/about_us/laws/bsis_regulations.pdf

4.7.3 Past Occurrences

There have been two terrorist attacks recorded in San Bernardino County. Table 4-10 describes both attacks.
Source: https://www.start.umd.edu/gtd/search/Results.aspx?search=san+bernardino&sa.x=0&sa.y=0&sa=Search

Table 4-10: Terrorist Attacks in San Bernardino County

Date	Perpetrator Group	Fatalities	Injured	Target Type
3/16/1970	White Extremists	0	1	Government (General)
12/2/2015	Unaffiliated Individuals	16	17	Government (General)

The state of California has experienced 574 terrorist attacks from 1970-2011 (Integrated United States Security Database (IUSSD): Data on the Terrorist Attacks in the United States Homeland, 1970-2011 2012). Figure 4-17 shows the types of terrorist attacks in the state of California from 1970 to the present.

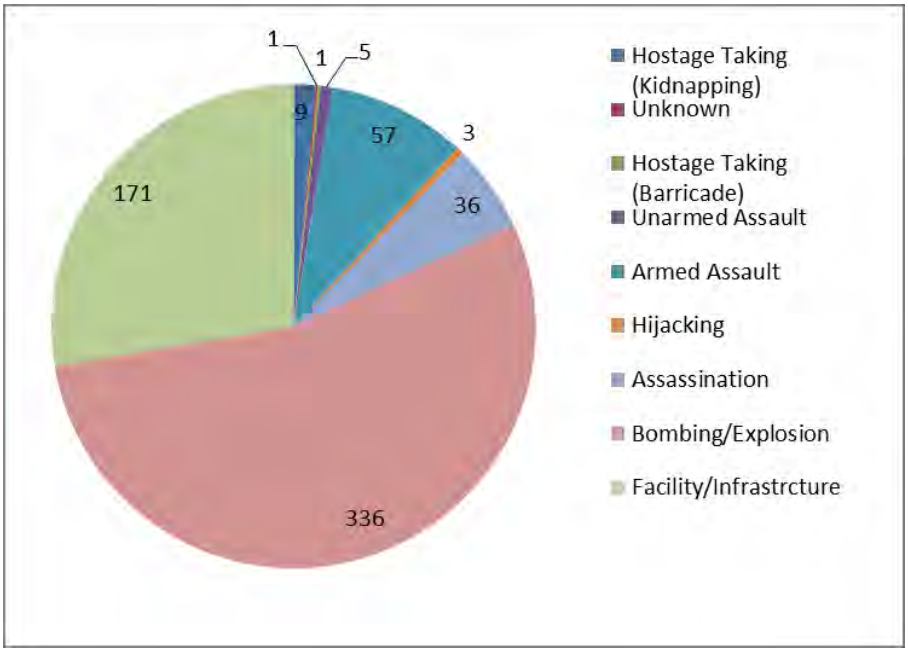
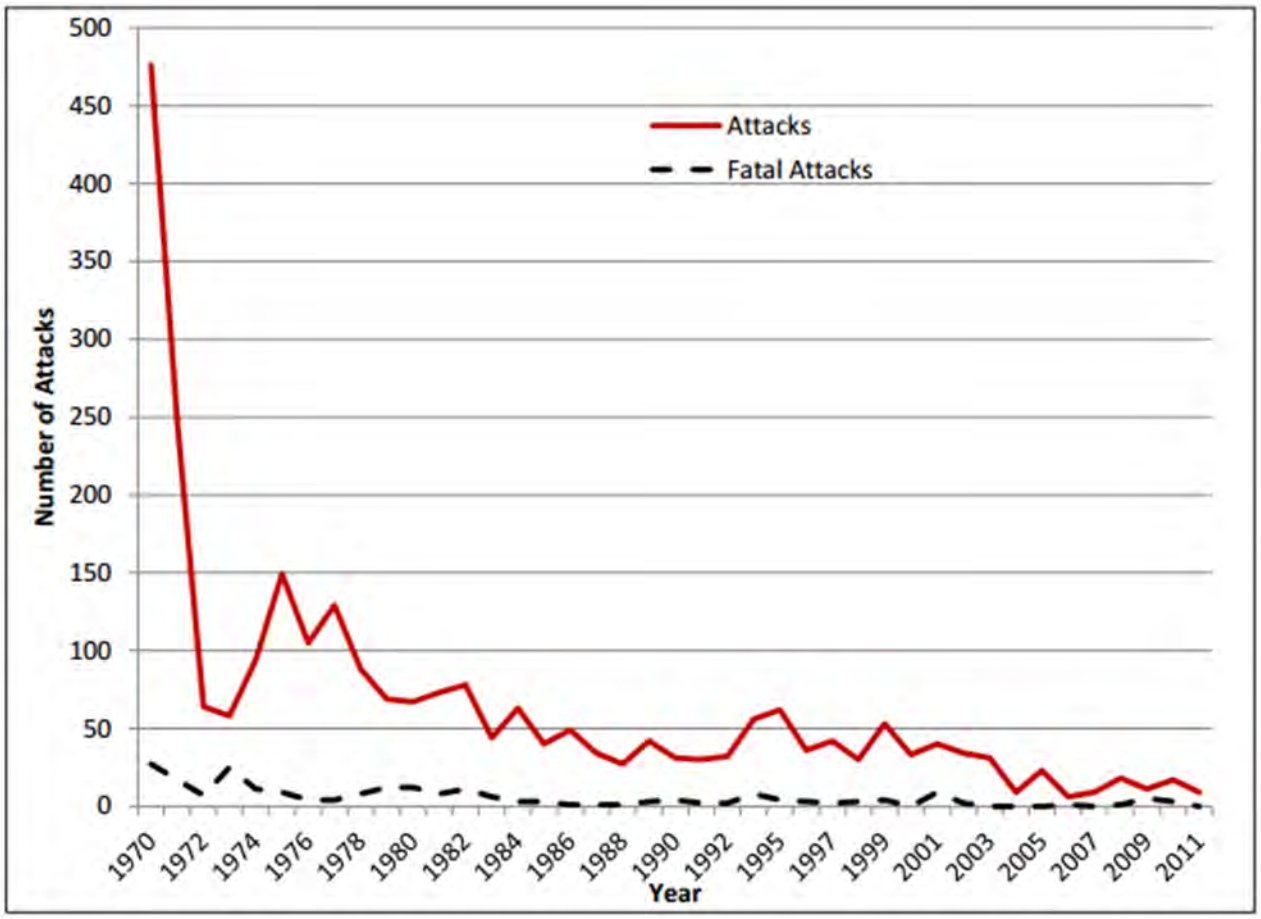


Figure 4-15: Types of Terrorist Attacks in California from 1970-Present

As seen in Figure 4-15 since 1970, the number of terrorist attacks in the United States has steadily decreased. According to http://www.heritage.org most terrorist attacks on America happen outside our nation's borders. The number of international terrorist attacks against the United States from 1970-2011 is shown in Figure 4-16 and Figure 4-17.



Note: There were 2,608 total attacks and 226 fatal attacks between 1970 and 2011.

Figure 4-16: Total and Fatal Terrorist Attacks in the United States by Year

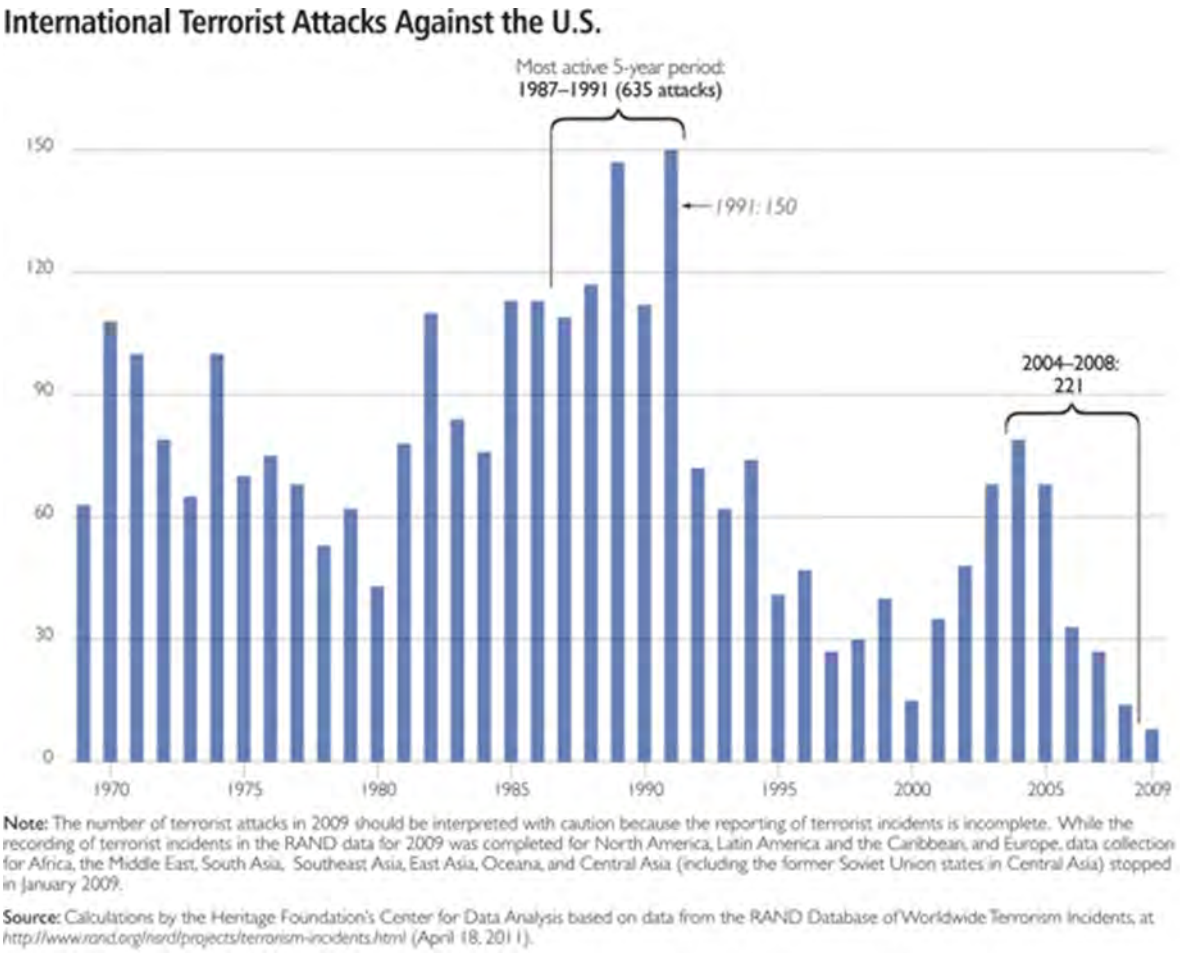


Figure 4-17: International Terrorist Attacks Against the United States

4.7.4 Location/Geographic Extent

Unlike natural hazards, which often follow patterns and can be forecasted, manmade hazards such as acts of terrorism are much more unpredictable. Terrorists have the ability to choose targets and tactics and can often adjust conditions to achieve their objective. Terrorist attacks are often in a more specific location rather than a widespread, more predictable area such as a flood plain. As demonstrated in the 12/2/15 mass shooting, “homegrown terrorists” (self-radicalizing and pulls off their attacks without any help or communication with people in other countries) are even harder to detect and predict.

Translating most manmade hazard profiles into meaningful geospatial information is difficult at best. Instead, the planning team will use an asset-specific approach, identifying potentially at-risk critical facilities and systems in the community. Once a comprehensive list of assets has been developed, it will be prioritized so that the community’s efforts can be directed to protect the most

important assets first. Then, beginning with the highest priority assets, the vulnerabilities of each facility or system to each type of hazard will be assessed (FEMA 2003).

4.7.5 Magnitude/Severity

As previously discussed, predicting terrorist attacks cannot be done with the same level of accuracy as predicting a natural hazard and its potential impacts on the community. However, we can learn from past terrorist incidents. Table 4-11 profiles 10 different types of terrorist attacks and technological hazards.

Table 4-11: Event Profiles for Terrorism and Technological Hazards

Hazard	Application Mode	Hazard Duration	Extent of Effects; Static/Dynamic	Mitigating and Exacerbating Conditions
Conventional Bomb/ Improvised Explosive Device	Detonation of explosive device on or near target; delivery via person, vehicle, or projectile.	Instantaneous; additional "secondary devices" may be used, lengthening the time duration of the hazard until the attack site is determined to be clear	Extent of damage is determined by type and quantity of explosive. Effects generally static other than cascading consequences, incremental structural failure, etc.	Overpressure at a given standoff is inversely proportional to the cube of the distance from the blast; thus, each additional increment of standoff provides progressively more protection. Terrain, forestation, structures, etc. can provide shielding by absorbing and/or deflecting energy and debris. Exacerbating conditions include ease of access to target; lack of barriers/shielding; poor construction; and ease of concealment of device
Chemical Agent *	Liquid/aerosol contaminants can be dispersed using sprayers or other aerosol generators; liquids vaporizing from puddles/ containers; or munitions.	Chemical agents may pose viable threats for hours to weeks depending on the agent and the conditions in which it exists.	Contamination can be carried out of the initial target area by persons, vehicles, water and wind. Chemicals may be corrosive or otherwise damaging over time if not remediated.	Air temperature can affect evaporation of aerosols. Ground temperature affects evaporation of liquids. Humidity can enlarge aerosol particles, reducing inhalation hazard. Precipitation can dilute and disperse agents but

Hazard	Application Mode	Hazard Duration	Extent of Effects; Static/Dynamic	Mitigating and Exacerbating Conditions
				can spread contamination. Wind can disperse vapors but also cause target area to be dynamic. The micro-meteorological effects of buildings and terrain can alter travel and duration of agents. Shielding in the form of sheltering in place can protect people and property from harmful effects.
Arson/ Incendiary Attack	Initiation of fire or explosion on or near target via direct contact or remotely via projectile.	Generally minutes to hours.	Extent of damage is determined by type and quantity of device/ accelerant and materials present at or near target. Effects generally static other than cascading consequences, incremental structural failure, etc.	Mitigation factors include built-in fire detection and protection systems and fire-resistive construction techniques. Inadequate security can allow easy access to target, easy concealment of an incendiary device and undetected initiation of a fire. Non-compliance with fire and building codes as well as failure to maintain existing fire protection systems can substantially increase the effectiveness of a fire weapon.
Armed Attack	Tactical assault or sniping from remote location.	Generally minutes to days.	Varies based upon the perpetrators' intent and capabilities	Inadequate security can allow easy access to target, easy concealment of weapons and undetected initiation of an attack.
Biological Agent *	Liquid or solid contaminants can be dispersed using sprayers/aerosol generators or by point or line	Biological agents may pose viable threats for hours to years depending on the agent and the	Depending on the agent used and the effectiveness with which it is deployed, contamination can	Altitude of release above ground can affect dispersion; sunlight is destructive to many bacteria and viruses; light to

Hazard	Application Mode	Hazard Duration	Extent of Effects; Static/Dynamic	Mitigating and Exacerbating Conditions
	sources such as munitions, covert deposits and moving sprayers.	conditions in which it exists	be spread via wind and water. Infection can be spread via human or animal vectors.	moderate wind will disperse agents but higher winds can break up aerosol clouds; the micro-meteorological effects of building and terrain can influence aerosolization and travel of agents.
Cyberterrorism	Electronic attack using one computer system against another.	Minutes to days	Generally no direct effects on built environment.	Inadequate security can facilitate access to critical computer systems, allowing them to be used to conduct attacks.
Agriterrorism	Direct, generally covert contamination of food supplies or introduction of pests and/or disease agents to crops and livestock.	Days to months	Varies by type of incident. Food contamination events may be limited to discrete distribution sites, whereas pests and diseases may spread widely. Generally no effects on built environment.	Inadequate security can facilitate adulteration of food and introduction of pests and disease agents to crops and livestock.
Radiological Agent **	Radioactive contaminants can be dispersed using sprayers/aerosol generators, or by point or line sources such as munitions, covert deposits and moving sprayers.	Contaminants may remain hazardous for seconds to years depending on material used.	Initial effects will be localized to site of attack; depending on meteorological conditions, subsequent behavior of radioactive contaminants may be dynamic.	Duration of exposure, distance from source of radiation, and the amount of shielding between source and target determine exposure to radiation.
Nuclear Bomb **	Detonation of nuclear device underground, at the surface, in the air or at high altitude.	Light/heat flash and blast/shock wave last for seconds; nuclear radiation and fallout hazards can persist for years. Electromagnetic pulse from a high altitude detonation lasts for seconds and affects only	Initial light, heat and blast effects of a subsurface, ground or air burst are static and are determined by the device's characteristics and employment; fallout of radioactive contaminants may	Harmful effects of radiation can be reduced by minimizing the time of exposure. Light, heat and blast energy decrease logarithmically as a function of distance from seat of blast. Terrain, forestation, structures, etc. can provide shielding by

Hazard	Application Mode	Hazard Duration	Extent of Effects; Static/Dynamic	Mitigating and Exacerbating Conditions
		unprotected electronic systems.	be dynamic, depending on meteorological conditions.	absorbing and/or deflecting radiation and radioactive contaminants.
Hazardous Material Release (fixed facility or transportation)	Solid, liquid and/or gaseous contaminants may be released from fixed or mobile containers.	Hours to days	Chemicals may be corrosive or otherwise damaging over time. Explosion and/or fire may be subsequent. Contamination may be carried out of the incident area by persons, vehicles, water and wind.	As with chemical weapons, weather conditions will directly affect how the hazard develops. The micro-meteorological effects of building and terrain can alter travel and duration of agents. Shielding in the form of sheltering in place can protect people and property from harmful effects. Non-compliance with fire and building codes as well as failure to maintain existing fire protection and containment features can substantially increase the damage from a hazardous materials release.

* Source: Jane's Chem-Bio Handbook
** Source: FEMA, Radiological Emergency Management Independent Study Course

4.7.6 Frequency/Probability of Future Occurrences

We can usually forecast the type, frequency and location of a natural hazard thanks to the laws of physics and nature. However, when dealing with manmade hazards such as terrorism, we are often dealing with functions of the human mind-malevolence, incompetence, carelessness and other behaviors. These actions cannot be predicted with any accuracy; therefore, there is the potential for an act of terrorism to occur anywhere, at any time.

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4.8 Climate Change



Climate change refers to any distinct change in measures of climate lasting for a long period of time, more specifically major changes in temperature, rainfall, snow, or wind patterns. Climate change may be limited to a specific region, or may occur across the whole Earth. Climate change may result from:

- Natural factors (e.g., changes in the Sun's energy or slow changes in the Earth's orbit around the Sun);
- Natural processes within the climate system (e.g., changes in ocean circulation); and
- Human activities that change the atmosphere's make-up (e.g., burning fossil fuels) and the land surface (e.g., cutting down forests, planting trees, building developments in cities and suburbs, etc.).

The effects of climate change are varied: warmer and more varied weather patterns, melting ice caps, and poor air quality, for example. As a result, climate change impacts a number of natural hazards.

The 2013 State of California Multi-Hazard Mitigation Plan stated that climate change is already affecting California. Sea levels have risen by as much as seven inches along the California coast over the last century, increasing erosion and pressure on the state's infrastructure, water supplies, and natural resources. The State has also seen increased average temperatures, more extreme hot days, fewer cold nights, a lengthening of the growing season, shifts in the water cycle with less winter precipitation falling as snow, and both snowmelt and rainwater running off sooner in the year. In addition to changes in average temperatures, sea level, and precipitation patterns, the intensity of extreme weather events is also changing.

4.8.1 Regulatory Environment

California's response to climate change is directed by Legislation and Regulations and by other Mandates such as executive orders.

4.8.1.1 The Sustainable Communities and Climate Protection Act of 2008

The Sustainable Communities and Climate Protection Act of 2008 (Sustainable Communities Act, SB 375, Chapter 728, Statutes of 2008) looks to reduce GHG emissions through coordinated transportation and land use planning with the goal of more sustainable communities. Regional targets are established for GHG emissions reductions from passenger vehicle use by the sustainable communities strategy (SCS) established by each metropolitan planning organization (MPO). The SCS is an integral part of the regional transportation plan (RTP) and contains land use, housing, and transportation strategies to meet GHG reductions targets. In San Bernardino County, the South Coast Air Quality Management District facilitates compliance with the federal Clean Air Act and implements the state's air quality program.

The Office of Planning and Research's General Plan Guidelines and SB 375 builds upon Assembly Bill 162 (flood protection) and Senate Bill 1241 (fire protection) and supports Safeguarding California implementation.

SB 375 also supports Assembly Bill 2140 which requires that a City/County General Plan contains a safety element in addition to a Hazard Mitigation Plan. AB 2140 also requires a vulnerability assessment, adaptation goals, policies and objectives, and a set of feasible implementation measures.

4.8.1.2 California Adaptation Planning Guide (APG)

The State of California has been taking action to address climate change for over 20 years, focusing on both greenhouse gas emissions reduction and adaptation. The California Adaptation Planning Guide (APG) continues the state's effort by providing guidance and support for communities addressing the unavoidable consequences of climate change.

Based on upon specific factors, 11 Climate impact regions were identified. Some of the regions were based on specific factors particularly relevant to the region. As illustrated in Figure 4-18 San Bernardino County is located in the Desert Region.

The Desert is a heavily urbanized inland region (4.3+ million people) made up of sprawling suburban development in the west near the South Coast region and vast stretches of open, largely federally owned desert land to the east. Prominent cities within the desert portion include Palm Springs (44,500+) and El Centro (42,500+). The region's character is defined largely by the San Gabriel Mountains, San Gorgonio Mountains, San Jacinto Mountains, and smaller inland mountains reaching through the desert to the Colorado River, which borders the region on the east. Communities in the Desert region should consider evaluating the following climate change impacts:

- Reduced water supply
- Increased temperature
- Reduced precipitation
- Diminished snowpack
- Wildfire risk
- Public health and social vulnerability
- Stress on special-status species

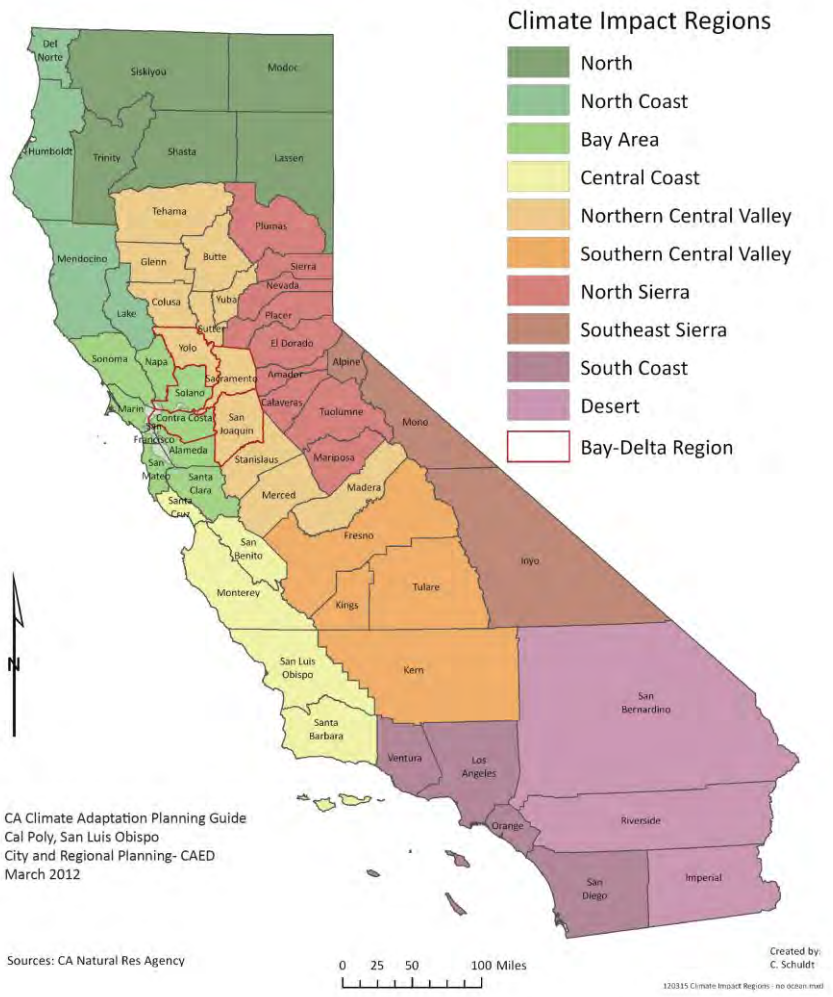


Figure 4-18: Climate Impact Regions

4.8.2 Past Occurrences

Climate change has never been directly responsible for any declared disasters. Past flooding, wildfire, levee failure, and drought disasters may have been exacerbated by climate change, but it is impossible to make direct connections to individual disasters. In addition, unlike earthquake and floods that occur over a finite time period, climate change is an on-going hazard the effects of which some are already experiencing. Other effects may not be seriously experienced for decades, or may be avoided altogether by mitigation actions taken today.

4.8.3 Location/Geographic Extent

The effects of climate change are not limited by geographical borders. San Bernardino County, the State of California, the United States, and the rest of the world are all at risk to climate change. As such, the entire County is at risk to the effects of climate change.

Figure 4-19 and Figure 4-20 provide Cal Adapt[2] modeled decadal July high temperature averages for 2010 and 2090. These figures provide current decade-long July temperature averages and possible annual high heating trends for the remaining portion of the century. The data presented in the figures represent a "projection" of potential future climate scenarios, they are not predictions. These figures illustrate how the climate may change based on a variety of different potential social and economic factors. The visualizations are comprised of average values from Coupled Climate model 2.1 (GFDL), Community Climate System Model Version 3 (CCSM3), Coupled Global Climate Model Version 3 (CNRM) and Parallel Climate Model 1 (PCM1). During the next few decades, scenarios project average temperature to rise between 1° and 2.3°F; however, the projected temperature increases begin to diverge at mid-century so that, by the end of the century, the temperature increases projected in the higher emissions scenario (A2) are approximately twice as high as those projected in the lower emissions scenario (B1). Customizable maps can be viewed at http://cal-adapt.org/temperature/decadal/

[2] Cal-Adapt has been funded to provide access to data and information that has been produced by the State's scientific and research community. The data available in this site offer a view of how climate change might affect California at the local level.

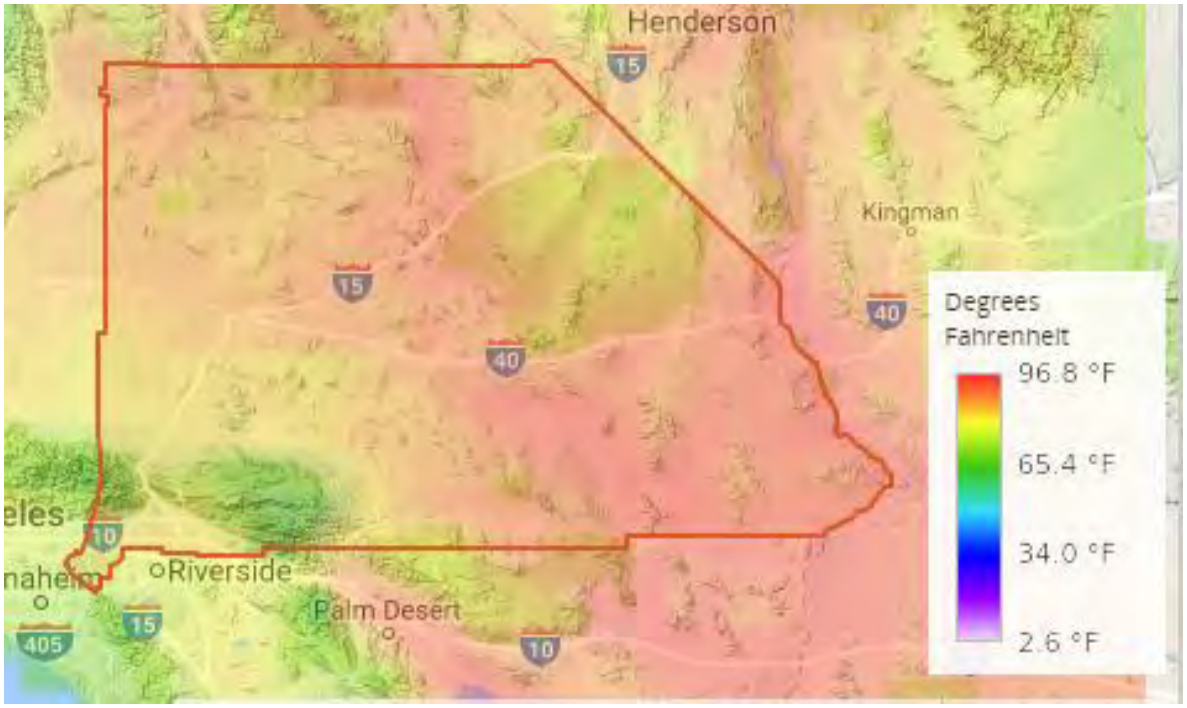


Figure 4-19: July Decadal Average High Temperature Map; 2010

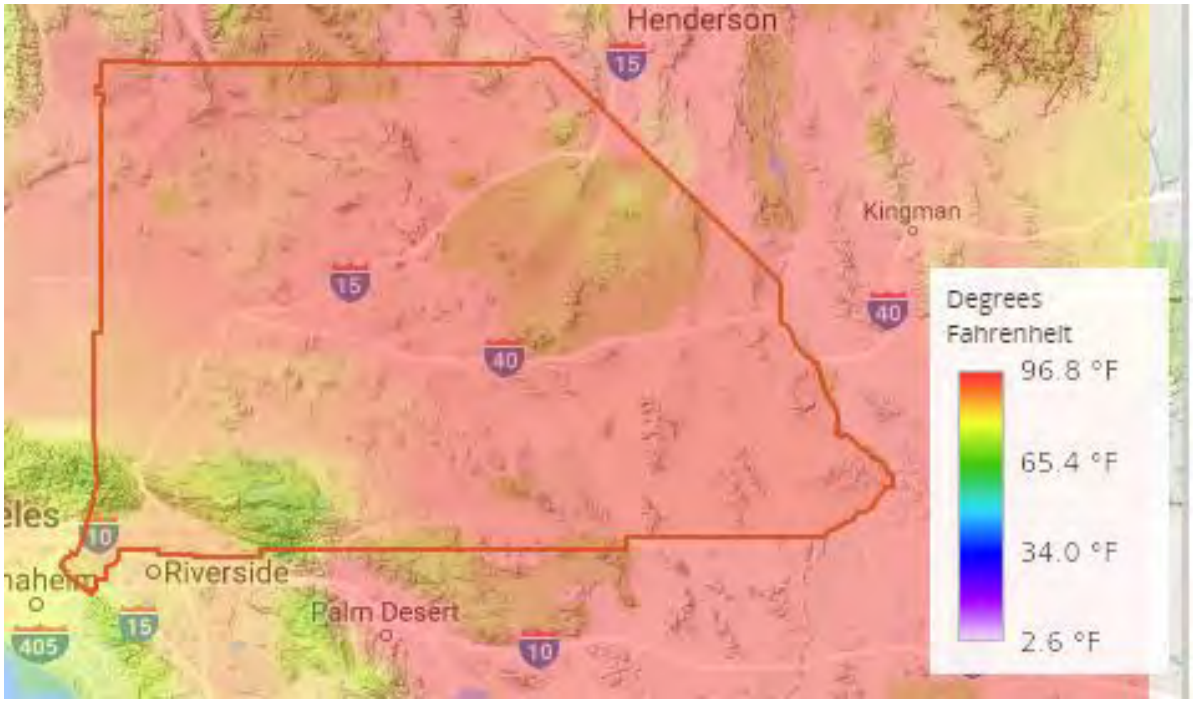


Figure 4-20: July Decadal Average High Temperature Map; 2090

4.8.4 Magnitude/Severity

The California Climate Adaptation Strategy (CAS), citing a California Energy Commission study, states that "over the past 15 years, heat waves have claimed more lives in California than all other declared disaster events combined." This study shows that California is getting warmer, leading to an increased frequency, magnitude, and duration of heat waves. These factors may lead to increased mortality from excessive heat, as shown in Figure 4-21: California Historical and Projected Temperature Increases 1961 to 2099

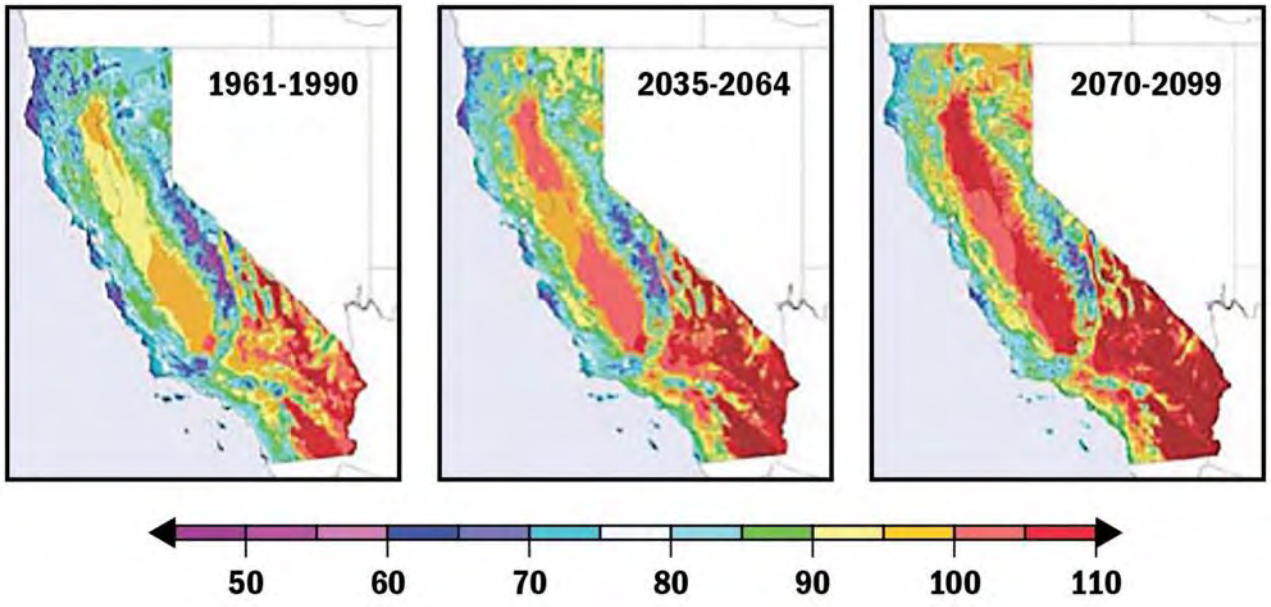


Figure 4-21: California Historical and Projected Temperature increases 1961-2099

Source: Dan Cayan; California Climate Adaptation Strategy

4.8.5 Frequency/Probability of Future Occurrences

According to the ABAG 2010 Local Hazard Mitigation Plan (LHMP), climate change is one of the few natural hazards where the probability of occurrence is influenced by human action. In addition, unlike earthquake and floods that occur over a finite time period, climate change is an on-going hazard.

The 2009 Climate Adaptation Strategy (CAS) delineated how climate change may impact and exacerbate natural hazards in the future, including wildfires, extreme heat, floods, drought, and levee failure:

Climate change is expected to lead to increases in the frequency, intensity, and duration of extreme heat events and heat waves in San Bernardino County and the rest of California, which

are likely to increase the risk of mortality and morbidity due to heat-related illness and exacerbation of existing chronic health conditions. Those most at risk and vulnerable to climate-related illness are the elderly, individuals with chronic conditions such as heart and lung disease, diabetes, and mental illnesses, infants, the socially or economically disadvantaged, and those who work outdoors.

- Higher temperatures will melt the Sierra snowpack earlier and drive the snowline higher, resulting in less snowpack to supply water to California users.
- Droughts are likely to become more frequent and persistent in the 21st century.
- Intense rainfall events, periodically ones with larger than historical runoff, will continue to affect California with more frequent and/or more extensive flooding.
- Storms and snowmelt may coincide and produce higher winter runoff from the landward side, while accelerating sea-level rise will produce higher storm surges during coastal storms. Together, these changes will increase the probability of levee and dam failures in the Sacramento-San Joaquin Delta.
- Warmer weather, reduced snowpack, and earlier snowmelt can be expected to increase wildfire through fuel hazards and ignition risks. These changes can also increase plant moisture stress and insect populations, both of which affect forest health and reduce forest resilience to wildfires. An increase in wildfire intensity and extent will increase public safety risks, property damage, fire suppression and emergency response costs to government, watershed and water quality impacts, vegetation conversions and habitat fragmentation.

4.8.6 El Niño Effect

El Niño is defined as an abnormal weather pattern that is caused by the warming of the Pacific Ocean near the equator, off the coast of South America. This occurs when the normal trade winds weaken (or even reverse), which lets the warm water that is usually found in the western Pacific flow instead towards the east. This warm water displaces the cooler water that is normally found near the surface of the eastern Pacific, setting off atmospheric changes that affect weather patterns in many parts of the world.

As a result of the predicted El Niño in 2015 the following meetings were held during the months of January – December 2015:

El Niño Awareness Program

- **January - December 2015**

- **October 28, 2015** (Two meetings) two separate meetings one with the Public with 200 High Desert residents attending, the other meeting was at the same location of the Victor Ville City Council Chambers of 80 operators

- **November 9, 2015** South Desert Meeting at the Town of Yucca Valley Community Center, with 50 Operators and 235 general public ,residents

- **November 12, 2015** 2:30pm-4:30pm Valley Cooperators Meeting, City of Rancho Cucamonga, Victoria Gardens, 90 Operators and 2nd Meeting at the same location held at 530pm-730pm meeting with 205 public and residents

- **November 16, 2015** Public Meeting at Upland city Hal l for San Antonio heights, Mt. Baldy and local residents 110 Public and Residents in attendance .

- **November 23, 2015** Wrightwood Community Center, 80 Operators and 330 Public and Residents

- **November 24, 2015** City of Yucaipa 40 operators at Yucaipa City Hall

- **December, 2015** 5000 English pamphlets and 5000 Spanish pamphlets distributed Winter Weather Workshop meetings (discuss long term weather models and predictions as far as estimated rain fall anticipated. and Extreme Heat Program meetings (stakeholder and Red Cross and SCE and other responders/operators meetings on anticipated overly hot days and local assistance plans. program in place by OES.

4.8.7 Extreme Weather

The Extreme Weather – Excessive Heat Standard Operating Guidelines (SOG) were developed in response to the potential for Excessive Heat and heat related Power Outage events in San Bernardino County. The following objectives and activities have been established to prevent the harmful effects of excessive heat on at-risk populations and the potential for life-threatening repercussions of power outages during excessive heat events.

The Extreme Weather – Excessive Heat SOG describe the County operations during heat related emergencies and provide guidance for local jurisdictions in their preparation for heat emergencies and other related activities.

The information included in this document is “situation” and/or “incident” driven and subject to revision by the Extreme Weather Committee as conditions warrant. Notifications are information dependent and modification of the activities in these guidelines may be required in response to changing conditions, situations and/or inaccurate weather predictions.
The Extreme Weather – Excessive Heat Standard Operating Guidelines (SOG) were developed through the collaborative efforts of the “Extreme Weather Committee”. The committee consists of

representatives from key County Departments and private sector partners who have a shared interest, responsibility and/or expertise in the County's preparation for an Excessive Heat event. It is designed to protect all of the County's population especially the most vulnerable populations.

For the last ten years the annual Winter Weather Workshop and Meeting brings together San Bernardino County Fire Office of Emergency Services with The San Bernardino County Special Districts key stakeholders and first responders as well as weather experts. The annual meeting is an accumulation of meetings with NOAA and other Meteorological experts on the possible winter weather outlook and forecast including possible precipitation levels and wide ranging forecasts.

The meeting includes discussions on possible plans of actions and response to flooding emergencies and or snow or white out events and the other possibility of continuing long duration droughts.

4.9 Other Hazards

As mentioned earlier, lower priority hazards are addressed at a lesser level of detail due to their relatively fewer impacts, as identified in the preceding hazard assessment section. The lower priority hazards for the unincorporated area are:

- Severe Thunderstorm
- Infestation
- Drought
- High Winds/Straight Line Winds
- Lightning
- Extreme Heat
- Hail
- Tornado

Although not part of the MJHMP, the remaining hazards are a part of the San Bernardino County 2007 General Plan and are addressed in the County Building Codes and Ordinance.

The information in this section provides an explicit representation of what a community stands to lose in a disaster. This is useful for county officials and other decision makers who will need to balance the costs of mitigation against the potential harm to citizens and damage to property. It provides comparable measurements of community natural hazard exposure and assists in determining which hazards and/or what parts of San Bernardino County to focus on making resilient to disaster first. Based upon possible assets at risk, hazard mitigation resources can be directed where need be, in-part, by a vulnerability assessment and information found in hazard profiles presented in Section 4.8.

4.10 Vulnerability Assessment

The information in this section provides an explicit representation of what a community stands to lose in a disaster. This is useful for county officials and other decision makers who will need to balance the costs of mitigation against the potential harm to citizens and damage to property. It provides comparable measurements of community natural hazard exposure[3] and assists in determining which hazards and/or what parts of San Bernardino County to focus on making resilient to disaster first. Based upon possible assets at risk, hazard mitigation resources can be directed where need be, in-part, by a vulnerability assessment and information found in hazard profiles presented in Section 4.2.

The vulnerability assessment is developed by providing the hazard mitigation analysts with quantitative and qualitative information for each hazard identified by the HMP Planning Team Through an exposure analysis, quantitative data is developed for each hazard. An exposure analysis provides quantities of people and assets at risk to particular hazards. Qualitative data has been developed and presented in this section for hazards without measurable data. Qualitative data provides information beyond quantities of people and assets at risk, but rather a description of how the hazard could affect a region like San Bernardino County.

Note: The hazard exposure analysis has been developed with best available data and follows methodology described in the FEMA publication Understanding Your Risks—Identifying Hazards and Estimating Losses.

Note: There are other intangible losses that could result from a natural hazard event, such as losses of historic or cultural integrity or damage to the environment that are difficult to quantify. Other costs, including response and recovery costs, are often unrecoverable and are not addressed in this document.

4.10.1 Methodology

A vulnerability assessment was conducted for each of the identified priority hazards. Geospatial data is essential in determining population and assets exposed to particular hazards. Geospatial analysis can be conducted if a natural hazard has a particular spatial footprint that can be overlaid against the locations of people and assets. In San Bernardino County, wildfire, flood, earthquake, and landslides have known geographic extents and corresponding spatial information about each hazard.

Several sources of data are necessary to conduct a vulnerability analysis. Figure 4-22provides an exhibit of the data inputs and outputs used to create the vulnerability analysis results presented in this section. U.S. Census data is the primary source in determining natural hazard exposure to residents. Census data has been used to determine the population at risk, which is generally referred to as population exposure. Population exposure is provided for wildfire, flooding, earthquakes and landslides as potential hazards later in this section.

[3] Elements at risk; Risk inventory; Exposure encompasses all elements, processes, and subjects that might be affected by a hazardous event. Consequently, exposure is the presence of social, economic, environmental or cultural assets in areas that may be impacted by a hazard.

Together with the U.S. Census data, asset data was used to provide a snapshot of how City assets are affected by natural hazards. For purposes of this vulnerability analysis, asset data includes parcels and critical infrastructure within the San Bernardino County boundaries. Critical infrastructure is described as assets that are essential for people and a community to function. Critical infrastructure includes such as utilities, San Bernardino County owned facilities, bridges, schools, and other community facilities that provide essential services to residents.

Critical facilities data was developed from a variety of sources including San Bernardino County owned and maintained data, state and federal government datasets, and private industry datasets. A critical infrastructure spatial database was developed to translate critical facilities information into georeferenced[4] points. Critical facility points are intersected with the spatial hazard layers to develop a list of "at risk" critical facilities. The San Bernardino County critical facilities that intersect with natural hazards are referred to as facilities with hazard "exposure". Exposure results are presented later in this section.

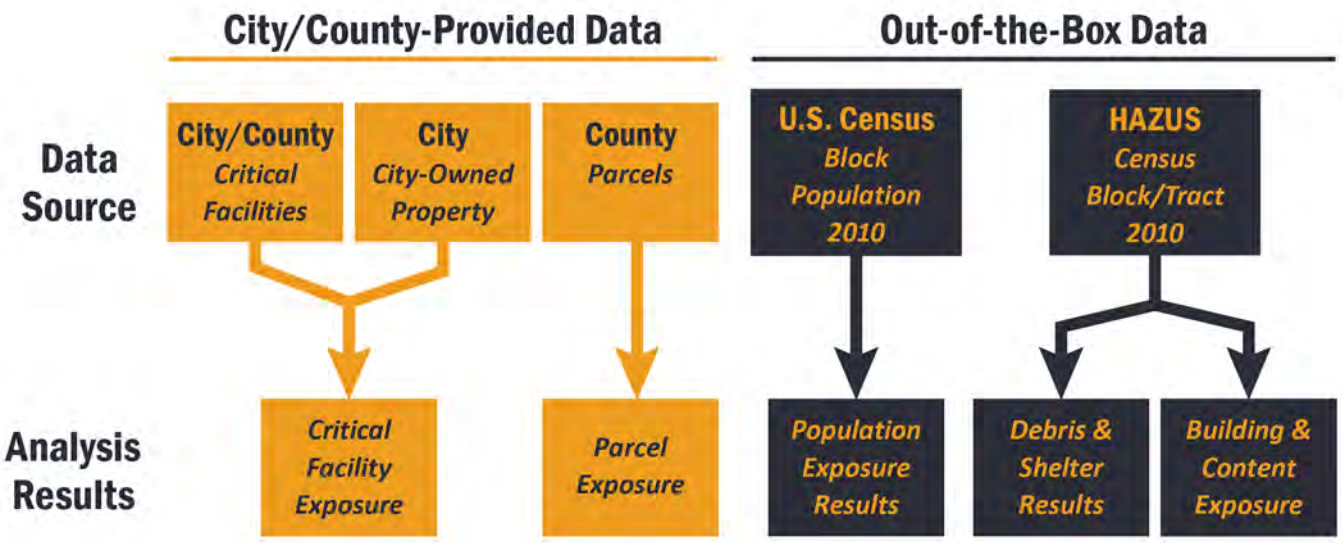


Figure 4-22: Data Source and Methodology

Lastly, FEMA's Hazus-MH MR5 (Hazus) software was implemented to conduct detailed loss estimation for flood and earthquake. Hazus is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. For purposes of this planning effort, Hazus was used to graphically illustrate the limits of identified high-risk locations due to possible earthquakes and floods.

[4] To georeference something means to define its existence in physical space. That is, establishing its location in terms of map projections or coordinate systems. The term is used both when establishing the relation between raster or vector images and coordinates, and when determining the spatial location of other geographical features.

The vulnerability and potential impacts from priority hazards that do not have specific mapped areas nor the data to support additional vulnerability analyses are discussed in more general terms in alphabetical order following the discussion on wildfire, flooding and earthquake hazards.

4.10.2 Hazus MH Inputs

FEMA's loss estimation software, Hazus MH, was used to analyze the San Bernardino County building risk to flood and earthquake hazards. Hazus contains a database of economic, demographic, building stock, transportation facilities, local geology, and other information that can be used for several steps in the risk assessment process. Hazus software operates on structure square footage, structure replacement, and content replacement costs aggregated to the census block and tract levels depending on type of hazard analysis. The following table provides value data for building categories at the census block and census tract levels. Census block and census tracts are used to provide input information for the Hazus analysis presented in this report.

The project team used the San Bernardino County Essential Facilities Risk Assessment (SBEFRA) project and incorporated the newly updated DFIRM data into HAZUS to assess potential losses in the mapped 100-year (with and without levee protection) and 500-year flood zones.

Note: The Hazus software utilizes different census level information inputs to develop loss estimates depending on the hazard module. The flood module uses census block information while the earthquake module uses census track information. It is important to understand the total values of each as estimated damage to the community is presented on a percent of total value basis.

Table 4-12: Hazus Flood Census Block Input Values

Building Type	Building Replacement Costs ($000)	Building Replacement Cost (%)	Content Replacement Cost ($000)	Content Replacement Cost (%)	Total Value ($000)	Total Value (%)
Agricultural	$ 70,841	0.3%	$ 70,841	0.3%	$ 141,682	1%
Commercial	$ 1,208,163	4.4%	$ 1,231,690	4.5%	$ 2,439,853	9%
Education	$ 120,017	0.4%	$ 127,161	0.5%	$ 247,178	1%
Governmental	$ 34,216	0.1%	$ 43,192	0.2%	$ 77,408	0%
Industrial	$ 452,710	1.6%	$ 610,063	2.2%	$ 1,062,773	4%
Religion	$ 176,012	0.6%	$ 176,012	0.6%	$ 352,024	1%
Residential	$ 15,483,634	56.2%	$ 7,744,650	28.1%	$ 23,228,284	84%
Total	**$ 17,545,593**	**64%**	**$ 10,003,609**	**36%**	**$ 27,549,202**	**100 %**

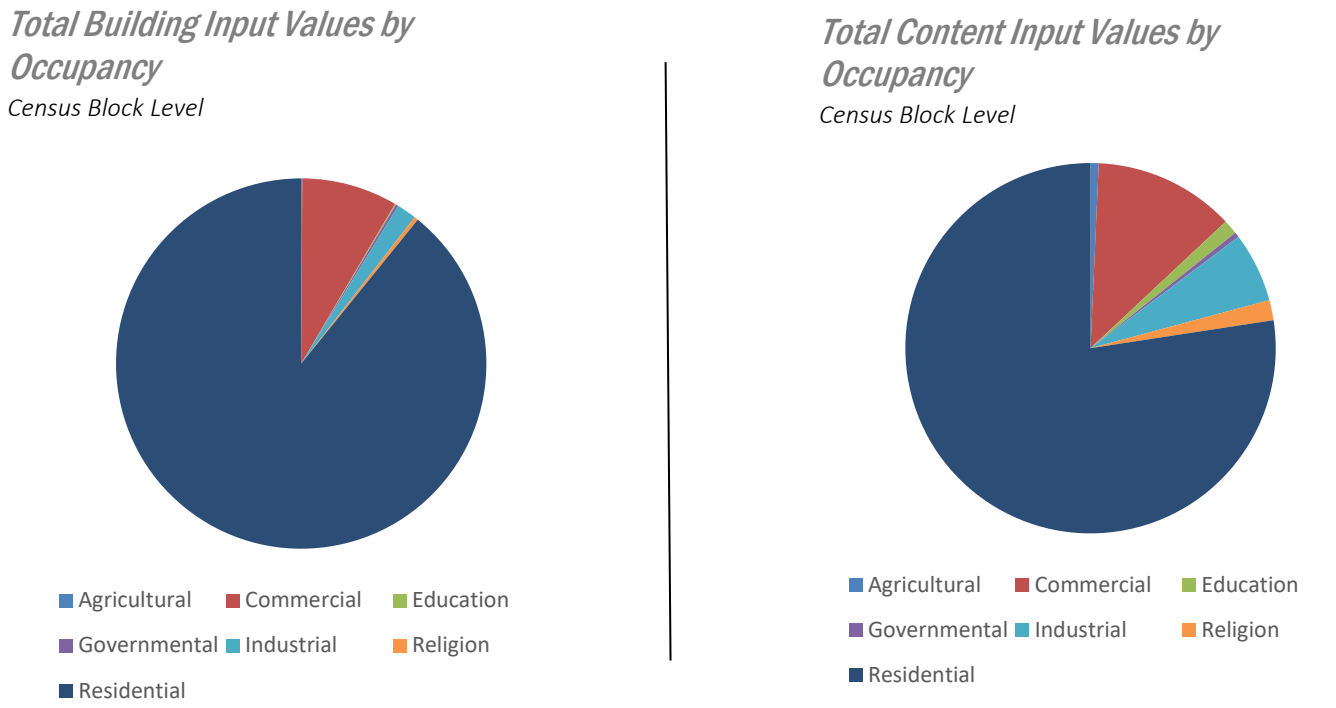


Figure 4-23: Census Block Building and Content Exposure Values

Table 4-13: Hazus Earthquake Census Tract Input Values

Building Type	Building Replacement Costs ($000)	Building Replacement Cost (%)	Content Replacement Cost ($000)	Content Replacement Cost (%)	Total Value ($000)	Total Value (%)
Agricultural	$ 264,949	50.0%	$ 264,949	50.0%	$ 529,898	1%
Commercial	$ 11,056,871	48.5%	$ 11,756,479	51.5%	$ 22,813,350	9%
Education	$ 819,946	48.4%	$ 874,703	51.6%	$ 1,694,649	1%
Governmental	$ 265,933	45.6%	$ 316,930	54.4%	$ 582,863	0%
Industrial	$ 3,733,265	41.4%	$ 5,276,431	58.6%	$ 9,009,696	4%
Religion	$ 958,122	50.0%	$ 958,122	50.0%	$ 1,916,244	1%
Residential	$ 84,302,884	66.7%	$ 42,159,954	33.3%	$ 126,462,838	84%
Total	**$ 101,401,970**	**62%**	**$ 61,607,568**	**38%**	**$ 163,009,538**	**100 %**

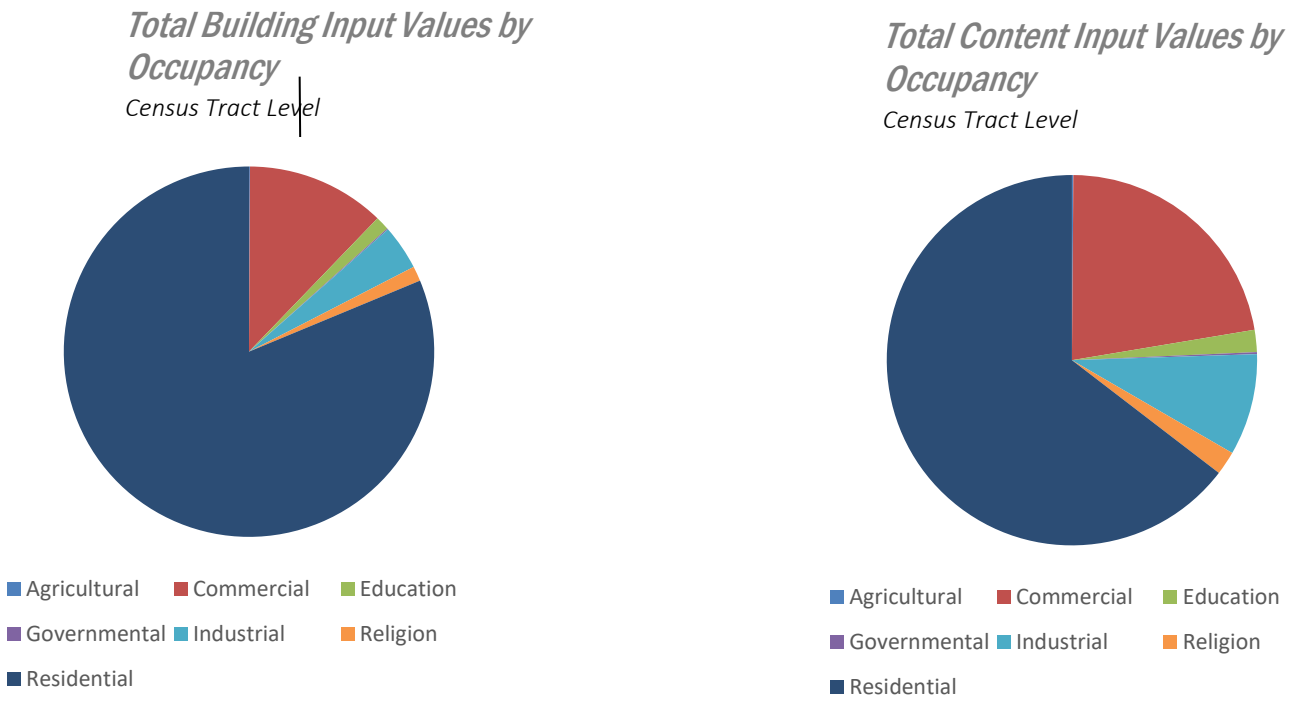


Figure 4-24: Census Tract Building and Content Exposure Values

4.11 Population and Assets

To describe vulnerability for each hazard, it is important to understand the "total" population and "total" assets at risk. The exposure for each hazard described in this section will refer to the percent of total population or percent of total assets. This provides the possible significance or vulnerability to people and assets for the natural hazard event and the estimated damage and losses expected during a "worst case scenario" event for each hazard. Sections below provide a description of the total population, critical facilities, and parcel exposure inputs.

Table 4-12 and Table 4-13 provide an estimate of the number and size of buildings in the County's unincorporated areas and its Special Districts, as well as the replacement value of the buildings and their contents. The table provides information by occupancy class (e.g., residential, commercial, etc.), as well as by construction type (e.g., concrete, wood frame, etc.).

4.11.1 Population

To develop hazard-specific vulnerability assessments, population near natural hazard risks should be determined to understand the total "at risk" population. We can understand how geographically defined hazards may affect San Bernardino County by analyzing the extent of the hazard in relation to the location of population. For purposes of the vulnerability assessment approximately 292,152 (100 %) of the San Bernardino County's population is exposed to one or more hazards within or near the County of San Bernardino boundaries. Each natural hazard scenario affects the San Bernardino County residents differently depending on the location of the hazard and the population density of where the hazard could occur. Vulnerability assessment sections presented later in this section summarize the population exposure for each natural hazard.

4.11.1.1 Vulnerable Populations

The severity of a disaster depends on both the physical nature of the extreme event and the socioeconomic nature of the populations affected by the event. Important socioeconomic factors tend to influence disaster severity. A core concept in a vulnerability analysis is that different people, even within the same region, have a different vulnerability to natural hazards.

4.11.1.2 Income and Housing Condition

Income or wealth is one of the most important factors in natural hazard vulnerability. This economic factor affects vulnerability of low income populations in several ways. Lower income populations are less able to afford housing and other infrastructure that can withstand extreme events. Low income populations are less able to purchase resources needed for disaster response and are less likely to have insurance policies that can contribute to recovery efforts. Lower income elderly populations are less likely to have access to medical care due to financial hardship. Because of these and other factors, when disaster strikes, low income residences are far more likely to be injured or left without food and shelter during and after natural disasters.

Figure 4-25 shows the median household income distribution for the County of San Bernardino in 2012. The “median” is the value that divides the distribution of household income into two equal parts (e.g., the middle). The average median household income in the County of San Bernardino between 2010 and 2014 was $54,100, in the United States during the same period the median house household income was $51,759.

4.11.1.3 Age

Children and the elderly tend to be more vulnerable during an extreme natural disaster. They have less physical strength to survive disasters and are often more susceptible to certain diseases. The elderly often also have declining vision and hearing and often miss reports of upcoming natural hazard events. Children, especially young children, have the inability to provide for themselves. In many cases, both children and the elderly depend on others to care for them during day to day life.

Finally, both children and the elderly have fewer financial resources and are frequently dependent on others for survival. In order for these populations to remain resilient before and after a natural hazard event, it may be necessary to augment city residents with resources provided by the City, state and federal emergency management agencies and organizations. See Figure 4-26 and Figure 4-27 for location of vulnerable population by age within the County of San Bernardino.

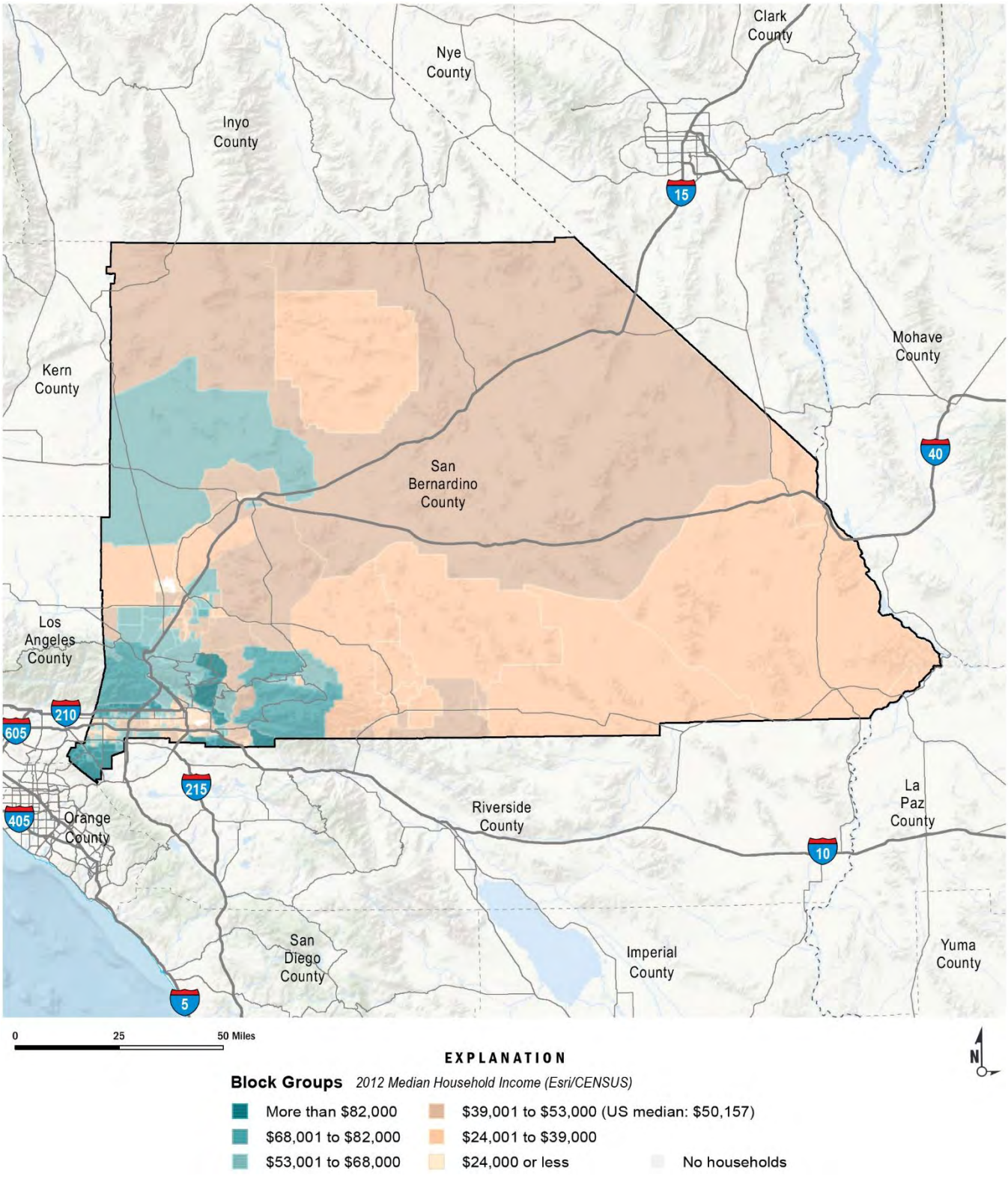


Figure 4-25: Median Household Income Distribution Maps

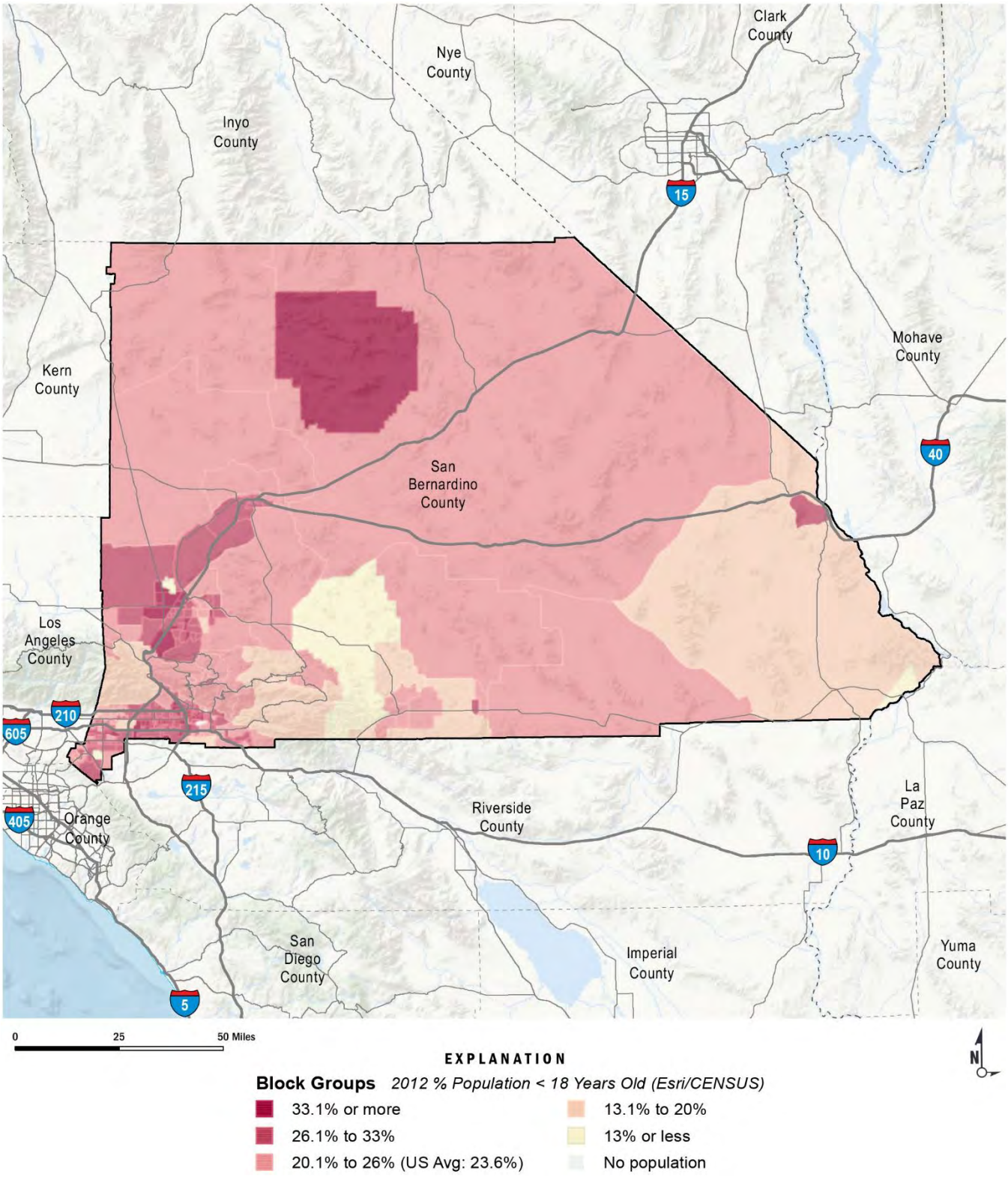


Figure 4-26: Population Under Age 18

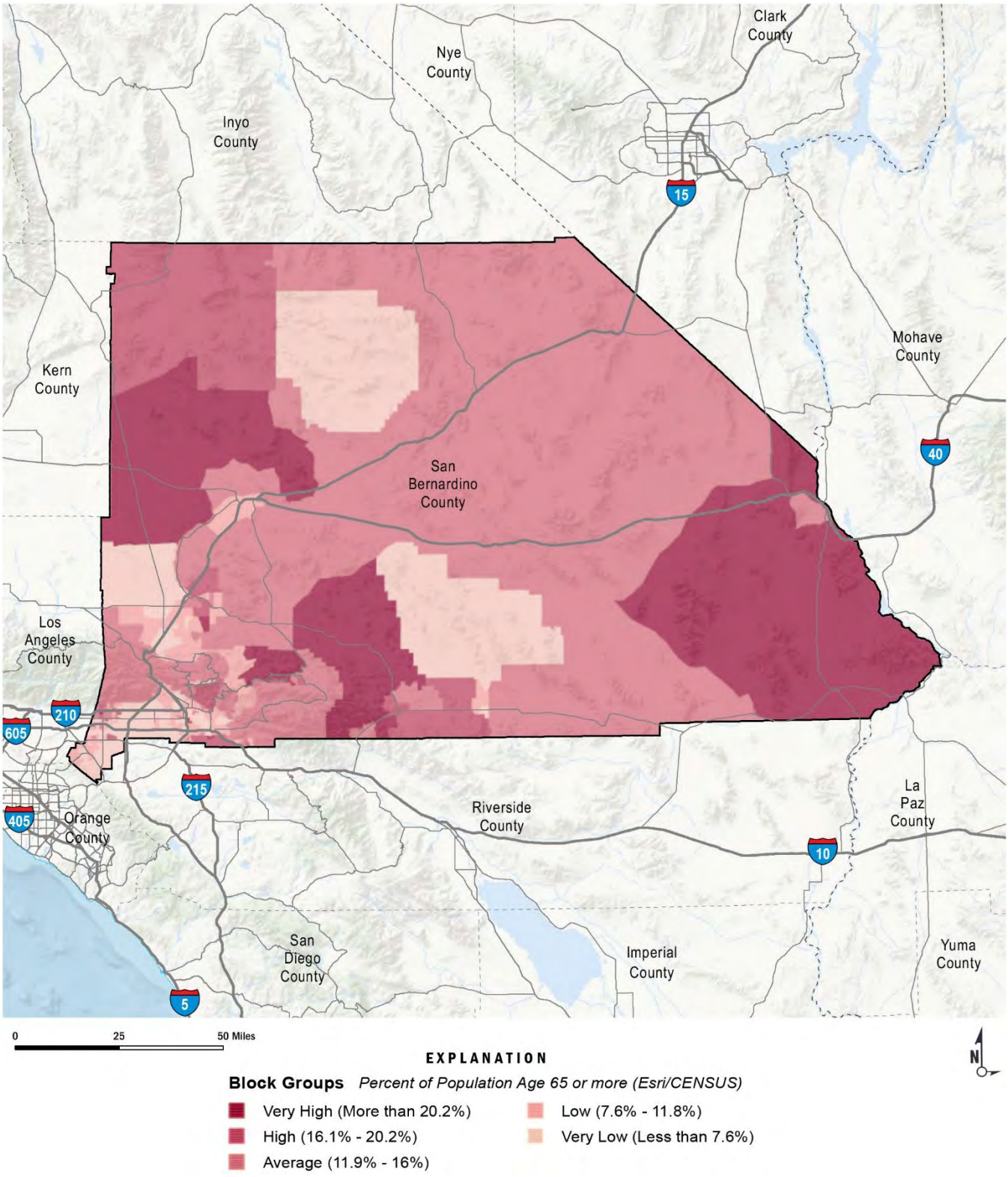


Figure 4-27: Population Over Age 65

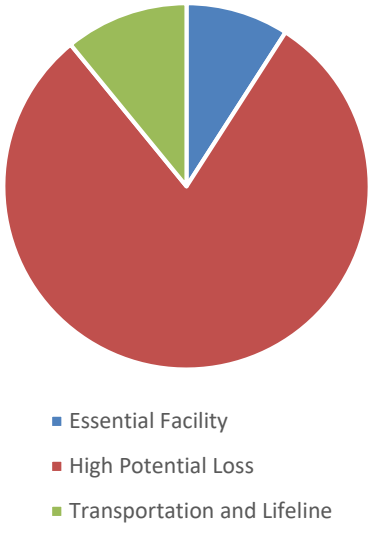
4.11.1.4 Critical Facility List

As stated in the San Bernardino County Emergency Operations Plan (EOP), the San Bernardino County Sheriff's Department (Sheriff) is the lead County agency in identifying critical infrastructure in the County and its Special Districts. A Sheriff's Department Working Group was established to identify Critical Facilities throughout San Bernardino County. Due to Homeland Security and issues related to terrorism, this list is not included in the MJHMP, but is available through the Sheriff's Department.

The Sheriff's Department maintains a Critical Infrastructure Database listing the site name, location, critical level, threat level, site type, and contact information. This database was created for the 2010 MJHMP and has been updated regularly by the Intelligence Division. The Sheriff's Intelligence Division has created Emergency Response Folders (Folders) on each of the locations. The Folders contain site-specific information needed by emergency personnel to respond to any type of emergency. The Folders contain floor plans, photographs, entry/exit points, utility locations, ingress and egress locations, known hazardous materials on site, and emergency contact information for the responsible persons of the site. The Sheriff's Department maintains control and transport of this information to an Incident Command Post/Department Operations Center/Emergency Operations Center when needed.

Table 4-14: Critical Facility Points

Infrastructure Type	Feature Count
Essential Facility	**268**
EOC	2
Fire Station	99
Hospital	9
Police Station	28
School	130
High Potential Loss	**1,155**
Child Care Center	91
Child Residential Care - 24 hour	2
Foster Family Agency	2
Adult Residential Care	52
Home Care Organization	2
Elder Residential Care	35
Communication Facility	40
Dam	24
Waste Water Facility	2



Infrastructure Type	Feature Count
HAZMAT	51
EPA FRS Facility	731
FCC ASR	107
Electric Power Facility	6
Natural Gas Facility	7
Potable Water Facility	3
Transportation and Lifeline	**636**
Airport	34
Runway	36
Bus Facility	2
Highway Bridge	553
Railway Bridge	11
Grand Total	**2,059**

Table 4-15: Linear Utilities

Infrastructure Type	Total Linear Mileage
Transportation and Lifeline	**16,992**
Railway	**719**
Roads	**16,273**
Interstate Highway	587
State / County Highway	1,259
Primary Highway	308
Local Road, Major	2,928
Local Road	6,530
Other Minor Road	4,031
Vehicular Trail	543
Cul-de-Sac / Traffic Circle	11
Ramp	68
Service Road	8
Grand Total	**16,992**

4.11.1.5 Utility Agencies

The utilities and transportation infrastructure is another significant concern for the County and its Special Districts. Various laws, ordinances, regulations, standards, and guidelines have been established to ensure proper and thorough mitigation measures to decrease the effects of hazards.

The following are two of the major utility agencies:

Southern California Edison (SCE) has undertaken an all-hazards approach to planning for an emergency event. SCE has developed an Emergency Response and Recovery Plan to provide a safe and reliable electric service. SCE also has a long-standing relationship with the County and is an active member of several local, state, and federal organizations. According to SCE they have acted to mitigate the impacts of hazards on their electrical system.

Southwest Gas Corporation (SWG) has also coordinated with the County, maintains a natural gas high-pressure system within the County, and consists of approximately 100 miles of underground pipelines. The system also includes some above ground facilities. The total replacement cost for the entire system is approximately $40,000,000. Southwest Gas conducts annual training for the first responders within their service territories to teach the proper methods of responding to and working with natural gas leaks. Staff from SWG serves on local emergency management committees within their service territory.

4.12 Hazard Specific Vulnerabilities

This section summarizes the possible impacts and quantifies, where data permits, the County's vulnerability to each of the priority hazards identified in the hazard profiles earlier in this section.

An estimate of the vulnerability of the County to each identified hazard, in addition to the estimate of risk of future occurrence, is provided in each of the hazard-specific sections that follow. Vulnerability is measured in general, qualitative terms and is a summary of the potential impact based on past occurrences, geographic extent, and damage and casualty potential. It is categorized into the following classifications:

Low: Minimal potential impact the occurrence and potential cost of damage to life and property is minimal.

Medium: Moderate potential impact this ranking carries a moderate threat level to the general population and/or built environment. Here the potential damage is more isolated and less costly than a more widespread disaster.

High: Widespread potential impact this ranking carries a high threat to the general population and/or built environment. The potential for damage is widespread. Hazards in this category may have occurred in the past.

Extremely High: Very widespread with catastrophic impact.

Vulnerability can be quantified in those instances where there is a known, identified hazard area, such as a mapped floodplain. In these instances, the numbers and types of buildings subject to the identified hazard can be inventoried and their values tabulated. Other information can be collected in regard to the hazard area, such as the location of critical community facilities, historic structures, and valued natural resources. Together, this information conveys the vulnerability of that area to a hazard.

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4.13 Earthquake



Major Impacts from earthquakes are primarily the probable number of casualties and damage to infrastructure occurring from ground movement along a particular fault (USGS, 2016). The degree of infrastructure damage depends on the magnitude, focal depth, distance from fault, duration of shaking, type of surface deposits, presence of high groundwater, topography, and the design, type, and quality of infrastructure construction.

To analyze the risk to San Bernardino County residents, the Great Shakeout scenario was chosen modeled by the California Integrated Seismic Network (CISN). The 2016 Great Southern California ShakeOut was based on a potential magnitude 7.8 Earthquake on the southern San Andreas Fault approximately 5,000 times larger than the magnitude 5.4 earthquake that shook southern California on July 29, 2008. Such an earthquake will cause unprecedented damage to Southern California greatly dwarfing the massive damage that occurred in Northridge's 6.7-magnitude earthquake in 1994. The hazard foot print for this scenario was used to develop exposure results for population, critical facilities, and single family residential parcel values. FEMA Hazus analyses was used to conducted loss estimation for both scenarios and include building and content loss estimation results based on peak ground acceleration, peak ground velocity, and peak spectral acceleration modeled for the 7.8 earthquake on the San Andreas Fault.

4.13.1 Population at Risk

According to the 2010 US Census, the population of jurisdiction is 297,425. Though rural residential construction is not particularly vulnerable to earthquakes, the chosen earthquake scenarios will directly or indirectly expose the entire population of San Bernardino County to ground shaking. Depending on the time of day (the population differs based on employment opportunities) and exact location of the modeled epicenter, the earthquake scenarios could be experienced differently. Figure 4-28 exhibit the population totals in each modeled earthquake severity zone. Population location is based upon information taken during the 2010 U.S. Census.

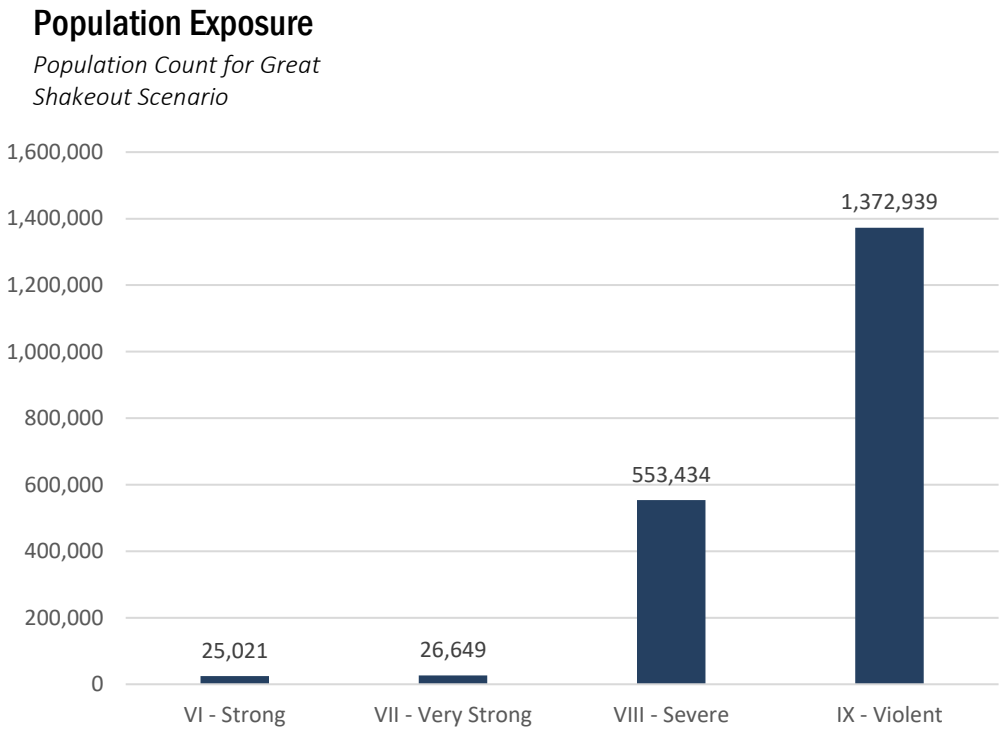


Figure 4-28: Population Exposure to the Great Shakeout EQ Shake Severity Zone

4.13.2 Improved Parcel Value at Risk

The County's parcel layer was used as the basis for the inventory of improved residential parcels. GIS was used to create centroids, or points, to represent the center of each parcel polygon this is assumed to be the location of the structure for analysis purposes. The centroids were then overlaid with the shake severity zones to determine the at-risk structures. Only improved parcels greater than $20,000 were analyzed. The analysis indicates residential parcels the chosen scenario will experience similar, but different shaking patterns. The type and year of construction will greatly influence damage for structures subject to similar shaking. Table 4-16 shows the count of at-risk structures and their associated improvement and land exposure values.

Table 4-16: Improved Parcel Value Exposure from Southern California Great ShakeOut

Shake Severity Zone	Improved Parcel Count	Improvement Value Exposure ($000)	Land Value Exposure ($000)	Total Exposure ($000)
IV - Light	1,099	$ 181,952	$ 64,548	$ 246,499
V - Moderate	4,382	$ 485,082	$ 215,875	$ 700,956

Shake Severity Zone	Improved Parcel Count	Improvement Value Exposure ($000)	Land Value Exposure ($000)	Total Exposure ($000)
VI - Strong	1,340	$ 142,763	$ 63,941	$ 206,704
VII - Very Strong	7,669	$ 824,794	$ 206,725	$ 1,031,519
VIII - Severe	46,889	$ 8,741,904	$ 3,039,484	$ 11,781,388
IX - Violent	46,974	$ 9,068,446	$ 3,591,379	$ 12,659,825
Grand Total	**108,353**	**$ 19,444,940**	**$ 7,181,951**	**$ 26,626,891**

4.13.3 Critical Facilities with Damage Potential

Earthquakes pose numerous risks to critical facilities and infrastructure. Seismic risks, or losses, that are likely to result from exposure to seismic hazards include:

- Casualties (fatalities and injuries).
- Utility outages.
- Economic losses for repair and replacement of critical facilities, roads, buildings, etc.
- Indirect economic losses such as income lost during downtime resulting from damage to private property or public infrastructure.

Roads or railroads that are blocked or damaged can prevent access throughout the area and can isolate residents and emergency service providers needing to reach vulnerable populations or to make repairs.

Linear utilities and transportation routes are vulnerable to rupture and damage during and after a significant earthquake event. The cascading impact of a single failure can have affects across multiple systems and utility sectors. Degrading infrastructure systems and future large earthquakes with epicenters near critical regional infrastructure could result in system outages that last weeks for the most reliable systems, and multiple months for others.
Table 4-17provides an inventory of critical facility locations (points only) with earthquake exposure to the Great Shakeout Scenario. The building codes have been amended to include provisions for seismic safety at various bench marks years. Depending on “year built”, each critical facility presented in the tables may have varying damage potential.

Table 4-17: Critical Facilities with Earthquake Risk Southern California Great ShakeOut

Infrastructure Type	Violent Shake Zone (IX)	Severe Shake Zone (VIII)	Very Strong (VII)	Strong Shake Zone (VI)	Feature Count
Essential Facility	3	12	80	122	217
EOC	-	-	2	-	2
Fire Station	3	7	31	34	75
Hospital	-	-	9	-	9
Police Station	-	-	3	24	27
School	-	5	35	64	104

Infrastructure Type	Violent Shake Zone (IX)	Severe Shake Zone (VIII)	Very Strong (VII)	Strong Shake Zone (VI)	Feature Count
High Potential Loss	31	56	213	484	784
Child Care Center	1	3	25	56	85
Child Residential Care – 24 hour	-	-	-	2	2
Foster Family Agency	-	-	-	2	2
Adult Residential Care	2	5	10	34	51
Home Care Organization	-	-	1	1	2
Elder Residential Care	-	1	9	25	35
Communication Facility	1	9	9	8	27
Dam	1	-	11	4	16
Electric Power Facility	1	-	-	-	1
Natural Gas Facility	2	-	-	-	2
Waste Water Facility	-	2	-	-	2
HAZMAT	-	-	6	16	22
EPA FRS Facility	21	27	115	307	470
FCC ASR	2	9	27	29	67
Transportation and Lifeline	16	20	41	131	208
Airport	5	5	8	-	18
Runway	5	6	7	1	19
Bus Facility	-	-	1	-	1
Highway Bridge	6	8	24	124	162
Railway Bridge	-	1	1	6	8
Grand Total	**50**	**88**	**334**	**737**	**1,209**

HazMat Fixed Facilities

Although earthquakes are low probability events, they produce hazardous materials (HazMat) threats at very high levels when they do occur. Depending on the year built and construction of each facility containing HazMat, earthquake initiated hazardous material releases (EIHR) potential will vary. HazMat contained within masonry or concrete structures built before certain benchmark years reflecting code improvements may be of particular vulnerability.

Transportation

Earthquake events can significantly impact bridges which often provide the only access to some neighborhoods. Since soft soil regions generally follow floodplain boundaries, bridges that cross water courses are considered vulnerable. Since most of the San Bernardino County bridges provide access across water courses, most are at least somewhat vulnerable to earthquakes. Key factors in the degree of vulnerability are the bridge's age and type of construction which indicate the standards to which the bridge was built. Special attention will be paid to the multiple bridges that cross interstates. Interstates would serve as major emergency response and evacuation routes.

Utilities

Linear utilities and transportation infrastructure would likely suffer considerable damage in the event of an earthquake. Due to the amount of infrastructure and sensitivity of utility data, linear utilities are difficult to analyze without further investigation of individual system components. Table 4-18 provides the best available linear data and it should be assumed that these systems are exposed to breakage and failure.

Table 4-18: Lifeline with Earthquake Risk Southern California Great ShakeOut

Facility Type	Strong	Very Strong	Severe	Violent	Total Mileage
Transportation and Lifeline	1,324	1,951	2,796	2,624	8,697
Railway	47	22	22	99	191
Roads	1,277	1,929	2,774	2,525	8,506
Interstate Highway	22	7	-	48	77
State / County Highway	57	90	263	233	644
Primary Highway	34	15	19	27	95
Local Road, Major	102	207	625	792	1,726
Local Road	540	1,153	1,728	1,128	4,550
Other Minor Road	494	423	109	96	1,122
Vehicular Trail	25	32	26	178	261
Cul-de-Sac / Traffic Circle	-	1	2	2	5
Ramp	2	1	2	20	25
Service Road	-	-	-	1	1
Grand Total	**1,324**	**1,951**	**2,796**	**2,624**	**8,695**

4.13.4 Loss Estimation Results

The Hazus Level 2 analysis was used to assess the risk from and vulnerability to earthquake shaking within San Bernardino County. Hazus buildings data is aggregated to the census tract level for earthquake models, known as the general building stock (GBS), which has a level of accuracy acceptable for planning purposes. Where possible the GBS was enhanced using GIS data from the county as described previously. The following sections describe risk to and vulnerability of the GBS within the San Bernardino County Hazus calculates losses to structures from earthquake shaking by considering the amount of ground displacement and type of structure. The software estimates the percentage of damage to structures and their contents by applying established building fragility curves. Damage estimates are then translated to estimated dollar losses.

For each Great ShakeOut Scenario ground shaking data (shakemaps) were acquired from CISN and imported into Hazus. The shakemap data consist of peak ground velocity, peak

ground acceleration, peak spectral acceleration at 0.3 seconds, and peak spectral acceleration at 1.0 seconds. The earthquake module operates on census tracts that often include population and structures in the incorporated cities and the unincorporated area within a single tract. Due to this fact the results include census tracts that have a substantial portion of land within the incorporated area (loss estimates for some tracts will include structures in incorporated cities).

The results are summarized in Table 4-17 for the Great ShakeOut Scenario. It is important to understand that the Hazus earthquake module uses the census tract as its enumeration unit rather than the more detailed census block. The loss estimation values for earthquakes are much higher than those of the flooding and dam failure due to this fact. The portions of incorporated areas included within boundary census tracts elevate the values due to the inclusion of additional GBS. Though the difference between census tracts and census blocks are extremely disparate, the most important summary information is the percent of loss estimation against the total value.

Residential building and content loss estimation from the Great ShakeOut Scenario is *$9.3* billion dollars and 57 percent of the total value of the residential buildings. In Great ShakeOut Scenario, residential damage will be the greatest. While there are several limitations to the FEMA Hazus model, it does allow for potential loss estimation. It is important to remember that the replacement costs are well below actual market values, thus, the actual value of assets at risk may be significantly higher than those included herein.

Table 4-19: Estimated Building and Content Loss Great ShakeOut Scenario Earthquake

Building Type	Building Replacement Costs ($000)	Building Replacement Cost (% of Total Value)	Content Replacement Cost ($000)	Content Replacement Cost (% of Total Value)	Total Estimated Loss ($000)	Total Loss Estimation (% of Total Value)
Agricultural	$ 51,431	9.7%	$ 17,215.68	3.2%	$ 68,646.80	13.0%
Commercial	$ 3,286,331	14.4%	$ 1,110,422.84	4.9%	$ 4,396,754.29	19.3%
Educational	$ 175,987	10.4%	$ 56,822.89	3.4%	$ 232,810.20	13.7%
Government	$ 53,348	9.2%	$ 20,298.84	3.5	$ 73,647.28	12.6%
Industrial	$ 1,179,339	13.1%	$ 590,913.81	6.6%	$ 1,770,253.41	19.6%
Religious	$ 243,891	12.7%	$ 80,862.72	4.2%	$ 324,754.33	16.9%
Residential	$ 7,841,645	6.2%	$ 1,525,181.65	1.2%	$ 9,366,826.84	7.4%
Grand Total	**$ 12,831,972**	**7.9%**	**$ 3,401,718.42**	**2.1%**	**$ 16,233,693.14**	**10.0%**

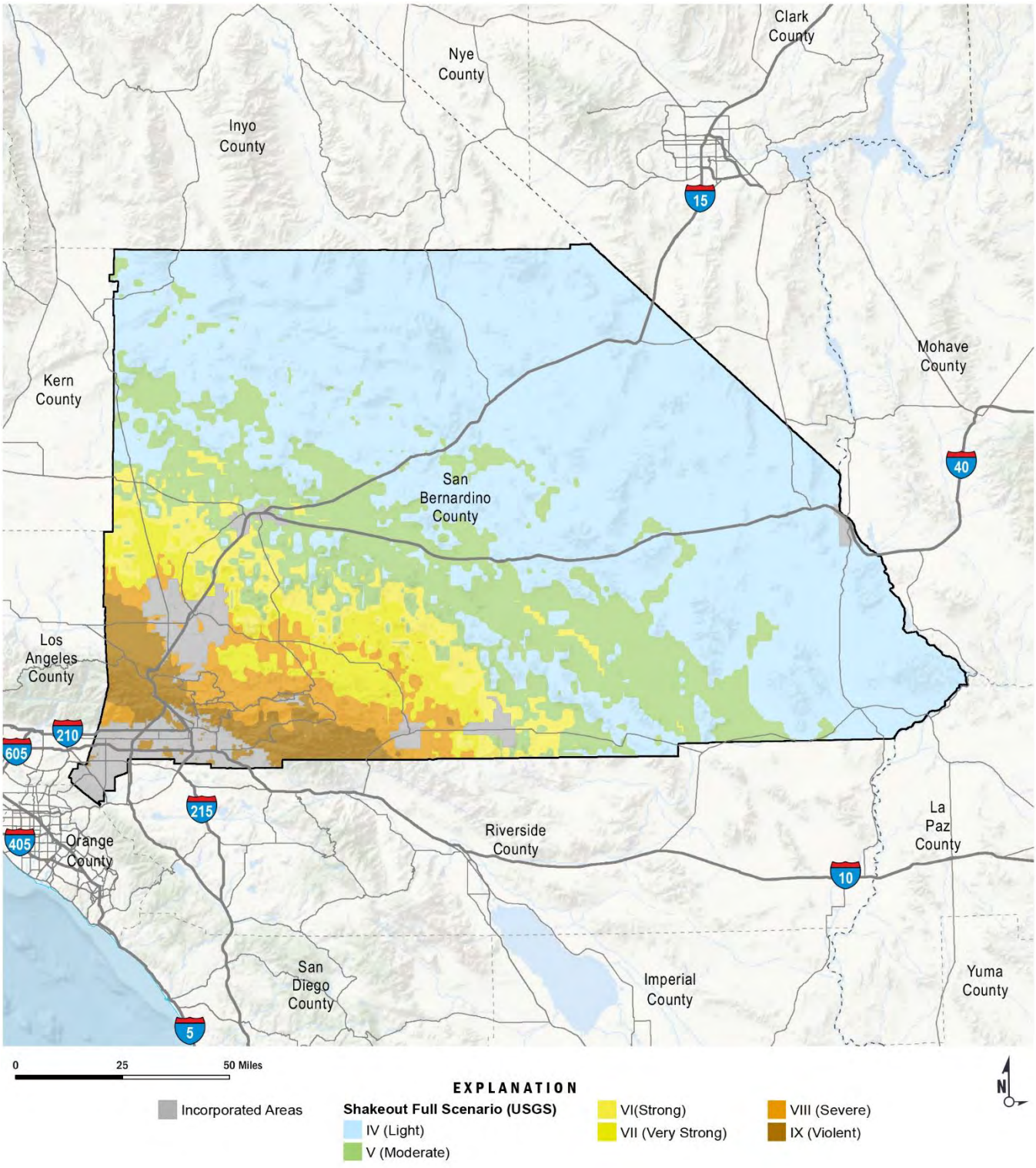


Figure 4-29: Great Shakeout Scenario MMI Classes

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4.14 Wildfire



Risk to the County of San Bernardino from wildfire is of significant concern. High fuel loads in the hills, along with geographical and topographical features, create the potential for both natural and human-caused fires that can result in loss of life and property. These factors, combined with natural weather conditions common to the area, including periods of drought, high temperatures, low relative humidity, and periodic winds, can result in frequent and sometimes catastrophic fires. During the May to October fire season the dry vegetation and hot and sometimes windy weather, combined with continued growth in the WUI areas, results in an increase in the number of ignitions. Any fire, once ignited, has the potential to quickly become large and out-of-control.

Potential losses from wildfire include human life, structures and other improvements, natural and cultural resources, quality and quantity of water supplies, cropland, timber, and recreational opportunities. Short and long-term economic losses could also result due to loss of business and other economic drivers associated with San Bernardino County summer season activities. Smoke and air pollution from wildfires can be a severe health hazard. In addition, catastrophic wildfire can create favorable conditions for other hazards such as flooding, landslides, and erosion during the rainy season.

Generally, there are three major factors that sustain wildfires and predict a given area's potential vulnerability to burn. These factors are fuel, topography, and weather.

- Fuel – Fuel is the material that feeds a fire and is a key factor in wildfire behavior. Fuel is generally classified by type and volume. Fuel sources are diverse and include everything from dead tree leaves, twigs, and branches, to dead standing trees, live trees, brush, and cured grasses. Manmade structures are also considered a fuel source, such as homes and other associated combustibles. The type of prevalent fuel directly influences the behavior of wildfire. Fuel is the only factor that is under human control. Development in the mountain region currently possesses the highest vulnerability to wildfire.

- The residents of this region are also considered to be the most vulnerable due to their age and income levels. This area is comprised of lower income (that is, lower than the US median income) homes as well as a higher than average amount of residents under age 18 and an average amount of residents 65 or older.
- Topography – An area's terrain and slope affect its susceptibility to wildfire spread. Both fire intensity and rate of spread increase as slope increases due to the tendency of heat from a fire to rise via convection. The arrangement of vegetation throughout a hillside can also contribute to increased fire activity on slopes.

- Weather – Weather components such as temperature, relative humidity, wind, and lightning also affect the potential for wildfire. High temperatures and low relative humidity dry out fuels that feed wildfires, creating a situation where fuel will ignite more readily and burn more intensely. Thus, during periods of drought the threat of wildfire increases. Wind is the most treacherous weather factor. The greater the wind, the faster a fire can spread and the more intense it can be. Wind shifts, in addition to wind speed, can occur suddenly due to temperature changes or the interaction of wind with topographical features such as slopes or steep hillsides. As part of a weather system, lightning also ignites wildfires, often in difficult to reach terrain for firefighters.

Factors contributing to the high, widespread wildfire risk in San Bernardino County include:

- Narrow and often one-lane and/or dead-end roads complicating evacuation and emergency response.
- Nature and frequency of ignitions; and increasing population density leading to more ignitions.
- Slope of the foothills;
- Residential development along the foothills;

4.14.1 Population at Risk

Wildfire risk is of greatest concern to populations residing in the moderate, high, and very high wildfire hazard zones. The San Bernardino County census block data was used to estimate populations within the hazard zones. There are a significant number of people living within the WUI described in the wildfire profiles. More than 34,000 residents in the unincorporated county live within areas considered very high fire hazard and more than 63,000 residents live within a very high hazard

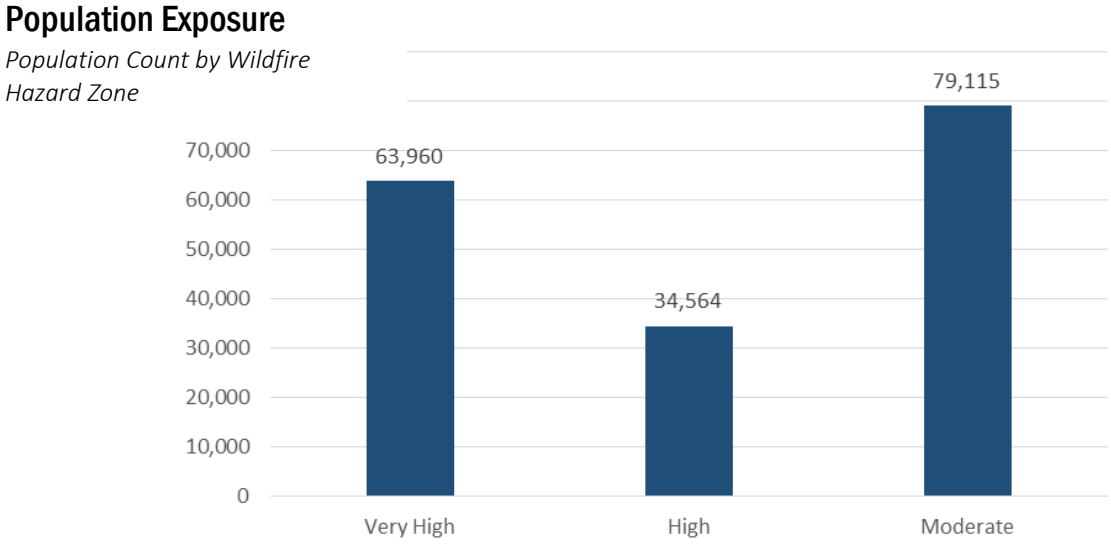


Figure 4-30: Population at Risk from Wildfire Hazards

4.14.2 Improved Parcel Value at Risk

The County's parcel layer was used as the basis for the inventory of improved residential parcels. In some cases, a parcel will be within in multiple fire threat zones. GIS was used to create centroids, or points, to represent the center of each parcel polygon – this is assumed to be the location of the structure for analysis purposes. The centroids were then overlaid with the fire threat layer to determine the risk for each structure. The fire threat zone in which the centroid was located was assigned to the entire parcel. This methodology assumed that every parcel with a square footage value greater than zero was developed in some way. Only improved parcels were analyzed. Table 4-20 exhibits portions of San Bernardino County that have significant assets at risk to wildfire in the Moderate, High and Very High fire severity zones.

Table 4-20: Residential Buildings and Content at Risk from Wildfire

Fire Hazard Severity Hazard Zone	Improved Parcel Count	Improvement Value Exposure ($000)	Land Value Exposure ($000)	Total Exposure ($000)
Very High	43,794	$ 8,602,590	$ 3,075,148	$ 11,677,739
High	11,512	$ 1,822,731	$ 551,160	$ 2,373,892
Moderate	25,477	$ 3,221,982	$ 950,044	$ 4,172,026
Non-Wildland/Non-Urban	621	$ 573,866	$ 294,283	$ 868,148
Urban Un-zoned	26,974	$ 5,223,286	$ 2,310,932	$ 7,534,219
Grand Total	**108,378**	**$ 19,444,456**	**$ 7,181,567**	**$ 26,626,023**

Note:
1-The table above does not display loss estimation results; the table exhibits total value at risk based upon the hazard overlay and San Bernardino County Assessor data.
2- Parcel information is for all county parcels with greater than $20,000 in assessed parcel improvement value only. The San Bernardino County Assessor's roles only provide spatial information on assessed improvement and land values.

4.14.3 Critical Facilities at Risk

Critical facilities data were overlain with fire hazard severity zone data to determine the type and number of facilities within each risk classification. Tables 4-21 and 4-22 list the critical facilities in the High and Very High wildfire hazard zones for San Bernardino County.

Table 4-21: Critical Facilities at Risk from Wildfire

Infrastructure Type	High	Very High	Feature Count
Essential Facility	11	105	116
EOC	2	0	2
Fire Station	4	45	49
Hospital	0	5	5
Police Station	0	24	24
School	5	31	36
High Potential Loss	72	177	249
Child Care Center	3	29	32
Child Residential Care - 24 hour	1	0	1
Foster Family Agency	0	0	0
Adult Residential Care	11	4	15
Home Care Organization	0	0	0
Elder Residential Care	8	5	13
Communication Facility	2	13	15
Dam	0	14	14
Electric Power Facility	0	0	0
Natural Gas Facility	0	0	0
Potable Water Facility	0	0	0
Waste Water Facility	0	0	0
HAZMAT	0	2	2
EPA FRS Facility	37	83	120
FCC ASR	10	27	37
Transportation and Lifeline	10	103	113
Airport	1	0	1
Runway	1	0	1
Bus Facility	1	0	1
Highway Bridge	7	101	108
Railway Bridge	0	2	2
Grand Total	**93**	**385**	**478**

Table 4-22: Lifelines with Wildfire Risk

Facility Type	High	Very High	Total Mileage
Transportation and Lifeline	819	1,906	2,725
Railway	19	47	66
Roads	800	1,859	2,659
Interstate Highway	4	37	41
State / County Highway	33	226	259
Primary Highway	17	13	30
Local Road, Major	311	521	832
Local Road	389	806	1,195
Other Minor Road	34	56	91
Vehicular Trail	10	184	195
Cul-de-Sac / Traffic Circle	1	2	3
Ramp	2	12	13
Service Road	0	1	1
Grand Total	**819**	**1,906**	**2,725**

4.14.4 Loss Estimation Results

Wildland fire cost impacts of damage done to land and structures and also to critical infrastructure

It is impossible to estimate the possible cost in dollars to replace and pay for actual firefighting as the damage costs that incur from wildland fires varies so greatly. One of the varied costs is the replacement and repair of structures and remediate of the damaged properties. Then the rebuilding costs and replacing of the structures with laws requiring new buildings to meet new criteria as a result of state laws that may require more stringent building and construction practices far greater than the original building of the said structure. Also the estimate of damages to critical infrastructures such as power lines and delivery systems as it is difficult the collateral loses to businesses and individuals losing power for and unknown time. Also damages to railroads and bridges also to road way, freeways as it is impossible to gauge the actual lose amounts from commerce being impeded.

Many of the County's landfills, transfer stations, and closed disposal sites are situated in areas subject to wildfires. In 2003, the Old Fire burned through three separate sites and caused major damage at the Heaps Peak Transfer Station when the fire burned through the office building and Transfer Station site.

None of this takes into account the costs of labor and retardants, vehicle damages and fuel and wear and tear as well as equipment expended and used and or damaged. Along with replace any safety gear or injuries to any persons working to mitigate the wildland fire

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4.15 Flooding



The County has experienced severe and widespread flooding throughout its history. Several major drainage basins have the potential to subject residents and structures to a high risk of flooding. In addition, the cumulative increase in impervious surfaces has increased problems related to surface run- off. While complete avoidance or protection through control facilities is not practical, considerable improvement can be made through structural and non-structural methods.

The County currently utilizes land use zoning districts to prohibit habitable structures in floodways as defined by the federal requirements necessary to participate in the National Flood Insurance Program. The consistent adoption of overlays is needed to require special review, conditions, and the prohibition of some uses in floodplain areas (areas subject to 100-year floods), including dry lakes. In addition, there are land use policies and development standards that can be implemented, including reduction of impervious surfaces; increase of percolation, infiltration, and recharge; and the control of urban run-off. There is a need for the County to identify all areas of flood and drainage hazards, especially in the Desert Region where mapping is sparse, as well as areas with a heavy concentration of debris or the potential for dam inundation. Flood hazards are more comprehensively discussed in the Safety Background Report.

The vulnerable areas are addressed in the County's General Plan. See Sections 5 and 6 for additional information. San Bernardino County has seven (7) properties listed in the Repetitive Loss and Severe Repetitive Loss properties. All of the properties are single-family residences. The properties are located in:

- Barstow – 2 properties (1999 and 2005)
- Crestline (1980 and 1982)
- Forest Falls (1995 and 1999)
- Lake Arrowhead (1998 and 2005)
- Lytle Creek (1998 and 2005)
- Sugarloaf (1993 and 1995)

These properties were damaged during unusual storms and/or immediately after a wildfire in the area and are isolated properties in widely scattered areas of the County. The properties were not damaged during the 2009 or 2010 winter storm events. Property addresses are not listed to comply with privacy laws.

The areas are now covered by the County General Plan and County Ordinance. These are in compliance with the National Flood Insurance Program.

4.15.1 Population at Risk

Of greatest concern in the event of a flood is the potential for loss of life. Using 2012 population data aggregated by census blocks, an estimate was made of the population exposed to the 100 and 500-year floodplain. To account for census blocks that were partially within the floodplain, a weighted average was employed to calculate the proportion of the population within the floodplain. The results of the population overlay are shown in Figure 4-31. More than 9,500 residents live near or within the 100-year floodplain and approximately 13,346 county residents live within the 500-year floodplain. Approximately 18,816 county residents live within areas protected by levees.

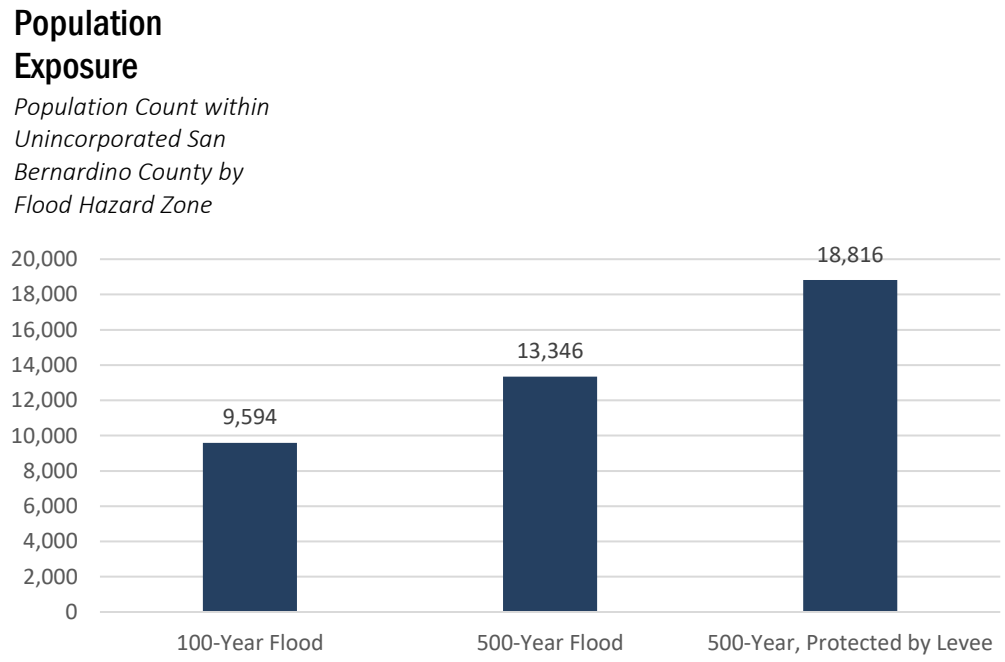


Figure 4-31: Population Exposed to NFIP Flood Zones

4.15.2 Residential Parcel Value with Flood Risk

The County's parcel layer was used as the basis for the inventory of improved residential parcels within the FEMA NFIP flood zones. In some cases, a parcel will be within in multiple flood zones. GIS was used to create centroids, or points, to represent the center of each parcel polygon – this is assumed to be the location of the structure for analysis purposes. The centroids were then overlaid with the floodplain layer to determine the flood risk for each structure. The flood zone in which the centroid was located was assigned to the entire parcel. This methodology assumed that every parcel with a square footage value greater than zero was developed in some way. Only improved parcels greater than $20,000 were analyzed.

Table 4-23 shows the count of at-risk parcels and their improvement and land exposure values.

Table 4-23: Parcels Exposed to NFIP Flood Zones

Flood Hazard Zone	Improved Parcel Count	Improvement Value Exposure ($000)	Land Value Exposure ($000)	Total Exposure ($000)
100-Year Flood	3,426	$ 518,483	$ 368,058	$ 886,541
500-Year Flood	3,397	$ 833,287	$ 338,728	$ 1,172,014
500-Year, Protected by Levee	4,608	$ 1,327,942	$ 527,317	$ 1,855,259
Grand Total	11,431	$ 2,679,711	$ 1,234,103	$ 3,913,814

While there are several limitations to this methodology, it does allow for potential loss estimation. It should be noted that the analysis may include structures in the floodplain that are elevated at or above the level of the base flood elevation, which will most likely decrease potential flood damage to these structures. Also, it is important to remember that the County Assessor's values are well below actual market values; thus, the actual value of assets at risk may be significantly higher than those included herein.

4.15.3 Critical Facilities Exposure

Critical facilities data were overlain with flood hazard data to determine the type and number of facilities within the 100- and 500-year floodplain. Flooding poses numerous risks to critical facilities and infrastructure:

- Roads or railroads that are blocked or damaged can prevent access throughout the area and can isolate residents and emergency service providers needing to reach vulnerable populations or to make repairs.
- Bridges washed out or blocked by floods or debris from floods also can cause isolation.
- Creek or river floodwaters can back up drainage systems causing localized flooding.
- Floodwaters can get into drinking water supplies causing contamination.
- Sewer systems can be backed up causing waste to spill into homes, neighborhoods, rivers, and streams.
- Underground utilities can also be damaged.

Tables 4-24 and 4-25 provide an inventory of critical facilities in the floodplain for San Bernardino County and it provides the location of lifelines relative to the floodplain in the areas of the San Bernardino County. With a total of 810 essential facilities, high potential losses, and transportation and lifeline structures located in either the 100 or 500-year flood zone, the impact to the community could be devastating if these critical facilities were damaged or destroyed during a flood event.

Table 4-24: Critical Facility Exposed to NFIP Flood Zones

Infrastructure Type	100 Year Flood Zone	500 Year Flood Zone	500 Year Flood Zone, Protected by Levee	Feature Count
Essential Facility	21	114	5	140
EOC	0	1	0	1
Fire Station	4	27	2	33
Hospital	0	4	0	4
Police Station	2	23	0	25
School	15	59	3	77
High Potential Loss	52	458	52	562
Child Care Center	13	57	3	73
Child Residential Care - 24 hour	0	2	0	2
Foster Family Agency	0	2	0	2
Adult Residential Care	0	37	3	40
Home Care Organization	0	2	0	2
Elder Residential Care	0	24	8	32
Communication Facility	0	7	0	7
Dam	2	3	0	5
Waste Water Facility	1	0	0	1
HAZMAT	0	16	1	17
EPA FRS Facility	33	286	35	354
FCC ASR	3	22	2	27
Transportation and Lifeline	26	77	5	108
Airport	2	5	0	7
Runway	2	5	0	7
Bus Facility	1	1	0	2
Highway Bridge	20	65	5	90
Railway Bridge	1	1	0	2
Grand Total	**99**	**649**	**62**	**810**

Table 4-25: Lifelines Exposure to NFIP Flood Zones

Facility Type	100 Year	500 Year Flood Zone	500 Year Flood Zone, Protected by Levee	Total Mileage
Transportation and Lifeline	204	1,952	69	2,225
Railway	9	44	6	59
Roads	195	1,908	63	2,166
Interstate Highway	1	34	1	36
State / County Highway	20	189	9	218
Primary Highway	7	20	-	28

Facility Type	100 Year	500 Year Flood Zone	500 Year Flood Zone, Protected by Levee	Total Mileage
Local Road, Major	32	377	38	447
Local Road	115	1,168	13	1,295
Other Minor Road	18	86	2	107
Vehicular Trail	2	15	-	17
Cul-de-Sac / Traffic Circle	0	1	-	1
Ramp	0	18	0	19
Grand Total	**204**	**1,952**	**69**	**2,225**

4.15.4 Loss Estimation Results

The Hazus analysis was used to assess the risk from and vulnerability to flooding within San Bernardino County. Hazus buildings data is aggregated to the census block level, known as the general building stock (GBS), which has a level of accuracy acceptable for hazard mitigation planning purposes. The following sections describe risk to and vulnerability of the GBS within the San Bernardino County mapped regulatory floodplain. The total value of exposed buildings and content within the San Bernardino planning area was generated using Hazus and is previously summarized.

Hazus calculates losses to structures from flooding by considering the depth of flooding and type of structure. Using historical flood insurance claim data, the software estimates the percentage of damage to structures and their contents by applying established depth-damage curves. Damage estimates are then translated to estimated dollar losses. The results are summarized in Tables 4-26 and 4-27 and Figure 4-32. While there are several limitations to the FEMA Hazus model, it does allow for potential loss estimation. It should be noted that the analysis may include structures in the floodplain that are elevated at or above the level of the base flood elevation, which will likely mitigate flood damage. Also, it is important to remember that the replacement costs are well below actual market values, thus, the actual value of assets at risk may be significantly higher than those included herein.

Table 4-26: Flood Loss Estimation (Based on Depth) in NFIP Flood Zones

Flood Hazard Zone	Building Loss ($000)	Building Loss (% of Total Value)	Content Loss ($000)	Content Loss (% of Total Value)	Total Estimated Loss ($000)	Total Estimated (% of Total Value)
100-Year	$ 34,749.00	0.1%	$ 24,858.00	0.1%	$ 59,849.00	0.2%
500-Year	$ 218,454.00	0.8%	$ 173,304.00	0.6%	$ 396,336.00	1.4%

Table 4-27: 100 Year Flood Los Estimation (Based on Depth) in NFIP Flood Zones by Occupancy Type

Building Type	Building Replacement Costs ($000)	Building Replacement Cost (% of Total Value)	Content Replacement Cost ($000)	Content Replacement Cost (% of Total Value)	Total Estimated Loss ($000)	Total Loss Estimation (% of Total Value)
Agriculture	$ 147.00	0.10%	$ 246.00	0.17%	$ 427.00	0.30%
Commercial	$ 1,874.00	0.08%	$ 4,458.00	0.18%	$ 6,463.00	0.26%
Education	$ 46.00	0.02%	$ 271.00	0.11%	$ 319.00	0.13%
Government	$ 56.00	0.07%	$ 304.00	0.39%	$ 370.00	0.48%
Industrial	$ 201.00	0.02%	$ 389.00	0.04%	$ 624.00	0.06%
Religious/Non-Profit	$ 326.00	0.09%	$ 1,946.00	0.55%	$ 2,279.00	0.65%
Residential	$ 32,099.00	0.14%	$ 17,244.00	0.07%	$ 49,367.00	0.21%
Grand Total	**$ 34,749**	**0.13%**	**$ 24,858**	**0.09%**	**$ 59,849**	**0.22%**

100 YR Flood Hazard

Estimated Content Loss by Occupancy Type

100 YR Flood Hazard

Estimated Building Loss by Occupancy Type

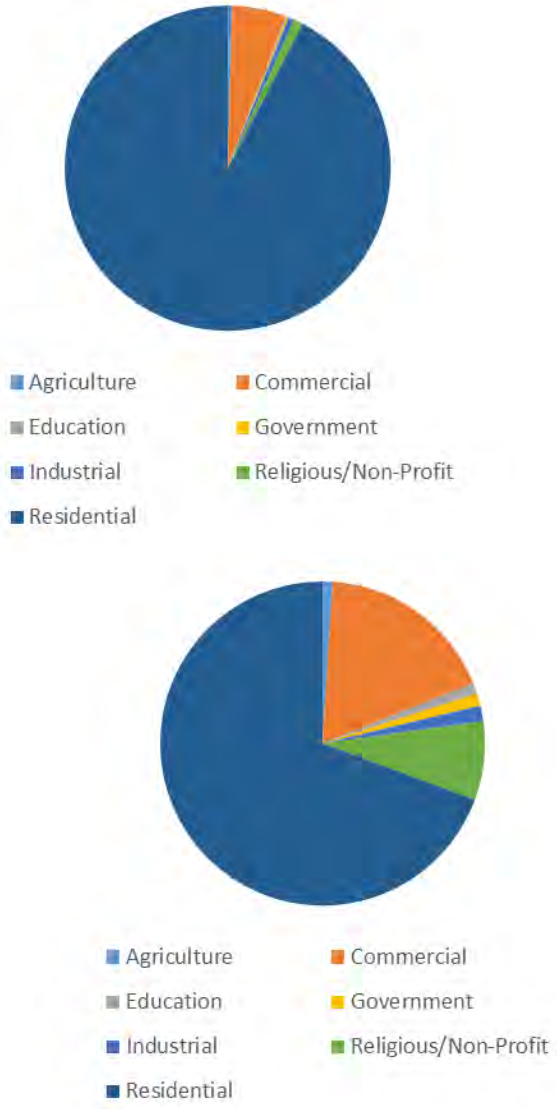
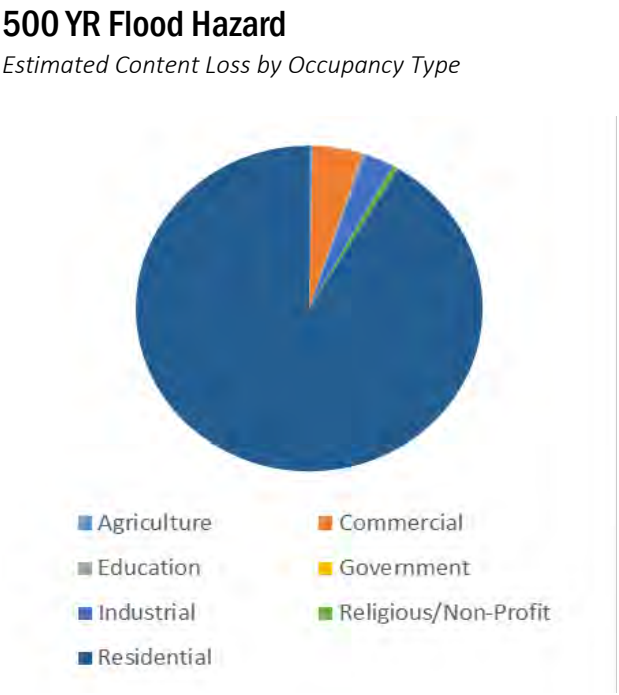


Figure 4-32: Total Building and Content Loss by Occupancy Type for 100 Year Flood

Table 4-28: 500 Year Flood Loss Estimation (Based on Depth) In NFIP Flood Zones by Occupancy Type

Building Type	Building Replacement Costs ($000)	Building Replacement Cost (% of Total Value)	Content Replacement Cost ($000)	Content Replacement Cost (% of Total Value)	Total Estimated Loss ($000)	Total Loss Estimation (% of Total Value)
Agriculture	$ 674.00	0.48%	$ 981.00	0.69%	$ 1,781.00	1.26%
Commercial	$ 10,080.00	0.41%	$ 27,640.00	1.13%	$ 39,179.00	1.61%
Education	$ 720.00	0.29%	$ 3,563.00	1.44%	$ 4,355.00	1.76%
Government	$ -	0.00%	$ 2.00	0.00%	$ 9.00	0.01%
Industrial	$ 6,036.00	0.57%	$ 13,975.00	1.31%	$ 22,438.00	2.11%
Religious/Non-Profit	$ 1,210.00	0.34%	$ 6,070.00	1.72%	$ 7,332.00	2.08%
Residential	$ 199,734.00	0.86%	$ 121,073.00	0.52%	$321,242.00	1.38%
Grand Total	**$ 218,454**	**0.79%**	**$ 173,304**	**0.63%**	**$ 396,336**	**1.44%**



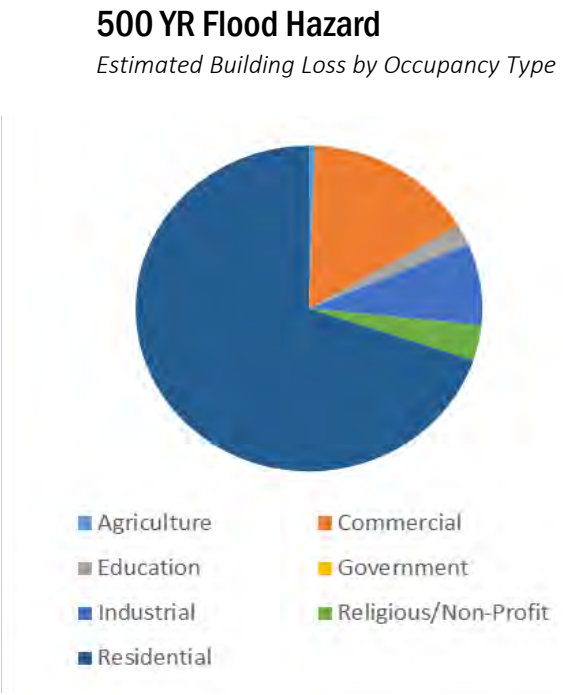


Figure 4-33: Total Building and Content Loss by Occupancy Type for 500 Year Flood

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4.16 Drought



Drought should not be viewed as merely a physical phenomenon or natural event. Its impacts on society result from the interplay between a natural event (less precipitation than expected resulting from natural climatic variability) and the demand people place on water supply.

Due to the lack of defined geographical boundaries, the vulnerability assessment for drought differs from other natural hazards. The impacts of drought can be categorized as economic, environmental, or social. Many economic impacts occur in agriculture and related sectors, including forestry and fisheries, because of the reliance of these sectors on surface and subsurface water supplies. In addition to obvious losses in yields in crop and livestock production, drought is associated with increases in insect infestations, plant disease, and wind erosion. Droughts also bring increased problems with insects and diseases to forests and reduce growth. The incidence of forest and range fires increases substantially during extended droughts, which in turn places human and wildlife populations, buildings, infrastructure and critical facilities, at higher levels of risk.

Income loss is another indicator used in assessing the impacts of drought because so many sectors are affected. Reduced income for farmers has a ripple effect. Retailers and others who provide goods and services to farmers face reduced business. This leads to unemployment, increased credit risk for financial institutions, capital shortfalls and loss of tax revenue for local, state and federal government. Less discretionary income affects the recreation and tourism industries. Prices for food, energy and other products increase as supplies are reduced. In some cases, local shortages of certain goods result in the need to import these goods from outside the stricken region.

4.16.1 Loss Estimation Results

No standardized methodology exists for estimating losses due to drought. Drought does not generally have a direct impact on critical and non-critical facilities and building stock. Instead, drought vulnerability is primarily measured by its potential impact to sectors of the County's economy and natural resources. In San Bernardino County some of the potential impacts to the economy include the following:

- Reduced agricultural and livestock production;
- Loss of timber from increased wildfires;
- Decreased municipal and industrial water supply;
- Loss of recreation/tourism; and
- Decreased wildlife and wildlife habitat.

4.16.2 Statewide Mandatory Water Reductions

Recognizing persistent, yet less severe, drought conditions throughout California, on May 18, 2016 the State Water Resources Control Board adopted an emergency water conservation

regulation requiring locally developed conservation standards based upon each water supplier's specific circumstances. It replaces the prior percentage reduction-based water conservation standard. In San Bernardino County, each water wholesaler (Mojave Water Agency) was required to calculate the supply of water for the next three years, considering drought conditions persist. Each water supply retailer subsequently self-certified the expected demand on water resources, determining whether or not there is sufficient supply to meet demand. Our Department certified that there is sufficient water supply to meet the demand over the next three years; however due to ongoing drought conditions in the region, water conservation efforts should continue. The County has developed a watering schedule, watering hour restrictions and additional end user watering restrictions which can be viewed here: http://www.specialdistricts.org/index.aspx?page=548

4.17 Terrorism



Translating most manmade hazard profiles into meaningful geospatial information is difficult at best. Instead, the planning team will use an asset-specific approach. Population, facilities, systems and assets will be prioritized and assessed in this vulnerability assessment.

Special consideration should be given to areas with high density and those containing vulnerable populations (young, old, and those whose primary language is not English).

Facilities at high risk may include gathering places, critical facilities/ transportation and lifelines and utilities.

4.17.1 Population at Risk

Since terrorism can happen anytime, anywhere, 100% of the population is vulnerable to terrorism. In particular, people with access and functional needs, the elderly and the very young are especially vulnerable because they often rely heavily on others in their daily lives. Persons with English as a second language are also vulnerable as they may not receive warnings or notifications related to an incident in their primary language.

4.17.2 Critical Facilities Exposure

Critical facilities may include essential facilities (such as hospitals, police and fire stations, evacuation centers, etc.), transportation systems, lifeline utility systems, high potential loss facilities (such as nuclear power plants, dams and military installations, etc.), and hazardous material facilities.

Gathering facilities should also receive special attention. Places of mass gathering not only present terrorists with potential opportunities for mass casualties, symbolism and high impact media coverage, they pose a broad range of security challenges for their owners and operators. The National Counter Terrorism Committee has noted that places of mass gathering have been specifically identified by religious and political extremists as attractive targets.

Places of mass gathering incorporate a diverse range of facilities including, but not limited to, sporting venues, shopping and business precincts, tourism/entertainment venues/attractions, hotels and convention centers, major events and public transport hubs. This also includes significant one off events.

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4.18 Climate Change



The vulnerability assessment for climate change is different from other natural hazards discussed in this HMP due to the lack of defined geographical boundaries. This section provides a summary of San Bernardino County's vulnerability to climate change.

The most serious threats to the public health of Californians will stem primarily from the higher frequency of extreme conditions, principally more frequent, more intense, and longer heat waves. A heat wave is defined as 5 or more consecutive extreme heat days. An increase in heat waves may increase the risk of directly related conditions such as heat stroke and dehydration.

In the desert areas of the County, the Extreme Heat Day Threshold temperatures are around 110°F and in the mountainous regions it is in the mid 80's. According to the Cal-Adapt Extreme Heat Tool, the number of extreme heat days (a day in April through October where the maximum temperature (Tmax) exceeds the 98th historical percentile of maximum temperatures based on daily temperature data between 1961 and 1990) will continue to increase rapidly from the present day to 2090.

Projections by Scripps Institution of Oceanography show little change in total annual precipitation in San Bernardino County. However, even modest changes would have a significant impact because California ecosystems are conditioned to historical precipitation levels and water resources are nearly fully utilized. The Mediterranean seasonal precipitation pattern is expected to continue, with most precipitation falling during winter from North Pacific storms. In the mountainous areas of the County, it is projected that the decadal average of snowpack will continue to decrease until 2090. As shown in Figure 4-34 the sharpest decreases in snowpack are projected to begin around 2030. The area projected to be burnt by wildfire toward the end of the century will not increase substantially in the County. The most change will be experienced in the mountainous regions.

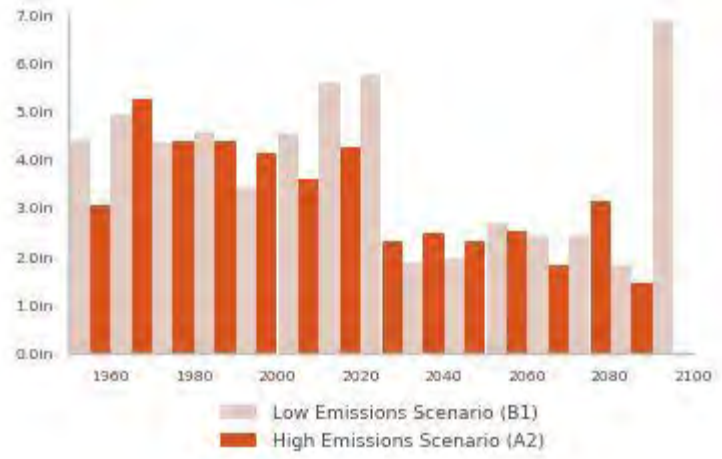


Figure 4-34: Decadal Snowpack Averages 1960-2090

Source: cal-adapt.org/snowpack/decadal

4.18.1 Population at Risk

Vulnerable populations should receive special attention when assessing the community's vulnerability to climate change. For example, care and sheltering during extreme heat conditions must be provided for vulnerable populations such as the elderly. Heat kills by taxing the human body beyond its abilities. In a normal year, about 175 Americans succumb to the demands of summer heat. According to the National Weather Service (NWS), among natural hazards, only the cold of winter—not lightning, hurricanes, tornados, floods, or earthquakes—takes a greater toll. In the 40-year period from 1936 through 1975, nearly 20,000 people were killed in the United States by the effects of heat and solar radiation. In the heat wave of 1980, more than 1,250 people died.

Section 5. Community Capability Assessment

5.1 Existing Plans, Policies and Programs

San Bernardino County is encouraging all departments, special districts, and agencies to share reports and common information. This sharing and exchanging of ideas has led to more coordinated efforts and better planning. The driving document in the County of San Bernardino is the County's General Plan. The County General Plan provides the foundation on which all development and future programs are built upon.

5.1.1 San Bernardino County General Plan

The State of California recommends that the General Plan is updated every 10-20 years; depending mostly on whether or not the plan is meeting the community's needs. The San Bernardino County General Plan was last updated and adopted in 2007. There are seven (7) mandatory elements in a General Plan:

- Circulation Element,
- Conservation Element,
- Housing Element,
- Land Use Element,
- Noise Element,
- Open Space Element, and
- Safety Element.

However, there are several optional elements. The County of San Bernardino General Plan includes an optional element, the Economic Development Element.

The Land Use Element of the General Plan establishes 18 land use zoning districts that apply only to lands governed by the County; not for lands controlled by other jurisdictions or lands controlled by federal and state government (see Section 1.3.5, page 8 for a listing of the 18 Land Use districts in the Land Use Element). The Land Use Element also describes land use compatibility for the primary three (3) hazards: Geologic; Flood; and, Wildfire. Because of these commonalities between the General Plan and the MJHMP, the county Board of Supervisors has adopted the MJHMP as part of the County's General Plan.

5.1.2 Regulations, Code, Policies and Ordinances

The following titles of the San Bernardino County Code include regulations and ordinances on the following issues and topics related to hazard mitigation:

Table 5-1: County Development Code Hazard Crosswalk

Hazard	Plan/Program/ Regulation	Description
Multi-Hazard	**Title 2**	Emergency Services Uniform Fire Code and related miscellaneous fire regulations Police Regulations and Public Protection
Multi-Hazard	**Title 3**	Emergency Medical Services Domestic Water Sources and Systems Hazardous Materials and Toxics Control Waste Management
Multi-Hazard	**Title 6**	California Building Code California Electrical Code California Plumbing Code California Mechanical Code
Multi-Hazard	**Title 7**	Airport Rules and Regulations
Multi-Hazard	**Title 8**	Development Code includes regulations relative to Land Use, Development Standards, Safety Standards, and Environmental Protection.
Multi-Hazard	**Zoning Ordinances**	The County has also adopted Zoning Ordinances that are not part of the County Code but are part of the General Plan. These ordinances regulate land use; map the official land use and hazard overlay districts to include safety hazard and environmental protection areas.

5.1.3 Local Programs for Mitigation Implementation

The information in Table 5-2 is used to construct mitigation actions aligned with existing planning and regulatory capabilities of the County. Planning and regulatory tools typically used by local jurisdictions to implement hazard mitigation activities are building codes, zoning regulations, floodplain management policies, and other County programs or planning documents.

Table 5-2: Planning and Regulatory Mitigation Capabilities Summary

Hazard	Plan/Program/ Regulation	Responsible Agency	Comments
Multi-Hazard	Mountain Mutual Aid	Fire District	Mountain Mutual Aid is an operational group of emergency responders. It is comprised of all of the agencies and volunteer relief groups that would be and have been involved in any and all disasters on the mountain. It is of note to that their main and most frequent call to service is in response to a wildfire. They meet monthly and maintain themselves in a constant state of readiness.
Wildfire	Forest Care	Cal Fire	Forest Care is a program dedicated to creating a healthier forest. This program provides foresters to assess individual properties for thinning the vegetation and then provides 75% of the funding to do so. Funding originates at the Federal level but is passed through Cal Fire and it employs Cal Fire Foresters as well as staff from the National Forest Association

5.1.3.1 Public Education and Alert Programs

Table 5-3: Public Education and Alert Programs

Hazard	Program	Responsible Agency	Comments
Multi-Hazard	MAST	Multiple	Mountain Area Safety Taskforce (MAST) has a substantial public education component. All agencies participate with the goal to have no one on the mountain uneducated about creating a thinner forest which is a more fire safe forest. For more information on MAST, see Annex A Section A.6 Fire Protection District Mitigation Project .
Multi-Hazard	CERT	Fire District	The Community Emergency Response Team (CERT) Program educates people about disaster preparedness and trains them in basic response

Hazard	Program	Responsible Agency	Comments
			skills. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .
Multi-Hazard	Listos	Fire District	Listos, which means “ready” in Spanish, is a twelve-hour disaster preparedness course created specifically for the Spanish-speaking community and is delivered entirely in Spanish. The program is intended to be adaptable, flexible and culturally relevant. This means participants are encouraged to involve the entire family and accommodations are made for young children. San Bernardino County Fire, Office of Emergency Services currently partners with the Cities of Fontana and Rialto to bring Listos to their communities
Multi-Hazard	California Disaster Corps	Fire District	The Disaster Corps is a first-in-the-nation effort to professionalize, standardize and coordinate highly trained disaster volunteers statewide. This program initiative was built collaboratively in partnership with California Volunteers from the ground up through public-private partnerships and with a wide range of subject matter experts. See Annex A Section A.6 Fire Protection District Mitigation Project .
Multi-Hazard	TENS	Fire District	Telephone Emergency Notification Systems (TENS) During an emergency, public safety can be a direct function of the speed and accuracy of the dissemination of information. This is particularly important during emergencies that require evacuations. To that end the Board of Supervisors dedicated General Fund money in 2003 to the implementation of an automated phone dialing system that calls telephones in specific geographic areas of concern. All areas of San Bernardino County have all been preprogrammed so that during an emergency, the specific target group can be notified as quickly as possible.

Hazard	Program	Responsible Agency	Comments
Multi-Hazard	ECS	Fire District	The Emergency Communications Service (ECS) is a volunteer group providing front-line communications, technical and logistical support to the San Bernardino County Fire Department and Office of Emergency Services. Their primary mission is to support County Fire, County Government and other local agencies in time of disaster. In addition, ECS has provided telecommunications and event support to other County departments including Public Health, Behavioral Health, Public Works, Pre-School Services, Sheriff's Search and Rescue and other County Departments.
Multi-Hazard	AM Radio	Fire District	Community Based AM Radio Transmitters The Fire Safe Councils discovered the existence of very inexpensive but very effective community based AM radio transmitters. The transmitters are very effective for providing information and updates to a community that is either preparing for a community emergency or just had one. As a delivery modality they are extremely reliable because in most all emergencies the AM radio in your car is likely to be operational particularly when the electricity is out in your house.
Multi-Hazard	IPAWS	Fire District	During an emergency, alert and warning officials need to provide the public with life-saving information quickly. The Integrated Public Alert and Warning System (IPAWS) is a modernization and integration of the nation’s alert and warning infrastructure and will save time when time matters most, protecting life and property. Federal, State, Territorial, Tribal, and local alerting authorities can use IPAWS and integrate local systems that use Common Alerting Protocol (CAP) standards with the IPAWS infrastructure. IPAWS provides public safety officials with an effective way to alert and warn the public about serious emergencies using the Emergency Alert System (EAS), Wireless Emergency Alerts (WEA), the

Hazard	Program	Responsible Agency	Comments
			National Oceanic and Atmospheric Administration (NOAA) Weather Radio, and other public alerting systems from a single interface.

5.1.3.2 Wildfire Mitigation Programs

San Bernardino County has one of the most comprehensive set of programs to mitigate the potential for catastrophic wildfires in the Nation. There is no other jurisdiction that has the comprehensive, multi-agency cooperation and coordination as is found in San Bernardino County. See Annex A Section A.6 Fire Protection District Mitigation Project to see how the Fire Protection District will implement the following programs:

Table 5-4: Wildfire Mitigation Programs

Hazard	Program	Responsible Agency	Comments
Wildfire	MAST	Multiple	The mission of the MAST is to facilitate a coordinated effort by cities, county, state, federal, and non-profit agencies to provide for protection from wildfire. For more information on MAST, see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	Community Based Fuels Reduction program	Fire District	This program is designed to create community based fuel modification programs across the mountain communities. For more information see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	Cal Fire	Cal Fire	Cal Fire provides programs to increase fire safety in high fire hazard severity zones. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	County Fire Hazard Abatement	Fire District	Fire Hazard Abatement works to reduce the potential for an individual's property to be the source of fire and structural ignitability. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .

Hazard	Program	Responsible Agency	Comments
Wildfire	Contractor Certification	City of Big Bear Lake Fire Department	This program trains and certifies landscape contractors to provide a qualified workforce to conduct fuels reduction activities on individual properties. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	Southern California Edison (SCE)	Southern California Edison (SCE)	SCE removes dead trees near power lines to reduce fire hazards. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	Wood Shake Roof Replacement	County	This code requires that all Wood Shake Roofs in the Fire Safety Overlay, as defined in the Development Code, ongoing effort.
Wildfire	Inland Empire Fire Safe Alliance	Inland Empire Fire Safe Alliance	The Alliance was created to act as a forum for all Fire Safe Councils in San Bernardino County. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	Community Wildfire Protection Plans (CWPP)	Fire District	CWPPs are designed to provide a means for a community to have input into and actively participate in the planning, strategy, goals, and objectives of creating a fire safe community. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	Organized Group Volunteer Activities	Fire District	There are several volunteer citizen groups throughout the County that are capable of providing significant resources that are not provided by traditional governmental agency services. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .

5.1.3.3 Earthquake/Geologic Mitigation Programs

San Bernardino County's seismic mitigation programs focus on two areas that have historically resulted in the greatest amount of damage and life loss from major earthquakes in California.

5.1.3.3.1 Bridge Retrofit Program

Caltrans inspects County and City bridges yearly every 2 years for structural sufficiency (which applies to earthquake) and functional obsolescence (which applies to floods). Caltrans provides reports that include recommended repairs or replacement. The County and Cities make the repairs and/or apply for bridge replacement funds thru the Federal Highway Bridge Program (HBR). Currently the County has 5 funded HBR replacements due to structural deficiencies:

- Dola Ditch, (out for bid to construct)
- Lanzit Ditch, (out for bid to construct)
- Garnett at Mill Creek (under construction)
- Yermo Rd at Manix Wash.(waiting for SCAG approval for additional funds to move forward with the Design & Environmental)
- Baker Blvd west of SR127. (waiting for HBP fund for Design & Environmental)
- National Trails Hwy at Kalmia Bridge (waiting for HBP funds)
- National Trails HWY @ Adena Ditch (Received HBP funds for design phase)
- Bridge Management (consultant on board that has prioritized all timber bridges on National Trails Highway and DPW is submitting groups of bridges for funding over a ten year period)

The design and environmental work has been started for Rock Springs Road (functionally obsolete bridge) using DPW funds, waiting for HBP funds for R/W phase.

The County has completed the construction of the Alabama Street at Plunge Creek bridge replacement using Federal Emergency Relief funds.

5.1.3.3.2 Unreinforced Masonry Building Program

In the 1990's, the County of San Bernardino compiled a master list of suspected Unreinforced Masonry Buildings within the unincorporated areas. Since that time, several sites have been incorporated and therefore, are now removed from County jurisdiction. In addition, several appear to have been demolished or retrofitted since the 1990's. The Land Use Services Department's Building and Safety Division is currently in the process of re-evaluating the URM list. Re-evaluation will include a field visit to each site photographing structures and verifying the occurrence of unreinforced masonry. This process is scheduled to be completed by the end of the 2010.The program would be an inspection program and maintenance and inspections as warranted.

There are no large publically utilized URM structures currently on the list. These types of structures are typically restricted to the incorporated areas of the County. There are only twenty-two (22) structures remaining on the list.

5.1.3.3.3 Geologic Hazard Mapping

The Seismic Hazards Mapping Act (Public Resources Code, Chapter 7.8 Section 2690-2699.6) directs the Department of Conservation, California Geological Survey (CGS) to identify and map areas prone to liquefaction, earthquake-induced landslides and amplified ground shaking. Although the San Bernardino area has a full spectrum of geologic hazards, CGS does not have adequate funding to complete the hazard mapping within the County.

5.1.3.4 Flood Mitigation Programs

The flood mitigation projects are programs that were established by San Bernardino County Flood Control District to protect life and property. These projects are typically designed to convey 1% annual chance or greater storm flows in order to mitigate danger to life and property, and critical infrastructure consisting of existing, new and future structures. Also, these projects include revisions to local land use and building codes where analysis or experience shows the need for code revisions or amendments to meet previously unidentified circumstances.

Hazard	Program	Responsible Agency	Comments
Flood	Flood Area Safety Taskforce(FAST)	Flood Control District	The FAST Organization stresses liaison with the communities, provides for community education and information, and places emphases on Community and city partnerships. For more information on FAST, see Annex B Section B.6 Flood Project Prioritization and Implementation.
Flood	Alluvial Fan Task Force	Alluvial Fan Task Force	The Task Force reviews the state of knowledge regarding alluvial fan floodplains, determine future research needs, and, if appropriate, develop recommendations relating to alluvial fan floodplain management, with an emphasis on alluvial fan floodplains that are being considered for development. For more information, see Annex B Section B.6 Flood Project Prioritization and Implementation.
Flood	StormReady	Flood Control District	San Bernardino County is a StormReady County. For more information, see Annex B Section B.6 Flood Project Prioritization and Implementation.

5.1.3.5 Climate Change Programs

5.1.3.5.1 Extreme Heat, Extreme Cold Programs

This document is a contingency plan supporting the San Bernardino County Emergency Operations Plan (EOP).

Excessive Cold events are commonplace in San Bernardino County and most often warrant monitoring activities only. These Standard Operating Guidelines provide GUIDANCE based on the most likely scenario, and can be expanded to meet the parameters of a “disaster” scenario if necessary.

The Extreme Weather – Excessive Cold Standard Operating Guidelines (SOG) were developed in response to the potential for Excessive Cold and cold related Power Outage events in San Bernardino County. The following objectives and activities are to prevent the harmful effects of excessive cold on at-risk populations and the potential for life-threatening repercussions of power outages during excessive cold events.

The information included in this plan is “situation” and/or “incident” driven and subject to revision by the Extreme Weather Committee as conditions warrant. Notifications are information dependent and modification of the activities in these guidelines may be required in response to changing conditions, situations and/or inaccurate weather predictions

5.1.3.5.2 San Bernardino County Fire Office of Emergency Services Heat Plan

This document is a contingency plan supporting the San Bernardino County Emergency Operations Plan (EOP). The Extreme Weather – Excessive Heat Standard Operating Guidelines (SOG) were developed in response to the potential for Excessive Heat and heat related Power Outage events in San Bernardino County. The following objectives and activities have been established to prevent the harmful effects of excessive heat on at-risk populations and the potential for life-threatening repercussions of power outages during excessive heat events. The Extreme Weather – Excessive Heat SOG describe the County operations during heat related emergencies and provide guidance for local jurisdictions in their preparation for heat emergencies and other related activities. The information included in this plan is “situation” and/or “incident” driven and subject to revision by the Extreme Weather Committee as conditions warrant. Notifications are information dependent and modification of the activities in these guidelines may be required in response to changing conditions, situations and/or inaccurate weather predictions.

5.2 Fiscal Resources

The 2016-17 recommended budgets of $5.4 Billion are balanced and consistent with policy and direction received from the Board of Supervisors. The 2016-17 Recommended Budgets address the following key issues:

- Ongoing funding for neglected raises for County employees
- Ongoing funding for maintenance of County roads
- Continues investment in facilities, infrastructure and operating systems.
- Ongoing funding of mental health and medical services for County residents.
- Maintains fiscal responsibility through contributions to the reserves of $62.8 million.

The budget represents the County General Fund and County restricted general funds .It also presents capitol project funds, special revenue funds, enterprise funds, internal service funds and permanent funds for all entities in the 2016-17 Recommended Budget including the County Board Governed County Service Areas, San Bernardino County Fire Protection District, San Bernardino County Flood Control District. Other agencies presented in the budget include County Industrial Development Authority, Inland Counties Emergency Medical Agency and the recently added Housing Authority of the County of San Bernardino. The total requirements for these funds in the 2016-17 are $5.4 billion, which includes amounts budgeted as contingencies or contributions to reserves. Excluding these amounts, total projected expenditures for the 2016-17 are $5.3 billion. The General fund Requirements total $2.9 billion and are funded by countywide discretionary revenues (primary property taxes), departmental revenues and other funding sources of the General Fund, of this $2.9 billion, only $558.3 million is truly discretionary.

5.2.1 The Budget in Brief

This budget book collectively presents the general fund, special revenue funds, capital project funds, internal service funds, and enterprise funds for the county and its Special Districts. The total spending authority for these funds in 2016– 2017 is $5.4 billion. The general fund spending authority totals $5.3 billion and is funded by countywide discretionary, and the beginning fund balance of the General Fund. Of this $2.9 billion, only $558.5 million is truly discretionary.

Table 5-5: Spending Authority for San Bernardino County

	Spending Authority (in Millions)		
	2015-16	**2016–2017**	**Change**
General Fund	$ 2,984.3	$ 2,911.1	$ (73.2)
Restricted Funds	49.3	49.7	(.4)
Capital Project Funds	1169.	911.3	(258.4)
Special Revenue Funds	257.6	298.4	40.7
Enterprise Funds	984.9	1001.	16.5
Internal Service Funds	1.6	0.0	(1.6)
	$ 5,692.0	**$ 5,420.0**	**272.0**

There is a $73.2 million net decrease in General Fund requirements due to a $106.1 million reduction in contributions to General Fund reserves, as the Board of Supervisors approved an increase to multiple County General Fund operational groups' requirements are increasing by $32.9 million. There are Law and Justice ($12.5 million). The Human Services Operational Group is anticipating increased State and Federal funding that will support Department of Behavioral Health services, including inpatient hospitalization, indigent hospital care, general mental health services, and services for children, youth, and families .The County is also continuing to allocate additional resources to meet the growing need for augmented health and mental health correctional services associated with Public Safety Realignment.

The net reduction of $258.4 Million is Special Revenue Funds is associated with the County's shift in 2015-16 from budgeting contingencies to instead placing unallocated resources in reserves. This technical change resulted in a large one-time contribution to reserves in 2015-16 that is not required in 2016-17. This reduction in contributions to reserves totaling $289.6 million is offset by increased operational costs of $31.2 million. This is due to increases within the Department of Behavioral Health's Mental Health Services Act (MHSA) budget unit and the County Fire Protection budget is increasing as a result of the pending annexation of fire prevention and suppression services from the City of San Bernardino (429.6 million) and Twentynine Palms ($1.7 million).

The $40.7 million increase in Capital Project Funds is primarily due to the planned construction of two Department of Behavioral funded Crisis Stabilization Centers and four Crisis Residential Treatment Centers totaling $36.5 million. This will enable Community Crisis Response Team (CCRT) clinics throughout the County to be expanded to provide 24 hour services and to respond to request by law enforcement for support during the night hours.

Enterprise Funds requirements are increasing a net $16.5 million. Notably, the Housing Authority of the County of San Bernardino has been added to the budget book and is contributing to the overall increase in Enterprise Fund requirements, including additional assumed payments for Housing Assistance and increased Capital Expenditures.

Table 5-6: 2015-2017 Staffing Budget

	Budgeted Staffing		
	2015–2016	2016–2017	Change
General Fund	14,332	14,425	93
Other Funds	6,375	6,508	133
Special Districts and Other Agencies	1402	15601	159
Total:	**22,109**	**36,534**	**385**

5.2.2 Budget Highlights (2016 – 2017)

Create and Maintain and Grow Jobs and Economic Value in the County

- The Real Estate Services Department of Project Management Division (formerly Architecture and Engineering) Capital improvement budget includes 355 active projects with total requirements of $295.2 million, including $128.2 million in new projects funded with $57.7 million of Discretionary General Funding includes an ongoing base budget of $12.0 million for maintenance and non-major Capital Improvement Plan (CIP) projects ,and $45.7 million for construction and major CIP projects .These major projects include $26.4 million for the 800 Megahertz Upgrade Project ,$12.2 million for various Sheriff's facility improvements ,$8.0 million for the County Buildings Acquisition and Retrofit Project including the upgrade of the County Government Center parking lots and grounds ,and $7.6 million for a variety of other projects.

Improve County Government Operations

- Enterprise Financial Management System: Implementation of the new system began in May 2016 with the first phase (out of two phases) continuing into 2016-17 at an estimated cost of $7.1 million. The total cost for the financial system is estimated to be $25.0 million and will streamline business processes and provide better management information.

- Public Health will continue its efforts to achieve and maintain National Accreditation, through the Public Health Accreditation Board (PHAB). Accreditation ensures the Department's continued focus on quality and performance improvement, transparency and accountability to all stakeholders, and the capacity to deliver core Public Health functions. The department will be submitting the required application to PHAB in December 2016.

- The County Library continues its plans to enhance service by replacing outdated computer hardware and software. Funding has been included in the Library's material's budget, which adds high demand items to the collection, including an expanded digital book collection.
- Land Use Services, in conjunction with Public Works, Information Services, and other County departments, continues to upgrade to a new enterprise permit solution, Accela. The new system will include a shared database, precise digital maps, and satellite images of land data that are linked to the County's GIS database. It will also provide field staff remote real-time access to the database. This solution will streamline the permitting process, offering the public access to a web portal to manage and monitor applications and permits online.

Operate in a Fiscally-Responsible and Business-like Manner

- The County Museum's budget of $3.8 million demonstrates the County's commitment to support the Museum through a time of transition. The budget includes $1.1 million in one-time Discretionary General Funding which includes bridge funds to support current operations and funding for activities related to re-accreditation. The County Museum continues to implement the consultant study recommendations as approved by the Board of Supervisors, to address organizational and financial challenges.

- The Transitional Assistance Department is in the second of a four year reduction to the State's CalFresh Match Waiver pursuant to the phase-out agreement adopted in the prior year State budget. This wavier allowed the County to draw additional Federal and half of the State funding without increasing the County's Maintenance of Effort. The budget includes the use of $2.5 million of the original $5.0 million general fund reserve that the Board approved in 2014-15 for this phase-out period.

Ensure Development of a Well-Planned, Balanced, and Sustainable County

- The County continues work on a complete overhaul of the County's General Plan, referred to as the Countywide Plan. This Countywide Plan will be a comprehensive web-based system to document land use planning and organizational governance policies. It will be comprised of three basic components: The Policy Plan (a comprehensive general plan); the County Business Plan (a system that will define and guide how the County government operates and manages itself); and the Regional Issues Forum (a web-based resource center containing information regarding shared Countywide issues). Additionally, the County is updating and expanding the community plans. When completed, there will be 27 web-based community plans involving 49 communities.

- A team of County departments will continue to monitor the drought and develop ways to reduce water usage at County facilities to show good stewardship of this valuable resource. The Special Districts Department, in collaboration with other County

departments, will continue to implement water conservation programs/strategies at various County Service Areas and Districts throughout the County.

- The Registrar of Voters budget fluctuates based on the 4-year election cycle, with the Presidential Election being the largest and most costly of the major elections. The Department is transitioning from a one minor and two major election cycles in 2015-16 to a one minor and one major election cycle for 2016-17. The budget includes provisions for the following: November 8, 2016 Presidential General Election (major); December 6, 2016 San Bernardino County Employees' Retirement Association Election (minor); and three anticipated, but unscheduled special elections (minor). The minor elections are 100% reimbursable; however, the November Presidential General Election is only 30% reimbursable and thus requires one-time Discretionary General Funding (Net County Cost) of $3.7 million for the year.

- The Public Works – Transportation budget includes over $35.0 million in major infrastructure projects, funded in part with Discretionary General Funding. Budgeted activities include design, right of way and/or construction for major projects including:
    - Bridge replacements on: Glen Helen Parkway, Baker Boulevard, Garnet Street, Rock Springs Road, Dola Ditch Bridge, Lanzit Ditch Bridge, Yermo Road and Arrowbear Drive;
    - New bridge on Shadow Mountain Road;
    - Widening of Slover Avenue in the Bloomington Area;
    - Installation of raised pavement markers on National Trails Highway in the Amboy area;
    - Reconstruction of Institution Road to improve access to the Sheriff facility in San Bernardino;
    - National Trails Highway Bridges: Bridge management plan for the repair, rehabilitation or replacement of 127 bridges on National Trails Highway and starting the design phase for replacement of 10 bridges:
    - Rehabilitation and re-profiling at various locations on Needles Highway in the Needles area;
    - Improvements to alleviate congestion and improve circulation of the interchange on Interstate 10 at Cedar Avenue

- The Public Works – Transportation budget includes $31.5 million worth of pavement improvement projects, funded in part with ongoing Discretionary General Funding, to preserve the County's roadways by investing enough to keep the system from deteriorating further.

- The Public Works – Solid Waste Management Division plans to complete $8.9 million of capital improvement projects, which includes the following:
    - $2.0 million for resurfacing the entrance and haul roads at the San Timoteo Landfill;
    - $957,000 for construction of Groundwater Treatment Systems at the closed Lenwood-Hinkley Landfill and Yucaipa Disposal Site;

- $1.5 million for the East Slope Stabilization and Mitigation project at the closed Heaps Peak Disposal Site;
- $1.5 million for construction of Landfill Gas Extraction Systems at the Barstow and Big Bear Landfills which includes $300,000 to bring electrical power to the Barstow Landfill

- The Public Works – Flood Control District (District) budget includes $37.6 million in capital improvement projects. The District anticipates completion of the following projects: Cactus Basin # 3, Wilson Creek Channel, Santa Ana River Flood Wall Repair, and the waterline relocations for Bandicoot Basin and Amethyst Basin. The District also plans to start construction on the following projects: Levee Certification Restoration for Patton Basin, Mojave River Levee, and Sand Creek/Warm Creek Confluence.

- Land Use Services Planning budget includes $150,000 of Discretionary General Funding for the preparation of a Morongo Basin Cultural Plan.

- The Special Districts department's budget includes $45.3 million capital improvement projects including the design and construction of the Big Bear Alpine Zoo relocation, rehabilitation of the Lake Gregory Dam, and construction of Snow Drop Road. Water and sanitation infrastructure projects of $19.2 million include pipeline replacements; water system improvements, and design and construction of a pipeline, a 75,000-gallon water reservoir, and a pump station in CSA 70 W-4 – Pioneertown.

- Community Development & Housing is constructing Phase 2 of the Bloomington Community and Neighborhood Revitalization. A total of 190 multi-generational affordable housing units include 120 family units and 70 senior units and the Bloomington Branch Library. The Bloomington Branch Library and the first phase of housing are completed. The second phase is currently under construction and will be completed by spring 2017.

Provide for the Safety, Health and Social Service Needs of County Residents

- The County is expanding efforts to provide homeless support to County residents through the flowing allocations included in the 2016-17 budget:
  - The Department of Behavioral Health is investing $4.0 million by providing basic needs, case management, outreach services, and additional built and supportive housing opportunities.
  - The Sheriff/Coroner/Public Administrator is continuing to fund the HOPE Program (Homeless Outreach Proactive Enforcement) Team ($620,000), which provides services to the homeless population by connecting them to the appropriate agencies for much needed services that help in the transition from homelessness.
  - The Probation Department has included $3.2 million towards transitional housing for adult offenders requiring Probation Department supervision.

- The Department of Behavioral Health is expanding Mental Health Treatment Services, notable in the following areas:
    - $1.0 million towards staffing Community Crisis Response Team clinics, which will now provide 24 hour services to departmental consumers and respond to requests by law enforcement for support during night hours. The department has also allocated $36.5 million towards the construction of new CCRT clinics throughout the County to expand these services.
    - $8.5 million for the Mental Health Act (MHSA) Comprehensive Children and Family Support Services program to support expanded mental health services for children.
    - $4.3 million for the MHSA Regional Adult Full Service Partnership (FSP) program support expanded mental health services to adults.
    - $1.0 million for the MHSA Forensic Integrated Mental Health Partnership program to expand services to develop peer support and mentoring strategies for individuals who have been released early from County jail or State prison.

- The Sheriff/Coroner/Public Administrator budget included $1.1 million of existing departmental resources for a program authorized by the Board as a pilot on December 15, 2015 (Item No. 72) related to the delivery of law enforcement services to unincorporated areas of the West End including the North Rancho/Etiwanda Preserve and the Mission Corridor, respectively. The program was successful and is now being incorporated as an ongoing service beginning in 2016-17 ,

- The Sheriff/Coroner/Public Administrator budget includes $9.0 million of one-time Discretionary General Funding (Net County Cost) to replace 2 aging and obsolete patrol helicopters: including equipment, travel and training for pilots and mechanics, installation of equipment, and delivery charges. The helicopter replacements will provide newer more reliable aircraft.
- The Public Defender Proposition 47 program will use media resources to reach all potential citizens who have convictions eligible for reclassification to further enhance their ability to rehabilitate within the community.

- County Fire is assuming fire, rescue, Emergency Medical Services (EMS), and prevention responsibilities within the Cities of San Bernardino ($29.6 million) and Twentynine Palms ($1.7 million) as a result of the pending annexations. This continued expansion of a regional approach will provide a more effective and efficient delivery of fire services for County residents.

- Land Use Services Code Enforcement is continuing to pilot various strategic initiatives to address issues with short-term rentals, particularly in the mountain areas. For 2016-17, a pilot program for a short-term rental hotline will be established where the public can report illegal or disruptive activities at short-term rental properties.

- The Information Services Department Telecommunication Services division is in the process of upgrading the County's Regional Public Safety Radio System (800 Mhz Upgrade Project). The project is currently on schedule, with an estimated completion date of 2020-21. The estimated cost of the project is $158.2 million primarily funded with Discretionary General Funding.

- The Department of Aging and Adult Services (DAAS) budget of $8.3 million will supplement programs such as the Elderly Nutrition, Supportive Services, Medicare Improvements for Patients and Providers Act, and Family Caregiver.

- The Arrowhead Regional Medical Center (ARMC) budget includes the addition of 14 positions to strengthen the Sterile Processing division to meet operational needs and ensure compliance with regulatory standards.

- The Department of Children and Family Services is implementing an After Hours Response Center (ARC) in June 2016 to provide optimal customer services to our community partners, children and families. The Center will enhance the departments critical after hour function of responding to child abuse, neglect and exploitation referrals called into the Child and Adult Abuse Hotline (CAAHL).

Pursue County Goals and Objectives by Working with Other Agencies

- ARMC is participating in California's 1115 waiver Renewal (Medi-Cal 2020), working alongside the California Association of Public Hospitals, the State of California, The Centers for Medicare & Medicaid Services, and multiple County departments focusing on improved patient outcomes, efficiencies and access in patient care integrated care models and procuring maximum reimbursement for performance of prescriptive clinical measures. The budget includes $52.5 million in revenues related to the Medicaid Waiver programs.

Focus on Recovery and Resiliency Following the December 2, 2015 Terrorist Attack (SB Strong)

- The County Administrative Office has commenced a countywide effort to document the impact and ongoing response to the December 2, 2015 terrorist attack while pursuing multiple sources of potential cost-reimbursement and to create a historic and best-practices document.

- The County has allocated approximately $10.2 million in funds towards improving security at County facilities. This includes $8.2 million in immediate improvements to facilities, such as expanded security guard services, upgraded security camera and key card access installations, and $2.0 million to conduct a security assessment of all County facilities.

Challenges in Fiscal Year 2016-17 and Beyond

Although the balancing of future costs with projected revenue has improved compared to prior County five year forecasts, broad economic challenges remain. The current economic expansion will be 7 years at the end of June 2016, which is the fourth longest in the history of the United States and cannot be assumed to last indefinitely. In addition, the fiscal uncertainly inherent in the State budget process continues to present a major challenge to the County's fiscal planning efforts.

Economic Challenges

The County's Five Year Financial Forecast covers July 2016 through June 2021 and includes moderate growth of major revenue streams throughout the period. Not included in the forecast are the impacts of a potential recession or the unknown economic impacts of the coming statewide $15 minimum wage.

By the end of the third year of the County's forecast the current economic expansion would match the longest expansion in history. Although the weakness of the current recovery and quantitative easing may have pushed off the next recession temporarily, it would be without precedent for the economy to expand throughout the County's entire five year forecast. In response to these unknown variables, the County has taken the approach of budgeting revenue growth in a conservative fashion over the entire five year forecast rather than assuming greater potential revenue increase in the immediate future with reductions in the later part of the forecast.

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Section 6. Mitigation Strategy

6.1 Mitigation Goals and Objectives

Goals and objectives discussed in this section help describe what actions should occur, using increasingly narrow descriptors. Long-term goals are developed which can be accomplished by objectives. To achieve the stated objectives "mitigation actions" provide specific measurable descriptors on how to accomplish the objective. The goals, objectives, and actions form the basis for the development of a Mitigation Action Strategy and specific mitigation projects to be considered for implementation.

The process consists of 1) setting goals and objectives, 2) considering mitigation alternatives, 3) identifying strategies or "actions", and 4) developing a prioritized action plan resulting in a mitigation strategy.

The following section provides an overview of the Mitigation Goals and Objectives for profiled hazards, Wildfire, Earthquake, Flood, Drought, Terrorism, and Climate Change for the County Unincorporated Area and the County's Special Districts. These goals were compiled from various sources including the County of San Bernardino 2007 General Plan. (See Section 3.5 for a detailed description of the process used by the County Planning Team)

6.1.1 All Hazard (AH)

AH GOAL: Increase readiness for all hazards in the unincorporated areas of San Bernardino County.

OBJECTIVE 1: Construct All-Hazard Response Facilities: Construct facilities to increase operational readiness to reduce impacts of natural hazards.

> **AH Action 1.1: Construct Valley Dispatch and Operations Center.** Construct facility and ensure cohesive working and response to any scale emergency and operations in a secure complex
>
> **AH Action 1.2: Construct Shelter Operations Compound (SHOC).** This shelter concept provides a new one-stop shelter concept. The SHOC combines a shelter, a Local Assistance Center (LAC) and a Non-LAC Unit in one easy location.

OBJECTIVE 2: Special District Funding: Continue Special Districts Projects relating to all hazards.

AH Action 2.1: Continue funding and support for Special Districts Projects relating to water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big

Bear Valley Recreation Park District and Bloomington Recreation and Park District for all hazards.

AH Action 2.2: Install Generators at Critical Facilities Retrofit existing buildings and facilities with connectors/ ATS for emergency generators and/or install permanent emergency generators at critical facilities, including wells and booster station locations.

AH Action 2.3: Water Systems Repair Plan Develop a plan for speeding the repair of and functional restoration of water and wastewater systems through stockpiling of shoring materials, temporary pumps, surface pipelines, portable hydrants, and other supplies.

AH Action 2.4: Smart Water Meters and SCADA Utilization of SCADA and Smart Water Meters to get real time data on problems with the system and reduce drive time emissions as a result of traditional meter reading.

AH Action 2.5: Provide Employees with Emergency Supplies Provide emergency supplies of food, water, and portable generators for employees at office and field locations.

AH Action 2.6: Annual Tower and Guide Wire Inspections Conduct annual tower and guide wire inspections to mitigate storm/wind/earthquake hazards from knocking out communications.

AH Action 2.7: **Maintain Tower Lighting** Maintain lights on all tower locations.

AH Action 2.8: Designate Emergency Operations Sites Conduct an inventory or list of County Park Facilities and Community Centers to establish a list of pre-designated emergency operations or disaster relief sites. Not all Community Centers are an appropriate size to accommodate large numbers of evacuees and may only serve as command and control centers or distribution centers.

AH Action 2.9: Establish Power Sources for Emergency Operations Sites Establish small solar energy fields or other forms of renewable power at County Community Centers to
facilitate stand-alone emergency operations for the community.

AH Action 2.10: Connect Water Systems to Generators Connect water systems to generators to ensure delivery even in disaster situations.

AH Action 2.11: Establish a Centralized Communications Network Establish a centralized communications network to monitor channel output for TV Districts and provide emergency information by way of character generator tied to channel transmissions.

AH Action 2.12: Incorporate as appropriate requirements from the State of California's most recent land use regulations regarding the hazard mitigation planning process (Government Code 65302 and 8685.9).

6.1.2 Wildfire (WF)

WF GOAL: Continue to reduce fire hazards in the unincorporated areas of San Bernardino County.

WILDFIRE OBJECTIVE 1: **Mountain Area Safety Taskforce.** Continue the cooperation and coordination of Fire Hazard Mitigation efforts with all stakeholders in the mountain areas of San Bernardino County through participation in MAST.

WF Action 1.1: Continue Mountain Area Safety Taskforce (MAST) funding to support mitigation activity.

WILDFIRE OBJECTIVE 2: Support Mountain Mutual Aid Objectives. Continue development of and continue the mission of mutual aid between the first responders in the County mountain areas through County Mitigation Planning.

WF Action 2.1: Update Mountain Mutual Aid Mapbook to document.

WF Action 2.2: Update Community Structure Protection Plans as necessary.

WILDFIRE OBJECTIVE 3: Community Based Fuels Reduction Program. Continue the community based Fuels Reduction Program through community based programs, both volunteer and government funded.

WF Action 3.1: Implement identified community based fuels reduction projects.

WF Action 3.2: Develop fuels reduction "maintenance program" by obtaining participation from citizens and/or homeowners associations.

WF Action 3.3: Vegetation Removal Clear vegetation from Road District facilities/yards.

WILDFIRE OBJECTIVE 4: Forest Care. Continue providing assistance to homeowners by expanding services to all communities in the Mountain areas of the County.

WF Action 4.1: Increase homeowner assistance services to mountain residents for fuel reduction.

WF Action 4.2: Continue working with Southern California Edison to remove dead trees near power lines.

WILDFIRE OBJECTIVE 5: County Fire Hazard Abatement. Overcome funding shortfalls while improving service delivery.

WF Action 5.1: Inspect every residence in the mountain communities within the next two years to enforce the new Fire Hazard Abatement code that addresses green fuels.

WF Action 5.2: Continue to collaborate with Forest Care, Red, Cross and Cal Fire to overcome increased costs of enforcement.

WILDFIRE OBJECTIVE 6: Decrease Wildfire Hazards at Private Property through the Fire Hazard Abatement Programs

WF Action 6.1: Train and Certify landscape contractors to comply with the new Fire Hazard Abatement Code.

WF Action 6.2: Continue wildfire mitigation efforts under the Wood Shake Roof Replacement Program.

WF Action 6.3: Protect Property in Wilderness Areas Rockscape or pave property grounds which have structures located in wilderness and or areas prone to wildfires. Double the width of external fire breaks.

WILDFIRE OBJECTIVE 7: Support Mitigation Strategies in Community Wildfire Protection Plans. Continue to improve CWPP's in cooperation with Cal Fire, the IEFSA and individual Fire Safe Councils.

WF Action 7.1: Modify independent and unique CWPPs into a more common framework making them similar but leaving room to provide specific hazard characteristics and mitigation actions for each community.

WILDFIRE OBJECTIVE 8: Improve Emergency Access. Improve and maintain emergency access for wildfire protection.

WF Action 8.1: Construct Arrowbear Drive Realignment and Widening

WF Action 8.2: Construct Cedar Glen Fire Access Road

WF Action 8.3: Structural Fire Breaks Widening Double the width of external fire breaks on grounds which have structures located in wilderness and or areas prone to wildfires.

WILDFIRE OBJECTIVE 9: Special District Funding: Continue Special Districts Projects relating to wildfire.

WF Action 9.1: Continue funding and support for Special Districts Projects relating to wildfire in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District.

WF Action 9.2: Emergency Water Supplies Purchase emergency water supply or water purification devices to ensure uninterrupted supply of water to emergency response personal. (completed with continuous fresh of supplies and rotation)

6.1.3 Earthquake/Geologic Hazards (EQ)

GOAL: Minimize exposure to structural and contents damage from geologic and seismic conditions. (Complements General Plan, Section VIII, Safety Element (Goal S 7)

EARTHQUAKE OBJECTIVE 1: Educate the public on reducing earthquake risk.

EQ Action 1.1: Improve public education programs and practices to residents for earthquake risk.

EARTHQUAKE OBJECTIVE 2: Protect occupants and structures in proposed developments from high levels of risk caused by rupture of the ground surface during an earthquake (Complements General Plan, Section VIII Safety Element Policy S 7.4).

EQ Action 2.1: Evaluate single family homes for Earthquake hazard when conducting permit applications and plan reviews.

EQ Action 2.2: Seismic Strapping for existing water tanks and future construction.

EQ Action 2.3: Employee Emergency Sheltering Develop a plan for short-term and intermediate-term sheltering of employees.

EARTHQUAKE OBJECTIVE 3: Continue geologic hazard mapping projects to minimize and prevent damage caused by earthquakes and other geologic hazards.

EQ Action 3.1: Identify liquefaction hazard areas outside the currently designated Geologic Hazard Overlay Districts.

EARTHQUAKE OBJECTIVE 4: Protect life and property from risks resulting from gravity-derived and/or earthquake-triggered landslides, expansive soils and/or other poor soil conditions. (Complements General Plan, Section VIII, Safety Element Policy § 7.6)

EQ Action 4.1: Require development on hillsides to minimizes the extent of topographic alteration and erosion, to maintain slope stability, and to reduce the potential for offsite sediment transport (Complements General Plan, Section VIII, Safety Element Policy § 6.1).

EQ Action 4.2: Generator Installation Install generators at all road facilities. This will allow uninterrupted communications and provide power to refuel critical emergency response equipment.

EARTHQUAKE OBJECTIVE 5: Reduce runoff over the cliffs in the Rimforest neighborhood. (Complements Rimforest Drainage Feasibility Study)

EQ Action 5.1: Divert runoff to Little Bear Creek.

EARTHQUAKE OBJECTIVE 6: Special District Funding: Continue Special Districts Projects relating to earthquake hazards.

EQ Action 6.1: Continue funding and support for Special Districts Projects relating to earthquake hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District.

6.1.4 Flood (FL)

GOAL: Provide adequate flood protection to minimize hazards and structural damage. (General Plan, Safety Element, Goal S 5)

FLOOD OBJECTIVE 1: National Flood Insurance Program. Participate in the National Flood Insurance Program (NFIP), which provides flood insurance within designated floodplains. (General Plan, Safety Element, Policy S 5)

FL Action 1.1: Update NFIP data and maps with newly identified flood hazard areas in the County, as new information becomes available.

FLOOD OBJECTIVE 2: Alluvial Task Force. Review and analyze the findings and recommendations from the recently released Alluvial Fan Task Force reports, as funding permits.

FL Action 2.1: Determine whether or not additional amendments to development standards or policies are merited, based on the completed analysis.

FLOOD OBJECTIVE 3: Flood Hazard Reduction. Reduce flood hazards through development standards and policies stated in the County of San Bernardino General Plan and County of San Bernardino 2010 Development Code.

FL Action 3.1: Amend the Flood Plain Safety Overlay District through automatic map updates as new data is released and published by FEMA.

FL Action 3.2: Review development plans to ensure compliance with ordinances.

FL Action 3.3: Inspect construction to ensure compliance with approved development plans.

FL Action 3.4: Soil Stabilization on Roadways and Along Roadway Shoulders Soil stabilization on roadway shoulders and dirt roads. This will prevent erosion caused by flood conditions.

FL Action 3.5: Encasing Pipelines Encase water pipelines with specific sized rock, gravel, and road base in natural waterways to prevent continual washout or exposure during heavy storm events/floods.

FLOOD OBJECTIVE 4: Future Flood Mitigation Projects. Improve existing facilities and construct new facilities to mitigate flooding with the County.

FL Action 4.1: In each flood control zone, construct facilities identified in those zones by the Flood Control Advisory Committee. See Flood Control District Annex for a listing of projects.

FLOOD OBJECTIVE 5: Special District Funding: Continue Special Districts Projects relating to flood hazards.

FL Action 6.1: Continue funding and support for Special Districts Projects relating to flood hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District.

FL Action 6.2: On Call Contractors Employ on call contractors to assist in emergency situations.

6.1.5 Drought (DR)

GOAL: Minimize the effects of drought on the County in all aspects including economically and socially.

DROUGHT OBJECTIVE 1: Educate the public on water conservation methods.

DR Action 1.1: Create a public awareness campaign advising citizens, business owners and farmers on water conservation.

DR Action 1.2: Provide incentives for farmers to grow crops that are less water intensive.

DR Action 1.3: Continue to coordinate with the San Bernardino Valley Water Conservation District to provide Qualified Water Efficient Landscaper (QWEL) training.

DR Action 1.4: Continue to enforce the watering schedule and watering restrictions throughout the County.

DROUGHT OBJECTIVE 2: Protect the quality of the County's watersheds.

DR Action 2.1: Approve the County's Watershed Water Quality Management Plan written in 2013.

DROUGHT OBJECTIVE 3: Special District Funding: Continue Special Districts Projects relating to drought hazards.

DR Action 3.1: Continue funding and support for Special Districts Projects relating to drought hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District.

6.1.6 Anti-Terrorism (AT)

GOAL: Use antiterrorism strategies to discourage terrorism and protect the people, infrastructure and assets in San Bernardino County from the effects of terrorism.

ANTI-TERRORISM OBJECTIVE 1: Use anti-terrorism design strategies to discourage / prevent acts of terrorism.

AT Action 1.1: Identify and prioritize mitigation activities (anti-terrorism force protection) at critical facilities and gathering places that are vulnerable to terrorist attacks.

ANTI-TERRORISM OBJECTIVE 2: Special District Funding: Continue Special Districts Projects relating to terrorism hazards.

AT Action 2.1: Continue funding and support for Special Districts Projects relating to terrorism hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District.

6.1.7 Climate Change (CC)

GOAL: Reduce the impacts of climate change on the County and limit human activities that change the atmosphere's makeup.

CLIMATE CHANGE OBJECTIVE 1: Meet greenhouse gas (GHG) reductions targets set forth by the Clean Air Act.

> **CC Action 1.1:** Continue working with the South Coast Air Quality Management District and the Mojave Desert AQMD to meet GHG reductions targets.
>
> **CC Action 1.2:** Continue implementing the energy conservation and efficiency measures identified in the County of San Bernardino Greenhouse Gas Emissions Reduction Plan. (San Bernardino County Renewable Energy and conservation Element)

CLIMATE CHANGE OBJECTIVE 2: Educate the public on the effects of climate change and reducing our impact.

> **CC Action 2.1:** Encourage carpooling and the use of public/ alternative transportation methods.
>
> **CC Action 2.2:** Optimize energy efficiency in the built environment and promote the local economic benefits of energy efficiency retrofits. (San Bernardino County Renewable Energy and conservation Element)
>
> **CC Action 2.3:** Encourage residents and businesses to conserve energy. (San Bernardino County Renewable Energy and conservation Element)

CLIMATE CHANGE OBJECTIVE 3: Special District Funding: Continue Special Districts Projects relating to climate change hazards.

CC Action 3.1: Continue funding and support for Special Districts Projects relating to climate change hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District.

6.2 Mitigation Strategy

To narrow mitigation alternatives for inclusion, FEMA's six broad categories of mitigation alternatives were used. Each FEMA category is listed below. The HMP Planning Committee developed several mitigation alternatives for implementation under each mitigation category.

- Prevention (PRV)

- Property Protection (PPRO)
- Public Education and Awareness (PE&A)
- Natural Resource Protection (NRP)
- Emergency Services (ES)
- Structural Projects (SP)

Table 6-1 summarizes the mitigation alternatives for categories of projects addressing the hazards in the San Bernardino County Unincorporated Area Multi-Jurisdictional Hazard Mitigation Plan. The Table includes implementation strategies for the wildfire, earthquake/geologic hazards, flood, drought, climate change and terrorism.

Table 6-1: Mitigation Alternative Summary

Action	Lead Agency	Hazard	Funding Source
Prevention (PRV): **Preventative activities are intended to keep hazard problems from getting worse, and are typically administered through government programs or regulatory actions that influence the way land is developed and buildings are built. This includes the development of additional code requirements to further reduce or eliminate damages from the identified hazards.**	County Land Use Services	All Hazards	General Fund
Natural Resource Protection (NRP): **To locate and protect natural and cultural resources at risk from the identified hazards.**	Fire Protection District / Flood Control District	Wildfire and Flood	General Fund, Grants
Property Protection (PPRO): **Property protection measures involve the modification of existing buildings and structures to help them better withstand the forces of a hazard, or removal of the structures from hazardous locations.**	Fire Protection District.	Wildfire	General Fund, Grants
Public Education and Awareness (PE&A): **To continue and develop new public education programs targeting the top identified hazards.**	Fire Protection District.	All Hazards	General Fund, Grants

Action	Lead Agency	Hazard	Funding Source
Emergency Services (ES): **Although not typically considered a "mitigation" technique, emergency service measures do minimize the impact of a hazard event on people and property. These commonly are actions taken immediately prior to, during, or in response to a hazard event. Examples include:**	Fire Protections District	All Hazards	General Fund, Special District Funds, Grants
Structure Protection (SP) – Flooding **To continue to identify, fund, and build projects that reduce or eliminate flood hazards in the County.**	Flood Control District	Flooding Hazards	General Fund, Special District Funds, Grants
Structure Protection (SP)– Geological Hazards **To identify unknown hazards and develop additional new and retrofit requirements or programs to reduce or eliminate damage from geological hazards.**	Land Use Services	Geological Hazards	General Fund Grants
Structure Protection (SP) – Wildfire **To further protect structures at risk from wildfire through education, building, and enforcement codes and actions.**	Fire Protections District	Wildfire	General Fund, Special District Funds, Grants

6.2.1 Mitigation Action Plan

This section serves to identify *on-going* actions and projects in the County Unincorporated Area. With the results of the hazard risk assessment finalized, mitigation goal established, and capabilities assessed, the County and participating districts then set out to identify new mitigation actions that would reduce the outlined in the vulnerability assessment.

Not all identified mitigation actions are implementable in the 5-year plan cycle, due to technical feasibility, political acceptance, lack of funding, or other constraints. Once the mitigation actions for each participating jurisdiction were identified, they were evaluated and prioritized (by providing a time frame) to identify the most suitable mitigation actions for each participating jurisdiction to implement.

Cost effectiveness of each measure was a primary consideration when developing mitigation actions. Because mitigation is an investment to reduce future damages, it is important to select measures for which the reduced damages over the life of the measure are likely to be greater than the project cost. For structural projects, the level of cost effectiveness is primarily based on the likelihood of damages occurring in the future, the severity of the damages when they occur, and the level of effectiveness of the selected measure. While detailed analysis was not conducted during the mitigation action development process, these factors were of primary concern when selecting measures. For measures that do not result in a quantifiable reduction of damages, such as public education and outreach, the relationship of the probable future benefits and the cost of each measure was considered when developing the mitigation actions.

Based upon the participating jurisdiction capabilities, Table 6-2 shows primary actions selected for further implementation and development during the next planning cycle. Table 6-2 provides details for each mitigation action with mitigation action descriptions, FEMA mitigation category, responsible party, and timeframe.

Important to Note: See Jurisdictional Annexes for more information on implementation mechanisms and mitigation projects for each participating jurisdiction. If a participating jurisdiction is identified as a primary lead for implementation, the mitigation actions are also contained the corresponding jurisdictional annex.

Table 6-2: Mitigation Action Descriptions

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
ALL Hazard	**AH Action 1.1:** Valley Dispatch and Operations Center.	Update and maintain the operations of the facility and ensure cohesive working and response to any scale emergency and operations in a secure complex	ES	Budgetary Items from County and Federal Grant Funding, EMPG, HMPG, UASI.	Fire Protection District.	1-3 Years	See Fire Protection District Annex A. Section A.6 Fire Protection District Mitigation Project .
ALL Hazard	**AH Action 1.2:** Maintain Shelter Operations Compound (SHOC). This shelter concept provides a new one-stop shelter concept. The SHOC combines a shelter, a Local Assistance Center (LAC) and a Non-LAC Unit in one easy location.	After the 2003 Wildland Fires, the County and American Red Cross recognized the need to provide services beyond basic care and short-term sheltering, especially during large fires, floods, and earthquakes The Mass Care & Shelter Plan and Concept of Operations, outlines the framework of a new one-stop shelter concept, Shelter Operations Compound (SHOC). It combines a shelter, a Local Assistance Center (LAC) and a Non-LAC Unit in one easy location. Residents can access public information and referral services through the LAC, and then take a short walk to the Non-LAC Unit for communication, postal services, and other private organizations/business at little to no cost. The completion of the Plan in 2012 will help to sync local resources, encourage local self-sufficiency, foster partnership between public and private agencies, and serve as a reference document for the region. By June 2017, the program will have 32 trailers/caches equipped with mass care and shelter supplies, strategically placed throughout the County and ready for rapid deployment. It is expected to serve over 12,000 residents. In addition to enhancing the comfort levels of shelter residents, the program will produce standardized documents and protocols for procuring and maintaining Mass Care and Shelter trailers/caches. These plans and programs will help the County prepare for and mitigate damages from hazards. This is an update and expansion of the plan and done without more grant funds.	ES	To increase Mass Care and Shelter capability of the county, grants from 2008-2009 Homeland Security Grant Program (HSGP) and 2009 Riverside Regional Urban Area Security Initiative (UASI) funded the Mass Care and Shelter Trailer/Cache Program.	Fire Protection District/	1-5 Years	See Fire Protection District Annex A. Section A.6 Fire Protection District Mitigation Project .
All-Hazard	**AH Action 2.1:** Continue funding and support for Special Districts Projects relating to all hazards.	Continue funding and support for Special Districts Projects relating to water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District for all hazards. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	Ongoing	
All-Hazard	**AH Action 2.2:** Install Generators at Critical Facilities	Retrofit existing buildings and facilities with connectors/ ATS for emergency generators and/or install permanent emergency generators at critical facilities, including wells and booster station locations.	ES, SP	TBD	Water Systems	TBD	Critical sites are already set up for connection or has a permanently installed generator

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
All-Hazard	**AH Action 2.3:** Water Systems Repair Plan	Develop a plan for speeding the repair of and functional restoration of water and wastewater systems through stockpiling of shoring materials, temporary pumps, surface pipelines, portable hydrants, and other supplies.	PRV	SDD WAS	Water Systems	TBD	We have a warehouse and inventory. Add'l inventory would need to be purchased from local wholesaler
All-Hazard	**AH Action 2.4:** Smart Water Meters and SCADA	Utilization of SCADA and Smart Water Meters to get real time data on problems with the system and reduce drive time emissions as a result of traditional meter reading.	PRV	Individual CSAs	Water Systems	Ongoing	Both SCADA and Smart Meters have been installed and continue to be installed
All-Hazard	**AH Action 2.5:** Provide Employees with Emergency Supplies	Provide emergency supplies of food, water, and portable generators for employees at office and field locations.	ES	SDD/WAS	Water Systems	Ongoing	WAS has a stock of emergency food supplies, water, and generators.
All-Hazard	**AH Action 2.6:** Annual Tower and Guide Wire Inspections	Conduct annual tower and guide wire inspections to mitigate storm/wind/earthquake hazards from knocking out communications.	PRV	TBD	TV Districts	7/1/2016-7/1/2017	All Districts
All-Hazard	**AH Action 2.7**: Maintain Tower Lighting	Maintain lights on all tower locations.	SP	TBD	TV Districts	June-17	
All-Hazard	**AH Action 2.8:** Designate Emergency Operations Sites	Conduct an inventory or list of County Park Facilities and Community Centers to establish a list of pre-designated emergency operations or disaster relief sites. Not all Community Centers are an appropriate size to accommodate large numbers of evacuees and may only serve as command and control centers or distribution centers.	PRV	TBD	Park Districts	April-17	All Districts
All-Hazard	**AH Action 2.9:** Establish Power Sources for Emergency Operations Sites	Establish small solar energy fields or other forms of renewable power at County Community Centers to facilitate stand-alone emergency operations for the community.	PRV, SP	TBD	Park Districts	12/1/2016-7/1/2018	Lucerne Valley Joshua Tree
All-Hazard	**AH Action 2.10:** Connect Water Systems to Generators	Connect water systems to generators to ensure delivery even in disaster situations.	PRV, SP	TBD	Park Districts	TBD	
All-Hazard	**AH Action 2.11:** Establish a Centralized Communications Network	Establish a centralized communications network to monitor channel output for TV Districts and provide emergency information by way of character generator tied to channel transmissions.	PRV	TBD	TV Districts	7/1/2017-12/1/2017	All districts
All-Hazard	**AH Action 2.12** Incorporate as appropriate requirements from the State of California's	Government Code 65302.6 requires the following elements to be included in the hazard mitigation plan: (1) An initial earthquake performance evaluation of public facilities that provide essential services, shelter, and critical governmental functions.	PRV, NRP	TBD	Primary: Land Use Services	1-3 years	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
	most recent land use regulations regarding the hazard mitigation planning process (Government Code 65302 and 8685.9).	(2) An inventory of private facilities that are potentially hazardous, including, but not limited to, multiunit, soft story, concrete tilt-up, and concrete frame buildings. (3) A plan to reduce the potential risk from private and governmental facilities in the event of a disaster. Government Code 8685.9 requires that the state share shall not exceed 75 percent of total state eligible costs unless the local agency is located within a city, county, or city and county that has adopted a local hazard mitigation plan as part of the safety element of its general plan. In that situation, the Legislature may provide for a state share of local costs that exceeds 75 percent of total state eligible costs.			Secondary: Fire Protection District/		
All-Hazard	**AH Action 3.1:** Continue funding and support for Special Districts Projects relating to all hazards.	Continue funding and support for Special Districts Projects relating to water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District for all hazards. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	On-Going	
Wildfire	**WF Action 1.1** Continue Mountain Area Safety Taskforce (MAST) funding to support mitigation activity.	MAST was formed to mitigate the region wide risk of a catastrophic wildfire due to dead and dying trees in the mountain communities. The mission of the MAST is to facilitate a coordinated effort by cities, county, state, federal, and non-profit agencies to provide for the protection of property owners, residents, and property subject to the risk of catastrophic wildfire that could occur in San Bernardino County with an initial emphasis on the threat resulting from the Old and Grand Prix fires in 2003. MAST priorities are to continue reducing fire hazards through fuel reduction programs and hazard abatement though enforcement of county ordinances. The Mountain Area Safety Taskforce (MAST) Operations Section meets monthly. MAST Operations Section determines project priorities based on the benefit cost analysis of the projects and the effect of the project on the overall goals of the MAST organization. Goals can change as detailed Benefit Cost Analysis is conducted and CEQA/NEPA reviews are completed.	NRP, PPRO	Seeking additional funding through HMPG.	San Bernardino County Fire Protection District	On-Going	See Implementation plan on more information on MAST. See Fire Protection District Annex A. Section A.6 Fire Protection District Mitigation Project .
Wildfire	**WF Action 2.1:** Update Mountain Mutual Aid Map Book to document updated information contained in 2016 HMP.	The Map Book portion of the Community Safety and Structure Protection Plan provides not only a street network of the area but more importantly it provides the locations of strategic and critical resources for fire fighters. These include but are not limited to safe zones, open areas, locations for refuge. They also identify areas within communities that have narrow and steep winding streets and or with limited ingress and egress. The document is handed out to all responding strike teams from out of the area and has proved invaluable in directing and coordinating an effective firefighting response and reduces the potential for life loss and property damage.	ES	Seeking additional funding through HMPG.	San Bernardino County Fire Protection District	On-Going	See Fire Protection District Annex A. Section A.6 Fire Protection District Mitigation Project .

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Wildfire	**WF Action 2.2** Update Community Structure Protection Plans as necessary.	This is an on-going action (from the 2011 MJHMP) with the goal to continue development of and continue the mission of mutual aid between first responders in the County mountain areas.	PPRO		Fire Protection District	On-Going	
Wildfire	**WF Action 3.1:** Implement identified community based fuels reduction projects.	The Fuels Reduction Program is designed to create community based fuel modification programs across the mountain communities. These projects are selected specifically to reduce the potential for catastrophic wildfires and the damage that they can do to the communities. Project design, contracting, and operations are managed by the County's Public Works Department with priorities set by local fire chiefs in monthly MAST Operations Meetings. This program is the oldest and most significant for reducing wildfire threat on a mountain wide basis.	PPRO	Current Funding: Seeking additional funding through HMPG.	Primary: San Bernardino Public Works Department Secondary: County Fire Protection District	On-Going	
Wildfire	**WF Action 3.2:** Develop fuels reduction "maintenance program" by obtaining participation from citizens and/or homeowners associations.	To survive a wildfire, property owners need to manage the land surrounding their homes and communities effectively. Removing fuels in the wildland fuel reduction zone beyond the defensible space can reduce the speed and intensity of an oncoming wildfire. But if these areas aren't regularly **maintained**, they lose their effectiveness. Plants grow back, and flammable vegetation needs to be routinely removed and disposed of properly. This guide provides tips on how to create and maintain defensible space and wildland fuels treatments around your property.	PPRO, PE&A	Seeking additional funding through HMPG	Primary: Public Works Secondary: Fire Protection District	On-Going	
Wildfire	**WF Action 4.1** Increase homeowner assistance services to mountain residents for fuel reduction.	This is an ongoing wildfire mitigation action (from the 2011 MJHMP) for the group Forest Care to achieve the goal of providing assistance to homeowners by expanding services to all communities in the Mountain areas of the County. Forest Care is a program dedicated to creating a healthier forest. This program provides foresters to assess individual properties for thinning the vegetation and then provides 75% of the funding to do so.	PPRO, PE&A	Seeking additional funding through HMPG	San Bernardino County Fire Protection District	On-Going	
Wildfire	**WF Action 4.2** Continue working with Southern California Edison (SCE) to remove dead trees near power lines.	A significant number of fires across the State are caused by trees falling into power lines. When the forests in the mountain communities became infested with bark beetles the pine tree die off was unprecedented. Thousands of these dead trees were standing precariously close to power lines. Early in the Bark Beetle Emergency in 2004, Southern California Edison swiftly initiated a program to remove all trees that were dead, dying, and/or diseased that had the potential to fall into any SCE power lines.	PRV, PPRO	As of July of 2010 Southern California Edison (SCE) has spent $179,758,978 to remove dead dying and diseased trees.	San Bernardino County Fire Protection District	On-Going	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
		The role of Southern California Edison was critical to the success of MAST both operationally and financially. Edison still removes the most difficult trees, the most costly trees; and the ones that are most likely to be the source of ignition for a wild land fire. They are also removing the trees that are immediately threatening homes. They have removed 118,305 trees since the inception of the program in 2004. They also provided reimbursements to people that removed their own trees.					
Wildfire	**WF Action 5.1:** Inspect every residence in the mountain communities throughout the year to enforce the Fire Hazard Abatement code that addresses green fuels.	The Fire Hazard Abatement Program conducts surveys to identify fire hazards throughout the year. Fire hazards are identified and notices to abate the hazard(s) are mailed to property owners. Property owners are given 30 days to abate the violations. Failure to abate may result in citations, penalties, and/or fees for abatement by the County. The Fire Hazard Abatement Program responds to complaints year round in the unincorporated areas and contracting Cities and Fire Districts. The Division completes more than 430,000 inspections, issues more than 45,000 Notices to Abate Fire Hazards, issues over 4,000 citations for non-compliance, and abates the fire hazards on more than 2,000 parcels annually. Within the last 5 years, the Fire Hazard Abatement Division has received even more financial resources that enable them to abate all properties declared a fire hazard.	PRV, PPRO, PE&A	Seeking additional funding through HMPG	Primary: Land Use Services Secondary: Fire Protection District	On-Going	For more information on Contractor Certification, see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	**WF Action 5.2:** Continue to collaborate with Forest Care, Red, Cross and Cal Fire to overcome increased costs of enforcement.	This is an on-going action from the 2011 MJHMP with the goal of overcoming funding shortfalls for the County Fire Hazard Abatement Program.	PRV		San Bernardino County Fire Protection District	On-Going	
Wildfire	**WF Action 6.1** Train and Certify landscape contractors to comply with the Fire Hazard Abatement Code.	The City of Big Bear Lake created a program to train and certify landscape contractors to provide a qualified workforce to conduct fuels reduction activities on individual properties. The contractors are trained to comply with the new Fire Hazard Abatement Code that exists both in the City of Big Bear and the County unincorporated area. The City of Big Bear Lake Fire Department conducts the classes for landscapers and handy persons. This provides an incentive for the contractors and provides a level of certification that the homeowner can rely on when they are deciding to hire a landscape contractor to conduct fuels abatement around their home.	PRV, PPRO	Seeking additional funding through HMPG	San Bernardino County Fire Protection District	On-Going	On-Going

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Wildfire	**WF Action 6.2:** Continue wildfire mitigation efforts under the Wood Shake Roof Replacement Program.	The County successfully passed an ordinance that requires the replacement of wood shake roofs by 2014. MAST has successfully mapped all of the wood shake roofs in the fire safety overlay and has created a strategy as to which roofs will be selected to participate in the FEMA funded project. This is an on-going project in cooperation with Big Bear Lake Fire Protection District in order to provide more funding for wood shake roof replacements by property owners.	PRV, PPRO, SP		Primary: MAST Secondary: San Bernardino County Fire Protection District	On-Going	
Wildfire	**WF Action 6.3:** Protect Property in Wilderness Areas	Rockscape or pave property grounds which have structures located in wilderness and or areas prone to wildfires. Double the width of external fire breaks.	PPRO, PRV, SP	TBD	Sewer Systems	January-17	All sewer pump stations have paving
Wildfire	**WF Action 7.1:** Modify independent and unique CWPPs into a more common framework making them similar but leaving room to provide specific hazard characteristics and mitigation actions for each community.	Community Wildfire Protection Plans are designed to provide a means for a community, usually through the Fire Safe Council, to have input into and actively participate in the planning, strategy, goals, and objectives of creating a fire safe community.	PRV	Seeking additional funding through HMPG	San Bernardino County Fire Protection District	On-Going	On-Going For more information on CWPP see Annex A Section A.6 Fire Protection District Mitigation Project .
Wildfire	**WF Action 8.1:** Construct Arrowbear Drive Realignment and Widening.	The Arrowbear community off State Highway 18 has limited access to State Highway 138. The existing bridge/spillway and road needs to be realigned and widened to facilitate access by emergency personnel during wildfires and flooding. Mitigation strategy for this is to remove and replace existing bridge/spillway, realign and widen the road.	SP	Seeking grant funding Total Cost: $3,000,000 Approx.	Primary: Public Works Secondary: San Bernardino County Fire Protection District	1-3 Years	
Wildfire	**WF Action 8.2:** Construct Cedar Glen Fire Access Road.	Lack of paved roads inhibits traffic circulation and the ability to enter and exit the area without backtracking during wildfire emergencies. Strategy is to Construct road and drainage improvements to Little Bear Creek Road and Elder Drive.	SP	Seeking grant funding **Total Cost:** $2,500,000	Public Works	1-3 Years	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Wildfire	**WF Action 8.3:** Structural Fire Breaks Widening	Double the width of external fire breaks on grounds which have structures located in wilderness and or areas prone to wildfires.	SP, PRV	Individual CSAs	Water Systems	7/1/2017-7/19/2019	
Wildfire	**WF Action 9.1:** Continue funding and support for Special Districts Projects relating to wildfire.	Continue funding and support for Special Districts Projects relating to wildfire in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	On-Going	
Wildfire	**WF Action 9.2:** Emergency Water Supplies	Purchase emergency water supply or water purification devices to ensure uninterrupted supply of water to emergency response personal.(completed with continuous fresh of supplies and rotation)	ES	TBD	Roads	TBD	
Earthquake	**EQ Action 1.1:** Improve public education programs and practices to residents for earthquake risk.	Public education and outreach programs are an efficient and cost-effective way to promote meaningful changes within a community. A Program for Public Information (PPI) for earthquake awareness and mitigation could significantly reduce injury and property damage to earthquake. Use a suite of partnerships, activities, and products to educate the public about earthquake science and motivating homeowners to become prepared for earthquakes.	PE&A		Human Resources	5-10 Years	
Earthquake	**EQ Action 2.1:** Evaluate single family homes for Earthquake hazard when conducting permit applications and plan reviews.	82.15.040 Development Standards states that a structure used for human occupancy shall be located 50 feet or farther from any active earthquake fault traces. Lesser setbacks may be applicable in certain situations as determined by an appropriate geologic investigation and approved by the County Geologist or other engineering geologist designated by the Building Official. Alquist-Priolo Earthquake Fault Zoning Act (Public Resources Code Section 2621 et seq.) requires the delineation of potential damage areas along known active faults throughout California. It requires local governments to withhold approval of construction permits in those zones until geologic investigation has determined that the site is not threatened by surface displacement from future faulting.	PRV		Land Use Services	TBD	On-Going
Earthquake	**EQ Action 2.2:** Seismic Strapping	Seismic strapping for existing water tanks and future construction.	SP, PRV	CSA 64	Water Systems	7/17/2017-7/1/2019	Ongoing currently
Earthquake	**EQ Action 2.3:** Employee Emergency Sheltering	Develop a plan for short-term and intermediate-term sheltering of employees.	PRV	WAS	Sewer Systems	7/17/2017-7/19/2019	To purchase cots, small portable generators, tents, etc.

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Earthquake	**EQ Action 3.1:** Identify liquefaction hazard areas outside the currently designated Geologic Hazard Overlay Districts.	Supported by General Plan mechanism (General Plan, Section VIII, Safety Element Policy § 7.5; California Building Code §1803.5.11); Seismically- induced lateral spreading, and/or seismically-induced lateral flow, can cause devastating structural damage and a high potential for saturation exists when the groundwater level is within the upper 50 feet of alluvial material.	PRV		Land Use Services	5-10 Years	
Earthquake	**EQ Action 4.1**: Require development on hillsides to minimizes the extent of topographic alteration and erosion, to maintain slope stability, and to reduce the potential for offsite sediment transport (Complements General Plan, Section VIII, Safety Element Policy § 6.1).	This mitigation action is especially important in the San Bernardino and San Gabriel Mountains which have high slope failure / erosion potential. Typical slope mitigation techniques that are used include: Drainage Improvements - Since water is the biggest culprit in failing slopes, drainage improvements should be the first priority. Some drainage improvements may include: ▪ Collect or divert surface water from the problem slope. This may include catch basins, swales, or sealing tension cracks to prevent infiltration. ▪ Collect and remove subsurface water. This may include drains constructed within the subsurface to remove excess seepage, or lower ground water. Some earthwork mitigation techniques are as follows: ▪ Remove the upper soils of the slope to create a flatter slope. ▪ Buttress the slope toe by filling with rock, gravel, or soil. ▪ Benching the slope if each bench is on competent subgrade. ▪ Structural Improvements - Structural improvements include: ▪ Friction Piles ▪ Retaining walls ▪ Geo Grid ▪ Sheet Piles ▪ Rock Bolts ▪ Vegetative Cover Complements General Plan, Section VIII, Safety Element Policy § 7.6 Complements General Plan, Section VIII, Safety Element Policy § 6.1)	PRV	N/A	Land Use Services	On-Going	Provide enhanced information during the development review process to address slope failure concerns.
Earthquake	**EQ Action 4.2:** Generator Installation	Install generators at all road facilities. This will allow uninterrupted communications and provide power to refuel critical emergency response equipment.	SP, PPRO	TBD	Roads	TBD	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Earthquake	**EQ Action 5.1:** Divert runoff to Little Bear Creek.	To reduce the runoff over the cliff(s) in the Rimforest neighborhood, the runoff must be diverted to another path. This will be accomplished over three phases: • Phase 1: Reduce Runoff Tributary Area by 64%- 50.35 AC • Phase 2: Reduce Runoff Tributary Area by 30%- 23.79 AC • Phase 3: Reduce Runoff Tributary Area by 5%- 3.99 AC	SP, NRP, PRV		Primary: Public Works Secondary: Flood Control District		
Earthquake	**EQ Action 6.1:** Continue funding and support for Special Districts Projects relating to earthquake hazards.	Continue funding and support for Special Districts Projects relating to earthquake hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	On-Going	
Flood	**FL Action 1.1:** Update NFIP data and maps with newly identified flood hazard areas in the County, as new information becomes available.	As required by the State of California, National Flood Insurance Program (NFIP) maps published by FEMA must be included in the HMP or General Plan Safety Element. Keeping this information current is an important mitigation action.	PRV, PPRO		San Bernardino County Flood Control District	On-Going	
Flood	**FL Action 2.1:** Determine whether or not additional amendments to development standards or policies are merited, based on the Alluvial Fan Task Force Recommendation.	This is an on-going mitigation action from the 2011 MJHMP.	PRV		Primary: San Bernardino County Flood Control District Secondary: Land Use Services	On-Going	
Flood	**FL Action 3.1:** Amend the Flood Plain Safety Overlay District through automatic map updates as new data is released and published by FEMA.	Current San Bernardino County Hazard Maps can be found at: http://cms.sbcounty.gov/lus/Planning/ZoningOverlayMaps/HazardMaps.aspx.	PRV, NRP		Primary: San Bernardino County Flood Control District Secondary: Land Use Services	On-Going	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Flood	**FL Action 3.2:** Review development plans to ensure compliance with ordinances.	This is an on-going mitigation action from the 2011 MJHMP in order to reduce the flood hazards through development standards and policies stated in the General Plan and San Bernardino 2077 Development Code.	PRV		Primary: Land Use Services Secondary: San Bernardino County Flood Control District	On-Going	
Flood	**FL Action 3.3:** Inspect construction to ensure compliance with approved development plans.	This is an on-going mitigation action from the 2011 MJHMP in order to reduce the flood hazards through development standards and policies stated in the General Plan and San Bernardino 2077 Development Code.	PRV, PPRO, SP		Primary: Public Works Secondary: Flood Control District	On-Going	
Flood	**FL Action 3.4:** Soil Stabilization on Roadways and Along Roadway Shoulders	Soil stabilization on roadway shoulders and dirt roads. This will prevent erosion caused by flood conditions.	SP, PRV	TBD	Roads	TBD	
Flood	**FL Action 3.5:** Encasing Pipelines	Encase water pipelines with specific sized rock, gravel, and road base in natural waterways to prevent continual washout or exposure during heavy storm events/floods.	SP, PRV	CSA 70 J	Water Systems	7/17/2017-7/1/2027	
Flood	**FL Action 4.1:** In each flood control zone, construct facilities identified in those zones by the Flood Control Advisory Committee. See Flood Control District Annex for a listing of projects.	This is an ongoing mitigation action from the 2011 MJHMP to achieve the goal of improving existing facilities and construct new facilities to mitigate flooding within the County.	SP		Primary: Public Works Secondary: San Bernardino County Flood Control District	On-Going	
Flood	**FL Action 6.1:** Continue funding and support for Special Districts Projects relating to flood hazards.	Continue funding and support for Special Districts Projects relating to flood hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	On-Going	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Flood	**FL Action 6.2:** On Call Contractors	Employ on call contractors to assist in emergency situations.	PRV, ES	TBD	Roads	TBD	
Drought	**DR Action 1.1:** Create a public awareness campaign advising citizens, business owners and farmers on water conservation.	Public education and outreach programs are an efficient and cost-effective way to promote meaningful changes within a community. A program to raise awareness on the importance of water conservation could significantly reduce the amount of water used by the public.	PE&A, NRP		Human Resources	TBD	
Drought	**DR Action 1.2:** Provide incentives for farmers to grow crops that are less water intensive.	Farmers use 80% of the State's water. By offering incentives to produce less water intensive foods (such as beets, carrots and potatoes) as opposed to more water intensive foods such as almonds, beef and pork) would make a substantial difference in water consumption.	NRP, PRV,		DAO Community Services?	On-Going	
Drought	**DR Action 1.3:** Continue to coordinate with the San Bernardino Valley Water Conservation District to provide Qualified Water Efficient Landscaper (QWEL) training.	The Qualified Water Efficient Landscaper training presents an affordable proactive local approach to reducing landscape water demand. QWEL provides graduates with knowledge in water efficient and sustainable landscape practices including water management and preservation of other valuable resources.	PE&A		Economic Development Agency?	On-Going	
Drought	**DR Action 1.2:** Approve the County's Watershed Water Quality Management Plan.	The County's Watershed Water Quality Management Plan written in 2013.	PRV, NRP			On-Going	
Drought	**DR Action 1.4:** Continue to enforce the watering schedule and watering restrictions throughout the County.	In response to the State Water Resources Control Board's 2016 emergency water conservation regulation, the County enforces a watering schedule for residential and commercial addresses.	PRV, NRP		Land Use Services	On-Going	
Drought	**DR Action 3.1:** Continue funding and support for Special Districts Projects relating to drought hazards.	Continue funding and support for Special Districts Projects relating to drought hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7	VARIES	VARIES	VARIES	On-Going	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Anti-Terrorism	**AT Action 1.1:** Identify and prioritize mitigation activities (anti-terrorism force protection) at critical facilities and gathering places that are vulnerable to terrorist attacks.	Critical facilities may include essential facilities (such as hospitals, police and fire stations, evacuation centers, etc.), transportation systems, lifeline utility systems, high potential loss facilities (such as nuclear power plants, dams and military installations, etc.), and hazardous material facilities. Gathering facilities should also receive special attention. Places of mass gathering not only present terrorists with potential opportunities for mass casualties, symbolism and high impact media coverage, they pose a broad range of security challenges for their owners and operators.	PRV, PPRO		Land Use Services	On-Going	
Anti-Terrorism	**AT Action 2.1:** Continue funding and support for Special Districts Projects relating to terrorism hazards.	Continue funding and support for Special Districts Projects relating to terrorism hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	On-Going	
Climate Change	**CC Action 1.1:** Continue working with the South Coast Air Quality Management District to meet GHG reductions targets.	The San Bernardino County General Plan Amendment and Greenhouse Gas Reduction Plan addresses the environmental effects specific to the proposed General Plan Amendment, Greenhouse Gas Reduction Plan, and associated Development Code Amendment and can be found here: http://www.sbcounty.gov/Uploads/lus/Countywide/GreenhouseGas/Full-Vol-1.pdf	PRV, NRP		Land Use Services	On-Going	
Climate Change	**CC Action 1.2:** Continue implementing the energy conservation and efficiency measures identified in the County of San Bernardino Greenhouse Gas Emissions Reduction Plan.	According to the San Bernardino County Renewable Energy and conservation Element, San Bernardino County's commercial, institutional and residential communities will continue to grow in the foreseeable future. Access to dependable and affordable energy sources is critical to maintaining and enhancing the quality of life enjoyed by San Bernardino residents and businesses. As energy needs grow, so do the needs to develop new energy sources.	PRV, NRP		Land Use Services	On-Going	
Climate Change	**CC Action 2.1:** Encourage carpooling and the use of public/ alternative transportation methods.	Reduction Measure R2T1 of the County of San Bernardino Greenhouse Gas Emissions Reduction Plan establishes an Employment Based Trip and VMT Reduction Policy. Some features include a compressed work week, car/vanpools, employee bicycle/pedestrian programs, and shuttle/ transit programs.	PE&A, PRV, NRP		Human Resources	On-Going	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Climate Change	**CC Action 2.2:** Optimize energy efficiency in the built environment and promote the local economic benefits of energy efficiency retrofits. (San Bernardino County Renewable Energy and Conservation Element)	This is an on-going mitigation policy from the San Bernardino County Renewable Energy and Conservation Element.	SP, PE&A, PRV		Public Works	On-Going	
Climate Change	**CC Action 2.3:** Encourage residents and businesses to conserve energy. (San Bernardino County Renewable Energy and conservation Element)	This is an on-going mitigation policy from the San Bernardino County Renewable Energy and Conservation Element.	PE&A, NRP, PRV		Human Resources	On-Going	
Climate Change	**CC Action 3.1:** Continue funding and support for Special Districts Projects relating to climate change hazards.	Continue funding and support for Special Districts Projects relating to climate change hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	On-Going	

Section 7. Plan Maintenance

7.1 Monitoring Evaluating and Updating the HMP

The San Bernardino County Fire Protection District Office of Emergency Services (OES) is the custodian of the Multi-Jurisdictional Hazard Mitigation Plan (MJHMP). In the 2010 MJHMP, County of San Bernardino indicated that the MJHMP would be reviewed annually. Although no formal meetings were held, OES reviewed the plan annually and collected new hazard mitigation information and mitigation efforts throughout the county. Additionally, OES referenced/reviewed the MJHMP before submitting grant applications to ensure the project was captured in the plan when applying for all grants to assist their mitigation efforts.

There are three (3) main components to the MJHMP: hazards, projects, and stakeholder involvement (public, as well as, county staff). The County and its Special Districts have focused on these components and over the last 5 years have made steady improvements in all areas. The County and its Special Districts participated and facilitated several meetings and established several tasks forces to help advance the understanding of hazards in the community. This information was shared with other county personnel and the general public. OES believes that this sharing of information leads to a more informed community, thus a more robust MJHMP.

Departments and Special Districts with projects track the status of the projects through the entire life cycle from concept to completion. Projects in progress are tracked to ensure all milestones are met and payments are made in a timely manner. Each year proposed projects are reviewed during budget development every spring and selected projects are submitted for funding to the appropriate funding source. These funding sources include but are not limited to grant funding, General Fund funding, and Special District funding.

Because the MJHMP is a living document that reflects ongoing hazard mitigation activities, the process of monitoring, evaluating, and updating will be critical to the effectiveness of hazard mitigation within the County Unincorporated Area. The County and its Special Districts will hold internal planning meetings to discuss current projects and evaluate newly proposed projects resulting from internal staff meetings and input from the public. The results of these Departmental/Special District meetings will be presented to the Multi-Jurisdictional Planning Team meetings at their annual meetings. To facilitate the Multi-Jurisdictional Hazard Mitigation Planning process, OES is proposing to conduct these annual meeting with the Multi-Jurisdictional County Planning Team where the Team Members will discuss the projects, priorities, and goals in the current plan and from individual Special District meetings and suggest any necessary changes. Results of the annual meeting will be retained and compiled for the 2016 update. The County Planning Team will continue to support focused outreach for county Departments and Districts as well as support Countywide activities.

7.1.1 Plan Adoption

To comply with DMA 2000, the San Bernardino County Board of Supervisors has officially adopted the 2016 San Bernardino County Multi-Jurisdictional Hazard Mitigation Plan. The adoption of the 2016 MJHMP recognizes the County's commitment to reducing the impacts of natural hazards within the County limits. A copy of the 2016 MJHMP adoption resolution is included after the table of contents in this document.

7.1.2 Implementation

The knowledge gained from the MJHMP has helped the county enhance other planning efforts. One of the biggest results from the 2010 MJHMP efforts was the incorporation of the MJHMP into the 2007 General Plan's Safety Element. This merging of plans has help ensure development decisions are considering the most recent hazard information. It is the County's intent to incorporate by reference the updated MJHMP into the County General Plan upon approval from FEMA.

The MJHMP has also led to the strengthening and improvement of several County Ordinances, which are designed to ensure proper fuels reduction was completed in the Severe Fire Hazard Zones. Two new ordinances were passed requiring replacement of wood shake roofs in the Severe Fire Hazard Severity Zones by 2014 and the reduction of live fuel loads around structures in the Very High Fire Hazard zone.

The MJHMP goals and actions will be incorporated into various general operations of government. For example, much of the information from the MJHMP will be included in the County Operational Area Emergency Operation Plan (EOP). As any future County plans are developed, the Multi-Jurisdictional Hazard Mitigation Plan will be a great asset in any plan development efforts. As noted earlier, much of the information contained in this MJHMP is from the County General Plan and is already part of the planning process.

Additional benefit is gained from the County and its Special Districts reviewing existing mitigation projects and development of additional mitigation projects at their internal annual Planning Team meetings. This input includes comments and suggestions from the public as well as from the internal planning process of each County department and District.

7.1.2.1 Implementation through Existing County Mechanisms

7.1.2.1.1 All Hazards

7.1.2.1.2 Amendment to Title 6 County Code

An amendment to Title 6 of the County of San Bernardino Code to adopt by reference the 2010 Editions of the California Building Standards Codes went before the Board of Supervisors on

November 2, 2010 and was continued for a second reading on November 16, 2010 and approved unanimously. The amendment became effective on January 1, 2011.

The County of San Bernardino amendment to Title 6 of the County Code to adopt by reference the 2010 Editions of the California Building Standards Codes repealed the current chapters of Division 3 of Title 6 that reflect the 1994/1995 editions of the California Building Standards Codes and adopt the 2010 editions of these codes by reference.

The California Building Standards Commission approved the California Building Standards Code (Code) for a statewide effective date of January 1, 2011 and requires this Code apply in all parts of the state. This Code consists of the California Building, Residential, Plumbing, Mechanical, Electrical, Energy, Historical Buildings, Existing Building (Unreinforced Masonry) and the Green Building Standards Codes. Since this 2010 Edition was adopted by local ordinance, the prior editions of this code will be repealed and the most recent editions of the codes with applicable amendments requiring express findings and certain appendices necessary for the health and safety of the citizens of this County will be in effect within the unincorporated areas of San Bernardino County. The benefit of adopting this Code is that it provides consistency and clarification for the building community as well as building inspectors and plans examiners. State law (Health & Safety Code 18941.5 and 17958.7) requires the local government make express findings in order to amend building standards and the amendments must be necessary due to local climatic, geological, or topographical conditions.

Those amendments and findings are included in the County's ordinance and were filed with the California Building Standards Commission.

The recommended modifications not requiring express findings are administrative or procedural in nature and concern the local implementation issues that are not covered by building standards.

An example of this type of modification is to the California Residential Code, Section R105.3.1.1 which requires the Board of Appeals to confirm substantial valuations in the flood plain. The traditional purpose of the Board of Appeals has been reserved for a contested decision of the Building Official, and it is felt that it should remain as such.

With respect to grading and excavation regulations found in Appendix J of the 2010 State published code, the 2001 California Building Code dealt with grading with more clarity in regards to what activities require a permit and set forth rules to ensure large grading projects are scrutinized in greater detail than smaller projects by requiring more reporting and inspection of such work. The grading chapter in the 2001 Code has been trusted and in use in its primary form for years. The 2010 Appendix J grading chapter needs substantial amendment and modification to address all grading issues and is not recommended for adoption in its present form. The Board adopted the 2001 Appendix Chapter 33 regulations as part of this proposed ordinance. Relocation permit requirements have been moved to a new section of the Code, and it retains specific standards for relocation procedures in details not found in the 2010 State-published code. Clarification of the types of buildings affected by the new regulations has also been made.

Administrative changes to the 2010 California Existing Building Code (Part 10 of Title 24) were approved to outline the procedures required to set allowable time limits for the retrofit and repair of unreinforced masonry buildings. Staff is also recommending that authorization be given to the Building and Safety Division of the Land Use Services Department to issue Administrative Citations as an alternative means of enforcement of the County Code provisions.

Express findings are made for changes to the California Plumbing Code, Appendix K regarding the soil conditions that exist in this county. These changes are supported by the Environmental Health Division. These express findings are iterated in the ordinance and will be filed with the Building Standards Commission as required by law in order to become effective.

7.1.2.2 Wildfire

7.1.2.2.1 Inland Empire Fire Safe Alliance (IEFSA)

The Inland Empire Fire Safe Alliance (IEFSA) was created to act as a forum for all Fire Safe Councils in San Bernardino County. Some of the benefits are developing a consistent and comprehensive message to citizens about fire safety; coordinating efforts for grant administration, writing, and reporting; a one-stop shop for information, resources and research; and a centralized source for sharing of updates from cooperating governmental agencies. There are approximately 20 Fire Safe Councils active in San Bernardino County.

IEFSA has held bimonthly meetings for over 5 years and have been the focal point for all regional Fire Safe Councils including some from Riverside County. They have also held numerous workshops and seminars regarding fire resistive construction, and materials, BAER reports, CWPPs and grant writing. The IEFSA was the focal point for Fire Safe Councils (FSCs) that were working on completing their CWPPs and created a focus group and a steering committee to accomplish these critical plans. To support public education and involvement,

IEFSA created the web site www.fireinformation.com as well as participated in countless safety fairs and fire wise awareness activities. They also conducted a Public Education Media Exchange where all FSC and Agencies got together to share educational modalities and create common thought and educational threads. They have reached out to thousands of mountain residents in preparing them for wildfires.

7.1.2.2.2 Mountain Area Safety Taskforce (MAST)

MAST was formed to mitigate the region wide risk of a catastrophic wildfire due to dead and dying trees in the mountain communities. The mission of the MAST is to facilitate a coordinated effort by cities, county, state, federal, and non-profit agencies to provide for the protection of property owners, residents, and property subject to the risk of catastrophic wildfire that could occur in San Bernardino County with an initial emphasis on the threat resulting from the Old and Grand Prix fires in 2003. MAST priorities are to continue reducing fire hazards through fuel reduction programs and hazard abatement though enforcement of county ordinances.

The Mountain Area Safety Taskforce (MAST) Operations Section meets monthly. MAST Operations Section determines project priorities based on the benefit cost analysis of the projects and the effect of the project on the overall goals of the MAST organization.

The MAST Unified Command identified the following objectives as their focus and direction:

- Provide for Community Safety.
- Develop Coordinated Public Information Dissemination Between Cities, County, Special Districts, State, Federal, and Non-Profit Agencies.
- Develop Immediate, Mid-range and Long-range Coordinated Agency Plans.
- Identify and Secure Potential Funding Resources to Provide Protective Measures.
- Document Task Force Activities Including Mission, Goals and Objectives, Policies, Procedures, and Outcomes. Prior to any type of flood threat, the following precautionary measures may be taken by MAST members to reduce the impact of impending fires:
- Review mutual aid agreements
- Define evacuation areas and trigger points
- Review the use of alert and warning systems
- Provide information to the public of fire prone areas and protective measures in progress or planned for those areas
- Educate public on emergency self-help and preparedness
- Develop and maintain emergency notification procedures and checklists

MAST is the central point of coordination for all projects related to the reduction of the potential for catastrophic wildfires. There are numerous participants and all levels of government. MAST partners collaborate to provide multi-agency technical support to ensure project success. Economic impacts are considered and the result has been significant increase in economic activity through thoughtful application of grant funding. MAST has been so successful in the environmental management of projects that all of the local environmental groups including national affiliates are now supporters of MAST fuels projects.

The MAST group includes:

- San Bernardino County Board of Supervisors
- County Administrative Office
- County Public Works-Flood Control/Transportation/Solid Waste

- County Fire Protection District
- County Fire Protection District/Office of Emergency Services (OES)
- County Sheriff's Department
- Southern California Edison
- Bear Valley Electric
- Arrowbear Lake Fire Department
- Big Bear City Fire Protection District
- City of Big Bear Lake Fire Department
- Crest Forest Fire Protection District
- Running Springs Fire Department
- USFS
- San Bernardino National Forest Association
- Forest Care
- Cal Fire
- Caltrans
- California Highway Patrol
- Inland Empire Fire Safe Alliance
- Angelus Oaks Fire Safe Council
- Arrowhead Communities Fire Safe Council
- Bear Valley Fire Safe Council
- Lytle Creek Fire Safe Council
- Mill Creek Fire Safe Council
- Mountain Rim Fire Safe Council
- Wrightwood Fire Safe Council

Since its beginnings, MAST has been the Unified Command that has successfully implemented and completed numerous programs leading to safer communities, a more educated public and an improved environment.

MAST provides an extensive Fuels Reduction Program. The Fuels Reduction Program began with removal of dead hazardous trees from areas threatening electrical transmission lines, evacuation routes, and structures within the San Bernardino Mountains. Dead and dying trees pose an extreme fire danger, and MAST members began removing these trees under state and federal grants, including a $70 million grant from the USDA Natural Resources Conservation Service. At the height of the program, Southern California Edison contractors were taking out 650 trees a day. As the program developed, additional hazards were identified, such as green fuel load density and wood shake roofs on structures within the San Bernardino Mountains

The MAST mission has expanded to include reducing green fuel by thinning live trees in densely wooded areas. Property owners also are being urged to thin the live trees and vegetation on their property to gain an upper hand on the bark beetle infestation and reduce the risk of catastrophic wildfires like the Grand Prix and Old fires in 2003.

Other MAST Achievements include:

- Increasing awareness of the drought-related bark beetle emergency and the threat of catastrophic wildfires
- Distributing fire safety and prevention information to the public
- Developing evacuation plans and distributing emergency planning information to the public
- Developing commercial use or disposal options for waste wood products.

The Mountain Area Safety Taskforce (MAST) Operations Section meets monthly. MAST Operations Section determines project priorities based on the benefit cost analysis of the projects and the effect of the project on the overall goals of the MAST organization.

Goals can change as detailed Benefit Cost Analysis is conducted and CEQA/NEPA reviews are completed.

7.1.2.2.3 Fire Safety Overlay District Mitigation

A General Plan Amendment to the Safety Element of the County of San Bernardino 2007 General Plan updated the Fire Safety Overlay District effective March 11, 2010. The Safety Element includes several hazard overlays that are included in the General Plan mapping system to inform the public of potential hazards to development of property within certain areas of the County and to enable the County to mitigate the risks presented to property owners by these hazards, by requiring fire resistant building construction methods. The overlays include potential fire hazards within the mountain regions as well as the valley and desert “interface”. Over the past twenty years, certain federal and state agencies have been in the process of digitizing much of this hazard data. The digitization of this data has allowed for greater accuracy as well as more timely updates. In recognition of the new data from various federal and state agencies, the County updated the Fire Safety Overlay District contained within the Safety Element of the General Plan. The Fire Safety Overlay District is amended by modifying four General Plan Quad Maps to incorporate updated fire safety mapping published by Cal Fire for the Valley area.

As new information is received, the overlay maps are updated to reflect changes. These updates are made by the Land Use Services Department in collaboration with County Fire Protection District. More areas have been added through annexation and contract for services and so there has been large growth and the overlay will be updated. The future 2018 CountyWide Plan will replace the General Plan, and will contain more update maps and regulations that will allow development to occur but ensure safety and sustainability within the Fire Safety Overlay District.

7.1.2.2.4 Public Education Programs

The County through MAST conducted a comprehensive mountain-wide multi-modality Public Outreach Program from 2006 to 2008. It can be found at www.CalMAST.org. The program in both English and Spanish created and presented multiple public educational meetings, newsletters,

brochures, calendars, and posters. Because of the large number of visitors to the forest, MAST also created Emergency Information Visitors brochure and glove box sized Emergency Response Evacuation maps for the mountain communities. The program won national awards for advertising and public relations. Other jurisdictions initiated their own public education activities but brought them back through MAST so that the entire group could receive the benefit. The City of Big Bear Lake Fire Department was the most prolific in developing innovative and creative educational programs. They developed the Thin-Is-In website at (www.thinisin.org) that is an excellent site for citizens and agencies as well. Since the Big Bear Valley is served by an excellent radio station KBHR (k-bear) they have posted numerous public safety messages. Also during the Butler, Butler II and Slide Fires, KBHR provided constant updates to the community regarding the fire.

7.1.2.2.5 County Fire Hazard Abatement

Land Use Services Department, Environmental Health Division is responsible for Fire Hazard Abatement (FHA). Fire Hazard Abatement works to reduce the potential for an individual's property to be the source of fire and structural ignitability. Failing to maintain private property in a fire safe condition is seen as a fire threat and is considered a threat to neighbor's property rights. To obtain compliance, FHA issues notices of violation to properties that have dry vegetation and flammable green vegetation. If the property owner doesn't comply with the notice, FHA then obtains a warrant to go onto the property and abate the fire hazard.

The Fire Hazard Abatement portion of the County Code was completely rewritten and redesigned around real flammable fuels. The most significant change was to include certain types of green fuels as flammable vegetation.

Following in the City of Big Bear Lake's path, the County adopted the new code in the fall of 2008. In January of 2010 the County amended the Hazard Overlay maps.

The Fire Hazard Abatement Division of the Land Use Services Department conducts annual inspections of all parcels of land in mountain regions for the purpose of identifying exterior fire hazards. Biannual inspections are completed in valley and desert serviced areas. The targeted hazards include high energy release shrubs, dead and hazardous trees, flammable vegetation, weeds, grasses and combustible rubbish. The Division completes more than 430,000 inspections, issues more than 45,000 Notices to Abate Fire Hazards, issues over 4,000 citations for non-compliance, and abates the fire hazards on more than 2,000 parcels annually. Within the last 5 years, the Fire Hazard Abatement Division has received even more financial resources that enable them to abate all properties declared a fire hazard.

7.1.2.2.6 Countywide Fuels Management Program

In May of 2005 the San Bernardino County Fire Protection District and the San Bernardino County Flood Control District formed a partnership to implement the Hazardous Tree Removal Program, later the Fuels Management Program. In this endeavor the Flood Control District

formed the Hazardous Tree Removal Operations Division which was tasked with developing, bidding and administering Tree Removal and Fuel Reduction Contracts funded by various grants. Contracts originally focused on removing dead, dying, and diseased trees caused by the drought conditions and the bark beetle infestation. The program has evolved to include fuel modification projects which remove hazardous vegetative fuels through the thinning of live vegetation. In addition the location of the fuel reduction projects are moving beyond the limits of the San Bernardino Mountains and into the interface between the Mountain foothills and the high desert.

The following are the types of programs/projects included in the Fuels Management Program:

- Emergency Tree Removal Projects consist of the removal of a tree (or trees) that poses an immediate threat to safety, a structure, or the public right-of-way.
- Block Projects are dead dying diseased tree removal projects on multiple parcels which are located in close proximity to one another.
- Large Urban Parcel Projects are dead dying diseased tree removal projects on a single or multiple large parcels.
- Fuel Modification Projects focus on the removal of hazardous fire fuels in the wildland/urban interface. The fuels removed in these projects are both live and dead vegetation. The goal of these projects is to reduce a future forest fire's intensity as well as the removal of ladder fuels which carry the fire from the forest floor to the forest canopy and result in a crownfire.

In addition to the Hazardous Tree Removal Operations Division, the San Bernardino County Fire Fuels Management Crews are also funded by the same grant sources. The primary focus of the crews is to create and maintain fuel modification projects in the vicinity of communities at risk and construct fuel breaks. In addition the crews assist the public with curb side chipping programs throughout local partner jurisdictions.

7.1.2.2.7 Fireworks Interdiction

The unlawful transport of dangerous fireworks continues to be enforced by several local and state fire and law enforcement agencies, The program continues ensures that thousands of pounds of fireworks per year are seized and properly disposed of, preventing fires, fire injuries and fire deaths.

7.1.2.2.8 Programs Listed in Fire District Annex

Table 7-1: Wildfire Mitigation Implementation Methods

Mitigation type	Description
PPRO	SCE removes dead trees near power lines to reduce fire hazards. For more information, see Annex A Section A.6 Mitigation Project Prioritization and Implementation.
ES	Mountain Mutual Aid is an operational group of emergency responders.
PRV	The Alliance was created to act as a forum for all Fire Safe Councils in San Bernardino County. For more information, see Annex A Section A.6 Mitigation Project Prioritization and Implementation.
PRV	Fire Hazard Abatement works to reduce the potential for an individual's property to be the source of fire and structural ignitability. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .
PE&A	Cal Fire provides programs to increase fire safety in high fire hazard severity zones. For more information, see Annex A Section A.6 Mitigation Project Prioritization and Implementation.
PRV, PPRO	The Contractor Certification program trains and certifies landscape contractors to provide a qualified workforce to conduct fuels reduction activities on individual properties. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .
PRV, PPRO	CWPPs are designed to provide a means for a community to have input into and actively participate in the planning, strategy, goals, and objectives of creating a fire safe community. For more information, see Annex A Section A.6 Fire Protection District Mitigation Project .

7.1.2.3 Earthquake / Geologic

A General Plan Amendment to the Safety Element of the County of San Bernardino 2007 General Plan updated the Geologic Hazard Overlay Maps which became effective on March 11, 2010. The Safety Element includes several layers of hazard overlays that are included in the General Plan mapping system to inform the public of potential hazards to development of property within certain areas of the County and to enable the County to mitigate the risks presented to property owners by these hazards. These overlays include potential geologic hazards. Over the past twenty years, certain federal and state agencies have been in the process of digitizing much of this hazard data. The digitization of this data has allowed for greater accuracy as well as more timely updates. In recognition of the new data from various federal and state agencies, the County updated the geologic hazard overlay maps, specifically the Generalized Liquefaction

Susceptibility layer and the Generalized Landslide Susceptibility layer, contained within the Safety Element of the General Plan.

The Generalized Liquefaction Susceptibility layer was amended to modify four General Plan Quad Maps to incorporate new liquefaction data in the Big Bear Lake area designated by the County Geologist for the Big Bear Lake Valley. This information was then incorporated into the County-designated Geologic Hazard Overlay District.

The Generalized Landslide Susceptibility layer was amended by modifying 17 General Plan Quad Maps and one regional Quad Map, to incorporate updated existing landslide data published by the U. S. Geological Survey for the Mountain area. The County Geologist updated the landslide inventory within the Geologic Hazard Overlay District by incorporating new geologic mapping by the U.S. Geological Survey.

The following is a list of the updated General Plan Geologic Hazard Overlay Maps effective on March 11, 2010:

Table 7-2: General Plan Geologic Hazard Overlay Maps

Map #	Quad Name
FH08C	Fifteen Mile Valley
FH11C	Mt. San Antonio
FH12C	Telegraph Peak
FH13C	Cajon
FH14C	Silverwood Lake
FH15C	Lake Arrowhead
FH16C	Butler Peak
FH19C	Mt. Baldy
FH20C	Cucamonga Peak
FH21C	Devore
FH22C	San Bernardino North.
FH24C	Keller Peak
FH27C	Ontario
FH30C	San Bernardino South
FH31C	Redlands
FH32C	Yucaipa
FI09C	Fawnskin
FI10C	Big Bear City

Map #	Quad Name
FI17C	Big Bear Lake
FI18C	Moonridge
EH/FH C	SW Portion of County
FH23C	Harrison Mtn.

7.1.2.4 Flood

7.1.2.4.1 Existing Drainage Studies

Drainage studies including review of upstream properties, site drainage area, potential upstream development, and site-specific development will help to mitigate damage from future storm events. San Bernardino County owns landfill sites, transfer stations and closed disposal sites where combined site property totals several hundred acres. Landfills and disposal site properties include acreage that has been constructed to design grades and may include improved drainage systems. Also, within most landfill and disposal site properties there are many acres of property that remain in its natural state including native vegetation and natural grades. During severe weather events, both engineered areas and undisturbed areas are subject to erosion from storm run-off. The erosion can range from minor to severe depending on the storm event and amount of precipitation. Most sites where engineered drainage systems are in place hold up well experiencing only minor erosion and debris flow. However, during major storm events, runoff from native and unimproved areas carrying solids and debris flow may compromise downstream drainage systems and overwhelm system facilities. Much of the damage to landfill and disposal sites during the December 2010 Winter Storm event was caused by erosion with sediment carried from undeveloped/undisturbed areas or where no improved drainage system is in place.

Other events that may cause damage to property and structures include earthquakes, wildfires, high winds, extreme freezes, and lightning storms.

- Earthquakes have the potential of causing damage to site roadways, structures, and systems including concrete drainage systems, Landfill Gas systems (LFG) and Leachate Collection Recovery Systems (LCRS). With earthquakes, there is always the potential of slope failure and slides on the landfill surface. Damage to any of these facilities has the potential to result in an inability to temporarily service the community.
- High Winds can cause damage to temporary drainage structures, fencing, and metal structures. During past high wind events, Transfer Stations have experienced roof panels being torn from the beams. Landfill sites with exposed geo-synthetic liners may experience damage if the winds lift and tear the liners.
- In January 2007, the County experienced a loss of over $21,000 in damage when water pipes at three separate Transfer Stations froze, then burst, causing damage to offices and electrical equipment.

- Lightning storms have the potential to damage electrical components in scale houses, in-ground scales, LFG, and LCRS.

7.1.2.4.2 NFIP Program and County General Plan Policies

Because the County has entered into an agreement to participate in the National Flood Insurance Program (NFIP) which provides flood insurance within designated floodplains, the following goals, policies and programs shall apply:

As stated in the San Bernardino County General Plan Safety Element:

GOAL S 5
The County will provide adequate flood protection to minimize hazards and structural damage.

Policy S 5.1: Participate in the National Flood Insurance Program (NFIP), which provides flood insurance within designated floodplains.

Programs

1) Designate Floodway and Floodplain areas, as identified by the Federal Emergency Management Agency (FEMA) on flood insurance rate maps and flood boundary maps, as Floodway (FW) on the Land Use Maps and Floodplain Overlays on the Hazards Overlay Maps.

2) Designated floodway areas will be preserved for non-structural uses through restrictions of the FW Land Use Zoning District

3) All new development, including filling, grading, and construction, proposed within designated floodplains, will require submission of a written assessment prepared by a qualified hydrologist or engineer, in accordance with the latest "San Bernardino County Hydrology Manual" and the various detention basin policies (see Existing Policy FL-11), to determine whether the development will significantly increase flood hazard and to show that all new structures will be adequately protected. Development will be conditioned on receiving approval of this assessment by the San Bernardino County Surveyor Division of the Public Works Department. All new construction in a Floodplain Overlay area will be required to be flood-proofed, located, and designed to allow unrestricted flow of floodwaters.

4) The Land Use Compatibility Chart for 100-Year Flood Plains Table 5-1 will apply to County reviews of all discretionary and ministerial actions in County designated floodplains.

5) Lands within floodplain areas may be developed with non-critical and non-essential uses if mitigation measures are incorporated to ensure that the proposed development will not be hazardous, increase flood depths or velocities downstream, or degrade water quality, especially uses such as parks, trails, and open space.

6) Provide known flood hazard information with every discretionary or ministerial application.

7) When no mapped data exist, existing topographical, watershed, and drainage course data will be evaluated for a determination of potential flood hazard for every discretionary and ministerial action.

Policy S 5.2: Update data and maps with newly identified flood hazard areas in the County, as new information becomes available.

Programs

1) As new overflow studies and mapping are completed and approved by either the County's Land Development Engineer or the San Bernardino County Flood Control District, they will supplement the FEMA mapping and will be incorporated into Flood Hazard Overlay mapping.

2) Initiate and finance programs for the continuous evaluation and designation of floodway, floodplain, and drainage areas.

3) Timely application for FEMA mapping changes will be initiated to reflect any additions to or alterations in identified Floodways or Floodplains by the County Floodplain Management Administrator.

7.1.2.5 Drought

7.1.2.5.1 Water Efficient Landscape Ordinance

Over the years, the State of California has been promoting water conservation for all new development within the State. In a drought-prone California, where approximately 60 percent of all residential water is used in landscape applications, California lawmakers have adopted such legislation as Assembly Bill (AB) 325 (1990), AB 2717 (2004), and AB 1881 (2006) that outline, and in some instances mandate, the practice of water conservation in landscape applications. As part of AB 325, the Department of Water Resources (DWR) was charged to assemble a task force of stakeholders representing the landscape, water, and building industries as well as cities, counties, and other agencies that would help DWR prepare and promote the State's first Model Water Efficient Landscape Ordinance (MWELO).

While AB 325 did not require cities, counties, and other agencies within the State to comply with the first adopted MWELO, it did encourage local agencies to implement water conservation techniques into their local ordinances and codes. The County adopted Administrative Guidelines

that were amended several times and ultimately given the status of "regulation" when they were incorporated into the Development Code (Chapter 83.10) during the 2007 General Plan Update process.

In 2006, State lawmakers adopted AB 1881, which gave guidelines and timelines for revision of the State's MWELO and mandated that every city, county, or other agency within the State of California adopt the State's revised MWELO, or be in compliance with it through their own ordinance, by January 2010. Local agencies are required to report their final action, along with findings of ordinance effectiveness, to DWR by January 2011. While this process was underway, Senate Bill X7-7 was enacted (2009). This bill requires the State of California to achieve a 20 percent reduction in urban per capita water use by December 31, 2020; additionally, it requires the State to make incremental progress towards this goal by reducing per capita water use by at least 10 percent by December 31, 2015. These requirements were incorporated into the MWELO and, in February 2008, DWR made a draft of the State's revised MWELO available to all cities, counties, and other agencies within the State. The final version of the revised MWELO was released in September 2009.

Upon review of the final version of the State's MWELO and the provisions of AB 1881, staff determined the County would need to revise Development Code Chapter 83.10 which sets forth landscaping and irrigation standards within the unincorporated areas of the County. This would in part, become a mitigation measure to assist with any drought hazard the County may encounter. In the meanwhile, the County began enforcing the State's revised MWELO in January 2010, as required by law.
Once the proposed changes to the Development Code have been adopted by the Board of Supervisors, staff will notify and forward all required information regarding the adoption and effectiveness of the County's Water Efficient Landscaping Ordinance to the State DWR as required by January 2011.

The proposed Development Code Amendment will revise the landscaping standards to reflect the changes governed by and to be as effective as, the State of California's revised Model Water Efficient Landscape Ordinance, while continuing to recognize the unique character of the regions that make up the County of San Bernardino.
The ***proposed revisions*** will require the applicant/developer to:

- Design and install systems that meet more effective and efficient water conservation standards in all landscaped areas on a project site, including residential;
- Comply with the revised standards for all new and rehabilitated landscape areas regardless of square footage for projects that are not homeowner installed and for all new and rehabilitated landscape areas, that are homeowner installed, that are 5,000 square feet or greater. This includes the following:
    - Submit a comprehensive Landscape Documentation Package, which has been prepared by a landscape architect licensed to work in the State of California or other licensed professional authorized to design and prepare Landscape Plans within the State of California;

- Submit estimated annual water budget calculations for compliance with water conservation practices and the efficient use of water for each new or rehabilitated landscape. Calculations for the annual water budget for a project/site specific landscape shall use the formulas for the Maximum Applied Water Allowance (MAWA) and the Estimated Annual Water Use (EAWU) outlined in the ordinance;
- Submit a Landscape Certificate of Compliance prepared by the landscape professional who prepared the Landscape Documentation Package conveying the project's compliance with the requirements of Development Code prior to final inspection;
- Planting material within landscaped areas shall be chosen based on the information found in the Water Use Classification of Landscape Species, third edition (WUCOLS III) and the climate zone for the region based on information found in Sunset Western Garden Book;
- Irrigation systems shall be equipped with a "smart" irrigation controller, which automatically adjusts the frequency and/or duration of irrigation events in response to changing environmental conditions.
- Submit a rough and/or precise grading plan on all projects proposing more than 50 cubic yards of grading;
- Submit a soil management report, that includes recommendations for soil modification and/or amendment;
- Submit a project-specific regular maintenance schedule and two project-specific irrigation schedules for those projects subject to the ordinance.

Other provisions of the new regulations include standards for non-potable/recycled water use where it is available and new enforcement standards for compliance with water conservation practices.

Since the State law became effective on January 1, 2010, the Landscape Plan Review Fee was adjusted (Ordinance #4412, June 22, 2010) to reflect the increase in staff time necessary to meet these additional requirements.

The Planning Commission considered this ordinance on October 21, 2010. There was no one at the hearing who wished to address the Commission on this issue. The Commission recommended that the Board adopt the ordinance as presented on a vote of four commissioners in favor and one absent.

The proposed amendment is exempt from the California Environmental Quality Act (CEQA) in accordance with Section 15061(b) (3) of the CEQA Guidelines as the proposed change does not have the potential to cause a significant effect on the environment.

The proposed Ordinance is to be presented to the County of San Bernardino Board of Supervisors for adoption in the first quarter of 2011. Utilizing either the State Water Efficient Landscape Ordinance, which is in effect currently, or the County's specific Water Efficient Landscape Ordinance; the drought mitigation for this hazard is positive.

7.1.2.5.2 San Bernardino County Desert Area Groundwater Inventory and Atlas

As of January 2011, the California Department of Water Resources anticipates releasing the Final Local Groundwater Assistance (LGA) Guidelines later this calendar year. In December 2009, the draft LGA Guidelines and Proposal Solicitation Package (PSP) was available for public comment. The comment period ended on January 12, 2010.

Local public agencies with authority to manage groundwater resources are encouraged to apply Examples of projects that may be considered are: Groundwater data collection, modeling, monitoring and management studies; monitoring programs and installation of equipment; basin management; development of information systems; and other groundwater related work.

The County of San Bernardino Board of Supervisors may consider an action directing staff to apply for the grant when it becomes available for a Desert Area Groundwater Inventory (DGI) and Atlas. The DGI falls within the scope of the Local Groundwater Assistance (LGA) Program, which is funded with Prop 84 IRWM funds anticipated to be available for fiscal year 2010-2011. Grants are limited to $250,000 per recipient, and total funding is $4.7 million.

California Department of Water Resources will give priority to local agencies with adopted groundwater management plans (SB1938 compliant), and which demonstrate collaboration with other local agencies in managing groundwater basins. County's groundwater management ordinance satisfies this requirement.

By having a Desert Area Groundwater Inventory and Atlas, this would enable the County to have a database providing locational and water depth information for specific regions of the County that currently do not have a groundwater inventory. This Inventory and Atlas would provide information applicable for flood mitigation or ground water availability for usage during severe drought. The location and water depth in the inventory are important for an earthquake hazard analysis, if liquefaction potential exists.

Since there is not a Desert Area Groundwater Inventory currently, and if liquefaction is a concern in a specific region of the County, then the water depth data would estimate the vertical distance from the land surface to the top of the groundwater aquifer (i.e., the groundwater-saturated layer.)

Table 7-3: Tentative Schedule for the LGA Grant

Date	Event	
TBD	Release Final LGA Guidelines and PSP	Dependent upon Grant approval
TBD	Proposal Applications Due	Dependent upon Grant approval
TBD	Public Release of Draft Award Recommendations	Dependent upon Grant approval

Fund Source: Proposition 84

7.1.3 Continued Public Involvement

As indicated earlier, the County will continue to engage the general public and seek input on the mitigation and preparedness planning process. In addition to the San Bernardino County Board of Supervisor meetings, the actions include:

- Municipal Advisory Communities throughout the unincorporated County area,
- Flood Zone Advisor Committees,
- Special District Advisory Committees,
- Public hearings for County General Plan updates held four times a year,
- MAST and FAST meetings,
- Fire Safe Council meetings,
- Community Emergency Response Team meetings, and
- Public events where educational efforts are undertaken in the unincorporated areas.

Additionally, the public is kept involved through annual programs such as the Great Shakeout held annually in October, SKY Warn events sponsored by the National Weather Service, and other monthly safety programs. The County will continue to use several different methods to reach out to the public: mailers, cable TV, website, social networks, e-mail, posting in public libraries, and fairs.

Section 8. Works Cited

USGS. (2009).

USGS. (2016, April 7). *USGS Earthquake Hazards Program*. Retrieved from https://earthquake.usgs.gov/learn/glossary/?term=earthquake

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Appendix A. Outreach Documentation

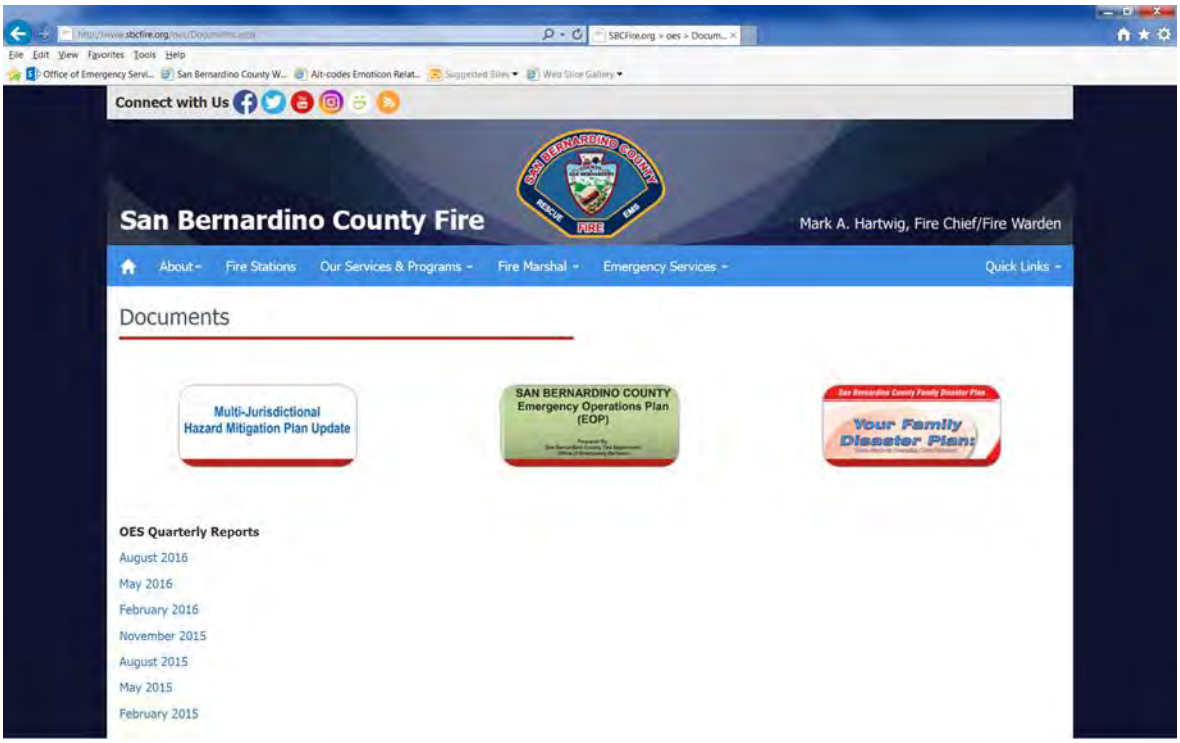
A.1 Ready SB County Preparedness App Message

An App message was sent out to over 15,000 persons with the App and it is attached to the San Bernardino County Fire Website. .Ready SB County Preparedness Mobile App can be used on either an Android or iPhone. This app provides multiple resources for our residents that will assist them in preparing for a disaster and enhancing the recovery process. Protect yourself and your loved ones before, during and after a disaster.

Get the Latest News from SBCounty.gov, CalTrans, National Weather Service, and San Bernardino County Fire Office of Emergency Services. This app will provide you with an emergency supply kit list, grocery list and checklists tailored to your needs. You can access and update your plan as needed. Learn all you need to plan for and respond to natural disasters, terrorism and pandemic flu in San Bernardino County

A.2. San Bernardino County Fire Public Input Requested

San Bernardino County Fire Department/Office of Emergency Services (OES) is coordinating the update of the San Bernardino County Unincorporated Area Multi Hazard Mitigation Plan. Hazard Mitigation Plans are updated every five years and must be approved by Cal OES and FEMA. The purpose of the public input and comment is to show progress being made and elimination of hazards since the last plan. Your input is appreciated by reviewing and commenting on the current plan (link below) by calling OES at 909-356-3998 – ask for David Davis. Comment period **closed at 5:00 p.m., Wednesday, November 3, 2016.**
http://www.sbcfire.org/oes/Documents.aspx

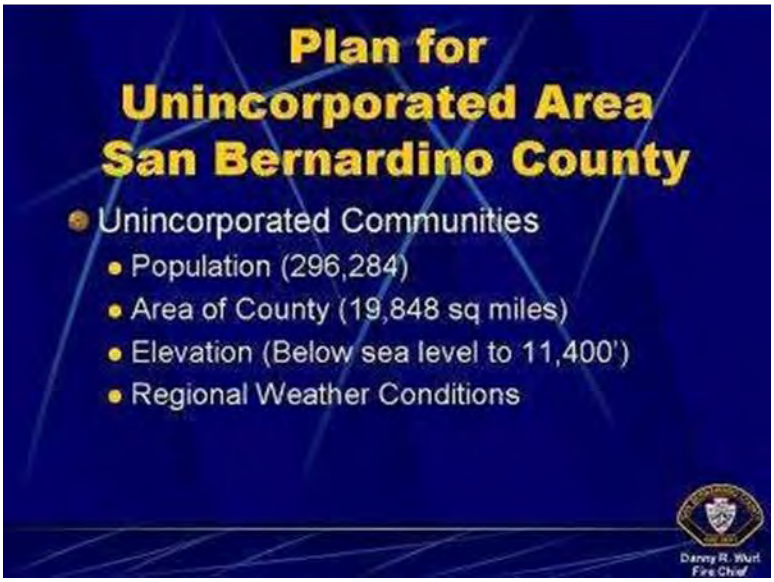

Connect with Us
San Bernardino County Fire
Mark A. Hartwig, Fire Chief/Fire Warden
About
Fire Stations
Our Services & Programs
Fire Marshal
Emergency Services
Quick Links
Documents
Multi-Jurisdictional Hazard Mitigation Plan Update
SAN BERNARDINO COUNTY Emergency Operations Plan (EOP)
Your Family Disaster Plan
OES Quarterly Reports
August 2016
May 2016
February 2016
November 2015
August 2015
May 2015
February 2015

A.3. MJHMP PowerPoint Presentation






Hazard Mitigation Planning
55 partners
Heavy Focus on Planning Process
Cal EMA Coordinated
FEMA Approved
Danny R. Wurl
Fire Chief


Plan for Unincorporated Area San Bernardino County
Unincorporated Communities
Population (296,284)
Area of County (19,848 sq miles)
Elevation (Below sea level to 11,400')
Regional Weather Conditions
Danny R. Wurl
Fire Chief

Annex A. Fire Protection District

A.1 Introduction

This Annex details the hazard mitigation planning elements specific to the Fire Protection District, a previously participating jurisdiction to the 2011 San Bernardino County Hazard Mitigation Plan Update. This Annex is not intended to be a standalone document, but appends to and supplements the information contained in the base plan document. As such, all sections of the base plan, including the planning process and other procedural requirements apply to and were met by the Fire Protection District. This Annex provides additional information specific to the Fire Protection District, with a focus on providing additional details on mitigation actions and projects.

The Board of Supervisors acts as the Board of Directors for the County Flood Control District, and as part of their responsibilities as an elected member of the County of San Bernardino Board of Supervisors.

A.2 Fire District Profile

The San Bernardino County Fire Department is an all-risk/full-service fire department committed to providing the highest level of service in the most efficient and cost effective manner to the citizens and communities that we serve. At 20,160 square miles, San Bernardino County is the largest county in the continental United States. Our jurisdiction encompasses 19,278 square miles of extremely diverse environments that stretch from the Los Angeles County line on the west, to the Colorado River on the east, to the Nevada State line and Kern and Inyo counties on the north. We provide services to more than 60 communities/cities and all unincorporated areas of the county.

Mission Statement
Community-based all-risk emergency services organization dedicated to the health and well-being of the citizens of San Bernardino County through a balance of regionalized services delivery and accountability to the local community supported by centralized management and services.

Service Motto
Duty, Honor, Community.

Standard of Commitment
"Where Courage, Integrity, and Service Meet."

Vision Statement
Committed to Providing Premier Fire Services.

Hazard Mitigation Planning Group:
Michael Antonucci – Emergency Services Manager

A.3 Planning Process

As described above, the County Fire District followed the planning process detailed in Section 3 of the base plan. In addition to providing representation on the San Bernardino County Hazard Mitigation Planning Committee (HMPC), the District formulated their own internal planning team to support the broader planning process requirements. Internal planning participants, their positions, and how they participated in the planning process are shown in Table A-1. Additional details on plan participation and District representatives are included in Appendix A.

Table A-1: Fire District Planning Team

Name	Title / Role
Michael Antonucci	Emergency Services Manager
Cindy Serrano	Assistant Emergency Services Manager
David Davis	Emergency Services Officer
Miles Wagner	Emergency Services Officer
Cheryl Nagy	Emergency Services Officer
Carrie Cruz	Emergency Services Officer
Elli Maldonado	Office Assistant
Mary Barnett	Technical Writer / Plan Update and Edits
Michael Horton	Fire Marshal

Weekly meetings held every Tuesday since July 2016 with conference calls to the consultant group and other stakeholders plus all meetings listed in this document.

A.4 Hazard Identification and Prioritization

The County Fire Protection District Planning Team participated in the County hazard identification and prioritization process described in the base plan. The Fire District Planning Team assisted to summarize the extent, probability of future occurrences, potential magnitude/severity, and significance specific to the Fire District in the base plan.

The Planning Team (all participating jurisdictions) determined that the County and its Special Districts should focus over the next five (5) years on hazards that fell within the HIGH and MEDIUM “Probability” and “Impact” categories. While all the hazards present a potential problem in the County, the Planning Team felt that if they were able to reduce or eliminate the risk from “fire related” hazards, it would provide a greater service to the people within the jurisdiction. Table 4-3 illustrates how the final prioritization of the hazard; the “Green” colored box represents the highest priority hazards; and the “White” colored boxes represent lower (second and third tier) priority hazards.

Table A-2: Fire District Hazard Priority Matrix

		Impact		
		High	Medium	Low
Probability	High	**Wildfire** Flood Earthquake/ Geologic Hazards	Drought	
	Medium	Terrorism	Climate Change (Extreme Heat and other)	Hail Infestation
	Low		Dam Inundation	Tornado High Winds Winter Storm Lightning Extreme Cold

A.5 Coordination with existing Fire District Mechanisms

Coordination with other District planning efforts is paramount to the successful implementation of this plan. This Section provides information on how the Fire Protection District integrated the previously-approved 2011 Plan into existing planning mechanisms and programs.

While not designed or proposed specifically as mitigation projects, the County Fire Protection District undertakes many activities that incorporate mitigation elements and integrate risk reduction as an additional benefit. The following describes a number of these projects which exemplify how the County integrates hazard mitigation into county-wide programs.

A.5.1 Critical Route Planning Committee

San Bernardino County Fire Protection District Office of Emergency Services has a “Critical Route Planning Committee” that is developing countywide routes and alternate routes for use in evacuating residents from a disaster area while simultaneously allowing first responders’ access into a disaster area without congestion and gridlock. The Committee members are from County departments, City and Town representatives, and key state and federal agencies. The Critical Route Planning effort is being coordinated with surrounding counties to prevent congestion and gridlock at the County boundaries.

A.5.2 Public Alert and Education Programs

A.5.2.1 Wireless Emergency Alerts (WEA)

During threatening emergencies in your area, authorized government agencies can send Wireless emergency Alerts to your mobile device. Messages regarding extreme weather, life threatening emergencies, AMBER alerts, and Presidential Alerts during a national emergency are all sent through the WEA system

A.5.2.2 Emergency Alert System (EAS)

The Emergency Alert Systems: national public warning system that requires TV and radio broadcasters, cable television systems, wireless cable systems, satellite digital audio radio service providers, direct broadcast satellite service providers and wireline video service providers to offer to the President the communications capability to address the American public during a national emergency. The FCC works with the Federal Emergency Management Agency and the National Oceanic and Atmospheric
Administration's National Weather Service to implement the EAS at the national level. Only the President determines when the EAS will be activated at the national level, and has delegated the administration of this function to FEMA.
Accordingly, FEMA activates the national EAS, and directs national EAS tests and exercises. The NWS uses the EAS on a local and statewide basis to provide the public with alerts and warnings regarding dangerous weather and other emergency conditions.

The EAS allows participating providers to send and receive emergency information quickly and automatically, even if their facilities are unattended. If one link in the system for spreading emergency alert information is broken, members of the public have multiple alternate sources of warning. EAS equipment also provides a method for automatic interruption of regular programming, and in certain instances is able to relay emergency messages in languages other than English.

A.5.2.3 Integrated Public Alert & Warning System (IPAWS)

During an emergency, alert and warning officials need to provide the public with lite-saving Information quickly. The Integrated Public Alert and Warning System (IPAWS) is a modernization and integration of the nation's alert and warning infrastructure and will save time when time matters most, protecting life and property. Federal, State, territorial, tribal and local alerting authorities can use IPAWS and integrate local systems that use Common Alerting Protocol (CAP) standards with the IPAWS infrastructure. IPAWS provides public safety officials with an effective way to alert and warn the public about serious emergencies using the Emergency Alert System {EAS}, Wireless Emergency Alerts (WEA), the National Oceanic and Atmospheric Administration (NOAA) Weather Radio and other public alerting systems from a single interface.

A.5.2.4 Telephone Emergency Notification System (TENS) Implementation

Emergency service agencies like the Sheriff's Office have implemented TENS on numerous occasions to notify residents in specified areas to evacuate. Most recently it was used to evacuate hundreds of homes in the eastern portion of Yucaipa during the Pendleton Fire and in Wrightwood during the Sheep Fire when the entire community was ordered evacuated.

A.5.2.5 Emergency Communications Services (ECS)

In the last 10 year the ECS program has continually provided support to all major and minor incidents. The more recent events were the Pilot Fire and the Blue Cut Fire in 2016. ECS provides communications and logistical support to public safety and disaster preparedness events. They have also set up a training program for other County Departments that are not typical emergency responders but provided support in an emergency. ECS delivered and set up amateur radio equipment for Department of Public Works, Department of Public Health, Preschool Services Department, and Department of Behavioral Health and provided training for the employees.

A.5.2.6 Fire Safe Council/CERT Community Based AM Radio Transmitters

The Wrightwood Fire Safe Council and the Big Bear City CSD set up and operates a local AM radio transmitter. It has been brought into use during local incidents including a power outage where it is very useful. In power outages, the AM radio in a person's car still works. It was also used to provide preparatory information to the citizens of Wrightwood as the Station Fire was approaching the community from the west. It is also used extensively during the Wrightwood Fire Wise Awareness Days to keep citizens apprised of community events.

A.5.3 OES Volunteer Programs

The San Bernardino County Fire, Office of Emergency Services (County OES) is proud to provide residents of San Bernardino County with meaningful disaster-related volunteer opportunities. Recognizing that during disasters and other emergencies professional responders may be overwhelmed or need assistance County OES trains residents to integrate with and support professional responders during incidents. County OES currently does these through three volunteer programs; the Community Emergency Response Team (CERT), Emergency Communications Service (ECS) and California Disaster Corps programs. Please visit the links below to learn about the programs offered.

A.5.3.1 Community Emergency Response Team (CERT)

The Community Emergency Response Team (CERT) Program educates people about disaster preparedness and trains them in basic response skills. Following a catastrophic event CERT

Members can assist themselves, their families, and others in their neighborhood or workplace until professional responders arrive. Fourteen (14) CERT programs are in the communities of:

- Angelus Oaks
- Big Bear Valley
- Helendale
- Lucerne Valley
- Lytle Creek
- Mill Creek Canyon
- Morongo Basin
- Mountain
- Oak Hills
- Phelan/Pinon Hills
- Rosena Ranch
- San Antonio Heights
- Silver Valley
- Wrightwood CERT

San Bernardino County Fire Protection District Office of Emergency Services has sworn in over 1000 CERT participants as California Disaster Service Workers. These participants have gone on to receive a Sheriff's Department background check to become members of their community's CERT.

The program receives guidance and resources from Department of Homeland Security, FEMA, Citizen Corps, and California Volunteers. The program is administered locally by the San Bernardino County Fire Protection District Office of Emergency Services.

A.5.3.2 LISTOS

Listos, which means “ready” in Spanish, is a twelve-hour disaster preparedness course created specifically for the Spanish-speaking community and is delivered entirely in Spanish. The program is intended to be adaptable, flexible and culturally relevant. This means participants are encouraged to involve the entire family and accommodations are made for young children. San Bernardino County Fire, Office of Emergency Services currently partners with the Cities of Fontana and Rialto to bring Listos to their communities

A.5.3.3 California Disaster Corps

The Disaster Corps is a first-in-the-nation effort to professionalize, standardize and coordinate highly trained disaster volunteers statewide. This program initiative was built collaboratively in partnership with California Volunteers from the ground up through public-private partnerships and with a wide range of subject matter experts including representatives from all levels of government, local emergency managers, state agency volunteer coordinators, and leaders in non-governmental volunteer programs.

Disaster Corps programs reside only in San Bernardino, San Francisco and Riverside Counties. San Bernardino County Disaster Corps volunteers are those volunteers participating in the volunteer programs residing within the unincorporated communities of San Bernardino County and have demonstrated commitment to their volunteer program and strive to continue developing their skills and training to better support their program and their community.

Within San Bernardino County Disaster Corps volunteers are set aside from regular CERT (Community Emergency Response Team) and ECS (Emergency Communication Services) volunteers by having the ability to be deployed throughout other areas of San Bernardino County and the state. They have received specialized training in SEMS and NIMS, plus have completed many other ICS courses and First Aid and CPR training. In addition there are additional training opportunities not offered to the regular CERT and ECS volunteers.

A.5.3.4 ECS Emergency Communications Service

The Emergency Communications Service (ECS) is a volunteer group providing front-line communications, technical and logistical support to the San Bernardino County Fire Department and Office of Emergency Services. Their primary mission is to support County Fire, County Government and other local agencies in time of disaster. In addition, ECS has provided telecommunications and event support to other County departments including Public Health, Behavioral Health, Public Works, Pre-School Services, Sheriff's Search and Rescue and other County Departments.

ECS coordinates disaster communications between city and county agencies, provides a communication link to Cal OES and ensures backup communication channels are kept open in times of a major disaster.

In an average calendar year, ECS supports approximately two-dozen events and incidents throughout the County. These events range from parades and community events, to major public safety incidents including fires and floods. The 200 ECS volunteers donate an average of 9,100 hours per year to the County of San Bernardino.

ECS currently provides multiple HAM licensing classes to County Departments and the residents of San Bernardino County each year.

A.5.4 ROPE Plan (Responders Organized For Pass Emergencies)

ROPE Field Operations Guide (FOG) and Standard Operating Guide (SOG) for use by participating Federal, State, County, and Municipal agencies and industries for day-to-day incidents in the Cajon Pass, as well as for larger regional incidents requiring coordinated and unified multi agency response. The ROPE FOG contains; communications information, emergency contact information, critical infrastructure mapping and ICS planning tools.

A.5.5 Great ShakeOut County Drill in all Disciplines (held annually)

The San Bernardino County Operational Area will be participating in the annual The Great ShakeOut drill which will focus on the Southern California Regional Catastrophic Plan (SCRCP). This plan is based on a large scale magnitude earthquake scenario along the southern section of the San Andres Fault. The purpose for participation in the Great ShakeOut Exercise is to address the County's potential to respond to a catastrophic earthquake event based on the plan, and to better prepare for such an occurrence. The goal of the exercise will be to conduct an effective multiagency/multi-jurisdictional evaluation of the Regional Catastrophic Plan with our Operational Area response partners.

A.5.6 "Ready SB" Smart Phone App for Disaster Preparedness Program

The new mobile app, Ready SB, provides residents with multiple resources that will assist them in preparing for a disaster. Ready SB is now available as a free download from the Apple App Store and the Google Play Store it can immediately help residents prepare themselves for emergencies.

Ready SB features include: "My Plan", an individual emergency plan and/or a family or group plan. The person that downloads the application will receive county wide alerts and notifications of emergency situations in that person's area. There is a feature called "Share My Status" it is a place to update your status via text or email.

The app also includes information about areas that need to be evacuated, where to go, what routes are open and also what resources are available during that emergency.
The app features include: Evacuation Routes and Shelters, Need to Know, and has a Resources List.

A.5.7 Cal Fire

Cal Fire provides programs to increase fire safety in high fire hazard severity zones. It funds and staffs programs from public education activities to performing fuel modifications with inmate crews. One example is the active Re-Leaf program where mountain residents are educated about drought tolerant and fire resistive landscaping that is available and sustainable. Cal Fire is also the lead agency on reforestation after a wildfire to ensure the stability of the environment. Cal Fire Foresters are active participants in the MAST process helping educate citizens and leading forestry activities on private lands within the USFS boundary.

Numerous fuels projects have been completed by State inmate crews that do significant hand work in dense fuels adjacent to communities. Cal Fire has also led the way in countless re-forestation projects that ensure that new stands of the same trees will repopulate an area and that the original forest won't be overtaken by a different type of replacement forest.

A.5.8 Organized Group Volunteer Activities

Mountain communities are populated by several volunteer citizen groups that are capable of providing significant resources that are not provided by traditional governmental agency services.

Volunteer groups particularly “Mountain Hearts and Lives” (MHL) responded to numerous emergencies particularly of note the Grass Valley and Slide Fires. These groups have also spent significant time working to prepare citizens for disasters. MHL has coordinated CERT training as well as HAM radio operator training. Other activities can be found at www.heartsandlives.org. Other partners that assist in coordinated endeavors for disaster preparedness and disaster relief are Rim Family Services and the Rim Resource Community Network. Members of these and other groups work very closely with MAST, Mountain Mutual Aid and the American Red Cross.

A.6 Fire Protection District Mitigation Project Prioritizing

Cost effectiveness of each measure was a primary consideration when developing mitigation actions. Because mitigation is an investment to reduce future damages, it is important to select measures for which the reduced damages over the life of the measure are likely to be greater than the project cost. For structural projects, the level of cost effectiveness is primarily based on the likelihood of damages occurring in the future, the severity of the damages when they occur, and the level of effectiveness of the selected measure. While detailed analysis was not conducted during the mitigation action development process, these factors were of primary concern when selecting measures. For measures that do not result in a quantifiable reduction of damages, such as public education and outreach, the relationship of the probable future benefits and the cost of each measure was considered when developing the mitigation actions.

Based upon the Fire Districts capabilities, Table A-3: Mitigation Project Prioritization and Implementation shows primary actions selected for further implementation and development during the next planning cycle. Table A-3 provides details for each mitigation action with mitigation action descriptions, FEMA mitigation category, responsible party, and timeframe.

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A.7 Fire Protection District Mitigation Project Actions

Table A-3: Mitigation Project Prioritization and Implementation

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
ALL Hazard	**AH Action 1.1:** Valley Dispatch and Operations Center.	Update and maintain the operations of the facility and ensure cohesive working and response to any scale emergency and operations in a secure complex	ES	General Fund and HMP Grant	Fire Protection District/	1-3 Years	See Fire Protection District Annex A. Section A.6 Fire Protection District Mitigation Project .
ALL Hazard	**AH Action 1.2:** Maintain Shelter Operations Compound (SHOC). This shelter concept provides a new one-stop shelter concept. The SHOC combines a shelter, a Local Assistance Center (LAC) and a Non-LAC Unit in one easy location.	After the 2003 Wildland Fires, the County and American Red Cross recognized the need to provide services beyond basic care and short-term sheltering, especially during large fires, floods, and earthquakes The Mass Care & Shelter Plan and Concept of Operations, outlines the framework of a new one-stop shelter concept, Shelter Operations Compound (SHOC). It combines a shelter, a Local Assistance Center (LAC) and a Non-LAC Unit in one easy location. Residents can access public information and referral services through the LAC, and then take a short walk to the Non-LAC Unit for communication, postal services, and other private organizations/business at little to no cost. The completion of the Plan in 2012 will help to sync local resources, encourage local self-sufficiency, foster partnership between public and private agencies, and serve as a reference document for the region. By June 2017, the program will have 32 trailers/caches equipped with mass care and shelter supplies, strategically placed throughout the County and ready for rapid deployment. It is expected to serve over 12,000 residents. In addition to enhancing the comfort levels of shelter residents, the program will produce standardized documents and protocols for procuring and maintaining Mass Care and Shelter trailers/caches. These plans and programs will help the County prepare for and mitigate damages from hazards. This is an update and expansion of the plan and done without more grant funds.	ES	To increase Mass Care and Shelter capability of the county, grants from 2008-2009 Homeland Security Grant Program (HSGP) and 2009 Riverside Regional Urban Area Security Initiative (UASI) funded the Mass Care and Shelter Trailer/Cache Program.	Fire Protection District/	1-5 Year	See Fire Protection District Annex A. Section A.6 Fire Protection District Mitigation Project .
All-Hazard	**AH Action 2.1** Incorporate as appropriate requirements from the State of California's most recent land use regulations regarding the hazard mitigation planning process (Government Code 65302 and 8685.9).	Government Code 65302.6 requires the following elements to be included in the hazard mitigation plan: (1) An initial earthquake performance evaluation of public facilities that provide essential services, shelter, and critical governmental functions.	PRV, NRP	General Fund	Primary: Land Use Services Secondary: Fire Protection District/	1-3 years	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
		(2) An inventory of private facilities that are potentially hazardous, including, but not limited to, multiunit, soft story, concrete tilt-up, and concrete frame buildings. (3) A plan to reduce the potential risk from private and governmental facilities in the event of a disaster. Government Code 8685.9 requires that the state share shall not exceed 75 percent of total state eligible costs unless the local agency is located within a city, county, or city and county that has adopted a local hazard mitigation plan as part of the safety element of its general plan. In that situation, the Legislature may provide for a state share of local costs that exceeds 75 percent of total state eligible costs.					
Wildfire	**WF Action 1.1** Continue Mountain Area Safety Taskforce (MAST) funding to support mitigation activity.	MAST was formed to mitigate the region wide risk of a catastrophic wildfire due to dead and dying trees in the mountain communities. The mission of the MAST is to facilitate a coordinated effort by cities, county, state, federal, and non-profit agencies to provide for the protection of property owners, residents, and property subject to the risk of catastrophic wildfire that could occur in San Bernardino County with an initial emphasis on the threat resulting from the Old and Grand Prix fires in 2003. MAST priorities are to continue reducing fire hazards through fuel reduction programs and hazard abatement though enforcement of county ordinances. The Mountain Area Safety Taskforce (MAST) Operations Section meets monthly. MAST Operations Section determines project priorities based on the benefit cost analysis of the projects and the effect of the project on the overall goals of the MAST organization. Goals can change as detailed Benefit Cost Analysis is conducted and CEQA/NEPA reviews are completed.	NRP, PPRO	Seeking additional funding through HMPG.	San Bernardino County Fire Protection District	On-Going	See Implementation plan on more information on MAST. See Fire Protection District Annex A. Section A.6 Fire Protection District Mitigation Project .
Wildfire	**WF Action 2.1:** Update Mountain Mutual Aid Map Book to document updated information contained in 2016 HMP.	The Map Book portion of the Community Safety and Structure Protection Plan provides not only a street network of the area but more importantly it provides the locations of strategic and critical resources for fire fighters. These include but are not limited to safe zones, open areas, locations for refuge. They also identify areas within communities that have narrow and steep winding streets and or with limited ingress and egress. The document is handed out to all responding strike teams from out of the	ES	Seeking additional funding through HMPG.	San Bernardino County Fire Protection District	On-Going	See Fire Protection District Annex A. Section A.6 Fire Protection District Mitigation Project .

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
		area and has proved invaluable in directing and coordinating an effective fire-fighting response and reduces the potential for life loss and property damage.					
Wildfire	**WF Action 2.2** Update Community Structure Protection Plans as necessary.	This is an on-going action (from the 2011 MJHMP) with the goal to continue development of and continue the mission of mutual aid between first responders in the County mountain areas.	PPRO	HMP Grant Funding	Primary: San Bernardino County Fire Protection District Secondary: Land Use Services	On-Going	
Wildfire	**WF Action 3.1:** Implement identified community based fuels reduction projects.	The Fuels Reduction Program is designed to create community based fuel modification programs across the mountain communities. These projects are selected specifically to reduce the potential for catastrophic wildfires and the damage that they can do to the communities. Project design, contracting, and operations are managed by the County's Public Works Department with priorities set by local fire chiefs in monthly MAST Operations Meetings. This program is the oldest and most significant for reducing wildfire threat on a mountain wide basis.	PPRO	Current Funding: Seeking additional funding through HMPG.	Primary: San Bernardino Public Works Department Secondary: County Fire Protection District	On-Going	
Wildfire	**WF Action 3.2:** Develop fuels reduction "maintenance program" by obtaining participation from citizens and/or homeowners associations.	To survive a wildfire, property owners need to manage the land surrounding their homes and communities effectively. Removing fuels in the wildland fuel reduction zone beyond the defensible space can reduce the speed and intensity of an oncoming wildfire. But if these areas aren't regularly **maintained**, they lose their effectiveness. Plants grow back, and flammable vegetation needs to be routinely removed and disposed of properly. This guide provides tips on how to create and maintain defensible space and wildland fuels treatments around your property.	PPRO, PE&A	Seeking additional funding through HMPG	Primary: Public Works Secondary: Fire Protection District	On-Going	
Wildfire	**WF Action 4.1** Increase homeowner assistance services to mountain residents for fuel reduction.	This is an ongoing wildfire mitigation action (from the 2011 MJHMP) for the group Forest Care to achieve the goal of providing assistance to homeowners by expanding services to all communities in the Mountain areas of the County. Forest Care is a program dedicated to creating a healthier forest. This program provides foresters to assess individual properties for thinning the vegetation and then provides 75% of the funding to do so.	PPRO, PE&A	Seeking additional funding through HMPG	San Bernardino County Fire Protection District	On-Going	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Wildfire	**WF Action 4.2** Continue working with Southern California Edison (SCE) to remove dead trees near power lines.	A significant number of fires across the State are caused by trees falling into power lines. When the forests in the mountain communities became infested with bark beetles the pine tree die off was unprecedented. Thousands of these dead trees were standing precariously close to power lines. Early in the Bark Beetle Emergency in 2004, Southern California Edison swiftly initiated a program to remove all trees that were dead, dying, and/or diseased that had the potential to fall into any SCE power lines. The role of Southern California Edison was critical to the success of MAST both operationally and financially. Edison still removes the most difficult trees, the most costly trees; and the ones that are most likely to be the source of ignition for a wild land fire. They are also removing the trees that are immediately threatening homes. They have removed 118,305 trees since the inception of the program in 2004. They also provided reimbursements to people that removed their own trees.	PRV, PPRO	As of July of 2010 Southern California Edison (SCE) has spent $179,758,978 to remove dead dying and diseased trees.	San Bernardino County Fire Protection District	On-Going	
Wildfire	**WF Action 5.1:** Inspect every residence in the mountain communities throughout the year to enforce the Fire Hazard Abatement code that addresses green fuels.	The Fire Hazard Abatement Program conducts surveys to identify fire hazards throughout the year. Fire hazards are identified and notices to abate the hazard(s) are mailed to property owners. Property owners are given 30 days to abate the violations. Failure to abate may result in citations, penalties, and/or fees for abatement by the County. The Fire Hazard Abatement Program responds to complaints year round in the unincorporated areas and contracting Cities and Fire Districts. The Division completes more than 430,000 inspections, issues more than 45,000 Notices to Abate Fire Hazards, issues over 4,000 citations for non-compliance, and abates the fire hazards on more than 2,000 parcels annually. Within the last 5 years, the Fire Hazard Abatement Division has received even more financial	PRV, PPRO, PE&A	Seeking additional funding through HMPG	Primary: Land Use Services Secondary: San Bernardino County Fire Protection District	On-Going	For more information on Contractor Certification, see Annex A Section A.6 Fire Protection District Mitigation Project .

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
		resources that enable them to abate all properties declared a fire hazard.					
Wildfire	**WF Action 5.2:** Continue to collaborate with Forest Care, Red, Cross and Cal Fire to overcome increased costs of enforcement.	This is an on-going action from the 2011 MJHMP with the goal of overcoming funding shortfalls for the County Fire Hazard Abatement Program.	PRV	HMP Grant Funding	San Bernardino County Fire Protection District	On-Going	
Wildfire	**WF Action 6.1** Train and Certify landscape contractors to comply with the Fire Hazard Abatement Code.	The City of Big Bear Lake created a program to train and certify landscape contractors to provide a qualified workforce to conduct fuels reduction activities on individual properties. The contractors are trained to comply with the new Fire Hazard Abatement Code that exists both in the City of Big Bear and the County unincorporated area. The City of Big Bear Lake Fire Department conducts the classes for landscapers and handy persons. This provides an incentive for the contractors and provides a level of certification that the homeowner can rely on when they are deciding to hire a landscape contractor to conduct fuels abatement around their home.	PRV, PPRO	Seeking additional funding through HMPG	San Bernardino County Fire Protection District	On-Going	On-Going
Wildfire	**WF Action 6.2:** Continue wildfire mitigation efforts under the Wood Shake Roof Replacement Program.	The County successfully passed an ordinance that requires the replacement of wood shake roofs by 2014. MAST has successfully mapped all of the wood shake roofs in the fire safety overlay and has created a strategy as to which roofs will be selected to participate in the FEMA funded project. This is an on-going project in cooperation with Big Bear Lake Fire Protection District in order to provide more funding for wood shake roof replacements by property owners.	PRV, PPRO, SP	Various Grant Funding from Edison, FEMA, Cal Fire	Primary: MAST Secondary: San Bernardino County fire Protection District	On-Going	
Wildfire	**WF Action 7.1:** Modify independent and unique CWPPs into a more common framework making them similar but leaving room to provide specific hazard characteristics and mitigation actions for each community.	Community Wildfire Protection Plans are designed to provide a means for a community, usually through the Fire Safe Council, to have input into and actively participate in the planning, strategy, goals, and objectives of creating a fire safe community.	PRV	Seeking additional funding through HMPG	San Bernardino County Fire Protection District	On-Going	On-Going For more information on CWPP see Annex A Section A.6 Fire Protection District Mitigation Project .

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Wildfire	**WF Action 8.1:** Construct Arrowbear Drive Realignment and Widening.	The Arrowbear community off State Highway 18 has limited access to State Highway 138. The existing bridge/spillway and road needs to be realigned and widened to facilitate access by emergency personnel during wildfires and flooding. Mitigation strategy for this is to remove and replace existing bridge/spillway, realign and widen the road.	SP	Seeking grant funding Total Cost: $2,000,000	Primary: Public Works Secondary: San Bernardino County Fire Protection District	1-3 Years	
Wildfire	**WF Action 8.2:** Construct Cedar Glen Fire Access Road.	Lack of paved roads inhibits traffic circulation and the ability to enter and exit the area without backtracking during wildfire emergencies. Strategy is to Construct road and drainage improvements to Little Bear Creek Road and Elder Drive.	SP	Seeking grant funding **Total Cost:** $2,500,000	Primary: Public Works Secondary: San Bernardino County Fire Protection District	1-3 Years	
Wildfire	**WF Action 9.1:** Continue funding and support for Special Districts Projects relating to wildfire.	Continue funding and support for Special Districts Projects relating to wildfire in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	On-Going	
Wildfire	**WF Action 9.2:** Emergency Water Supplies	Purchase emergency water supply or water purification devices to ensure uninterrupted supply of water to emergency response personal.(completed with continuous fresh of supplies and rotation)	ES	TBD	Roads	TBD	

Annex B. Flood Control District

B.1 Introduction

This Annex details the hazard mitigation planning elements specific to the Flood Control District, a previously participating jurisdiction to the 2010 San Bernardino County Hazard Mitigation Plan Update. This Annex is not intended to be a standalone document, but appends to and supplements the information contained in the base plan document. As such, all sections of the base plan, including the planning process and other procedural requirements apply to and were met by the Flood Control District. This Annex provides additional information specific to the Flood Control District, with a focus on providing additional details on mitigation actions and projects.

The Board of Supervisors acts as the Board of Directors for the County Flood Control District, and as part of their responsibilities as an elected member of the County of San Bernardino Board of Supervisors.

B.2 Flood District Profile

Flood Control District Functions:
The Flood Control functions are handled through the San Bernardino County Flood Control District under State legislation enacted in 1939. The District has developed a very extensive system of facilities, including dams, conservation basins, channels, and storm drains. The purpose of these facilities is to intercept and convey flood flows through and away from the major developed areas of the County. The principle functions are:

- Flood protection on major streams.
- Water conservation.
- Storm Drain construction.

Mission:
To enhance the quality of life for our communities by developing and maintaining public infrastructure, and providing a variety of municipal services that complements our natural resources and environment.

Vision:
Lead the way to a thriving community through innovation in public works, fiscal responsibility, and environmental stewardship.

B.3 Planning Process

As described above, the County Flood Control District followed the planning process detailed in Section 3 of the base plan. In addition to providing representation on the San Bernardino County Hazard Mitigation Planning Committee (HMPC), the District formulated their own internal planning team to support the broader planning process requirements. Internal planning participants, their positions, and how they participated in the planning process are shown in Table B-4. Additional details on plan participation and District representatives are included in Appendix A.

Table B-4: Flood Control District Hazard Mitigation Planning Team

Name	Title	Role
Kevin Blakeslee	Deputy Director – Flood Control	Public Works Deputy Director
Kenneth Eke	Chief Flood Control Planning/ Water Resources Division	Public Works Engineer
Michael Fam	Flood Control Planning	Public Works Engineer
Mona Sadek	Flood Control Planning	Flood Control Planner
Marjorie Schrage	Flood Control Planning	Public Works Engineer Technician

B.4 Hazard Identification and Prioritization

The Flood Control District Planning Team participated in the County hazard identification and prioritization process described in the base plan. The Flood Control District Planning Team assisted to summarize the extent, probability of future occurrences, potential magnitude/severity, and significance specific to the Flood Control District (See Section 4).

The Planning Team determined that the County and its Special Districts should focus over the next five (5) years on hazards that fell within the HIGH and MEDIUM "Probability" and "Impact" categories. While all the hazards present a potential problem in the County, the Planning Team felt that if they were able to reduce or eliminate the risk from "food and drought related" hazards, it would provide a greater service to the people within the jurisdiction. Table 4-3 illustrates how the final prioritization of the hazard; the "Green" colored box represents the highest priority hazards; and the "White" colored boxes represent lower (second and third tier) priority hazards.

Table B-5: Prioritized Hazard Assessment Matrix

		Impact		
		High	Medium	Low
Probability	High	Wildfire **Flood**[x] Earthquake/ Geologic Hazards	Drought	
	Medium	Terrorism	Climate Change (Extreme Heat and other)	Hail Infestation
	Low		Dam Inundation	Tornado High Winds Winter Storm Lightning Extreme Cold

[x] = Flood District Area of Concentration

B.5 Coordination with Existing Flood District Mechanisms

Coordination with other County planning efforts is paramount to the successful implementation of this plan. This Section provides information on how the Flood Control District integrated the previously-approved 2011 Plan into existing planning mechanisms and programs. Specifically, the District incorporated into or implemented the 2011 MJHMP through other plans and programs shown below.

B.5.1 Flood Area Safety Taskforce (FAST)

During the devastating fires in the fall of 2003, there was great concern of what the ramifications might be for flooding in the burned areas, as well as in the valleys. In response to these concerns, an organization was established that mirrored the Mountain Area Safety Taskforce (MAST), mentioned above, which played a key role in minimizing damage.

While the fires were ravishing the countryside, representatives from multiple agencies met often to address potential issues associated with flood, mud and debris flows develop a strategy and to protect communities from flooding incidents. These agencies united together to become the Flood Area Safety Taskforce (FAST). FAST is structured as an ICS/SEMS Organization for managing incident activities both readiness and response. The FAST Organization stresses liaison with the communities, provides for community education and information, and places emphases on Community and city partnerships.

The FAST group includes:

- Elected State officials
- Representatives from all five (5) County Supervisorial Districts
- State Office of Emergency Services
- County Administrative Office
- County Public Works-Flood Control/ Transportation/Solid Waste
- County Fire Protection District
- County Fire Protection District/Office of Emergency Services (OES)
- County Sheriff's Department
- Representatives from the cities of Fontana, Highland Rancho Cucamonga, Rialto, and San Bernardino.
- USFS
- Caltrans
- CHP

The mission of the FAST is to facilitate a coordinated effort by cities, county, state, federal, and non-profit agencies to provide for the protection of property owners, residents, and property subject to the risk of erosion, mudflows, and flooding that could occur in San Bernardino County with an initial emphasis on the threat resulting from the Old and Grand Prix fires in 2003.

The FAST Unified Command identified the following objectives as the focus and direction of the FAST:

- Provide for Community Safety.
- Develop Coordinated Public Information Dissemination between Cities, County, State, Federal and Non-Profit Agencies.
- Develop Immediate, Mid-range and Long-range Coordinated Agency Plans.
- Identify and Secure Potential Funding Resources to Provide Document Task Force Activities Including Mission, Goals and Objectives, Policies, Procedures, and Outcomes.

Prior to any type of flood threat, the following precautionary measures may be taken by FAST members to reduce the impact of impending flooding:

- Review mutual aid agreements
- Define evacuation areas and trigger points
- Review the use of alert and warning systems
- Provide information to the public of potentially susceptible flooding areas and protective measures in progress or planned for those areas
- Educate public on emergency self-help and preparedness
- Develop and maintain emergency notification procedures and checklists.

A FAST Concept of Operations (CONOPS) was developed to provide activity guidelines for pre-flood activities related to National Weather Service (NWS) watches and warnings. Due to the unstable condition of the burned areas, activities and coordination needed to be established and implemented between departments.

The CONOPS is “situation” and “incident” driven and subject to revision by the Unified Command which includes County Flood Control District & Co Roads, County Fire Protection District, United States Forest Service (USFS), California Department of Transportation (Caltrans), California Highway Patrol (CHP), County Sheriff, City of Fontana, City of Highland, City of Rancho Cucamonga, City of Rialto, and City of San Bernardino. The Unified Command has the ability to modify activities in these guidelines in response to current situations and predicted changes. Currently, the CONOPS includes both summer and Winter Storm Event Readiness.

In addition, the CONOPS includes the San Bernardino County Flood Area Safety Taskforce Paging Network and a draft of the Alert Communication Matrix by Rain Amount/NWS Warning.

Over the past 10 years, the County has used the FAST CONOPS many times, greatly enhancing the County’s ability to respond to flash flood in the desert and foothill areas. The CONOPS activity coordination between the agencies has been very successful. Because of the great success of the CONOPS, State Emergency Management Agency (Cal EMA) is using the CONOPS as a model for other agencies throughout the State.

In addition, San Bernardino County the CONOPS and FAST Plan is updated every two years and has done so since been put in to action the latest update being May of 2015.

B.5.2 Alluvial Fan Task Force

In December of 2002, the California Floodplain Management Task Force Report recommended that "The State should convene a task force specifically for alluvial fans, with stakeholder participation, to review the state of knowledge regarding alluvial fan floodplains, determine future research needs, and, if appropriate, develop recommendations relating to alluvial fan floodplain management, with an emphasis on alluvial fan floodplains that are being considered for development."

In September of 2004, Governor Arnold Schwarzenegger signed Assembly Bill 2141, which recommended the creation of the Alluvial Fan Task Force (Task Force). The Director of the Department of Water Resources (DWR) convened the Task Force in December of 2007 after funding to support Task Force activities was secured from a Pre-Disaster Mitigation Planning Grant from the Federal Emergency Management Agency (FEMA) and a state match was authorized by Assembly Bill 466. Funding supported the tasks charged to the Task Force including:

- Review the state of knowledge regarding alluvial fan floodplains;
- Determine future research needs;
- Develop a voluntary locally-adopted model ordinance for communities subject to alluvial fan flooding that supports land use decisions on alluvial fans;
- Develop local planning tools to assist local communities evaluate development on alluvial fans;
- Prepare recommendations relating to alluvial fan floodplain management.

Appointments to the Task Force by DWR Director Lester Snow represented a broad range of interests. Members included elected officials, represented by five Supervisors from Kern, Los Angeles, Riverside, San Diego and San Bernardino County where future alluvial fan development is projected. Appointments also included representatives of the development and environmental community, local floodplain managers and associated state and federal agencies, including the Federal Emergency Management Agency (FEMA), plus at-large members representing other issues related to future development on alluvial fans. The entire process was coordinated by the Water Resources Institute at California State University San Bernardino.

Primarily, the purpose of the Alluvial Fan Taskforce *Findings and Recommendations Report* (July 2010) and *The Integrated Approach for Sustainable Development on Alluvial Fans* (July 2010) documents are to provide a non-prescriptive and flexible model that local governments can use at their own discretion adapting to local conditions and needs that supports wise future land use decisions associated with development on alluvial fans.

As one of the ten Southern California counties studied by the Task Force, the County may review the development of the suite of local planning tools for pre-project screening for future development proposals on alluvial fans. If funding allows for the review, these planning tools may be useful as an optional database reference for project management. Additionally, the flood management tools designed to analyze alluvial fan flood hazards and formulate flood hazard protection, which were developed to be consistent with FEMA guidelines, may provide an optional data source for project development. Long term funding for updating and maintaining the pre-project screening tools database is a concern regarding the reliability for current data.

If funding exists, for the implementation of the *Integrated Approach for Sustainable Development on Alluvial Fans*, the methods contained therein may be used as some of the approaches for planning and evaluating the suitability of development on alluvial fans. During the analysis and review, if budgets allow, the long term ecological and financial sustainability issues would also be evaluated.

Based on the Findings from the Alluvial Fan Task Force process, recommendations were made for specific future actions that the State and other public agencies should consider regarding alluvial fans. The San Bernardino County Departments of Land Use, Special Districts and the Flood Control District are all coordinating on the below recommendations:

Recommendation 1: *on-going*

In February 2010, a General Plan Amendment (GPA) to the Safety Element of the 2007 General Plan was adopted to amend the Flood Plain Safety Overlay District to incorporate revised FEMA (Federal Emergency Management Agency) Flood Plain data, modifying 47 detail and seven regional General Plan Quad Maps. The GPA also adopted the FEMA Digital Flood Insurance Rate Map database as released by FEMA as it currently exists and as updated in the future for the County allowing for automatic map updates as new data are published by FEMA. This action by the County of San Bernardino Board of Supervisors implements the portion of the first recommendation from the Alluvial Fan Task Force by working with FEMA to continue updating flood insurance rate maps.

In addition, the GPA for the Safety Element in 2010 (a) amended the Generalized Landslide Susceptibility layer, modifying 17 General Plan Quad Maps and one regional Quad Map, to incorporate updated existing landslide data published by the U. S. Geological Survey for the Mountain area; (b) amended the Fire Safety Overlay District, modifying four General Plan Quad Maps to incorporate updated fire safety mapping published by Cal Fire for the Valley area; and (c) amended the Generalized Liquefaction Susceptibility layer, modifying four General Plan Quad Maps to incorporate new liquefaction data in the Big Bear Lake area designated by the County Geologist for the Big Bear Lake area.

Recommendation 2: *on-going*

The County will coordinate with the California Geological Survey (CGS) and the United States Geological Survey (USGS) to review any newly developed Quaternary geologic maps in alluvial fan areas in order to identify potential hazards in areas projected for future development.

Recommendation 4: *on-going*

Historical, documentation of flooding occurrences are preserved by the County's Flood Control District that would review the recommendation to identify flooding events that were associated with alluvial fans.

Recommendation 6: *on-going*

The increased severity and intensity of wildfires in Southern California increase flood risk because the same structures subject to fire risk are also prone to post-fire debris flows. Many of the debris basins that were constructed some time ago did not anticipate the increased severity and intensity of wildfires or the additional developments that would follow. The CalOES projects that climate change will further increase the severity of storms, wildland fires, flooding, mudslides and landslides in areas of Southern California where existing debris basins are located.

All of San Bernardino County Flood Control District's Debris Basins in the valley area; from the Los Angeles County Line to Yucaipa, were analyzed after the Grand Prix and Old Fires. Flood Control District Safety Assessment Teams utilized the Corps of Engineers' Los Angeles District methodology to determine debris production, the same methodology the Corps uses when designing debris basins. In many cases basins were physically expanded and additional measures such as K-rails and debris racks were installed. The understanding of post-fire debris flows continues to evolve; we work closely with the USGS as they develop Post Wildfire Debris Flow Hazard Assessments. The rainfall "Trigger Points" in our FAST CONOPS is a result of the USGS assessments. All Flood Control Basins are also studied on an annual basis to determine existing capacity.

Any additional funding to support our efforts will meet the intent of recommendation #6 which states that the State and local agencies should conduct assessments of the adequacy of strategically located debris basins under a range of scenarios in urbanized areas in light of increased fire and post-fire debris-flow events.

Recommendation 8: *on-going*

When funding sources become available for the maintenance and further development of the database for the web-based portal; which would be utilized as a pre-project screening and flood management tool for special alluvial fan areas, the County may evaluate the benefits of its use in the planning process.

Recommendation 9: future proposal

As financial resources are allocated, the County will consider the analysis of the Integrated Approach tools to be studied for use in land use planning for development on alluvial fans.

Recommendation 10: f*uture proposal*

If funding is provided, the County will review and propose for adoption a model ordinance tailored for the specific needs of the County.

Recommendation 12: *future proposal*

The County's Office of Legislative Affairs, after consulting with the appropriate departments and staff, may explore supporting the economic strategies recommended in the Integrated Approach regarding future maintenance of flood management infrastructure.

B.5.3 StormReady

On July 29, 2009, the National Weather Service recognized San Bernardino County as a "StormReady County". This recognition is valid until July 29, 2012 and has been renewed in use (2016) when the National Weather Service will review the County's weather related planning and notification procedures prior to renewing the "StormReady County" status.

San Bernardino County is the only StormReady jurisdiction in the United States covered by three Weather Forecast Offices. The NWS Offices are:

- San Diego, CA;
- Las Vegas, NV; and
- Phoenix, AZ.

This NWS Recognition may provide the County residents with a discount on their Flood Insurance premiums.

B.6 Mitigation Project Prioritization and Implementation

Flood Project Prioritization and Implementation

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Earthquake	**EQ Action 5.1:** Divert runoff to Little Bear Creek.	To reduce the runoff over the cliff(s) in the Rimforest neighborhood, the runoff must be diverted to another path. This will be accomplished over three phases: • Phase 1: Reduce Runoff Tributary Area by 64%- 50.35 AC • Phase 2: Reduce Runoff Tributary Area by 30%- 23.79 AC • Phase 3: Reduce Runoff Tributary Area by 5%- 3.99 AC	SP, NRP, PRV	TBD	Primary: Public Works Secondary: San Bernardino County Flood Control District		
Flood	**FL Action 1.1:** Update NFIP data and maps with newly identified flood hazard areas in the County, as new information becomes available.	As required by the State of California, National Flood Insurance Program (NFIP) maps published by FEMA must be included in the HMP or General Plan Safety Element. Keeping this information current is an important mitigation action.	PRV, PPRO	TBD	San Bernardino County Flood Control District	On-Going	
Flood	**FL Action 2.1:** Determine whether or not additional amendments to development standards or policies are merited, based on the Alluvial Fan Task Force Recommendations.	This is an on-going mitigation action from the 2011 MJHMP.	PRV	TBD	Primary: San Bernardino County Flood Control District Secondary: Land Use Services	On-Going	
Flood	**FL Action 3.1:** Amend the Flood Plain Safety Overlay District through automatic map updates as new data is released and published by FEMA.	Current San Bernardino County Hazard Maps can be found at: http://cms.sbcounty.gov/lus/Planning/ZoningOverlayMaps/HazardMaps.aspx.	PRV, NRP	TBD	Primary: San Bernardino County Flood Control District Secondary: Land Use Services	On-Going	
Flood	**FL Action 3.2:** Review development plans to ensure compliance with ordinances.	This is an on-going mitigation action from the 2011 MJHMP in order to reduce the flood hazards through development standards and policies stated in the General Plan and San Bernardino 2077 Development Code.	PRV	TBD	Primary: Land Use Services Secondary: San Bernardino	On-Going	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
					County Flood Control District		
Flood	**FL Action 3.3:** Inspect construction to ensure compliance with approved development plans.	This is an on-going mitigation action from the 2011 MJHMP in order to reduce the flood hazards through development standards and policies stated in the General Plan and San Bernardino 2077 Development Code.	PRV, PPRO, SP	TBD	Primary: Public Works Secondary: San Bernardino County Flood Control District	On-Going	
Flood	**FL Action 4.1:** In each flood control zone, construct facilities identified in those zones by the Flood Control Advisory Committee. See the following pages for a listing of projects.	This is an ongoing mitigation action from the 2011 MJHMP to achieve the goal of improving existing facilities and construct new facilities to mitigate flooding within the County.	SP	TBD	Primary: Public Works Secondary: San Bernardino County Flood Control District	On-Going	

B.7 Flood Project Prioritization and Implementation

The Flood District project rankings utilize the same format as the 2011 Multi-Jurisdictional Hazard Mitigation Plan, and rankings are based on the current project funding status as shown on the County Flood Control District's 10 year Plan. A 'High' Local Priority, or (3), indicates that project funding is expected to be complete within about the next three years, depending on the Flood Zone and its' available revenue. A 'Medium' Local Priority (2) indicates that project funding is expected to be complete within about four to seven years. A 'Low' Local Priority (1) indicates that the project is on the 10-Year Plan but complete funding is likely eight to ten years or more in the future.

The task of determining local project priority is the responsibility of the County Flood Control District's staff and City Engineers. Each of the six zones of the District is represented by a Citizens Advisory Committee, composed of eleven members and serving by appointment of the Board of Supervisors without compensation. Each committee is formed of spirited citizens and public officials with unselfish and devoted interests, organized to meet annually or on call to afford recommendations to the Board of Supervisors on matters of tax levies, budgets, work programs, priority of projects, ventures and other counsel. The Mayor of each incorporated city in the District is a committee member with full standing for the appropriate zone.

County Flood Control District staff and the City Engineers for each zone meet twice per year to discuss future project needs and current project status. Projects are proposed based on the public safety needs within the particular zone. In addition to public safety, other issues are considered in the prioritization process such as grant funding, environmental reviews and approvals, and other impediments that may cause construction of the project to be delayed. (See Annex 1 for examples of how these prioritization factors are applied to proposed projects.)

Almost without reservation, the recommendations of these organized committees have been accepted by the Board of Supervisors in its administration of County Flood Control District functions.

Each flood control zone constructs facilities identified in those zones by the Flood Control Advisory Committee. The City Engineers for each zone along with the Flood Control District I Advisory Committee establishes Project Priorities based on Benefit Cost Analysis, Community input, and fiscal resources available for the project in addition to any other noted factors. The following three tables illustrate priority rankings based on three key factors: Total Cost, Hazard Assessment, and Potential Fatalities.

Table B-6: Priority Flood Control Projects

Project No	Completion Date	Total Cost	Total Funding	Status
1-112	5 Year Plan	$10,000,000	$10,000,000	Priority
1-114	10 Year Plan	$15,000,000	$1,000,000	Priority

Project No	Completion Date	Total Cost	Total Funding	Status
1-701	5 Year Plan	$1,100,000	$1,100,000	Priority
1-806	10 Year Plan	$5,000,000	$1,000,000	Priority
1-809	5 Year Plan	$8,500,000	$1,000,000	Priority
1-910	10 Year Plan	$10,000,000	$2,000,000	Priority
2-113	10 Year Plan	$3,100,000	$500,000	Priority
2-308	10 Year Plan	$27,000,000	$500,000	Priority
F01272	10 Year Plan	$31,600,000	$600,000	Priority
F01336	2017-2018	$12,800,000	$13,740,000	Priority
F01389-2	10 Year Plan	$2,700,000	$1,430,000	Priority
F01417	10 Year Plan	$39,500,000	$21,150,000	Priority
F01452-2	2017-2018	$38,400,000	$1,170,000	Priority
F01473	10 Year Plan	$8,100,000	$5,001,000	Priority
F01650	2017-2018	$5,200,000	$3,440,000	Priority
F01667	10 Year Plan	$26,900,000	$16,000,000	Priority
F01911	2018-2019	$8,700,000	$3,140,000	Priority
F02129	10 Year Plan	$16,700,000	$1,024,000	Priority
F02228	10 Year Plan	$8,700,000	$7,600,000	Priority
F02243	10 Year Plan	$2,400,000	$400,000	Priority
Totals:		$281,400,000	$91,795,000	

B.7.1 Priority Project Descriptions

B.7.1.1 1-112 West State Storm Drain – Priority

Channel Invert Repair
Status: Proposed
Completion Date: 5-year plan
Total Cost: 11.4 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Public Safety; protection of local and downstream infrastructure
Hazard Mitigated: Downstream flooding

B.7.1.2 1-114 Carbon Canyon Channel – Priority

Channel improvement
Status: Proposed
Completion Date: 10-year plan
Total Cost: 15 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Public Safety; protection of local and downstream infrastructure
Hazard Mitigated: Downstream flooding

B.7.1.3 1-701 Etiwanda Channel Invert Repair – Priority

Channel Invert Repair
Status: Proposed
Completion Date: 5-year plan
Total Cost: 1.1 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Public Safety; protection of local and downstream infrastructure
Hazard Mitigated: Downstream flooding

B.7.1.4 1-806 Hawker Crawford Channel and Rich Basin – Priority

Channel / Basin improvement
Status: Proposed
Completion Date: 10-year plan
Total Cost: 5 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Public Safety; protection of local and downstream infrastructure by reducing peak Q
Hazard Mitigated: Downstream flooding

B.7.1.5 1-809 West Fontana Channel (From Banana Basin to Hickory Basin) – Priority

Channel Repair
Status: Proposed
Completion Date: 5-year plan
Total Cost: 8.5 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Public Safety; protection of local and downstream infrastructure
Hazard Mitigated: Downstream flooding

B.7.1.6 1-910 Grove Basin-Priority

Basin out improvement
Status: Proposed
Completion Date: 10-year plan
Total Cost: 10 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Public Safety; protection of local and downstream infrastructure by reducing peak Q
Hazard Mitigated: Downstream flooding

B.7.1.7 2-113 Randal Basin outlet improvement – Priority

Outlet improvements D/S of the Basin
Status: Proposed
Completion Date: On 10-year plan

Local Priority: Medium
Total Cost: $3.1 million
Funding Description: San Bernardino County Flood Control Property Taxes
Project Selected for: Public Safety
Hazard Mitigated: Potential failure & flooding downstream
Resources to Implement: Medium
Cost to Implement: High
Time to Implement: High

B.7.1.8 2-308 Cable Creek Channel – Priority

Channel improvements
Status: Proposed
Completion Date: On 10-year plan
Local Priority: Low
Total Cost: $27 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Compliance with FEMA Levee Certification program
Hazard Mitigated: Reduction of floodplain; reduction of potential for major flooding
Resources to Implement: High
Cost to Implement: High
Time to Implement: High

B.7.1.9 F01272 Rialto Channel, Etiwanda Avenue to Willow Avenue – Priority

Construct Rialto channel to ultimate condition
Status: Proposed
Completion Date: On 10-year plan
Local Priority: Low
Total Cost: $31.6 million
Funding Description: San Bernardino County Flood Control Property Taxes, City of Rialto
Project Selected for: Public Safety & convenience Hazard Mitigated: Residential area flooding and road closures due to wash-outs
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.1.10 F01336 Amethyst Detention Basin – Priority

Construct a detention basin at Amethyst and Sycamore
Status: Design completed, Permits In process
Completion Date: Estimated 2017/2018
Local Priority: High
Total Cost: $12.8 million
Funding Description: San Bernardino County Flood Control Property Taxes, City of Victorville
Project Selected for: Public Safety; protection of local and downstream infrastructure by reducing peak Q
Hazard Mitigated: downstream flooding

Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.1.11 F01389-2 Mojave River Phase II – Priority

Construct earthen levee lined with 1/2 ton rock slope protection between Oro Grande Wash and Mojave River Phase I
Status: Proposed
Completion Date: On 10-year plan
Local Priority: Low
Total Cost: $2.7million
Funding Description: San Bernardino County Flood Control Property Taxes
Project Selected for: To finalize levee improvement construction; protection of Amtrak station
Hazard Mitigated: Local flooding, railroad flooding
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.1.12 F01417 Bandicoot Detention Basin (Phase I&II) – Priority

Construction of detention basin, inlet/outlet facilities, fencing to attenuate 10-year storm flows adjacent to California Aqueduct and downstream residential and commercial properties developments.
Status: Proposed
Completion Date: On 10-year plan
Local Priority: Low
Total Cost: $39.5 million
Funding Description: San Bernardino County Flood Control Property Taxes
Project Selected for: To protect the State water aqueduct
Hazard Mitigated: Flood damage to aqueduct & local area
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.1.13 F01452-2 West Fontana Channel, Phase I – Priority

Construction of concrete channel from Juniper to Banana Basin
Status: In process
Completion Date: Estimated 2017/2018
Local Priority: Medium
Total Cost: $38.4 million
Funding Description: San Bernardino County Flood Control Taxes, City of Fontana
Project Selected for: Public safety & convenience
Hazard Mitigated: Flooding of railroad & Metrolink tracks; road damage & closure
Resources to Implement: Medium
Cost to Implement: High

Time to Implement: High

B.7.1.14 F01473 Rialto Channel – Priority

Construct channel improvements south of Interstate 10
Status: Proposed
Completion Date: On 10-year plan
Local Priority: Medium
Total Cost: $8.1 million
Funding Description: San Bernardino County Flood Control Property Taxes, City of Rialto
Project Selected for: Public Safety
Hazard Mitigated: Existing channel is interim and undersized
Resources to Implement: Medium
Cost to Implement: High
Time to Implement: High

B.7.1.15 F01650 Sand Creek/ Warm Creek Channels – Priority

Improve existing confluence of Sand Creek and Warm Creek Channels
Status: In process
Completion Date: Estimated 2017/2018
Local Priority: Medium
Total Cost: $5.2 million
Funding Description: San Bernardino County Flood Control
Project Selected for: channel improvements to interim storm drain system
Hazard Mitigated: Potential damage to infrastructure
Resources to Implement: High
Cost to Implement: High
Time to Implement: High

B.7.1.16 F01667 Cactus Basins #4 & 5 – Priority

Construction of detention basins to mitigate downstream flooding of Rialto Channel Work includes inlet/outlet structures
Status: Proposed
Completion Date: 10-year plan
Local Priority: Low
Total Cost: $26.9 million
Funding Description: San Bernardino County Flood Control, City of Rialto
Project Selected for: Ability to reduce downstream peak Q
Hazard Mitigated: flooding of nearby area

B.7.1.17 F01911 Elder Gulch – Priority

Construct trapezoidal rock-lined channel
Status: Proposed
Completion Date: Estimated FY 18/19
Local Priority: High

Total Cost: $8.7 million
Funding Description: San Bernardino County Flood Control Property Taxes
Project Selected for: Public safety
Hazard Mitigated: Flooding of local area
Resources to Implement: Low
Cost to Implement: High
Time to Implement: Medium

B.7.1.18 F02129 Wildwood Channel – Priority

Channel improvement
Status: In preliminary design process
Completion Date: On 10-year plan
Local Priority: High
Total Cost: $16.7 million
Funding Description: San Bernardino County Flood Control Property Taxes, City of Yucaipa
Project Selected for: History of flooding due to high debris flows
Hazard Mitigated: reduction in size of floodplain; minimized flooding
Resources to Implement: Low
Cost to Implement: High
Time to Implement: Low

B.7.1.19 F02228 Plunge Creek Spillway – Priority

Repair of severe damage caused by storms in 2005
Status: Proposed
Completion Date: On 10-year plan
Local Priority: High
Total Cost: $3 million
Funding Description: San Bernardino County Flood Control Property Taxes
Project Selected for: Necessary repairs due to previous flood damage
Hazard Mitigated: Potential failure & flooding downstream
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.1.20 F02243 Rialto Channel Priority Crossings – Priority

Status: In preliminary design process
Completion Date: On 10-year plan
Local Priority: Low
Total Cost: $2.4 million
Funding Description: San Bernardino County Flood Control Property Taxes, City of Rialto

Project Selected for: Public Safety & convenience
Hazard Mitigated: Elimination of flooding at intersections
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.2 Projects with Mitigation Benefits

Table B-7 is a list of the proposed projects to mitigate the Flood hazard within the County Unincorporated Area.

Table B-7: In Progress Flood Control Mitigation Projects

Project No	Completion Date	Total Cost	Total Funding	Status
F01312	2017/2018	4,400,000	2,200,000	Under Construction
F01666	2017/2018	17,800,000	17,800,000	Under Construction
F02094	2017	4,000,000	4,000,000	Under Construction
F02126	2017/2018	8,300,000	6,180,000	Under Construction
	Totals:	34,500,000	30,180,000	

B.7.2.1 F01312 English Channel/ Peyton Drive (Under Construction)

Construct triple RCB and channel upstream and downstream of Peyton Drive.
Status: In preliminary design process
Completion Date: Estimated 2017/2018
Local Priority: High
Total Cost: $4.4 million
Funding Description: San Bernardino County Flood Control Property Taxes, 50% and City of Chino Hills 50%
Project Selected for: Public safety & convenience
Hazard Mitigated: Flooding of roads in residential area
Resources to Implement: High
Cost to Implement: High
Time to Implement: Medium

B.7.2.2 F01666 Cactus Basin #3/ Expansion of Basin #3 – (Under Construction)

Status: In process
Completion Date: Estimated 2017/2018
Local Priority: High
Total Cost: $17.8 million
Funding Description: San Bernardino County Flood Control Property Taxes, City of Rialto

Project Selected for: Public safety & improved future development; protection of water filtration plant across the street; reduction of peak Q downstream.
Hazard Mitigated: Flooding of immediate area and downstream along Rialto Channel
Resources to Implement: Low
Cost to Implement: High
Time to Implement: Medium

B.7.2.3 F02094 Cucamonga Basin #6, Phase II – (Under Construction)

Landscaping improvements
Status: Partial Completed
Completion Date: Mid-2011 – (Landscaping Phase Completion date end of 2017)
Local Priority: High
Total Cost: $4.0 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Environmental compliance & aesthetics
Hazard Mitigated:
Resources to Implement: Low
Cost to Implement: High
Time to Implement: Low

B.7.2.4 F02126 Francis Street Storm Drain (Under Construction)

Construct ultimate storm drain improvements from Sultana Avenue east to beyond Grove Avenue
Status: In preliminary design process
Completion Date: Estimated 2017/2018
Local Priority: Low
Total Cost: $8.3 million
Funding Description: San Bernardino County Flood Control Property Taxes 75% and City of Ontario 25%
Project Selected for: Public safety & convenience
Hazard Mitigated: Existing storm drain is undersized/interim; local flooding
Resources to Implement: Medium

B.7.3 Future Year Projects

Table B-8: Future Year Projects

Project Number/Name	Completion Date	Total Cost	Status
2-509 Little Sand Creek	10 Year Plan	$10,500,000	Future
3-501 Mission Channel	10 Year Plan	$28,800,000	Future
3-601 Wilson Creek (10th St-I-10)	10 Year Plan	$38,800,000	Future
CSDP Drain Project	10 Year Plan	$18,500,000	Future
Extension of VV Line E-01	10 Year Plan	$2,000,000	Future
F01284	10 Year Plan	$7,200,000	Future
F01582	10 Year Plan	$19,000,000	Future
F01584	2018/2019	$11,700,000	Future
F01609	10 Year Plan	$32,500,000	Future

Project Number/Name	Completion Date	Total Cost	Status
F02225	10 Year Plan	$33,100,000	Future
F02475	10 Year Plan	$9,000,000	Future
F02476	10 Year Plan	$32,300,000	Future
H1458	2021	$3,000,000	Future
Institution Road	2021	$30,000,000	Future
Line C-01 Hesperia	10 Year Plan	$5,300,000	Future
Line D-01 Hesperia	10 Year Plan	$32,500,000	Future
Line E-01 Apple Valley	10 Year Plan	$36,300,000	Future
Lone Pine Canyon Road Culvert	TBD	$25,000,000	Future
National Trails Hwy Bridge	TBD	$40,000,000	Future
Old Waterman Canyon Rd Culvert	TBD	$2,500,000	Future
Pine View Dr. Storm Drain	TBD	$6,000,000	Future
Piute Wash	2021	$34,500,000	Future
Rimforest Drainage Project	10 Year Plan	$6,900,000	Future
Rock Springs Rd Bridge Replacement	TBD	$32,876,000	Future
Tussing Ranch-Juniper Basin	10 Year Plan	$6,500,000	Future
Yermo Rd/National Trails Hwy Bridge	TBD	$40,000,000	Future
	Totals:	$544,776,000	

B.7.3.1 2-509 Little Sand Creek

Creek improvements between Date Street and Del Lemon basin
Status: Proposed
Completion Date: 10-year plan
Local Priority: Medium
Total Cost: $10.5 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety; residential area with school nearby
Hazard Mitigated: Flooding and pedestrian hazards
Resources to Implement: Medium
Cost to Implement: High
Time to Implement: High

B.7.3.2 3-501 Mission Channel

Channel Repair, Construct concrete channel improvements
Status: Proposed
Completion Date: 10-year plan
Local Priority: Medium
Total Cost: $28.8 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety; residential area with school nearby
Hazard Mitigated: Flooding and pedestrian hazards
Resources to Implement: Medium

Cost to Implement: High
Time to Implement: High

B.7.3.3 3-601 Wilson Creek (from 10st Street to I-10)

Channel Repair, between 10st Street to I-10
Status: Proposed
Completion Date: 10-year plan
Local Priority: Medium
Total Cost: $38.8 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety; residential area with school nearby
Hazard Mitigated: Flooding and pedestrian hazards
Resources to Implement: Medium
Cost to Implement: High
Time to Implement: High

B.7.3.4 CSDP -- Storm Drain Project – Colton

Construction of storm drains from Randall Basin to the Santa Ana River according to Comprehensive Storm Drain Plan (CSDP) 3-5 and 3-8
Status: Proposed
Completion Date: On 10-year plan
Local Priority: Medium
Total Cost: $18.5 million
Funding Description: San Bernardino County Flood Control Property Taxes
Hazard Mitigated: Existing channel is interim and undersized
Resources to Implement: Medium
Cost to Implement: High
Time to Implement: High

B.7.3.5 Extension of Victorville Line E-01

Construct Storm Drain line E-01
Status: In preliminary design process
Completion Date: On 10-year plan
Local Priority: High
Total Cost: $2.0 million
Funding Description: San Bernardino County Flood Control Property Taxes, City of Victorville
Project Selected for: Public safety of commercial area
Hazard Mitigated: local flooding; road closure/road damage (State Hwy)
Resources to Implement: High
Cost to Implement: High
Time to Implement: Low

B.7.3.6 F01284 Donnell Basin (Phase I&II)

Construct detention basin.
Status: Proposed
Completion Date: 10-year plan
Local Priority: Medium
Total Cost: $7.2 million
Funding Description: San Bernardino County Flood Control Property Taxes
Project Selected for: Public Safety; roadway protection; Safe Routes to School Program (SR2S)
Hazard Mitigated: Flood protection for homes, infrastructure, and pedestrians
Resources to Implement: Low

B.7.3.7 F01582 Desert Knolls II

Construct flood control channel from Apple Valley Road to Tuscola Road
Status: Proposed
Completion Date: On 10-year plan
Local Priority: High
Total Cost: $19 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety/future development
Hazard Mitigated: Potential localized flooding due to increased development
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.3.8 F01584 Desert Knolls

Construct channel improvements from the Mojave River to Phase I
Strategy: Construct concrete lined channel to provide for 100 year storm flows and debris flows.
Status: Proposed
Completion Date: Estimated FY 18/19
Local Priority: High
Total Cost: $11.7 million
Funding Description: San Bernardino County Flood Control Tax Revenues
Project Selected for: Environmental requirements
Hazard Mitigated: This project is the mitigation aspect of Phase II
Resources to Implement: Low
Cost to Implement: High
Time to Implement: Medium

B.7.3.9 F01609 Ranchero Basin

Construct detention basin
Status: Proposed

Completion Date: 10-year plan
Local Priority: High
Total Cost: $32.5 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety and reduction of peak Q
Hazard Mitigated: Potential damage to bridges and roads downstream due to high flows
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.3.10 F02225 Del Rosa

Channel Repair, Construct concrete channel improvements between Pacific Street and Del Rosa Avenue
Status: Proposed
Completion Date: 10-year plan
Local Priority: Medium
Total Cost: $33.1 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety; residential area with school nearby
Hazard Mitigated: Flooding and pedestrian hazards
Resources to Implement: Medium
Cost to Implement: High
Time to Implement: High

B.7.3.11 F02475 Seneca Basin

Construct detention basin
Status: Proposed
Completion Date: 10-year plan
Local Priority: High
Total Cost: $9 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety and reduction of peak Q
Hazard Mitigated: Potential damage to bridges and roads downstream due to high flows
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.3.12 F02476 Oak Hills Basin

Construct detention basin
Status: Proposed
Completion Date: 10-year plan
Local Priority: High
Total Cost: $32.3 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety and reduction of peak Q
Hazard Mitigated: Potential damage to bridges and roads downstream due to high flows
Resources to Implement: Low

Cost to Implement: High
Time to Implement: High

B.7.3.13 H1458 Arrowbear Dr. Bridge Replacement

Replacement of bridge crossing on Arrowbear Drive and increase spillway flow capacity to prevent flooding
Status: Proposed
Completion Date: 2021
Total Cost: $3,000,000.00
Funding Description: Major Local Highway Project Funds
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

B.7.3.14 Institution Road

Construction of bridge crossing along Institution Road on Cajon Wash
Status: Proposed
Completion Date: 2021
Total Cost: $30,000,000.00
Funding Description: seeking grant funding
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

B.7.3.15 Line C-01 Hesperia

Construction of concrete trapezoidal channel improvements, short reach of levee along the channel, 96 inch RCP and reconstruction of the existing deficient reach as a concrete trapezoidal channel with a portion of riprap channel
Status: Proposed
Completion Date: 10-year plan
Total Cost: $5.3 million
Funding Description: San Bernardino County flood Control
Project selected for: Public safety and roadway protection
Hazard Mitigated: Flooded roads and residential area
Resources to implement: High
Cost to implement: High
Time to implement: High

B.7.3.16 Line D-01 Hesperia

Improve the storm drain facility.
Status: Proposed
Completion Date: 10-year plan
Total Cost: $32.5 million
Funding Description: San Bernardino County flood Control
Project selected for: Public safety and roadway protection
Hazard Mitigated: Flooded roads and residential area
Resources to implement: High
Cost to implement: High

Time to implement: High

B.7.3.17 Line E-01 Apple Valley

Improve the storm drain facility.
Status: Proposed
Completion Date: 10-year plan
Total Cost: $36.3 million
Funding Description: San Bernardino County flood Control
Project selected for: Public safety and roadway protection
Hazard Mitigated: Flooded roads and residential area
Resources to implement: High
Cost to implement: High
Time to implement: High

B.7.3.18 Lone Pine Canyon Road Culvert

Construction of Culvert on Long Pine Canyon Road
Status: Proposed
Completion Date: No date until funding is available
Total Cost: $2,500,000.00
Funding Description: TBD
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

B.7.3.19 National Trails Highway Bridge Replacement

Removal of approximately 31 old timber bridges and construction of replacement bridges spanning Under 20' on National Trails Highway
Status: Preliminary engineering and environmental study only
Completion Date: No date until funding is available
Total Cost: $40,000,000.00
Funding Description: TBD
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

B.7.3.20 Old Waterman Canyon Road Culvert

Removal of approximately 31 old timber bridges and construction of replacement bridges spanning less than 20' on National Trails Highway
Status: Preliminary engineering and environmental study only
Completion Date: No date until funding is available
Total Cost: $2,500,000.00
Funding Description:
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

B.7.3.21 Pine View Dr. Storm Drain

Construction of storm drain on Pine View Drive
Status: Proposed
Completion Date: Shelf ready but no date until funding is available
Total Cost: $6,000,000.00
Funding Description: TBD
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

B.7.3.22 Piute Wash

Construction of bridge crossing along Needles highway road on Piute washes to prevent flooding and washing the road out.
Status: Proposed
Completion Date: 2021
Total Cost: $34,500,000
Funding Description: seeking grant funding
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

B.7.3.23 Rimforest Drainage Project – Rimforest Area

Capture the surface water within Rimforest and convey it to Little Bear Creek, away from the escarpment.
Status: In preliminary design process
Completion Date: On 10-year plan
Local Priority: High
Total Cost: $6.9 million
Funding Description: San Bernardino County Flood Control Property Taxes
Project Selected for: Public safety of commercial area
Hazard Mitigated: Public safety and reduction of peak Q
Resources to Implement: High
Cost to Implement: High
Time to Implement: Low

B.7.3.24 Rock Springs Road Bridge Replacement

Construct Replacement Bridge on Glen Helen Parkway over Cajon Wash It will increase flow capacity with a longer span and reduce flooding of the roadway.
Status: Proposed
Completion Date: No date until full funding is available
Total Cost: $32,876,000
Funding Description: Partially funded with General Fund Money
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

B.7.3.25 Tussing Ranch – Juniper Basin

Construct detention basin
Status: Proposed
Completion Date: 10-year plan
Local Priority: High
Total Cost: $6.5 million
Funding Description: San Bernardino County Flood Control
Project Selected for: Public safety and reduction of peak Q
Hazard Mitigated: Potential damage to bridges and roads downstream due to high flows
Resources to Implement: Low
Cost to Implement: High
Time to Implement: High

B.7.3.26 Yermo Road and National Trails Highway Bridge Replacement

Removal of approximately 11 old timber bridges and construction of replacement bridges spanning under 20' on National Trails Highway and Yermo Road. The military is using high load tractors and trailers warranting the need to increase the load capacity of the bridges.
Status: Preliminary engineering and environmental study only
Completion Date: No date until funding is available
Total Cost: $40,000,000.00
Funding Description: TBD
Project Selected for: Public Safety and convenience
Hazard Mitigated: flood damage, road closures and road damage

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Annex C. Special Districts Department

C.1 Introduction

Special Districts Department, under the direction of the San Bernardino County Board of Supervisors, provides administrative oversight and manages the operation of over 100 special districts throughout San Bernardino County. Through the formation of County Service Areas (CSAs) and Improvement Zones, these special districts provide a variety of municipal-type services to unincorporated areas of the county.

C.2 Special Districts Profile

Special District Functions:
The County Service Areas (CSAs) and Improvement Zones can provide one or all of the following services to meet the individual needs of communities, neighborhoods and new developments depending on needs and financial feasibility:

- Cemetery
- Dam Operation
- Detention Basin
- Engineering and Construction
- Landscaping
- Open Spaces
- Park and Recreation
- Public Financing
- Refuse
- Roads
- Streetlights
- Television Translator
- Water and Sanitation

Mission:
The Special Districts Department works to ensure safe, healthy, and enjoyable communities by providing customizable programs and municipal services for those who work, play and stay in San Bernardino County.

Vision:
To be recognized as the preeminent provider of customized municipal services focusing on improved quality of life for the residents and visitors of San Bernardino County.

C.3 Planning Process

As described above, the County Flood Control District followed the planning process detailed in Section 3 of the base plan. In addition to providing representation on the San Bernardino County Hazard Mitigation Planning Committee (HMPC), the District formulated their own internal planning team to support the broader planning process requirements. Internal planning participants, their positions, and how they participated in the planning process are shown in Table C-9. Additional details on plan participation and District representatives are included in Appendix A.

Table C-9: Special District Hazard Mitigation Planning Team

Name	Title
Jeffrey Rigney	Director of Special Districts
Steve Samaras	Water and Sanitation Division Manager
Tim Millington	Engineering Division Manager,
Reese Troublefield	Operations Division Manager
Erin Opliger	Districts Services Coordinator

The Special Districts Department has attending the following planning meetings:

Meeting Date	Meeting Type	Attendees	Additional Details
6/23/16	LHMP Update - Kickoff Meeting	Steve Samaras, Erin Opliger	
8/30/16	LHMP Group Meeting	Erin Opliger	
10/26/16	LHMP Blue Jeans Meeting	Erin Opliger	

The County of San Bernardino Special Districts Department (Department) has historically identified goals, objectives, and projects to mitigate the negative effects of hazards. The Department continues to work with various Advisory Commissions and the public to identify and mitigate the impacts of hazards to the various services that the Department provides, including: cemetery operations, dam operations, detention basin operations, landscaping services, open space, parks and recreation, refuse services, roads, streetlights, television translator, water distribution and treatment system operations, sewer collection system operations, and wastewater treatment plant operations.

The Department diligently identifies the hazards that each service district or County Service Area (CSA) and its zones face, and has assessed the vulnerability according to the potential event. Hazards, whether they are technological or natural, affect CSAs with varying frequency and can cause injury, impose monetary losses, and the disruption of services, affecting the Department's mission as a public agency service provider. Losses can be substantially reduced or eliminated through comprehensive pre- disaster planning and mitigation actions.

Many groups and individuals have contributed to the Department's planning for Disasters and the necessary hazard mitigation efforts. Advisory Committees, located in the Department's various CSAs, provide on-going input and support for the various aspects of hazard mitigation, including identifying persistent hazards that develop after storm events and options for mitigation.

Department staff participates in the hazard mitigation process by completing semi-annual audits of various CSAs, recommending temporary fixes and/or permanent solutions. CSA customers and the public have also participated in hazard mitigation planning by approaching staff in the field, contacting the office, and/or attending public meetings to identify temporary and ongoing hazards that need to be addressed. These resources have proved valuable to the Department in identifying and mitigating potential hazards. The Department also uses the following process to prepare hazard mitigation plans:

- Identify and prioritize disaster events that are most probable and destructive;
- Identify critical facilities;
- Identify areas within communities that are most vulnerable;
- Develop goals and objectives for reducing the effects of a disaster event;
- Develop specific projects to be implemented for each goal;
- Identify funding sources;
- Develop procedures for monitoring progress;
- Mitigate identified potential hazards.

The Department has identified areas for mitigation projects within the Special Districts of San Bernardino County as a result of their internal planning processes. These projects, shown below, are organized by type of special district these proposed projects are in the conceptual stage and detailed planning will be done in the future as funding becomes available. Prioritization of projects will be done in the planning stages, based on the risk prioritizations developed for the current Multi-Jurisdictional Hazard Mitigation Plan.

C.4 Hazard Identification and Prioritization

The Special Districts Planning Team participated in the County hazard identification and prioritization process described in the base plan. The Special Districts Planning Team assisted to summarize the extent, probability of future occurrences, potential magnitude/severity, and significance specific to the Special Districts (See Section 4).

C.5 Coordination with County Planning Efforts

Coordination with other County planning efforts is paramount to the successful implementation of this plan. This Section provides information on how the Special Districts integrated the previously-approved 2011 Plan into existing planning mechanisms and programs. Specifically, the District incorporated into or implemented the 2011 MJHMP through other plans and programs shown below.

C.5.1 3.2 Water Systems (Distribution Systems):

Fire:

- Rockscape or paved property grounds which have structures located in wilderness and or areas prone to wildfires. Double the width of external fire breaks.
- Re-roof buildings and structures with tile, metal or fire resistant material.

Flood:

- Add drainage, elevate facilities and adjust sloping for facilities in low-lying areas and in natural waterways or floodplains. (Recent Completion)
- Conduct hydrologic and hydraulic studies for all facilities located near flood plains/natural waterways.
- Encase water pipelines with specific sized rock, gravel, and road base in natural waterways to prevent continual washout or exposure during heavy storm events/floods.

Earthquake:

- Retrofit structures to higher seismic standards.
- Purchase portable containers (Conex containers) to stage emergency supplies and equipment for the first responders (i.e. water, food, small off road vehicles, fuel, cots, toiletries, communication devices, blankets, wet weather gear, etc.) at strategic water system locations throughout County of San Bernardino. Conex containers can be relocated if necessary to assist field staff during a disaster to maintain the operations of water systems. (Recent Completion and in implementation phase)

General Hazard (Fire/Flood/Earthquake):

- Retrofit existing buildings and facilities with connectors/ATS for emergency generators and/or install permanent emergency generators at critical facilities, including wells and booster station locations.
- Develop a plan for speeding the repair of and functional restoration of water and wastewater systems through stockpiling of shoring materials, temporary pumps, surface pipelines, portable hydrants, and other supplies.
- Develop a plan for areas subject to high ground shaking, earthquake-induced ground failure, and surface fault rupture to determine a replacement schedule for pipelines (along with importance, age, type of construction material, size, condition, and maintenance or repair history).(Project now in effect)
- Develop a plan for short-term and intermediate-term sheltering of employees.
- Develop a plan to work with local agencies that handle hazardous materials to coordinate mitigation efforts for the possible release of these materials due to a natural disaster such as an earthquake, flood, fire, or landslide.

- Utilization of SCADA and Smart Water Meters to get real time data on problems with the system and reduce drive time emissions as a result of traditional meter reading.
- Provide emergency supplies of food, water, and portable generators for employees at office and field locations.
- Install emergency generators at district facilities

C.5.2 3.3 Sewer Systems (Collection Systems):

Fire:

- Rockscape or pave property grounds which have structures located in wilderness and or areas prone to wildfires. Double the width of external fire breaks.(Completion and program implementation by January 2017 estimated)
- Re-roof buildings and structures with tile or fire resistant material.

Flood:

- Add drainage, elevate facilities and adjust sloping for facilities in low-lying areas and in natural waterways or floodplains.
- Encase sewer pipelines with specific sized rock, gravel, and road base in natural waterways to prevent continual washout or exposure during heavy storm events/floods.

Earthquake:

- Develop a plan for short-term and intermediate-term sheltering of employees.
- Retrofit structures to higher seismic standards.

General Hazard (Fire/Flood/Earthquake):

- Retrofit existing buildings and facilities with connectors/ATS for emergency generators and/or install permanent emergency generators.

- Develop a plan for speeding the repair and functional restoration of water and wastewater systems through stockpiling of shoring materials, temporary pumps, surface pipelines, portable hydrants, and other supplies.
- Develop a plan for areas subject to high ground shaking, earthquake-induced ground failure, and surface fault rupture to determine a replacement schedule for pipelines (along with importance, age, type of construction material, size, condition, and maintenance or repair history).
- Install emergency power generators at district facilities.

C.5.3 3.4 Wastewater Treatment Plant

Fire:

- Rockscape or pave property grounds which have structures located in wilderness and or areas prone to wildfires. Double the width of external fire breaks.
- Purchase and store water pumps capable of suppressing fire.

Flood

- Add drainage, elevate facilities and adjust sloping for facilities in low-lying areas and in natural waterways or floodplains.

Earthquake:

- Develop a plan for short-term and intermediate-term sheltering of employees.

C.5.4 3.5 Roads

Fire:

- Install generators at all road facilities. This will allow uninterrupted communications and provide power to refuel critical emergency response equipment.
- Purchase emergency water supply or water purification devices to ensure uninterrupted supply of water to emergency response personal.(completed with continuous fresh of supplies and rotation)
- Clear vegetation from Road District facilities/yards

Flood:

- Upgrade culverts in all flood prone areas. Most existing culvert sizes were never designed for high water volume. Upgrading will prevent roadway washouts caused by water bypassing existing culverts.(Complete and continuous maintenance)
- Upgrade culvert sizes in Main Channels and replace old culverts in Main Channels as required.(complete and continuous maintenance)
- Slope stabilization at water crossing areas along roadways. This will prevent the loss of the roadways at these areas by preventing undermining by the water.
- Install generators at all road facilities. This will allow uninterrupted communications and provide power to refuel critical emergency response equipment.
- Purchase emergency water supply or water purification devices to ensure uninterrupted supply of water to emergency response personal.
- Soil stabilization on roadway shoulders. This will prevent erosion caused by flood conditions.

- Soil stabilization of dirt roadways. This will help mitigate the loss of material from the roadway during flooding conditions.
- Employ on call contractors to assist in emergency situations.

Earthquake:
Install generators at all road facilities. This will allow uninterrupted communications and provide power to refuel critical emergency response equipment.
Purchase emergency water supply or water purification devices to ensure uninterrupted supply of water to emergency response personal. (Completed and refresh of supplies as needed)

C.5.5 3.6 Television Translator Districts

General Hazard (Fire, Flooding, Earthquake):

- Install and maintain emergency generators at all TV Translator sites. Newberry Springs, Lucerne Valley, and Morongo Valley TV Transmitter sites are in need emergency generators. Pinto and Elephant Mountain sites have existing generators. Installing emergency generators at these sites will enable emergency information to be disseminated to the residents living in these remote locations.(Complete and maintenance of upgrades)
- Establish a centralized communications network to monitor channel output for TV Districts and provide emergency information by way of character generator tied to channel transmissions.
- Conduct annual tower and guide wire inspections to mitigate storm/wind/earthquake hazards from knocking out communications.
- Install poly insulators on power poles with high voltage power lines for Pinto Mountain. Establish an open purchase order for a High Voltage Electrician to provide annual inspections of power poles and service lines.(Completed and continuous maintenance)
- Maintain roadways on mountaintops and within washes leading to remote tower sites. Earthquakes and flash floods can block roadways, making them impassable to restore emergency communications.
- Maintain lights on all tower locations.

C.5.6 3.7 Parks Districts

- Trim large trees in parks to avert limb breakage and toppling during storm events.
- Establish emergency centers to ration drinking water at various County Park Community Centers.
- Establish community garden plots in designated County Park areas as an ongoing and emergency food source, including planting fruit bearing trees.
- Conduct an inventory or list of County Park Facilities and Community Centers to establish a list of pre-designated emergency operations or disaster relief sites. Not all Community

Centers are an appropriate size to accommodate large numbers of evacuees and may only serve as command and control centers or distribution centers.

- Establish small solar energy fields or other forms of renewable power at County Community Centers to facilitate stand-alone emergency operations for the community.
- Conduct repair and replacement of old roofs, and clearing of gutters and roof drains to minimize potential damage from major storm events.(Completed and continuous maintenance)
- Conduct an evaluation or study of County Park and Community Center facilities to install curbs, retaining walls, and drains to carry or divert water away from buildings.
- Connect water systems to generators to ensure delivery even in disaster situations.
- Provide emergency supply of food and water for employees in disaster situations.

C.6 Special Districts Mitigation Project Prioritizing

Cost effectiveness of each measure was a primary consideration when developing mitigation actions. Because mitigation is an investment to reduce future damages, it is important to select measures for which the reduced damages over the life of the measure are likely to be greater than the project cost. For structural projects, the level of cost effectiveness is primarily based on the likelihood of damages occurring in the future, the severity of the damages when they occur, and the level of effectiveness of the selected measure. While detailed analysis was not conducted during the mitigation action development process, these factors were of primary concern when selecting measures. For measures that do not result in a quantifiable reduction of damages, such as public education and outreach, the relationship of the probable future benefits and the cost of each measure was considered when developing the mitigation actions.

Based upon the Special Districts capabilities, Table C-10 shows primary actions selected for further implementation and development during the next planning cycle. Table C-10 provides details for each mitigation action with mitigation action descriptions, FEMA mitigation category, responsible party, and timeframe.

C.7 Special Districts Mitigation Actions

Table C-10: Mitigation Project Prioritization and Implementation

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
All-Hazard	**AH Action 2.1:** Continue funding and support for Special Districts Projects relating to all hazards.	Continue funding and support for Special Districts Projects relating to water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District for all hazards. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	Ongoing	
All-Hazard	**AH Action 2.2:** Install Generators at Critical Facilities	Retrofit existing buildings and facilities with connectors/ ATS for emergency generators and/or install permanent emergency generators at critical facilities, including wells and booster station locations.	ES, SP	TBD	Water Systems	TBD	Critical sites are already set up for connection or has a permanently installed generator
All-Hazard	**AH Action 2.3:** Water Systems Repair Plan	Develop a plan for speeding the repair of and functional restoration of water and wastewater systems through stockpiling of shoring materials, temporary pumps, surface pipelines, portable hydrants, and other supplies.	PRV	SDD WAS	Water Systems	TBD	We have a warehouse and inventory. Add'l inventory would need to be purchased from local wholesaler
All-Hazard	**AH Action 2.4:** Smart Water Meters and SCADA	Utilization of SCADA and Smart Water Meters to get real time data on problems with the system and reduce drive time emissions as a result of traditional meter reading.	PRV	Individual CSAs	Water Systems	Ongoing	Both SCADA and Smart Meters have been installed and continue to be installed
All-Hazard	**AH Action 2.5:** Provide Employees with Emergency Supplies	Provide emergency supplies of food, water, and portable generators for employees at office and field locations.	ES	SDD/WAS	Water Systems	Ongoing	WAS has a stock of emergency food supplies, water, and generators.
All-Hazard	**AH Action 2.6:** Annual Tower and Guide Wire Inspections	Conduct annual tower and guide wire inspections to mitigate storm/wind/earthquake hazards from knocking out communications.	PRV	TBD	TV Districts	7/1/2016-7/1/2017	All Districts
All-Hazard	**AH Action 2.7**: Maintain Tower Lighting	Maintain lights on all tower locations.	SP	TBD	TV Districts	June-17	
All-Hazard	**AH Action 2.8:** Designate Emergency Operations Sites	Conduct an inventory or list of County Park Facilities and Community Centers to establish a list of pre-designated emergency operations or disaster relief sites. Not all Community Centers are an appropriate size to accommodate large numbers of evacuees and may only serve as command and control centers or distribution centers.	PRV	TBD	Park Districts	April-17	All Districts
All-Hazard	**AH Action 2.9:** Establish Power Sources for Emergency Operations Sites	Establish small solar energy fields or other forms of renewable power at County Community Centers to facilitate stand-alone emergency operations for the community.	PRV, SP	TBD	Park Districts	12/1/2016-7/1/2018	Lucerne Valley Joshua Tree
All-Hazard	**AH Action 2.10:** Connect Water Systems to Generators	Connect water systems to generators to ensure delivery even in disaster situations.	PRV, SP	TBD	Park Districts	TBD	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
All-Hazard	**AH Action 2.11:** Establish a Centralized Communications Network	Establish a centralized communications network to monitor channel output for TV Districts and provide emergency information by way of character generator tied to channel transmissions.	PRV	TBD	TV Districts	7/1/2017-12/1/2017	All districts
Wildfire	**WF Action 3.3:** Vegetation Removal	Clear vegetation from Road District facilities/yards	PRV	TBD	Roads	TBD	
Wildfire	**WF Action 6.3:** Protect Property in Wilderness Areas	Rockscape or pave property grounds which have structures located in wilderness and or areas prone to wildfires. Double the width of external fire breaks.	PPRO, PRV, SP	TBD	Sewer Systems	January-17	All sewer pump stations have paving
Wildfire	**WF Action 8.3:** Structural Fire Breaks Widening	Double the width of external fire breaks on grounds which have structures located in wilderness and or areas prone to wildfires.	SP, PRV	Individual CSAs	Water Systems	7/1/2017-7/19/2019	
Wildfire	**WF Action 9.1:** Continue funding and support for Special Districts Projects relating to wildfire.	Continue funding and support for Special Districts Projects relating to wildfire in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	Ongoing	
Wildfire	**WF Action 9.2:** Emergency Water Supplies	Purchase emergency water supply or water purification devices to ensure uninterrupted supply of water to emergency response personal.(completed with continuous fresh of supplies and rotation)	ES	TBD	Roads	TBD	
Earthquake	**EQ Action 2.2:** Seismic Strapping	Seismic strapping for existing water tanks and future construction.	SP, PRV	CSA 64	Water Systems	7/17/2017- 7/1/2019	Ongoing currently
Earthquake	**EQ Action 2.3:** Employee Emergency Sheltering	Develop a plan for short-term and intermediate-term sheltering of employees.	PRV	WAS	Sewer Systems	7/17/2017-7/19/2019	To purchase cots, small portable generators, tents, etc.
Earthquake	**EQ Action 4.2:** Generator Installation	Install generators at all road facilities. This will allow uninterrupted communications and provide power to refuel critical emergency response equipment.	SP, PPRO	TBD	Roads	TBD	
Earthquake	**EQ Action 6.1:** Continue funding and support for Special Districts Projects relating to earthquake hazards.	Continue funding and support for Special Districts Projects relating to earthquake hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	Ongoing	
Flood	**FL Action 3.4:** Soil Stabilization on Roadways and Along Roadway Shoulders	Soil stabilization on roadway shoulders and dirt roads. This will prevent erosion caused by flood conditions.	SP, PRV	TBD	Roads	TBD	

Hazard	Mitigation Action	Description / Background	Mitigation Strategy Type	Funding	Responsible Agency	Time Frame	Status / Comments / Implementation Mechanisms
Flood	**FL Action 3.5:** Encasing Pipelines	Encase water pipelines with specific sized rock, gravel, and road base in natural waterways to prevent continual washout or exposure during heavy storm events/floods.	SP, PRV	CSA 70 J	Water Systems	7/17/2017-7/1/2027	
Flood	**FL Action 6.1:** Continue funding and support for Special Districts Projects relating to flood hazards.	Continue funding and support for Special Districts Projects relating to flood hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	Ongoing	
Flood	**FL Action 6.2:** On Call Contractors	Employ on call contractors to assist in emergency situations.	PRV, ES	TBD	Roads	TBD	
Drought	**DR Action 3.1:** Continue funding and support for Special Districts Projects relating to drought hazards.	Continue funding and support for Special Districts Projects relating to drought hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	Ongoing	
Anti-Terrorism	**AT Action 2.1:** Continue funding and support for Special Districts Projects relating to terrorism hazards.	Continue funding and support for Special Districts Projects relating to terrorism hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	Ongoing	
Climate Change	**CC Action 3.1:** Continue funding and support for Special Districts Projects relating to climate change hazards.	Continue funding and support for Special Districts Projects relating to climate change hazards in the categories of water systems, sewer systems, wastewater treatment, roads, TV districts, park districts, Big Bear Valley Recreation Park District and Bloomington Recreation and Park District. For more information regarding these projects, see Annex C Section C.7.	VARIES	VARIES	VARIES	Ongoing	

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EXHIBIT O

Highway 330, Closed For Two Months As A Consequence Of The Line Fire, Now Open

Posted on **November 29, 2024** by **Venturi**

Highway 330 reopened on November 22, a full two weeks prior to the previously rescheduled opening of the roadway connecting Highland in the Central Valley of San Bernardino County to the eastern San Bernardino Mountain communities.

The closure was necessitated by the ravages of the Line Fire, which charred 43,978 acres was ignited on September 5, in the midst of a long-running heat wave, at roughly 6 p.m. in northeast Highland near the intersection o of Baseline Road and Alpin Street by an arsonist in what is now believed to have been his third attempt at starting the fire.

Originally dubbed the Baseline Fire, it resisted efforts by the California Division of Forestry, known by the acronym CalFire, which serves as the contract fire department for the City of Highland, and the San Bernardino County Fire Division, to knock it down.

A CalFire incident management team was activated on September 6, as the steep terrain of the area into which the fire was spreading created challenges.

With the escalation of the surrounding heat, the fire began to expand rapidly on September 7 into the San Bernardino Mountains, and Governor Gavin Newsom declared a state of emergency existed in San Bernardino County as a consequence of the fire, and he authorized the use of a Fire Management Assistance Grant from the Federal Emergency Management Agency to cover elements of the firefighting effort.

Evacuation orders for the communities of Running Springs and Arrowbear Lake were issued, thereafter followed by evacuation orders to those in the communities of Angelus Oaks, Seven Oaks and all campgrounds and cabins in the area; Green Valley Lake north from Highway 18 along Green Valley Lake Road; the community of Forest Falls; and the community of Mountain Home Village. Those orders pertained to 11,400 structures under what was deemed to be immediate threat.

At one point, there were 56,100 structures threatened, i.e., in the logical path of the directions in which the fire was prone to spread. In addition to the 11,400 structures most immediately under threat being put under evacuation orders, the remaining 44,700, primarily within the communities of Cedar Glen, Lake Arrowhead, Twin Peaks, Crestline, and Valley of Enchantment, along with the area from Garnett Street east to Bryant Street and Carter Street north to Mill Creek and the area of Big Bear Valley from the dam to Cactus Road, Erwin Lake, Sugar Loaf, Big Bear City, Big Bear Lake, and Fawnskin, were provided evacuation warnings.

Evacuation orders were based upon the incident commander's determination that there was an immediate threat to life in the area covered by the order. The issuance of the orders carried the full weight of California law, authorizing law enforcement officers to arrest those who did not comply. The areas were lawfully closed to public access.

The California National Guard was deployed, including four UH-60 Blackhawk helicopters, two C-130 aircraft, hand crews, and one military police company to assist with evacuations.

A state military police company, consisting of a California National Guard unit, was dispatched to support the San Bernardino County Sheriff's Department with evacuations and traffic control points in evacuated areas. In addition, the United States Forest Service issued Forest Order NO. 05-12-00-24-09, creating a forest closure area around the Line Fire. All National Forest lands, trails, and roads were closed to the public within that zone.

On Tuesday, September 10, 36 miles from where the fire had started in Highland, detectives with the San Bernardino County Sheriff's Department sojourned across the San Bernardino County/Riverside County line to a home at 1394 Detroit Street in Norco, where they arrested 34-year-old Justin Wayne Halstenberg, whom they maintain was the persistent arsonist who had touched off the Line Fire near the intersection of Baseline Road and Alpin Street on September 5.

Investigators, led by Battalion Chief Matt Kirkhart with CalFire and Jake Hernandez of the San Bernardino County Sheriff's Department's specialized arson unit, determined that the fire had been deliberately set with the use of materials later identified as coins wrapped in paper soaked in a flammable liquid. That team examined available video footage including traffic cameras around Baseline Road, identifying a white truck as the vehicle used by the arsonist. Further evidence implicating Halstenberg was obtained from at least one license plate reader in the area. Investigators made a direct link between Halstenberg and the ignition of the fire on the basis of his vehicle license plate, which was documented by a license plate recorder as being in the area at the time of what can be shown as the third and successful effort to start the fire, as well as at two previous unsuccessful attempts.

A search warrant was served at Halstenberg's home at the time of his arrest. According to investigators, material indicating he was responsible for setting the wildfire was found during that search.

The San Bernardino County District Attorney's Office charged Halstenberg, who remains in jail, with eleven felony counts, including a single count of aggravated arson, three counts of arson on structure or forest land, three counts of possession of material or a device for arson, one count of arson resulting in bodily harm, and a count of arson of an inhabited structure.

He was arraigned on the charges on September 17 in Rancho Cucamonga Superior Court.

According to prosecutors, on September 5, Halstenberg succeeded in creating a grass fire in a field near Bacon and Lytle lanes in Highland. That fire was reported and quickly extinguished by local firefighters. Halstenberg, who was lurking in the area, made a second attempt at igniting a fire just east of Bacon Lane, near Base Line and Aplin streets, authorities maintain. A passer-by acted quickly to stomp the fire out. "Undeterred, he ignited a third fire, which is what we now know as the Line Fire," according to the San Bernardino County District Attorney's Office.

By September 12, the fire had to that point covered 37,207 acres and was at 18 percent containment. The fire raged on for more than three weeks.

Highway 330 was closed on September 24. Statements made by responsible officials was that by the end of October it would be reopened.

Crucial elements of the road infrastructure, including the guardrails, were damaged by the fire. With some of the guardrails gone entirely and other compromised to the point that they might not be able to prevent a vehicle that slammed into them or even scrapped them from continuing off the road and over the ledge to the steep canyon below, officials closed the road entirely to anything other than emergency personnel.

The closure pertained to cars going both up the mountain from Highland Avenue in Highland to Live Oak Drive just outside of Running Springs and then down the mountain between those two places.

Three days before the closure, contractors hired by the state, began, on September 21, to repair and reconstruct roughly 4.8 miles of burned and damaged pavement, damaged guardrails and signs. It also initiated efforts to clear timber, sand, gravel, rocks and boulders from the drainage system along the road and to repair damage to culverts, drainage ditches and channels. While there had been hope the road might be reopened by October 20, that did not happen. On October 28 it was announced that the road was to remain closed indefinitely, as the $9.8 million repair effort, using money was disbursed form the state's emergency project funding, was to be carried out the California Department of Transportation. The closure was far more radical than what most members of the public anticipated.

Caltrans set a target of December 9 for the reopening of the roadway.

It turns out now, however, that the road has been reopened, in time for today's opening of Snow Valley near Running Springs and Saturday's initiation of the ski season at Snow Summit in Big Bear.

Those heading to the mountain resorts this holiday weekend and into the Christmas season will be able to do so using Highway 330. Nevertheless, the scene as they take the drive

up the mountain may put a damper on their festive spirits, as the devastation wrought by Halstenberg is overwhelmingly visually apparent. Much of the green forest is now depressingly burnt black. Still present are the vehicles and machiner employed by Caltrans contractors looking to restore the road. Work includes the removal of dead and dying trees ravaged by the fire, road asphalt, fractured bridges, debris and sediment that came down the mountain slopes with light rains earlier this season because of the fire's destruction of the underbrush and accompanying erosion, and the spans of still unrepaired guardrails.

According to Caltrans, the project's first phase of repairs are nearing completion. Material to fashion new guardrails has arrived and the first set of repairs are now under way. Artificial temporary dams are in place to protect workers from flash-flooding if a rainstorm develops while the repair work is yet ongoing.

The second phase is to begin next Wednesday, if things go according to schedule. The damaged culverts along the road have now been cleared of debris to allow those repairs to start.

This entry was posted in **Uncategorized** by **Venturi**. Bookmark the **permalink [https://sbcsentinel.com/2024/11/se/]** .

EXHIBIT P

KBHR 93.3 & 102.5 FM BIG BEAR NEWS

BIG BEAR WEATHER ROAD CONDITIONS BIG BEAR NEWS CONTACT US

SR-330 to Remain Closed Through February 24th for Repairs per CalTrans

02/14/2025 by KBHR NEWS

Big Bear News – Running Springs, CA – CalTrans has announced that crews have a lot of extra work ahead of them on State Route-330 from the Line Fire debris flow that was triggered after heavy rainstorms on Thursday, February 13, 2025. The storm caused some additional damage such as slope erosion, culvert blockage, basin load capacity, and a lot of rock fall and debris flow. CalTrans has a plan to fix and reestablish all high bank berms, clear cut side embankments, clean all culverts that are currently blocked, drain all basins that are filled, repair guardrail and slopes. **At this time, the estimated reopening of SR-330 will be Monday, February 24 at 5pm.** Crews will need to utilize the full roadway to expedite repair so this date may change meaning it could reopen sooner or later than we are planning. The reason is because there is still a lot of water rushing off the roadway, and this will prolong some repair work. An expected dryer weather week ahead should help greatly with the repair project and CalTrans appreciates the community's patience and understanding. Travelers will need to use the alternate routes of Highway 38 to Mentone or Highway 18 to Lucerne Valley for travel to/from Big Bear.

Related Posts:









Filed Under: Big Bear News, Government, Roads/Travel

Caltrans says Highway 38 will have a soft opening on December 24 at 4 p.m. for holiday travel. Emergency storm-damage repairs continue with full weekday closures resuming January 5.





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EXHIBIT Q

CALIFORNIA

Lake fire evacuation orders lifted as firefighters make progress in San Bernardino County



A Cal Fire crew member fights the Lake fire off Highway 138. (Gina Ferazzi / Los Angeles Times)

By Ruben Vives, Gina Ferazzi and Seema Mehta

Published June 28, 2025 | **Updated** June 29, 2025 8:56 PM PT

- The Lake fire broke out at the Silverwood Lake State Recreation Area.
- More than 100 people were at the reservoir when the fire started and were forced to flee.

The Lake fire in San Bernardino County had blackened more than 480 acres as of Sunday night, but officials said crews were gaining some control, stopping the fire's forward rate of spread.

Mandatory evacuations were reduced to warnings in the Summit Valley area south of Highway 138.

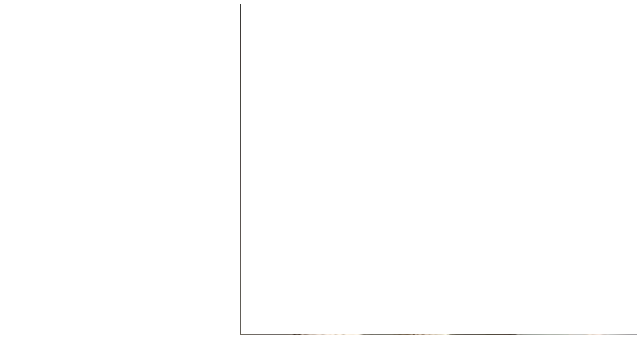
More than 100 people were temporarily stranded off a highway after fleeing 100-foot flames from the brush fire after it broke out late Saturday afternoon near a reservoir. The blaze prompted road closures and evacuations.

Amid hot, dry and windy conditions, the fire remained only 15% contained Sunday night, according to Chloe Castillo, a spokesperson for Cal Fire in San Bernardino County.

Visitors who left vehicles, camping gear or other personal belongings at the Silverwood Lake State Recreation Area as they fled are now allowed to return and retrieve them, Castillo said.

Cal Fire said visitors should go to a road closure checkpoint at Highway 138 and Highway 173 in Hesperia and be prepared to show identification. Castillo said California Highway Patrol officers will escort people to their belongings. The lake will be closed through Wednesday, and reservations that were booked have been canceled, she added.

ADVERTISEMENT



LIVE MAP

California fire map: Track this fire live

The blaze broke out shortly before 4 p.m. Saturday at Silverwood Lake State Recreation Area, near Highway 173 and Cedar Springs Dam Trail. By 8:48 p.m. on Saturday, the fire had increased to 478 acres from 60 acres just hours earlier, according to Cal Fire officials.

More than 100 people were at the reservoir when the fire broke out and were forced to flee the flames. Boaters and jet skiers helped evacuate people away from the beach to another area where they were then taken to a roadside turnout on Highway 173, just north of the lake. Many people were wearing beach attire and flip-flops.



CALIFORNIA

Southern California on alert for severe wildfires after dry winter

June 27, 2025

Shaun Kirkman and his girlfriend, Amber King, were among those who had to flee.

“I was west of the beach, fishing in vegetation,” Kirkman said. “The fire sounded like Velcro so I kept fishing, then it got louder. I saw 100-foot flames. Me and my girlfriend ran out of there.“

Gloria Orejel, spokesperson for the San Bernardino County Sheriff’s Department, said about 75 to 100 people were camping in the area and had to evacuate with whatever they had on. She said park rangers helped transport people to another spot on the highway. As of 8 p.m., the group had been taken back to their vehicles.

Although evacuation orders were downgraded to warnings, road closures remained in effect, Castillo said. Highway 138 was closed from Highway 173 to Old Mill Road.

Shaun Kirkman and his girlfriend, Amber King, were among the visitors evacuated Saturday from Cleghorn Beach because of the Lake fire. (Gina Ferazzi / Los Angeles Times)

Fire crews were battling the blaze over the weekend both on the ground and in the air.

After an expected increase in humidity overnight, providing firefighters some relief, crews had to contend Sunday with drier conditions as well as gusting winds, which caused the smoke to billow and spread.

“They had a wind shift this afternoon around 12 o’clock ... at the fire’s head,” Castillo said. “It sent up lot of smoke so people were under the impression there was a new fire in the area. There wasn’t. It was the fire within the existing perimeter.”

But she warned that the weather in the desert was likely to make fire conditions worse in coming weeks and months.

“The hotter it gets, the drier it gets,” Castillo said. “A lot of the vegetation is still green, so that doesn’t look very good for coming months as it gets drier and hotter and all of this green vegetation dries out. It’s a fuel bed, a really large, dry bed.”

She urged homeowners to focus on defensible spaces around their homes, cleaning their gutters of debris and moving fireworks at least 150 feet from structures.

“If they don’t make sure [debris is] cleared away from their home, it’s going to ultimately catch their home on fire,” Castillo said.

The cause of the Lake fire remained under investigation.

Also burning in San Bernardino County on Sunday was the Cable fire, which had scorched 15 acres and was at 0% containment by evening, according to Castillo.

Evacuation orders for roughly half a dozen homes were being reevaluated because of the progress firefighters have made.

On Friday, Southern California fire chiefs warned that a season of devastating wildfires was likely amid low rainfall and dry conditions.

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Ruben Vives

Ruben Vives is a general assignment reporter for the Los Angeles Times. A native of Guatemala, he got his start in journalism by writing for The Times' Homicide Report in 2007. He helped uncover the financial corruption in the city of Bell that led to criminal charges against eight city officials. The 2010 investigative series won the Pulitzer Prize for public service and other prestigious awards.

Gina Ferazzi

Gina Ferazzi has been a staff photographer with the Los Angeles Times since 1994. Her photos are a part of the staff Pulitzer Prizes for breaking news in 2016 for the San Bernardino terrorist attack and for the wildfires in 2004. Her video documentaries include stories on black tar heroin, health clinics, women priests and Marine suicide. Raised in Longmeadow, Mass., she was a two-sport scholarship athlete at the University of Maine, Orono.

Seema Mehta

Seema Mehta is a veteran political writer for the Los Angeles Times covering national and state politics, currently the 2026 gubernatorial contest and critical California congressional races that may determine control of the House in next year's midterm election. Since starting at Los Angeles Times in 1998, she has covered multiple presidential, state and local races. In 2019, she completed a Knight-Wallace fellowship at the University of Michigan.

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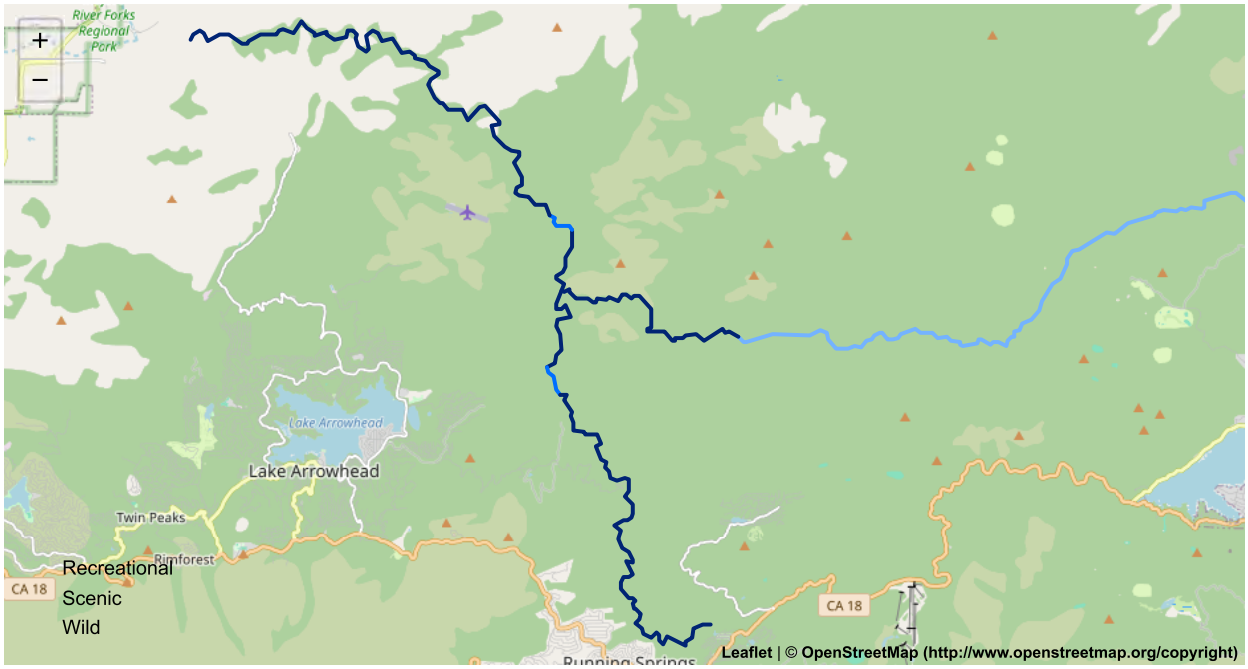
EXHIBIT R



Deep Creek

California

Located only 60 miles east of Los Angeles, Deep Creek flows through the San Bernardino Mountains to the East Mojave River, dropping approximately 3,000 feet through boulder-strewn reaches and deep pools. The river's outstandingly remarkable values include its scenery, recreation, geology, fish, wildlife, cultural and botanical values.



VIEW LARGER MAP (/APPS/MAP?RIVER=DEEP-CALIFORNIA)

Designated Reach

March 12, 2019. Deep Creek from 0.125 miles downstream of the Rainbow Dam site in Section 33, T 2 N, R 2 W, San Bernardino Meridian, to the upper limit of the Mojave Dam flood zone in Section 17, T 3 N, R 3 W, San Bernardino Meridian. Holcomb Creek from 100 yards downstream of the Road 3N12 crossing to the confluence with Deep Creek.

Outstandingly Remarkable Values ⓘ ()

Botany

Deep Creek is considered to have outstandingly remarkable botanical values, because it represents some of the greatest diversity of vegetation communities of any drainage on the San Bernardino National Forest. Fourteen vegetation communities, representing transition zones from the mountains at 6,...

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Culture

Deep Creek is also significant cultural pathway; the Vanyume Serrano Indians followed Deep Creek from their villages in the Mojave Desert to collect acorns and access other food sources in the mountains. Evidence of Native American use of the Deep Creek Canyon, especially for the last 2,000 years...

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Fish

Deep Creek is a renowned regional freshwater fisheries resource, one of the finest in the forest and, in fact, southern California. It has been designated a state of California Wild Trout Program Stream.

Geology

The most prominent geologic feature along Deep Creek is the thermal hot springs, a popular backpacker destination.

Recreation

Direct access up and down the creek is generally by non-motorized trails. Premier fishing opportunities are found throughout the Deep Creek drainage. Sightseeing, swimming, picnicking, hiking, backpacking, angling, and wildlife viewing opportunities abound. Much of the upper portion of Holcomb Cr...

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Scenery

Deep Creek has unique, diverse, and spectacular scenery for southern California. The river travels through a remarkable life-zone journey of the San Bernardino Mountains, from conifer at higher elevations, mixed oak and pinyon-juniper woodlands at middle elevations, and chaparral- and grassland-c...

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Wildlife

Deep Creek is home to nationally significant populations of endangered southwest willow flycatcher and arroyo toad. California spotted owls nest in nearby conifers and oaks, while golden eagles soar overhead. San Bernardino flying squirrels are also known to utilize Holcomb Creek. It is an area o...

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Documents

Deep Creek CRMP Environmental Assessment (https://rivers.gov/apps/sites/rivers/files/2025-08/deep-creek-plan-ea.pdf)

Deep Creek CRMP FONSI (https://rivers.gov/apps/sites/rivers/files/2025-08/deep-creek-plan-fonsi.pdf)

Deep Creek Comprehensive River Management Plan (https://rivers.gov/apps/sites/rivers/files/2025-08/deep-creek-plan.pdf)

Public Law 116-9 (https://rivers.gov/apps/sites/rivers/files/2022-10/Public%20Law%20116-9.pdf)

Classification/Mileage



Recreational — 11 miles; Scenic — 1 miles; Wild — 22.5 miles; Total — 34.5 miles.

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Bureau of Land Management (https://blm.gov/programs/national-conservation-lands/wild-and-scenic-rivers)

National Park Service (https://www.nps.gov/orgs/1912/index.htm)

NPS Partnership Rivers (https://www.nps.gov/orgs/1912/partnership-wild-and-scenic-rivers.htm)

U.S. Fish & Wildlife Service (https://www.fws.gov/story/wild-and-scenic-rivers)

U.S. Forest Service (https://www.fs.usda.gov/managing-land/wild-scenic-rivers)

River Management Society (http://river-management.org/)

REFERENCES

Bibliography (/rivers/rivers/bibliography)

Interagency Council (/rivers/rivers/council)

Stewardship (/rivers/rivers/stewardship)

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EXHIBITS

Science of the Total Environment 927 (2024) 171153

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Where the rubber meets the road: Emerging environmental impacts of tire wear particles and their chemical cocktails

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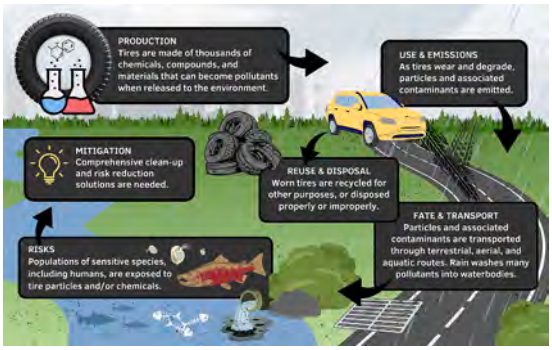
https://doi.org/10.1016/j.scitotenv.2024.171153

Available online 7 March 2024
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HIGHLIGHTS

- Billions of tires are produced each year and hundreds of millions of tires become waste.
- Tires are a complex source of pollutants including whole tires, particles, compounds, and chemicals.
- As they wear, tires emit pollutants *via* atmospheric, aquatic, and terrestrial pathways.
- Tire wear pollutants represent an environmental and human health risk.
- Comprehensive clean-up solutions are needed to reduce the risk of tire wear pollutants.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Dimitra A Lambropoulou

Keywords:
Persistent pollutants
Emerging contaminants
Microplastics
Tire wear particles
6PPD-quinone

ABSTRACT

About 3 billion new tires are produced each year and about 800 million tires become waste annually. Global dependence upon tires produced from natural rubber and petroleum-based compounds represents a persistent and complex environmental problem with only partial and often-times, ineffective solutions. Tire emissions may be in the form of whole tires, tire particles, and chemical compounds, each of which is transported through various atmospheric, terrestrial, and aquatic routes in the natural and built environments. Production and use of tires generates multiple heavy metals, plastics, PAH's, and other compounds that can be toxic alone or as chemical cocktails. Used tires require storage space, are energy intensive to recycle, and generally have few post-wear uses that are not also potential sources of pollutants (*e.g.*, crumb rubber, pavements, burning). Tire particles emitted during use are a major component of microplastics in urban runoff and a source of unique and highly potent toxic substances. Thus, tires represent a ubiquitous and complex pollutant that requires a comprehensive examination to develop effective management and remediation. We approach the issue of tire pollution holistically by examining the life cycle of tires across production, emissions, recycling, and disposal. In this paper, we synthesize recent research and data about the environmental and human health risks associated with the production, use, and disposal of tires and discuss gaps in our knowledge about fate and transport, as well as the toxicology of tire particles and chemical leachates. We examine potential management and remediation approaches for addressing exposure risks across the life cycle of tires. We consider tires as pollutants across three levels: tires in their whole state, as particulates, and as a mixture of chemical cocktails. Finally, we discuss information gaps in our understanding of tires as a pollutant and outline key questions to improve our knowledge and ability to manage and remediate tire pollution.

1. Introduction

Global dependence on tires produced from petroleum-based compounds, synthetic materials, heavy metals, and added chemicals, represents a persistent and complex environmental problem with only partial, and often-times ineffective, solutions. Used tires require storage space, are energy intensive to recycle, and end-of-life uses for tires (*e.g.*, crumb rubber, pavements, combusted tires) generally continue to release pollutants as particles or leached chemicals, or both. Tires are a significant source of highly mobile, persistent microplastics (Moran et al., 2021; Brander et al., 2021) that are a major component of pollutants in urban stormwater runoff (Wik and Dave, 2009). Furthermore, recent research has demonstrated that tires are a source of previously unrecognized chemicals, some are highly toxic to aquatic organisms, and many of which are currently unknown or poorly described (Tian et al., 2021a; Siddiqui et al., 2022; Cunningham et al., 2022). Production and use of tires generate a suite of heavy metals and other contaminants that can be toxic alone or as chemical cocktails, which represent combinations of elements novel to the Anthropocene (*sensu* Kaushal et al., 2020). Given that roads are ubiquitous in developed nations (Ibisch et al., 2016), cover extensive areas in urban ecosystems (Elmore and Kaushal, 2008), and that road construction and traffic are increasing worldwide (Meijer et al., 2018), the impacts of tires are vast and are expected to increase globally. Roads can represent hot spots of tire pollutants and effective pathways of pollutants to aquatic, terrestrial, atmospheric, and groundwater resources (Cooper et al., 2014; Sommer et al., 2018; Uliasz-Misiak et al., 2022).

Here we synthesize recent research and data about the environmental and human health risks associated with tire production, use, and disposal. We discuss gaps in our knowledge about fate and transport, as well as the toxicology of tire particles and leachates. We examine potential management and remediation approaches for addressing exposure risks across the life cycle of tires and associated contaminants. We consider tires as pollutants across three levels: whole tires, tire wear particles, and as a mixture of chemical constituents. Finally, we outline key questions to expand our knowledge and ability to manage and remediate pollution from tires.

2. The composition of tires

Tires are constructed of multiple, highly engineered components, including tread, belts, inner liners, and sidewall, each designed to meet performance characteristics that together create durable, strong, reliable, and safe tires (USTMA, 2018) which are the same properties that ensure the persistence of tire particles and tire materials in the environment. Tires contain myriad materials and chemicals, many of which

are proprietary (Tian et al., 2021b). Tires typically use metal mesh or textiles for structure and rubber for all other components. Tire rubber consists of complex proprietary formulations that vary among brands, tire types, and tire components (Hüffer et al., 2019; Kreider et al., 2010; Selbes et al., 2015; Wagner et al., 2018; Chibwe et al., 2022). In general, tire rubber consists of synthetic and/or natural rubber (40–60 %), fillers and reinforcing agents like carbon black and silica (20–25 %), process or extender oils (12–15 %), vulcanization agents like Zn and thiazoles (1–2 %), and other additives such as preservatives and processing aids (5–10 %) (Wagner et al., 2018). Tires contain approximately 50:50 ratio of natural to synthetic rubber; passenger car tires contain more synthetic rubber, while truck tires more natural rubber, and heavy-duty vehicles tires contain little or no synthetic rubber (Grammelis et al., 2021). Tires contain thousands of chemicals, including those deliberately added, such as N-(1,3-dimethylbutyl)-*N*′-phenyl-*p*-phenylenediamine (6PPD, DTXSID9025114; CAS 793–24-8), contaminants in manufacturing feedstocks, such as polycyclic aromatic hydrocarbons (PAHs), and weathering or transformation products as tires age (Tian et al., 2021b; European Tyre and Rubber Manufacturer's Association, 2021; Kovochich et al., 2021). As a result, there is no standard chemical composition of tire wear particles. This creates challenges for monitoring and characterizing tire particles and tire-derived chemicals in environmental samples, for estimating tire microplastics fate, and for conducting ecotoxicology impact assessments. Determining the complete and quantitative chemical composition of tire rubber remains a critical research need.

3. Environmental and health impacts along the life cycle of tires

The life cycle of a tire can be characterized by stages including a) raw materials and production of the whole tire, b) transportation of the tire to a destination, c) use on a vehicle, and d) end of life management through downcycling into non-tire products or disposal (Dong et al., 2021; Trudsø et al., 2022). Here, we examine these stages as a continuum along the life cycle of a tire (Fig. 1) where tires and their components are produced and used. In the process, energy and resources are consumed while particles and elements are emitted and transported through the environment across various pathways (Trudsø et al., 2022). At points along those pathways, there are potential mitigation approaches to reduce environmental impacts including reuse or disposal, and, in some cases, recycling into new tires and tire related products. Manufacturing tires requires copious water and electricity and produces nitrogen oxides (NOx), benzene, and PAHs (Dong et al., 2021). Each tire life cycle stage has multiple impacts on climate and acidification from energy use and production of CO_2, ozone depletion, photochemical oxidation, and eutrophication from NOx production and use of PO_4^{3-} in manufacturing (Dong et al., 2021; Sun et al., 2016).

3.1. Environmental and health impacts from the production of tires

Global demand for automobile tires is large and growing. In 2019 alone, 3 billion tires were produced globally (Ruwona et al., 2019; Dong et al., 2021), an amount that, if stacked on top of one another, would reach *ca.* 675,000 km, nearly twice the distance to the moon. Recent tire production in the EU is about 335 million annually (Torretta et al., 2015), while tire production was about 300 million in the US (USTM, 2022) and about 800 million in China (Dong et al., 2021). Tire production begins with acquisition of natural rubber for the tread, textiles and steel for the cord and belts, and chemicals such as carbon black, silicon dioxide, and clay (Dong et al., 2021). A significant environmental impact of tire production is from the cultivation of natural rubber which involves clearing native, diverse forests for growing monocultures of rubber trees. This type of agriculture is an especially important cause of deforestation in Asia and Africa (Pendrill et al., 2022). High resolution maps of southeast Asia show that rubber tree cultivation accounted for at least 4 million ha of deforestation since 1993, 2 million ha of which was lost since 2000, including 1 million ha of rubber plantations that have been established in high biodiversity areas (Wang et al., 2023).

Combining tire components during production emits carcinogens and radioactive compounds (*e.g.* radon-222 and carbon-14), contributes to stratospheric ozone depletion, and requires massive consumption of water and electricity, and land in the form of extraction of minerals and fossil fuels, and water (Piotrowska et al., 2019). Combined, the various chemical components and the particles create chemical cocktails (*sensu* Kaushal et al., 2018, Kaushal et al., 2020, Kaushal et al., 2022) of heavy metals (*e.g.*, Zn), natural and synthetic rubber and plastics, hydrocarbons (*e.g.*, PAHs), and traces of other chemicals (*e.g.*, 6PPD) that can have negative effects on human health and the environment.

Manufacturing a single tire produces an estimated 243 g particulate matter to the air, 0.19 g NH_4^+ and 0.69 g suspended solids to the water (Sun et al., 2016). On average, 6 MJ of electrical energy, 45 L of water, and 0.02 kg of dissolvent are needed to manufacture one tire while

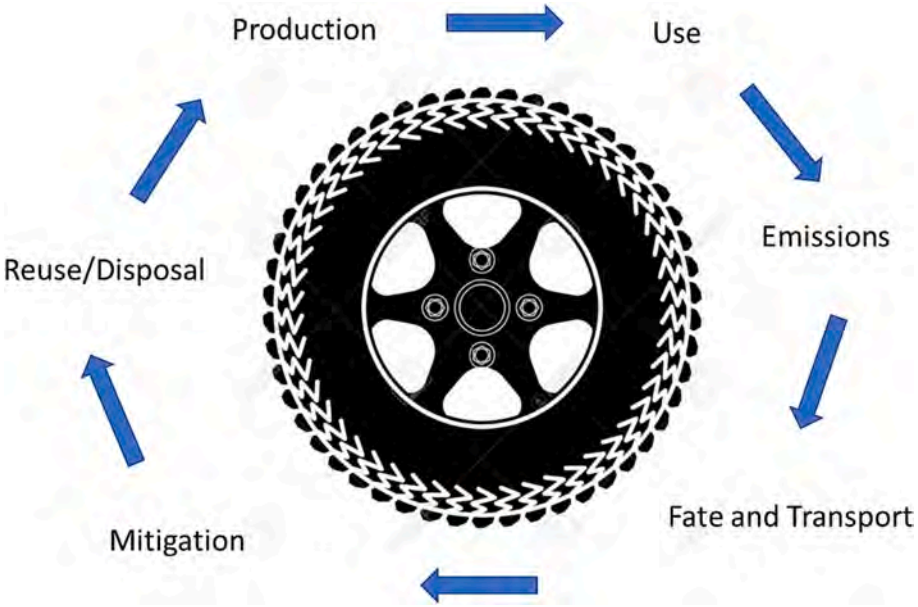


Fig. 1. Life cycle of tires

yielding 0.5 kg of waste (Piotrowska et al., 2019). Extrapolating from an estimated 3 billion tires produced annually, tire manufacture may produce as much as 729 million kg particulate matter, 570,000 kg NH_4^+, and over 2 million kg suspended solids annually, while as much as 104 billion MJ energy may be consumed along with over 70 billion liters of water though, water and energy consumption could be reduced through existing technologies, including high-pressure steam to shorten vulcanization time and recovery of waste steam (Sun et al., 2016). Using the Intergovernmental Panel on Climate Change (IPCC) methodology, each tire requires over 333,000 kg CO2 Eq during production while 2116 kg of CO2 Eq are recovered by recycling a tire (Piotrowska et al., 2019). Some tire manufacturers are striving to reduce their factory carbon footprint and/or exploring new tire designs with longer lifespan or which could be retread like industrial tires, thereby saving significantly on the amounts of materials required for production (https://www.motortrend.com/features/future-tire-technology/?id=applenews).

3.2. Environmental and health impacts from the use of tires

Significant ecosystem impacts are from tire emissions of carbon dioxide and sulfur oxides or nitrogen oxides, which are greatest during the use stage of the life cycle and a function of fuel use of the vehicle (Piotrowska et al., 2019). Tire wear during use results in tire wear particle emissions into the environment. Vehicle tire wear produces an estimated 1.2–6.7 kg of particles, or about 10–16 % of the weight of the tire, over the lifetime of the tire (Sun et al., 2016; USTMA, 2021). Tire wear and evolution of tire wear products may be exacerbated by the heavier weight and increased acceleration and torque produced by EVs (Zhao et al., 2019). Tire microplastics from synthetic rubber tires are a major contributor of microplastic pollution to the environment (Kole et al., 2017; Sieber et al., 2020; Siegfried et al., 2017). Measurable and sometimes significant amounts of tire particles have been collected in air, aquatic environments, and organisms (Baensch-Baltruschat et al., 2020; Leads and Weinstein, 2019; Siegfried et al., 2017; Tian et al., 2017; Werbowski et al., 2021; Wik and Dave, 2009). For example, untreated stormwater runoff samples collected from San Francisco Bay watersheds contained up to 15.9 tire particles/L, almost 50 % of all microparticles in these samples (Sutton et al., 2019; Werbowski et al., 2021). Globally, tires may be one of the top sources of microplastics to the environment (Boucher and Friot, 2017; Kole et al., 2017; Sieber et al., 2020), with a pollutant mass exceeding the total environmental emissions of other pollutant classes like pharmaceuticals and pesticides (Wagner et al., 2018).

Tire emissions generally relate to vehicle weight, tire size, and distance traveled, with larger heavier vehicles (trucks) emitting more than small light ones. Higher traffic speeds result in increased generation of tire particles (Wang, 2017; Pohrt, 2019; Kwak et al., 2013; Foitzik et al., 2018). Particle generation from any specific vehicle or in specific roadway segments can vary depending on driving speed or style (*e.g.*, urban stop/go *vs.* highway), road surface condition, type of contact (rolling *vs.* slipping) and temperature (Alexandrova et al., 2007; Knight et al., 2020; Kole et al., 2017). Based on relatively limited data, country-specific tire particle generation across size classes 10 nm to 1000 μm has been estimated to be as low as 0.23 kg/yr/capita in India to as high as 5.5 kg/yr/capita in the US due to its longer per-capita annual vehicle travel distances (Mennekes and Nowack, 2022; Baensch-Baltruschat et al., 2020; Councell et al., 2004; Wagner et al., 2018; Kole et al., 2017). Thus, approximately 1.7 million tons of tire wear particles are produced annually in the US based on 2021 population size. Where automobile and truck traffic are higher, production of particles may be significantly greater. Based on empirical and extrapolated data synthesized from Europe, Japan, China, Australia, Brazil, India, and USA annual global tire wear emissions, across size classes 10 nm −1000 μm, were estimated to be nearly 6 million tons (Baensch-Baltruschat et al., 2020).

Annually, about 800 million tires become waste material worldwide (Tsang, 2012). In the US, scrap tire generation in 2019 was about 260 million tires (USTMA, 2020). The global annual production of waste tires is estimated to reach 1.2 billion tons by the 2030s (Liu et al., 2020). Others estimate that, globally, 1.5 billion tires are discarded annually currently with an expected to increase to 5 billion tires by 2030 (Grammelis et al., 2021). Generally, waste tires remain in the region of their production. For example, only 3.1 % and 5.7 % of waste tires are exported from the US (USTMA, 2020) and the EU (Sienkiewicz et al., 2012), respectively. Waste tires are often recycled into various products, including outdoor products with high potential to disperse tire particles or tire-derived chemicals into the environment (Dabic-Miletic et al., 2021). For example, the majority of waste tire use in California, USA includes burning for fuel, crumb rubber production, and integration in civil engineering applications (Table 1). Worldwide, the fate of tires is similar with most going into energy production or recycled (Table 2). Tires are often downcycled into microplastic-containing products like tire crumb and tire buffings. Used tire processors separate tire rubber from tire structural components (*e.g.*, steel belts) to produce various sized tire rubber pieces (Valente and Sibai, 2019) classified as buffings, ground, crumb, or aggregate, some of which contain or are entirely composed of microplastics. Products created from used tires include retreaded tires, tire-derived fuel, artificial turf infill, rubberized asphalt, shock absorption applications, landscaping mulch, playground and recreational areas, rubber-containing pavement seal coats, rubberized building and floor materials, railroad ties, and doormats (Dabic-Miletic et al., 2021). There are 12,000–13,000 synthetic turf fields in the US with 1200–1500 new installations annually (USEPA, 2019). Wear of turf fields, tracks, and other recreational areas where recycled tire crumb rubber is used can release tire microplastics into the environment (Wang et al., 2021).

4. Fate and transport

4.1. Cycling of tire particles in the environment

Studies of the fate and transport of tire microplastics and associated contaminants has been limited. A handful of studies have helped to characterize tire microplastics and affiliated leachate in the environment associated with urban runoff (Werbowski et al., 2021; Johannessen et al., 2021; Klöckner et al., 2020; Klöckner et al., 2021; Peter et al., 2018; Peter et al., 2020; Tian et al., 2021b). Data from Europe show that most of the mass of tire microplastics is deposited near roadsides, but that water and atmospheric pathways can move particles significantly farther (Baensch-Baltruschat et al., 2021; Evangeliou et al., 2020; Sieber et al., 2020; Sommer et al., 2018; Verschoor et al., 2016). Moran et al. (2021) conceptualized the sources and pathways of rubber particles to urban stormwater (Fig. 2).

Table 1
California waste tire use summary 2018*. Source: CalRecycle, 2019. *Includes material imported from out of state. Reprinted from Moran et al. (2021).

Use	Examples	Quantity (Metric Tons)
Combustion (export)	Burned at non-California facilities	130,000
Combustion	"Tire-derived fuel" burned at four California facilities	82,000
Landfill	Disposal, alternative daily cover	98,000
Reuse on vehicles	Used tires and retreads	82,000
Crumb/ground rubber	Rubberized asphalt pavement (60–67 %) Artificial turf infill (11–14 %) Mulch and ground covers (3–5 %) Molded & extruded products (19–20 %)	81,000
Civil engineering applications	Landfill structures, construction fill, vibration damping, and stormwater capture and treatment systems	4600
Other recycling	Unspecified	3100

Table 2
Fate of End of Life (Scrap) Tires in the United States and Europe in 2019. 76 % of scrap tires in the US are utilized in some fashion (not disposed of) and 95 % in the EU27 + NO+CH + RS + TR + UK. Sources: [1]USTMA 2019. U.S. Scrap Tire Management Summary. U.S. Tire Manufacturer Association. Washington, D.C. 20005. [2] European Tyre and Rubber Manufacturing Association (ETRMA). Press Release: In Europe 95 % of all End of Life Tyres were collected and treated in 2019. https://www.etrma.org/news/in-europe-94-of-all-end-of-life-tyres-were-collected-and-treated-in-2019/

Disposition (thousands of metric tons)	United States[1]	Europe[2] EU27 + NO+CH + RS + TR + UK	Notes
Civil Engineering and Similar Uses	333.20 (8.2 %)	112.95 (3.2 %)	USA: includes Steel, Reclamation Projects, Agricultural, Baled Tires to Market and Punched Stamped. EU: includes public works and backfilling
Recycling	987.92 (24.4 %)	1841.20 (51.8 %)	USTMA does not use Recycling category. Ground Rubber included in total here. For EU, includes granulation and additions to cement manufacturing.
Energy Production	1493.98 (36.9 %)	1428.82 (40.2 %)	EU: Cement kilns 75 % and 25 % Urban Heating and power plants
Exported	125.19 (3.1 %)		
Other	119.64 (3.0 %)		
Land disposed	616.89 (15.2 %)		
Unknown/stocks	372.84 (9.2 %)	165.16 (4.6 %)	
Total	4049.67	3555.61	Totals are from Source Tables

Abrasion by pavement during vehicle use creates small tire wear particles. After their initial release to the air, tire wear particles may travel short (1–10 m) to long (km) distances prior to deposition, often promoted by localized effects of high-speed traffic. Roadway-derived particles (including tires) may compose >80 % of all microplastic air deposition, (Brahney et al., 2021). Notably, inhalation of atmospheric particulate matter is a critically important mechanism of human exposure to tire rubber microplastics and tire-derived chemicals. Recent studies documented substantial contributions of tire rubbers and associated chemicals to atmospheric particulate matter phases and associated human exposure risks *via* inhalation (Cao et al., 2022; Johannessen et al., 2022a; Zhang et al., 2021; Zhang et al., 2022).

Particles, especially those deposited on pavements, may be resuspended, redistributed, or modified by vehicle traffic and environmental conditions. Vehicle tire abrasion grinds tire wear particles into pavement debris and soil, reducing particle size, encrusting particles with other road debris, and modifying particle shape (Kreider et al., 2010; Park et al., 2018) and chemical composition. Particles may also release tire related chemicals, including additive chemicals and their industrial and environmental transformation products, into air and water phases, or within biota that ingest particles (Peter et al., 2020; Tian et al., 2021b; Wagner et al., 2018).

For understanding particle transport, tire particles can be divided into three groups based on diameter: coarse (>2.5 μm), fine (<2.5 μm and > 0.1 μm), and ultrafine (<0.1 μm) (Wagner et al., 2018). Particle size governs transport distance, with fine and ultrafine particles most subject to long-distance aerial transport, depositing far from their sources (*e.g.*, the Arctic, mountain wilderness) (Brahney et al., 2021; Evangeliou et al., 2020; Thornton Hampton et al., 2022; Wagner et al., 2018). Larger particles >10 μm typically deposit close to the point of emission (Cadle and Williams, 1978; Fauser et al., 2002; Kreider et al., 2010; Wagner et al., 2018). Available particle size distribution data indicate that most tire wear particle volume (and therefore mass) is in the coarse fraction (particles >50 μm), which deposit quickly from the source, landing on or close to pavements. While no studies show the full range of particle sizes, most tire wear particles are fine and ultrafine (Alves et al., 2020; Cadle and Williams, 1978; Fauser et al., 2002; Kreider et al., 2010). The smaller coarse and larger fine particles (between 1 μm and 10 μm), can be entrained into the atmosphere through mechanical processes, such as from the intense turbulence generated by high speed vehicle traffic (Brahney et al., 2021) and have atmospheric residence times of 8 days (<10 μm; "PM10") to 28 days (<2.5 μm; "PM2.5") (Evangeliou et al., 2020).

Fine (<10 μm) and ultrafine (<2.5 μm) tire particles comprise only a small fraction of the total mass of tire wear particles. However, they compose a large fraction of the total number of emitted particles, and their surface area might make them important vectors for tire chemical transport beyond the immediate roadside area. This is particularly true for smaller organisms and/or sensitive life stages. Due to limited data addressing tire particles across the full particle size distribution and the lack of surface area measurements for each size fraction, the role and importance of air deposition in tire particle and chemical transport within and between watersheds remains largely unknown (Moran et al., 2021).

Ultimately, tire wear particles are incorporated into soils and surfaces, washed off outdoor surfaces with runoff (Field et al., 2000; American Society of Civil Engineers, 1998), or washed out of the air by rainfall or snow. Particle wash-off from impervious surfaces (*e.g.*, streets, sidewalks, roofs) is far more efficient than from permeable surfaces (*e.g.*, lawns, gardens, agricultural fields) (Field et al., 2000; Pitt et al., 2008). Estimates of the portion of tire wear debris that is washed off of urban outdoor surfaces into urban runoff are highly variable and likely a function of many system and condition specific variables; *e.g.*, 15–50 %, Wagner et al., 2018; 35 %, Blok, 2005; 80 %, Kennedy et al., 2002).

Modern urban and roadway drainage systems direct stormwater runoff directly (or indirectly *via* storm drains), untreated, into local water bodies. While tire particles may be temporarily retained in low points in stormwater collection systems under low flow conditions due to their density, turbulent flows during larger storm events will likely mobilize these particles and carry them into surface waters (Hoellein et al., 2019).

Tire particles may be washed by stormwater runoff into wastewater treatment systems. There are no current data on fate or volumes of tire particles specifically in wastewater treatment plants; however, data suggest that a high percentage of other microplastic particles transfer from the water into sewage sludge (Baensch-Baltruschat et al., 2021). Even with high removal rates, significant annual loadings of tire and road wear particles have been estimated in treated wastewater effluent in the UK (Parker-Jurd et al., 2021). Sewage sludge is typically incinerated, disposed of in landfills or spread on agricultural fields (Duis and Coors, 2016) where tire particles may remain in the soil or be mobilized and distributed by wind or by surface runoff to the aquatic environment (Duis and Coors, 2016; Baensch-Baltruschat et al., 2021).

Air transport and runoff may carry tire particles and associated chemicals into surface water drinking water sources (Johannessen and Metcalfe, 2022; Zhang et al., 2023). Drinking water treatment plants draw water from surface water, groundwater, and/or seawater, all of which may contain microplastics including tire particles (Collivignarelli et al., 2018). Drinking water treatment typically starts with screening and grit removal, followed by addition of alum to the raw water for coagulation, flocculation, and settling in tanks. Drinking water treatment plants are effective at removing small particles including 70–83 % of microplastics (<100 μm) with treatment by coagulation and membrane filtration showing high effectiveness (Nikiema and Asiedu, 2022; Pivokonsky et al., 2018). However, the level and types of drinking water treatment varies widely and effectiveness of drinking water treatment technologies to remove tire particles specifically is unknown.

Particle density affects particle transport. While tire rubber has a

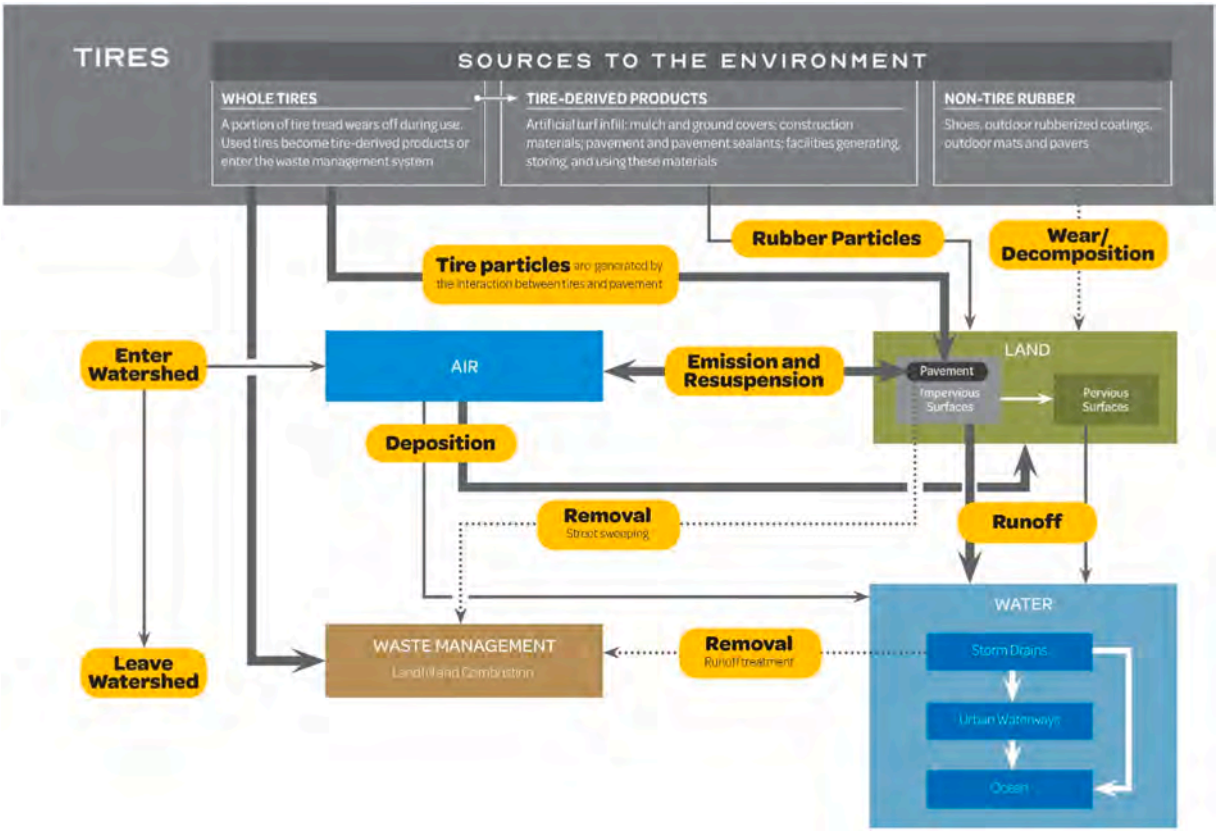


Fig. 2. Conceptual model of the sources and pathways of rubber particles to urban stormwater. Major pathways are indicated by larger arrows, and dotted arrows represent minor pathways. The major source of rubber particles is tire wear, with tire-derived and non-tire rubber products representing smaller sources. Reprinted from Moran et al. (2021).

density of about 1.1–1.2 g/cm^3 (Degaffe and Turner, 2011; Tang et al., 2006), slightly denser than water, tire wear particles collected near roads and generated by road simulators typically contain encrustations that increase density. Encrustations are diverse and consist of soil, pavement material, vehicle debris, road marking materials, *etc.* (Penkała et al., 2018; Thorpe and Harrison, 2008). Depending on the nature and quantity of encrustations, tire wear particle densities can range across 1.25–1.8 g/cm^3 (Klöckner et al., 2021; Wagner et al., 2018). Higher density, encrusted particles will settle out more quickly, slowing transport and increasing potential for these particles to become sequestered on land or in aquatic sediment. Non-encrusted particles have sufficiently low density to transport readily in moving water (Tang et al., 2006). While some microplastics can be re-entrained into atmospheric pathways such as re-emission of previously deposited particles from the oceans to land (Allen et al., 2020), because tire wear particles are denser than seawater, the ocean to land pathway is unlikely for tire particles, except potentially the ultrafine particles.

4.2. *Weathering of tires and chemical transformations*

Tire particles are relatively persistent in the environment but are subject to phototransformation, oxidation/reduction, hydrolysis, biotransformation, and mechanical degradation processes (Wagner et al., 2018; Fig. 3). Tire rubber is susceptible to ozonolysis, or the oxidative cleavage of carbon-carbon C=C double bonds, leading to cracks and crazing in the rubber (Newton, 1945). Tire particles are also subject to thermal degradation, sometimes reaching temperatures of up to 60 °C on hot asphalt (Higashiyama et al., 2016). Given tire rubber durability, physical modification other than by mechanical degradation should be relatively limited over short-term time scales (Wagner et al., 2018), although tire particles could potentially agglomerate with other particles in the environment (Moran et al., 2021). Currently, few studies have investigated the physical effects of weathering on tire wear particles, with most studies investigating bulk tire material or microplastics composed of other polymers.

Photoaging may have significant effects on the specific surface area of tire particles, thus facilitating chemical release. One study found a 55-fold increase in the surface area of tire particles obtained from a recycling plant, compared to a 13-fold increase in the surface area of polypropylene microplastics (Fan et al., 2021). The effects of environmental weathering processes on tire wear particle physical properties like specific surface area and particle deterioration remain an important knowledge gap. Additionally, there is little known about the role of microbiological processes in the degradation of tire particles and associated pollutants and the fate and transfer of pollutants carried into trophic chains.

Tire additives begin to transform during the production process and continue throughout the tire life cycle. Tire chemicals can transform and degrade at the surface and interior of the tire, the surface and interior of tire wear particles, and in the gaseous or dissolved phases following release from the tire polymer matrix. Oxidation reactions are common, including thermooxidation, photooxidation, ozonolysis, shear stress, biodegradation, and hydrolysis (Wagner et al., 2022). Chemical polarity can increase because of radical formation, hydrogen abstraction, oxygen addition, and formation of polar functional groups, including ketones and carbonyls (P. Fan and Lu, 2011; Rånby, 1989).

During rain, roadway runoff transports tire wear particles into receiving waters where ozonation and thermal degradation cease and photooxidation slows due to low temperature, low oxygen availability, and attenuation of ultraviolet light with depth and turbidity. When exposed to water, the dominant transformation processes for tire-related compounds include leaching, hydrolysis, and biodegradation.



Fig. 3. Degraded tire on an Oregon, USA beach (photo courtesy of James Kaldy)

Depending on location, tire leachate compounds may be directly or indirectly (through storm drains) released into nearby waterways or transported to a treatment facility through combined sewer systems. Transformation products of tire additives have been detected in both the influent and effluent of wastewater treatment plants and municipal drinking water treatment plants (Johannessen and Metcalfe, 2022).

Transformation of tire compounds due to environmental weathering processes can drastically change the chemical signature and ecotoxicity of leachates. Transformation and degradation can lead to reduced or enhanced toxicity of certain compounds. Recent research efforts have put a spotlight on one product of 6PPD oxidation, 6PPD-quinone (N-(1,3-Dimethylbutyl)-*N*′-phenyl-*p*-phenylenediamine-quinone (DTXSID301034849; CAS 2754428–18-5) due to its lethal effects in coho salmon and other salmonids. This chemical is an ozonation product of the anti-ozonant 6PPD, which is intentionally added to tires to prevent ozonolysis and oxidation (Tian et al., 2021a; Brinkmann et al., 2022; Lo et al., 2023). Tires are typically composed of a mixture of several types of anti-aging additives including amine, phenolic, heterocyclic, and phosphite antioxidants (Castan et al., 2023).

4.3. Fate and transport of tire-related chemicals

Known chemical emissions from tires include benzothiazoles, PAHs, vulcanizers, antidegradants, aromatic and paraffinic oils, formaldehyde, and styrene-butadiene rubber polymers, along with heavy metals like Zn (Adachi and Tainosho, 2004; Cadle and Williams, 1978; Fauser et al., 1999; Klöckner et al., 2019; Kumata et al., 2011). A comprehensive list is shown in Supplementary Table 1. Despite their medium to long-term durability, both manufacture and aging of tire particles induce transformation of additive chemicals that generate complex mixtures of tire-derived environmental contaminants (Huang et al., 2021; Johannessen et al., 2022b; Peter et al., 2018, 2020; Tian et al., 2021a), which are subsequently transported by urban runoff into near-urban ecosystems (Johannessen et al., 2022b; Peter et al., 2018, 2020; Tian et al., 2021b; Halama et al., 2024). Particles transported to roadside soils, sediments, and surface water likely continue to release chemicals into aquatic environments and organisms that take up the particles. Supplementary Table 1 lists known or suspected chemical contaminants associated with tire rubbers.

Numerous chemicals are present at relatively high concentrations in aqueous leachates from tire materials, such as chemicals used or formed as byproducts during production, including metals (especially Zn, but also Al, Cu, Ni, Co, Mn); PAHs; vulcanization accelerators; crosslinking agents, corrosion inhibitors and their transformation products [*e.g.*, benzothiazole (DTXSID7024586), diphenylguanidine (DTXSID3025178), hexamethoxymethyl melamine (DTXSID9027520)], anti-ozonates/oxidants (*e.g.*, 6PPD); plasticizers (*e.g.*, bisphenol A, phthalide, phthalates), organic compounds (*e.g.*, dicyclohexylurea, 1-indanone)], and chemicals present at very low or non-detectable concentrations in tire material itself but that are apparently readily leachable and many unknowns or suspect chemicals (Capolupo et al., 2020; Chibwe et al., 2022; Halsband et al., 2020; Peter et al., 2020).

Urban environments harbor atmospheric cocktails of tire contaminants and other traffic-related pollutants, including nitrogen oxides and ozone from photochemical smog. In the atmosphere, volatile compounds and particles generated by volatilization and recondensation of semivolatile organic compounds are subject to reactions with atmospheric radicals (OH, O_3, and NOx) in the presence of ultraviolet light. These reactions create the potential for chemicals from tire particles to generate carcinogenic nitrosamines formed by the reaction of parent molecules containing amine functional groups with nitrogen oxides (Johannessen et al., 2022a; Johannessen and Metcalfe, 2022). Other tire wear chemicals with implications for atmospheric transport include 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ), 4,4′ -dithiodimorpholine (DTDM), and tetramethyl thiram disulfide (TMTD), though their fate and transport are poorly understood (Johannessen et al., 2022a). The toxic tire wear compounds 6PPD-quinone and 4-aminodiphenylamine (4-ADPA) were detected in atmospheric samples collected at 5, 15, and 30 m from roads at levels estimated at 2.90 and 1.14 ng L^{-1} for 6PPD-quinone and 4-ADPA, respectively, suggesting a potential human and wildlife health hazard (Olubusoye et al., 2023). While exposure is likely higher closer to roads, due to the long residence time of atmospheric tire particles (up to 28 days), tire chemicals can also travel long distances and contaminate distant environments (Evangeliou et al., 2020).

The magnitude of leaching from tire particles depends on numerous chemical and system-specific factors, including chemical properties (*e.g.*, diffusivity, hydrophobicity, polarity, structure), tire material properties (*e.g.*, chemical composition, aging/weathering or other surface alteration, particle size or surface area), and location and binding interactions of the chemical to the tire matrix. Additionally, leachate generation system variables also influence boundary conditions of mass transfer and thermodynamic equilibrium, such as liquid-to-solid ratio, time, mixing regime, temperature, and water phase composition, including pH, salinity, and presence of co-solvents, organic matter, or infinite sink conditions. Observed leachate concentrations of individual chemicals can vary widely across studies due to these many system variables. For example, changing temperature and turbulence/flow regimes were found to significantly affect tire leachate toxicity (Kolomijeca et al., 2020). More hydrophobic compounds, such as high molecular weight PAHs and 6PPD, were observed to preferentially leach and then sorb to sediments when leaching occurs in the presence of natural sediment (Unice et al., 2015). Leaching of Zn and other metals increases in acidic solutions and freshwaters (*versus* saltwater) due to the influence of pH and ionic strength on metal solubility (Capolupo et al., 2020; Selbes et al., 2015).

Chemical reaction and transformation in leachates also occur, and while transformation products are often observed in laboratory studies, it can be especially difficult to interpret temporal dynamics in complex mixtures and to represent environmental field conditions in the laboratory. Studies often report leachate concentrations and may also calculate an aqueous loading (μg chemical in solution/g tire) that accounts for the mass of tire in solution, or the liquid-to-solid ratio, used to generate the leachate (μg/L * g tire/L). However, this does not account for the mass of the chemical compound in the system, which is dependent upon both the tire mass and the rubber phase concentration of the chemical. For studies reporting the solid phase concentration (μg chemical in tire/g tire), the fraction (or %) of chemical leached into solution can be calculated (μg chemical in solution/g tire divided by μg chemical in tire/g tire * 100 %). To illustrate, data from four studies on benzothiazole leaching, a compound frequently reported in tire leachates, is compiled in Table 3. Tire material loading in the leaching studies (Table 3) is at least 10× but usually several orders of magnitude higher than water concentrations of tire particles observed in the environment (*i.e.*, <0.1 g/L; Wagner et al., 2018). Halsband et al. (2020) found similar leachate concentration of benzothiazole after 48 h and 14 d at a concentration of 100 g tire/L (liquid:solid ratio 10 L/kg), indicating rapid release and approach to batch equilibrium. Aging and weathering of material in the environment can reduce the pool of leachable chemicals like benzothiazole (Unice et al., 2015), making certain organic compounds like (N-cyclohexylbenzothiazole-2-sulfenamide (CBS), N-(1,3-dimethylbutyl)-*N*′-phenyl-1,4-phenylenediamine (6-PPD), and 1,3-diphenylguanidine (DPG) less practical as tire pollutant markers in environmental samples.

4.4. Monitoring fate and transport of tire wear particles in the environment

Stormwater is considered a significant pathway for tire wear particles to enter aquatic systems (Wei et al., 2023). However, few studies have rigorously monitored tire wear particles in urban runoff. Most tire wear particles are smaller than <220 μm (Cadle and Williams, 1978; Fauser et al., 2002; Kreider et al., 2010). For example, in contrast to stormwater microplastic monitoring studies that employed a 300 μm filter (Sutton et al., 2019; Werbowski et al., 2021), monitoring in the San Francisco Bay area (California, USA) revealed that black, rubbery tire particles in untreated urban stormwater could pass through a smaller 125 μm pore filter (Moran et al., 2021). Even where environmental sampling methods do not exclude particles <220 μm (*e.g.*, sediment samples), common density-based methods for separating microplastics from environmental samples often exclude denser tire wear particles (Klöckner et al., 2019).

Some tire chemical ingredients such as benzothiazoles, styrene-butadiene rubber, and Zn have been used as markers for the environmental presence of tires and occasionally as the basis for quantification of tire particles in environmental samples (Adachi and Tainosho, 2004; Cadle and Williams, 1978; Fauser et al., 1999; Klöckner et al., 2019; Kumata et al., 2011). While the markers have provided valuable insights on tire wear particle transport, due to other environmental sources, the high variability among tire formulations, and the potential leaching of marker chemicals from the tire matrix, recent analyses suggest such methods are unreliable for quantification of tire wear particles in environmental samples (Rauert et al., 2021; Wagner et al., 2018).

Both on-road and laboratory road- simulator-generated tire particles have similar, bimodal particle size distributions with peaks in both the ultrafine and coarse particle size groups (Cadle and Williams, 1978; Dahl et al., 2006; Fauser et al., 2002; Gustafsson et al., 2008; Kreider et al., 2010), making it difficult to measure particles across the size distribution by a single method (Wagner et al., 2018). For example, air quality monitoring typically focuses on particle sizes <10 μm (PM10) or < 2.5 μm (PM2.5) (*e.g.*, Cadle and Williams, 1978; Dahl et al., 2006; Fauser et al., 2002), while aquatic and terrestrial monitoring typically focuses on particles >10 μm (*e.g.*, Kreider et al., 2010).

Because tire wear particles are denser than fresh or estuarine water, there is high likelihood for them to become entrenched in aquatic sediments, making accurate sampling of tire particles in water difficult, though non-encrusted tire particles may be readily mobilized in flowing water (Tang et al., 2006). Thus, sediment sampling may be necessary to fully assess tire particle pollutant loads in streams or rivers.

Table 3
Leaching of benzothiazole (Log KOW = 2.17, EpiSuite) from tire particles (TWP or crumb rubber) or tire road wear particles (TRWP). [1] Calculated from data provided in the study. [2] A new tire was used, but since particles were generated under more realistic conditions, TRWPs are classified here as "worn". [3] Freshwater and marine algal growth media contained nutrients, trace metals and vitamins, which affected leaching of metals more than organic compounds (Capolupo et al., 2020). [4] Based on a 1:1 ratio of tread to road-derived minerals in TRWP (Peter et al., 2020). * L:S = liquid-to-solid ratio.

Reference	Study design			Leachate conc., (μg/L)	Aqueous loading from tire (μg/g tire)		Leached into aqueous solution (% of tire concentration)	
	Particle generation; size	Leachate preparation	L:S* (L/kg) (conc., kg/L)	"Worn"	"Worn"	"New"	"Worn"	"New"
Unice et al. (2015)	TRWP generated in road simulator; no size information	Column, hard water, 30d, 20 °C	10 L/kg (0.1 kg/L)	1300[1] TRWP	13 TRWP 26[4] TWP	–	37[2] TRWP	–
Halsband et al., 2020	Crumb rubber granulate; 1–2.8 mm	Batch, seawater, 14d, 20 °C	1000 L/kg (0.001 kg/L) highest L:S	68	68[1]	80[1]	62[1]	76[1]
			10 L/kg (0.1 kg/L)	1415	14[1] ("pre-use")	17[1]	13[1] ("pre-use")	16[1]
Halle et al., 2021	Tire tread on grindstone; avg. 176 um (worn), 210 um ("pristine")	Batch, DI, 48 h, 25 °C	15 L/kg (0.067 kg/L)	254[1]	3.8	3.9	16	19
Capolupo et al., 2020	Tire derived granulate; 1–2 mm	Batch, freshwater (fw) or marine algal growth medium[3], 14d, 25 °C	12.5 L/kg (0.08 kg/L)	2313 (fw) 1460 (marine)	29[1] (fw) 18[1] (marine)	–	–	–

4.5. Ecotoxicological effects

Tire particles can be ingested or respired, and toxicity is likely size-dependent and/or influenced by chemical composition (*e.g.*, additives, associated pollutants, influence of weathering) and abiotic factors (Wagner et al., 2018). Tire particles likely behave similarly to other types of micro- and nanoplastics (MNPs), and a handful of studies, mainly in model aquatic organisms, indicate that mechanisms elicited by tire wear particle exposure are similar to other MNPs (Cunningham et al., 2022; Siddiqui et al., 2022). However, much remains unknown about absorption, distribution, metabolism, and excretion (ADME) processes across taxa, including humans. Additionally, no published studies have examined the difference in toxicity between new and weathered particles, tire particle mixtures from different tire types and brands, or the combination of tire, brake, and road wear that most realistically represents actual emissions to the environment.

Once entrained in sediments and soils, tire wear particles may serve as a source of adverse effects to benthic and soil populations, communities, and ecosystems. Consequently, tire particles and associated chemical additives have biological and larger scale ecological effects across the range of species and populations, types of communities and ecosystems, characteristics of the chemical additives, extent of particle weathering, and route of chemical exposure. For example, differing tire particle effects, such as 6PPD-quinone toxicity to some salmonids (McIntyre et al., 2021; Tian et al., 2022), have been found among matrices, such as sediment, water, and food (Khan et al., 2019; Redondo-Hasselerharm et al., 2018) and from both particles and additive leachates.

In general, MNPs contribute to food dilution, a phenomenon of reduced growth following ingestion due to either a false sense of satiation on the part of the organism, stress interfering with swimming and prey capture ability, or reduction of nutrient absorption (Siddiqui et al., 2022, Cunningham et al., 2022, Panko et al., 2013, Brander et al., 2024, Thornton Hampton et al., 2022), as well as oxidative damage if small enough (< 10 μm estimated) to translocate (Mehinto et al., 2022). Exposure to tire particles has been shown to result in differences in behavior, development, and other sublethal effects (Cunningham et al., 2022; Magni et al., 2022; Siddiqui et al., 2022; Sheng et al., 2021). Recent studies also indicate that nanoplastics (defined as particles 1 to 1000 nm; Gigault et al., 2018; Cunningham et al., 2023) may be able to translocate from the gut to other tissues and in some cases may be able to translocate into cells (Brander et al., 2024, Coffin et al., 2022, McIlwraith et al., 2021). Markers of oxidative stress have been demonstrated to increase following exposure to tire particles (Sheng et al., 2021; Shin et al., 2022). However, an increase in antioxidant defense may indicate an adaptive response to the presence of the tire particles. In episodic exposure to tire particles, mummichog (*Fundulus heteroclitus*) showed an adaptive response wherein DNA damage and repair were both increased, and antioxidant response mechanisms were altered in a dose-dependent manner (LaPlaca et al., 2022). To date, most studies on tire particles have focused on leachates, rather than particles, or have examined the combined toxicity of particles and heavy metals such as Zn (*e.g.*, Yang et al., 2022). Differentiating the effects of particles themselves from the effects of harmful chemical leachates such as heavy metals is complex, and more research is needed to determine which variables cause oxidative stress and whether this is an adaptive *versus* a toxicological response.

Aqueous leachates of laboratory-generated tire tread particles and tire crumb are complex mixtures of chemicals, many of which have toxic effects (Capolupo et al., 2020; Celeiro et al., 2021; Unice et al., 2015). Several cationic metals associated with tire particles, including Zn, Fe, Cr, Pb, Ni, Cu, Ti, Sr, Ba, Se, Cd, and Pb, are routinely used materials in tires, brakes, catalytic converters, and road asphalt and are commonly detected in tire and road dust (Adamiec et al., 2016; Hong et al., 2020), potentially causing toxic effects in aquatic ecosystems. While there is a lack of direct information concerning TWP toxicity, there is toxicity information on the constituents of TWP such as heavy metals and PAHs. This information can be extrapolated, but matrix effects, biological uptake, and particular speciation of adjuvants/leachates may influence the toxicity of the individual toxicants in the TWP matrix. Zn has been identified as a major toxicant in tire particles and associated leachates (Liu et al., 2022; Wik et al., 2009; Yang et al., 2022) because ZnO and ZnS are added to tires during the vulcanization process (Adamiec et al., 2016). Zn levels as low as 0.65 μg/L and Cd levels as low as 0.56 μg/L can cause significant declines in marine copepod egg production, which is linked to population-level effects (Fisher and Hook, 2002). In addition, Ni can affect population structure in the estuarine copepod, *Eurytemora affinis* (30 μg/L for males and 50 μg/L for females) (Zidour et al., 2019). Other cationic metals such as Al and Cu, also found in tire particles, have exhibited population-level effects in a variety of aquatic organisms (Cleveland et al., 1991; Cribiu et al., 2020; Zidour et al., 2019). Because tires are not the only source, the proportional

contribution of cationic metals from tires to the environment, remains a critical data gap.

Soils and water bodies near major roadways are typically contaminated with elevated levels of heavy metals, and concentrations are often positively correlated with increasing traffic and/or industrial activity (Aslam et al., 2013; Alsbou and Al-Khashman, 2017; Ghosh and Maiti, 2018). Chronic heavy metal exposure is known to cause ecotoxicological effects in wildlife including developmental abnormalities, neurotoxicity, and reduced reproduction and survival (Redondo-Hasselerharm et al., 2018; Capolupo et al., 2020; Ding et al., 2020; Sheng et al., 2021; Simon et al., 2021; Leifheit et al., 2022; Yang et al., 2022). For most studies, toxicological effects cannot be definitively linked to heavy metals alone due to the variability and complexity of the detected chemical constituents (Capolupo et al., 2020; Ding et al., 2020). However, a recent study by Yang et al. (2022) employed a Toxicity Identification Evaluation (TIE) approach to identify Zn as the causative agent for mortality in the marine copepod, *Tigriopus japonicus*, following exposure to tire particle leachate. Different experimental conditions (*e.g.*, temperature, pH, soil organic content), differences in manufacturing or weathering among tire materials, and/or species sensitivity may influence bioavailability of heavy metals and alter toxicity profiles.

In addition to heavy metals, the toxicity of tires has often been attributed to non-polar organic compounds, such as PAHs (Wik and Dave, 2006), created by the incomplete combustion of organic matter and which are found in tires, crude oil, and gasoline (Hussain et al., 2018). The amounts and types of PAHs vary among tires (Sadiktsis et al., 2012). PAHs are leached from tire particles and other tire debris in water, soil, and biological fluids (Marwood et al., 2011; Panko et al., 2013; LaPlaca and van den Hurk, 2020) and can persist in the environment (Shuttleworth and Cerniglia, 1995) or transform into other potentially toxic compounds (Lundstedt et al., 2007). Much of the toxicity observed in leachate and tire debris exposures has been attributed to PAHs (Wik and Dave, 2006; McIntyre et al., 2014; Wu et al., 2014); however, the proportion of PAHs in the environment that originates from tires is unknown. Observed abnormalities from PAH exposure are like those seen in fish exposed to tire debris (McIntyre et al., 2014). PAHs and their metabolites can cause carcinogenic and non-carcinogenic impacts (Martins et al., 2013; Martins et al., 2015). For example, uptake of PAHs released from tire particles (Stephensen et al., 2003; LaPlaca and van den Hurk, 2020) can cause developmental defects and mortality in fish (Incardona et al., 2004; Fallahtafti et al., 2012; Incardona et al., 2012; Philibert et al., 2016) and PAH exposure can cause immunotoxicity, cardiotoxicity, and impact reproduction in wildlife (Honda and Suzuki, 2020).

The toxicity of PAHs is photo-enhanced by sunlight. For example, Pelletier et al. (2000) found potential population level effects from PAHs and UV light exposures in bivalves that had bioaccumulated 5000 μg PAH/g lipid (Pelletier et al., 2000). Bellas and Thor (2007) reported adverse effect levels for the marine calanoid copepod *Acartia tonsa* for pyrene and UV exposures, with concentrations that affect 50 % of the organisms (EC50s) of 16 μg/L (egg production rate) and 8.3 μg/L (recruitment rate). Environmental mixtures of PAHs can affect reproductive endpoints in mussels at tissue concentrations as low as 60 μg/Kg dw (Ruiz et al., 2011). PAHs decreased nauplii and copepodite production in an estuarine copepod (*Schizopera knabeni*) at sediment concentrations as low as 38 μg/Kg dw. Because of the many sources of PAHs in the environment, distinguishing the contribution from tires remains an important data gap.

In addition to PAHs, many other organic compounds exist in tires (Supplementary Table 1). Alkylphenols, including bisphenol A (BPA: DTXSID7020182), and other related alkylphenols such as octyl- and nonyl-phenol and alkyl-phenolic ethoxylates, have also been found in tire particles and associated leachates. These compounds are known endocrine disruptors in vertebrates, including several fish species (*e.g.*, medaka, fathead minnow, sheepshead minnow, and rainbow trout) at concentrations as low as 100 μg/L (David et al., 2019) and are suspected to cause toxic effects on larvae, molting, and metamorphosis in invertebrates such as American lobster (*Homarus americanus*) (Laufer et al., 2013). 6PPD-quinone (DTXSID301034849), the degradate of 6PPD, an antiozonant used in tires, is highly toxic to juvenile Coho salmon (*Oncorhynchus kisutch*) (24 h LC50 of 0.095 μg/L) an ecologically, economically, and culturally important fish (Tian et al., 2022). Chinook salmon (*Oncorhynchus tshawytscha*) also suffer mortality from 6PPD-quinone, though juvenile coho were 3 orders of magnitude more sensitive than juvenile Chinook; 24-h median LC50 estimates were 41.0 *versus* 67,307 ng/L, respectively (Lo et al., 2023). Notably, coho LC50 was 2.3-fold lower than previously reported for adult coho (95 ng/L), emphasizing age-related differences in sensitivity (Lo et al., 2023). Brook trout (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*) also showed high sensitivity to this compound with reported 24 h LC50s of 0.59 and 1.96 μg/L, respectively (Brinkmann et al., 2022). The mode of action for 6PPD-quinone toxicity to salmonids remains unknown, as other species such as arctic char (*Salvelinus alpinus*), white sturgeon (*Acipenser transmontanus*), zebrafish (*Danio rerio*), and invertebrates (*Daphnia magna* and *Hyalella azteca*) are far less sensitive (Hiki et al., 2021; Brinkmann et al., 2022; Varshney et al., 2022). Studies on the aquatic toxicity of 6PPD-quinone are summarized in Table 4 and 6PPD-quinone occurrence in the environment is shown in Table 5.

Aside from their chemical composition, differences in tire particle size and shape (*e.g.*, aspect ratio) may have varying levels of biological effects, as is the case for other types of MNPs (*e.g.*, Schell et al., 2022). Overall, smaller MNPs can induce more significant biological effects compared to larger ones (Mehinto et al., 2022; Thornton Hampton et al., 2022). This may be because of their ability to disrupt epithelial barriers and affect tissue viability, recently demonstrated by Donkers et al. (2022) using a variety of different material types and sizes (nylon microfibers, tire particles, polystyrene, polyethylene). This phenomenon is size rather than material dependent, with particles <10 μm having the greatest propensity to translocate. Across plastic pollution in general, particles may be ingested but don't appear to bioaccumulate (Gouin, 2020). Tire particles and their leachates are subject to influence from variation in conditions such as salinity, temperature, and pH that can lead to changes in particle chemistry and behavior, as well as toxicity. Abiotic variability is also known to influence particle behavior such as agglomeration, which plays a large role in particle fate and transport (Chang et al., 2022; Shupe et al., 2021). At increasing salinities for example, inland silverside (*Menidia beryllina*) and mysid shrimp (*Americamysis bahia*) both exhibited greater alterations in swimming behavior following exposure to nano-size tire particles (< 1 μm) and leachate (Siddiqui et al., 2022). Comparatively, the same organisms exhibited greater behavioral changes in the lowest salinity following exposure to micro-size tire particles (1–20 μm) (Siddiqui et al., 2022). In a study on fathead minnows *(Pimephales promelas*), temperature and mechanical stress had a significant negative effect on tire leachate toxicity; however, UV-A treatment of the tire particles (~ 1 mm) and range of pH conditions studied (8.2–8.6) did not alter toxicity (Kolomijeca et al., 2020). Future studies on varying abiotic factors on tire particle toxicity should consider incorporation of abiotic factors into their design since research on how these factors affect tire particle toxicity is largely unexplored to date.

Organisms can vary significantly in their response to tire particles (Table 6). For example, in estuarine organisms exposed to tire particles during the first few days of life, reduced growth was observed in larval fish (*Menidia beryllina*) and juvenile mysid shrimp (*Americamysis bahia*) (Siddiqui et al., 2022). Similarly, in the freshwater species *Danio rerio*, growth was reduced following exposure to tire particles (Magni et al., 2022). However, this trend does not hold across all species; *Daphnia magna* growth was not impacted in the same study, but fecundity was reduced due to internalization of tire particles (Magni et al., 2022). Another study with *D. magna* showed particle-based enhancement of toxicity, with greater toxicity from nanosized (<1 μm) in comparison to microsized (1–20 μm) tire particles; specifically, at high concentrations

Table 4
6PPD-quinone aquatic toxicity in peer-reviewed literature. LC50 = median lethal concentration, C.L. = confidence limits. [1] Tian et al., 2021a; [2] Tian et al., 2022; [3] Hiki et al., 2021; [4] Varshney et al., 2022; [5] Brinkmann et al., 2022; [6] Di et al., 2022; [7]Peng et al., 2022; [8]Lo et al., 2023; [a] Based on measured concentration at the start of exposure; [b] Time weighted average concentration; [c] ISO (International Standards Organization) Standard Fish Media; [d] Based on nominal concentrations; [e] Hardness as mg/L $CaCO_3$; *Concentrations measured using in-house standards without internal standard normalization. Tian et al. (2022) observed that use of a commercial standard yielded ~15-fold higher peak area response for the same 6PPD-quinone concentration in their in-house standard, and 6PPD-quinone recovery without internal standard normalization was ~60–70 %.; [+]Concentrations measured using a commercial standard; [^]Hiki et al. (2021) also created their own in-house standard and did not use an internal control when measuring exposure concentrations. Therefore, their reported concentrations may be overestimated, similar to Tian et al., 2021a.

Species	pH	Conductivity (μS/cm)	Temp. (°C)	Exp Time	Solution renewal	LC50 (μg/L; 95 % C.L.)	Ref.
Oncorhynchus kisutch	7.6–7.8	1250–1300	10–12	24 h	None	0.79 (0.6–1.0)[a,*]	1
Oncorhynchus kisutch	7.6–7.8	1250–1300	10–12	24 h	None	0.10 (0.08–0.11)[a,+]	2
Danio rerio	7.7 ± 0.0	3090 ± 200	25.9 ± 0.1	96 h	48 h	>70[b,^]	3
Danio rerio	7.4 ± 0.1	ISO[c]	27 ± 1	24 h	24 h	308.7 (258.3–368.9)[d]	4
Oryzias latipes	7.9 ± 0.1	3420 ± 1100	24.4 ± 0.2	96 h	48 h	>40[b,^]	3
Daphnia magna	8.0–8.4	6380–6430	21.6–21.9	48 h	None	>60[b,^]	3
Hyallela azteca	8.0 ± 0.1	3100 ± 1100	23.5 ± 0.2	96 h	48 h	>90[b,^]	3
Salvelinus fontinalis	6.7 ± 0.1	131 ± 2.33[e]	10.3 ± 0.7	24 h	24 h	0.59 (0.48–0.63)[b,+]	5
Oncorhynchus mykiss	8.4 ± 0.5	132 ± 6.80[e]	12.8 ± 0.8	72 h	24 h	1.00 (0.95–1.05)[b,+]	5
Oncorhynchus mykiss	6.5 ± 0.0	143 ± 2	16 ± 1	96 h	48 h	2.26 (2.13–2.44)[a]	6
Salvelinus alpinus	8.4 ± 0.5	132 ± 6.80[e]	12.8 ± 0.8	96 h	24 h	>14.2[b,+]	5
Acipenser transmontanus	8.4 ± 0.5	132 ± 6.80[e]	12.8 ± 0.8	96 h	24 h	>12.7[b,+]	5
Gobiocypris rarus	8.0 ± 0.0	149 ± 2	25 ± 1	96 h	48 h	>500[a]	6
Danio rerio			28 ± 0.5	96 h	24 h	2200	7
Oncorhynchus tshawytscha	6.8–7.3	89.8 CaCO3	13.8 ± 0.3	24 h	none	67.3	8
Oncorhynchus kisutch	3.7–7.0	102 CaCO3	13.6 ± 0.3	24 h	none	0.041	8

of nano and micro-sized tire particles, developmental deformities were observed in *D. rerio* as was mortality in both *D. rerio* and *D. magna* (Cunningham et al., 2022).

In experiments that evaluated the reproduction of *D. magna*, 15 and 150 mg/L of tire rubber particles significantly reduced the numbers of daphnids and their neonates (Schell et al., 2022). Furthermore, Magni

Table 5
6PPD-quinone occurrence in the environment. ([1]Tian et al., 2022, [2]Nedrich, 2022; [3]Eurofin presentation to EPA group 2022; [4]Johannessen et al., 2021, 2022a, 2022b; [5]Challis et al., 2021; [6]Monaghan et al., 2021; [7]Cao et al., 2022; [8]Rauert et al., 2022; [9]Geometric mean of lowest observed effect concentration for mortality from Tian et al., 2022, Lo et al., 2022, Greer et al., 2023).

Location and timing	Sample method	Sample type	Land use	Detected	Non-detected	6PPD-quinone (μg/L)	Coho NOEC[9] 0.034 (μg/L)
Seattle, WA, US[1] During storm event	Grab	Road surface	Urban highway	6	1	<0.05–1.27	Above
Seattle, WA, US[1] During storm	Grab	Creek	Urbanized residential watersheds (Miller Creek, Longfellow Creek, Thornton Creek)			<0.02–0.21	Above
Seattle, WA, US[1] Between storms	Grab	Creek	Urbanized residential watersheds (Miller Creek, Longfellow Creek, Thornton Creek)	0	15	NA	Below
Los Angeles, CA, US[1] During storm	Grab	Road surface	Urban highway	2	0	0.49–0.74	Above
San Francisco Bay Area, CA, US[1] During storm	Time Composite Samples	Creek	Urban and Reference sites	4	6	0.12–0.42	Above
Michigan, US[2] Post storm 35 h	Grab	Creek	Various	2	17	0.012–0.037	Above
Michigan, US[2] During storm	Grab	Road surface & puddles	Various	5	0	0.054–0.66	Above
Central California, US Dry Season	Grab	River		0	10	NA	NA
Central California, US Wet Season[3]	Grab	River		2	8	0.002–0.014	Below
Toronto, Canada[1]	Composite (42 h)	River	Urban, downstream of high-traffic corridor (Don River)			0.3–2.3	Above
Saskatoon, Canada[2]	Composite	Outfall	Urban (residential / light industrial)			0.086–1.40	Above
Saskatoon, Canada[5]	Composite (8–12 snow piles)	Snowmelt	Urban (residential / light industrial)			0.015–0.756	Above
Nanaimo, BC, Canada[3]	Grab	Creek	Not available	2	0	0.096–0.112	Above
Nanaimo, BC, Canada[6]	Grab	Stormwater	Not available	4		0.048–5.58	Above
Hong Kong[4]	Grab	Road surface	Dense traffic, urban area	9	0	0.021–0.243	Above
Brisbane, Australia[5] post storm 18 days dry	Grab	Creek	Sub-urban (low density residential, open space)	9	0	0.0004–0.08	Above

Table 6
Published toxicological studies on tire particles and leachates.

Reference	Tested species (* indicates those with observed significant effects)	Type of exposure			Authors consider exposures to be Environmentally Relevant Concentrations	Observed Affected Endpoints	Notes
		Micro particles	Nano particles	Leachates			
Carrasco-Navarro et al., 2022	California blackworm (*Lumbriculus variegatus*) Harlequin fly (*Chironomus riparius*)	x			x	None	
Garrard et al., 2022	*Scrobicularia plan *Ragworm (*Hediste diversicolor*)	x				Behavior Oxidative stress	
LaPlaca et al., 2022	*Mummichog (*Fundulus heteroclitus*)	x			x	DNA damage	Episodic exposures
Magni et al., 2022	*Zebrafish (*Danio rerio*) *Daphnia magna*	x			x	Growth fecundity	Used end-of-life tires
Schell et al., 2022	*Daphnia magna* *Hyalella azteca* Water louse (*Asellus aquaticus*) California blackworm (*Lumbriculus variegatus*)	x			x	Reproduction mortality	
Shin et al., 2022	*Rotifer (*Brachionus plicatilis*)			x		Mortality Oxidative stress	
Siddiqui et al., 2022	*Inland Silverside (*Menidia beryllina*) *Mysid shrimp (*Americamysis bahia*)	x	x	x	x	Behavior growth	
Carrasco-Navarro et al., 2021	*Harlequin fly (*Chironomus riparius*)	x			x	Gene expression	
Chibwe et al., 2022	*Fathead minnow (*Pimephales promelas*)			x		Development	
Cunningham et al., 2022	*Zebrafish (*Danio rerio*) *Daphnia magna*	x	x	x		Behavior development mortality	Toxicity affected by changes in salinity
Halle et al., 2021	**Hyalella azteca*	x		x		Growth mortality	
Koski et al., 2021	*Acartia tonsa* *Temora longicornis*	x			x	None	Used new tires, old tires, and rubber granules from artificial turfs
McIntyre et al., 2021	*Coho salmon (*Oncorhynchus kisutch*) Chum salmon (*Oncorhynchus keta*)			x	x	Mortality	
Selonen et al., 2021	Enchytraeid worm (*Enchytraeus crypticus*) *Springtail (*Folsomia candida*) Woodlouse (*Porcellio scaber*)	x			x	Reproduction mortality	
Sheng et al., 2021	*Earthworm (*Eisenia fetida*)	x				Oxidative stress	
Capolupo et al., 2020	*Mediterranean mussel (*Mytilus galloprovincialis*)			x		Reproduction	
Ding et al., 2020, 2023	*Soil worm (*Enchytraeus crypticus*)	x		x	x	Intestinal pathology, mortality	Tire brand-specific toxicity
Kolomijeca et al., 2020	*Fathead minnow (*Pimephales promelas*)			x		Reproduction Growth	Toxicity affected by temperature and mechanical stress
Khan et al., 2019	**Hyalella azteca*	x				Mortality Growth Reproduction	
Pochron et al., 2018	*Earthworm (*Eisenia fetida*)	x				Mortality Growth	
Redondo-Hasselerharm et al., 2018	*Gammarus pulex* *Asellus aquaticus* Tubifex *spp.* *Lumbriculus variegatus*.	x				None	
Pochron et al., 2017	*Earthworm (*Eisenia fetida*)	x				Growth	
Panko et al., 2013	*Hyalella azteca* *Ceriodaphnia dubia* *Chironomus dilutus *Fathead minnow (*Pimephales promelas*)	x				Growth	Mimicked abrasion of tires to produce particles

(*continued on next page*)

Table 6 (*continued*)

Reference	Tested species (* indicates those with observed significant effects)	Type of exposure			Authors consider exposures to be Environmentally Relevant Concentrations	Observed Affected Endpoints	Notes
		Micro particles	Nano particles	Leachates			
Zhao et al., 2011	*Soil nematodes	x				Abundance Community structure	
Wik et al., 2009	**Ceriodaphnia dubia*			x		Reproduction	

et al. (2022) reported a Lowest Observed Effect Concentration (LOEC) of 9.8 mg/L for the same species exposed to TWPs. However, in 48 h tests with two levels of feeding and three types of tire materials, at concentrations up to 10,000 particles/L, reproduction of marine copepods *Acartia tonsa* and *Temora longicornis* was unaffected (Koski et al., 2021). Reproduction of the daphnid *Ceriodaphnia dubia* over 9 days was the most sensitive to tire rubber leachate exposure, with an EC50 of 10 mg/L (Wik et al., 2009). When the rotifer (*Brachionus plicatilis*) was exposed to tire particle leachate, a No Effect Concentration (NOEC) of 200 mg/L (0.2 g/L) was found (Shin et al., 2022). In experiments conducted with the mussel *Mytilus galloprovincialis,* gamete fertilization was affected by tire rubber leachates (Capolupo et al., 2020), a result attributed to a reduced motility of spermatozoa, possibly caused by leached metals (Capolupo et al., 2020). For the freshwater amphipod *Hyalella azteca*, Khan et al. (2019) found that neonate production, mortality, and growth, were all significantly impacted by TWP (500 to 2000 particles/mL) after a 21-d exposure. Additional studies with the amphipod *H. azteca* (Halle et al., 2021) with a concentration up to 250,000 particles/L, showed no significant effects on the reproductive output. In experiments using tire and road wear particles spiked in sediment (10,000 mg/Kg) or its elutriate, no reproductive endpoints were affected in the amphipod *H. azteca* or *C. dubia,* (Panko et al., 2013), and only slight growth effects were demonstrated in the insect midge *Chironomus dilutus* larvae and freshwater fish *Pimephales promelas*. However, the authors report reproductive measures in the *C. dubia* and *H. azteca* controls were also significantly reduced, most likely due to turbidity. This study is one of the few available investigations where abrasion of tires was mimicked to produce the TWP (Panko et al., 2013). The lack of effects in sediment exposures was corroborated in studies using several sediment organisms (Redondo-Hasselerharm et al., 2018; Carrasco-Navarro et al., 2022; Schell et al., 2022).

Reported adverse effects of TWPs on soil invertebrates are highly variable for oligochaetes, annelids, and nematodes (Ding et al., 2020; Pochron et al., 2017, 2018; Zhao et al., 2011). For example, Pochron et al. (2017) found that earthworms (*Eisenia fetida*) exposed to crumb rubber contamination in soil experienced reduced weight gain by 14 %; however, earthworm survivorship or stress response to heat and light was not impacted. Furthermore, crumb rubber contamination did not inhibit microbial respiration rates despite soils containing toxic concentrations of Zn (Pochron et al., 2017). In a similar study, exposure to virgin crumb rubber reduced weight gain by 14 % while aged crumb rubber did not have the same effect. However, exposure to aged crumb rubber reduced earthworm survival time during a stress test by 16 % relative to the survival time for worms in clean soil (Pochron et al., 2018). Ding et al. (2020) found that TWPs decreased survival of the soil worm (*Enchytraeus crypticus*) by >25 % and reproduction by >50 %. Tire particle exposure disturbed the microbiota of the worm's guts causing an enrichment of microbes associated with opportunistic pathogenesis, suggesting that TWPs might impact soil biota and microbiota. Ding et al. (2023) found that *E. crypticus* avoided consuming TWP but that tire leachates exerted toxic effects on gut microbiota, intestinal histopathology, and metabolites at environmentally relevant concentrations and that toxicity varied with brand of tire. Zhao et al., 2011 studied the effects of waste crumb rubber in soils on nematode abundance, community structure and soil characteristics and found significant decreases in the numbers of plant parasitic nematodes, the most abundant trophic group. Furthermore, crumb rubber exposure decreased Shannon's diversity index, evenness, and plant parasite index of soil nematodes, but increased dominance and maturity indexes. In a study exposing enchytraeid worms (*Enchytraeus crypticus*), springtails (*Folsomia candida*), and woodlice (*Porcellio scaber*) to TWPs (<180 μm) in soil and food at concentrations of 0.02 %, 0.06 %, 0.17 %, 0.5 %, and 1.5 % (*w*/w), Zn was again found to be the dominant metal and organic contaminants included benzothiazole, pyrene, chlorpyrifos, HCB, methoxychlor, and BDE (Selonen et al., 2021). At the highest test concentration in soil (1.5 %), TWPs decreased *F. candida* reproduction by 38 % and survival by 24 %, and acetylcholinesterase (AChE) activity of *P. scaber* by 65 %. In food, the 1.5 % test concentration of TWPs reduced *F. candida* survival by 38 % (Selonen et al., 2021). Altogether, the highly variable outcomes of the studies may be due to differences in particle size and chemical composition, and/or differences in species sensitivity, but suggest that TWPs can adversely affect soil invertebrates at concentrations found at roadsides in the environment (Selonen et al., 2021).

4.6. Population, community, and ecosystem effects

Population, community, and ecosystem level effects are important measures of the impacts of tires as pollutant as they integrate individual toxicological effects and are often measures of wide-scale change. Species especially sensitive to toxic effects of certain chemicals can be early warning indicators of decline and extinction, community function, and ecosystem services. Population level changes can occur because of individual toxic effects such as changes in reproduction (*e.g.*, sperm motility, delayed hatch, and smaller brood size), as well as reduced fitness caused by nutrient substitution. In addition, changes in community structure, such as increased or decreased predation or shifts in prey availability, may have adverse effects on populations. The few studies of population level effects from tire particles and associated chemical additives include laboratory toxicity studies demonstrating effects on reproduction that may affect wild populations and ecosystems (Table 6). In general, studies that spike tire particles into sediments appear to show fewer adverse effects than those using tire particles in water. However, the method by which tire wear particles are produced for toxicity studies may make a large impact on their environmental relevance and toxicity. Most studies use pieces of a single tire to cryomill particles, which results in tire fragments that may look and act quite differently from particles generated by tire use. Panko et al. (2013) is one of the few studies where the environmentally relevant abrasion of tires was mimicked to produce the tire particles used for toxicity testing. Whether how tire particles are produced makes a significant difference in their toxicity is an important data gap for interpreting most tire particle toxicity studies to date.

Both tire particles and associated leachates can cause shifts in microbial marine communities that may affect nitrogen metabolism in marine sediments (Liu et al., 2022; Wik et al., 2009; Yang et al., 2022). While there are few studies of community level effects resulting from direct tire particle exposure, there are data on some of the chemical additives associated with tires, including metals. For example, changes in community tolerance to increased Zn levels in sediments (>124 mg/Kg dw) has been demonstrated for microbial communities (van Beelen, 2003), and with Zn, Cd, and Cu for river periphyton (Blanck, 2002). Effects of Ni on diatom communities were reported at 1000 μg/L (Ivorra

et al., 2002) and for freshwater benthic communities at ~500 mg/Kg depending upon the acid volatile sulfide and total organic carbon concentrations of the impacted sediments (Nguyen et al., 2011). Schlekat et al. (2016) summarized studies on benthic freshwater communities and determined that NOEC Ni levels ranged between 100 and 230 mg Ni/Kg dw. Among freshwater nematode communities, shifts in species composition start at 13 mg/Kg to 19 mg/Kg dw and porewater concentrations of 20 μg/L to 30 μg/L (Louati et al., 2013). PAHs have also shown community level effects. Alpha diversity and evenness of sediment prokaryotic communities changed after pyrene exposure at 250 mg/Kg (Ding et al., 2017). Sediment meiofauna community and microbial processes were altered at PAH concentrations of 130 to 1300 μg/Kg dw sediment (Lindgren et al., 2014) and the meiofauna community was disrupted by environmentally occurring PAH mixtures of 45 mg/Kg, 30 mg/Kg, and 25 mg/Kg of dry sediment for fluoranthene, pyrene, and phenanthrene, respectively (Louati et al., 2013). Other tire additives such as BPA also can cause microbial community changes; effects of BPA were seen at concentrations of 180 mg BPA/Kg dw sediment (Yang et al., 2014).

While most published studies on adverse effects caused by tire particles, metals, hydrocarbons, and associated chemical additives are related to the aquatic environment, terrestrial endpoints may also be impacted. For example, Selonen et al. (2021) found a significant reduction in the reproduction of the springtail *Folsomia candida* in soils spiked with tire rubber particles at concentrations up to 1.5 % of soil dry weight. In contrast, at the same concentration, no significant effects were found on reproduction of the worm *Enchytraeus crypticus* (Selonen et al., 2021) or of *F. candida* exposed to tire particles from bicycles, cars, and e-scooters (Kim et al., 2022).

Reported adverse effects of tire particles on soil invertebrates are highly variable for oligochaetes, annelids, isopods, arthropods, and nematodes, but suggest that tire wear particles could adversely affect soil invertebrates at concentrations found at roadsides in the environment (Ding et al., 2020; Pochron et al., 2017, 2018; Selonen et al., 2021; Zhao et al., 2011). In addition, a 15 % treatment of crumb rubber reduced soil bulk density by 28 % and soil moisture by 6 % (Zhao et al. (2011). While the concentration of tire particles found to have an effect in this study was relatively high, it is likely representative of current or future soil tire content given the constant generation of tire particles on roadways and a lack of mitigation strategies. At the ecosystem level, whole tires collect water, serving as habitat and shelter for pests such as mosquitoes and bacteria or disease-carrying rodents (Torretta et al., 2015). MNPs, under which tire particles can be categorized, can influence the structure and function of ecosystems (Rillig and Lehmann, 2020). Therefore, tire particles should be considered as an agent of change at the ecosystem level. Tire particles may serve as substrata for colonization by microbes (Torretta et al., 2015). Ecosystem level effects from metals, as well as other impacts caused by environmental parameters (*e.g.*, ionic strength, pH) may also result when tire wear particles are present. For example, in a laboratory study of a marine benthic system from the Baltic Sea, Sundelin and Elmgren (1991) reported adverse impacts to nematode abundance, total meiofauna abundance and biomass, non-nematode biomass, ostracod abundance, and Turbellarian abundance resulting from exposure to Cd. In contaminated sediments on the northern Australian coast, based on genomic analysis, the presence of several metals (*e.g.*, Al, V, Zn, Cu, Ga, Pb, Cd, and As) negatively impacted Archaea and bacterial (Cornall et al., 2016). In another field study from Australia, invertebrate predator ratios and taxa richness in freshwater streams were negatively affected by Cu and Zn (Liess et al., 2017). Versteeg et al. (1999) demonstrated the impacts of metals to ecosystems ranging from disruptions to community structure, colonization, and productivity, to reductions in taxa richness, growth, and survival. Their synthesis demonstrated that cationic metals such as those leached from tire particles could cause adverse effects to ecosystems. However, no ecosystem level studies have been performed on tire particles themselves in aquatic systems. Both aquatic and terrestrial ecosystem effects of tire particles and associated chemical additives are, to date, poorly studied and represent a large data gap in our understanding of the adverse ecological effects of tires.

In addition to tire particles and associated chemicals, environmental factors such as elevated ion concentrations from road salt (*e.g.*, Ca^{2+}, Na^{+}, Cl^{-}) can cause synergistic effects (Kaushal et al., 2020). For example, Klauschies and Isanta-Navarro (2022) found that, at environmentally relevant concentrations, the joint action of salt and 6PPD-quinone had an antagonistic, negative effect on the reproduction and survival of freshwater rotifers. Further, the presence of tire debris can change soil pH, potentially influencing availability of nutrients and toxic metals (Smolders and Degryse, 2002; Councell et al., 2004). MNPs can contribute to the formation of anthropogenic soils and carbon stabilization by influencing bulk density, soil aggregate size, porosity, and water holding capacity (Rillig et al., 2021) which, in turn, limits growth and survival of plants (Bollman et al., 2019). While the effect of nanoplastics on terrestrial ecosystems is largely unknown, nano-sized particles may be taken up by plants themselves (Rillig et al., 2021). Leifheit et al. (2022) showed experimentally that tire abrasion particles reduced aboveground and belowground plant biomass, increased soil respiration and pH, and affected litter decomposition even at their lowest treatment concentrations of 10 mg/g of tire particles (average size of 125 μm; range of 34–265 μm). Castan et al. (2023) showed that lettuce plants exposed to tire-derived compounds including diphenylguanidine, hexamethoxymethylmelamine, benzothiazole, 6PPD, and 6PPD-quinone at concentrations of 1 mg/L were readily taken up and metabolized by the plants and, furthermore, leaching from tire particles continually resupplied the metabolized compounds to the lettuce leaves. The role of tire wear particles as stimulators or inhibitors of biogeochemical and ecosystem functions in urban systems and the potential for ecological and human health risks warrants further consideration and investigation.

Studies show that tire particles can influence C, N, and P cycles directly and indirectly by serving as a source for these elements in food webs (Bucci et al., 2020; Xu et al., 2020). The high C:N ratios of tires and aromatic hydrocarbons stimulate immobilization of N in soils by microbes (Rillig et al., 2021). Conversely, plastics are of lower quality and lability than simpler natural and anthropogenic carbohydrates. Consequently, in the presence of lower litter quality, microbes seek N in the soil organic matter to process the C from the litter, thus inducing excess C loss from soils (Averill and Waring, 2018). Such processes may vary among ecosystem types or along successional gradients (Mayer, 2008). Future studies could investigate the effects of tire particles on decomposition rates because toxic cationic metals and toxic organic chemicals can inhibit microbial and biogeochemical processes and rates (Baensch-Baltruschat et al., 2020; Rødland et al., 2022). Tire particles can release nonpolar hydrocarbons, which may lead to accumulation of C in upper soil horizons due to their limited mobility (*sensu* Lajtha et al., 2005). Ingestion of plastic particles like tire particles may cause lesions and reduce reproductive success in earthworms and affect other soil arthropods (Büks and Kaupenjohann, 2020), though the full range of effects of tire particles on soil macrofauna are unknown. Tires and tire particles are also rich in organic N and P, but less is known regarding their bioavailability compared to C.

4.7. Human health effects

Some tire chemicals are known toxicants to terrestrial organisms and humans (*e.g.*, many metals, PAHs), but the potential toxic effects of many tire-derived chemicals on terrestrial organisms remain unknown. For humans, oral and dermal exposure to tire particles is expected to be minimal compared to inhalation exposure (Kreider et al., 2020). While the larger fraction of particles is primarily in the non-respirable size range (5 μm–220 μm, mode approximately 75 um; Kreider et al., 2010), smaller sized tire particles (PM10 and PM2.5) contribute to particulate air pollution that can get deep into the lungs and into the bloodstream.

Du et al. (2022) found 6PPD and 6PPD-quinone in the urine of children and adults including pregnant women in China, showing that tire-derived chemicals can get into the bloodstream, presumably from inhalation exposure to tire particles. While tires are a major source, other rubber materials such as belts hoses and cables also may emit 6PPD and 6PPD-quinone (Bohara et al., 2024; Cao et al., 2022), and facilities such as sports fields constructed wth tire crumb may be exposure points for humans (Skoczyńska et al., 2021). Mice exposed orally to 6PPD and 6PPD-quinone showed signs of hepatotoxicity from bioaccumulation in liver tissue along with disorders of lipid metabolism and inflammatory immune response due to gene upregulation, suggesting potential health risks to mammals (Fang et al., 2023).

The toxicity of tire particles has been investigated in various *in vitro* studies, which have consistently shown DNA damage and inflammatory effects, while *in vivo* studies using rats and mice have found inflammatory response and pulmonary toxicity from exposure to tire particles (Baensch-Baltruschat et al., 2020). Based on a mouse model and epigenic markers, inhalation of tire wear particles in the size range of <1 μm (hydrodynamic diameter distributed at 100 nm) caused significant pulmonary fibrotic injury (Li et al., 2022). Kreider et al. (2020) developed a species- and time- adjusted no-observed-adverse-effect-concentration (NOAEC) for respirable tire and road wear particles of 55 $\mu g/m^3$ based on cardiopulmonary effects. Comparing this NOAEC to predicted exposure concentrations, they concluded that tire and road wear particles present a low risk to human health, especially when compared to other air pollution sources like diesel exhaust. However, this analysis is based on limited data and did not consider particularly sensitive or highly exposed population groups or other effects such as development of asthma, cancer, or reproductive toxicity.

5. Managing and remediating pollution from tires

Currently, few remediation and management technologies are focused on tire particles or related chemicals (Schmaltz et al., 2020). Potential mitigation opportunities for uncontrolled environmental release of tire particles and chemicals include actions by four sectors: tire manufacturers, vehicle manufacturers, government, and the general population. Approaches for mitigating tire particle and related chemical pollution range from prevention (*e.g.*, reformulating tires to remove toxic ingredients and reducing tire wear debris formation and emissions) to collection and treatment (*e.g.*, capturing tire particles or tire-related chemicals after dispersal into the environment) (Fig. 4). Efforts to reduce overall vehicle kilometers traveled by promoting or making more accessible alternative forms of travel or public transportation could reduce tire emissions. Addressing tire particles and tire-related chemicals will require a holistic approach to address both the tire microplastics and the chemicals they contain because multiple entities and agencies typically manage different components of the tire life cycle. In an extensive review, Baensch-Baltruschat et al. (2020) summarized possible mitigation approaches for reducing tire wear particles emitted to the environment including: modernized installation and retrofitting of stormwater treatment systems, improved runoff treatment systems on rural roads and highways including disposal of sediment, incineration of sewage sludge containing road runoff sediments instead of spreading on agricultural areas or natural soil, regular maintenance of roads, lighter weight vehicles, reduced traffic and speed limits, and optimization of tire materials to improve wear resistance. Autonomous cars may improve emissions because they could be operated to brake and accelerate less often. Treating road runoff, particularly at pollution hotspots such as tunnels, was also suggested (Baensch-Baltruschat et al., 2020). However, because tire particles follow various paths, estimated at proportions of 49 % for runoff, 49 % for soil and 2 % for aerial transport

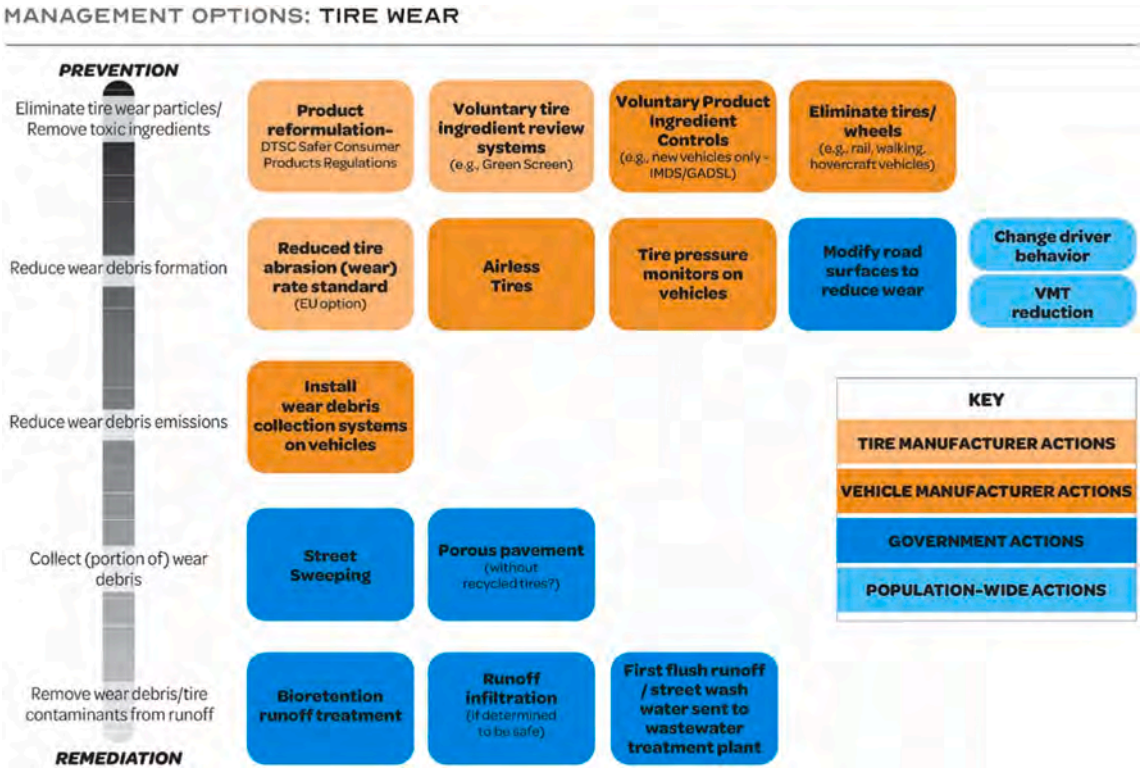


Fig. 4. Management options for tire wear particle pollution, framed on a scale from preventative (reducing use and release) to remedial (collection and removal) measures. Options are color-coded by who would be responsible for implementation, with tire manufacturers in light orange, vehicle manufacturers in dark orange, government in dark blue, and community-wide in light blue. Reprinted from Moran et al. (2021).

(Unice et al., 2019), multiple mitigation approaches along pathways are necessary for effective control.

5.1. Reformulation

Ingredient assessments (*e.g.*, as implemented by the California Department of Toxic Substances Control; California DTSC, 2021) could provide information to inform potential tire tread reformulation to address aquatic toxicity associated with existing formulations. Existing chemical hazard evaluation tools like Green Screen for Safer Chemicals or the USEPA Hazard Comparison tool (*vide infra* Vegosen and Martin, 2020) might provide a framework for such evaluations (Clean Production Action, 2021). The international Global Automotive Declarable Substance List (GADSL) provides a list of chemicals of interest due to existing or anticipated regulation, human or environmental hazard, or association with functional problems in vehicle parts (Technology, 2021; Global Automotive Stakeholders Group, 2021). The GADSL provides vehicle manufacturers with data on chemical ingredients for use in tires that could be considered in reformulations to address potential toxicity concerns. Tire manufacturers report seeking sustainable materials to develop next generation tires (Amick, 2018). However, limitations to this search include manufacturer competition, proprietary information protection, and technological barriers to formulating tires with desired wear and handling characteristics.

5.2. Reduced tire wear debris formation

Multiple organizations are working to redesign and reformulate tires to reduce wear debris formation, potentially involving regulatory standards (*e.g.*, European TRWP Platform, 2019; Hann et al., 2018; Piscitello et al., 2021; European Tyre and Rubber Manufacturer's Association, 2021; Verschoor et al., 2016). Between 2015 and 2021, tire manufacturer Michelin claims to have reduced its overall tire wear mass emissions by 5 % (de Peufeilhoux et al., 2021), which may explain why a comparison test of tires from major European manufacturers showed Michelin had the lowest tire wear rates (Silvestro, 2022). In 2022, the European Commission proposed to regulate tire wear rates (European Commission, 2022).

Maintaining tire pressure, either through airless tires (a technology already entering the market) or tire pressure monitors, has potential to reduce wear rates by an estimated 14 % (Verschoor and de Valk, 2017). Improvements in tire pressure monitoring systems, such as tire-specific warnings and a more sensitive trigger for the warning could maximize reductions. Resurfacing roads and increasing road maintenance to create smoother surfaces may reduce tire wear rates (Alexandrova et al., 2007; Kole et al., 2017) but may entail high implementation costs likely to limit the widespread implementation of such measures. Changing driver behavior (*e.g.*, reducing speed, hard cornering, and braking) could reduce wear debris formation (Kole et al., 2017). However, public education is only effective when costs, benefits, and social norms support changed behaviors. Future vehicle automation could provide a more realistic path for behavior-related tire emissions reductions. Also, roads could be designed to reduce travel speeds that would, in turn, reduce tire wear though, road reconstruction or retrofit may be prohibitively costly and would have its own impacts.

5.3. Reduced tire wear debris emissions

Capturing pollutant emissions at the source typically is more cost-effective than removal from the environment after dispersal. Three companies are patenting systems to collect tire wear debris on vehicles (The Tyre Collective, Nexen Tire, and GelbKo Environmental Solutions). The effectiveness of such systems will depend, in part, on capturing particle sizes with the greatest potential to release chemicals or to harm aquatic organisms. Understanding which vehicle classes (*e.g.*, cars, heavy duty trucks) emit the greatest total quantity of tire wear debris would inform priorities for installation of such systems.

5.4. Collection and treatment of dispersed tire particles

Collecting tire particles in the environment poses significant challenges. Existing street sweeping programs are episodic and do not address all impervious surfaces where tire particles deposit (*e.g.*, sidewalks, driveways, and rooftops). Mechanical street sweepers are only moderately efficient at collecting particles in the size range of tire wear debris and may release microplastics from the sweeping brushes themselves (Amato et al., 2010; Piscitello et al., 2021; Selbig and Bannerman, 2007). Particles may also be collected by clearing deposition locations in the runoff transport system like roadside ditches, catch basins, and storm drainpipes before they are washed into surface water (Navickis-Brasch et al., 2022). Larger tire fragments, such as those from failed retread tires, could be manually collected at roadsides prior to decomposition. Currently, the portion of all tire wear particles collected cannot be reliably estimated from available data (Klöckner et al., 2020; Polukarova et al., 2020; Sieber et al., 2020).

Although it increases tire wear, porous pavement may reduce tire particle wash off by retaining a significant fraction (as much as 40 %) of emitted tire wear particles (Stanard et al., 2007; Verschoor et al., 2016). It is unknown if retained particles subsequently wash away. Furthermore, retained tire particles could continue to release tire-related chemicals into the environment over time. While some countries (*e.g.*, Netherlands) make extensive use of porous pavement (Verschoor et al., 2016), such pavement for automobile traffic is uncommon in the US (Caltrans, 2021; Passeport et al., 2013), may not last as long as conventional pavement, and it may be cost prohibitive to replace existing pavement.

5.5. Treatment to remove tire particles and chemicals from water

Because urban and road stormwater is a significant pathway for tire particle transport (Moran et al., 2021; Werbowski et al., 2021), prioritizing stormwater runoff is key to capturing tire particles and chemicals. Urban runoff treatment systems or combinations of these systems ("best management practices" or BMPs) have potential to reduce tire particles and chemicals released to waterways. Examples of urban runoff BMPs include "green infrastructure" such as vegetative buffers along water bodies (Mayer et al., 2007), rain gardens, grassed swales, retention structures such as ponds, sand filters and filter strips, wetlands, and infiltration features such as trenches and basins (Martins et al., 2015; Galella et al., 2023) and "gray infrastructure" such as hydrodynamic separators. Studies have demonstrated that stormwater bioretention facilities can effectively remove inorganic and organic pollutants from stormwater, including removal of tire wear particles (Gilbreath et al., 2019, Smyth et al., 2021, Mengistu et al., 2022, and McIntyre et al., 2023). The effectiveness of these facilities varies depending on a range of factors, including their design and maintenance. Assessing stormwater treatment effectiveness is a significant challenge when not all of the constituent chemicals in tires are currently known. The most promising stormwater treatment systems for tire particles and chemicals are rain gardens (bioretention cells) and similar soil-based pollutant capture and infiltration systems. Rain gardens (engineered depression features of soil, organic matter, and vegetation) are known to be highly effective at capturing pollutants from stormwater including metals, salts, and nutrients (*e.g.*, Passeport et al., 2013; Gilbreath et al., 2019; Lange et al., 2021; Laws et al., 2011; McIntyre et al., 2015; Smyth et al., 2021; Galella et al., 2023; Kaushal et al., 2022; Maas et al., 2023). Both Gilbreath et al. (2019) and Werbowski et al. (2021) found that rain gardens were effective at reducing microplastic concentrations in water (>90 %). Removal was greatest for particles 3.5–5.0 mm but lesser for particles <0.5 mm, yet reportedly 100 % for rubbery fragments which were assumed to be primarily from tires (Werbowski et al., 2021). McIntyre et al. (2015) observed high efficacy of engineered soil matrixes

typically used in bioretention systems for attenuating the toxic leachates from tires responsible for coho salmon mortality in the Pacific Northwest USA. Optimizing filtration systems will be partially a function of the capture system design, including the soil or aggregate matrix selected for filtration (Bollman et al., 2019; Zhang et al., 2021) and the balance of organic matter, clay, other potential additives (*e.g.*, biochar), and sand and trade-offs with other microbial and biogeochemical processes such as nutrient transformation (*e.g.*, denitrification) where organic matter type and proportion can unintentionally contribute to metal or phosphorus mobilization (Duan et al., 2019).

A few green infrastructure designs have shown promise for some removal of other microplastic types (Stang et al., 2022). Significant tire particle and chemical removal would only be expected in systems that provide significant removal of fine solids or dissolved pollutants, suggesting soil and wetland-based green infrastructure would likely outperform gray infrastructure and many retention pond designs (Clary et al., 2020; Wagner et al., 2018; Navickis-Brasch et al., 2022). Infiltration-based runoff treatment systems could allow soluble tire-related chemicals to pass into groundwater, raising questions about the safety implications for groundwater aquifers that are current or future drinking water sources. Furthermore, biofiltration-based stormwater features may, in the long term, be a source or a sink of tire-derived chemicals like 6PPD-quinone, and metals or base cations depending on hydrology, soils, or other factors such as redox potential, pH, and salinity (Galella et al., 2021; Galella et al., 2023; Navickis-Brasch et al., 2022). Though not widely implemented in the US, some municipalities direct "first flush" runoff from select road segments into the municipal wastewater collection system that flows to wastewater treatment plants, which likely remove a significant portion of tire particles (Wagner et al., 2018). Deliberate, pre-rain event washing to reduce pollutants on road surfaces has also been suggested (Kreiger Jr., 1994).

Emphasis on management and mitigation of tire-derived chemicals has recently been focused on 6PPD due to its connection with coho salmon mortality in the Pacific Northwest USA. For example, the Washington State Department of Ecology produced a comprehensive document on BMPs for stormwater treatment of tire contaminants (Navickis-Brasch et al., 2022) which concluded that capture and attenuation methods will depend upon the characteristics of 6PPD and 6PPD-quinone, which appear to bind to soil and organic matter, remain undissolved and buoyant, and may have long half-lives (6PPD has a half-life of *ca.* 5 h, while 6PPD-quinone's half-life may be several days; DTSC 2022 Product Chemical Profile). Furthermore, 6PPD will continue to leach from tire particles and continue to transform to 6PPD-quinone in the presence of ozone or oxygen. Therefore, retention methods will need to be effective over the lifespan of release of the particles, depending upon environmental and physical conditions, including temperature, pH, presence of metals, redox, salinity, *etc.* BMPs with the highest potential to reduce 6PPD and 6PPD-quinone are infiltration, dispersion, and biofiltration combined with sorption, especially those containing soil media or compost (Navickis-Brasch et al., 2022). In a controlled experiment, salmon survived otherwise deadly, untreated stormwater when the stormwater was filtered through a bioretention soil mixture containing 60 % sand, 15 % compost, 15 % shredded bark, and 10 % drinking water treatment residuals (McIntyre et al., 2015). Similarly, Spromberg et al. (2016) successfully prevented mortality of coho salmon by treating stormwater through biofiltration media. In a more recent study, McIntyre et al. (2023) found that experimental bioretention filtration through a mixture of sand and compost (60:40 by volume) overlying a gravel drainage layer and covered with wood bark mulch, removed bacteria, dissolved metals, and polycyclic aromatic hydrocarbons, and likely also effective removal of 6PPD, thereby preventing all mortality of adult coho salmon and alevin, or newly hatched salmon, exposed to stormwater. In another study, stormwater bioretention cells designed to redirect stormwater away from receiving waters provided a 10-fold reduction in 6PPD-quinone mass loadings to receiving waters (Rodgers et al., 2023). The mechanism of action and longevity of such treatments are unknown (Navickis-Brasch et al., 2022). Identifying optimal soil media mixtures for bioretention and other characteristics is a critical need (Bollman et al., 2019). Designing effective bioretention systems will depend upon tailoring their construction to specific urban landscapes and/or retrofitting existing systems (USEPA, 2023). Bioremediation facilities require inspection and maintenance to ensure adequate performance over multiple years. Occasionally material may need to be removed, tested for contaminants, and disposed of properly (USEPA, 2016).

6. Tire recycling, reuse, and disposal

Waste (scrap) tires or "end of life tires" represent a significant volume of the international solid waste stream (Grammelis et al., 2021). In 2019, over 4.05 million metric tons of scrap tires were generated in the US compared to 3.56 million metric tons in the EU (Table 2). Brazil produced 473,000 tons of waste tires in 2015 alone (Machin et al., 2017). While the volume of waste tires over time has increased since 1960, fewer tires are landfilled, and more are either recycled or combusted as an energy source (USEPA, 2022a, 2022b; Fig. 5). Tiered waste management hierarchy starting with pollution prevention is usually more cost effective than control or treatment and disposal of waste products (USEPA, 2023). The most effective pollution prevention approaches involve creating a circular economy where product-related waste becomes the source material for another generation of the same product. Tires pose a challenge for this hierarchy, as they wear away during their lifetimes, losing about 10 % of their mass in the form of tire wear particles emitted into the environment (USTMA, 2021). While such emission and subsequent dispersion prevent a fully closed-loop life cycle, new prevention options are in development, some of which could feed into a future circular economy (*e.g.*, on-vehicle collection of tire wear particles and end-of-life tire rubber separation and devulcanization; The Tyre Collective, 2021; Markl and Lackner, 2020).

International, national, and US state regulations prohibit the disposal of most tires in landfills (*e.g.*, Dabic-Miletic et al., 2021; Dajić et al., 2016). While there are no US federal programs to facilitate recycling or reuse of tires, 48 states have regulations that control tire disposal. Similarly, there are no special EU standards for used tires and countries may choose a management system (Torretta et al., 2015). Some US states have developed sustainable statewide market infrastructure for tire-derived products such as California's Department of Resource Recycling and Recovery (CalRecycle, 2019, 2020, 2021).

In the EU, only about 4 % of tires are deposited in landfills while 38 % are used for energy, 40 % are recycled, and 18 % are reused in some way (Torretta et al., 2015). Stockpiled, landfilled, and illegally dumped tires can be a source of pollution to groundwaters (Skoczyńska et al., 2021) and can hold water, making them notorious breeding sites for disease-carrying mosquitoes and bacteria (Torretta et al., 2015). In the EU, 2 million tons of tires are stockpiled or abandoned illegally (Torretta et al., 2015). In the US, stockpiled tires have declined steadily from 1 billion tires in 1990 to about 56 million tons in 2019, with stockpile concentrations in a few states such as Texas and Colorado (USTMA, 2020). Only six states do not have storage and disposal regulations, 11 allow whole tires in landfills, and 37 states allow cut or shredded tires to be deposited in landfills (USTMA, 2020), while about half of all states have an active stockpile cleanup program. Stockpiles are susceptible to tire fires either inadvertently (*e.g.*, wildfires), through arson, or as a disposal method which releases smoke containing particles and toxic pollutants such as carbon monoxide (CO), cyanide, sulfur dioxide, butadiene, and styrene (Singh et al., 2015). Such fires may burn out of control for many days or months, consuming millions of tires (Kordoghli et al., 2014; Singh et al., 2015). Assessment of an uncontrolled fire at a landfill showed emission of high concentrations of CO, CO_2, SO_2, fine particulate (PM2.5), and PAHs including nitrogen heteroatoms (azaarenes) and picene, which are also found in coal combustion (Downard et al., 2015).

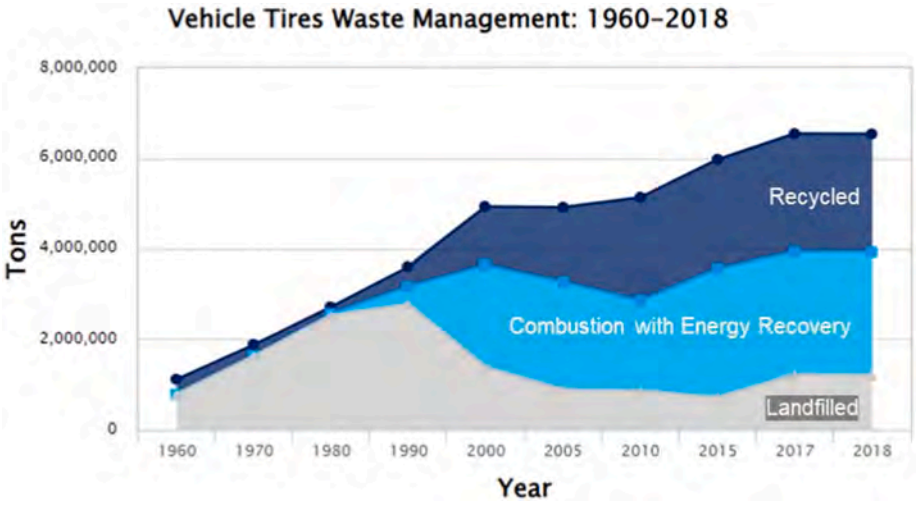


Fig. 5. Vehicle tires waste management: 1960–2018. Weights in US tons. Reprinted from https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/durable-goods-product-specific-data#VehicleTires.

In 2019, 75.6 % of scrap tires in the US and 95.6 % in the EU were processed in some manner that kept them out of landfills (USTMA, 2020; European Tyre and Rubber Manufacturer's Association, 2021). The three major categories of tire disposition other than deposit in landfills are energy production, recycling, and civil engineering. Whole tires are often used as fuel to generate electricity or for manufacturing processes (USTMA, 2020; Ruwona et al., 2019). For example, in the EU, 40 % of tires are burnt, mostly in cement kilns (Piotrowska et al., 2019). In the US, 100 million tires (1.4 million tons) were burned as fuel for cement kilns, paper industry, and industrial boilers (USTMA, 2020). Combusting tires for fuel is primarily employed in developed countries and mainly for cement manufacturing which requires significant energy consumption (Grammelis et al., 2021). The energy value of tires for fuel is equivalent to oil but produces fewer NOx emissions (Grammelis et al., 2021). However, the combustion of waste tires produces atmospheric pollutants such as dioxins, dibenzofurans, NO_x, SO_x, and heavy metals remain in the ash such as Zn, Mn, Cr, Pb which present disposal issues (Chen et al., 2022). However, Cu can be removed from industrial wastewater using tire ash as an absorbant (Mousavi et al., 2010). Tire ash is also often incorporated into asphalt and Portland cement (Al-Akhras and Smadi, 2004). Tires may also be pyrolyzed or gasified which provides higher energy efficiencies, produces less gaseous pollutants than combustion and enables recovery of by-products like Zn or char for activated carbon production and carbon black, though there are limits to the utility of this type of char due to impurities (Grammelis et al., 2021; Chen et al., 2022). While the gas, liquid, and solid (char) products from pyrolysis of tires are useful for energy production, carbon black, graphene, and others, further research and technologies are needed for tire pyrolysis to be a sustainable process for disposing tires at an industrial and economic scale (Kommineni et al., 2018; Gao et al., 2022).

Recycling tires yields rubber, steel, textile fibers, and carbon black (Fazli and Rodrigue, 2020). Rubber may be reused as fillers, in asphalt and road pavements, and in manufacturing of new tires, while recycled steel can replace anthracite and coke, and textile fibers which amount to about 5 % of the total mass of the tire, may be recycled or incorporated into products such as sound absorbing materials or mixed into plastics or cement for reinforcement, or as a geopolymer to reinforce soils (Dong et al., 2021; Grammelis et al., 2021). The second largest use of scrap tires in the US is for ground rubber. About 66 million tires (1 billion tons) are used in asphalt, sports surfaces, artificial mulch, and for other molded manufactured goods (USTMA, 2020). Europe disposes of over 51 % of scrap tires, including significant amounts of granulated rubber (ETRMA 2021). A smaller but still significant use of scrap tires is for civil engineering purposes (Grammelis et al., 2021), including backfilling and road construction (Table 2). Tires used as fuel can release potent carcinogenic particulates to the atmosphere including HCN, NOx, SOx, CO, and CO_2 (Glushankova et al., 2019). NOx and SOx emissions occur when tires are used to fuel combustion in cement kilns (Nakomcic-Smaragdakis et al., 2016). If facilities are designed properly, emissions from use of tires as fuel are unlikely to be greater than those from conventional fuels such as coal, coke, or wood (USEPA, 1997).

About 226,000 tons of tires were used in civil engineering projects in the US in 2019 (USTMA, 2020). Tire rubber pieces (tire-derived aggregate, crumb rubber) are sometimes used in stormwater capture and treatment systems (*e.g.*, bioretention) or as bottom fill for roadside drains (CalRecycle, 2016; Deng et al., 2016). Crumb rubber may remove some pollutants (*e.g.*, metals) from runoff (Deng et al., 2016). However, tire microplastics and tire-related chemicals may be released into urban runoff or groundwater (Moran et al., 2021) as may be the case for whole tires used in engineering such as for road fill and construction (Torretta et al., 2015). Shredded tires are sometimes used as landfill liners, which may pose risks from groundwater seepage and, in some cases, inadvertent burning (Downard et al., 2015). For example, tire-derived aggregates in stormwater management features can leach Fe, Cu, and Zn at levels above chronic criteria for aquatic biota (Singh et al., 2023).

Artificial turf installations use infill composed of crumb (ground) rubber microplastics created by cryomilling or granulation of whole used tires into microplastics 0.25–4 mm in size (USEPA, 2019). Turf installations can represent significant inputs of tire rubber to the environment with over 11,000 synthetic turf fields across the US (Perkins et al., 2019). In 2017, there were over 60,000 synthetic turf football fields and pitches in the EU, not including children's playgrounds or indoor recreation facilities (Skoczyńska et al., 2021). While crumb rubber loss estimates vary (Hann et al., 2018; Kole et al., 2017), the wide use of crumb rubber in the construction of artificial turf on football fields has prompted concerns about potential health risks of hazardous substances present in recycled rubber and a possible link to lymphoma and leukemia risk among sports players (Skoczyńska et al., 2021). These concerns, in part, led to the development of the "Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds" (USEPA, 2019). Human exposure to toxics from crumb rubber may be *via* inhalation, ingestion, or contact depending upon specific use of the playing surface as well as environmental factors such as temperature; for example, heavy metals may be inadvertently ingested from particles, while PAHs are more likely to be inhaled through off-gassing of turf during high temperatures (Armada et al., 2023; Perkins et al., 2019; Zhang et al., 2008). Chemical leaching from crumb rubber also has potential negative effects on aquatic biota (Halsband et al., 2020).

Road surfaces may contain tire crumb, either as a component of asphalt pavement (rubberized asphalt) or as a component of a surface coating (chip seal or slurry seal). In California, USA, while tire crumb rubber composes only a small fraction (about 1.6 %) of the final pavement by weight, each metric ton of pavement contains about 16 kg of crumb rubber (Caltrans, 2020). Particles released when rubberized asphalt, chip seal, and rubberized seal coats wear away are primarily rock and non-rubbery asphalt/tire crumb blends, though volumes of emissions from rubberized asphalt are currently unknown and questions remain on potential impacts to air and water pollution (Buttlar, 2021). Lokesh et al. (2023) found that rubberized asphalt concrete mixtures both sorbed and released 6PPD-q in leachates over time.

Overall, the fate of end-of-life tires is varied, and each end use has different environmental impacts, ranging from the virtual elimination from the waste stream (*e.g.*, incineration, incorporation into cement) to a continued presence (*e.g.*, asphalt, tire crumb) that requires additional disposal considerations (Sienkiewicz et al., 2012; Fazli and Rodrigue, 2020).

7. Regulation and legislation

Regulations and policies can reduce emissions and negative impacts from tire particles (Trudsø et al., 2022; https://unece.org/transport/vehicle-regulations). Policy instruments directed at multiple levels to address risks across the tire life cycle have the potential to affect the production, dispersal, or characteristics of tire pollutants (Johannesson and Lithner, 2022), including:

- tires (degradability, type of tire, wear propensity, tire pressure, hazardous substances).
- vehicles (weight, number of axles, engine power, acceleration, wheel alignment).
- road layout (engineering designs that encourage high speeds or sudden braking and acceleration).
- road operation and characteristics (snow clearing, road cleaning, road surfacing material, management of stormwater, presence of roadside vegetation).
- traffic patterns (physical planning, public transport, taxes, parking fees).

Various countries and jurisdictions are using guidance and regulatory tools to address management of tire pollutants. For example, legislation in Europe addressing tires as hazardous waste dates to 1975 while other legislation over years has addressed disposal of tires, shipment of waste, and "polluter pays" principles (Grammelis et al., 2021). In the EU, there are three options for managing end-of-life tires: a) Extended Producer Responsibility where the producer is fully or partially responsible for an end-of-life product; b) Free Market System where countries operate under specific contract agreements and often report to respective regulatory agencies (*e.g.* Austria, Switzerland, Germany, and the UK; c) Tax System where a tax is imposed upon tire producers, which is indirectly paid by the consumer (*e.g.* Croatia and Denmark).

The World Forum for Harmonization of Vehicle Regulations (WP.29), part of the United Nations Economic Commission for Europe, issued global technical guidance for regulation of tires (Global Technical Regulation no.16; UNECE, 2014) with environmental and performance-oriented test requirements. These regulations encompass tire wear indicators but not tire wear particles or emissions of other tire-derived chemicals. World Forum regulations are not enforceable. Rather, contracting parties agree to adopt regulations and enforce respectively (UNECE, 2014). Under-inflated tires release more wear particles than those properly inflated. The European Parliament and Council required all new passenger vehicles in the European Union to be fitted with tire pressure monitoring systems beginning in 2014. The US, China, Taiwan, and South Korea (van Zyl et al., 2013) also mandate tire pressure monitoring systems. The Regulation of the European Parliament and Council (EU 2020/740) on tire labeling includes provisions for adding parameters on tire abrasion and when tires need to be replaced due to wear (European Council, 2020). Currently, the only European Union restriction on chemical content of tires is a PAH limit of 1 mg/kg for benzo[*a*]pyrene (BaP) and 10 mg/kg for the sum of PAHs. The Austrian National Road Administration requires that road runoff is treated when the annual daily traffic reaches 15,000 vehicles/day and road tunnel wash water in Austria is not allowed to be discharged untreated (Meland, 2016). In Switzerland, if a new road project is projected to have >14,000 vehicles/day, runoff water will be required to discharge through an appropriate treatment system (Meland, 2016). Similarly, in Ireland, wash water from road tunnels in Ireland is sent to wastewater treatment plants (Meland, 2016). In Poland, permits are required for runoff and many require water treatment such as oil interceptors, small sedimentation tanks, infiltration ponds, wet ponds, and post-construction discharge monitoring for sediment (100 mg/L) and hydrocarbons (15 mg/L; Meland, 2016). In the US, California has proposed regulating microplastics (California State Water Resources Control Board, 2023) and has finalized a regulation that lists vehicle tires containing 6PPD under its Safer Consumer Products regulations (https://dtsc.ca.gov/scp/motor_vehicle_tires_containing_6ppd/). For particles associated with artificial turf and crumb rubber, there is recognition globally of the risks associated with the microplastics, PAHs, heavy metals, and PFAS chemicals of these rubber particles, though few countries and jurisdictions, with perhaps exception of the EU, have implemented adequate regulations and surveillance to address health risks and limit human exposure (Zuccaro et al., 2022).

8. Data gaps and research needs

While there has been an upsurge in tire related research, many data gaps remain that require attention to develop effective comprehensive approaches to managing risks (Wang et al., 2023). Research has been concentrated among US, China, and Europe with lesser focus in Africa or Asia (Wang et al., 2023). While our synthesis here is intended to be global, we acknowledge a limitation of our study in that there are fewer data and studies from developing countries and, as such, understanding the diverse nature of tire pollution and identifying effective solutions will require more work in regions outside the US, EU, and China where policies and infrastructure may not be adequate to address the complexities of risk management. Addressing the following data gaps and priority research areas will allow for more comprehensive and effective strategies to mitigate and prevent the effects of tire particles and tire-derived chemicals on the diverse terrestrial, aquatic, and marine ecosystems that become the sinks of these contaminants.

8.1. Tire production and use

Determining the complete and quantitative chemical composition of tire rubbers remains a critical and pressing research need, meriting systemic and intensive global effort. Study of how tire particles may vary across commonly used brands and tire types (*e.g.*, snow tires, tires from hybrid and electric cars) and associated road wear, including particles from brake pads and mixtures with other particle types such as fibers being emitted from roadways (described in Brahney et al., 2021) is greatly needed. Data on which types of tires have the most use and tire wear particle emissions would help guide risk assessments of tire particles and tire-derived chemicals.

Given the ubiquitous nature of transportation, tires, and tire wear particles, this legacy pollutant footprint in the environment has the potential to be extensive. Developing multi-scalar and multi-disciplinary strategies for prioritizing mitigations for sensitive species population declines could support smarter transportation infrastructure planning.

8.2. Fate and transport

Given that there are thousands of compounds associated with tire leachate, including many compounds with considerable known toxicity, efforts to elucidate chemical structures of environmentally relevant tire contaminants remains a high priority. The fate and transport of tire wear particles is challenging due to special and temporal variation in the environment and by lack of standardized sampling methods as well as variability in tire composition and proprietary formulations which preclude adoption of analytical markers (Khan et al., 2024). Monitoring data of tire particles and many tire-derived chemicals remains limited, often due to a lack of reliable methods to extract and quantify them. Quantifying concentrations of tire particles and tire-related chemicals across environmental phases (*e.g.*, urban runoff and wet and dry air deposition) are needed to understand the fate and transport of tire particles and tire-derived contaminants (Halle et al., 2020). Different sample matrices and the broad size distribution of tire microplastics require different methodologies to characterize and quantify tire microplastics in environmental samples, creating challenges for estimating their environmental fate and transport, as well as comparing data across studies (Luo et al., 2021; Wagner et al., 2018). Development of accurate sample collection, separation, and quantification methods for tire particles spanning the full particle size distribution and comprising different sample matrices (*e.g.*, sediment, ambient surface water *vs.* effluent/stormwater, tissue, *etc.*) is needed to better characterize the fate and transport of tire particles (Baensch-Baltruschat et al., 2021; Halle et al., 2020; Luo et al., 2021).

Better characterization (*e.g.*, size, shape, surface properties) of tire particles and determination of how particle characteristics affect particle fate and transport, as well as the formation and release of tire-related chemicals and their degradates is also needed. Larger tire particles are relatively easy to identify visually in environmental samples given their color and rubbery character (Gray et al., 2018; Miller et al., 2021), but are challenging to characterize analytically using commonly available instrumentation due to their high carbon content (Nava et al., 2021). Measuring the proportion of common environmental contaminants such as heavy metals and PAHs that tires are contributing to the environment relative to other sources would also help prioritize and focus source control efforts.

8.3. Biological and ecological effects

Like all microplastic types, it is critical to understand toxicological concerns centering on both the associated chemicals and the particles themselves. Toxicity testing is essential to fully understand both the physical and chemical impacts of tire particles. Toxicity experiments should reflect the size range of tire particles thought to be released into the environment, including the fine and ultrafine particles <1 μm. Research on the combined toxicity of tire-related chemicals and the particles themselves is also necessary to determine the true impact on both aquatic and terrestrial ecosystems, and humans. These studies should be coupled with investigations into the fate of tire-derived chemicals of high ecological concern, such as 6PPD and Zn, since it is not yet clear what chemical concentrations continue to be associated with particles once they are emitted into the environment and following weathering. As many tire-associated chemicals are not unique to tires and have well-understood hazards, researchers should draw upon existing toxicological data to help prioritize which chemical constituents found in tires may be most hazardous to biota. Studies of other micro- and nanoplastic particle types indicate that chemicals may largely leach out prior to internalization (Koelmans, 2015), yet because stabilizers such as 6PPD can be acutely toxic to sensitive species at low concentrations (Tian et al., 2021a), continued assessment of the fate and toxicity of chemicals used in the manufacture of tires and those suggested as replacements for toxic additives should be conducted. Additionally, the prediction of the toxic transformation products (*e.g.* 6PPD-quinone) will be challenging or impossible without additional manufacturer information which often is restricted or proprietary.

Determining differences in effects across different tire particle properties such as particle size, chemical composition, and level of degradation, as well as across both common lab species and more sensitive species will help inform risk assessment and prioritize remediation efforts. Species-specific ecotoxicology studies will help inform what corresponding habitats are most susceptible to tire emission exposure. Overall, the duration of most current toxicological investigations (usually only tens days) is one of the greatest drawbacks of these studies when the results need to be extrapolated to populations, communities, and ecosystems. Chronic, multigenerational exposures in the environment may lead to a reduction in the size of populations and to negative effects in communities and ecosystems. There is thus a need to conduct longer and *in-situ* exposures to discern community- and ecosystem-level effects of tire particles and associated chemicals over longer time horizons and across different ecosystems. New genomics tools may make these types of assessments more feasible and accurate (*e.g.* Giroux et al., 2023). Landscape-scale risk assessments would help focus source identification and reconnaissance studies. Few studies have addressed human health risks of tire wear particles or associated tire-derived chemicals (Wang et al., 2023).

8.4. Management and remediation

Toxic source control becomes more complex and challenging the further away from the source it travels. Focusing on prevention over remediation is therefore imperative. The range of solutions to plastic pollution, including tire particles, can be sorted by cost and harm, with design and material solutions having lowest cost and harm and recycling and cleanup at the high end of the cost-harm continuum (Erdle and Eriksen, 2023). Furthermore, because tires are a complex mixture of constituents, there must be tailored solutions for each category of pollutant and stage in the tire life cycle (Erdle and Eriksen, 2023). Understanding how watershed and climate characteristics, particularly under a rapidly changing climate, may drive tire emission pollution to vulnerable ecological areas will help determine where, when, and how often to mitigate tire wear emissions across various land uses.

The ability to measure and quantify tire emissions among water, sediment, air, and biota is critical to support the efficacy of toxic cleanup and reduction strategies. Emissions estimates based on measured data rather than summarized databases are critically needed to judge environmental loads locally and regionally (Khan et al., 2024). The variability in geographic attributes such as climate, geology, land use, vulnerable species distribution, population density, transportation infrastructure, and water quality regulations will determine the fate, transport, and biological exposure of tire emissions. For example, preliminary monitoring efforts have revealed that 6PPD-quinone is found ubiquitously in tires and on transportation pavement, yet its prevalence in receiving waters or sediments is more variable and less well understood (Rauert et al., 2022; Zeng et al., 2023).

Testing BMPs for tire particle and chemical removal efficiency to understand their stormwater treatment effectiveness is needed. Green infrastructure approaches like constructed wetlands, bioretention, and filtration features are promising BMPs for tire particle capture, but more research is needed on measuring efficacy based on multiple variables such as particle size and mobility as well as inflow rate and storm intensity (Wei et al., 2023). For BMPs such as bioretention gardens that are known to remove particles, further optimization (*e.g.*, identifying optimal soil media mixtures and maintenance cycles; Bollman et al., 2019) is a critical need. Other emerging technologies have proved effective at removing other types of microplastics, including acoustic waves (Akiyama et al., 2020), electrocoagulation (Perren et al., 2018), photocatalysis (Koe et al., 2020), magnetic extraction (Grbic et al., 2019), and spider webs (Goßmann et al., 2022), and may also be promising for tire particles and/or tire-derived chemicals. It will also be

necessary to identify the role of these BMPs as hot spots, biogeochemical reactors for transformations and/or entry pathways for tire particles or the pollutants they carry into local trophic chains.

8.5. Recycling, reuse, and disposal

Although the efforts to reuse and recycle tires at their end-of-life stage have increased (Shulman, 2019), new technologies and efforts are needed to increase the circularity of tire materials even further. Finding recycling, reuse, and disposal strategies for tires that minimize release of toxicants to the environment is critical. Thus, while more tire emissions will likely be generated in developed countries *versus* developing countries by virtue of the larger number of vehicles and more roads, the recycling infrastructure and/or pollution abatement services may be more readily available or effective. Conversely, developing countries may have fewer vehicles and therefore fewer emissions, the infrastructure and/or policy mechanisms may be lacking to deal with tire recycling or the associated pollution emissions. Technological solutions for capturing tire wear particles will likely progress more rapidly if the scientific community can effectively collaborate with the tire industry (Khan et al., 2024).

8.6. Data management and toxicity assessment

There are many needs to be addressed regarding data management associated with chemicals and toxicity associated with tires, whether they be initial constituents making up the tires or, as in the case of 6PPD-quinone, the transformation products associated with parent chemicals. For toxicological assessment, there is a critical need to elucidate both particle and leachate effects and to distinguish among the effects of single emerging chemicals as well as chemical cocktails and any transformation products (Khan et al., 2024). The aggregation of relevant data, whether experimental or predicted, has been addressed by systems including PubChem (https://pubchem.ncbi.nlm.nih.gov/), and ChemSpider (http://www.chemspider.com/; Pence and Williams, 2010) which provide access to 116 million and 128 million, respectively (as of December 2023). Currently, only the CompTox Chemicals Dashboard (Williams et al., 2017; https://comptox.epa.gov/dashboard/) provides access to an aggregated list of chemicals with associated, curated property and toxicity data for over 1.2 million chemical substances (as of December 2023). These data include physicochemical properties, fate and transport data, *in vivo* and *in vitro* toxicity, and exposure data. Chemicals can be searched individually or in batches of thousands of chemical identifiers (Lowe and Williams, 2021). The Dashboard can provide detailed information for chemicals such as 6PPD or summarized showing quantitative hazard data and *in vitro* bioactivity screening data. The Dashboard also lists tire crumb rubber chemicals based on data contained within the Federal Research Action Plan (FRAP) on Recycled Tire Crumb Used on Playing Fields and Playgrounds. Data can be harvested en masse by passing any list through the batch search. Note that many parameters are predicted *versus* measured which may represent significant uncertainty in ascertaining toxic effects. A new suite of prototype cheminformatics tools is publicly available with a hazard profile module allowing for comparison of toxicity effects across sets of chemicals including experimental and predicted human health effects, ecotoxicity, and fate (Vegosen and Martin, 2020).

9. Conclusion

Tires are a complex pollutant consisting of particles and chemicals that can be transported by air, water, and terrestrial pathways. The life cycle of tires spans production, use, and disposal. There are thousands of known and potentially toxic compounds contained in tires. Tires can pose risks to environmental and human health across the entire life cycle. Mitigating these risks is challenging given the volume of tires in use and produced as waste. Tire emissions may be in the form of whole tires, tire particles, and chemical compounds. Production and use of tires generates multiple heavy metals, radioactive compounds, and nutrients that can be toxic alone or as chemical cocktails. Tire particles emitted during use is a major component of microplastics in urban runoff and a source of unique and highly potent toxic substances, many of which are currently unknown or poorly described. Source control such as reducing the need for tires, recycling, or reuse is easier than remediating particles or chemicals that are released to the environment. Pollution from tires must be examined holistically across production, emissions, recycling, and disposal to develop effective management and remediation. There are many gaps in our knowledge about fate and transport, and toxicology of tire particles and leachates. Further research is needed to characterize the gamut of effects from tire pollution and to identify effective methods of remediation and risk management across environmental, socioeconomic, and political boundaries. However, it is currently clear that tire wear particles and their chemical cocktails are emerging contaminants of global concern, and that action should therefore be taken to reduce the risks to human health and the environment.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2024.171153.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

The information in this document has been subjected to United States Environmental Protection Agency (Agency) peer and administrative review, and it has been approved for publication as an Agency document. The views expressed in this article are those of the authors and do not necessarily represent the views or policies of the Agency. Any mention of trade names, products, or services does not imply an endorsement by the United States Government or the Agency. The authors declare no competing or conflicting interests. SJH currently works for an environmental consulting firm that provides technical support related to TWPs to private and public stakeholders. We thank V. Nicole Deycard, Mark Jankowski, Patti Meeks, David Olszyk, and Ruth Sofield for their astute reviews and comments on earlier drafts. We thank Christine Philippsen and Rhea Smith for creating the graphic abstract. Funding for this manuscript was supported by the California Ocean Protection Council (Agreement No. C0831015), the Regional Monitoring Program for Water Quality in San Francisco Bay, and the National Science Foundation Growing Convergence Research Big Idea, grant #1935028. Victor Carrasco-Navarro received funding from the Finnish Cultural Foundation (grant #00200215) and the University of Eastern Finland through a grant to J.V.K. Kukkonen. We thank Jaqueline Doremus (California Polytechnic State University), Chris Sommers (EOA, Inc.), and staff and representatives from California State Water Board, CalRecycle, and California Department of Toxic Substance Control for their thoughtful input, and Ruth Askevold for design input.

References

Adachi, K., Tainosho, Y., 2004. Characterization of heavy metal particles embedded in tire dust. Environ. Int. 30, 1009–1017. https://doi.org/10.1016/j.envint.2004.04.004.

Adamiec, E., Jarosz-Krzemińska, E., Wieszała, R., 2016. Heavy metals from non-exhaust vehicle emissions in urban and motorway road dusts. Environ. Monit. Assess. 188, 369. https://doi.org/10.1007/s10661-016-5377-1.

Akiyama, Y., Egawa, T., Koyano, K., Moriwaki, H., 2020. Acoustic focusing of microplastics in microchannels: a promising continuous collection approach. Sens. Actuators B 304, 127328. https://doi.org/10.1016/j.snb.2019.127328.

Al-Akhras, N.M., Smadi, M.M., 2004. Properties of tire rubber ash mortar. Cem. Concr. Compos. 26, 821–826.

Alexandrova, O., Kaloush, K.E., Allen, J.O., 2007. Impact of asphalt rubber friction course overlays on Tire Wear emissions and air quality models for Phoenix, Arizona, Airshed. Transp. Res. Rec. 2011, 98–106. https://doi.org/10.3141/2011-11.

Allen, S., Allen, D., Moss, K., Roux, G.L., Phoenix, V.R., Sonke, J.E., 2020. Examination of the ocean as a source for atmospheric microplastics. PloS One 15, e0232746. https://doi.org/10.1371/journal.pone.0232746.

Alsbou, E.M.E., Al-Khashman, O.A., 2017. Heavy metal concentrations in roadside soil and street dust from Petra region. Jordan. Environ Monit Assess 190, 48. https://doi.org/10.1007/s10661-017-6409-1.

Alves, C.A., Vicente, E.D., Vicente, A.M.P., Rienda, I.C., Tomé, M., Querol, X., Amato, F., 2020. Loadings, chemical patterns and risks of inhalable road dust particles in an Atlantic city in the north of Portugal. Sci. Total Environ. 737, 139596. https://doi.org/10.1016/j.scitotenv.2020.139596.

Amato, F., Querol, X., Johansson, C., Nagl, C., Alastuey, A., 2010. A review on the effectiveness of street sweeping, washing and dust suppressants as urban PM control methods. Sci. Total Environ. 408, 3070–3084. https://doi.org/10.1016/j.scitotenv.2010.04.025.

American Society of Civil Engineers, 1998. Urban Runoff Quality Management. Water Environ. Fed., 1572780398. ISBN:9781572780392.

Amick, S., 2018. Sustainability: Driving the US Tire Manufacturing Industry. U.S., Tire Manufacturers Association. https://www.ustires.org/sustainability-driving-force-us-tire-manufacturing-industry.

Armada, D., Martinez-Fernandez, A., Celeiro, M., Dagnac, T., Llompart, M., 2023. Assessment of the bioaccessibility of PAHs and other hazardous compounds present in recycled tire rubber employed in synthetic football fields. Sci. Total Environ. 857, 159485 https://doi.org/10.1016/j.scitotenv.2022.159485.

Aslam, J., Khan, S.A., Khan, S.H., 2013. Heavy metals contamination in roadside soil near different traffic signals in Dubai, United Arab Emirates. J. Saudi Chem. Soc. 17, 315–319. https://doi.org/10.1016/j.jscs.2011.04.015.

Averill, C., Waring, B., 2018. Nitrogen limitation of decomposition and decay: how can it occur? Glob. Chang. Biol. 24, 1417–1427. https://doi.org/10.1111/gcb.13980.

Baensch-Baltruschat, B., Kocher, B., Stock, F., Reifferscheid, G., 2020. Tyre and road wear particles (TRWP) - a review of generation, properties, emissions, human health risk, ecotoxicity, and fate in the environment. Sci. Total Environ. 733, 137823 https://doi.org/10.1016/j.scitotenv.2020.137823.

Baensch-Baltruschat, B., Kocher, B., Kochleus, C., Stock, F., Reifferscheid, G., 2021. Tyre and road wear particles - a calculation of generation, transport and release to water and soil with special regard to German roads. Sci. Total Environ. 752, 141939 https://doi.org/10.1016/j.scitotenv.2020.141939.

Bellas, J., Thor, P., 2007. Effects of selected PAHs on reproduction and survival of the calanoid copepod *Acartia tonsa*. Ecotoxicology 16, 465–474. https://doi.org/10.1007/s10646-007-0152-2.

Blanck, H., 2002. A critical review of procedures and approaches used for assessing pollution-induced community tolerance (PICT) in biotic communities. Hum. Ecol. Risk Assess. Int. J. 8, 1003–1034. https://doi.org/10.1080/1080-700291905792.

Blok, J., 2005. Environmental exposure of road borders to zinc. Sci. Total Environ. 348, 173–190. https://doi.org/10.1016/j.scitotenv.2004.12.073.

Bohara, K., Timilsina, A., Adhikari, K., Kafle, A., Basyal, S., Joshi, P., Yadav, A.K., 2024. A mini review on 6PPD quinone: a new threat to aquaculture and fisheries. Environ. Pollut. 340, 122828 https://doi.org/10.1016/j.envpol.2023.122828.

Bollman, M.A., DeSantis, G.E., DuChanois, R.M., Etten-Bohm, M., Olszyk, D.M., Lambrinos, J.G., Mayer, P.M., 2019. A framework for optimizing hydrologic performance of green roof media. Ecol. Eng. 140, 105589 https://doi.org/10.1016/j.ecoleng.2019.105589.

Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans: A Global Evaluation of Sources. IUCN, Gland, Switzerland.

Brahney, J., Mahowald, N., Prank, M., Cornwell, G., Klimont, Z., Matsui, H., Prather, K. A., 2021. Constraining the atmospheric limb of the plastic cycle. Proc. Natl. Acad. Sci. 118, e2020719118 https://doi.org/10.1073/pnas.2020719118.

Brander, S.M., Hoh, E., Unice, K.M., Bibby, K.R., Cook, A.M., Holleman, R.C., Kone, D.V., Rochman, C.M., Thayer, J.A., 2021. Microplastic Pollution in California: A Precautionary Framework and Scientific Guidance to Assess and Address Risk to the Marine Environment. California Ocean Science Trust, Sacramento, California, USA.

Brander, S.M., König, A., Carney, B.A., Thornton Hampton, L., 2024. The potential for toxicity to fishes from Micro and Nanoplastics, and their additives. In: Willet, K., Aluru, N. (Eds.), The Toxicology of Fishes. CRC Press, Boca Raton, Florida, USA.

Brinkmann, M., Montgomery, D., Selinger, S., Miller, J.G.P., Stock, E., Alcaraz, A.J., Challis, J.K., Weber, L., Janz, D., Hecker, M., Wiseman, S., 2022. Acute toxicity of the Tire rubber-derived chemical 6PPD-quinone to four fishes of commercial, cultural, and ecological importance. Environ. Sci. Technol. Lett. 9, 333–338. https://doi.org/10.1021/acs.estlett.2c00050.

Bucci, K., Tulio, M., Rochman, C.M., 2020. What is known and unknown about the effects of plastic pollution: a meta-analysis and systematic review. Ecol. Appl. 30, e02044 https://doi.org/10.1002/eap.2044.

Büks, F., Kaupenjohann, M., 2020. Global concentrations of microplastics in soils – a review. SOIL 6, 649–662. https://doi.org/10.5194/soil-6-649-2020.

Buttlar, W.G., 2021. State of Knowledge Report on Rubber Modified Asphalt. Tire Manufacturers Association, U.S.. https://www.ustires.org/sites/default/files/2021-06/Rubber-Modified-Asphalt_5-27-2021-FINAL.pdf

Cadle, S.H., Williams, R.L., 1978. Gas and particle emissions from automobile tires in laboratory and Field studies. J. Air Pollut. Control Assoc. 28, 502–507. https://doi.org/10.1080/00022470.1978.10470623.

California Department of Toxic Substances Control, 2021. Three year priority product work plan (2021−2023). Safer Consumer Products Program. https://dtsc.ca.gov/wp-content/uploads/sites/31/2021/04/Final-2021-2023-Priority-Product-Work-Plan.pdf.

California State Water Resources Control Board, 2023. 2024 California Integrated Report. Surface Water Quality Assessments.

CalRecycle. 2016. Evaluation of Tire Derived Aggregate (TDA) as a Media for Stormwater Treatment; Sacramento, California, USA, 2016. https://www2.calrecycle.ca.gov/Publications/Download/1338?opt=dln.

CalRecycle. 2019. California Waste Tire Market Report: 2018; Prepared for CalRecycle by Boisson Consulting. https://www2.calrecycle.ca.gov/Publications/Download/1417.

CalRecycle. 2020. California Waste Tire Market Report: 2019; Prepared for CalRecycle by Boisson Consulting. https://www2.calrecycle.ca.gov/Publications/Download/1593.

CalRecycle. 2021. California Waste Tire Market Report: 2020; Prepared for CalRecycle by Boisson Consulting, 2021. https://www2.calrecycle.ca.gov/Publications/Download/1748.

Caltrans. 2021. Hydraulics and Stormwater;. https://dot.ca.gov/programs/design/hydraulics-stormwater.

Cao, G., Wang, W., Zhang, J., Wu, P., Zhao, X., Yang, Z., Hu, D., Cai, Z., 2022. New evidence of rubber-derived Quinones in water, air, and soil. Environ. Sci. Technol. 56, 4142–4150. https://doi.org/10.1021/acs.est.1c07376.

Capolupo, M., Sorensen, L., Jayasena, K.D.R., Booth, A.M., Fabbri, E., 2020. Chemical composition and ecotoxicity of plastic and car tire rubber leachates to aquatic organisms. Water Res. 169, 115270 https://doi.org/10.1016/j.watres.2019.115270.

Carrasco-Navarro, V., Muñiz-González, A.-B., Sorvari, J., Martínez-Guitarte, J.-L., 2021. Altered gene expression in Chironomus riparius (insecta) in response to tire rubber and polystyrene microplastics. Environ. Pollut. 285, 117462 https://doi.org/10.1016/j.envpol.2021.117462.

Carrasco-Navarro, V., Nuutinen, A., Sorvari, J., Kukkonen, J.V.K., 2022. Toxicity of Tire rubber microplastics to freshwater sediment organisms. Arch. Environ. Contam. Toxicol. 82, 180–190. https://doi.org/10.1007/s00244-021-00905-4.

Castan, S., Sherman, A., Peng, R., Zumstein, M.T., Wanek, W., Hüffer, T., Hofmann, T., 2023. Uptake, metabolism, and accumulation of Tire Wear particle-derived compounds in lettuce. Environ. Sci. Technol. 57, 168–178. https://doi.org/10.1021/acs.est.2c05660.

Celeiro, M., Armada, D., Ratola, N., Dagnac, T., de Boer, J., Llompart, M., 2021. Evaluation of chemicals of environmental concern in crumb rubber and water leachates from several types of synthetic turf football pitches. Chemosphere 270. https://doi.org/10.1016/j.chemosphere.2020.128610.

Challis, J.K., Popick, H., Prajapati, S., Harder, P., Giesy, J.P., McPhedran, K., Brinkmann, M., 2021. Occurrences of Tire rubber-derived contaminants in cold-climate urban runoff. Environ. Sci. Technol. Lett. 8, 961–967. https://doi.org/10.1021/acs.estlett.1c00682.

Chang, S., Bao, H., Huang, W., 2022. Size-dependent Redispersion or agglomeration of ag clusters on CeO2. J. Phys. Chem. C 126, 11537–11543. https://doi.org/10.1021/acs.jpcc.2c01207.

Chen, B., Zheng, D., Xu, R., Leng, S., Han, L., Zhang, Q., Liu, N., Dai, C., Wu, B., Yu, G., Cheng, J., 2022. Disposal methods for used passenger car tires: one of the fastest growing solid wastes in China. Green Energy and Environment 7, 1298–1309. https://doi.org/10.1016/j.gee.2021.02.003.

Chibwe, L., Parrott, J.L., Shires, K., Khan, H., Clarence, S., Lavalle, C., Sullivan, C., O'Brien, A.M., De Silva, A.O., Muir, D.C.G., Rochman, C.M., 2022. A deep dive into the complex chemical mixture and toxicity of Tire Wear particle leachate in fathead minnow. Environ. Toxicol. Chem. 41, 1144–1153. https://doi.org/10.1002/etc.5140.

Clary, J., Jones, J., Leisenring, M., Hobson, P., Strecker, E., 2020. International Stormwater BMP Database: 2020 Summary Statistics. The Water Research Foundation.

Clean Production Action, 2021. Green Screen for Safer Chemicals. https://www.greenscreenchemicals.org.

Cleveland, L., Little, E.E., Ingersoll, C.G., Wiedmeyer, R.H., Hunn, J.B., 1991. Sensitivity of brook trout to low pH, low and elevated aluminum concentrations during laboratory pulse exposures. Aquat. Toxicol. 19, 303–317. https://doi.org/10.1016/0166-445X(91)90055-E.

Coffin, S., Weisberg, S.B., Rochman, C., Kooi, M., Koelmans, A.A., 2022. Risk characterization of microplastics in San Francisco Bay. California. Microplastics and Nanoplastics 2, 19. https://doi.org/10.1186/s43591-022-00037-z.

Collivignarelli, M.C., Abbà, A., Benigna, I., Sorlini, S., Torretta, V., 2018. Overview of the Main disinfection processes for wastewater and drinking water treatment plants. Sustainability 10, 86. https://doi.org/10.3390/su10010086.

Cooper, C.A., Mayer, P.M., Faulkner, B.R., 2014. Effects of road salts on groundwater and surface water dynamics of sodium and chloride in an urban restored stream. Biogeochemistry 121, 149–166. https://doi.org/10.1007/s10533-014-9968-z.

Cornall, A., Rose, A., Streten, C., McGuinness, K., Parry, D., Gibb, K., 2016. Molecular screening of microbial communities for candidate indicators of multiple metal impacts in marine sediments from northern Australia. Environ. Toxicol. Chem. 35, 468–484. https://doi.org/10.1002/etc.3205.

Councell, T.B., Duckenfield, K.U., Landa, E.R., Callender, E., 2004. Tire-wear particles as a source of zinc to the environment. Environ. Sci. Technol. 38, 4206–4214. https://doi.org/10.1021/es034631f.

Cribiu, P., Devaux, A., Garnero, L., Abbaci, K., Bastide, T., Delorme, N., Quéau, H., Degli Esposti, D., Ravanat, J.-L., Geffard, O., Bony, S., Chaumot, A., 2020. A "population dynamics" perspective on the delayed life-history effects of environmental contaminations: An illustration with a preliminary study of cadmium transgenerational effects over three generations in the crustacean Gammarus. Int. J. Mol. Sci. 21, 4704. https://doi.org/10.3390/ijms21134704.

Cunningham, B., Harper, B., Brander, S., Harper, S., 2022. Toxicity of micro and nano tire particles and leachate for model freshwater organisms. J. Hazard. Mater. 429, 128319 https://doi.org/10.1016/j.jhazmat.2022.128319.

Cunningham, B.E., Sharpe, E.E., Brander, S.M., Landis, W.G., Harper, S.L., 2023. Critical gaps in nanoplastics research and their connection to risk assessment. Front. Toxicol. 5, 1154538. https://doi.org/10.3389/ftox.2023.1154538.

Dabic-Miletic, S., Simic, V., Karagoz, S., 2021. End-of-life tire management: a critical review. Environ. Sci. Pollut. Res. 28, 68053–68070. https://doi.org/10.1007/s11356-021-16263-6.

Dahl, A., Gharibi, A., Swietlicki, E., Gudmundsson, A., Bohgard, M., Ljungman, A., Blomqvist, G., Gustafsson, M., 2006. Traffic-generated emissions of ultrafine particles from pavement–tire interface. Atmos. Environ. 40, 1314–1323. https://doi.org/10.1016/j.atmosenv.2005.10.029.

Dajić, A., Mihajlović, M., Jovanović, M., Karanac, M., Stevanović, D., Jovanović, J., 2016. Landfill design: need for improvement of water and soil protection requirements in EU landfill directive. Clean Techn. Environ. Policy 18, 753–764. https://doi.org/10.1007/s10098-015-1046-2.

David, V., Joachim, S., Porcher, J.-M., Beaudouin, R., 2019. Modelling BPA effects on three-spined stickleback population dynamics in mesocosms to improve the understanding of population effects. Sci. Total Environ. 692, 854–867. https://doi.org/10.1016/j.scitotenv.2019.07.274.

de Peufeilhoux, E., Hassaïri, P., Huet, F., 2021. Tire and Road Wear Particles State of Knowledge. https://reifenpresse.de/wp-content/uploads/2021/02/Michelin-2020.pdf.

Degaffe, F.S., Turner, A., 2011. Leaching of zinc from tire wear particles under simulated estuarine conditions. Chemosphere 85, 738–743. https://doi.org/10.1016/j.chemosphere.2011.06.047.

Deng, Y., Morris, C., Rakshit, S., Landa, E., Punamiya, P., Sarkar, D., 2016. Water treatment residuals and scrap Tire rubber as green sorbents for removal of Stormwater metals. Water Environ. Res. 88, 500–509. https://doi.org/10.2175/106143016X14504669768697.

Di, S., Liu, Z., Zhao, H., Li, Y., Qi, P., Wang, Z., Xu, H., Jin, Y., Wang, X., 2022. Chiral perspective evaluations: enantioselective hydrolysis of 6PPD and 6PPD-quinone in water and enantioselective toxicity to *Gobiocypris rarus* and *Oncorhynchus mykiss*. Environ. Int. 166, 107374 https://doi.org/10.1016/j.envint.2022.107374.

Ding, Q., Huang, X., Hu, H., Hong, M., Zhang, D., Wang, K., 2017. Impact of pyrene and cadmium co-contamination on prokaryotic community in coastal sediment microcosms. Chemosphere 188, 320–328. https://doi.org/10.1016/j.chemosphere.2017.08.124.

Ding, J., Lv, M., Wang, Q., Zhu, D., Chen, Q., Li, X., Yu, C., Xu, X., Chen, L., Zhu, Y., 2023. Brand-Specific toxicity of tire tread particles helps identify the determinants of toxicity. Environ. Sci. Technol. 57, 11267–11278. https://doi.org/10.1021/acs.est.3c02885.

Ding, J., Zhu, D., Wang, H.-T., Lassen, S.B., Chen, Q.-L., Li, G., Lv, M., Zhu, Y.-G., 2020. Dysbiosis in the gut microbiota of soil Fauna explains the toxicity of Tire tread particles. Environ. Sci. Technol. 54, 7450–7460. https://doi.org/10.1021/acs.est.0c00917.

Dong, Y., Zhao, Y., Hossain, Md.U., He, Y., Liu, P., 2021. Life cycle assessment of vehicle tires: a systematic review. Cleaner Environmental Systems 2, 100033. https://doi.org/10.1016/j.cesys.2021.100033.

Donkers, J.M., Höppener, E.M., Grigoriev, I., et al., 2022. Advanced epithelial lung and gut barrier models demonstrate passage of microplastic particles. Micropl. Nanopl. 2, 6. https://doi.org/10.1186/s43591-021-00024-w.

Downard, J., Singh, A., Bullard, R., Jayarathne, T., Rathnayake, C.M., Simmons, D.L., Wels, B.R., Spak, S.N., Peters, T., Beardsley, D., Stanier, C.O., Stone, E.A., 2015. Uncontrolled combustion of shredded tires in a landfill – part 1: characterization of gaseous and particulate emissions. Atmos. Environ. 104, 195–204. https://doi.org/10.1016/j.atmosenv.2014.12.059.

Du, B., Liang, B., Li, Y., Shen, M., Liu, L.-Y., Zeng, L., 2022. First Report on the occurrence of N-(1,3-Dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD) and 6PPD-Quinone as pervasive pollutants in human urine from South China. Environ. Sci. Technol. Lett. 9, 1056–1062. https://doi.org/10.1021/acs.estlett.2c00821.

Duan, S., Mayer, P.M., Kaushal, S.S., Wessel, B.M., Johnson, T., 2019. Regenerative stormwater conveyance (RSC) for reducing nutrients in urban stormwater runoff depends upon carbon quantity and quality. Sci. Total Environ. 652, 134–146. https://doi.org/10.1016/j.scitotenv.2018.10.197.

Duis, K., Coors, A., 2016. Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. Environ. Sci. Eur. 28, 2. https://doi.org/10.1186/s12302-015-0069-y.

Elmore, A.J., Kaushal, S.S., 2008. Disappearing headwaters: patterns of stream burial due to urbanization. Front. Ecol. Environ. 6, 308–312. https://doi.org/10.1890/070101.

Erdle, L.M., Eriksen, M., 2023. Monitor compartments, mitigate sectors: a framework to deconstruct the complexity of plastic pollution. Mar. Pollut. Bull. 193, 115198 https://doi.org/10.1016/j.marpolbul.2023.115198.

European Commission. Commission proposes new Euro 7 standards to reduce pollutant emissions from vehicles and improve air quality. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495.

European Council, 2020. Labelling of tyres: Council adopts new rules. In: . https://www.consilium.europa.eu/en/press/pressreleases/2020/02/25/labelling-of-tyres-council-adopts-new-rules/European.

European Tyre and Rubber Manufacturers'' Association, 2019. The way forward Report; European TRWP platform. https://www.etrma.org/wp-content/uploads/2019/10/20200330-FINAL-Way-Forward-Report.pdf.

European Tyre and Rubber Manufacturer's Association, 2021. Europe 95% of all End of Life Tyres were collected and treated in 2019 [Press Release]. https://www.etrma.org/wp-content/uploads/2021/05/20210520_ETRMA_PRESS-RELEASE_ELT-2019.pdf.

Evangeliou, N., Grythe, H., Klimont, Z., Heyes, C., Eckhardt, S., Lopez-Aparicio, S., Stohl, A., 2020. Atmospheric transport is a major pathway of microplastics to remote regions. Nat. Commun. 11, 3381. https://doi.org/10.1038/s41467-020-17201-9.

Technology, 2021. IMDS Information Pages. In: International Material Data System. https://public.mdsystem.com/en/web/imds-public-pages.

Fallahtafti, S., Rantanen, T., Brown, R.S., Snieckus, V., Hodson, P.V., 2012. Toxicity of hydroxylated alkyl-phenanthrenes to the early life stages of Japanese medaka (Oryzias latipes). Aquat. Toxicol. 106–107, 56–64. https://doi.org/10.1016/j.aquatox.2011.10.007.

Fan, P., Lu, C., 2011. A study on functionalization of waste Tire rubber powder through Ozonization. J. Polym. Environ. 19, 943–949. https://doi.org/10.1007/s10924-011-0352-y.

Fan, X., Ma, Z., Zou, Y., Liu, J., Hou, J., 2021. Investigation on the adsorption and desorption behaviors of heavy metals by tire wear particles with or without UV ageing processes. Environ. Res. 195, 110858 https://doi.org/10.1016/j.envres.2021.110858.

Fang, L., Fang, C., Di, S., Yu, Y., Wang, C., Wang, X., Jin, Y., 2023. Oral exposure to tire rubber-derived contaminant 6PPD and 6PPD-quinone induce hepatotoxicity in mice. Sci. Total Environ. 869, 161836 https://doi.org/10.1016/j.scitotenv.2023.161836.

Fauser, P., Tjell, J.C., Mosbaek, H., Pilegaard, K., 1999. Quantification of Tire-tread particles using extractable organic zinc as tracer. Rubber Chem. Technol. 72, 969–977. https://doi.org/10.5254/1.3538846.

Fauser, P., Tjell, J.C., Mosbaek, H., Pilegaard, K., 2002. Tire-tread and bitumen particle concentrations in aerosol and soil samples. Pet. Sci. Technol. 20, 127–141. https://doi.org/10.1081/LFT-120002092.

Fazli, A., Rodrigue, D., 2020. Recycling waste tires into Ground Tire Rubber (GTR)/rubber compounds: a review. J. Compos. Sci. 4, 103. https://doi.org/10.3390/jcs4030103.

Field, R., Heaney, J.P., Pitt, R. (Eds.), 2000. Innovative Urban Wet-Weather Flow Management Systems. Technomic Publishing Co.

Fisher, N.S., Hook, S.E., 2002. Toxicology tests with aquatic animals need to consider the trophic transfer of metals. Toxicology 181–182, 531–536. https://doi.org/10.1016/S0300-483X(02)00475-4.

Foitzik, M.-J., Unrau, H.-J., Gauterin, F., Dörnhöfer, J., Koch, T., 2018. Investigation of ultra fine particulate matter emission of rubber tires. Wear 394–395, 87–95. https://doi.org/10.1016/j.wear.2017.09.023.

Galella, J.G., Kaushal, S.S., Wood, K.L., Reimer, J.E., Mayer, P.M., 2021. Sensors track mobilization of 'chemical cocktails' in streams impacted by road salts in the Chesapeake Bay watershed. Environ. Res. Lett. 16, 035017 https://doi.org/10.1088/1748-9326/abe48f.

Galella JG, SS Kaushal, PM Mayer, CM Maas, RR Shatkay, RA Stutzke. 2023. Stormwater Best Management Practices: Experimental Evaluation of Chemical Cocktails Mobilized by Freshwater Salinization Syndrome. Frontiers in Environmental Science https://doi:https://doi.org/10.3389/fenvs.2023.1020914.

Gao, N., Wang, F., Quan, C., Santamaria, L., Lopez, G., Williams, P.T., 2022. Tire pyrolysis char: processes, properties, upgrading and applications. Prog. Energy Combust. Sci. 93, 101022 https://doi.org/10.1016/j.pecs.2022.101022.

Garrard, S., Spicer, J., Thompson, R., 2022. Tyre particle exposure affects the health of two key estuarine invertebrates. Environ. Pollut. 314, 120244 https://doi.org/10.1016/j.envpol.2022.120244.

Ghosh, S.P., Maiti, S.K., 2018. Evaluation of heavy metal contamination in roadside deposited sediments and road surface runoff: a case study. Environ. Earth Sci. 77, 267. https://doi.org/10.1007/s12665-018-7370-1.

Gigault, J., Ter Halle, A., Baudrimont, M., Pascal, P.-Y., Gauffre, F., Phi, T.-L., et al., 2018. Current opinion: What is a nanoplastic? Environ. Pollut. 235, 1030–1034. https://doi.org/10.1016/j.envpol.2018.01.024.

Gilbreath, A., McKee, L., Shimabuku, I., Lin, D., Werbowski, L.M., Zhu, X., Grbic, J., Rochman, C., 2019. Multiyear water quality performance and mass accumulation of PCBs, mercury, methylmercury, copper, and microplastics in a bioretention rain garden. Journal of Sustainable Water in the Built Environment 5, 04019004. https://doi.org/10.1061/JSWBAY.0000883.

Giroux, M.S., Reichman, J.R., Langknecht, R., Burgess, R.M., Ho, K.T., 2023. Using eRNA/eDNA metabarcoding to detect community-level impacts of nanoplastic exposure to benthic estuarine ecosystems. Environ. Pollut. 338, 122650. https://doi.org/10.1016/j.envpol.2023.122650.

Global Automotive Stakeholders Group, 2021. Global automotive declarable substance list (GADSL). https://www.gadsl.org/.

Glushankova, I., Ketov, A., Krasnovskikh, M., Rudakova, L., Vaisman, I., 2019. End of life tires as a possible source of toxic substances Emission in the process of combustion. Resources 8, 113. https://doi.org/10.3390/resources8020113.

Goßmann, I., Süßmuth, R., Scholz-Böttcher, B.M., 2022. Plastic in the air?! - spider webs as spatial and temporal mirror for microplastics including tire wear particles in urban air. Sci. Total Environ. 832, 155008 https://doi.org/10.1016/j.scitotenv.2022.155008.

Gouin, T., 2020. Toward an improved understanding of the ingestion and trophic transfer of microplastic particles: critical review and implications for future research. Environ. Toxicol. Chem. 39, 1119–1137. https://doi.org/10.1002/etc.4718.

Grammelis, P., Margaritis, N., Dallas, P., Rakopoulos, D., Mavrias, G., 2021. A review on management of end of life tires (elts) and alternative uses of textile fibers. Energies 14, 571. https://doi.org/10.3390/en14030571. https://doi.org/10.3390/en14030571.

Gray, A.D., Wertz, H., Leads, R.R., Weinstein, J.E., 2018. Microplastic in two South Carolina estuaries: occurrence, distribution, and composition. Mar. Pollut. Bull. 128, 223–233. https://doi.org/10.1016/j.marpolbul.2018.01.030.

Grbic, J., Nguyen, B., Guo, E., You, J.B., Sinton, D., Rochman, C.M., 2019. Magnetic extraction of microplastics from environmental samples. Environ. Sci. Technol. Lett. 6, 68–72. https://doi.org/10.1021/acs.estlett.8b00671.

Greer, J.B., Dalsky, E.M., Lane, R.F., Hansen, J.D., 2023. Establishing an *in vitro* model to assess the toxicity of 6ppd-quinone and other tire wear transformation products. Environ. Sci. Technol. Lett. 10, 533–537. https://doi.org/10.1021/acs.estlett.3c00196.

Gustafsson, M., Blomqvist, G., Gudmundsson, A., Dahl, A., Swietlicki, E., Bohgard, M., Lindbom, J., Ljungman, A., 2008. Properties and toxicological effects of particles from the interaction between tyres, road pavement and winter traction material. Sci. Total Environ. 393, 226–240. https://doi.org/10.1016/j.scitotenv.2007.12.030.

Halama, J., McKane, R.B., Barnhart, B.L., Pettus, P.P., Brookes, A.F., Adams, A.K., Gockel, C.K., Djang, K.S., Phan, V., Chokshi, S.M., Graham, J.J., Tian, Z., Peter, K.T., Kolodziej, E., 2024. Watershed analysis of urban stormwater contaminant 6PPD-Quinone hotspots and stream concentrations using a process-based ecohydrological model. Front. Environ. Sci. https://doi.org/10.3389/fenvs.2024.1364673.

Halle, L.L., Palmqvist, A., Kampmann, K., Khan, F.R., 2020. Ecotoxicology of micronized tire rubber: past, present and future considerations. Sci. Total Environ. 706, 135694 https://doi.org/10.1016/j.scitotenv.2019.135694.

Halle, L.L., Palmqvist, A., Kampmann, K., Jensen, A., Hansen, T., Khan, F.R., 2021. Tire wear particle and leachate exposures from a pristine and road-worn tire to Hyalella azteca: comparison of chemical content and biological effects. Aquat. Toxicol. 232, 105769 https://doi.org/10.1016/j.aquatox.2021.105769.

Halsband, C., Sørensen, L., Booth, A.M., Herzke, D., 2020. Car Tire crumb rubber: does leaching produce a toxic chemical cocktail in coastal marine systems? Frontiers in environmental. Science 8.

Hann, S., Kershaw, P., Sherrington, C., Bapasola, A., Jamieson, O., Cole, G., Hickman, M., 2018. Investigating Options for Reducing Releases in the Aquatic Environment of Microplastics Emitted by Products (Prepared for the European Commission by Eunomia in partnership with ICF).

Higashiyama, H., Sano, M., Nakanishi, F., Takahashi, O., Tsukuma, S., 2016. Field measurements of road surface temperature of several asphalt pavements with temperature rise reducing function. Case Studies in Construction Materials 4, 73–80. https://doi.org/10.1016/j.cscm.2016.01.001.

Hiki, K., Asahina, K., Kato, K., Yamagishi, T., Omagari, R., Iwasaki, Y., Watanabe, H., Yamamoto, H., 2021. Acute toxicity of a Tire rubber-derived chemical, 6PPD Quinone, to freshwater fish and crustacean species. Environ. Sci. Technol. Lett. 8, 779–784. https://doi.org/10.1021/acs.estlett.1c00453.

Hoellein, T.J., Shogren, A.J., Tank, J.L., Risteca, P., Kelly, J.J., 2019. Microplastic deposition velocity in streams follows patterns for naturally occurring allochthonous particles. Sci. Rep. 9, 3740. https://doi.org/10.1038/s41598-019-40126-3.

Honda, M., Suzuki, N., 2020. Toxicities of polycyclic aromatic hydrocarbons for aquatic animals. Int. J. Environ. Res. Public Health 17, 1363. https://doi.org/10.3390/ijerph17041363.

Hong, N., Guan, Yingjie, Yang, B., Zhong, J., Zhu, P., Ok, Y.S., Hou, D., Tsang, D.C.W., Guan, Yuntao, Liu, A., 2020. Quantitative source tracking of heavy metals contained in urban road deposited sediments. J. Hazard. Mater. 393, 122362 https://doi.org/10.1016/j.jhazmat.2020.122362.

Huang, W., Shi, Y., Huang, J., Deng, C., Tang, S., Liu, X., Chen, D., 2021. Occurrence of substituted p-Phenylenediamine antioxidants in dusts. Environ. Sci. Technol. Lett. 8, 381–385. https://doi.org/10.1021/acs.estlett.1c00148.

Hüffer, T., Wagner, S., Reemtsma, T., Hofmann, T., 2019. Sorption of organic substances to tire wear materials: similarities and differences with other types of microplastic. TrAC Trends Anal. Chem. 113, 392–401. https://doi.org/10.1016/j.trac.2018.11.029.

Hussain, K., et al., 2018. Monitoring and Risk Analysis of PAHs in the Environment. In: Hussain, C. (Ed.), Handbook of Environmental Materials Management. Springer, Cham. https://doi.org/10.1007/978-3-319-58538-3_29-2.

Ibisch, P.L., Hoffmann, M.T., Kreft, S., Pe'er, G., Kati, V., Biber-Freudenberger, L., DellaSala, D.A., Vale, M.M., Hobson, P.R., Selva, N., 2016. A global map of roadless areas and their conservation status. Science 354, 1423–1427. doi:https://doi.org/10.1126/science.aaf7166.

Incardona, J.P., Collier, T.K., Scholz, N.L., 2004. Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. Toxicol. Appl. Pharmacol. 196, 191–205. https://doi.org/10.1016/j.taap.2003.11.026.

Incardona, J.P., Vines, C.A., Anulacion, B.F., Baldwin, D.H., Day, H.L., French, B.L., Labenia, J.S., Linbo, T.L., Myers, M.S., Olson, O.P., Sloan, C.A., Sol, S., Griffin, F.J., Menard, K., Morgan, S.G., West, J.E., Collier, T.K., 2012. Ylitalo. G.M, Cherr, G.N., Scholz, N.L.

Ivorra, N., Barranguet, C., Jonker, M., Kraak, M.H.S., Admiraal, W., 2002. Metal-induced tolerance in the freshwater microbenthic diatom Gomphonema parvulum. Environ. Pollut. 116, 147–157. https://doi.org/10.1016/S0269-7491(01)00152-X.

Johannessen, C., Metcalfe, C.D., 2022. The occurrence of tire wear compounds and their transformation products in municipal wastewater and drinking water treatment plants. Environ. Monit. Assess. 194, 731. https://doi.org/10.1007/s10661-022-10450-9.

Johannessen, C., Helm, P., Metcalfe, C.D., 2021. Detection of selected tire wear compounds in urban receiving waters. Environ. Pollut. 287, 117659 https://doi.org/10.1016/j.envpol.2021.117659.

Johannessen, C., Helm, P., Lashuk, B., Yargeau, V., Metcalfe, C.D., 2022a. The Tire Wear compounds 6PPD-Quinone and 1,3-Diphenylguanidine in an urban watershed. Arch. Environ. Contam. Toxicol. 82, 171–179. https://doi.org/10.1007/s00244-021-00878-4.

Johannessen, C., Liggio, J., Zhang, X., Saini, A., Harner, T., 2022b. Composition and transformation chemistry of tire-wear derived organic chemicals and implications for air pollution. Atmos. Pollut. Res. 13, 101533 https://doi.org/10.1016/j.apr.2022.101533.

Johannesson, M., Lithner, D., 2022. Potential Policy Instruments and Measures against Microplastics from Tyre and Road Wear: Mapping and Prioritisation.

Kaushal, S.S., Gold, A.J., Bernal, S., et al., 2018. Watershed 'chemical cocktails': forming novel elemental combinations in Anthropocene fresh waters. Biogeochemistry 141, 281–305. https://doi.org/10.1007/s10533-018-0502-6.

Kaushal, S.S., Wood, K.L., Galella, J.G., Gion, A.M., Haq, S., Goodling, P.J., Haviland, K. A., Reimer, J.E., Morel, C.J., Wessel, B., Nguyen, W., Hollingsworth, J.W., Mei, K., Leal, J., Widmer, J., Sharif, R., Mayer, P.M., Newcomer Johnson, T.A., Newcomb, K. D., Smith, E., Belt, K.T., 2020. Making 'chemical cocktails' – evolution of urban geochemical processes across the periodic table of elements. Appl. Geochem. 119, 104632 https://doi.org/10.1016/j.apgeochem.2020.104632.

Kaushal, S.S., Reimer, J.E., Mayer, P.M., Shatkay, R.R., Maas, C.M., Nguyen, W.D., Boger, W.L., Yaculak, A.M., Doody, T.R., Pennino, M.J., Bailey, N.W., Galella, J.G., Weingrad, A., Collison, C., Wood, K.L., SHaq, TA Newcomer-Johnson, S Duan, KT Belt., 2022. Freshwater salinization syndrome alters retention and release of 'chemical cocktails' along Flowpaths: from Stormwater management to urban streams. Freshwater Science 41, 420–441. https://doi.org/10.1086/721469.

Kennedy, P., Gadd, J., Moncrieff, I., 2002. Emission Factors for Contaminants Released by Motor Vehicles in New Zealand. Kingett Mitchell Ltd and Fuels & Energy

Management Group Ltd for Ministry of Transport and Infrastructure Auckland, Auckland, New Zealand.
Khan, F.R., Halle, L.L., Palmqvist, A., 2019. Acute and long-term toxicity of micronized car tire wear particles to Hyalella azteca. Aquat. Toxicol. 213, 105216 https://doi.org/10.1016/j.aquatox.2019.05.018.
Khan, F.R., Rødland, E.S., Kole, J.P., Van Belleghem, F.G.A.J., Jaén-Gil, A., Hansen, S.F., Gomiero, A., 2024. An overview of the key topics related to the study of tire particles and their chemical leachates: from problems to solutions. Trends Anal. Chem. 172, 117563 https://doi.org/10.1016/j.trac.2024.117563.
Kim, L., Lee, T.-Y., Kim, H., An, Y.-J., 2022. Toxicity assessment of tire particles released from personal mobilities (bicycles, cars, and electric scooters) on soil organisms. J. Hazard. Mater. 437, 129362 https://doi.org/10.1016/j.jhazmat.2022.129362.
Klauschies, T., Isanta-Navarro, J., 2022. The joint effects of salt and 6PPD contamination on a freshwater herbivore. Sci. Total Environ. 829, 154675 https://doi.org/10.1016/j.scitotenv.2022.154675.
Klöckner, P., Reemtsma, T., Eisentraut, P., Braun, U., Ruhl, A.S., Wagner, S., 2019. Tire and road wear particles in road environment – quantification and assessment of particle dynamics by Zn determination after density separation. Chemosphere 222, 714–721. https://doi.org/10.1016/j.chemosphere.2019.01.176.
Klöckner, P., Seiwert, B., Eisentraut, P., Braun, U., Reemtsma, T., Wagner, S., 2020. Characterization of tire and road wear particles from road runoff indicates highly dynamic particle properties. Water Res. 185, 116262 https://doi.org/10.1016/j.watres.2020.116262.
Klöckner, P., Reemtsma, T., Wagner, S., 2021. The diverse metal composition of plastic items and its implications. Sci. Total Environ. 764, 142870 https://doi.org/10.1016/j.scitotenv.2020.142870.
Knight, L.J., Parker-Jurd, F.N.F., Al-Sid-Cheikh, M., Thompson, R.C., 2020. Tyre wear particles: an abundant yet widely unreported microplastic? Environ. Sci. Pollut. Res. 27, 18345–18354. https://doi.org/10.1007/s11356-020-08187-4.
Koe, W.S., Lee, J.W., Chong, W.C., Pang, Y.L., Sim, L.C., 2020. An overview of photocatalytic degradation: photocatalysts, mechanisms, and development of photocatalytic membrane. Environ. Sci. Pollut. Res. 27, 2522–2565. https://doi.org/10.1007/s11356-019-07193-5.
Koelmans, A.A., 2015. Modeling the role of microplastics in bioaccumulation of organic chemicals to marine aquatic organisms. A critical review. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), Marine Anthropogenic Litter. Springer International Publishing, Cham, pp. 309–324. https://doi.org/10.1007/978-3-319-16510-3_11.
Kole, P.J., Löhr, A.J., Van Belleghem, F.G.A.J., Ragas, A.M.J., 2017. Wear and tear of Tyres: a stealthy source of microplastics in the environment. Int. J. Environ. Res. Public Health 14, 1265. https://doi.org/10.3390/ijerph14101265.
Kolomijeca, A., Parrott, J., Khan, H., Shires, K., Clarence, S., Sullivan, C., Chibwe, L., Sinton, D., Rochman, C.M., 2020. Increased temperature and turbulence Alter the effects of leachates from Tire particles on fathead minnow (Pimephales promelas). Environ. Sci. Technol. 54, 1750–1759. https://doi.org/10.1021/acs.est.9b05994.
Kommineni, R., Boddapu, H., Thomas, S., 2018. Scope of pyrolysis process as a sustainable method to dispose waste tires: A review. In: Sharma, N., Agarwal, A., Eastwood, P., Gupta, T., Singh, A. (Eds.), Air Pollution and Control. Energy, Environment, and Sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-10-7185-0_14.
Kordoghli, S., Paraschiv, M., Kuncser, R., Tazeruot, M., Prisecaru, M., Zagrouba, F., Georgescu, I., 2014. Managing the environmental hazards of waste tires. Journal of Engineering Studies and Research 20, 1–11.
Koski, M., Søndergaard, J., Christensen, A.M., Nielsen, T.G., 2021. Effect of environmentally relevant concentrations of potentially toxic microplastic on coastal copepods. Aquat. Toxicol. 230, 105713 https://doi.org/10.1016/j.aquatox.2020.105713.
Kovochich, M., Parker, J.A., Oh, S.C., Lee, J.P., Wagner, S., Reemtsma, T., Unice, K.M., 2021. Characterization of individual Tire and road Wear particles in environmental road dust, tunnel dust, and sediment. Environ. Sci. Technol. Lett. 8, 1057–1064. https://doi.org/10.1021/acs.estlett.1c00811.
Kreider, M.L., Panko, J.M., McAtee, B.L., Sweet, L.I., Finley, B.L., 2010. Physical and chemical characterization of tire-related particles: comparison of particles generated using different methodologies. Sci. Total Environ. 408, 652–659. https://doi.org/10.1016/j.scitotenv.2009.10.016.
Kreider, M.L., Unice, K.M., Panko, J.M., 2020. Human health risk assessment of Tire and road Wear particles (TRWP) in air. Hum. Ecol. Risk Assess. Int. J. 26, 2567–2585. https://doi.org/10.1080/10807039.2019.1674633.
Kreiger Jr., F.W.. Method for controlling street surface pollutants (Patent No. US5316589A). https://patents.justia.com/patent/5316589.
Kumata, H., Mori, M., Takahashi, S., Takamiya, S., Tsuzuki, M., Uchida, T., Fujiwara, K., 2011. Evaluation of hydrogenated resin acids as molecular markers for Tire-wear debris in urban environments. Environ. Sci. Technol. 45, 9990–9997. https://doi.org/10.1021/es202156f.
Kwak, J., Kim, H., Lee, J., Lee, S., 2013. Characterization of non-exhaust coarse and fine particles from on-road driving and laboratory measurements. Sci. Total Environ. 458–460, 273–282. https://doi.org/10.1016/j.scitotenv.2013.04.040.
Lajtha, K., Crow, S.E., Yano, Y., Kaushal, S.S., Sulzman, E., Sollins, P., Spears, J.D.H., 2005. Detrital controls on soil solution N and dissolved organic matter in soils: a Field experiment. Biogeochemistry 76, 261–281. https://doi.org/10.1007/s10533-005-5071-9.
Lange, K., Magnusson, K., Viklander, M., Blecken, G.-T., 2021. Removal of rubber, bitumen and other microplastic particles from stormwater by a gross pollutant trap - bioretention treatment train. Water Res. 202, 117457 https://doi.org/10.1016/j.watres.2021.117457.
LaPlaca, S.B., van den Hurk, P., 2020. Toxicological effects of micronized tire crumb rubber on mummichog (Fundulus heteroclitus) and fathead minnow (Pimephales promelas). Ecotoxicology 29, 524–534. https://doi.org/10.1007/s10646-020-02210-7.
LaPlaca, S.B., Rice, C.D., van den Hurk, P., 2022. Chronic toxicity of tire crumb rubber particles to mummichog (Fundulus heteroclitus) in episodic exposures. Sci. Total Environ. 846, 157447 https://doi.org/10.1016/j.scitotenv.2022.157447.
Laufer, H., Chen, M., Baclaski, B., Bobbitt, J.M., Stuart, J.D., Zuo, Y., Jacobs, M.W., 2013. Multiple factors in marine environments affecting lobster survival, development, and growth, with emphasis on alkylphenols: a perspective. Can. J. Fish. Aquat. Sci. 70, 1588–1600. https://doi.org/10.1139/cjfas-2013-0148.
Laws, B.V., Dickenson, E.R.V., Johnson, T.A., Snyder, S.A., Drewes, J.E., 2011. Attenuation of contaminants of emerging concern during surface-spreading aquifer recharge. Sci. Total Environ. 409, 1087–1094. https://doi.org/10.1016/j.scitotenv.2010.11.021.
Leads, R.R., Weinstein, J.E., 2019. Occurrence of tire wear particles and other microplastics within the tributaries of the Charleston Harbor estuary, South Carolina, USA. Mar. Pollut. Bull. 145, 569–582. https://doi.org/10.1016/j.marpolbul.2019.06.061.
Leifheit, E.F., Kissener, H.L., Faltin, E., Ryo, M., Rillig, M.C., 2022. Tire abrasion particles negatively affect plant growth even at low concentrations and alter soil biogeochemical cycling. Soil Ecol. Lett. 4, 409–415. https://doi.org/10.1007/s42832-021-0114-2.
Li, Y., Shi, T., Li, X., Sun, H., Xia, X., Ji, X., Zhang, J., Liu, M., Lin, Y., Zhang, R., Zheng, Y., Tang, J., 2022. Inhaled tire-wear microplastic particles induced pulmonary fibrotic injury via epithelial cytoskeleton rearrangement. Environ. Int. 164, 107257. https://doi.org/10.1016/j.envint.2022.107257.
Liess, M., Gerner, N.V., Kefford, B.J., 2017. Metal toxicity affects predatory stream invertebrates less than other functional feeding groups. Environ. Pollut. 227, 505–512. https://doi.org/10.1016/j.envpol.2017.05.017.
Lindgren, J.F., Hassellöv, I.-M., Dahllöf, I., 2014. PAH effects on meio- and microbial benthic communities strongly depend on bioavailability. Aquat. Toxicol. 146, 230–238. https://doi.org/10.1016/j.aquatox.2013.11.013.
Liu, L., Cai, G., Zhang, J., Liu, X., Liu, K., 2020. Evaluation of engineering properties and environmental effect of recycled waste tire-sand/soil in geotechnical engineering: a compressive review. Renew. Sust. Energ. Rev. 126, 09831 https://doi.org/10.1016/j.rser.2020.109831.
Liu, Yan, Zhou, H., Yan, M., Liu, Yang, Ni, X., Song, J., Yi, X., 2022. Toxicity of tire wear particles and the leachates to microorganisms in marine sediments. Environ. Pollut. 309, 119744 https://doi.org/10.1016/j.envpol.2022.119744.
Lo, B.P., Marlatt, V.L., Liao, X., Reger, S., Gallilee, C., Ross, A.R.S., Brown, T.M., 2023. Acute toxicity of 6PPD-Quinone to Early Life Stage Juvenile Chinook (*Oncorhynchus tshawytscha*) and Coho (*Oncorhynchus kisutch*) Salmon. Environ. Toxicol. Chem. 42, 815–822. https://doi.org/10.1002/etc.5568.
Lokesh, S., Arunthavabalan, S., Hajj, E., Hitti, E., Yang, Y., 2023. Investigation of 6PPD-Quinone in rubberized asphalt concrete mixtures. ACS Environ. Au 3, 336–341. https://doi.org/10.1021/acsenvironau.3c00023.
Louati, H., Ben Said, O., Soltani, A., Got, P., Mahmoudi, E., Cravo-Laureau, C., Duran, R., Aissa, P., Pringault, O., 2013. The roles of biological interactions and pollutant contamination in shaping microbial benthic community structure. Chemosphere 93 (10), 2535–2546. https://doi.org/10.1016/j.chemosphere.2013.09.069.
Lowe, C.N., Williams, A.J., 2021. Enabling high-throughput searches for multiple chemical data using the U.S.-EPA CompTox chemicals dashboard. J. Chem. Inf. Model. 61, 565–570. https://doi.org/10.1021/acs.jcim.0c01273.
Lundstedt, S., White, P.A., Lemieux, C.L., Lynes, K.D., Lambert, I.B., Öberg, L., Haglund, P., Tysklind, M., 2007. Sources, fate, and toxic hazards of oxygenated polycyclic aromatic hydrocarbons (PAHs) at PAH- contaminated sites. Ambio 36, 475–485. doi: https://doi.org/10.1579/0044-7447(2007)36[475,SFATHO]2.0.CO;2.
Maas, C.M., Kaushal, S.S., Mayer, P.M., Rippy, M., Grant, S., Shatkay, R.R., Malin, J., Bhide, S.V., Vikesland, P., Krauss, L., Reimer, J.E., Yaculak, A.M., 2023. Freshwater salinization syndrome limits management efforts to improve water quality. Front. Environ. Sci. https://doi.org/10.3389/fenvs.2023.1106581.
Machin, E.B., Travieso Pedroso, D., de Carvalho, Andrade, Jr., J., 2017. Energetic valorization of waste tires. Renew. Sustain. Energy Rev. 68, 306–315. https://doi.org/10.1016/j.rser.2016.09.110.
Magni, S., Tediosi, E., Maggioni, D., Sbarberi, R., Noé, F., Rossetti, F., Fornai, D., Persici, V., Neri, M.C., 2022. Ecological impact of end-of-life-Tire (ELT)-derived rubbers: acute and chronic effects at organism and population levels. Toxics 10, 201. https://doi.org/10.3390/toxics10050201.
Markl, E., Lackner, M., 2020. Devulcanization Technologies for Recycling of Tire-derived rubber: a review. Materials 13, 1246. https://doi.org/10.3390/ma13051246.
Martins, M., Costa, P.M., Ferreira, A.M., Costa, M.H., 2013. Comparative DNA damage and oxidative effects of carcinogenic and non-carcinogenic sediment-bound PAHs in the gills of a bivalve. Aquat. Toxicol. 142–143, 85–95. https://doi.org/10.1016/j.aquatox.2013.07.019.
Martins, M., Santos, J.M., Diniz, M.S., Ferreira, A.M., Costa, M.H., Costa, P.M., 2015. Effects of carcinogenic versus non-carcinogenic AHR-active PAHs and their mixtures: lessons from ecological relevance. Environ. Res. 138, 101–111. https://doi.org/10.1016/j.envres.2015.02.010.
Marwood, C., McAtee, B., Kreider, M., Ogle, R.S., Finley, B., Sweet, L., Panko, J., 2011. Acute aquatic toxicity of tire and road wear particles to alga, daphnid, and fish. Ecotoxicology 20, 2079–2089. https://doi.org/10.1007/s10646-011-0750-x.
Mayer, P.M., 2008. Ecosystem and decomposer effects on litter dynamics along an old field to old-growth forest successional gradient. Acta Oecol. 33, 222–230. https://doi.org/10.1016/j.actao.2007.11.001.
Mayer, P.M., Reynolds Jr., S.K., McCutchen, M.D., Canfield, T.J., 2007. Meta-analysis of nitrogen removal in riparian buffers. J. Environ. Qual. 36, 1172–1180. https://doi.org/10.2134/jeq2006.0462.

McIlwraith, H.K., Kim, J., Helm, P., Bhavsar, S.P., Metzger, J.S., Rochman, C.M., 2021. Evidence of microplastic translocation in wild-caught fish and implications for microplastic accumulation dynamics in food webs. Environ. Sci. Technol. 55, 12372–12382. https://doi.org/10.1021/acs.est.1c02922.

McIntyre, J.K., Davis, J.W., Incardona, J.P., Stark, J.D., Anulacion, B.F., Scholz, N.L., 2014. Zebrafish and clean water technology: assessing soil bioretention as a protective treatment for toxic urban runoff. Sci. Total Environ. 500–501, 173–180. https://doi.org/10.1016/j.scitotenv.2014.08.066.

McIntyre, J.K., Davis, J.W., Hinman, C., Macneale, K.H., Anulacion, B.F., Scholz, N.L., Stark, J.D., 2015. Soil bioretention protects juvenile salmon and their prey from the toxic impacts of urban stormwater runoff. Chemosphere 132, 213–219. https://doi.org/10.1016/j.chemosphere.2014.12.052.

McIntyre, J.K., Prat, J., Cameron, J., Wetzel, J., Mudrock, E., Peter, K.T., Tian, Z., Mackenzie, C., Lundin, J., Stark, J.D., King, K., Davis, J.W., Kolodziej, E.P., Scholz, N.L., 2021. Treading water: Tire Wear particle leachate recreates an urban runoff mortality syndrome in Coho but not chum Salmon. Environ. Sci. Technol. 55, 11767–11774. https://doi.org/10.1021/acs.est.1c03569.

McIntyre, J.K., Spromberg, J., Cameron, J., Incardona, J.P., Davis, J.W., Scholz, N.L., 2023. Bioretention filtration prevents acute mortality and reduces chronic toxicity for early life stage coho salmon (Oncorhynchus kisutch) episodically exposed to urban stormwater runoff. Sci. Total Environ. 902, 165759. https://doi.org/10.1016/j.scitotenv.2023.165759.

Mehinto, A.C., Coffin, S., Koelmans, A.A., Brander, S.M., Wagner, M., Thornton Hampton, L.M., Burton, A.G., Miller, E., Gouin, T., Weisberg, S.B., Rochman, C.M., 2022. Risk-based management framework for microplastics in aquatic ecosystems. Microplastics and Nanoplastics 2, 17. https://doi.org/10.1186/s43591-022-00033-3.

Meijer, J.R., Huijbregts, M.A.J., Schotten, K.C.G.J., Schipper, A.M., 2018. Global patterns of current and future road infrastructure. Environ. Res. Lett. 13, 064006 https://doi.org/10.1088/1748-9326/aabd42.

Meland, S., 2016. Management of Contaminated Runoff Water: Current Practice and Future Research Needs (Conference of European Directors of Roads). ISBN: 979-10-93321-18-9.

Mengistu, D., Coutris, C., Paus, K.A.H., Heistad, A., 2022. Concentrations and retention efficiency of tirewear particles from road runoff in bioretention cells. Water 14, 3233. https://doi.org/10.3390/w14203233.

Mennekes, D., Nowack, B., 2022. Tire wear particle emissions: measurement data where are you? Sci. Total Environ. 830, 154655 https://doi.org/10.1016/j.scitotenv.2022.154655.

Miller, E., Sedlak, M., Lin, D., Box, C., Holleman, C., Rochman, C.M., Sutton, R., 2021. Recommended best practices for collecting, analyzing, and reporting microplastics in environmental media: lessons learned from comprehensive monitoring of San Francisco Bay. J. Hazard. Mater. 409, 124770 https://doi.org/10.1016/j.jhazmat.2020.124770.

Monaghan, J., Jaeger, A., Agua, A.R., Stanton, R.S., Pirrung, M., Gill, C.G., Krogh, E.T., 2021. A direct mass spectrometry method for the rapid analysis of ubiquitous tire-derived toxin *N*-(1,3-Dimethylbutyl)-*N*′-phenyl-*p*-phenylenediamine Quinone (6-PPDQ). Environ. Sci. Technol. Lett. 8, 1051–1056. https://doi.org/10.1021/acs.estlett.1c00794.

Moran, K., Miller, E., Mendez, M., Moore, S., Gilbreath, A., Sutton, R., Lin, D., 2021. A Synthesis of Microplastic Sources and Pathways to Urban Runoff (No. SFEI Contribution No. 1049). San Francisco Estuary Institute, Richmond, California, USA.

Mousavi, H.Z., Hosseinifar, A., Jahed, V., 2010. Removal of cu(II) from wastewater by waste tire rubber ash. J. Serb. Chem. Soc. 75, 845–853.

Nakomcic-Smaragdakis, B., Cepic, Z., Senk, N., Doric, J., Radovanovic, Lj, 2016. Use of scrap tires in cement production and their impact on nitrogen and sulfur oxides emissions. Energy Sources, Part A 38, 485–493. https://doi.org/10.1080/15567036.2013.787473.

Nava, V, Frezzotti, ML, Leoni, B, 2021. Raman spectroscopy for the analysis of microplastics in aquatic systems. Appl. Spectrosc. 75, 1341–1357. https://doi.org/10.1177/00037028211043119.

Navickis-Brasch, A.S., Maurer, M., Hoffman-Ballard, T., Bator, S., Diamond, J., 2022. Stormwater Treatment of Tire Contaminants Best Management Practices. Washington Department of Ecology, Olympia, Washington, USA.

Nedrich, S., 2022. Preliminary investigation of 6PPD-quinone in surface water and standing road water in Michigan. 2022 Emerging Contaminants in the Environment Conference (ECEC22).

Newton, R.G., 1945. Mechanism of exposure-cracking of rubbers. With a review of the influence of ozone. Rubber Chemistry and Technology 18, 504–556. https://doi.org/10.5254/1.3546750.

Nguyen, L.T.H., Burton Jr., G.A., Schlekat, C.E., Janssen, C.R., 2011. Field measurement of nickel sediment toxicity: role of acid volatile sulfide. Environ. Toxicol. Chem. 30, 162–172. https://doi.org/10.1002/etc.358.

Nikiema, J., Asiedu, Z., 2022. A review of the cost and effectiveness of solutions to address plastic pollution. Environ. Sci. Pollut. Res. 29, 24547–24573. https://doi.org/10.1007/s11356-021-18038-5.

Olubusoye, B.S., Cizdziel, J.V., Bee, M., et al., 2023. Toxic Tire Wear Compounds (6PPD-Q and 4-ADPA) Detected in Airborne Particulate Matter Along a Highway in Mississippi, USA. Bull. Environ. Contam. Toxicol. 111, 68. https://doi.org/10.1007/s00128-023-03820-7.

Panko, J.M., Kreider, M.L., McAtee, B.L., Marwood, C., 2013. Chronic toxicity of tire and road wear particles to water- and sediment-dwelling organisms. Ecotoxicology 22, 13–21. https://doi.org/10.1007/s10646-012-0998-9.

Park, I., Kim, H., Lee, S., 2018. Characteristics of tire wear particles generated in a laboratory simulation of tire/road contact conditions. J. Aerosol Sci. 124, 30–40. https://doi.org/10.1016/j.jaerosci.2018.07.005.

Parker-Jurd, F.N.F., Napper, I.E., Abbott, G.D., Hann, S., Thompson, R.C., 2021. Quantifying the release of Tyre wear particles to the marine environment via multiple pathways. Mar. Pollut. Bull. 172, 112897 https://doi.org/10.1016/j.marpolbul.2021.112897.

Passeport, E., Vidon, P., Forshay, K.J., Harris, L., Kaushal, S.S., Kellogg, D.Q., Lazar, J., Mayer, P., Stander, E.K., 2013. Ecological engineering practices for the reduction of excess nitrogen in human-influenced landscapes: a guide for watershed managers. Environ. Manag. 51, 392–413. https://doi.org/10.1007/s00267-012-9970-y.

Pelletier, M.C., Burgess, R.M., Cantwell, M.G., Serbst, J.R., Ho, K.T., Ryba, S.A., 2000. Importance of maternal transfer of the photoreactive polycyclic aromatic hydrocarbon fluoranthene from benthic adult bivalves to their pelagic larvae. Environ. Toxicol. Chem. 19, 2691–2698. https://doi.org/10.1002/etc.5620191112.

Pence, H.E., Williams, A., 2010. ChemSpider: An online chemical information resource. J. Chem. Educ. 87, 1123–1124. https://doi.org/10.1021/ed100697w.

Pendrill, F., Gardner, T.A., Meyfroidt, P., Persson, U.M., Adams, J., Azevedo, T., Bastos Lima, M.G., Baumann, M., Curtis, P.G., De Sy, V., Garrett, R., Godar, J., Goldman, E. D., Hansen, M.C., Heilmayr, R., Herold, M., Kuemmerle, T., Lathuillière, M.J., Ribeiro, V., Tyukavina, A., Weisse, M.J., West, C., 2022. Disentangling the numbers behind agriculture-driven tropical deforestation. Science 377, 6611. https://doi.org/10.1126/science.abm9267.

Peng, W., Liu, C., Chen, D., Duan, X., Zhong, L., 2022. Exposure to N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD) affects the growth and development of zebrafish embryos/larvae. Ecotoxicol. Environ. Saf. 232, 113221 https://doi.org/10.1016/j.ecoenv.2022.113221.

Penkała, M., Ogrodnik, P., Rogula-Kozłowska, W., 2018. Particulate matter from the road surface abrasion as a problem of non-exhaust Emission control. Environments 5, 9. https://doi.org/10.3390/environments5010009.

Perkins, A.N., Inayat-Hussain, S.H., Deziel, N.C., Johnson, C.H., Ferguson, S.S., Garcia-Milian, R., Thompson, D.C., Vasiliou, V., 2019. Evaluation of potential carcinogenicity of organic chemicals in synthetic turf crumb rubber. Environ. Res. 169, 163–172. https://doi.org/10.1016/j.envres.2018.10.018.

Perren, W., Wojtasik, A., Cai, Q., 2018. Removal of microbeads from wastewater using electrocoagulation. ACS Omega 3, 3357–3364. https://doi.org/10.1021/acsomega.7b02037.

Peter, K.T., Tian, Z., Wu, C., Lin, P., White, S., Du, B., McIntyre, J.K., Scholz, N.L., Kolodziej, E.P., 2018. Using high-resolution mass spectrometry to identify organic contaminants linked to urban Stormwater mortality syndrome in Coho Salmon. Environ. Sci. Technol. 52, 10317–10327. https://doi.org/10.1021/acs.est.8b03287.

Peter, K.T., Hou, F., Tian, Z., Wu, C., Goehring, M., Liu, F., Kolodziej, E.P., 2020. More than a first flush: Urban Creek storm hydrographs demonstrate broad contaminant Pollutographs. Environ. Sci. Technol. 54, 6152–6165. https://doi.org/10.1021/acs.est.0c00872.

Philibert, D.A., Philibert, C.P., Lewis, C., Tierney, K.B., 2016. Comparison of diluted bitumen (Dilbit) and conventional crude oil toxicity to developing zebrafish. Environ. Sci. Technol. 50, 6091–6098. https://doi.org/10.1021/acs.est.6b00949.

Piotrowska, K., Kruszelnicka, W., Bałdowska-Witos, P., Kasner, R., Rudnicki, J., Tomporowski, A., Flizikowski, J., Opielak, M., 2019. Assessment of the environmental impact of a Car Tire throughout its lifecycle using the LCA method. Materials 12, 4177. https://doi.org/10.3390/ma12244177.

Piscitello, A., Bianco, C., Casasso, A., Sethi, R., 2021. Non-exhaust traffic emissions: sources, characterization, and mitigation measures. Sci. Total Environ. 766, 144440 https://doi.org/10.1016/j.scitotenv.2020.144440.

Pitt, R., Chen, S.-E., Clark, S.E., Swenson, J., Ong, C.K., 2008. Compaction's impacts on urban storm-water infiltration. J. Irrig. Drain. Eng. 134, 652–658. https://doi.org/10.1061/(ASCE)0733-9437(2008)134:5(652).

Pivokonsky, M., Cermakova, L., Novotna, K., Peer, P., Cajthaml, T., Janda, V., 2018. Occurrence of microplastics in raw and treated drinking water. Sci. Total Environ. 643, 1644–1651. https://doi.org/10.1016/j.scitotenv.2018.08.102.

Pochron, S.T., Fiorenza, A., Sperl, C., Ledda, B., Lawrence Patterson, C., Tucker, C.C., Tucker, W., Ho, Y.L., Panico, N., 2017. The response of earthworms (Eisenia fetida) and soil microbes to the crumb rubber material used in artificial turf fields. Chemosphere 173, 557–562. https://doi.org/10.1016/j.chemosphere.2017.01.091.

Pochron, S., Nikakis, J., Illuzzi, K., Baatz, A., Demirciyan, L., Dhillon, A., Gaylor, T., Manganaro, A., Maritato, N., Moawad, M., Singh, R., Tucker, C., Vaughan, D., 2018. Exposure to aged crumb rubber reduces survival time during a stress test in earthworms (Eisenia fetida). Environ. Sci. Pollut. Res. 25, 11376–11383. https://doi.org/10.1007/s11356-018-1433-4.

Pohrt, R., 2019. Tire wear particle hot spots – review of influencing factors. Facta Universitatis, Series: Mechanical Engineering 17, 17–27. https://doi.org/10.22190/FUME190104013P.

Polukarova, M., Markiewicz, A., Björklund, K., Strömvall, A.-M., Galfi, H., Andersson Sköld, Y., Gustafsson, M., Järlskog, I., Aronsson, M., 2020. Organic pollutants, nano- and microparticles in street sweeping road dust and washwater. Environ. Int. 135, 105337 https://doi.org/10.1016/j.envint.2019.105337.

Rånby, B., 1989. Photodegradation and photo-oxidation of synthetic polymers. J. Anal. Appl. Pyrolysis 15, 237–247. https://doi.org/10.1016/0165-2370(89)85037-5.

Rauert, C., Rødland, E.S., Okoffo, E.D., Reid, M.J., Meland, S., Thomas, K.V., 2021. Challenges with quantifying Tire road Wear particles: recognizing the need for further refinement of the ISO technical specification. Environ. Sci. Technol. Lett. 8, 231–236. https://doi.org/10.1021/acs.estlett.0c00949.

Rauert, C., Charlton, N., Okoffo, E.D., Stanton, R.S., Agua, A.R., Pirrung, M.C., Thomas, K.V., 2022. Concentrations of tire additive chemicals and tire road wear particles in an Australian urban tributary. Environ. Sci. Technol. 56, 2421–2431. https://doi.org/10.1021/acs.est.1c07451.

Redondo-Hasselerharm, P.E., de Ruijter, V.N., Mintenig, S.M., Verschoor, A., Koelmans, A.A., 2018. Ingestion and chronic effects of Car Tire tread particles on

freshwater benthic macroinvertebrates. Environ. Sci. Technol. 52, 13986–13994. https://doi.org/10.1021/acs.est.8b05035.
Rillig, M.C., Lehmann, A., 2020. Microplastic in terrestrial ecosystems. Science 368, 1430–1431. https://doi.org/10.1126/science.abb5979.
Rillig, M.C., Leifheit, E., Lehmann, J., 2021. Microplastic effects on carbon cycling processes in soils. PLoS Biol. 19, e3001130 https://doi.org/10.1371/journal.pbio.3001130.
Rodgers, T.F.M., Wang, Y., Humes, C., Jeronimo, M., Johannessen, C., Spraakman, S., Giang, A., Scholes, R.C., 2023. Bioretention cells provide a 10-fold reduction in 6ppd-quinone mass loadings to receiving waters: evidence from a field experiment and modeling. Environ. Sci. Technol. Lett. 10, 582–588. https://doi.org/10.1021/acs.estlett.3c00203.
Rødland, E.S., Lind, O.C., Reid, M.J., Heier, L.S., Okoffo, E.D., Rauert, C., Thomas, K.V., Meland, S., 2022. Occurrence of tire and road wear particles in urban and peri-urban snowbanks, and their potential environmental implications. Sci. Total Environ. 824, 153785 https://doi.org/10.1016/j.scitotenv.2022.153785.
Ruiz, Y., Suarez, P., Alonso, A., Longo, E., Villaverde, A., San Juan, F., 2011. Environmental quality of mussel farms in the Vigo estuary: pollution by PAHs, origin and effects on reproduction. Environ. Pollut. 159, 250–265. https://doi.org/10.1016/j.envpol.2010.08.031.
Ruwona, W., Danha, G., Muzenda, E., 2019. A review on material and energy recovery from waste Tyres. In: Procedia Manufacturing, the 2nd International Conference on Sustainable Materials Processing and Manufacturing, SMPM 2019, 8–10 March 2019, Sun City, South Africa 35, pp. 216–222. https://doi.org/10.1016/j.promfg.2019.05.029.
Sadiktsis, I., Bergvall, C., Johansson, C., Westerholm, R., 2012. Automobile tires—a potential source of highly carcinogenic Dibenzopyrenes to the environment. Environ. Sci. Tech. 46, 3326–3334. https://doi.org/10.1021/es204257d.
Schell, T., Martinez-Perez, S., Dafouz, R., Hurley, R., Vighi, M., Rico, A., 2022. Effects of polyester fibers and Car Tire particles on freshwater invertebrates. Environ. Toxicol. Chem. 41, 1555–1567. https://doi.org/10.1002/etc.5337.
Schlekat, C.E., Garman, E.R., Vangheluwe, M.L., Burton Jr., G.A., 2016. Development of a bioavailability-based risk assessment approach for nickel in freshwater sediments. Integr. Environ. Assess. Manag. 12, 735–746. https://doi.org/10.1002/ieam.1720.
Schmaltz, E., Melvin, E.C., Diana, Z., Gunady, E.F., Rittschof, D., Somarelli, J.A., Virdin, J., Dunphy-Daly, M.M., 2020. Plastic pollution solutions: emerging technologies to prevent and collectmarineplastic pollution. Environ. Int. 144, 106067 https://doi.org/10.1016/j.envint.2020.106067.
Selbes, M., Yilmaz, O., Khan, A.A., Karanfil, T., 2015. Leaching of DOC, DN, and inorganic constituents from scrap tires. Chemosphere 139, 617–623. https://doi.org/10.1016/j.chemosphere.2015.01.042.
Selbig, W.R., Bannerman, R.T., 2007. Evaluation of Street Sweeping as a Stormwater-Quality-Management Tool in Three Residential Basins in Madison. Wisconsin (No. 2007–5156). U.S. Geological Survey Scientific Investigations Report.
Selonen, S., Dolar, A., Jemec Kokalj, A., Sackey, L.N.A., Skalar, T., Cruz Fernandes, V., Rede, D., Delerue-Matos, C., Hurley, R., Nizzetto, L., van Gestel, C.A.M., 2021. Exploring the impacts of microplastics and associated chemicals in the terrestrial environment – exposure of soil invertebrates to tire particles. Environ. Res. 201, 111495 https://doi.org/10.1016/j.envres.2021.111495.
Sheng, Y., Liu, Y., Wang, K., Cizdziel, J.V., Wu, Y., Zhou, Y., 2021. Ecotoxicological effects of micronized car tire wear particles and their heavy metals on the earthworm (Eisenia fetida) in soil. Sci. Total Environ. 793, 148613 https://doi.org/10.1016/j.scitotenv.2021.148613.
Shin, H., Sukumaran, V., Yeo, I.-C., Shim, K.-Y., Lee, S., Choi, H.-K., Ha, S.Y., Kim, M., Jung, J.-H., Lee, J.-S., Jeong, C.-B., 2022. Phenotypic toxicity, oxidative response, and transcriptomic deregulation of the rotifer Brachionus plicatilis exposed to a toxic cocktail of tire-wear particle leachate. J. Hazard. Mater. 438, 129417 https://doi.org/10.1016/j.jhazmat.2022.129417.
Shulman, V.L., 2019. Chapter 26 - Tire recycling. In: Letcher, T.M., Vallero, D.A. (Eds.), Waste, Second edition. Academic Press, pp. 489–515. https://doi.org/10.1016/B978-0-12-815060-3.00026-8.
Shupe, H.J., Boenisch, K.M., Harper, B.J., Brander, S.M., Harper, S.L., 2021. Effect of Nanoplastic type and surface chemistry on particle agglomeration over a salinity gradient. Environ. Toxicol. Chem. 40, 1820–1826. https://doi.org/10.1002/etc.5030.
Shuttleworth, K.L., Cerniglia, E., 1995. Environmental aspects of PAH biodegradation. Appl. Biochem. Biotechnol. 54, 291–302. https://doi.org/10.1007/BF02787927.
Siddiqui, S., Dickens, J.M., Cunningham, B.E., Hutton, S.J., Pedersen, E.I., Harper, B., Harper, S., Brander, S.M., 2022. Internalization, reduced growth, and behavioral effects following exposure to micro and nano tire particles in two estuarine indicator species. Chemosphere 296, 133934. https://doi.org/10.1016/j.chemosphere.2022.133934.
Sieber, R., Kawecki, D., Nowack, B., 2020. Dynamic probabilistic material flow analysis of rubber release from tires into the environment. Environ. Pollut. 258, 113573 https://doi.org/10.1016/j.envpol.2019.113573.
Siegfried, M., Koelmans, A.A., Besseling, E., Kroeze, C., 2017. Export of microplastics from land to sea. A modelling approach. Water Research 127, 249–257. https://doi.org/10.1016/j.watres.2017.10.011.
Sienkiewicz, M., Kucińska-Lipka, J., Janik, H., Balas, A., 2012. Progress in used tyres management in the European Union: a review. Waste Manag. 32, 1742–1751.
Silvestro, D., 2022. ADAC Tyre test: Tyre abrasion - on road tests. https://wiki.unece.org/download/attachments/166724916/TA-02-02%20Study_ADAC_tyre_abrasion_110522_en-GB.pdf?api=v2.
Simon, M., Hartmann, N.B., Vollertsen, J., 2021. Accelerated weathering increases the release of toxic leachates from microplastic particles as demonstrated through altered toxicity to the green algae Raphidocelis subcapitata. Toxics 9, 185. https://doi.org/10.3390/toxics9080185.
Singh, A., Spak, S.N., Stone, E.A., Downard, J., Bullard, R.L., Pooley, M., Kostle, P.A., Mainprize, M.W., Wichman, M.D., Peters, T.M., Beardsley, D., Stanier, C.O., 2015. Uncontrolled combustion of shredded tires in a landfill e part 2: population exposure, public health response, and an air quality index for urban fires. Atmos. Environ. 104, 273–283.
Singh, R., Chen, Y., Gulliver, J.S., Hozalski, R.M., 2023. Leachability and phosphate removal potential of tire derived aggregates in underground stormwater chambers. J. Clean. Prod. 395, 136428 https://doi.org/10.1016/j.jclepro.2023.136428.
Skoczyńska, E., Leonards, P.E.G., Llompart, M., de Boer, J., 2021. Analysis of recycled rubber: development of an analytical method and determination of polycyclic aromatic hydrocarbons and heterocyclic aromatic compounds in rubber matrices. Chemosphere 276, 130076. https://doi.org/10.1016/j.chemosphere.2021.130076.
Smolders, E., Degryse, F., 2002. Fate and effect of zinc from Tire debris in soil. Environ. Sci. Technol. 36, 3706–3710. https://doi.org/10.1021/es025567p.
Smyth, K., Drake, J., Li, Y., Rochman, C., Van Seters, T., Passeport, E., 2021. Bioretention cells remove microplastics from urban stormwater. Water Res. 191, 116785 https://doi.org/10.1016/j.watres.2020.116785.
Sommer, F., Dietze, V., Baum, A., Sauer, J., Gilge, S., Maschowski, C., Gieré, R., 2018. Tire abrasion as a major source of microplastics in the environment. Aerosol Air Qual. Res. 18, 2014–2028. https://doi.org/10.4209/aaqr.2018.03.0099.
Spromberg, J.A., Baldwin, D.H., Damm, S.E., McIntyre, J.K., Huff, M., Sloan, C.A., Anulacion, B.F., Davis, J.W., Scholz, N.L., 2016. Coho salmon spawner mortality in western US urban watersheds: bioinfiltration prevents lethal storm water impacts. J. Appl. Ecol. 53, 398–407. https://doi.org/10.1111/1365-2664.12534.
Stanard, C., Candaele, R., Charbeneau, Barrett, M., 2007. State of the Practice: Permeable Friction Courses (No. FHWA/TX-08/0-5220-1). Transportation Research, Prepared for the Texas Department of Transportation.
Stang, C., Mohamed, B.A., Li, L.Y., 2022. Microplastic removal from urban stormwater: current treatments and research gaps. J. Environ. Manage. 317, 115510 https://doi.org/10.1016/j.jenvman.2022.115510.
Stephensen, E., Adolfsson-Erici, M., Celander, M., Hulander, M., Parkkonen, J., Hegelund, T., Sturve, J., Hasselberg, L., Bengtsson, M., Förlin, L., 2003. Biomarker responses and chemical analyses in fish indicate leakage of polycyclic aromatic hydrocarbons and other compounds from car tire rubber. Environ. Toxicol. Chem. 22, 2926–2931. https://doi.org/10.1897/02-444.
Sun, X., Liu, J., Hong, J., Lu, B., 2016. Life cycle assessment of Chinese radial passenger vehicle tire. Int. J. Life Cycle Assess. 21, 1749–1758. https://doi.org/10.1007/s11367-016-1139-0.
Sundelin, B., Elmgren, R., 1991. Meiofauna of an experimental soft bottom ecosystem – effects of macrofauna and cadmium exposure. Mar. Ecol. Prog. Ser. 70, 245–255.
Sutton, R., Franz, A., Gilbreath, A., Lin, D., Miller, L., Sedlak, M., Wong, A., Box, C., Holleman, R., Munno, K., et al., 2019. Understanding microplastic levels, pathways, and transport in the San Francisco Bay region; SFEI Contribution No. San Francisco Estuary Institute, Richmond, CA.
Tang, Z., Butkus, M.A., Xie, Y.F., 2006. Crumb rubber filtration: a potential technology for ballast water treatment. Mar. Environ. Res. 61, 410–423. https://doi.org/10.1016/j.marenvres.2005.06.003.
The Tyre Collective, 2021. https://www.thetyrecollective.com.
Thornton Hampton, L.M., Brander, S.M., Coffin, S., Cole, M., Hermabessiere, L., Koelmans, A.A., Rochman, C.M., 2022. Characterizing microplastic hazards: which concentration metrics and particle characteristics are most informative for understanding toxicity in aquatic organisms? Microplastics and Nanoplastics 2, 20. https://doi.org/10.1186/s43591-022-00040-4.
Thorpe, A., Harrison, R.M., 2008. Sources and properties of non-exhaust particulate matter from road traffic: a review. Sci. Total Environ. 400, 270–282. https://doi.org/10.1016/j.scitotenv.2008.06.007.
Tian, Z., Dietze, V., Sommer, F., Baum, A., Kaminski, U., Sauer, J., Maschowski, C., Stille, P., Cen, K., Gieré, R., 2017. Coarse-particle passive-sampler measurements and single-particle analysis by transmitted light microscopy at highly frequented motorways. Aerosol Air Qual. Res. 17, 1939–1953. https://doi.org/10.4209/aaqr.2017.02.0064.
Tian, Z., Wark, D.A., Bogue, K., James, C.A., 2021a. Suspect and non-target screening of contaminants of emerging concern in streams in agricultural watersheds. Sci. Total Environ. 795, 148826 https://doi.org/10.1016/j.scitotenv.2021.148826.
Tian, Z., Zhao, H., Peter, K.T., Gonzalez, M., Wetzel, J., Wu, C., Hu, X., Prat, J., Mudrock, E., Hettinger, R., Cortina, A.E., Biswas, R.G., Kock, F.V.C., Soong, R., Jenne, A., Du, B., Hou, F., He, H., Lundeen, R., Gilbreath, A., Sutton, R., Scholz, N.L., Davis, J.W., Dodd, M.C., Simpson, A., McIntyre, J.K., Kolodziej, E.P., 2021b. A ubiquitous tire rubber–derived chemical induces acute mortality in coho salmon. Science. https://doi.org/10.1126/science.abd6951.
Tian, Z., Gonzalez, M., Rideout, C.A., Zhao, H.N., Hu, X., Wetzel, J., Mudrock, E., James, C.A., McIntyre, J.K., Kolodziej, E.P., 2022. 6PPD-Quinone: revised toxicity assessment and quantification with a commercial standard. Environ. Sci. Technol. Lett. 9, 140–146. https://doi.org/10.1021/acs.estlett.1c00910.
Torretta, V., Rada, E.C., Ragazzi, M., Trulli, E., Istrate, I.A., Cioca, L.I., 2015. Treatment and disposal of tyres: two EU approaches. A review. Waste Management, Urban Mining 45, 152–160. https://doi.org/10.1016/j.wasman.2015.04.018.
Trudsø, L.L., Nielsen, M.B., Hansen, S.F., Syberg, K., Kampmann, K., Khan, F.R., Palmqvist, A., 2022. The need for environmental regulation of tires: challenges and recommendations. Environ. Pollut. 311, 119974 https://doi.org/10.1016/j.envpol.2022.119974.
Tsang, H.H., 2012. Uses of scrap rubber tires. In: Rubber: Types, Properties and Uses. Nova Science Publishers, Inc., New York, New York, US.

U.S. Tire Manufacturers Association. 2018. U.S. Scrap Tire Markets 2017. https://www.ustires.org/scrap-tire-markets.
U.S. Tire Manufacturers Association, 2020. U.S. Scrap Tire Markets 2020; https://www.ustires.org/sites/default/files/U.S.%20Scrap%20Tire%20Management%20Summary.pdf.
U.S. Tire Manufacturers Association, 2021. USTMA Tire Wear Rate Calculations for the United States and California (Submitted to the California Department of Toxic Substances Control).
U.S. Tire Manufacturers Association. 2022. 2022 Tire Shipment Outlook. www.ustires.org/2022-tire-shipment-outlook.
Uliasz-Misiak, B., Winid, B., Lewandowska-Śmierzchalska, J., Matuła, R., 2022. Impact of road transport on groundwater quality. Sci. Total Environ. 824, 153804 https://doi.org/10.1016/j.scitotenv.2022.153804.
UNECE, 2014. Addendum 16: Global technical regulation No. 16: Global technical regulation on tyres. http://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29wgs/wp29gen/wp29registry/ECETRANS-180a16e.pdf.
Unice, K.M., Bare, J.L., Kreider, M.L., Panko, J.M., 2015. Experimental methodology for assessing the environmental fate of organic chemicals in polymer matrices using column leaching studies and OECD 308 water/sediment systems: application to tire and road wear particles. Sci. Total Environ. 533, 476–487. https://doi.org/10.1016/j.scitotenv.2015.06.053.
Unice, K.M., Weeber, M.P., Abramson, M.M., Reid, R.C.D., van Gils, J.A.G., Markus, A.A., Vethaak, A.D., Panko, J.M., 2019. Characterizing export of land-based microplastics to the estuary - part II: sensitivity analysis of an integrated geospatial microplastic transport modeling assessment of tire and road wear particles. Sci. Total Environ. 646, 1650–1659. https://doi.org/10.1016/j.scitotenv.2018.08.301.
US Environmental Protection Agency, 1997. Air Emission from Scrap Tire Combustion; EPA-600/R-97-115. Washington DC, USA. https://www3.epa.gov/ttncatc1/dir1/tire_eng.pdf.
US Environmental Protection Agency, 2016. Operation and Maintenance of Green Infrastructure Receiving Runoff from Roads and Parking Lots. Washington DC, USA. https://www.epa.gov/sites/default/files/2016-11/documents/final_gi_maintenance_508.pdf.
US Environmental Protection Agency, 2019. Synthetic Turf Field Recycled Tire Crumb Rubber Research under the Federal Research Action Plan; EPA/600/R-19/051. Washington DC, USA.
US Environmental Protection Agency, 2022a. Facts and Figures about Materials, Waste and Recycling, 2022. Washington DC, USA. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/durable-goods-product-specific-data#VehicleTires.
US Environmental Protection Agency, 2022b. Federal Research on Recycled Tire Crumb Used on Playing Fields. Washington DC, USA. https://www.epa.gov/chemical-research/federal-research-recycled-tire-crumb-used-playing-fields.
US Environmental Protection Agency, 2023. Learn about Pollution Prevention. Washington DC, USA. https://www.epa.gov/p2/learn-about-pollution-prevention.
Valente, M., Sibai, A., 2019. Rubber/Crete: mechanical properties of scrap to reuse tire-derived rubber in concrete; a review. Journal of Applied Biomaterials & Functional Materials 17, 2280800019835486. https://doi.org/10.1177/2280800019835486.
van Beelen, P., 2003. A review on the application of microbial toxicity tests for deriving sediment quality guidelines. Chemosphere 53, 795–808. https://doi.org/10.1016/S0045-6535(03)00716-1.
van Zyl, S., van Goethem, S., Kanarachos, S., Rexeis, M., Hausberger, S., Smokers, R., 2013. Study on Tyre Pressure Monitoring Systems (TPMS) as a means to reduce Light- Commercial and Heavy-Duty Vehicles fuel consumption and CO2 emissions (No. TNO 2013 R10986).
Varshney, S., Gora, A.H., Siriyappagouder, P., Kiron, V., Olsvik, P.A., 2022. Toxicological effects of 6PPD and 6PPD quinone in zebrafish larvae. J. Hazard. Mater. 424, 127623 https://doi.org/10.1016/j.jhazmat.2021.127623.
Vegosen, L., Martin, T.M., 2020. An automated framework for compiling and integrating chemical hazard data. Clean Techn. Environ. Policy 22, 441–458. https://doi.org/10.1007/s10098-019-01795-w.
Verschoor, A., de Valk, E., 2017. Potential Measures against Microplastic Emissions to Water (No. RIVM Report 2017-0193). Dutch National Institute for Public Health and the Environment.
Verschoor, A., de Poorter, L., Dröge, R., Kuenen, J., de Valk, E., 2016. Emission of Microplastics and Potential Mitigation Measures: Abrasive Cleaning Agents, Paints and Tyre Wear (no. RIVM Report 2016-0026). Dutch National Institute for Public Health and the Environment.
Versteeg, D.J., Belanger, S.E., Carr, G.J., 1999. Understanding single-species and model ecosystem sensitivity: data-based comparison. Environ. Toxicol. Chem. 18, 1329–1346. https://doi.org/10.1002/etc.5620180636.
Wagner, S., Hüffer, T., Klöckner, P., Wehrhahn, M., Hofmann, T., Reemtsma, T., 2018. Tire wear particles in the aquatic environment - a review on generation, analysis, occurrence, fate and effects. Water Res. 139, 83–100. https://doi.org/10.1016/j.watres.2018.03.051.
Wagner, S., Klöckner, P., Reemtsma, T., 2022. Aging of tire and road wear particles in terrestrial and freshwater environments – a review on processes, testing, analysis and impact. Chemosphere 288, 132467. https://doi.org/10.1016/j.chemosphere.2021.132467.
Wang, T., 2017. Analysis on Tyre Wear Modelling and Simulations. KTH Royal Institute of Technology, School of Engineering Sciences. https://www.diva-portal.org/smash/get/diva2:1416550/FULLTEXT01.pdf.
Wang, Y., Hollingsworth, P.M., Zhai, D., et al., 2023. High-resolution maps show that rubber causes substantial deforestation. Nature 623, 340–346. https://doi.org/10.1038/s41586-023-06642-z.
Wang, C., Zhao, J., Xing, B., 2021. Environmental source, fate, and toxicity of microplastics. J. Hazard. Mater. 407, 124357 https://doi.org/10.1016/j.jhazmat.2020.124357.
Werbowski, L.M., Gilbreath, A.N., Munno, K., Zhu, X., Grbic, J., Wu, T., Sutton, R., Sedlak, M.D., Deshpande, A.D., Rochman, C.M., 2021. Urban Stormwater runoff: a major pathway for anthropogenic particles, black rubbery fragments, and other types of microplastics to urban receiving waters. ACS EST Water 1, 1420–1428. https://doi.org/10.1021/acsestwater.1c00017.
Wik, A., Dave, G., 2006. Acute toxicity of leachates of tire wear material to Daphnia magna—variability and toxic components. Chemosphere 64, 1777–1784. https://doi.org/10.1016/j.chemosphere.2005.12.045.
Wik, A., Dave, G., 2009. Occurrence and effects of tire wear particles in the environment – a critical review and an initial risk assessment. Environ. Pollut. 157, 1–11. https://doi.org/10.1016/j.envpol.2008.09.028.
Wik, A., Nilsson, E., Källqvist, T., Tobiesen, A., Dave, G., 2009. Toxicity assessment of sequential leachates of tire powder using a battery of toxicity tests and toxicity identification evaluations. Chemosphere 77, 922–927. https://doi.org/10.1016/j.chemosphere.2009.08.034.
Williams, A.J., Grulke, C.M., Edwards, J., McEachran, A.D., Mansouri, K., Baker, N.C., Patlewicz, G., Shah, I., Wambaugh, J.F., Judson, R.S., Richard, A.M., 2017. The CompTox chemistry dashboard: a community data resource for environmental chemistry. J. Chem. 9, 61. https://doi.org/10.1186/s13321-017-0247-6.
Wu, L., Jiang, Y., Zhang, L., Chen, L., Zhang, H., 2014. Toxicity of urban highway runoff in Shanghai to zebrafish (Danio rerio) embryos and luminous bacteria (Vibrio qinghaiensis.Q67). Environ. Sci. Pollut. Res. 21, 2663–2676. https://doi.org/10.1007/s11356-013-2193-9.
Xu, S., Ma, J., Ji, R., Pan, K., Miao, A.-J., 2020. Microplastics in aquatic environments: occurrence, accumulation, and biological effects. Sci. Total Environ. 703, 134699 https://doi.org/10.1016/j.scitotenv.2019.134699.
Yang, Y., Wang, Z., Xie, S., 2014. Aerobic biodegradation of bisphenol a in river sediment and associated bacterial community change. Sci. Total Environ. 470–471, 1184–1188. https://doi.org/10.1016/j.scitotenv.2013.10.102.
Yang, K., Jing, S., Liu, Yang, Zhou, H., Liu, Yan, Yan, M., Yi, X., Liu, R., 2022. Acute toxicity of tire wear particles, leachates and toxicity identification evaluation of leachates to the marine copepod. *Tigriopus japonicus*. Chemosphere 297, 134099. https://doi.org/10.1016/j.chemosphere.2022.134099.
Zeng, L., Li, Y., Sun, Y., Liu, L., Shen, M., Du, B., 2023. Widespread occurrence and transport of p-phenylenediamines and their quinones in sediments across urban rivers, estuaries, coasts, and deep-sea regions. Environ. Sci. Technol. 57, 2393–2403. https://doi.org/10.1021/acs.est.2c07652.
Zhang, J.J., Han, I.-K., Zhang, L., Crain, W., 2008. Hazardous chemicals in synthetic turf materials and their bioaccessibility in digestive fluids. J. Expo. Sci. Environ. Epidemiol. 18, 600–607. https://doi.org/10.1038/jes.2008.55.
Zhang, L., Lu, Q., Ding, Y., Wu, J., 2021. A procedure to design road bioretention soil media based on runoff reduction and pollutant removal performance. J. Clean. Prod. 287, 125524 https://doi.org/10.1016/j.jclepro.2020.125524.
Zhang, Y.-J., Xu, T.-T., Ye, D.-M., Lin, Z.-Z., Wang, F., Guo, Y., 2022. Widespread N-(1,3-Dimethylbutyl)-N′-phenyl-p-phenylenediamine Quinone in size-fractioned atmospheric particles and dust of different indoor environments. Environ. Sci. Technol. Lett. 9, 420–425. https://doi.org/10.1021/acs.estlett.2c00193.
Zhang, H.-Y., Huang, Z., Liu, Y.-H., Hu, L.-X., He, L.-Y., Liu, Y.-S., Zhao, J.-L., Ying, G.-G., 2023. Occurrence and risks of 23 tire additives and their transformation products in an urban water system. Environ. Int. 171, 107715 https://doi.org/10.1016/j.envint.2022.107715.
Zhao, S., He, T., Duo, L., 2011. Effects of crumb rubber waste as a soil conditioner on the nematode assemblage in a turfgrass soil. Appl. Soil Ecol. 49, 94–98. https://doi.org/10.1016/j.apsoil.2011.06.011.
Zhao, B., Xu, N., Chen, H., Guo, K., Huang, Y., 2019. Stability control of electric vehicles with in-wheel motors by considering tire slip energy. Mech. Syst. Signal Process. 118, 340–359. https://doi.org/10.1016/j.ymssp.2018.08.037.
Zidour, M., Boubechiche, Z., Pan, Y.-J., Bialais, C., Cudennec, B., Grard, T., Drider, D., Flahaut, C., Ouddane, B., Souissi, S., 2019. Population response of the estuarine copepod Eurytemora affinis to its bioaccumulation of trace metals. Chemosphere 220, 505–513. https://doi.org/10.1016/j.chemosphere.2018.12.148.
Wei, L., Yue, Q., Chen, G., Wang, J., 2023. Microplastics in rainwater/stormwater environments: Influencing factors, sources, transport, fate, and removal techniques. TrAC, Trends Anal. Chem. 165, 117147. https://doi.org/10.1016/j.trac.2023.117147.
Zuccaro, P., Thompson, D.C., de Boer, J., Watterson, A., Wang, Q., Tang, S., Shi, X., Llompart, M., Ratola, N., Vasiliou, V., 2022. Artificial turf and crumb rubber infill: an international policy review concerning the current state of regulations. Environ. Chall. 9, 100620. https://doi.org/10.1016/j.envc.2022.100620.

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Sci Rep. 2018 Feb 12;8:2830. doi: 10.1038/s41598-018-21209-z

Urban stormwater runoff negatively impacts lateral line development in larval zebrafish and salmon embryos

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PMCID: PMC5809384 PMID: 29434264

Abstract

After a storm, water often runs off of impervious urban surfaces directly into aquatic ecosystems. This stormwater runoff is a cocktail of toxicants that have serious effects on the ecological integrity of aquatic habitats. Zebrafish that develop in stormwater runoff suffer from cardiovascular toxicity and impaired growth, but the effects of stormwater on fish sensory systems are not understood. Our study investigated the effect of stormwater on hair cells of the lateral line in larval zebrafish and coho salmon. Our results showed that although toxicants in stormwater did not kill zebrafish hair cells, these cells did experience damage. Zebrafish developing in stormwater also experienced impaired growth, fewer neuromasts in the lateral line, and fewer hair cells per neuromast. A similar reduction in neuromast number was observed in coho salmon reared in stormwater. Bioretention treatment, intended to filter out harmful constituents of stormwater, rescued the lateral line defects in zebrafish but not in coho salmon, suggesting that not all of the harmful constituents were removed by the filtration media and that salmonids are particularly sensitive to aquatic toxicants. Collectively, these data demonstrate that sub-lethal exposure to stormwater runoff negatively impacts a fish sensory system, which may have consequences for organismal fitness.

Introduction

After storm events in urban areas, water runs off from roads, bridges, and other impervious surfaces. Some of this runoff is conveyed to the sanitary sewer where it may be treated in a wastewater plant before being released into a waterway, however, most stormwater runoff is conveyed directly into aquatic environments[1]. This runoff may contain many chemicals deposited on road surfaces by vehicles, including metals and polycyclic aromatic hydrocarbons (PAHs) such as petroleum products, tire dust, exhaust, and brake pad dust[2–5]. Stormwater runoff represents a large input of non-point source pollution to local watersheds[4,6]. Pollutant concentrations vary widely between storm events and within a storm, with water from the earliest part of the storm (first flush) often containing the highest levels of many potential toxicants[3,4]. First flush water is therefore associated with the majority of the toxicity[7]. In addition, PAH mixtures are themselves complex and highly variable, making stormwater chemistry exceedingly complicated to decipher[8].

Pollutants in stormwater runoff can negatively impact the development of aquatic life. Multiple studies demonstrate that stormwater can be fatal to larval fishes, including zebrafish and Pacific salmonids, as well as to juvenile and adult coho salmon[5,9–13]. Outside of acutely lethal effects,

exposure to aquatic pollutants can cause sub-lethal effects that have long-term repercussions on organismal fitness[14,15]. In zebrafish and walleye embryos, stormwater or PAH exposure causes delayed development, cardiovascular dysfunction, and craniofacial deformities[9,12,13,16]. Cardiac defects are also reported in larvae of large marine fishes that contact crude oil, suggesting that cardiotoxicity is widespread in fish exposed to PAHs[17,18]. Early life exposure to PAHs can have long-lasting results, including negative impacts on cardiac structure and function in adulthood[19]. PAH exposure also alters neurodevelopment, and changes in locomotion were reported in adult fishes, suggesting delayed effects of embryonic PAH exposure on nervous system or muscle development[20,21].

We examined the effects of urban stormwater runoff on the lateral line, the mechanosensory system on the head and body of fishes and aquatic amphibians. The lateral line is composed of stereotypically located clusters of cells, called neuromasts, that each contain sensory hair cells interdigitated with non-sensory supporting cells[22,23]. Fishes use this system to detect nearfield water movement from both abiotic and biotic sources, including predators, prey, and stream flow[24]. The lateral line contributes to behaviors such as orientation to current (rheotaxis), which may be important for navigation and migration[25,26]. As a surface structure, the lateral line directly contacts compounds in the aquatic environment, and sensory hair cells are highly susceptible to many toxicants of both biomedical and environmental origins[27–29]. The lateral line in larval zebrafish is an excellent model system for toxicology studies, owing to the small size of the organism, rapid *ex utero* development, and high fecundity[30]. The zebrafish lateral line is a tractable model system for toxicology studies, contributing to our understanding of how aquatic pollutants such as copper and bisphenol-A affect fish sensory systems[29,31–33].

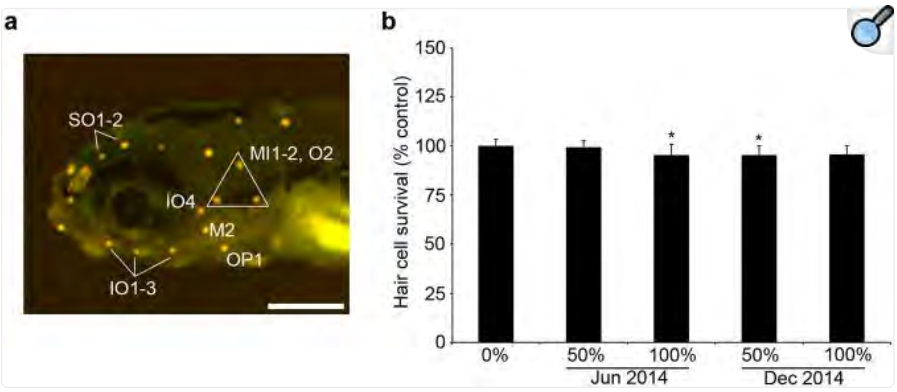
Here we assessed the effects of acute urban stormwater exposure on the lateral line in larval zebrafish. We also examined developmental effects of stormwater exposure in both zebrafish and coho salmon. Finally, we examined the effectiveness of green stormwater infrastructure, specifically soil bioretention treatments, to reduce stormwater-related lateral line defects. We found that acute stormwater exposure caused a reduction in hair cell viability, and that fish reared in stormwater had fewer hair cells per neuromast, and often fewer neuromasts, than fish raised in clean water. These data suggest that sub-lethal stormwater exposure can negatively impact sensory function, potentially impairing prey capture, predator avoidance, and rheotaxis.

Results

Acute exposure in older zebrafish larvae

We first exposed 5–6 days post-fertilization (dpf) larvae to a brief stormwater pulse to determine if short-term stormwater exposure was toxic to lateral line hair cells. Twenty-four hr of exposure to 50% or 100% stormwater did not kill lateral line hair cells (compared to control fish treated with embryo medium), as determined with quantification of DASPEI fluorescence or direct counts of GFP + hair cells in Brn3c:mGFP larvae (Fig. 1 and data not shown). We observed this same result with water from two different storm events, making it likely that runoff from other storms would have little effect on acute hair cell survival. However, water from either the December 2014 or June 2015 storms significantly reduced hair cell uptake of the vital dye FM 1–43FX (Fig. 2; $F_{2,25} = 19.81$, $p < 0.0001$), with approximately 50% reduction in FM 1–43FX fluorescence in all treatment groups. FM1–43FX uptake is a strong indicator of mechanotransduction channel function[34,35]. These results suggest that developed hair cells survive acute stormwater exposure but that function is compromised.

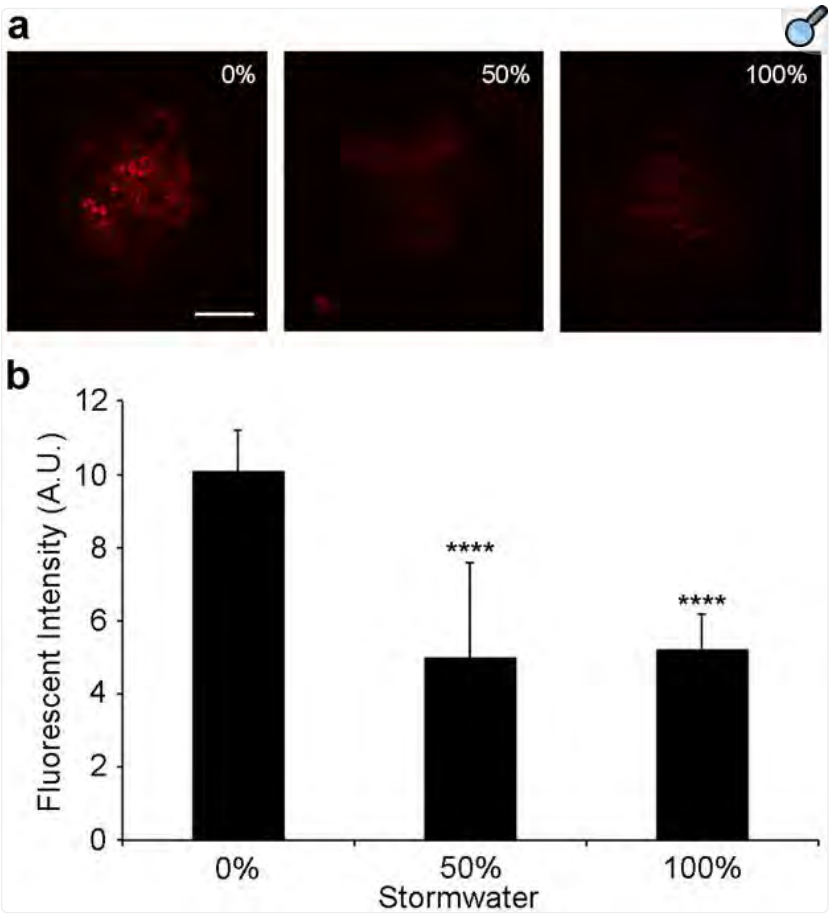
Figure 1.



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(**a**) Morphology of the head neuromasts in a larval zebrafish, visualized with DASPEI. Labels indicate the neuromasts that were quantified to assess hair cell damage. Scale bar = 250 μm. (**b**) Acute stormwater exposure does not kill lateral line hair cells. 5–6 dpf fish were exposed to stormwater for 24 hr (from June or December 2014 storm events), then hair cells were labeled with DASPEI. There is a slight but significant effect of stormwater (one-way ANOVA, $F_{4,62} = 4.02$, $p = 0.006$). Bonferroni-corrected post-hoc testing shows decreased hair cell survival for fish in the 100% June or 50% December groups (*$p < 0.0001$ for each). N = 13–14 fish per group, bars are + 1 s.d.

Figure 2.



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Acute stormwater exposure decreases uptake of the transduction-dependent dye FM 1–43FX by hair cells. (**a**) Representative confocal images of neuromast IO3 from fish treated with no stormwater (0%), 50%, or 100% stormwater for 24 hr, then labeled with FM 1–43FX. The bar in the left panel = 10 μm and applies to all panels. (**b**) There is a significant reduction in FM 1–43FX fluorescence in stormwater-treated fish (one-way ANOVA, $F_{2,25} = 19.81$, $p < 0.0001$). Bonferroni-corrected post-hoc testing shows decreased fluorescence at 50% or 100% stormwater (****$p < 0.0001$ for each). Fluorescence was quantified in arbitrary units (A.U.). This experiment used stormwater from a June 2014 storm event. N = 7–11 fish per group, bars are + 1 s.d.

Zebrafish robustly regenerate damaged hair cells, and toxicants such as copper and bisphenol-A negatively impact regenerative potential[29,36]. We therefore examined hair cell regeneration during exposure to stormwater. Fish were treated with the hair cell toxicant neomycin[28,37], then the neomycin was removed and fish were allowed to recover in stormwater (or fresh embryo medium as a control) prior to hair cell assessment. Stormwater exposure (50% or 100%) did not attenuate hair cell regeneration at the 24 or 48-hr timepoints (data not shown). These data suggesting that stormwater does not influence progenitor cell proliferation in relatively mature neuromasts, as hair cell regeneration after neomycin is almost entirely dependent on proliferation of neighboring supporting cells[36,38].

Stormwater exposure during zebrafish development

We then asked if exposure to stormwater runoff influenced lateral line development in zebrafish embryos. Fish reared in stormwater from 4 hpf to 4 dpf showed a variety of developmental phenotypes, ranging from normal gross morphology to cardiac edema and reduced swim bladder inflation, consistent with prior studies[5,13] (Fig. 3). Stormwater also caused increased fish mortality, with up to 50% mortality observed for some stormwater concentrations from the January 2016 storm event. By contrast, no mortality was seen for the lower stormwater concentrations used from the June 2015 storm event. Control fish, which were raised in fish facility water, did not show gross morphological defects (Fig. 3a).

Figure 3.

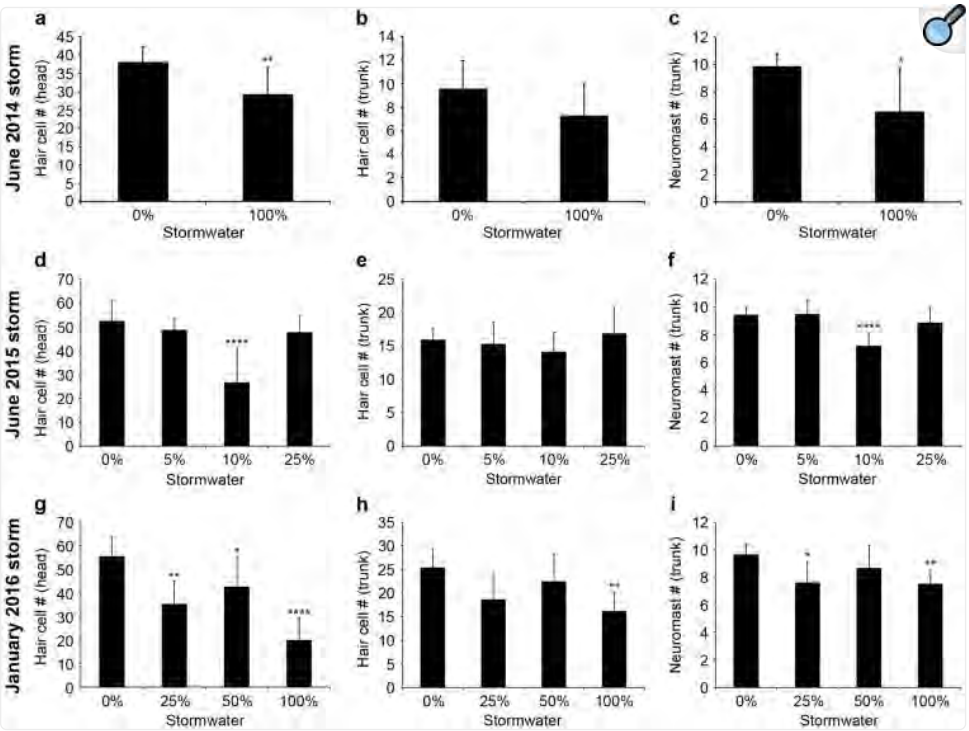


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Stormwater alters gross morphology of 4 dpf larvae exposed to runoff throughout development. (**a**) Untreated larvae (0% stormwater) showing normal development. (**b**-**c**) Examples of stormwater-treated larvae. (**b**) Some treated fish have not yet inflated their swim bladders (blue outlines). (**c**) Other treated fish show pericardial edema (blue arrows). Scale bar in a = 0.5 mm and applies to all panels.

We consistently observed detrimental effects of stormwater exposure on lateral line development, but the magnitude of the effect differed based on the stormwater event (Fig. 4). Brn3c:mGFP fish treated with stormwater from 4 hpf – 4 dpf had fewer GFP + hair cells per neuromast (as compared to control animals reared in fish facility water), particularly for head neuromasts, and fewer neuromasts along the trunk. By contrast, treatment from 1–3 dpf had little effect on lateral line morphology (data not shown). Initial experiments with stormwater from June 2014 found that rearing in 100% stormwater resulted in a 23% reduction in hair cells in both head and trunk neuromasts, although only the reduction in head neuromasts was statistically significant (Fig. 4a,b; $p = 0.009$). These fish also had 33% fewer trunk neuromats overall (Fig. 4c). For the June 2015 stormwater event, we exposed the developing zebrafish to a low percentage of stormwater (5–25%) because high concentrations were lethal, suggesting a higher contaminant load in the June 2015 runoff. These lower stormwater concentrations caused a significant reduction in hair cells of head neuromasts (40%; $F_{3,43} = 17.99$, $p < 0.0001$) and in the number of trunk neuromasts (24% reduction; $F_{3,43} = 15.84$, $p = 0.004$), but only at the 10% stormwater concentration, an effect observed multiple times with water from this storm. Water from the January 2016 storm also caused a reduction in the number of hair cells per head neuromast for all three stormwater concentrations tested (25, 50, 100%), with decreases of 36%, 23%, and 64%, respectively ($F_{3,27} = 15.29$, $p < 0.0001$). There was also a significant reduction in hair cell number of anterior trunk neuromasts (in 100% stormwater only, 36% decrease; $F_{3,28} = 5.613$, $p = 0.0038$), and a reduction in the number of trunk neuromasts, with 21% fewer neuromasts in the 25% stormwater group, and 22% fewer neuromasts in the 100% stormwater group (Fig. 4h,i; $F_{3,28} = 5.564$, $p = 0.004$). Collectively, these data demonstrate that embryonic stormwater exposure causes lateral line defects in zebrafish larvae.

Figure 4.



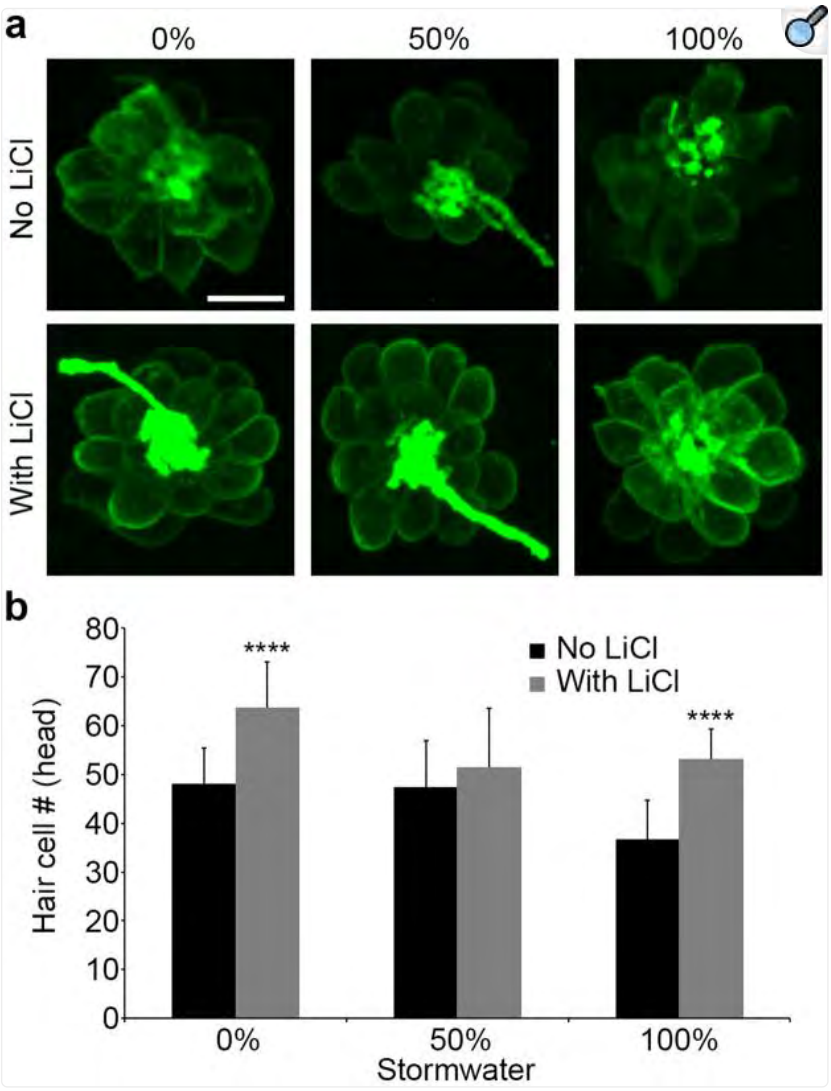
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Stormwater runoff causes detrimental effects on zebrafish lateral line development. (**a**–**c**) show data from a storm in June 2014, (**d**–**f**) from a June 2015 storm, and (**g**–**i**) from a January 2016 storm. All experiments were performed on Brn3c:mGFP fish treated from 4 hpf to 4 dpf. (**a**–**c**) Fish treated in stormwater from June 2014 had (**a**) a significant decrease in hair cell number in five head neuromasts (2-tailed t-test, $p = 0.009$), (**b**) no significant difference in hair cell number in the two most terminal neuromasts on the tail (2-tailed t-test, $p = 0.1024$), and (**c**) a significant decrease in the number of trunk neuromasts (2-tailed t-test, $p = 0.014$). (**d**) Fish exposed to stormwater from June 2015 showed a significant decrease in hair cell number in head neuromasts (one-way ANOVA, $F_{3,43} = 17.99$, $p < 0.0001$). For this storm, concentrations higher than 25% were lethal to the fish. (**e**) The same stormwater did not have any significant effect on hair cell number in the two most anterior trunk neuromasts (one-way ANOVA, $F_{3,43} = 1.688$, $p = 0.1837$). (**f**) The number of trunk neuromasts was significantly decreased in fish treated with stormwater from June 2015 (one-way ANOVA, $F_{3,43} = 15.84$, $p = 0.004$). (**g**-**h**) Fish exposed to stormwater from January 2016 showed a significant decrease in hair cell number in head neuromasts (**g**; one-way ANOVA, $F_{3,27} = 15.29$, $p < 0.0001$), and trunk neuromasts (**h**; one-way ANOVA, $F_{3,28} = 5.613$, $p = 0.0038$). (**i**) There was also a significant decrease in the number of trunk neuromasts in the January 2016 group (one-way ANOVA, $F_{3,28} = 5.564$, $p = 0.004$). For all groups asterisks denote significant differences from untreated animals, as determined with t-tests (panels a–c) or Bonferroni-corrected posthoc testing (panels d–i) (*$p < 0.05$, **$p < 0.01$, ****$p < 0.0001$). N = 7–13 fish per group treatment, bars are + 1 s.d.

We next examined possible causes of the lateral line defect. We focused on Wnt signaling, as this pathway is critical for neuromast deposition, cell proliferation, and hair cell addition in deposited neuromasts[39–42]. Zebrafish were treated with 50% or 100% stormwater from the January 2016 storm event in the presence or absence of the Wnt activator LiCl (15 mM). We elected to focus on the head neuromasts, as all storm events led to a significant reduction in hair cell number in this region. As previously found, 100% stormwater exposure during development reduced the number of hair cells in

the head neuromasts (compared to facility water-treated controls), and this effect was rescued by co-treatment with LiCl (Fig. 5; $p < 0.0001$). LiCl treatment also significantly increased the number of hair cells in fish treated with facility water only (no stormwater), consistent with prior reports[41,42].

Figure 5.



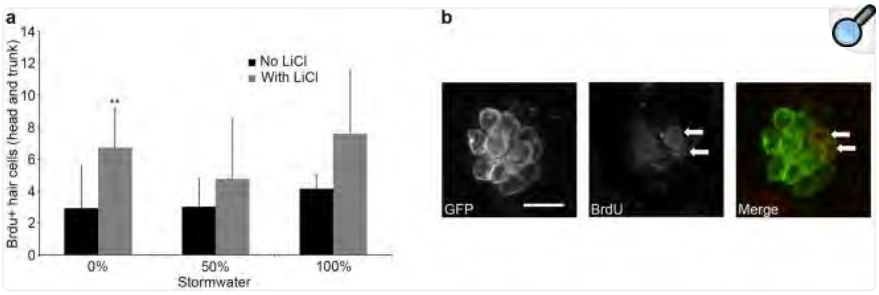
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The Wnt activator Lithium chloride (LiCl) reduces the detrimental effects of stormwater treatment on the developing lateral line. All experiments were performed on Brn3c:mGFP fish treated from 4 hpf to 4 dpf. (**a**) Representative confocal images of the OP1 neuromast from zebrafish larvae raised in different stormwater concentrations, with and without the presence of LiCl. The scale bar in the upper left = 10 μm and applies to all panels. (**b**) Quantitative data showing significantly fewer hair cells in fish raised in stormwater from January 2016 (black bars), and prevention of hair cell loss when fish were raised in the same stormwater with LiCl present (gray bars). Similar to previous experiments, stormwater caused a significant decrease in hair cell number (two-way ANOVA, $F_{2,72} = 10.15$, $p = 0.0001$). LiCl-treated fish had significantly more hair cells than fish reared without LiCl (two-way ANOVA, $F_{1,72} = 35.09$, $p < 0.0001$). The interaction between the stormwater and LiCl treatments was also significant (two-way ANOVA, $F_{2,72} = 3.819$, $p = 0.026$). Asterisks indicate significant pairwise differences between -LiCl and + LiCl groups for a given stormwater concentration (****$p < 0.0001$). N = 10–16 fish per group treatment, bars are + 1 s.d.

Since Wnt signaling regulates cell division in the lateral line, we next examined cell proliferation with a BrdU assay in Brn3c:mGFP larvae. BrdU + hair cells were defined as those cells which were also

GFP+. There was no significant difference in the number of BrdU-labeled hair cells in stormwater-treated fish compared to controls reared in fish facility water (2.9–4.1 BrdU+/GFP + hair cells across groups), suggesting that stormwater does not negatively impact cell proliferation in the developing lateral line (Fig. 6). However, there was a significant increase in BrdU-labeled hair cells in fish treated with LiCl, regardless of stormwater treatment ($F_{1,44} = 13.72$, $p = 0.0006$), consistent with previous studies showing that Wnt activation stimulates proliferation during lateral line development[42]. The combination of stormwater, LiCl, and BrdU was particularly toxic to zebrafish embryos, with 70–80% mortality observed in these groups.

Figure 6.

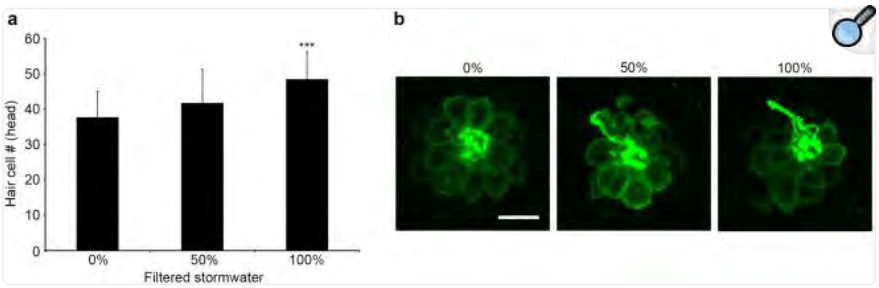


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Developmental stormwater exposure does not alter cell proliferation within zebrafish neuromasts. Experiments were performed in Brn3c:mGFP fish, allowing for quantification of BrdU + /GFP + cells (hair cells). Fish were exposed to stormwater from 4 hpf – 4 dpf, and BrdU was pulsed at 32.5–34 hpf. (**a**) There was no change in the number of BrdU + hair cells in stormwater-treated embryos (black bars, two-way ANOVA, $F_{2,44} = 1.701$, $p = 0.19$). There was a significant increase in BrdU-labeled hair cells in LiCl-treated zebrafish (gray bars, two-way ANOVA, $F_{1,44} = 13.72$, $p = 0.0006$). Asterisks indicate significant pairwise differences between - LiCl and + LiCl groups for a given stormwater concentration. N = 7–13 zebrafish per group with exception of 50% stormwater + LiCl, where N = 4. Bars are + 1 s.d. (**b**) Representative confocal images showing BrdU labeling in the P2 neuromast of the trunk, with two hair cells double-labeled with GFP and BrdU (white arrows). Scale bar = 10 μm and applies to all panels.

Previous research showed that stormwater filtration with bioretention columns significantly reduced developmental toxicity in zebrafish embryos[5,11,13]. We therefore asked if filtration attenuated the lateral line defects caused by stormwater exposure. As shown in Fig. 7, larvae raised in filtered stormwater had more hair cells than larvae reared in clean fish facility water, with 29% more hair cells observed in fish treated with 100% filtered stormwater compared with clean water controls ($F_{2,63} = 8.092$, $p = 0.0007$). Data are shown for the head neuromasts only, as the most consistent effect of stormwater rearing was observed in this region. These data suggest that stormwater treatment with bioretention columns is sufficient to remove the toxicants that affect lateral line development. There was no increase in mortality in fish reared in filtered stormwater vs. clean fish facility water.

Figure 7.



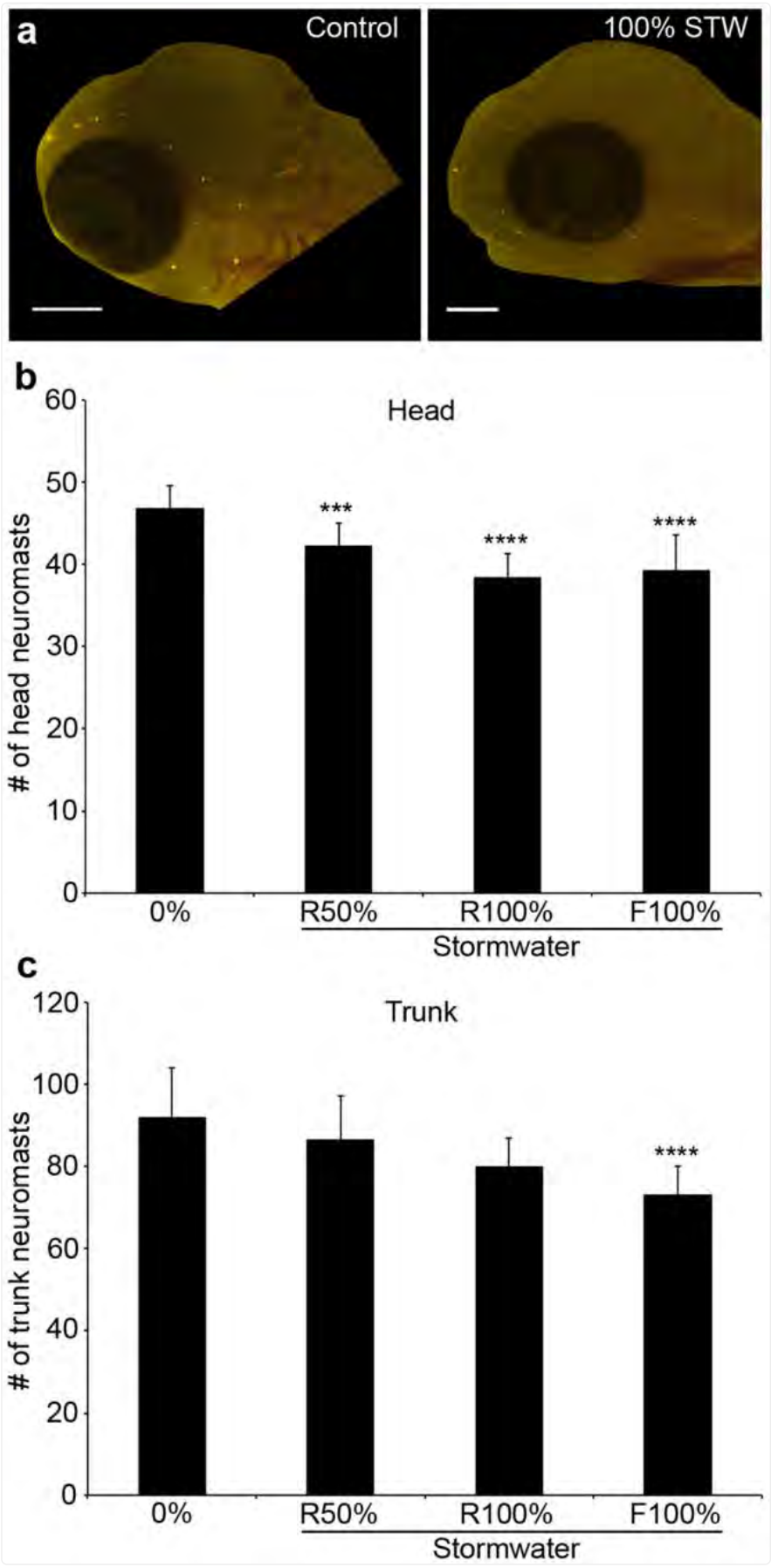
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Filtered stormwater rescues neuromasts from the toxic effects of stormwater. All experiments were performed on Brn3c:mGFP fish treated from 4 hpf to 4 dpf. Filtered stormwater was diluted with EM; 0% therefore represents fish treated with clean water. (**a**) Fish exposed to filtered stormwater from January 2016 showed a significant increase in hair cell number in head neuromasts (one-way ANOVA, $F_{2,63} = 8.092$, $p = 0.0007$); post-hoc testing (Bonferroni-corrected) shows increase in the 100% filtered stormwater group (***$p < 0.001$). (**b**) Representative confocal images of the OP1 neuromast from zebrafish larvae raised in different filtered stormwater concentrations. N = 19–24 fish per group treatment, bars are + 1 s.d., scale bar = 10 μm and applies to all panels in (**b**).

Effects of stormwater on coho lateral line development

While zebrafish are a tractable model for toxicity studies, in the Pacific northwest, Pacific salmonids (*Oncorynchus* spp.) are of greater ecological and economic interest. We therefore used coho salmon to better understand how stormwater influences lateral line development in a commercially important species. Coho salmon embryos were episodically exposed during rearing to 50% stormwater diluted in well water, 100% stormwater, or 100% stormwater that was first filtered through a bioretention column. Coho embryos treated with any of these three treatments had fewer head neuromasts than control embryos continuously reared in well water, with a 10% reduction in head neuromasts in embryos treated with 50% stormwater, and an 18% reduction in neuromasts in embryos treated with 100% stormwater or filtered stormwater (Fig. 8a,b; $F_{3,46} = 14.84$, $p < 0.0001$). There was also an effect of stormwater treatment on the number of neuromasts on the trunk (lateral body surfaces) ($F_{3,46} = 8.33$, $p = 0.0002$), with control fish averaging 92.1 neuromasts and treated fish averaging 86.6, 80, and 73.1 neuromasts, respectively, for the 50% stormwater, 100% stormwater, and 100% filtered stormwater groups. However, this effect was only significant for the fish reared in filtered stormwater (Fig. 8c, $p < 0.0001$).

Figure 8.


a
Control
100% STW
b
Head
of head neuromasts
60
50
40
30
20
10
0
***
****
****
0%
R50%
R100%
F100%
Stormwater
c
Trunk
of trunk neuromasts
120
100
80
60
40
20
0
****
0%
R50%
R100%
F100%
Stormwater

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Stormwater exposure during development reduces the number of lateral line neuromasts in coho salmon. (**a**) Fluorescent images of DASPEI-labeled coho salmon embryos from a control fish (left) and a fish exposed to 100% stormwater (STW; right). Scale bars = 0.5 mm. (**b**) There are fewer head neuromasts in stormwater-exposed embryos (one-way ANOVA, $F_{3,46} = 14.84$, $p < 0.0001$). R = regular (unfiltered) stormwater, F = filtered stormwater. (**c**) There are also fewer trunk neuromasts in these embryos (one-way ANOVA, $F_{3,46} = 8.33$, $p = 0.0002$). For both (**b**) and (**c**), Bonferroni-corrected post-hoc analyses demonstrate significant differences from control embryos (***$p < 0.001$, ****$p < 0.0001$). N = 6–20 fish per treatment, bars are + 1 s.d.

There was a significant effect of stormwater treatment on fish size, with fish developing in stormwater being slightly but significantly smaller than fish developing in clean water or filtered stormwater (1-way ANOVA, $F_{3,46} = 14.72$, $p < 0.001$). We therefore examined the interaction between treatment and fish size (total length) on neuromast number in embryonic coho. There was no significant interaction between treatment and fish length, suggesting that observed differences in neuromast number are an effect of stormwater treatment rather than of size (2-way ANOVA, $F_{6,50} = 0.646$, $p = 0.69$).

Water Chemistry

Given the variability in lateral line toxicity among water samples from different storms, water chemistry was measured for runoff collected from the storm events on June 2014 and January 2016 as part of other studies. Concentrations of solids and dissolved metals in 100% runoff collected on these dates (Table 1) were similar to those previously published for runoff from this collection site[5,43]. Bioretention filtration of runoff from the 2016 event resulted in increased salts and reduced solids, ammonia, copper, and zinc (Table 1). These changes are similar to a previous study reporting effectiveness of bioretention for runoff from this collection site[5,43].

Table 1.

Water chemistry measured in stormwater runoff samples from two collection dates. Metals are dissolved (water passed through a 0.45 µm filter). Filtered runoff had been passed through a bioretention treatment system as described in the Methods section.

Parameter	Method[c]	Detection Limit	Units	Jun 16 2014[a]	Jan 14 2016[b]	
				100% Runoff	100% Runoff	100% Filtered Runoff
pH	SM 4500HB	0.1	none	6.5 (0.1)	6.9	6.6
TSS[d]	SM 2540D	1	mg/L	52 (4)	180	12
SSC[e]	ASTM D3977–97	1	mg/L	43 (3)	220	15
DOC[f]	SM 5310B	0.5	mg/L	13 (0)	5.1	6.9
Alkalinity	SM 2320B	1	mg/L[g]	16 (0)	40	26
Hardness	EPA 200.7 calc	1	mg/L[g]	28 (1)	44	920
Ca	EPA 200.7	0.05	mg/L	9.83 (0.15)	12	230
Mg	EPA 200.7	0.01	mg/L	0.96 (0.03)	3.3	85
Ammonia[h]	EPA 350.1	0.01	mg/L	1.3 (0.02)	1.17	0.14
Nitrate	EPA 300.0	0.025	mg/L	0.88 (0.01)	0.206	<
Ortho-P	SM 4500-PE	0.005	mg/L	0.019 (0.003)	<	0.114
Cd	EPA 200.8	0.025	µg/L	0.101 (0.012)	0.076	0.076
Cu	EPA 200.8	0.1	µg/L	33.7 (0.9)	15.6	7.06
Pb	EPA 200.8	0.05	µg/L	0.44 (0.02)	0.15	0.18
Ni	EPA 200.8	0.05	µg/L	1.22 (0.98)	2.02	4.97
Zn	EPA 200.8	0.5	µg/L	92.4 (2.5)	44.9	8.9

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[a]Triplicate samples showing average (standard deviation).

[b]Unique samples (no replication).

[c]Analysis method following: SM = Standard Method; ASTM = ASTM International; EPA = U.S. Environmental Protection Agency.

[d]Total suspended solids.

[e]Suspended sediment concentration.

[f]Dissolved organic carbon.

[g]as $CaCO_3$.

[h]Total ammonia nitrogen. < Used when values less than detection limit.

Discussion

We investigated the effect that stormwater runoff has on sensory hair cells of the lateral line in larval zebrafish and coho salmon. In 5–6 dpf zebrafish larvae, acute exposure does not kill hair cells, but it does reduce uptake of the dye FM 1–43FX, a key marker of hair cell function. A previous study also did not see an effect of stormwater exposure on lateral line hair cell survival, but that study used a 3 hr incubation period, rather than the 24 hr exposure period used here[5]. Their study assessed hair cell survival with DASPEI, which is not as sensitive to changes in function of the mechanotransduction apparatus as is FM 1–43FX. The lateral line is acutely sensitive to many aquatic toxicants, including bisphenol-A and heavy metals such as copper and cadmium, likely due to the external location of this sensory system and the relative permeability of hair cells to molecules in the surrounding environment[29,31,33,44]. Hair cells in 5 dpf zebrafish larvae exhibit adult-like sensitivity to some drugs, such as aminoglycoside antibiotics and chemotherapy agents[28,45,46]. Given that larval hair cells demonstrate responses to some toxicants that are similar to responses in adult fishes, our data suggest that hair cells in adult fish may also be negatively impacted by short-term stormwater exposure.

It is unclear how stormwater exposure reduces mechanotransduction function in lateral line hair cells. Crude oil exposure can alter intracellular calcium dynamics within fish cardiomyoctes[47,48], and in hair cells, mechanosensitivity is tightly regulated by intracellular calcium levels in the hair bundle[49–51]. Therefore, the reduction in uptake of FM 1–43FX could be due to increased intracellular calcium, which could directly reduce dye uptake by closing mechanotransduction channels. In cardiomyoctes, however, crude oil exposure reduces intracellular calcium[47,48], which would increase hair cell permeability to toxicants and facilitate hair cell damage. While PAHs can directly block some ion channels[47,48], it is unlikely that FM 1–43FX uptake was reduced because of a direct channel block, as our experiments were performed after the fish were removed from stormwater. Altered calcium dynamics were observed in lateral line hair cells treated with aminoglycoside antibiotics and inhibition of calcium mobility prevented hair cell death from these drugs[52,53]. Therefore, stormwater exposure may disrupt intracellular calcium mobility, leading to hair cell damage. Future studies are needed to explore this hypothesis and determine the molecular signaling cascades involved.

In addition to acutely toxic effects on the lateral line, stormwater exposure during embryogenesis caused lateral line defects in both zebrafish and coho salmon. Direct comparisons between zebrafish and coho salmon data are not possible due to differences in the developmental stage at which each species was treated, the overall developmental timeline (coho salmon develop much more slowly), and experimental factors such as the stormwater exposure paradigm used here. However, these data suggest that stormwater exposure is likely to cause defects in lateral line development in a variety of fish species. This developmental effect was highly variable, with 10% stormwater from some storm events causing a reduction in neuromasts and hair cells per neuromast, while for other storm events a similar effect was only observed with 100% stormwater exposure. The concentration of PAHs and other toxicants varies with each storm, and storms following a dry period usually cause more toxic runoff than storms in the middle of the rainy season, as toxicants build up on impervious roadways during dry spells[3,4]. Stormwater with higher PAH concentrations causes more severe cardiac phenotypes[13], and a similar effect is likely in the lateral line. Developmental stormwater exposure is also associated with reduced fish growth[5], so it is possible that the lateral line defects are secondary to other developmental deficits such as small size. We consider this unlikely, as there was no interaction between size and neuromast number in stormwater-treated coho embryos. However, we cannot rule out a size effect, as fish development is more closely correlated with size than age.

While it is possible that PAHs are responsible for the observed defects, urban stormwater runoff contains a very complex mixture of contaminants[54], including suspended particles and dissolved metals, in addition to organics such as PAHs. A recent study on runoff from the same stormwater collection site used for our study detected, through high resolution quadrupole time-of-flight mass

spectrometry, hundreds to thousands of organic compounds - the vast majority of which remain unidentified and uncharacterized[55]. Although several metals (*e.g.*, copper) are classically known to be neurotoxic to peripheral sensory systems[32,56], toxicity is mediated by the presence of metal-scavenging organic matter (typically measured as dissolved organic carbon)[57,58]. Furthermore, metals not measured in the current study (*e.g.*, cobalt) can also be toxic to the fish lateral line[59], as can low pH and organic contaminants including pesticides and surfactants[60].

Therefore, measuring a short list of contaminants present in urban runoff does not guarantee an ability to explain relative differences in toxicity among samples. For example, there were higher concentrations of the neurotoxic metal copper in the June 2014 sample compared to the January 2016 sample, and yet the January sample caused a stronger reduction of hair cells in zebrafish head neuromasts (64%) compared to the June 2014 sample (23%). Lower relative DOC concentrations in the January sample may help explain the difference in toxicity between the two samples, but robust analysis of water chemistry is not productive without a better understanding of the relative toxic potencies of the many different chemicals in the mixture. Similarly, the beneficial effect of bioretention filtration on zebrafish lateral line development observed for the January sample may have as much to do with what is added to the water (*e.g.*, DOC, salts; Table 1) as what is removed (*e.g.*, neurotoxic metals). Future studies are needed to determine the precise water constituents that caused the lateral line defects.

In zebrafish, lateral line defects were rescued by activation of Wnt signaling. Wnt controls several facets of lateral line development, including neuromast deposition along the trunk, proliferation of precursor cells, and hair cell addition[39–42]. PAHs can dysregulate ß-catenin, a key component of the Wnt pathway, leading to patterning defects in zebrafish and Pacific herring[52]. Wnt signaling is important for early cardiac development, and cardiac dysfunction is a major outcome of PAH toxicity[14,61,62]. It is unclear if the cardiac defects in PAH-exposed embryos are partially due to disrupted Wnt signaling; several studies demonstrate that PAHs act through the aryl hydrocarbon receptor (AHR) to cause cardiotoxicity[15,61]. AHR activation may cause cardiotoxicity in zebrafish by downstream disruption of Wnt signaling, suggesting that Wnt could play a central role in developmental stormwater toxicity[62]. However, as Wnt activation leads to excess hair cells in untreated zebrafish, it is possible that stormwater does not inhibit Wnt signaling, but instead that stormwater acts through a separate pathway for which Wnt can compensate. One candidate is retinoic acid signaling, which is involved in lateral line development and disrupted by PAH exposure[63,64]. Future experiments are needed to determine the signaling pathway(s) responsible for stormwater-mediated lateral line defects.

Stormwater exposure during embryonic and larval development caused a reduction in the number of trunk neuromasts, at least for some storm events, and a reduction in the number of hair cells per neuromast. Both phenotypes could occur by stormwater-mediated attenuation of cell proliferation in the developing lateral line. However, we did not find a difference in the number of BrdU-labeled hair cells in stormwater-treated larvae. These data imply that stormwater exposure does not alter proliferation. We incubated fish in BrdU from 32.5–34 hpf, a window of high proliferation during lateral line primordium migration[40,65]. However, our BrdU pulse was restricted in time to avoid embryo toxicity, so we may have missed observing an effect on progenitor proliferation. Hair cell regeneration proceeded normally in stormwater-treated larvae that were exposed to the hair cell toxicant neomycin, further evidence that stormwater does not affect cell proliferation in the lateral line. Therefore, the developmental effect likely results from a non-proliferative mechanism, such as progenitor cell survival.

We did not detect lateral line defects in zebrafish embryos raised in filtered stormwater, while filtration did not rescue lateral line morphology in coho salmon embryos. This may be due to differential sensitivity to trace levels of toxicants between the species, or to the different exposure paradigms for each species; zebrafish were exposed continuously for 4 days, while coho embryos were exposed in a pulsed manner for 43 or 71 days. Zebrafish are warm-water fishes that exhibit rapid development, while Pacific salmon are cold-water fishes with longer developmental trajectories. It is therefore unsurprising that coho embryos may be more sensitive to trace amounts of toxicants. Previous work in coho salmon shows that stormwater treatment with bioretention columns

completely amelioriates overall mortality, and filtered stormwater reduces several markers of toxicity in zebrafish, including cardiac edema and fish size[5,11]. Bioretention treatment reduces the severity of micropthalmia (small eyes) but does not completely prevent this phenotype, similar to our finding that bioretention does not prevent lateral line defects in developing coho salmon. Bioretention filtration is highly effective at removing the bulk of the developmental toxicants from stormwater runoff, but sensory systems such as the eye and lateral line appear particularly susceptible to residual toxicants that remain after filtration.

In conclusion, our data demonstrate that either acute or developmental stormwater exposure can have negative consequences for the mechanosensory lateral line of zebrafish and coho salmon. While mortality and cardiotoxicity are certainly the greatest concerns, our data add to the growing body of evidence suggesting that sublethal stormwater exposure can have detrimental effects on fishes. Stormwater-related lateral line deficits have the potential to reduce prey capture and predator avoidance behaviors, increasing the risk for fish mortality.

Methods

Animals

All procedures were approved by the Institutional Animal Care and Use Committee at Washington State University. All experiments were performed in accordance with the relevant guidelines and regulations of Washington State University and the American Veterinary Medical Association.

Zebrafish

We used 5–6 days post-fertilization (dpf) zebrafish (*Danio rerio*) for acute toxicity experiments because their hair cells exhibit adult-like sensitivity to known hair cell toxicants[45,46]. Developmental studies were initiated shortly after the eggs were fertilized (4–24 hours post-fertilization (hpf)). *AB wildtype or Brn3C:mGFP transgenic fish were used for all experiments. Hair cells of Brn3c:mGFP animals express membrane-bound green fluorescent protein (GFP) in all hair cells and the transgene is turned on early in hair cell development, making this fish line ideal for developmental studies[66].

Coho Salmon

Embryonic coho salmon (*Oncorhynchus kisutch*) were obtained from Grovers Creek Salmon Hatchery in Poulsbo, Washington. As part of a separate study, eggs fertilized on 23 November 2015 were reared in flow-through heath stacks with well water during development and episodically exposed to recirculating stormwater runoff treatments. Fish were collected from the hatchery on 5 January 2016 and 2 February 2016 and transported to Washington State University Vancouver for lateral line assessment.

Stormwater collection and filtration

Stormwater runoff was collected from SR 520, a floating bridge that crosses Lake Washington in Seattle, WA as described previously[5]. Briefly, downspouts from an on-ramp to SR520 directed runoff during rain events into a stainless steel IBC tote. For studies with zebrafish, runoff was frozen in amber glass bottles and stored at −20 °C. For developmental tests with coho salmon, runoff was transported within 24 h to the hatchery where it was dispensed to stainless steel sumps for recirculting exposure to embryos. The filtered runoff treatment used bioretention cells. Cells were constructed in 55-gallon polyethylene drums fitted with a slotted PVC underdrain embedded in 30.5 cm of gravel. The well-mixed bioretention soil media (BSM) overlying the gravel (61-cm) was composed of 60% sand and 40% compost by volume as per the Western Washington Stormwater Management Manual[67]. The BSM was overlain by 2” of bark mulch. Runoff was treated at 2 L/min and transported to the filtered runoff sump in high density polyethylene buckets. Dilutions of runoff used the same water source as that used for rearing embryos between stormwater exposures. Analytical

chemistry of the June 2014 and January 2016 stormwater samples was conducted as previously described[5,43].

Stormwater exposure

Zebrafish

For acute exposure, 5–6 dpf zebrafish were incubated in varying concentrations of thawed stormwater for 1–24 hr, with E2 embryo medium[68] (EM) used to dilute stormwater to the desired concentration (1 mM $MgSO_4$, 0.15 mM KH_2PO_4, 1 mM $CaCl_2$, 0.5 mM KCl, 15 mM NaCl, 0.05 mM Na_2HPO, and 0.7 mM $NaHCO_3$ in dH_2O, pH 7.2). After exposure, fish were rinsed twice in fresh EM, and hair cells were assessed as described below. For hair cell regeneration studies, 5 dpf zebrafish were treated for 1 hr with 300 μM neomycin, a known hair cell toxicant[28]. Fish were then rinsed in fresh EM and allowed to recover for 24 or 48 hr prior to hair cell assessment. In either set of experiments, control fish were treated with EM only (no stormwater).

For developmental studies, zebrafish were exposed to varying dilutions of thawed stormwater (diluted with fish facility water), beginning at 4–24 hpf and ending at 3–4 dpf. Stormwater was refreshed daily. For a subset of these studies, the Wnt activator lithium chloride was added as a cotreatment with stormwater[42]. 4–6 hpf Brn3c:mGFP zebrafish were exposed to 15 mM LiCl with or without stormwater, again with solutions refreshed daily. All experiments were conducted with water from multiple storm events; in some cases, only one representative result is shown for experiments where the results were consistent across storm events. In pilot tests with zebrafish, freezing runoff did not affect its developmental toxicity[5]. Control fish were treated with fish facility water only; this water has lower conductivity than EM and is preferable for developmental studies (Coffin, unpublished observation).

Coho salmon

For developmental studies in coho salmon, embryonic coho were episodically exposed for 24–48 hr to either 50% or 100% stormwater, or with 100% stormwater that was first treated in bioretention columns as described above. At the end of the exposure, the water source was switched back to flow-through with well water. Control fish were exposed to well water only. Runoff tended to be slightly cooler than the well water used for rearing between runoff exposures, such that there was a slight difference in degree days of the embryos across treatments. On 5 January (43 dpf), embryos had been exposed to 10 episodic runoff exposures, totaling 19 days of development. Their degree-days (accumulated thermal units, in degree Celcius) were 352 for controls, 345 for 50% runoff treatment, 338 for 100% runoff, and 337 for 100% filtered runoff. On 2 February (71 dpf) embryos had been exposed to an additional 5 runoff events, for a total exposure of 29 days.

Lateral line assessment

Vital dye labeling

Neuromasts in live, anesthetized fish were assessed using the mitochondrial dye 2-(4-(dimethylamino)styryl)-N-Ethylpyridinium iodide (DASPEI, Life Technologies, Carlsbad, CA, USA), which specifically labels lateral line hair cells and olfactory receptors[28,37]. Zebrafish larvae were incubated in EM containing 0.005% DASPEI for 15 min, rinsed twice with fresh EM, then anesthetized by immersion in buffered 0.001% MS-222 in fresh EM (3-aminobenzoic acid ethyl ester methanesulfonate, Argent Labs, Redmond, WA, USA). Neuromasts were viewed with a Leica M165F fluorescent stereomicroscope (Leica Microsystems, Buffalo Grove, IL, USA). We assessed the same 10 anterior neuromasts for each fish[23] (SO1, SO2, IO1-IO4, M2, MI1, MI2, O2, see Fig. 1), with each neuromast scored as 0 (no labeling), 1 (moderate labeling), or 2 (bright labeling). Scores for each neuromast were summed, resulting in a total score of 0–20 per fish[28]. As neuromast locations are stereotyped in zebrafish larvae, absence of a neuromast is likely a treatment effect rather than

developmental variation. While hair cell assessment was not performed blind, we have previously performed side-by-side comparisons of blinded vs. unblinded DASPEI assessment and found no differences in scoring[69]. The reader is referred to Raible and Kruse (2000) for details on zebrafish neuromast nomenclature[23].

For embryonic coho salmon, fish were manually dechorionated and incubated with DASPEI as described above, except that we used a 20 min incubation period, which better labels the lateral line in salmonids, including the canal neuromasts[70]. We then counted the number of neuromasts in four head regions: the infraorbital canal, the preopercular canal, the stitch of opercular superficial neuromasts, and the y-shaped stitch of superficial neuromasts on the dorsal surface of the head[70,71]. Details of salmonid lateral line morphology are shown in Brown *et al*. (2013)[70]. We also quantified the number of neuromasts on the trunk. Counts from the four head regions were summed to obtain one head value per fish. Coho embryos were evaluated blind to treatment.

Hair cells counts

Hair cell counts were conducted in Brn3c:mGPF zebrafish larvae, where all hair cells are GFP+. Fish were rinsed in fresh EM, anesthetized with buffered 0.001% MS-222, and mounted on bridged coverslips. Fish were visualized with a Leica DMI4000 B compound fluorescent microscope or Leica SP8 confocal microscope. Hair cells in neuromasts IO1-IO3, M2, and OP1 were quantified and summed to arrive at one value for each fish (see Fig. 1). We also examined multiple trunk neuromasts. For the June 2014 storm we quantified hair cells on the two most posterior neuromasts on the tail, which exhibited considerable variation even in control animals. Therefore, we elected to focus on the head region and the anterior-most neuromasts of the trunk for additional experiments.

FM 1–43

To examine the relative health of surviving hair cells, we used the vital dye FM 1–43FX, which enters hair cells through the mechanotransduction channels and is considered a proxy for hair cell viability[34,35]. Fish were exposed to 3 μM FM 1–43FX (Life Technologies) for 30 sec. Fish were then rinsed 3 times in fresh EM, euthanized with an overdose of buffered MS-222, and fixed in 4% paraformaldehyde (PFA) overnight at 4 °C. FM 1–43FX-labeled fish were imaged with a Leica SP8 confocal microscope, and relative fluorescent intensity was quantified from defined regions of interest using ImageJ[72].

Cell proliferation assay

At 32.5–34 hpf, Brn3c:mGFP zebrafish embryos were dechorionated, then exposed to 10 mM 5-bromo-2-deoxyuridine (BrdU, Sigma-Aldrich, St. Louis, MO, USA), supplemented with 15% dimethylsulfoxide (DMSO) in EM[65]. BrdU treatment was conducted for 90 min; 30 min at 4 °C, followed by 60 min at 28 °C. Embryos were rinsed in fresh EM, then transferred to fish room water and allowed to develop to 4 dpf. The exposure window of 32.5–34 hpf is based on previous studies showing substantial levels of proliferation in lateral line precursors during this developmental period[40,65].

At 4 dpf, zebrafish were processed for BrdU detection modified from published protocols[28]. All compounds were obtained from Sigma-Aldrich unless specified, and all steps were performed at room temperature unless noted. Embryos were euthanized with buffered MS-222 and fixed for 1 hr in 4% PFA. Tissue was permeabilized in three rinses of PBDT (1% DMSO and 0.5% Triton-X 100 in phosphate buffered saline (PBS)) at 20 min increments, incubated in purified water for 30 min, and blocked in antibody block solution (5% normal goat serum (NGS) in PBDT) for 1 hr. Tissue was then incubated in polyclonal anti-GFP primary antibody (Life Technologies), diluted 1:200 in PBDT with 1% NGS, applied overnight at 4 °C. Tissue was rinsed in PBDT prior to 5 hr of secondary antibody exposure (Alexa Fluor 488 goat anti-rabbit IgG in PBDT, 1:500, Life Technologies). The fish were refixed with PFA for 20 minutes and placed in methanol for 1 hour at −20 °C. After rehydrating in a graded methanol series, fish were rinsed with PBDT and digested with Proteinase K (10 ug/mL in

PBDT) for 20 min. Tissue was rinsed with PBDT, refixed with PFA for 20 min, rinsed again, and exposed to 2 N HCl for 1 hr. Fish were rinsed again, blocked in 10% NGS in PBDT for 1 hr, and incubated overnight at 4 °C in monoclonal anti-BrdU antibody diluted 1:100 in PBDT with 1% NGS. Fish were then rinsed in PBDT and exposed to secondary antibody (Alexa Fluor 568 goat anti-mouse IgG in PBDT, 1:200, Life Technologies) for 5 hr. Fish were again rinsed and stored in 50% PBS:glycerol for imaging on a Leica SP8 confocal microscope.

BrdU-positive hair cells represent hair cells that resulted from proliferation of precursor cells. These cells were defined as cells that were positive for BrdU (which labels all proliferating cells), but also for GFP, as all hair cells in the Brn3c:mGFP transgenic line express GFP. BrdU + hair cells were quantified in 5 head neuromasts (IO1- IO3, M2, and OP1) and in the two most anterior trunk neuromasts. Numbers were summed to achieve one value per fish.

Statistical analysis

Data were analyzed using a 2-tailed t-test or one- or two-way ANOVA, as appropriate, with Prism v. 7 or SPSS Statistics. Data are presented as mean + 1 s.d.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Acknowledgements

This research was funded by the Washington State University Center for Environmental Research, Education, and Outreach and in part by Washington Sea Grant, University of Washington, pursuant to National Oceanic and Atmospheric Administration Award No. NA14OAR4170078. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies. We thank Erin Cooper and Maria Sokolova for fish husbandry assistance. We also thank two anonymous reviewers who helped strengthen the final manuscript.

Author Contributions

A.Y., V.K., J.K.M. and A.B.C. performed the experiments and drafted the manuscript. J.D.S., A.B.C. and J.K.M. designed the experiments, and J.D.S. edited the manuscript.

Competing Interests

The authors declare no competing interests.

Footnotes

Alexander Young and Valentin Kochenkov contributed equally to this work.

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References

1. Burns MJ, Fletcher TD, Walsh CJ, Ladson AR, Hatt BE. Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. Landscape and

Urban Planning. 2012;105:230–240. doi: 10.1016/j.landurbplan.2011.12.012. [DOI] [Google Scholar]

2. Hoffman EJ, Mills GL, Latimer JS, Quinn JG. Urban runoff as a source of polycyclic aromatic hydrocarbons. Environ. Sci. Technol. 1984;18:580–587. doi: 10.1021/es00126a003. [DOI] [PubMed] [Google Scholar]

3. Characklis GW, Wiesner MR. Particles, metals, and water quality in runofffrom large urban watersheds. J. Environ. Eng. 1997;123:753–759. doi: 10.1061/(ASCE)0733-9372(1997)123:8(753). [DOI] [Google Scholar]

4. Stein ED, Tiefenthaler LL, Schiff K. Watershed-based sources of polycyclic aromatic hydrocarbons in urban storm water. Environ. Toxicol. Chem. 2006;25(2):373–385. doi: 10.1897/05-285R.1. [DOI] [PubMed] [Google Scholar]

5. McIntyre, et al. Zebrafish and clean water technology: Assessing soil bioretention as a protective treatment for toxic urban runoff. Science of the Total Environment. 2014;500-501:173–180. doi: 10.1016/j.scitotenv.2014.08.066. [DOI] [PubMed] [Google Scholar]

6. Paul MJ, Meyer JL. Streams in the urban landscape. Annu. Rev. Ecol. Syst. 2001;32:333–365. doi: 10.1146/annurev.ecolsys.32.081501.114040. [DOI] [Google Scholar]

7. Kayhanian M, Stransky C, Bay S, Lau L, Stenstrom MK. Toxicity of urban highway runoff with respect to storm duration. Science of the Total Environment. 2008;389(2-3):386–406. doi: 10.1016/j.scitotenv.2007.08.052. [DOI] [PubMed] [Google Scholar]

8. Shen, et al. Global atmospheric emissions of polycyclic aromatic hydrocarbons from 1960 to 2008 and future predictions. Environ. Sci. Technol. 2013;47:6415–6424. doi: 10.1021/es400857z. [DOI] [PMC free article] [PubMed] [Google Scholar]

9. Skinner L, de Peyster A, Schiff K. Developmental effects of urban storm water in medaka (Oryzias latipes) and inland silverside (Menidia beryllina) Archives of Environmental Contamination and Toxicology. 1999;37(2):227–235. doi: 10.1007/s002449900509. [DOI] [PubMed] [Google Scholar]

10. Scholtz, et al. Recurrent die-offs of adult coho salmon returning to spawn in Puget Sound lowland urban streams. PLoS One. 2013;6(12):e28013. doi: 10.1371/journal.pone.0028013. [DOI] [PMC free article] [PubMed] [Google Scholar]

11. McIntyre, et al. Soil bioretention protects juvenile salmon and their prey from the toxic impacts of urban stormwater runoff. Chemosphere. 2015;132:213–219. doi: 10.1016/j.chemosphere.2014.12.052. [DOI] [PubMed] [Google Scholar]

12. McIntyre, et al. Severe coal tar sealcoat runoff toxicity to fish is prevented by bioretention filtration. Environ. Sci. Technol. 2016;50:1570–1578. doi: 10.1021/acs.est.5b04928. [DOI] [PubMed] [Google Scholar]

13. McIntyre, et al. Confirmation of stormwater bioretention treatment effectiveness using molecular indicators of cardiovascular toxicity in developing fish. Environ. Sci. Technol. 2016;50:1561–1569. doi: 10.1021/acs.est.5b04786. [DOI] [PubMed] [Google Scholar]

14. Incardona JP, Collier TK, Scholz NL. Defects in cardiac function precede morphological abnormalities in fish embyros exposed to polycyclic aromatic hydrocarbons. Toxicol. Appl. Pharmacol. 2004;196:191–205. doi: 10.1016/j.taap.2003.11.026. [DOI] [PubMed] [Google Scholar]

15. Incardona JP. Molecular mechanisms of crude oil developmental toxicity in fish. Arch. Environ. Contam. Toxicol. 2017;73:19–32. doi: 10.1007/s00244-017-0381-1. [DOI] [PubMed] [Google Scholar]

16. Raine *et al*. The effect of oil sands tailing pond sediments on embryo-larval walleye (*Sander vitreus*). *Environ*. 10.1016/j.envpol.2017.06.038 (2017). [DOI] [PubMed]

17. Incardona, et al. Deepwater Horizon crude oil impacts the developing hearts of large predatory pelagic fish. Proc. Natl. Acad. Sci. USA. 2014;111(15):E1510–1518. doi: 10.1073/pnas.1320950111. [DOI] [PMC free article] [PubMed] [Google Scholar]

18. Esbaugh, et al. The effects of weathering and chemical dispersion on Deepwater Horizon crude oil toxicity to mahi-mahi (Coryphaena hippurus) early life stages. Sci. Total Environ. 2016;543(Pt A):644–651. doi: 10.1016/j.scitotenv.2015.11.068. [DOI] [PubMed] [Google Scholar]

19. Hicken, et al. Sublethal exposure to crude oil during embryonic development alters cardiac morphology and reduces aerobic capacity in adult fish. Proc. Natl. Acad. Sci. USA. 2011;108(17):7086–7090. doi: 10.1073/pnas.1019031108. [DOI] [PMC free article] [PubMed] [Google Scholar]

20. He, et al. Exposure of Sebastiscus marmoratus embryos to pyrene results in neurodevelopmental defects and disturbs related mechanisms. Aquat. Toxicol. 2012;116-117:109–115. doi: 10.1016/j.aquatox.2012.03.009. [DOI] [PubMed] [Google Scholar]

21. Vignet, et al. Long-term disruption of growth, reproduction, and behavior after embryonic exposure of zebrafish to PAH-spiked sediment. Environ. Sci. Pollut. Res. 2014;21:13877–13887. doi: 10.1007/s11356-014-2585-5. [DOI] [PubMed] [Google Scholar]

22. Metcalfe WK, Kimmel CB, Schabtach E. Anatomy of the posterior lateral line system in young larvae of the zebrafish. J. Comp. Neurol. 1985;233:377–389. doi: 10.1002/cne.902330307. [DOI] [PubMed] [Google Scholar]

23. Raible DW, Kruse GJ. Organization of the lateral line system in embryonic zebrafish. J. Comp. Neurol. 2000;421:189–198. doi: 10.1002/(SICI)1096-9861(20000529)421:2<189::AID-CNE5>3.0.CO;2-K. [DOI] [PubMed] [Google Scholar]

24. Montgomery, J. C., Bleckmann, H. & Coombs, S. Sensory ecology and neuroethology of the lateral line in *The Lateral Line System* (eds. Coombs, S., Bleckmann, H., Fay, R. R. & Popper, A.N.) 121–150 (Springer, 2014).

25. Baker CF, Montgomery JC. The sensory basis of rheotaxis in the blind Mexican cave fish Astyanax fasciatus. J. Comp. Physiol. A. 1999;184:519–527. doi: 10.1007/s003590050351. [DOI] [Google Scholar]

26. Montgomery JC, Baker CF, Carton AG. The lateral line can mediate rheotaxis in fish. Nature. 1997;389:960–963. doi: 10.1038/40135. [DOI] [Google Scholar]

27. Song J, Yan HY, Popper AN. Damage and recovery of hair cells in fish canal (but not superficial) neuromasts after gentamicin exposure. Hear. Res. 1995;91(1-2):63–71. doi: 10.1016/0378-5955(95)00170-0. [DOI] [PubMed] [Google Scholar]

28. Harris, et al. Neomycin-induced hair cell death and rapid regeneration in the lateral line of zebrafish (Danio rerio) J. Assoc. Res. Otolaryngol. 2003;4:219–234. doi: 10.1007/s10162-002-3022-x. [DOI] [PMC free article] [PubMed] [Google Scholar]

29. Hayashi, et al. The effect of the aquatic contaminants bisphenol-A and PCB-95 on the zebrafish lateral line. Neurotoxicology. 2015;46:125–136. doi: 10.1016/j.neuro.2014.12.010. [DOI] [PMC free article] [PubMed] [Google Scholar]

30. Coffin, A. B., Brignull, H., Raible, D. W. & Rubel, E. W. Hearing loss, protection, and regeneration in the larval zebrafish lateral line. In *The Lateral* Line System (eds. Coombs, S., Bleckmann, H., Fay, R. R. & Popper, A.N.) 313–347 (Springer, 2014).

31. Hernández PP, Moreno V, Olivari FA, Allende ML. Sub-lethal concentrations of waterborne copper are toxic to lateral line neuromasts in zebrafish (Danio rerio) Hear. Res. 2006;213(1-2):1–10. doi: 10.1016/j.heares.2005.10.015. [DOI] [PubMed] [Google Scholar]

32. Linbo TL, Stehr CM, Incardona JP, Scholtz NL. Dissolved copper triggers cell death in the peripheral mechanosensory system of larval fish. Environ. Toxicol. Chem. 2006;25(2):597–603. doi: 10.1897/05-241R.1. [DOI] [PubMed] [Google Scholar]

33. Froehlicher, et al. Zebrafish (Danio rerio) neuromast: promising biological endpoint linking developmental and toxicological studies. Aquat. Toxicol. 2009;95(4):307–319. doi: 10.1016/j.aquatox.2009.04.007. [DOI] [PubMed] [Google Scholar]

34. Gale JE, Marcotti W, Kennedy HJ, Kros CJ, Richardson GP. FM1-43 dye behaves as a permeant blocker of the hair-cell mechanotransducer channel. J. Neurosci. 2001;21(18):7013–7025. doi: 10.1523/JNEUROSCI.21-18-07013.2001. [DOI] [PMC free article] [PubMed] [Google Scholar]

35. M*eyers et al*. Lighting up the senses: FM1-43 loading of sensory cells through nonselective ion channels. J. *Neurosci*. **23(**10), 4054–4065 (2003). [DOI] [PMC free article] [PubMed]

36. Mackenzie SM, Raible DW. Proliferative regeneration of zebrafish lateral line hair cells after different ototoxic insults. PLOS One. 2012;7(10):e47257. doi: 10.1371/journal.pone.0047257. [DOI] [PMC free article] [PubMed] [Google Scholar]

37. Coffin AB, Reinhart KE, Owens KN, Raible DW, Rubel EW. Extracellular divalent cations modulate aminoglycoside-induced hair cell death in the zebrafish lateral line. Hear. Res. 2009;253:42–51. doi: 10.1016/j.heares.2009.03.004. [DOI] [PMC free article] [PubMed] [Google Scholar]

38. Ma, E. Y., Rubel, E. W. & Raible, D. W. Notch signaling regulates the extent of hair cell regeneration in the zebrafish lateral line. *J. Neurosci*. **28**(9), 2261–2273 (2008). [DOI] [PMC free article] [PubMed]

39. Aman A, Piotrowski T. Wnt/beta-catenin and Fgf signaling control collective cell migration by restricting chemokine receptor expression. Dev. Cell. 2008;15(5):749–461. doi: 10.1016/j.devcel.2008.10.002. [DOI] [PubMed] [Google Scholar]

40. McGraw, et al. Lef1 is required for progenitor cell identity in the zebrafish lateral line primordium. Development. 2011;138(18):3921–3930. doi: 10.1242/dev.062554. [DOI] [PMC free article] [PubMed] [Google Scholar]

41. Head JR, Gacioch L, Pennisi M, Meyers JR. Activation of canonical Wnt/ ß-catenin signaling stimulates proliferation in neuromasts in the zebrafish posterior lateral line. Dev. Dyn. 2013;242(7):832–846. doi: 10.1002/dvdy.23973. [DOI] [PubMed] [Google Scholar]

42. Jacques, et al. The role of Wnt/ß-catenin signaling in proliferation and regeneration of the developing basilar papilla and lateral line. Dev. Neurobiol. 2014;74(4):438–456. doi: 10.1002/dneu.22134. [DOI] [PubMed] [Google Scholar]

43. Spromberg *et al*. Widespread coho salmon spawner mortality in western U.S. urban watersheds: Lethal stormwater impacts are reversed by soil bioinfiltration. *J. Appl. Ecol*. 10.1111/1365-2664.12534 (2015).

44. Faucher K, Fichet D, Miramand P, Lagardère JP. Impact of chronic cadmium exposure at environmental dose on escape behavior in sea bass (Dicentrarchus labrax L.; Teleostei, Moronidae) Environ. Pollut. 2008;151(1):148–157. doi: 10.1016/j.envpol.2007.02.017. [DOI] [PubMed] [Google Scholar]

45. Santos F, MacDonald G, Rubel EW, Raible DW. Lateral line hair cell maturation is a determinant of aminoglycoside susceptibility in zebrafish (Danio rerio) Hear. Res. 2006;213(1-2):25–33. doi: 10.1016/j.heares.2005.12.009. [DOI] [PubMed] [Google Scholar]

46. Ou HC, Raible DW, Rubel EW. Cisplatin-induced hair cell loss in zebrafish (Danio rerio) lateral line. Hear. Res. 2007;233(1–2):46–53. doi: 10.1016/j.heares.2007.07.003. [DOI] [PMC free article] [PubMed] [Google Scholar]

47. Brette, et al. Crude oil impairs cardiac excitation-contraction coupling in fish. Science. 2014;343(6172):772–776. doi: 10.1126/science.1242747. [DOI] [PubMed] [Google Scholar]

48. Brette, et al. A novel cardiotoxic mechanism for a pervasive global pollutant. Sci. Rep. 2017;7:41476. doi: 10.1038/srep41476. [DOI] [PMC free article] [PubMed] [Google Scholar]

49. Corey DP, Hudspeth AJ. Kinetics of the receptor current in bullfrog saccular hair cells. J. Neurosci. 1983;3(5):962–976. doi: 10.1523/JNEUROSCI.03-05-00962.1983. [DOI] [PMC free article] [PubMed] [Google Scholar]

50. Crawford AC, Evans MG, Fettiplace R. The actions of calcium on the mechano-electrical transducer current of turtle hair cells. J. Physiol. 1991;434:369–398. doi: 10.1113/jphysiol.1991.sp018475. [DOI] [PMC free article] [PubMed] [Google Scholar]

51. Ricci AJ, Fettiplace R. Calcium permeation of the turtle hair cell mechanotransducer channel and its relation to the composition of endolymph. J. Physiol. 1998;506:159–173. doi: 10.1111/j.1469-7793.1998.159bx.x. [DOI] [PMC free article] [PubMed] [Google Scholar]

52. Esterberg R, Hailey DW, Coffin AB, Raible DW, Rubel EW. Disruption of intracellular calcium regulation is integral to aminoglycoside-induced hair cell death. J. Neurosci. 2013;33(17):7513–7525. doi: 10.1523/JNEUROSCI.4559-12.2013. [DOI] [PMC free article] [PubMed] [Google Scholar]

53. Esterberg R, Hailey DW, Rubel EW, Raible DW. ER-mitochondrial calcium flow underlies vulnerability of mechanosensory hair cells to damage. J. Neurosci. 2014;34(29):9703–9719. doi: 10.1523/JNEUROSCI.0281-14.2014. [DOI] [PMC free article] [PubMed] [Google Scholar]

54. Kayhanian, et al. Review of highway runoff characteristics: Comparative analysis and universal implications. Water Res. 2012;46(20):6609–6624. doi: 10.1016/j.watres.2012.07.026. [DOI] [PubMed] [Google Scholar]

55. Du, et al. Development of suspect and non-target screening methods for detection of organic contaminants in highway runoff and fish tissue with high-resolution time-of-flight mass spectrometry. Environ. Sci. Process Impacts. 2017;19(9):1185–1196. doi: 10.1039/C7EM00243B. [DOI] [PubMed] [Google Scholar]

56. Baldwin DH, Sandahl JF, Labenia JS, Scholz NL. Sublethal effects of copper on coho salmon: impacts on non-overlapping receptor pathways in the peripheral olfactory nervous system. Environ. Toxicol. Chem. 2003;22(10):2266–2274. doi: 10.1897/02-428. [DOI] [PubMed] [Google Scholar]

57. McIntyre JK, Baldwin DH, Meador JP, Scholz NL. Chemosensory deprivation in juvenile coho salmon exposed to dissolved copper under varying water chemistry conditions. Environ. Sci. Technol. 2008;42:1352–1358. doi: 10.1021/es071603e. [DOI] [PubMed] [Google Scholar]

58. Linbo TL, Baldwin DH, McIntyre JK, Scholz NL. Effects of water hardness, alkalinity, and dissolved organic carbon on the toxicity of copper to the lateral line of developing fish. Environ. Toxicol. Chem. 2009;28:1455–1461. doi: 10.1897/08-283.1. [DOI] [PubMed] [Google Scholar]

59. Karlsen HE, Sand O. Selective and reversible blocking of the lateral line in freshwater fish. J. Exp. Biol. 1987;133:249–262. [Google Scholar]

60. Tierney, et al. Olfactory toxicity in fishes. Aquat. Toxicol. 2010;96(1):2–26. doi: 10.1016/j.aquatox.2009.09.019. [DOI] [PubMed] [Google Scholar]

61. Cherr GN, Fairbairn E, Whitehead A. Impacts of petroleum-derived pollutants on fish development. Annu. Rev. Anim. Biosci. 2017;5:185–203. doi: 10.1146/annurev-animal-

022516-022928. [DOI] [PubMed] [Google Scholar]

62. Zhang, et al. Crosstalk between AhR and wnt/ß-catenin signal pathways in the cardiac developmental toxicity of PM2.5 in zebrafish embryos. Toxicology. 2016;355-356:31–38. doi: 10.1016/j.tox.2016.05.014. [DOI] [PubMed] [Google Scholar]

63. Sarrazin, et al. Origin and early development of the posterior lateral line system of zebrafish. J. Neurosci. 2010;30(24):8234–8244. doi: 10.1523/JNEUROSCI.5137-09.2010. [DOI] [PMC free article] [PubMed] [Google Scholar]

64. Beníšek M, Kubincová P, Bláha L, Hilscherová K. The effect of PAHs and N-PAHs on retinoid signaling and Oct-4 expression in vitro. Toxicol. Lett. 2011;200(3):169–175. doi: 10.1016/j.toxlet.2010.11.011. [DOI] [PubMed] [Google Scholar]

65. Laguerre L, Soubiran F, Ghysen A, König N, Dambly-Chaudière C. Cell proliferation in the developing lateral line system of zebrafish embryos. Dev. Dyn. 2005;233(2):466–472. doi: 10.1002/dvdy.20343. [DOI] [PubMed] [Google Scholar]

66. Xiao T, Roeser T, Staub W, Baier H. A GFP-based genetic screen reveals mutations that disrupt the architecture of the zebrafish retinotectal projection. Development. 2005;132:2955–2967. doi: 10.1242/dev.01861. [DOI] [PubMed] [Google Scholar]

67. SWMMWW. Stormwater Management Manual for Western Washington. Washington State Dept. of Ecology (2014).

68. Westerfield, M. The Zebrafish Book: A Guide for the Laboratory Use of Zebrafish (Danio rerio). (University of Oregon, 2000).

69. Coffin AB, Rubel EW, Raible DW. Bax, Bcl2, and p53 differentially regulate neomycin- and gentamicin-induced hair cell death in the zebrafish lateral line. J. Assoc. Res. Otolaryngol. 2013;14:645–659. doi: 10.1007/s10162-013-0404-1. [DOI] [PMC free article] [PubMed] [Google Scholar]

70. Brown AD, Sisneros JA, Jurasin T, Nyugen C, Coffin AB. Differences in lateral line morphology between hatchery- and wild-origin steelhead. PLoS One. 2013;8(3):e59162. doi: 10.1371/journal.pone.0059162. [DOI] [PMC free article] [PubMed] [Google Scholar]

71. Webb, J. F. Morphological diversity, development, and evolution of the mechanosensory lateral line system. In The Latera*l Line System* (eds. Coombs, S., Bleckmann, H., Fay, R. R. & Popper, A.N.) 17–72 (Springer, 2014).

72. Kruger, et al. Natural Bizbenzoquinoline derivatives protect zebrafish lateral line sensory hair cells from aminoglycoside toxicity. Front. Cell. Neurosci. 2016;10:83. doi: 10.3389/fncel.2016.00083. [DOI] [PMC free article] [PubMed] [Google Scholar]

Associated Data

This section collects any data citations, data availability statements, or supplementary materials included in this article.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Articles from Scientific Reports are provided here courtesy of **Nature Publishing Group**

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Author manuscript
Water Resour Res. Author manuscript; available in PMC 2023 September 15.
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Published in final edited form as:
Water Resour Res. 2022 September 15; 58(9): 1–28. doi:10.1029/2021wr030699.

Wildfire Induces Changes in Receiving Waters: A Review With Considerations for Water Quality Management

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Abstract

Wildfires have increased in frequency in many ecosystems, with implications for human health and the environment, including water quality. Increased fire frequency and urbanization also raise the prospect of fires burning into urban areas, mobilizing pollutants few have considered to date. As a result, water quality managers lack information to anticipate, respond to and potentially mitigate wildfire impacts. Here, we reviewed the scientific literature to assess wildfire effects on response endpoints of a conceptual model linking fire to water quality, quantifying response directionality, magnitude and duration. Physically, water yield, sediments, and temperature all increased post-fire. Chemically, nutrients, ions, organic chemicals, and metals increased in burned watersheds, sometimes by orders of magnitude over pre-fire or reference conditions. In select cases, post-fire concentrations exceeded aquatic life criteria or drinking water standards, at times even in the finished drinking water. Biological assemblages commonly declined after post-fire runoff events. The duration of effects was less than 5 yr for most endpoints (e.g., metals) on average following fire, although effects did extend 15 yr or more in some individual cases. We found only a few studies on pollutants mobilized from wildfire impacted urban areas with benzene

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contamination in drinking water and high metal concentrations in ash prominent exceptions. Overall, this review provides a resource for understanding wildfire impacts on water quality endpoints, with the goal of informing the response of managers and other decision makers to this growing problem.

Plain Language Summary

Wildfires are increasing in frequency due in part to climate change, and the pollutants mobilized during and after fire threaten water quality. Water quality managers should be aware of these threats so they can plan for and respond to them. We reviewed the scientific literature on wildfire effects on water quality. Streamflow typically increases following wildfire, as do sediments and temperature. Nutrients, ions, metals, and certain organic chemicals often increase as well, sometimes 10–100 times or more above reference levels. Some post-fire chemicals can exceed regulatory limits, even in finished drinking water (e.g., arsenic). Wildfire also commonly affects biological assemblages. Most impacts last less than 5 yr, although they can be much longer. Unfortunately, only a few studies measured pollutants from urban areas impacted by wildfire. This is a major knowledge gap since these events are likely becoming more common, can mobilize pollutants from built materials and may impact many water uses. Finally, our paper describes the implications for water quality programs, such as drinking water, water quality standards, assessment, restoration and non-point source programs. We hope water quality managers and communities can use this information to better respond to this growing problem.

1. Introduction

Wildfires in the United States (U.S.) have increased in frequency since the mid-1980s (Dennison et al., 2014; Miller et al., 2012; Singleton et al., 2019). This is most pronounced in the western U.S. (Dennison et al., 2014; Singleton et al., 2019) and increases have been observed for both forest and grassland wildfire (Westerling, 2016) Much of the increase in wildfire frequency and area burned has been correlated with drier conditions, earlier snowmelt (especially at mid elevations) and severe droughts associated with climate change (Abatzoglou & Williams, 2016; Dennison et al., 2014; Holden et al., 2018; Westerling, 2016). Greater fire activity is not limited to the U.S., with increases observed in regions and ecosystem types across the globe (e.g., Cochrane et al., 2003; Fairman et al., 2015; Seidl et al., 2014).

Increases in fire frequency have profound implications for human health and environmental quality. These effects have been relatively well studied for air quality (e.g., USEPA, 2019a), yet fires pose potential risks to water resources as well, including those for drinking water supply, recreation and aquatic habitat. Wildfires alter stream flow response to precipitation (Gao et al., 2017; Hallema, Sun, Bladon, et al., 2017; Hallema, Sun, Caldwell, et al., 2017; Shakesby & Doerr, 2006), and mobilize a variety of pollutants through downwind deposition or subsequent runoff. These pollutants include sediment (Dahm et al., 2015; Smith et al., 2011; Verkaik et al., 2013), dissolved organic compounds (Hohner et al., 2016, 2019), and metals (Bladon et al., 2014; Smith et al., 2011) that threaten drinking water sources. Nutrients released following fires can contribute to downstream eutrophication and harmful algal blooms, adversely affecting drinking water quality and recreational uses,

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such as boating and swimming (Cook & Holland, 2012; Emelko et al., 2016). The same fire-mobilized pollutants impacting water quality can also be harmful to aquatic life, at least in the short-term (Bixby et al., 2015; Kelly et al., 2006).

When coupled with urbanization, increased fire frequency raises the prospect of direct damage to water infrastructure and mobilization of pollutants few have considered to date (e.g., benzene). In recent decades, urban development has expanded the area of the wildland urban interface (WUI, Martinuzzi et al., 2015). The WUI is the area where structures and other human development interface or intermix with undeveloped wildland, and where wildfires most impact people (Martinuzzi et al., 2015). In 2010, approximately 10% of U.S. land area, 34% of homes, 59% of secondary homes, and 32% of the U.S. population were within the WUI (Martinuzzi et al., 2015). Wildfires burning into urbanized areas within the WUI and damaging houses, vehicles and other human infrastructure have been tragically demonstrated in recent years (e.g., in Paradise, CA and Boulder County, CO), but water quality effects of such fires remain largely unknown.

Here, we review the effects of wildland fire and destructive, urban fires in the WUI on water quality stressors important to many water quality management programs. While wildfire impacts have been reviewed before, most reviews have focused on water quality in general or primarily on drinking water (e.g., Smith et al., 2011). In this paper, we take a broader perspective on water quality management to include many endpoints water quality regulators focus on, not only drinking water. For instance, under the Clean Water Act (CWA) in the US, the Environmental Protection Agency (EPA) approves water quality standards (WQS) promulgated by states and authorized tribes. These WQS are a combination of designated uses for waterbodies, such as aquatic life habitat and recreation, and the necessary water quality criteria to protect those designated uses. Wildfire can impact many designated uses and criteria pollutant concentrations. Though we primarily discuss endpoints of concern for U.S. federal and state regulatory programs, other countries have similar regulatory endpoints and programs. Water quality managers beyond regulators are likely to benefit from this broader management perspective, including drinking water facility operators, soil and water conservationists, watershed stakeholder groups, and land managers—namely, anyone who is likely to face the increasing impacts of fire on water quality.

We anticipate this review will help water quality managers and decision makers better understand the likely impacts of fire, and ultimately inform the design of mitigation and recovery strategies and policies. For researchers, the review highlights the state of current knowledge, while identifying key knowledge gaps for future work.

2. Methods

2.1. Review

To guide our review, we created a conceptual model of the myriad ways fire can affect endpoints of interest to water quality management programs (Figure 1 provides an overview, while a more detailed figure is provided in the Supporting Information S2). The model was based on existing knowledge and iterated with U.S. EPA experts across a range of water programs whose feedback was used to revise and improve the model (Figure 1). The

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management goals at the bottom are represented by designated uses, including the common aquatic life, recreation, and drinking water uses. These uses are an important component of WQS, which are the foundation of CWA water quality programs including wastewater permitting, assessment, total maximum daily loads (TMDLs), and non-point source control —all of which are designed to protect and restore designated uses. Concomitantly, drinking water standards enforced under the Safe Drinking Water Act (SDWA) are used by water quality programs to protect drinking water.

Based on the conceptual model, we conducted a literature search to identify relevant peer-reviewed materials published after 1980. Among other techniques, we used the SWIFT-Active Screener web application to screen the initial batch of literature (Howard et al., 2020). SWIFT uses expert decisions to train a machine learning algorithm, automating the reduction of documents to a representative subset. From this subset, we manually identified papers specifically applicable to our conceptual model using EndNote software, for a total of 184 papers (see Supporting Information S1 for more methodological details).

2.2. Analysis

Using these papers, we created an extraction database, recording information for each paper (e.g., title, waterbody type studied, fire type, etc.) and the response of the variables measured following fire. We particularly focused on three items for each post-fire response: the *directionality*, *magnitude*, and *duration*. *Directionality* was whether a particular variable increased, decreased or showed no change in response to fire. *Magnitude* was the strength of the response measured as a percent change from pre- or reference watershed conditions, and *duration* was the length of time of the response reported by the study. We recorded instances in the database where the duration of the response was limited by study length. There was often more than one response or response variable (e.g., nitrogen and phosphorus) per paper, and each received a separate entry in the database.

Estimates of direction and magnitude were based on what authors reported and the design of their work. Sample timing is important and studies differed in when they first sampled. For example, those missing the first flush events may underestimate the largest magnitudes and bias their averages. We constrained ourselves to what authors reported in terms of magnitude from their designs, recording each value when multiple were reported. Similarly, our duration estimates were constrained by the length of the studies and what they reported. Most studies were of limited duration and did not follow the trajectory of response trends until they returned to reference conditions. As a result, our duration estimates are likely conservative.

From the extraction database, we summarized our findings for this review. For directionality, we calculated the percentage of observations for each response showing an increase, decrease or no-change (e.g., 61% of streamflow/water export measurements following fire reported an increase). We calculated the magnitude of the response as a percent change compared to any unburned or pre-fire reference site(s) used in each paper, and reported the median and full range of values across all observations. Likewise, we calculated the duration for each variable across all observations, and reported the median and full range. We generally referred to short-term durations as those lasting <5 yr, medium duration as 5–

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10 yr and long-term as >10 yr. This was derived from the distribution of observed responses, but also aligns with assessment program periods, often on 5 yr cycles. All papers reviewed and extracted are provided in the reference section, even those not cited directly in the text but used in the quantitative estimates. The data are included in the extraction database provided as Supporting Information S3.

3. Results

When considering the results below, it is important to acknowledge that many factors modify the relationship between wildfire and water quality responses (Figure 1), contributing in part to the high variation observed. Critical modifying factors include: characteristics of the fire, such as severity, extent, and proximity, and post-fire hydrologic responses, including timing and magnitude of precipitation. Most chemical concentrations in water, for example, increase with greater fire severity (Rhoades et al., 2011, 2019; Rust et al., 2019). Notable exceptions include organic carbon and nitrogen, however, which can volatilize at higher temperatures (>450°C) (Hohner et al., 2019). Thus, organic carbon and nitrogen responses can exhibit unimodal responses to severity (Chow et al., 2019; Hohner et al., 2019). Likewise, the extent of the fire in the watershed can also impact concentrations observed, though this is often underreported (Rhoades et al., 2019). Further, water quality responses are driven by hydrology—there is the potential for aerial deposition, but the pollutants generated by wildfire are most often moved by water. As a result, precipitation following fires and the hydrologic regime of the watersheds are primary modifying factors (Moody et al., 2013). Indeed, many responses were not observed until the first major runoff event post-fire (e.g., Rinne, 1996).

Below, we do not dissect the individual context of each reported study, but rather focus on general trends and synthesis important for the water regulatory linkages, while also noting modifying factors where most relevant. The results sections are organized by physical, chemical, and biological response variables. Each subsection of the results starts with the introduction of fire effects, describes the results, and then ends with further context and interpretation.

3.1. Physical Responses

3.1.1. Hydrologic Characteristics—Fire impacts many characteristics of the hydrologic regime, important to all subsequent water quality responses since water transports pollutants and affects their concentrations (Bladon et al., 2014; Chanasyk et al., 2003; Moody et al., 2013; Rhoades et al., 2011). Wildfire often kills and partially combusts vegetation and can alter soil hydrophobicity, depending upon the vegetation burned and fire severity, among other factors (Chanasyk et al., 2003; Murphy et al., 2018; Shakesby & Doerr, 2006). Reductions in the interception and infiltration of precipitation in burnt watersheds can result in greater overland flow. This is exacerbated by increased surface velocities and connectivity of flow paths due to bare ground (Moody et al., 2013). These can result in higher peak flows and shorter response times between precipitation and discharge (Shakesby & Doerr, 2006), hydrologic dynamics similar to watersheds with more impervious cover (e.g., paved roads, parking lots).

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Of the studies we surveyed reporting hydrologic characteristics, 66% found that wildfires generally increased surface runoff, streamflow or water export, and peak flows, 10% reported reductions (in infiltration only), and 24% reported no change in streamflow (Table 1). The increase in post-fire surface runoff was generally more than a 100% to nearly 10,000% compared to before or reference conditions (Figure 2). The magnitude of streamflow and water export increases ranged from no change to nearly 10,000% increases (Figure 2), with a median increase of approximately 60% increase. Conversely, the magnitude of infiltration response was an approximate 40% decline (Figure 2). Hydrologic responses usually lasted until vegetation re-established. The median duration of surface runoff and stream flow response was 5 yr while that for infiltration response was 15 yr, although the sample size was limited ($N = 3$, Figure 3).

Compared to streamflow or peak flows, the effect of fire on groundwater and baseflow measurements remain relatively understudied (Hallema, Sun, Bladon, et al., 2017; Moody et al., 2013). Increased overland flow and decreased infiltration are expected to reduce groundwater recharge and lead to lower baseflows (Morales et al., 2013; Murphy et al., 2018; Parlak et al., 2015) and water quality models predict as much (Rodrigues et al., 2019). Long-term, however, the opposite may also occur: if infiltration recovers, yet vegetation is slow to respond or the recovered vegetation has lower rates of evapotranspiration, recharge may increase and baseflows may not decline as much or may increase (Bart & Tague, 2017; Poon & Kinoshita, 2018).

3.1.2. Suspended and Bedded Sediment (Including Debris Flows and Ash) and Stream Channel Morphology—Given the increase in overland flow, one of the more commonly reported water quality risks after fires is increased erosion, including debris flows, and suspended solid concentrations, especially where post-fire rainfall intensities are high and the hydrogeomorphic regime (sensu Moody et al., 2013) consists of more erodible, high slope conditions (Bodí et al., 2014; Cannon & Reneau, 2000; Emelko et al., 2011; Nyman et al., 2015). Indeed, this effect is so common, the United States Geological Survey (USGS) has developed several tools to predict debris flows following fires (e.g., USGS, 2020a, 2020b), and national Burned Area Emergency Response programs have a significant focus on erosion control and debris flow protection (NIFC, 2020; USGS, 2020c). Elevated suspended solids, including initial pulses of ash from storms following wildfire, can impact water treatment, threatening attainment of drinking water standards for turbidity and increasing filtration and coagulation costs (Emelko et al., 2011; Murphy et al., 2015). Sediments can overwhelm these systems, requiring closure of water intakes in some cases (e.g., following the 2012 High Park wildfire in Colorado, Hohner et al., 2016), and sediments and ash often contain contaminants, including organic pollutants and metals (e.g., Burton et al., 2016).

Of the measurements of suspended solids or turbidity across the studies reviewed, 91% observed an increase in suspended sediments, 9% observed no change and none observed a decrease (Table 1). In magnitude, values ranged from little change to more than a 25,000 fold increase compared to control or prior conditions (Figure 2), with the median of study responses near 1,000 fold. In Arizona, for example, wildfire led to increased total suspended solids in the 1,000s of mg/L, orders of magnitude above background concentrations (Rinne,

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1996), and the ash flows measured following wildfire in New Mexico led to turbidities in excess of 1,500 nephelometric turbidity units (Dahm et al., 2015). In duration, the median was less than 5 yr of elevated sediment and in some cases only minor increases in suspended solids occurred and declined quickly (Spencer & Hauer, 1991). Severely burned catchments can take longer to recover (Rhoades et al., 2019) and the longest measured duration was up to 14 yr (Figure 3).

Bedload sediment is presumed to increase following fires, given the presence of erosion and debris flows, but we identified only two studies measuring bedload. One of those, a 3 yr study of sediment from a burned watershed in Wyoming, found heightened suspended loads during post-fire storms, but very little change in bedload from the watershed outlet (Ryan & Dixon, 2008). Bedload response is a longer-term process as heavier sediment requires substantial time to move through the drainage network; it may be that longer duration studies (or space for time substitution studies) are needed.

Changes in the balance of sediment transport capacity (i.e., flow) and sediment supply influence channel form. Not surprisingly, since both drivers are affected by wildfire, channel morphology is often altered following fires, but this process can take years to manifest (Minshall et al., 1997; Shakesby & Doerr, 2006). A study of stream channels in Yellowstone National Park, for example, found that stream power, channel dimensions, and bank failure rates were still adjusting 12–13 yr after wildfires in 1988 (Legleiter et al., 2003). As expected, fires resulted in higher stream power, increasing with percent burn area, and led to substantial increases in channel dimension and bank failure. In Mediterranean climate regions (e.g., California), morphological recovery may be comparatively faster than in temperate areas due, in part, to earlier native vegetation recovery which reduces erosion rates (Verkaik et al., 2013).

3.1.3. Light Availability and Water Temperatures—Light availability and temperature are important physical drivers for aquatic life. Growth of algae and vascular plants is often limited by available light, and aquatic organisms are mostly cold-blooded and their distributions are limited by temperature. Many U.S. states have regulatory targets for temperature based both on aquatic life physiological requirements (e.g., those of cold water fishes), as well as the effect of temperature on other pollutants. Not surprisingly, in-stream light availability tends to increase following wildfires, depending on the amount and severity of riparian vegetation burned (Bixby et al., 2015), and can be even more elevated where debris flows occur, opening up more of the canopy to light (Dunham et al., 2007). The consequences of these light increases may be offset by increases in turbidity, but these are short-lived and the loss of vegetation typically has a greater impact (Beakes et al., 2014). The result of increased direct radiation to streams is increased annual and seasonal stream temperatures, often lasting until riparian vegetation reestablishment (Minshall et al., 1997; Rhoades et al., 2011; Wagner et al., 2014).

Of the studies measuring temperature in receiving waterbodies following wildfire, 79% reported increases and 21% reported no change—no studies reported a decrease (Table 1). The magnitude of temperature responses was, on average, approximately a doubling, but ranged from 0% to a 400% increase (Figure 2). In degrees, this was an average increase

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of 7.9°C maximum temperature (range: 1–18) and 2.6°C mean temperature (range: 1.5–5). These effects lasted as long as 11 yr (Dunham et al., 2007) with a median across studies between 5 and 10 yr (Figure 3).

The studies surveyed almost exclusively focused on streams. Shifts in thermal regimes have also been observed in wetlands (Gu et al., 2008) and lakes in burned watersheds, but both of these waterbody types have been understudied (McCullough et al., 2019). This is an important knowledge gap given the importance of temperature for a wide range of lake processes (e.g., dissolved oxygen concentration, nutrient cycling, fish energetics).

3.2. Chemical Responses

3.2.1. Nutrients—Nutrients are one of the more commonly studied chemical responses to wildfire. Both nitrogen and phosphorus generally increase in streams post-fire, and this has been observed in temperate, Mediterranean, and boreal forests as well as grasslands and wetlands (Chanasyk et al., 2003; Emelko et al., 2016; Hohner et al., 2016, 2019; Knoepp & Swank, 1993; Minshall et al., 1997; Ranalli, 2004; Rust et al., 2018; Sherson et al., 2015; Smith et al., 2011). Elevated nutrient inputs can lead to enhanced algal growth and harmful algal blooms, with the potential to negatively affect aquatic life, recreation, and drinking water (see Section 3.3.4). Because of this and other effects, many U.S. states are developing numeric nutrient thresholds to protect against the impacts of eutrophication (USEPA, 2022). Moreover, there is a primary drinking water standard for nitrate.

Across the measurements within the studies reviewed, 77% found increases in nitrogen, 7% decreases, and 16% no changes; 65% found increases in phosphorus, 27% decreases, and 8% no change (Table 1). Response magnitudes were generally greater for phosphorus than nitrogen (Figure 2). Nutrient responses were typically rapid, observed in streams during and especially following storms immediately after fires (Harris et al., 2015; Hauer & Spencer, 1998; Spencer & Hauer, 1991), but delayed responses have been observed in more arid environments (Murphy et al., 2015; Rhoades et al., 2011). Elevated nutrient concentrations can persist, but usually return to reference conditions within 5 yr (median); with phosphorus levels taking marginally longer than nitrogen to return to pre-fire conditions on average (Figure 3). However, the maximum reported duration was for nitrogen (Figure 3), with severe fires in Colorado resulting in elevated nitrate/total dissolved nitrogen concentrations 14 yr after the fire (Rhoades et al., 2019). This was attributed to the slow rate of upland and riparian recovery post-fire at this particular site due to the severity of the fire and increased drought (Rhoades et al., 2019). Nitrogen and phosphorus increases have also been reported for lakes in post-fire watersheds (McCullough et al., 2019).

Proposed mechanisms explaining increased responses of nutrients post-fire include volatilization and deposition, reduced plant and microbial uptake, and increased leaching and runoff into waterbodies (Emelko et al., 2016; Rust et al., 2018; Smith et al., 2011). Of total nitrogen, nitrate from nitrification of ammonium tends to dominate (Ranalli, 2004). A significant increase in public water nitrate violations in the U.S. has been associated with wildfire and should be a concern for water suppliers (Pennino et al., 2022). In contrast, phosphorus is generally not lost through volatilization (Certini et al., 2005), and total

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phosphorus composition is dominated by soluble reactive phosphorus from the dissolution of ash (Ranalli, 2004).

3.2.2. Calcium, Potassium, and Other Ions—Cations contribute to water hardness, which can influence the toxicity of certain metals to aquatic life (e.g., cadmium, chromium III, copper, lead, nickel, and zinc), and to total dissolved solids, for which there is a secondary drinking water standard. Cations like calcium, potassium, and magnesium generally follow nutrient trends, increasing after post-fire precipitation events as a function of burned area and burn severity (Bitner et al., 2001; Rust et al., 2018; Smith et al., 2011) as they are primarily generated from ash (Ranalli, 2004). Such responses are consistent with the ash-alkaline hypothesis reviewed in Bayley and Schindler (1991), whereby alkaline fire ash, high in base cations like potassium and calcium, generally leads to an increase in calcium carbonate alkalinity and other associated base cation complexes.

For calcium and potassium, cations with the most reported responses, 77% of studies reported increases, 18% decreases and 5% no trend (Table 1). The magnitude of values included no increases to very large increases (up to 60,000% higher), but the central tendency was an approximately 300% increase from reference conditions (Figure 2). Concentrations of these cations typically remained elevated for less than 5 yr (Figure 3). For example, fires in the Sierra Nevada led to higher ion concentrations in streams for less than a year (Beche et al., 2005).

For cations generally, this pattern of a general increase occurred across biomes (Bayley et al., 1992; Beche et al., 2005; Betts & Jones, 2009; Bitner et al., 2001; Burke et al., 2013; Murphy et al., 2018), but not in all cases. Boreal streams in Alaska, for instance, exhibited a calcium decline downstream of a fire, even though potassium increased (Betts & Jones, 2009). Further, stream reaches draining a burned urbanized area in the WUI in California exhibited calcium and potassium increases, but not sodium (Burke et al., 2013). Such variability in responses was attributed to geology, soils, and changes in subsurface flow (and thus dissolution) affected by soil hydrophobicity and decreased infiltration. In Colorado, an increase in surface flow was associated with stream calcium and potassium increases, but not sodium and silica, since they are derived more from subsurface flow paths in that system (Murphy et al., 2018). Yellowstone Lake exhibited only minor changes in ion concentrations after the 1988 fire, which was attributed to its large volume relative to the area of watershed burned (~25%, Lathrop, 1994).

Sulfate and chloride were often elevated in streams draining burned watersheds—sulfate more than chloride—but the sample size of studies for either was relatively small. Increases for both were relatively short-lived and did not exceed World Health Organization water quality aesthetic use guidelines for sulfate (Beche et al., 2005; Smith et al., 2011). Elevated sulfate concentrations were most often associated with responses in boreal/peatland region lakes (Bayley et al., 1992; Brown et al., 2013; Crilly et al., 2017; Lydersen et al., 2014), but elevated sulfate has also been observed in temperate streams (Beche et al., 2005). Decreases in sulfate were observed in Yellowstone Lake following the 1988 fires (Lathrop, 1994).

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3.2.3. Conductivity—Conductivity, the ability of liquid to conduct electricity, and total dissolved solids, the mass of dissolved constituents in water, are correlated measures of the dissolved ion content of water. Increased conductivity can stress biota and require additional treatment to remove. Moreover, as mentioned above, there is a secondary drinking water standard in the U.S. for total dissolved solids (500 mg/L). Like nutrients and cations, conductivity also increased after fires in 69% of observations, decreased in 6% and showed no trend in 25% (Table 1). This pattern generally followed burn severity due to greater ash and mineralization at higher temperatures (Rhoades et al., 2011). Not surprisingly, observed magnitudes followed those for cations, with a median increase of just over 100% (Figure 2). Most conductivity responses tended to be immediate and lasted less than 5 yr, even for severe fires (Figure 3), but they were also dynamic. Stream conductivity response in New Mexico, for example, exhibited large swings over space and time, extending from headwaters to far downstream following precipitation events (Dahm et al., 2015; Sherson et al., 2015). We encountered one study of conductivity in lakes which exhibited a decline post-fire (Allen et al., 2003). Conductivity responses will likely be muted where lake volumes are large (Lathrop, 1994).

3.2.4. pH/Alkalinity—The pH of water directly affects aquatic life, but also indirectly affects it through its influence on mobilization and toxicity of pollutants. It is also important to drinking water treatment facilities, which have a voluntary secondary pH standard to protect taste, treatment process, and infrastructure. pH changes are affected by the acid-neutralizing capacity (often measured as alkalinity), or buffering capacity, of recipient waterbodies. The ash-alkaline hypothesis suggests alkaline ash input leads to an increase in alkalinity and stream pH following fire (reviewed in Bayley & Schindler, 1991). The literature we reviewed, however, ranged from approximately half reporting pH or alkalinity increases in boreal lakes, everglade wetlands, temperate and Mediterranean streams (e.g., Costa et al., 2014; Korsman & Segerstroem, 1998; Son et al., 2015) and half reporting decreases or no change in boreal streams and lakes (especially those with excessive sulfur from atmospheric deposition or peatlands) and Mediterranean streams (Table 1). In magnitude, the central tendency of changes in hydrogen ion concentrations was roughly a tripling (300% or 0.5 pH units, Figure 2), but higher increases have been observed. Only one study reported a magnitude for an alkalinity response (a decrease of 50% in an acidic Norwegian lake, Lydersen et al., 2014). In duration, studies report that pH and alkalinity responses were relatively short-lived (median <5 yr, Figure 3), likely linked to short-lived ash exports (Bodi et al., 2014), and rarely violated aquatic life and secondary drinking water standards.

The diverse response in post-fire pH and alkalinity is a function of the buffering capacity of a given waterbody and the acidity or alkalinity of the post-fire inputs. One study of a well buffered stream, for example, in southern California observed no change in pH following fires (Burton et al., 2016). In cases where the buffering capacity was low, decreases in pH observed in the literature were attributed to acidity from export of reduced sulfur and subsequent oxidation (Bayley et al., 1992), increased nitrate (Crilly et al., 2017), application of phosphorus-based fire retardant (Angeler et al., 2004, 2005, 2006) and increased DOC that included organic acids (Bladon et al., 2014). Studies of alkalinity from boreal regions

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(with peatlands) generally exhibited alkalinity decreases in receiving streams and lakes, and this has been attributed both to peatland release of hydrogen ions as well as oxidation of reduced sulfur (Allen et al., 2003; Bayley et al., 1992; Crilly et al., 2017; Lydersen et al., 2014). By contrast, studies in more temperate, non-peatland areas away from acid deposition reported alkalinity increases, including in two streams draining burned watersheds in Colorado (Murphy et al., 2018; Rhoades et al., 2011). Across both biomes, however, the timing of the response was generally a large change in years 1 and 2, followed by a return to pre-fire or unburned reference levels within 4–5 yr (Lydersen et al., 2014; Rhoades et al., 2011). Studies from lakes were similarly diverse in pH response (McCullough et al., 2019).

3.2.5. Organic Carbon and Organic Nitrogen—Organic carbon and nitrogen, especially DOC and DON, are important considerations in drinking water because of their potential to contribute to disinfection byproduct (DBP) formation and metal binding (Regan et al., 2017; Westerhoff & Mash, 2002). Particulate organic carbon can similarly affect metal toxicity. Post-fire nutrient runoff resulting in eutrophication and excess algal growth can also produce organic compounds, causing taste and odor issues downstream of burned sites (Bladon et al., 2014; Hohner et al., 2019).

Slightly less than 50% of studies reporting on this endpoint recorded increases in organic carbon with fires, 26% decreases and the remaining 26% no change (Table 1). The magnitude of organic carbon released during fires ranged from slightly negative values to increases above 1,400%; the median was just slightly positive (Figure 2). The median duration of organic carbon responses was less than 5 yr, but has been reported for as long as 10–14 yr (Rhoades et al., 2019, Figure 3).

Increases in organic carbon have been observed in temperate (Emelko et al., 2011; Murphy et al., 2018; Writer et al., 2014) and boreal regions (Allen et al., 2003, 2005; Crilly et al., 2017). The magnitude of response appears to be fire temperature dependent, according to laboratory heating experiments with water extractable organic carbon and nitrogen exhibiting highest concentrations at medium temperatures (≤350°C; Hohner et al., 2019). By contrast, higher temperatures (≥450°C) volatilized most carbon and nitrogen, suggesting high-intensity fires may result in lower organic carbon and nitrogen export to downstream waterbodies (Hohner et al., 2016, 2019). At least some organic carbon increases in aquatic ecosystems below burned watersheds, especially lakes, are likely attributable to algae. Algal biomass in these downstream lakes, especially oligotrophic lakes, often increased in response to dissolved nutrient export from burned watersheds and contributed organic carbon through exudation or lysis (Allen et al., 2003, 2005; McCullough et al., 2019).

3.2.6. Dissolved Oxygen—Oxygen is critical for aquatic life and biogeochemical processes, and there are water quality criteria in the U.S. for a variety of dissolved oxygen (DO) endpoints related to life stage, thermal regime, waterbody type, etc. (USEPA, 2020c). In general, we found a limited number of studies reporting DO concentrations after wildfire. Only two observations recorded increases and four recorded decreases after the wildfire. Only one recorded magnitude (−55%), while for the duration, seven observations were reported with a maximum of 2 yr and a median of 1 yr. This lack of information is a

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surprising result given the importance of DO to aquatic biota and many biogeochemical processes.

Given that organic matter drives respiration in receiving waters, large inputs of organic matter (including ash) post-fire likely lead to DO deficits or sags in receiving waters (e.g., Allan & Castillo, 2007). Indeed, in New Mexico, a fire led to large DO declines along streams in the Gila River watershed from the headwaters to main-stem due to ash inputs (Dahm et al., 2015; Reale, 2015; Sherson et al., 2015). Dissolved oxygen dynamics returned to pre-fire or unburned reference levels within 2 yr. Lentic waterbodies would be expected to exhibit even greater effects given their higher residence time and slower reaeration (McCullough et al., 2019). A study of temporary ponds in Spain found that DO decreased following fires and lasted for the duration of the 1 yr study (Cunillera-Montcusi et al., 2019).

3.2.7. Metals and Other Inorganic Chemicals With Water Quality and Drinking Water Standards—Wildfires can mobilize metals and other inorganic chemicals which are then transported by precipitation events into downstream waters (e.g., see Abraham et al., 2017b; Rust et al., 2018; Smith et al., 2011). Many of these chemicals have CWA or SDWA standards, or are listed as Contaminant Candidate List chemicals. The latter are contaminants not currently subject to any proposed or promulgated national primary drinking water regulations in the U.S., but are known or anticipated to occur in public water systems (PWS; USEPA, 2021). Fire mobilized metals can also impact aquatic organisms, with potentially lethal and sub-lethal effects including the bioaccumulation of metals in tissue and decreased mobility (Silva et al., 2015, 2016).

Of the studies reviewed, 57% measured increases in metals, 10% decreases, and 33% no changes following fire (Table 1). Increases in receiving stream metal concentrations from wildfire were striking, spanning from little or no increase to over 100,000% (1,000x) of unburned or pre-burned conditions. Median magnitudes across metals ranged from near 0% for vanadium to 5,000% for cadmium (Figure 2). The reported durations of metal responses were generally less than 5 yr, a finding consistent with that of Rust et al. (2018), which surveyed post-fire water quality responses across multiple watersheds in the western U.S. Mercury was the one exception, with one study finding elevated mercury in lake fishes 10 yr after a wildfire (Figure 3) and a second observed decreased mercury deposition rates in a burned watershed after 33 yr, largely attributed to vegetation differences (Johnson et al., 2007).

Increases in metals were observed following fire across biomes, including boreal peatlands (Brown et al., 2013), temperate forests (Rust et al., 2018), and Mediterranean forests (Burton et al., 2016; Nunes et al., 2017), and from wildfires as well as prescribed burns (Harper et al., 2018). The latter were less represented, and concentrations were typically lower, but Harper et al. (2018) recorded iron and manganese release downstream of prescribed burns. Increased remobilization of some metals and metalloids has also been shown to occur during prescribed burns in fire-prone areas with legacy mining (Abraham et al., 2017a). In general, metal concentrations increased with greater fire severity (Rust et al., 2019). The most common metal measured was mercury, followed by lead and copper. Mercury has been frequently observed in elevated concentrations below fires and is a common

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target of inquiry given its toxicity and potential for bioaccumulation (see Biological Responses section). Lakes also experience elevated inorganic chemical concentrations, including metals, following fires (McCullough et al., 2019; Smith et al., 2011), but there was comparatively less information on elevated metals in lakes than in streams.

Notably, fires can mobilize metals previously concentrated above background levels by human activities. Atmospheric deposition from anthropogenic sources can increase metals in soils (e.g., lead deposition from legacy fossil fuel combustion and deposition), with the potential for remobilization by fire (e.g., Abraham et al., 2017a; Burke et al., 2013). Historically mined watershed areas can also be at risk for fires, especially in parts of the western U.S. (e.g., see USGS, 2020d). Altered surface and subsurface hydrological flow features may accelerate remobilization and dispersal of arsenic- and metals-containing waste in burned areas surrounding historical mining sites (Murphy et al., 2020). One of the few studies exploring fires burning urbanized areas in the WUI found that ash from building materials in southern California was higher in arsenic, copper, lead, nickel, and zinc than wildland ash (Burton et al., 2016). In this same study, most dissolved metal concentrations were elevated in streams but did not exceed aquatic life use criteria. However, there were 19 observed exceedances of aquatic life use criteria for particulate metal concentrations including for iron, lead, nickel, and zinc, which were 10–1,000x higher than unburned or pre-burn concentrations (Table 2).

Finally, arsenic and cyanide are two, non-metal inorganic chemicals mobilized post-fire. Recent research suggests wildfire may liberate arsenic from soil minerals into a highly mobile form, with the potential for subsequent runoff into surface waterbodies or leaching into groundwater (Johnston et al., 2019). Elevated arsenic concentrations have been reported in multiple watersheds post-fire in the western U.S. (Rust et al., 2018). Pennino et al. (2022) reported significant average increases in public water supply (PWS) arsenic concentrations (0.92 μg/L) and drinking water violations (1.08 violations per PWS) in finished drinking water following wildfire. Similarly, fires can form hydrogen cyanide through the pyrolysis of plant material, and this cyanide may directly enter downwind waterbodies or runoff or leach from ash or soil to nearby waterbodies (Barber et al., 2003). Following a fire in North Carolina and Tennessee, cyanide concentrations averaged 49 μg/L in water droplets at the base of the burned areas, concentrations similar to the median lethal concentration for rainbow trout (Barber et al., 2003). Notably, these concentrations were in water droplets and not in the stream where dilution could occur. The 2000 Cerro Grande fire in New Mexico also resulted in elevated cyanide in runoff samples from burned areas (Gallaher & Koch, 2004; see Table 2). Pyrogenic formation of cyanide or sodium ferrocyanide in fire retardants were suggested as the likely source.

3.2.8. Organic Compounds and Persistent Organic Pollutants—Organic compounds with potential health effects may also be released during combustion, mobilized following the fire or used in firefighting. Many of these compounds cause health impacts to humans and aquatic life and are regulated by a range of programs. Of organic compounds in waterbodies post-fire, polyaromatic hydrocarbons (PAHs) have received the most research attention (Table 1), with some notable exclusions (e.g., polychlorinated dibenzodioxins/dibenzofurans). Once in transport, UV radiation in sunlight can activate certain PAH species,

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enhancing their toxicity to a diverse range of aquatic taxa (Ankley et al., 2003; Hooper et al., 2013).

PAH concentrations generally increased in streams below fires. Of the studies reviewed, 71% measured increases in PAHs and 29% decreases following wildfire (Table 1). Reported magnitudes in receiving water ranged from 0% to 500% of background/reference conditions (Figure 2). Studies suggest PAH increases may be relatively short, but these results are uncertain as the database was limited to three studies monitoring only up to 2 yr post-fire (Figure 3). Moreover, even short duration increases in toxics, including those generally persistent and bioaccumulative like PAHs, may cause lasting harm to the health of exposed organisms and populations.

PAH increases occurred in boreal, temperate, and Mediterranean biomes (Campo et al., 2017; Smith et al., 2011; Stein et al., 2012; Wisløff, 2018). In Spain and Portugal, for example, diphenyl ethers and a variety of priority pollutant PAHs, including acenaphthylene, benzopyrene, fluorene, naphthalene, and pyrene have all been observed in surface soils, sediment, groundwater, runoff, and surface water impacted by fires (Campo et al., 2017; Mansilha et al., 2014, 2019; Nunes et al., 2017). Concentrations in overland runoff were generally higher than in streams, suggesting attenuation along the overland flow path or dilution. Still, absolute PAH concentrations post-fire rarely exceeded the World Health Organization guideline for benzo(a)pyrene (0.0007 mg/L, Smith et al., 2011).

In addition to PAHs in runoff, fire can directly impact drinking water infrastructure in WUI urban areas, causing organic compound contamination. A recent paper reported benzene and other volatile organic compounds (VOCs) at concentrations 2–3 orders of magnitude above drinking water standards, likely caused by thermal degradation of plastic materials (Macler et al., 2020). Fires in Santa Rosa, CA and Paradise, CA in 2017 and 2018, respectively, burned houses and melted plastic water service lines. The partial melting of the pipes and back siphonage of smoke, ash, and other materials during depressurization of the water system likely led to the spreading of VOC contamination through the water pipes. Benzene was detected at concentrations exceeding federal and state standards (Table 2). Do not drink orders were issued, and contaminants sorbed to plastic pipes required flushing and, in some cases, wholesale infrastructure replacement to remedy (Macler et al., 2020).

Although generally banned in the U.S., persistent organic pollutants like polychlorinated biphenyls (PCBs) still have drinking water standards because they endure in the landscape due to relatively slow decay rates. Smoke and ash from fires can transport these over longer distances and subsequently deposit them (Smith et al., 2011), yet we found no data reported for these chemicals in the research papers reviewed. Finally, per- and polyfluoroalkyl substances (PFAS) are a large group of persistent, human-made chemicals with numerous uses and exposures linked to adverse human health outcomes. In the U.S., fire fighting foams employed at places such as military bases have contained PFAS compounds, but fire retardants currently approved for federal wildlands do not. A study of fire effects in Spain, including the use of aerial fire retardants, did not find elevated PFAS concentrations in burned sites (Campo et al., 2017).

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3.2.9. Disinfection Byproducts (DBPs)—As noted previously, concentrations of carbon and nitrogen compounds often increase following fire, and these compounds can react with disinfectants (e.g., chlorine, chloramine) to form DBPs during drinking water treatment (Bladon et al., 2014; Hohner et al., 2016, 2019). Some DBPs pose health risks, with the ability to cause certain cancers, reproductive issues, and anemia (USEPA, 2020a). Predominantly, the reviewed studies measured DBP formation potential, reacting source water with drinking water treatment chemicals (halogens) in the laboratory.

Most studies (58%) identified little change in the response of DBP formation potential post-fire, with the rest of the studies equally divided between those identifying increases and decreases (21% each, Table 1). On average the magnitude of DBP formation potential responses ranged between 0% and 500% (Figure 2) and these changes were relatively short-lived (<5 yr, Figure 3). However, given the health risk of these chemicals, even short-lived increases may be important.

A recent study on DBPs and wildfire described the formation potential risk as being greatest below fires of medium intensity, since at high temperatures more carbon and nitrogen are volatized and, at lower temperatures, insufficient transformations take place to generate dissolved carbon and nitrogen compounds (Hohner et al., 2019). The authors found formation potential of trihalomethane (THM) and haloacetic acids (HAA), two classes of DBPs, at concentrations above drinking water regulatory levels due to a supply of low molecular weight DOC compounds from runoff in a burned watershed in Colorado (Hohner et al., 2019). The study also observed the formation potential of unregulated haloacetonitriles (HANs), another type of DBP, from low molecular weight DON molecules (Hohner et al., 2019). DBP formation potential from wildfire-generated DON/DOC has been found in several other experimental studies as well, including increased HAA/HAN/THM formation potential from source water collected below other fires in Colorado and exposed to chlorine; dissolved black carbon extracted from burnt leaves of several species in South Carolina; and water extracted organic matter taken from California wildfire ash (Majidzadeh et al., 2015; Wang et al., 2015; Writer et al., 2014). Each experimental study found both elevated carbon- and nitrogen-based DBPs.

Beyond the study of DBP formation potential, a recent study of contaminants in public drinking water found actual increases in DBPs (not merely a laboratory based potential, but detection in the delivery system itself) in finished drinking water sourced from burned watersheds (Pennino et al., 2022). The authors found 71% of drinking water facilities below burned watersheds showed an increase in total THM violations (an average of +0.58 violations per PWS) in the first 2 yr post-fire compared to pre-fire levels (Pennino et al., 2022). Total THM concentrations increased an average of 10.4 μg/L in the first year post-fire and remained generally elevated for 5 yr (Pennino et al., 2022). For total HAA, containing 5 haloacetic acid compounds (see USEPA, 2010; USEPA, 2020a), 50% of sites below burned watersheds increased in violations post-fire (an average of +0.82 violations per PWS over 5 yr). Total HAA concentrations increased by 8.5 μg/L in the first year and stayed elevated for 5 yr, while violations remained higher 8 yr post-fire.

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3.2.10. Fire Fighting Chemicals—In addition to chemicals mobilized directly or indirectly by fire, chemicals are used to fight wildfire. Wildfire fighting chemicals include three primary types: long-term retardants, foam suppressants, and water enhancers (USFS, 2020a). Long-term fire retardants are typically fertilizers (phosphate, ammonia, and sulfate) and smaller concentrations of colorants, corrosion inhibitors, thickeners, and stabilizers mixed with water (USFS, 2020a). They reduce the flammability of fuel through a chemical reaction and are effective even after the water evaporates and so are often used ahead of the fire to decrease or stop fire from spreading. Fire suppressant foams are detergents used to suppress fire directly and prevent reignition. They are used with water and often applied directly on burning fuel. Water enhancers are composed of polymers and other thickeners that reduce aerial dispersion and increase application thickness and adherence, improving water's fire suppression effectiveness (USFS, 2020a).

The United States Forest Service (USFS) is the lead agency overseeing the use of wildland fire chemicals on U.S. federal wildlands, maintaining a Qualified Products Lists (QPL) of fire chemical products (USFS, 2020a). Unacceptable ingredients in long-term retardants include sodium ferrocyanide, PCBs, and PFAS chemicals, among others (USFS, 2020b). Sodium ferrocyanide, a corrosion inhibitor, is no longer an acceptable ingredient because this can subsequently degrade into free cyanide in water (Crouch et al., 2006; Giménez et al., 2004). Notably, the list of unacceptable ingredients may not apply in other circumstances outside of federal wildlands, such as in the chemicals used by state and local firefighting entities, or on U.S. military bases where PFAS-containing foams were employed for decades to fight fires (US GAO, 2021).

Beyond the types of chemicals used, the USFS protocols specify avoidance zones for the use of aerially dispersed fire fighting chemicals, including the avoidance of waterways and their surrounding buffers, except in cases where retardant use within avoidance areas is needed for public safety (USFS, 2020c). Nevertheless, the potential exists for misapplication or application and subsequent runoff of these chemicals. Studying four separate wildfires, Crouch et al. (2006) compared concentrations of ammonia, phosphorus, and cyanide in streams draining burned areas where fire retardants were applied vs. burned areas where fire retardants were not applied. They found similar concentrations regardless of the use of fire retardants, suggesting the fire retardants employed at these fires did not affect surface water quality. They further concluded the low amounts of cyanide detected were pyrogenically formed, not originating from the fire retardants.

3.2.11. Radionuclides—Finally, radionuclides have been remobilized by wildfire in locations characterized by elevated background radiation, such as the Chernobyl Exclusion Zone and watersheds in proximity to Los Alamos National Laboratory in New Mexico. Bondar et al. (2014) applied an empirical model to assess the contribution of wildfire activity to radionuclide contamination of two water bodies in the Chernobyl Exclusion Zone. In years with greater number of wildfires, fallout of ^{137}cesium and $^{239,\,240}$plutonium to the water surface increased, suggesting that radionuclides were being introduced to water bodies from the wildfire events. The Cerro Grande fire in New Mexico in 2000 impacted the Los Alamos Laboratory site. Four years of water quality monitoring data following the fire showed increased transport of radionuclides in initial runoff events, with median

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concentrations of total radionuclides increasing by 10–50 times from prefire levels (Gallaher & Koch, 2004). By 4 yr post-fire, however, elevated concentrations had subsided (Gallaher & Koch, 2004). Wildfires have been shown to condense and mobilize radionuclides in soils. In burned plots in Colorado and New Mexico, soils had concentrations of ^{137}Cesium 400%–2,200% of those in unburned plots (Bitner et al., 2001). Although the article did not specify, the presumed mechanism for radionuclide release is combustion of contaminated organic matter or vegetation. In locations not in proximity to sources of radiation, remobilization of radionuclides in runoff from past radioactive global fallout has been applied as a technique to trace sources and transport of sediments in runoff following wildfire events (Blake et al., 2009; Wilkinson et al., 2009).

3.3. Biological Responses

3.3.1. Microorganisms/Pathogens—Beyond the physical and chemical effects of wildfire, there is the potential for biological responses as well. There are several microorganisms of concern for drinking water supplies and recreation that are either pathogens or are used as indicators for the possible presence of microbial pathogens (e.g., coliforms, such as *E. coli*, are used as indicators). Contamination of waterbodies by these microorganisms of concern is generally not expected post-fire, unless wastewater infrastructure is damaged. Fire frequently reduces soil microbial populations directly due to heating (Neary et al., 1999). Moreover, toxicological tests have found that ash (i.e., AEA) can inhibit bacterial growth (Silva et al., 2015) and that wildfire residues reduce the persistence of some bacteria, including, *E. coli* (Valenca et al., 2020). Microbial populations in the soil recover over time (LeDuc & Rothstein, 2007), but microorganisms of concern for drinking water and recreation generally originate from human or animal waste. Fire damage to wastewater infrastructure (e.g., wastewater pipes, waste treatment facilities) could lead to subsequent spills or leaching of waste and associated microorganisms into surface- or groundwater. We did not, however, identify any studies characterizing the effects of fire on microbial pathogens or indicators in waterbodies.

3.3.2. Benthic Invertebrates—Invertebrate assemblages are an integral component of water monitoring programs across the U.S. and globally, with declines in species richness, diversity, and density associated with impaired aquatic habitat. Most studies found a negative impact of wildfire on macroinvertebrate assemblages (57% of studies, Table 1), the magnitude of which was, on average, a 45% decline (Figure 2). Increases in ash, sediment, temperature, metals, altered pH, alkalinity and conductivity, and increases in other pollutant loads are all known to adversely impact invertebrate assemblages (Allan & Castillo, 2007). In addition, changes in physical habitat resulting from altered sediment loads, especially debris flows, and concomitant scour and channel adjustments all affect invertebrates (Allan & Castillo, 2007). Shifts in food resources post-fire with changes in light and nutrients (e.g., either more or less algal dominated) also affect assemblage structure (Minshall et al., 1997). Invertebrate assemblages, however, typically recover rapidly following alleviation of stress (e.g., Allan & Castillo, 2007). Most invertebrates generally recovered within 5 yr of disturbance, with individual taxa recovery lasting as long as 10 yr following fire (Figure 3).

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In the majority of studies, invertebrate diversity in streams was reduced following wildfire, especially sensitive taxa (e.g., from the Ephemeroptera, Plecoptera, and Trichoptera orders), and this was true in boreal, temperate, and Mediterranean biomes (Beche et al., 2005; Brown et al., 2013; Earl & Blinn, 2003; Harper et al., 2018; Harris et al., 2015; Minshall et al., 2001; Rinne, 1996; Spencer et al., 2003; Verkaik et al., 2013; Whitney et al., 2015). In several studies, invertebrate densities also decreased following wildfires. In New Mexico, for example, invertebrate densities declined in one burned watershed, but recovered within a year (Earl & Blinn, 2003). In the second study in New Mexico, invertebrate biomass declined almost 82% after more severe fires and some declines lasted for nearly 2 yr (Whitney et al., 2015). By contrast, studies also show an increase in invertebrate biomass post-fire (e.g., Malison & Baxter, 2010). For instance, in a survey in the northern Rocky Mountains, invertebrate abundance was two times higher in fire-impacted streams compared to reference streams (Martens et al., 2019). This was 8 yr post-fire, likely allowing time for invertebrates to recover and take advantage of resource expansion. Even still, reference streams were characterized by higher relative abundance of sensitive taxa (Martens et al., 2019). In individual cases, macroinvertebrate impacts can last as long as 5 yr or more, with the duration likely depending on the extent of changes in physical habitat (channel morphology) and food resources. After a large-area fire (>15,000 ha) in Montana, for example, invertebrate carbon and nitrogen isotope signatures 4–5 yr post-fire still reflected greater dependence on algal food resources than those in unburned watersheds (Spencer et al., 2003).

In many studies, initial invertebrate responses are negligible until it rains, and runoff carrying sediment and other pollutants occurs. For example, immediately after a fire in Arizona, invertebrate densities were unchanged from pre-fire conditions, whereas after the first storm, invertebrate densities declined precipitously (Rinne, 1996). Other factors influence invertebrate responses. For example, in burned watersheds with debris flows, the diversity and biomass of stream invertebrates exported (drifting) from the water was much lower than in burned watersheds without debris flow or unburned watersheds (Harris et al., 2015). As predicted, food webs in streams draining burned watersheds do exhibit shifts toward opportunistic, shorter life-cycle generalists (Minshall et al., 1997) or toward more algal based food resources when fires led to increased algal growth (Cooper et al., 2015; Rugenski & Minshall, 2014). For lakes, we identified only two studies and two reviews discussing littoral invertebrates or zooplankton responses (Allen et al., 2005; Lewis et al., 2014; McCormick et al., 2010; McCullough et al., 2019). Where they have been documented, however, the changes are similar to those in streams post-fire, with shifts in diversity combined with changes in the food web.

There has been some work on the effects of fire fighting chemicals on invertebrates. Foam suppressants were generally reported to be more acutely toxic to *Hyallella* amphipods than fire retardants (McDonald et al., 1997). The authors postulated that surfactants affected oxygen diffusion. In these experiments, ammonia concentrations also exceeded aquatic life criteria by 120x, which was hypothesized as a major cause of acute toxicity. In Spain, studies of vernal pools exposed to the fire retardant FireTrol 934 found that ammonia and conductivity increased and pH decreased, and these were associated with a decline in invertebrate diversity (Angeler et al., 2006). The same chemical was found to exhibit a toxic

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effect on zooplankters in lab studies (Martin, 2016). Lastly, the fire-retardant GTS-R was found to release cyanide when exposed to ultraviolet light (Calfee & Little, 2003). Neither of these two retardants is on the current USFS QPL (USFS, 2020a). Lastly, toxicological experiments show adverse effects of some retardants and foam suppressants on lentic invertebrates, including both zooplankters (Angeler et al., 2006) and benthic invertebrates (McDonald et al., 1997).

3.3.3. Fish—Wildfire effects on fish populations can be direct, such as localized extirpation occurring during or immediately following a fire event, or indirect such as post-fire physical and chemical alteration of fish habitat (Gresswell, 1999). Reported fish assemblage responses to wildfires are similar to those of invertebrates: the majority of studies (63%) indicate declines in abundance and diversity of taxa (ranging from 30% to 100% declines, Table 1 and Figure 2). Fish biomass can decline rapidly after fire, most commonly after the first storm introduces pollutants. In Arizona, a severe fire resulted in little decline until the first post-fire storm, after which salmonids were completely absent and only showed some recovery after 2 yr and restocking efforts (Rinne, 1996). Notably, longer-term outcomes may be better than these findings suggest. For instance, fires may contribute to improved fish habitat, particularly through increases in woody debris to streams (Flitcroft et al., 2016). Nonetheless, fish generally do not disperse as quickly as invertebrates, so recovery after fires can take longer depending on fish movement and habitat connectivity (Rosenberger et al., 2015). The average duration of effect in studies surveyed was indeed longer than that for invertebrates, yet still generally within 5–10 yr (Figure 3).

One research focus area has been on post-fire thermal effects on fish. Many cold-water taxa (e.g., salmonids) have strict thermal requirements and much of their remaining habitat is at the extent of their tolerance. As discussed previously, water temperatures generally increase following burning, especially when severe fires remove riparian vegetation. This can reduce cold-water habitat, including refugia, leading to extirpation. In Idaho, salmonid densities (age class 1+) were lower 10 yr following wildfires in watersheds that burned and experienced debris flows. This response was likely due to the effect of higher water temperatures from slow riparian recovery (Rosenberger et al., 2015). In California, salmonid declines following fires were attributed to an increase in stream pool thermal refugia temperatures, leading to higher energetic maintenance costs (Beakes et al., 2014).

Besides temperatures, post-fire mercury bioaccumulation is another area of focus, with implications for fish consumption advisories. Some studies on mercury bioaccumulation in fish following burning note no or minimal response while others recorded increases. For example, mercury increased in rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) and European perch (*Perca fluviatilis*) in Canadian and Norwegian lakes impacted by wildfires (Kelly et al., 2006; Moreno et al., 2016). Factors affecting this increase included both higher water concentrations of mercury and methylmercury following wildfires, as well as a restructuring of the food web and lengthening of trophic pathways, leading to greater potential for bioaccumulation. Still other studies have not observed increases, as in the lack of a mercury increase in yellow perch (*P. flavescens*) following fires in northern Minnesota (Riggs et al., 2017). Many factors affect mercury cycling, and identifying the specific risks for any single waterbody may be necessary.

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Lastly, experimental studies have examined the effects of fire fighting chemicals on fish. In one study, rainbow trout (*O. mykiss*) avoided elevated concentrations of fire retardants (Wells et al., 2004), suggesting these chemicals may affect movement and impose metabolic costs. The authors did not identify specific compounds responsible for the avoidance cue, although they experimentally ruled out colorants or corrosion inhibitors, and suggested that ammonium salts may be a culprit given the sensitivity of this taxon and other fishes to salts. Fire retardants caused acute toxicity to *O. tshawytscha* (chinook salmon) yearlings at concentrations possible during accidental applications (Dietrich et al., 2013). The resulting ammonia concentrations were above those sufficient for acute mortality and were a presumed contributor (Dietrich et al., 2013). Foam suppressants were generally reported to be more acutely toxic to chinook salmon larvae and juveniles than fire retardants (Buhl & Hamilton, 2000).

3.3.4. Algae—As noted previously, algal growth is important to water regulatory programs because excess algal biomass can interfere with water treatment systems, creating compounds that lead to DBP formation and taste and odor issues. Additionally, several harmful algal taxa produce toxins threatening human, livestock, and aquatic life (Chorus & Welker, 2021). Algal growth can also affect food webs and cause chemical responses like hypoxia (low DO), with the potential to produce fish kills, mobilization of sediment metals, and other adverse ecosystem impacts.

Algal assemblages can be impacted by wildfire, both through changes in biomass and composition, depending on waterbody type, context, and timing (Bixby et al., 2015; McCullough et al., 2019). Physical scour of stream substrate by erosion and sediment transport during runoff is one factor leading to decreases in initial stream algal biomass. This has been offset over time by increased light availability from riparian canopy loss, increasing algal biomass and shifting competition toward high light taxa (Bixby et al., 2015; Klose et al., 2015; Verkaik et al., 2013). Wildfire-mediated nutrient enrichment also can increase algal biomass and shift composition (Kelly et al., 2006; McCullough et al., 2019). Some studies of lakes, however, have shown this effect could be dampened by decreased light availability from post-fire dissolved or suspended material (e.g., Allen et al., 2003).

Most studies reported no directional change in algal response to fire (48%), with the balance roughly equally split between increases or decreases (Table 1). The magnitude of the response was also relatively modest (Figure 2), and most reported algal response durations lasted less than 10 yr after the fire (Figure 3). Wildfires in New Mexico and southern California led to initial declines in stream algal biomass, up to an order of magnitude lower than pre-fire levels (Klose et al., 2015; Whitney et al., 2015). In California, however, where the riparian canopy was removed by fire, algal biomass ultimately increased 5–20x over pre-burn levels over time, indicating the importance of light (Klose et al., 2015). The duration of effects on algae in streams will likely depend on how long nutrient concentrations stay elevated and how quickly riparian vegetation recovers to limit light availability.

Algal responses in lakes post-fire were variable as well, with some lakes experiencing increases and others not (Lewis et al., 2014; McCullough et al., 2019). The characteristics of the fire and antecedent lake conditions likely influence the response. For example, already

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productive lakes might not see an increase in algal growth post-fire, whereas oligotrophic systems would likely respond to nutrient input if sufficient light is available. In Spain, algal biomass increased in ponds following a burn, largely attributed to increased nutrient levels (Cunillera-Montcusi et al., 2019). Post-fire increases in nutrients can lead to increased algal growth in water supply reservoirs, with the potential to impact human health by increasing algal DOC and DBP formation risk (Hohner et al., 2019).

Fire retardants may also be another factor affecting algal responses. In laboratory experiments, fertilizers in fire retardants have increased algal growth (Angeler et al., 2004). As noted previously, best management practices are to avoid riparian areas when spreading fire retardants (USFS, 2020c), yet there is the potential for misapplication or subsequent runoff into waterbodies after a fire.

3.4. Key Knowledge Gaps

Although the effects of wildfire on many endpoints have been well-characterized, matching our literature review with the topics in the conceptual model (Figure 1) makes it clear that some endpoints and pathways have not. Unfortunately, some of the topics receiving little research also pose some of the greatest threats to water quality programs.

Most strikingly, little is known about the effects on water endpoints from wildfire in urban areas in the WUI. Downwind air quality aside, these areas are where the largest number of people will be affected now and in the future. We fully acknowledge that there are legal, safety, and resource constraints on sampling these areas during immediate post-fire runoff events, but the lack of study is glaring. We identified one peer-reviewed study that found ash generated from residential and building materials had higher metal concentrations (e.g., arsenic, copper, lead, nickel, and zinc) than wildland ash (Burton et al., 2016). A second set of articles described increases in benzene and other VOCs due to damaged pipes following two destructive wildland fires affecting WUI urbanized areas in California (Macler et al., 2020; Proctor et al., 2020). No other study we found focused explicitly on the effects of these types of fires on endpoint responses. Major outstanding research questions include: is the mixture of pollutants mobilized different than those of wildland fire as Burton et al. (2016) suggest? Do these chemicals rapidly move into nearby drains or waterways in subsequent storm events given the higher proportion of impervious surfaces in the WUI? And, what priority contaminants should be tested for—downstream, at the tap and/or at the drinking water facility—when these fires occur?

Beyond urban fires, there is a large research gap in wildfire responses for many chemicals, including many regulated pollutants. Of the 82 non-pathogen related primary drinking water standards (USEPA, 2020a), wildfire effects were reported for 13 (Table 1). For the secondary drinking WQS, effects were reported for 5 of 15 (Table 1). Many primarily synthetic chemicals with knowledge gaps may not arise from forested watersheds, but may originate from fires burning urbanized areas. Studies of the risk of HABs and cyanotoxins post-fire are also urgently needed.

Other important knowledge gaps include those surrounding waterbody type. Studies of wildfire effects on streams are far more common than those in lakes, reservoirs, wetlands, or

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estuaries, creating a knowledge gap. Whether responses in lakes and other lentic waterbodies differ in important ways is an especially critical question given municipalities often rely on lakes and reservoirs for their drinking water. Beyond surface water, Pennino et al. (2022) found post-fire contamination in municipal groundwater sources, yet impacts on groundwater remain little studied. Communities that rely on individual or municipal wells for drinking water need more information on this emerging topic.

4. Considerations for Water Quality Programs

The purpose of this review was to synthesize what is known about the effects of wildland fires and fires burning urban areas in the WUI on stressors relevant to water quality programs. Here, we highlight how some of the programs could be affected, a few of the most consequential stressors, and select prevention or mitigation steps that could be considered.

Stressors generated by wildfire can affect drinking water programs by impacting drinking water sources, increasing treatment needs and costs, and affecting drinking water infrastructure directly (Table 3). Across the literature reviewed, post-fire chemical concentrations for several analytes were reported at concentrations exceeding drinking water standards (Table 2). This included samples in finished drinking water in the case of nitrate, arsenic, and DBPs (total haloacetic acids and total trihalomethanes; Pennino et al., 2022). Managers of public water supplies should be aware of the potential for post-fire contamination from these chemicals in particular. Physical damage from fire is also a threat to drinking water infrastructure, such as the cases observed in California (Macler et al., 2020). Areas in the fire-prone WUI may need to consider mitigation measures, such as backflow preventers to keep contaminants from burning infrastructure out of drinking water distribution systems. Moreover, smaller drinking water suppliers are especially vulnerable from sedimentation or damage if they only have one drinking water source, potentially requiring a regional approach to help reduce risk (Bladon et al., 2014).

Programs focused on WQS and wastewater may also need to consider impacts from fire. Under the CWA, states and tribes adopt WQS that assign designated uses (e.g., recreation) to water bodies and water quality criteria to protect those designated uses. These standards form the basis of wastewater permitting, assessment and restoration of waterbodies. Standards and wastewater programs in the U.S. may face increased requests for variances, allowing waterbodies to temporarily exceed criteria due to wildfire. Alternatively, states and tribes may propose site specific criteria for pollutants, justifying wildfires as natural conditions. Other impacts might include the incorporation of natural variability from fires into threshold setting for biocriteria, and like drinking water providers, wastewater facilities should be aware of their susceptibility to physical damage from the direct and indirect effects of fires.

Water quality assessment programs may also need to consider fire impacts as they influence variability in physical, chemical, and biological conditions of water in reference watersheds (e.g., Bixby et al., 2015), especially as these impacts can last for many years (e.g., Emelko et al., 2016; Minshall et al., 2001; Rhoades et al., 2019). Across the literature reviewed, post-fire chemical concentrations for several analytes were reported at concentrations

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exceeding national recommended aquatic life use criteria, including: cadmium, iron, lead, nickel, selenium, and zinc (Table 2). Pathogen-related recreational criteria are likely to be minimally impacted by wildfire, unless physical damage of waste infrastructure occurs. However, increased nutrient loads may contribute to downstream harmful algal blooms and the potential for cyanotoxins to exceed advisory levels for recreation (e.g., swimming).

Efforts to restore impaired waters may also need to account for fire in TMDL planning. For example, TMDL programs may need to be aware of how burning can affect low flow statistics (e.g., Shakesby & Doerr, 2006), as well as the background pollutant levels upon which load allocations may be derived. Restoration may be further confounded if wildfires generate pollutants undergoing management (e.g., sediment or temperature). These effects may need to be incorporated into load reductions. Destructive fires in urbanized areas in the WUI may also make discriminating contributions from human and forested sources difficult.

Additionally, wildfire has the potential to affect non-point source management (CWA Section 319) efforts to reduce stressors, and burned watersheds, in turn, could be targeted for restoration to reduce non-point sources. Revegetation of burned watersheds shortens the duration of many wildfire water quality effects (e.g., nutrients, sediment, and temperature) and it may be important to prioritize non-point source improvements, such as hillslope and riparian revegetation, as well as other management practices in watersheds where wildfire has impacted water quality. For instance, the Pueblo of Santa Clara utilized U.S. EPA's Section 319 resources (https://www.epa.gov/nps/319-grant-program-states-and-territories) to install erosion control measures following the Las Conchas Fire in 2011, with these efforts leading to improved water quality conditions (USEPA, 2019b).

Finally, prescribed fire is a tool by which managers may potentially lessen the risk of extensive, high-severity fires and their subsequent water quality effects. Prescribed fire is likely to be most effective in ecosystems that historically experienced frequent, low severity fires, yet less so in ecosystems characterized by infrequent, high severity fires (Moritz et al., 2014). In this review, we found fewer studies (21) on prescribed burn responses than we did on wildfire responses (126). Since prescribed fires are typically low severity fires, they generally elicit decreased magnitude and/or duration of physical, chemical, and biological responses in waterbodies. One study, for example, found similar runoff responses following prescribed burns but for shorter duration when compared to that of wildfire (dos Santos et al., 2017). Similarly, nutrient increases were less under prescribed burns and also of shorter duration than for wildfire (e.g., Knoepp & Swank, 1993), and two studies of prescribed burns on macroinvertebrates found generally moderate responses of <1 yr duration (Beche et al., 2005; Brown et al., 2013). Utilizing prescribed burning in particularly fire-prone watersheds or with vulnerable drinking water or wastewater resources may be an effective means to reduce risks to water programs.

5. Summary and Conclusions

Fire is a natural disturbance in many ecosystems, yet the increase in fire frequency poses a risk to water quality in the U.S. and globally. Here, we synthesized the effects of wildfires on the physical, chemical, and biological endpoints relevant to water quality management

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programs. We acknowledge that for any specific wildfire response, the individual watershed context is important, including factors like the fire regime and post-fire hydrology, and contributes to the large variation in reported responses. Still, general trends emerged from this review.

Physically, wildfires result in vegetation mortality and expose and alter the soil, leading to reduced infiltration, greater runoff, higher streamflows and greater erosion and sediment export. The loss of tree canopy can also increase water temperatures. Increases in physical responses surveyed in this review ranged between 100% and 10,000% of unburned or pre-fire reference conditions, with the highest values for surface runoff and sediment responses. On average, the duration of effects was shortest for suspended sediments (<5 yr), while longer (5–10 yr) for streamflow and temperature. In most cases, duration estimates were constrained by the length of the studies, so any duration estimate should be considered conservative.

For the chemicals reviewed, concentrations generally increased in response to fires. Similar to the other studies (e.g., Rust et al., 2018, 2019), we found that nutrients and metals were commonly elevated post-fire. Nutrient concentrations nearly universally increased, with few exceptions. Metals and polycyclic aromatic hydrocarbons were typically higher post-fire as well. Concentration increases, especially for individual metals, can be quite high compared to reference or before conditions (as much as 100,000%), with studies observing increases of iron, lead, manganese, nickel, zinc, and arsenic above regulatory standards or aquatic criteria (Table 2). On average, chemical effects lasted less than 5 yr post-fire, although individual cases lasting longer did occur.

Biological assemblages most commonly decline with fire, with the exception of tolerant or opportunistic organisms. The most common observations were declines in biomass (or densities) of all assemblages (except for algae, which may increase in biomass in response to increased light and nutrients), declines in diversity due to the loss of sensitive taxa, and, for invertebrates, an increase in opportunistic or tolerant species. The average duration of these effects was shorter for invertebrates (median of ~1 yr) than fish (median of ~3 yr).

Through our review, we also identified key knowledge gaps; a principal one being the mobilization of pollutants from fires burning anthropogenic sources in the WUI. This problem is only likely to grow as urbanization expands and fire frequency increases with climate change. Some of these communities rely on a single municipal source or individual private wells that, if damaged or contaminated, could substantially impede recovery.

Finally, we conclude that an array of water quality programs in the U.S. and globally will likely need to consider the effects of fire. Previous reviews have emphasized the problems to water quality posed by sediments, nutrients, and metals, among other chemicals (e.g., Bladon et al., 2014; Rust et al., 2018; Smith et al., 2011). We echo these findings, and also particularly highlight cases where nitrate, arsenic, and two classes of DBPs exceeded U.S. drinking water standards in the finished drinking water itself following fire (Pennino et al., 2022). This occurred in both surface and groundwater, highlighting the vulnerability of the latter to chemicals highly mobile in the environment. Although not a focus of our

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review, to our knowledge the effects of fire on groundwater quality has received little attention to date. We also note the recent finding of benzene and VOCs in tapwater from infrastructure damage in the WUI as a potentially important, emerging issue. By providing this information, we hope communities, water quality managers, and other decision makers can better plan for, mitigate, and, if necessary, recover from wildfire impacts.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The authors would like to acknowledge the help of Katelin Kelly and Kristen Parry in organizing the literature and conducting the abstract screening, as well as Katie Boaggio, Emma Leath and Cynthia Nolt-Helms for help reviewing and extracting information, and making figures. The authors also thank US EPA Regional and Programmatic staff who provided feedback on our list of water quality endpoints and the conceptual model, and helped us to understand how fire might impact their programs. The authors acknowledge Drs. Michael Pennino and Joe Ebersole and others at US EPA who provided constructive criticism on earlier drafts of this manuscript. Finally, the authors thank Dr. Charles Rhoades, Dr. Sheila Murphy, and an anonymous reviewer for their comments, greatly improving this manuscript. The views expressed in this manuscript are those of the authors and do not necessarily reflect the views or policies of the US EPA.

Data Availability Statement

All extracted information from citations used in this review are being provided as raw data, searchable atomized statements and summary synthetic statements in a keyword searchable Excel workbook provided in a data repository (to be added if/when publication occurs). These are included in Supporting Information S3.

References

Abatzoglou JT, & Williams AP (2016). Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences of the United States of America, 113(42), 11770–11775. 10.1073/pnas.1607171113 [PubMed: 27791053]

Abraham J, Dowling K, & Florentine S. (2017a). The unquantified risk of post-fire metal concentration in soil: A review. Water, Air, and Soil Pollution, 228(5), 175. 10.1007/s11270-017-3338-0

Abraham J, Dowling K, & Florentine S. (2017b). Risk of post-fire metal mobilization into surface water resources: A review. Science of the Total Environment, 599, 1740–1755. 10.1016/j.scitotenv.2017.05.096 [PubMed: 28535601]

Allan JD, & Castillo MM (2007). Stream ecology: Structure and function of running waters. Springer Science & Business Media.

Allen EW, Prepas EE, Gabos S, Strachan W, & Chen W. (2003). Surface water chemistry of burned and undisturbed watersheds on the boreal plain: An ecoregion approach. Journal of Environmental Engineering and Science, 2, S73–S86. 10.1139/s03-035

Allen EW, Prepas EE, Gabos S, Strachan WMJ, & Weiping Z. (2005). Methyl mercury concentrations in macroinvertebrates and fish from burned and undisturbed lakes on the Boreal Plain. Canadian Journal of Fisheries and Aquatic Sciences, 62, 1963–1977. 10.1139/f05-103

Angeler DG., Martín S, & Moreno JM (2005). Daphnia emergence: A sensitive indicator of fire-retardant stress in temporary wetlands. Environment International, 31, 615–620. 10.1016/j.envint.2004.10.015 [PubMed: 15788202]

Angeler DG, Rodriguez M, Martin S, & Moreno JM (2004). Assessment of application-rate dependent effects of a long-term fire retardant chemical (Fire Trol 934®) on Typha domingensis germination. Environment International, 30, 375–381. 10.1016/j.envint.2003.09.003 [PubMed: 14987869]

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Angeler DG, Sanchez B, Garcia G, & Moreno JM (2006). Community ecotoxicology: Invertebrate emergence from Fire Trol 934 contaminated vernal pool and salt marsh sediments under contrasting photoperiod and temperature regimes. Aquatic Toxicology, 78, 167–175. 10.1016/j.aquatox.2006.02.030 [PubMed: 16621061]

Ankley GT, Burkhard LP, Cook PM, Diamond SA, Erickson RJ, & Mount DR (2003). Assessing risks from photoactivated toxicity of PAHs to aquatic organisms. In Douben P. (Ed.), PAHs: Ecotoxicological perspective. John Wiley & Sons, Ltd. Chapter 15.

Barber TR, Lutes CC, Doorn MR, Fuchsman PC, Timmenga HJ, & Crouch RL (2003). Aquatic ecological risks due to cyanide releases from biomass burning. Chemosphere, 50(3), 343–348. 10.1016/s0045-6535(02)00532-5 [PubMed: 12656253]

Bart RR, & Tague CL (2017). The impact of wildfire on baseflow recession rates in California. Hydrological Processes, 31(8), 1662–1673. 10.1002/hyp.11141

Bayley SE, & Schindler DW (1991). The role of fire in determining stream water chemistry in northern coniferous forests. In Mooney H, Medina E, Schindler DW, Schulze ED, & Walker BH (Eds.), Ecosystem experiments. Scope # 45 (pp. 141–165). New York: John Wiley & Sons Ltd.

Bayley SE, Schindler DW, Parker BR, Stainton MP, & Beaty KG (1992). Effects of forest fire and drought on acidity of a base-poor boreal forest stream—Similarities between climatic warming and acidic precipitation. Biogeochemistry, 17, 191–204. 10.1007/bf00004041

Beakes MP, Moore JW, Hayes SA, & Sogard SM (2014). Wildfire and the effects of shifting stream temperature on salmonids. Ecosphere, 5(5), 1–14. 10.1890/es13-00325.1

Beche LA, Stephens SL, & Resh VH (2005). Effects of prescribed fire on a Sierra Nevada (California, USA) stream and its riparian zone. Forest Ecology and Management, 218, 37–59. 10.1016/j.foreco.2005.06.010

Betts EF, & Jones JB Jr. (2009). Impact of wildfire on stream nutrient chemistry and ecosystem metabolism in boreal forest catchments of interior Alaska. Arctic Antarctic and Alpine Research, 41. 10.1657/1938-4246-41.4.407

Bitner K, Gallaher B, & Mullen K. (2001). Review of wildfire effects on chemical water quality. Los Alamos National Laboratory.

Bixby RJ, Cooper SD, Gresswell RE, Brown LE, Dahm CN, & Dwire KA (2015). Fire effects on aquatic ecosystems: An assessment of the current state of the science. Freshwater Science, 34(4), 1340–1350. 10.1086/684073

Bladon KD, Emelko MB, Silins U, & Stone M. (2014). Wildfire and the future of water supply. Environmental Science and Technology, 48, 8936–8943. 10.1021/es500130g [PubMed: 25007310]

Blake WH, Wallbrink PJ, Wilkinson SN, Humphreys GS, Doerr SH, Shakesby RA, & Tomkins KM (2009). Deriving hillslope sediment budgets in wildfire-affected forests using fallout radionuclide tracers. Geomorphology, 104(3–4), 105–116. 10.1016/j.geomorph.2008.08.004

Bodi MB, Martin DA, Balfour VN, Santin C, Doerr SH, Pereira P, et al. (2014). Wildland fire ash: Production, composition and eco-hydro-geomorphic effects. Earth-Science Reviews, 130, 103–127. 10.1016/j.earscirev.2013.12.007

Bondar YI, Navumau AD, Nikitin AN, Brown J, & Dowdall M. (2014). Model assessment of additional contamination of water bodies as a result of wildfires in the Chernobyl exclusion zone. Journal of Environmental Radioactivity, 138, 170–176. 10.1016/j.jenvrad.2014.08.018 [PubMed: 25240987]

Brown LE, Johnston K, Palmer SM, Aspray KL, & Holden J. (2013). River ecosystem response to prescribed vegetation burning on blanket peatland. PLoS One, 8(11), e81023. 10.1371/journal.pone.0081023

Buhl KJ, & Hamilton SJ (2000). Acute toxicity of fire-control chemicals, nitrogenous chemicals, and surfactants to rainbow trout. Transactions of the American Fisheries Society, 129(2), 408–418. 10.1577/1548-8659(2000)129<0408:atofcc>2.0.co;2

Burke MP, Hogue TS, Kinoshita AM, Barco J, Wessel C, & Stein ED (2013). Pre- and post-fire pollutant loads in an urban fringe watershed in Southern California. Environmental Monitoring and Assessment, 185, 10131–10145. 10.1007/s10661-013-3318-9 [PubMed: 23912423]

EPA Author Manuscript EPA Author Manuscript EPA Author Manuscript

Burton CA, Hoefen TM, Plumlee GS, Baumberger KL, Backlin AR, Gallegos E, & Fisher RN (2016). Trace elements in stormflow, ash, and burned soil following the 2009 Station Fire in Southern California. PLoS One, 11(5), e0153372. 10.1371/journal.pone.0153372

Calfee RD, & Little E. (2003). Effects of a fire-retardant chemical to fathead minnows in experimental streams. Environmental Science and Pollution Research International, 10, 296–300. 10.1065/espr2003.03.148 [PubMed: 14535643]

Campo J, Lorenzo M, Cammeraat ELH, Pico Y, & Andreu V. (2017). Emerging contaminants related to the occurrence of forest fires in the Spanish Mediterranean. Science of the Total Environment, 603, 330–339. 10.1016/j.scitotenv.2017.06.005 [PubMed: 28633110]

Cannon SH, & Reneau SL (2000). Conditions for generation of fire-related debris flows, Capulin Canyon, New Mexico. Earth Surface Processes and Landforms, 25, 1103–1121. 10.1002/1096-9837(200009)25:10<1103::aid-esp120>3.0.co;2-h

Certini G. (2005). Effects of fire on properties of forest soils: A review. Oecologia, 143(1), 1–10. 10.1007/s00442-004-1788-8 [PubMed: 15688212]

Chanasyk DS, Whitson IR, Mapfumo E, Burke JM, & Prepas EE (2003). The impacts of forest harvest and wildfire on soils and hydrology in temperate forests: A baseline to develop hypotheses for the boreal plain. Journal of Environmental Engineering and Science, 2, S51–S62. 10.1139/s03-034

Chorus I, & Welker M. (2021). Toxic cyanobacteria in water: A guide to their public health consequences, monitoring, and management (2nd ed.). CRC Press, Boca Raton, Florida, on behalf of the World Health Organization.

Chow AT, Tsai KP, Fegel TS, Pierson DN, & Rhoades CC (2019). Lasting effects of wildfire on disinfection by-product formation in forest catchments. Journal of Environmental Quality, 48(6), 1826–1834. 10.2134/jeq2019.04.0172

Cochrane M. (2003). Fire science for rainforests. Nature, 421, 913–919. 10.1038/nature01437 [PubMed: 12606992]

Cook P, & Holland D. (2012). Long term nutrient loads and chlorophyll dynamics in a large temperate Australian lagoon system affected by recurring blooms of cyanobacteria. Biogeochemistry, 107, 261–274. 10.1007/s10533-010-9551-1

Cooper SD, Page HM, Wiseman SW, Klose K, Bennett D, Even T, et al. (2015). Physicochemical and biological responses of streams to wildfire severity in riparian zones. Freshwater Biology, 60(12), 2600–2619. 10.1111/fwb.12523

Costa MR, Calvão AR, & Aranha J. (2014). Linking wildfire effects on soil and water chemistry of the Marão River watershed, Portugal, and biomass changes detected from Landsat imagery. Applied Geochemistry, 44, 93–102. 10.1016/j.apgeochem.2013.09.009

Crilly A, Evans C, Norris D, Malcolm I, Shilland E, Rose N, et al. (2017). Sustained biogeochemical impacts of wildfire in a mountain lake catchment. Ecosystems, 20, 813–829.

Crouch RL, Timmenga HJ, Barber TR, & Fuchsman PC (2006). Post-fire surface water quality: Comparison of fire retardant vs. wildfire-related effects. Chemosphere, 62, 874–889. 10.1016/j.chemosphere.2005.05.031 [PubMed: 16023176]

Cunillera-Montcusi D, Boix D, Tornero I, Sala J, Nuria A, Stephanie G, & Quintana XD (2019). Direct and indirect impacts of wildfire on faunal communities of Mediterranean temporary ponds. Freshwater Biology, 64, 323–334. 10.1111/fwb.13219

Dahm CN, Candelaria-Ley RI, Reale CS, Reale JK, & Van Horn DJ (2015). Extreme water quality degradation following a catastrophic forest fire. Freshwater Biology, 60, 2584–2599. 10.1111/fwb.12548

Dennison PE, Brewer SC, Arnold JD, & Moritz MA (2014). Large wildfire trends in the western United States, 1984–2011. Geophysical Research Letters, 41(8), 2928–2933. 10.1002/2014gl059576

Dietrich JP, Myers MS, Strickland SA, Van Gaest A, & Arkoosh MR (2013). Toxicity of forest fire retardant chemicals to stream-type chinook salmon undergoing parr-smolt transformation. Environmental Toxicology and Chemistry, 32(1), 236–247. 10.1002/etc.2052 [PubMed: 23161484]

EPA Author Manuscript EPA Author Manuscript EPA Author Manuscript

dos Santos JCN, de Andrade EM, Medeiros PHA, Guerreiro MJS, & Palacio HAD (2017). Land use impact on soil erosion at different scales in the Brazilian semi-arid. Revista Ciencia Agronomica, 48, 251–260. 10.5935/1806-6690.20170029

Dunham JB., Rosenberger AE, Luce CH, & Rieman BE (2007). Influences of wildfire and channel reorganization on spatial and temporal variation in stream temperature and the distribution of fish and amphibians. Ecosystems, 10(2), 335–346. 10.1007/s10021-007-9029-8

Earl SR, & Blinn DW (2003). Effects of wildfire ash on water chemistry and biota in southwestern USA streams. Freshwater Biology, 48(6), 1015–1030. 10.1046/j.1365-2427.2003.01066.x

Emelko MB, Silins U, Bladon KD, & Stone M. (2011). Implications of land disturbance on drinking water treatability in a changing climate: Demonstrating the need for “source water supply and protection” strategies. Water Research, 45(2), 461–472. 10.1016/j.watres.2010.08.051 [PubMed: 20951401]

Emelko MB, Stone M, Silins U, Allin D, Collins AL, Williams CHS, et al. (2016). Sediment-phosphorus dynamics can shift aquatic ecology and cause downstream legacy effects after wildfire in large river systems. Global Change Biology, 22, 1168–1184. 10.1111/gcb.13073 [PubMed: 26313547]

Fairman TA, Nitschke CR, & Bennett LT (2015). Too much, too soon? A review of the effects of increasing wildfire frequency on tree mortality and regeneration in temperate eucalypt forests. International Journal of Wildland Fire, 25, 831–848.

Flitcroft RL, Falke JA, Reeves GH, Hessburg PF, McNyset KM, & Benda LE (2016). Wildfire may increase habitat quality for spring chinook salmon in the Wenatchee River subbasin, WA, USA. Forest Ecology and Management, 359, 126–140. 10.1016/j.foreco.2015.09.049

Gallaher BM, & Koch RJ (2004). Cerro Grande Fire Impact to Water Quality and Stream Flow near Los Alamos National Laboratory: Results of Four Years of Monitoring. Technical Report LA-14177.

Gao JH, Holden J, & Kirkby M. (2017). Modeling impacts of agricultural practice on flood peaks in upland catchments: An application of the distributed TOPMODEL. Hydrological Processes, 31, 4206–4216. 10.1002/hyp.11355

Giménez A, Pastor E, Zárate L, Planas E, & Arnaldos J. (2004). Long-term forest fire retardants: A review of quality, effectiveness, application, and environmental considerations. International Journal of Wildland Fire, 13, 1–15.

Gresswell RE (1999). Fire and aquatic ecosystems in forested biomes of North America. Transactions of the American Fisheries Society, 128(2), 193–221. 10.1577/1548-8659(1999)128<0193:faaeif>2.0.co;2

Gu BH, Miao SL, Edelstein C, & Dreschel T. (2008). Effects of a prescribed fire on dissolved inorganic carbon dynamics in a nutrient-enriched Everglades wetland. Fundamental and Applied Limnology, 171, 263–272. 10.1127/1863-9135/2008/0171-0263

Hallema DW, Sun G, Bladon KD, Norman SP, Caldwell PV, Liu YQ, & McNulty SG (2017). Regional patterns of postwildfire streamflow response in the western United States: The importance of scale-specific connectivity. Hydrological Processes, 31, 2582–2598. 10.1002/hyp.11208

Hallema DW, Sun G, Caldwell PV, Norman SP, Cohen EC, Liu YQ, et al. (2017). Assessment of wildland fire impacts on watershed annual water yield: Analytical framework and case studies in the United States. Ecohydrology, 10. 10.1002/eco.1794

Harper AR, Doerr SH, Santin C, Froyd CA, & Sinnadurai P. (2018). Prescribed fire and its impacts on ecosystem services in the UK. Science of the Total Environment, 624, 691–703. 10.1016/j.scitotenv.2017.12.161 [PubMed: 29272838]

Harris HE, Baxter CV, & Davis JM (2015). Debris flows amplify effects of wildfire on magnitude and composition of tributary subsidies to mainstem habitats. Freshwater Science, 34(4), 1457–1467. 10.1086/684015

Hauer FR, & Spencer CN (1998). Phosphorus and nitrogen dynamics in streams associated with wildfire: A study of immediate and longterm effects. International Journal of Wildland Fire, 8, 183–198. 10.1071/wf9980183

EPA Author Manuscript EPA Author Manuscript EPA Author Manuscript

Hohner AK, Cawley K, Oropeza J, Summers R, & Rosario-Ortiz FL (2016). Drinking water treatment response following a Colorado wildfire. Water Research, 105, 187–198. 10.1016/j.watres.2016.08.034 [PubMed: 27619495]

Hohner AK, Rhoades CC, Wilkerson P, & Rosario-Ortiz FL (2019). Wildfires alter forest watersheds and threaten drinking water quality. Accounts of Chemical Research, 52(5), 1234–1244. 10.1021/acs.accounts.8b00670 [PubMed: 31059225]

Holden ZA, Swanson A, Luce CH, Jolly WM, Maneta M, Oyler JW, et al. (2018). Decreasing fire season precipitation increased recent western US forest wildfire activity. Proceedings of the National Academy of Sciences of the United States of America, 115(36), E8349–E8357. 10.1073/pnas.1802316115 [PubMed: 30126983]

Hooper MJ, Ankley GT, Cristol DA, Maryoung LA, Noyes PD, & Pinkerton KE (2013). Interactions between chemical and climate stressors: A role for mechanistic toxicology in assessing climate change risks. Environmental Toxicology and Chemistry, 32(1), 32–48. 10.1002/etc.2043 [PubMed: 23136056]

Howard BE, Phillips J, Tandon A, Maharana A, Elmore R, Mav D, et al. (2020). SWIFT-Active Screener: Accelerated document screening through active learning and integrated recall estimation. Environment International, 138, 105623. 10.1016/j.envint.2020.105623

Johnson KB, Haines TA, Kahl JS, Norton SA, Amirbahman A, & Sheehan KD (2007). Controls on mercury and methylmercury deposition for two watersheds in Acadia National Park, Maine. Environmental Monitoring and Assessment, 126, 55–67. 10.1007/s10661-006-9331-5 [PubMed: 17057984]

Johnston SG, Niloofar K, & Burton ED (2019). Fire promotes arsenic mobilization and rapid arsenic (III) formation in soil via thermal alteration of arsenic-bearing iron oxides. Frontiers of Earth Science, 7, 139. 10.3389/feart.2019.00139

Kelly EN, Schindler DW, St Louis VL, Donald DB, & Vladicka KE (2006). Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs. Proceedings of the National Academy of Sciences of the United States of America, 103, 19380–19385. 10.1073/pnas.0609798104 [PubMed: 17158215]

Klose K, Bennett DM, & Cooper SD (2015). Effects of wildfire on stream algal abundance, community structure, and nutrient limitation. Freshwater Science, 34, 1494–1509. 10.1086/683431

Knoepp JD, & Swank WT (1993). Site preparation burning to improve Southern Appalachian pine hardwood stands—Nitrogen responses in soil, soil-water, and streams. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 23, 2263–2270. 10.1139/x93-280

Korsman T, & Segerstroem U. (1998). Forest fire and lake-water acidity in a northern Swedish boreal area: Holocene changes in lake-water quality at Makkassjön. Journal of Ecology, 86, 113–124. 10.1046/j.1365-2745.1998.00239.x

Lathrop RG Jr. (1994). Impacts of the 1988 wildfires on the water quality of Yellowstone and Lewis Lakes, Wyoming. International Journal of Wildland Fire, 4(3), 169–175. 10.1071/wf9940169

LeDuc SD, & Rothstein DE (2007). Initial recovery of soil carbon and nitrogen pools and dynamics following disturbance in jack pine forests: A comparison of wildfire and clearcut harvesting. Soil Biology and Biochemistry, 39(11), 2865–2876. 10.1016/j.soilbio.2007.05.029

Legleiter CJ, Lawrence RL, Fonstad MA, Andrew Marcus W, & Aspinall R. (2003). Fluvial response a decade after wildfire in the northern Yellowstone ecosystem: A spatially explicit analysis. Geomorphology, 54, 119–136. 10.1016/s0169-555x(02)00332-x

Lewis TL., Lindberg MS, Schmutz JA, & Bertram MR (2014). Multi-trophic resilience of boreal lake ecosystems to forest fires. Ecology, 95(5), 1253–1263. 10.1890/13-1170.1 [PubMed: 25000757]

Lydersen E, Hogberget R, Moreno CE, Garmo OA, & Hagen PC (2014). The effects of wildfire on the water chemistry of dilute, acidic lakes in southern Norway. Biogeochemistry, 119, 109–124. 10.1007/s10533-014-9951-8

Macler B, Heaney Y, Watada M, Cajina S, & Newton D. (2020). Smoke and water do not mix. Opflow, 46(3), 10–15. 10.1002/opfl.1336

Majidzadeh H, Wang J-J, & Chow AT (2015). Prescribed fire alters dissolved organic matter and disinfection by-product precursors in forested watersheds—Part I. A controlled laboratory study.

EPA Author Manuscript EPA Author Manuscript EPA Author Manuscript

In Recent advances in disinfection by-products (pp. 271–292). American Chemical Society. 10.1021/bk-2015-1190.ch015

Malison RL, & Baxter CV (2010). Effects of wildfire of varying severity on benthic stream insect assemblages and emergence. Journal of the North American Benthological Society, 29(4), 1324–1338. 10.1899/09-022.1

Mansilha C, Carvalho A, Guimaraes P, & Marques JE (2014). Water quality concerns due to forest fires: Polycyclic aromatic hydrocarbons (PAH) contamination of groundwater from mountain areas. Journal of Toxicology and Environmental Health Part A: Current Issues, 77, 806–815. 10.1080/15287394.2014.909301

Mansilha C, Cláudia Gaspar D, Melo A, Ribeiro J, Flores D, & Marques JE (2019). Impact of wildfire on water quality in Caramulo Mountain ridge (Central Portugal). Sustainable Water Resources Management, 5, 319–331. 10.1007/s40899-017-0171-y

Martens AM, Silins U, Proctor HC, Williams CHS, Wagner MJ, Emelko MB, & Stone M. (2019). Long-term impact of severe wildfire and post-wildfire salvage logging on macroinvertebrate assemblage structure in Alberta's Rocky Mountains. International Journal of Wildland Fire, 28(10), 738–749. 10.1071/wf18177

Martin DA (2016). At the nexus of fire, water, and society. Philosophical Transactions of the Royal Society B: Biological Sciences, 371(1696), 20150172.

Martín S, Rodríguez M, Moreno JM, & Angeler DG (2014). Complex ecological responses to drought and fire-retardant contamination impacts in ephemeral waters. Water, Air, and Soil Pollution, 225(8), 1–13.

Martinuzzi S, Stewart SI, Helmers DP, Mockrin MH, Hammer RB, & Radeloff VC (2015). The 2010 wildland urban interface of the conterminous United States. Research Map NRS-8. (pp. 124). US Department of Agriculture, Forest Service, Northern Research Station.

McCormick FH, Riemen BE, & Kershner JL (2010). Biological responses to stressors in aquatic ecosystems in western North America: Cumulative watershed effects of fuel treatments, wildfire, and post-fire remediation. Chapter 11 In Elliot WJ, Miller IS, & Audin L, (Eds.), Cumulative watershed effects of fuel management in the western United States. General Technical Report RMRS-GTR-231. (pp. 206–233). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

McCullough IM, Cheruvelil KS, Lapierre JF, Lottig NR, Moritz MA, Stachelek J, & Soranno PA (2019). Do lakes feel the burn? Ecological consequences of increasing exposure of lakes to fire in the continental United States. Global Change Biology, 25(9), 2841–2854. 10.1111/gcb.14732 [PubMed: 31301168]

McDonald SF, Hamilton SJ, Buhl KJ, & Heisinger JF (1997). Acute toxicity of fire retardant and foam-suppressant chemicals to Hyalella azteca (Saussure). Environmental Toxicology and Chemistry, 16. 10.1897/1551-5028(1997)016<1370:atofra>2.3.co;2

Miller JD, Skinner C, Safford H, Knapp EE, & Ramirez C. (2012). Trends and causes of severity, size, and number of fires in northwestern California, USA. Ecological Applications, 22(1), 184–203. 10.1890/10-2108.1 [PubMed: 22471083]

Minshall GW, Robinson CT, & Lawrence DE (1997). Postfire responses of lotic ecosystems in Yellowstone National Park, USA. Canadian Journal of Fisheries and Aquatic Sciences, 54(11), 2509–2525. 10.1139/f97-160

Minshall GW, Royer TV, & Robinson CT (2001). Response of the cache creek macroinvertebrates during the first 10 yr following disturbance by the 1988 Yellowstone wildfires. Canadian Journal of Fisheries and Aquatic Sciences, 58(6), 1077–1088. 10.1139/f01-056

Moody JA, Shakesby RA, Robichaud PR, Cannon SH, & Martin DA (2013). Current research issues related to post-wildfire runoff and erosion processes. Earth-Science Reviews, 122, 10–37. 10.1016/j.earscirev.2013.03.004

Morales D, Rostagno CM, & La Manna L. (2013). Runoff and erosion from volcanic soils affected by fire: The case of austrocedrus chilensis forests in Patagonia, Argentina. Plant and Soil, 370, 367–380. 10.1007/s11104-013-1640-1

EPA Author Manuscript EPA Author Manuscript EPA Author Manuscript

Moreno CE, Fjeld E, & Lydersen E. (2016). The effects of wildfire on mercury and stable isotopes (δ 15N, δ 13C) in water and biota of small boreal, acidic lakes in southern Norway. Environmental Monitoring and Assessment, 188, 1–23. 10.1007/s10661-016-5148-z [PubMed: 26627206]

Moritz MA, Batllori E, Bradstock RA, Gill AM, Handmer J, Hessburg PF, et al. (2014). Learning to coexist with wildfire. Nature, 515, 58–66. 10.1038/nature13946 [PubMed: 25373675]

Murphy SF, McCleskey RB, Martin DA, Holloway JM, & Writer JH (2020). Wildfire-driven changes in hydrology mobilize arsenic and metals from legacy mine waste. Science of the Total Environment, 743, 140635. 10.1016/j.scitotenv.2020.140635

Murphy SF, McCleskey RB, Martin DA, Jeffrey HW, & Ebel BA (2018). Fire, flood, and drought: Extreme climate events alter flow paths and stream chemistry. Journal of Geophysical Research: Biogeosciences, 123, 2513–2526. 10.1029/2017jg004349

Murphy SF, Writer JH, McCleskey RB, & Martin DA (2015). The role of precipitation type, intensity, and spatial distribution in source water quality after wildfire. Environmental Research Letters, 10(8), 084007. 10.1088/1748-9326/10/8/084007

National Interagency Fire Center (NIFC). (2020). Burned Area Emergency Response (BAER). Retrieved from https://www.nifc.gov/BAER/index.html

Neary DG, Klopatek CC, DeBano LF, & Ffolliott PF (1999). Fire effects on belowground sustainability: A review and synthesis. Forest Ecology and Management, 122(1–2), 51–71. 10.1016/s0378-1127(99)00032-8

Nunes B, Goncalves F, Campos I, Keizer JJ, Pereira JL, Abrantes N, et al. (2017). Off-site impacts of wildfires on aquatic systems— Biomarker responses of the mosquitofish Gambusia holbrooki. Science of the Total Environment, 581–582, 305–313. 10.1016/j.scitotenv.2016.12.129

Nyman P, Smith HG, Sherwin CB, Langhans C, Patrick NJL, & Sheridan GJ (2015). Predicting sediment delivery from debris flows after wildfire. Geomorphology, 250, 173–186. 10.1016/j.geomorph.2015.08.023

Parlak AO, Parlak M, Blanco-Canqui H, Schacht WH, Guretzky JA, & Mamo M. (2015). Patch burning: Implications on water erosion and soil properties. Journal of Environmental Quality, 44, 903–909. [PubMed: 26024270]

Pennino MJ, Leibowitz SG, Compton JE, Beyene MT, & LeDuc SD (2022). Wildfires can increase regulated nitrate, arsenic, and disinfection byproduct violations and concentrations in public drinking water supplies. Science of the Total Environment, 804, 149890. 10.1016/j.scitotenv.2021.149890 [PubMed: 34520927]

Poon PK, & Kinoshita AM (2018). Spatial and temporal evapotranspiration trends after wildfire in semi-arid landscapes. Journal of Hydrology, 559, 71–83. 10.1016/j.jhydrol.2018.02.023

Proctor CR., Lee J, Yu D, Shah AD, & Whelton AJ (2020). Wildfire caused widespread drinking water distribution network contamination. AWWA Water Science, 2(4), e1183. 10.1002/aws2.1183

Ranalli AJ (2004). A Summary of the Scientific Literature on the Effects of Fire on the Concentration of Nutrients in Surface Waters. Open File Report 2004–1296. US Geological Survey.

Reale JK (2015). The effects of catastrophic wildfire on water quality along a river continuum. Freshwater Science, 34, 1426–1442. 10.1086/684001

Regan S, Hynds P, & Flynn R. (2017). An overview of dissolved organic carbon in groundwater and implications for drinking water safety. Hydrogeology Journal, 25(4), 959–967. 10.1007/s10040-017-1583-3

Rhoades CC, Chow AT, Covino TP, Fegel TS, Pierson DN, & Rhea AE (2019). The legacy of a severe wildfire on stream nitrogen and carbon in headwater catchments. Ecosystems, 22, 643–657. 10.1007/s10021-018-0293-6

Rhoades CC, Entwistle D, & Butler D. (2011). The influence of wildfire extent and severity on stream water chemistry, sediment, and temperature following the Hayman Fire, Colorado. International Journal of Wildland Fire, 20(3), 430–442. 10.1071/wf09086

Riggs CE, Kolka RK, Nater EA, Witt EL, Wickman TR, Woodruff LG, & Butcher JT (2017). Yellow perch (Perca flavescens) mercury unaffected by wildland fires in northern Minnesota. Journal of Environmental Quality, 46, 623–631. 10.2134/jeq2016.10.0418 [PubMed: 28724108]

EPA Author Manuscript EPA Author Manuscript EPA Author Manuscript

Rinne JN (1996). Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the southwestern United States. North American Journal of Fisheries Management, 16, 653–658. 10.1577/1548-8675(1996)016<0653:mbsteo>2.3.co;2

Rodrigues EL, Jacobi CM, & José Eugênio Côrtes F. (2019). Wildfires and their impact on the water supply of a large neotropical metropolis: A simulation approach. Science of the Total Environment, 651, 1261–1271. 10.1016/j.scitotenv.2018.09.289 [PubMed: 30360258]

Rosenberger AE, Dunham JB, Neuswanger JR, & Railsback SF (2015). Legacy effects of wildfire on stream thermal regimes and rainbow trout ecology: An integrated analysis of observation and individual-based models. Freshwater Science, 34(4), 1571–1584. 10.1086/683338

Rugenski AT, & Minshall GW (2014). Climate-moderated responses to wildfire by macroinvertebrates and basal food resources in montane wilderness streams. Ecosphere, 5(3), 1–24. 10.1890/es13-00236.1

Rust AJ, Hogue TS, Saxe S, & McCray J. (2018). Post-fire water quality response in the western United States. International Journal of Wildland Fire, 27, 203–216. 10.1071/wf17115

Rust AJ, Saxe S, McCray J, Rhoades CC, & Hogue TS (2019). Evaluating the factors responsible for post-fire water quality response in forests of the western USA. International Journal of Wildland Fire, 28, 769–784. 10.1071/wf18191

Ryan SE, & Dixon MK (2008). Spatial and temporal variability in stream sediment loads using examples from the Gros Ventre Range, Wyoming, USA. In Habersack H, Piégay H, & Rinaldi M. (Eds.), Gravel-bed rivers VI: From process understanding to river restoration. Elsevier. Chapter 15.

Seidl R, Schelhaas MJ, Rammer W, & Verkerk PJ (2014). Increasing forest disturbances in Europe and their impact on carbon storage. Nature Climate Change, 4, 806–810. 10.1038/nclimate2318

Shakesby R, & Doerr S. (2006). Wildfire as a hydrological and geomorphological agent. Earth-Science Reviews, 74(3–4), 269–307. 10.1016/j.earscirev.2005.10.006

Sherson LR, Van Horn DJ, Gomez-Velez JD, Crossey LJ, & Dahm CN (2015). Nutrient dynamics in an alpine headwater stream: Use of continuous water quality sensors to examine responses to wildfire and precipitation events. Hydrological Processes, 29(14), 3193–3207. 10.1002/hyp.10426

Silva V, Abrantes N, Costa R, Keizer JJ, Gonçalves F, & Pereira JL (2016). Effects of ash-loaded post-fire runoff on the freshwater clam Corbicula fluminea. Ecological Engineering, 90, 180–189. 10.1016/j.ecoleng.2016.01.043

Silva V, Pereira JL, Campos I, Keizer JJ, Gonçalves F, & Abrantes N. (2015). Toxicity assessment of aqueous extracts of ash from forest fires. Catena, 135, 401–408. 10.1016/j.catena.2014.06.021

Singleton MP, Thode AE, Sánchez Meador AJ, & Iniguez JM (2019). Increasing trends in high-severity fire in the southwestern USA from 1984 to 2015. Forest Ecology and Management, 433, 709–719. 10.1016/j.foreco.2018.11.039

Smith HG, Sheridan GJ, Lane PN, Nyman P, & Haydon S. (2011). Wildfire effects on water quality in forest catchments: A review with implications for water supply. Journal of Hydrology, 396(1–2), 170–192. 10.1016/j.jhydrol.2010.10.043

Son JH, Kim S, & Carlson KH (2015). Effects of wildfire on river water quality and riverbed sediment phosphorus. Water Air and Soil Pollution, 226, 26. 10.1007/s11270-014-2269-2

Spencer CN, Gabel KO, & Hauer FR (2003). Wildfire effects on stream food webs and nutrient dynamics in Glacier National Park, USA. Forest Ecology and Management, 178, 141–153. 10.1016/s0378-1127(03)00058-6

Spencer CN, & Hauer FR (1991). Phosphorus and nitrogen dynamics in streams during a wildfire. Journal of the North American Benthological Society, 10, 24–30. 10.2307/1467761

Stein ED, Brown JS, Hogue TS, Burke MP, & Kinoshita A. (2012). Stormwater contaminant loading following southern California wildfires. Environmental Toxicology and Chemistry, 31(11), 2625–2638. 10.1002/etc.1994 [PubMed: 22927117]

United States Environmental Protection Agency (USEPA). (2010). Comprehensive disinfectants and disinfectant byproduct rules (stage 1 and stage 2): Quick reference guide. United States Environmental Protection Agency. Retrieved 27 January 2022 from https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100C8XW.txt

EPA Author Manuscript EPA Author Manuscript EPA Author Manuscript

United States Forest Service (USFS). (2020a). Wildland fire chemicals. Retrieved from https://www.fs.fed.us/rm/fire/wfcs/index.htm

United States Geological Survey (USGS). (2020a). Emergency assessment of post-fire debris-flow hazards. Retrieved from https://landslides.usgs.gov/hazards/postfire_debrisflow/

United States Government Accountability Office (US GAO). (2021). Firefighting Foam Chemicals: DOD is Investigating PFAS and Responding to Contamination, but Should Report More. Report GAO-21–421. Retrieved from https://www.gao.gov/assets/gao-21-421.pdf

USEPA. (2019a). Wildfire Smoke: A Guide for Public Health Officials. EPA-452/R-19–901. United States Environmental Protection Agency. Retrieved from https://www.airnow.gov/sites/default/files/2019-10/wildfire-smoke-guide-revised-2019.pdf

USEPA. (2019b). Tribal Nonpoint Source Programs: Working to Solve Water Quality Problems. EPA 840-R-19–001. Retrieved from https://www.epa.gov/sites/production/files/2019-09/documents/tribalnpshighlights_aug19_final_508.pdf

USEPA. (2020a). National primary drinking regulations. Retrieved from https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

USEPA. (2020b). Secondary drinking water standards: Guidance for nuisance chemicals. Retrieved from https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals

USEPA. (2020c). National recommended water quality criteria—Aquatic life criteria table. Retrieved from https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

USEPA. (2020d). Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2016. EPA 822-R-16–006. United States Environmental Protection Agency.

USEPA. (2020e). National recommended water quality criteria—Human health criteria table. Retrieved from https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table

USEPA. (2021). Drinking water Contaminant Candidate List (CCL) and regulatory determination. Retrieved from https://www.epa.gov/ccl

USEPA. (2022). Nutrient pollution policy and data. Retrieved from https://www.epa.gov/nutrient-policy-data

USFS. (2020b). Long-Term Retardant, Wildland Firefighting. US Department of Agriculture Forest Service, Specification 5100–304d. Retrieved from https://www.fs.fed.us/rm/fire/wfcs/documents/5100-304d_LTR_Final%20Draft_010720.pdf

USFS. (2020c). Interagency wildland fire chemicals policy and guidance. Retrieved from https://www.fs.usda.gov/managing-land/fire/chemicalsUSGS. (2020b). Post-fire flooding and debris flow. Retrieved from https://ca.water.usgs.gov/wildfires/wildfires-debris-flow.html

USGS. (2020c). Predicting postfire debris flows saves lives. Retrieved from https://www.usgs.gov/news/predicting-postfire-debris-flows-saves-lives

USGS. (2020d). Mineral resources data system. Retrieved from https://mrdata.usgs.gov/mrds/map-graded.html

Valenca R, Ramnath K, Dittrich TM, Taylor RE, & Mohanty SK (2020). Microbial quality of surface water and subsurface soil after wildfire. Water Research, 175, 115672. 10.1016/j.watres.2020.115672

Verkaik I, Rieradevall M, Cooper S, Melack J, Dudley T, & Prat N. (2013). Fire as a disturbance in mediterranean climate streams. Hydrobiologia, 719, 353–382. 10.1007/s10750-013-1463-3

Wagner MJ, Bladon KD, Silins U, Williams CHS, Martens AM, Boon S, et al. (2014). Catchment-scale stream temperature response to land disturbance by wildfire governed by surface-subsurface energy exchange and atmospheric controls. Journal of Hydrology, 517, 328–338. 10.1016/j.jhydrol.2014.05.006

Wang JJ, Dahlgren RA, Ersan MS, Karanfil T, & Chow AT (2015). Wildfire altering terrestrial precursors of disinfection byproducts in forest detritus. Environmental Science & Technology, 49, 5921–5929. 10.1021/es505836m [PubMed: 25894116]

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Wells JB, Little EE, & Calfee RD (2004). Behavioral response of young Rainbow Trout (Oncorhynchus mykiss) to forest fire-retardant chemicals in the laboratory. Environmental Toxicology & Chemistry, 23, 621–625. 10.1897/02-635 [PubMed: 15285354]

Westerhoff P, & Mash H. (2002). Dissolved organic nitrogen in drinking water supplies: A review. Journal of Water Supply: Research and Technology—AQUA, 51(8), 415–448. 10.2166/aqua.2002.0038

Westerling AL (2016). Increasing western US forest wildfire activity: Sensitivity to changes in the timing of spring. Philosophical Transactions of the Royal Society B: Biological Sciences, 371(1696), 20150178. 10.1098/rstb.2015.0178

Whitney JE, Gido KB, Pilger TJ, Propst DL, & Turner TF (2015). Consecutive wildfires affect stream biota in cold-and warmwater dryland river networks. Freshwater Science, 34(4), 1510–1526. 10.1086/683391

Wilkinson SN, Wallbrink PJ, Hancock GJ, Blake WH, Shakesby RA, & Doerr SH (2009). Fallout radionuclide tracers identify a switch in sediment sources and transport-limited sediment yield following wildfire in a eucalypt forest. Geomorphology, 110(3–4), 140–151. 10.1016/j.geomorph.2009.04.001

Wisløff D-R (2018). Effects of boreal forest wildfire on levels of metal and PAH in lacustrine sediments, (Master's thesis). University of Southeast Norway.

Writer JH, Hohner A, Oropeza J, Schmidt A, Cawley K, & Rosario-Ortiz FL (2014). Water treatment implications after the high Park wildfire in Colorado. Journal American Water Works Association, 106. 10.5942/jawwa.2014.106.0055

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Key Points:

- Post-fire increases in many water quality pollutants exceeded pre-fire levels, often by multiple orders of magnitude
- Nitrate, some metals, benzene, and disinfection by-products exceeded regulatory levels in treated drinking water following some wildfires
- Little is known about pollutants from fires burning infrastructure and materials (e.g., houses, cars) within the wildland urban interface

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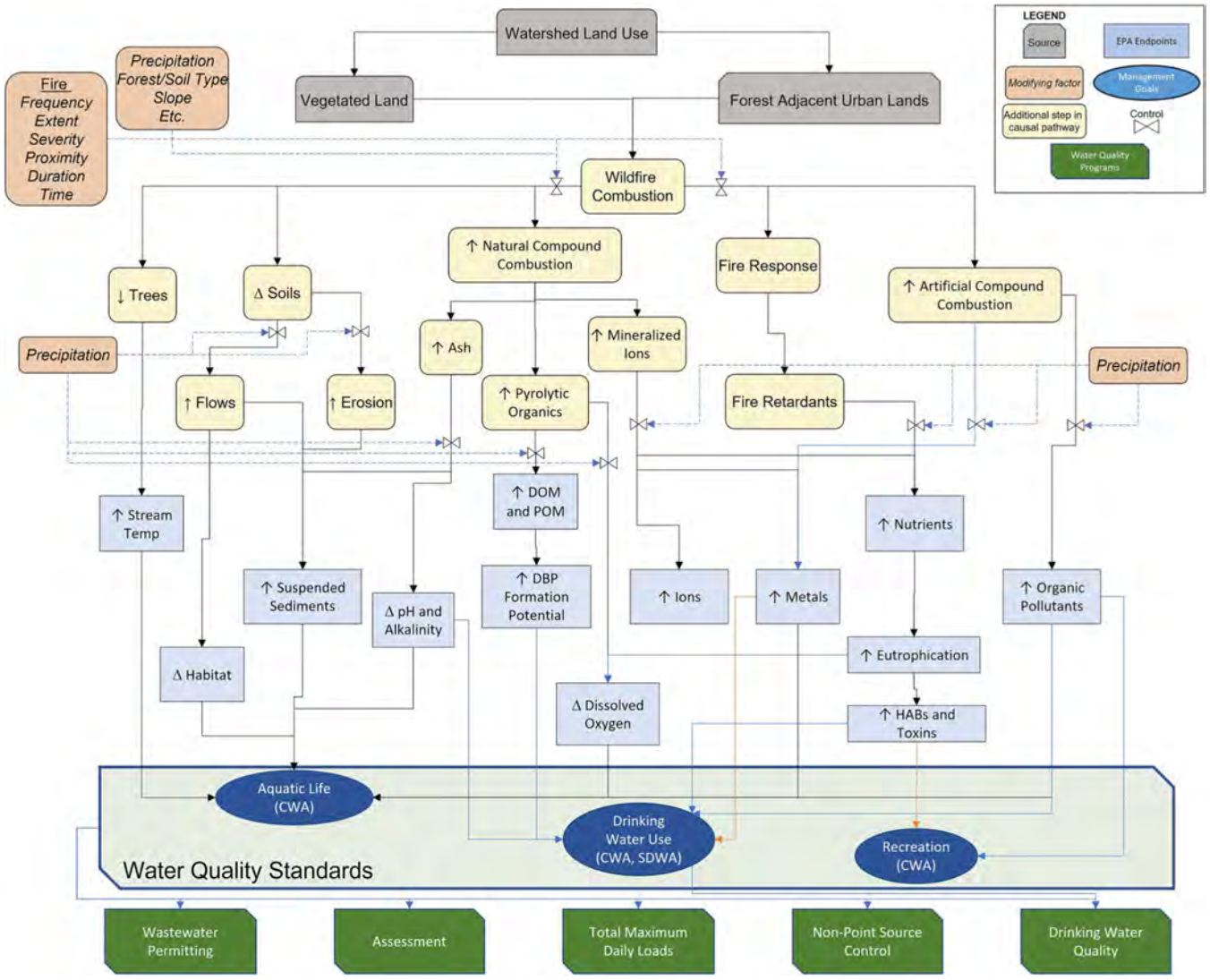


Figure 1.

Simple conceptual model of wildland fire effects on water quality endpoints, management goals and water quality programs in wildland and urbanized landscapes. Different colored arrows indicate pathways that cross but do not intersect (i.e., join) and dashed lines emphasize the regulating effect of modifying factors such as fire, climate, and landscape characteristics on pollutant export. BOD, biological oxygen demand; DOM and POM, dissolved and particulate organic matter; DBP, disinfection byproducts; HABs, harmful algal blooms; CWA, Clean Water Act; SDWA, Safe Drinking Water Act. A more detailed conceptual model is provided in Supplemental Information.

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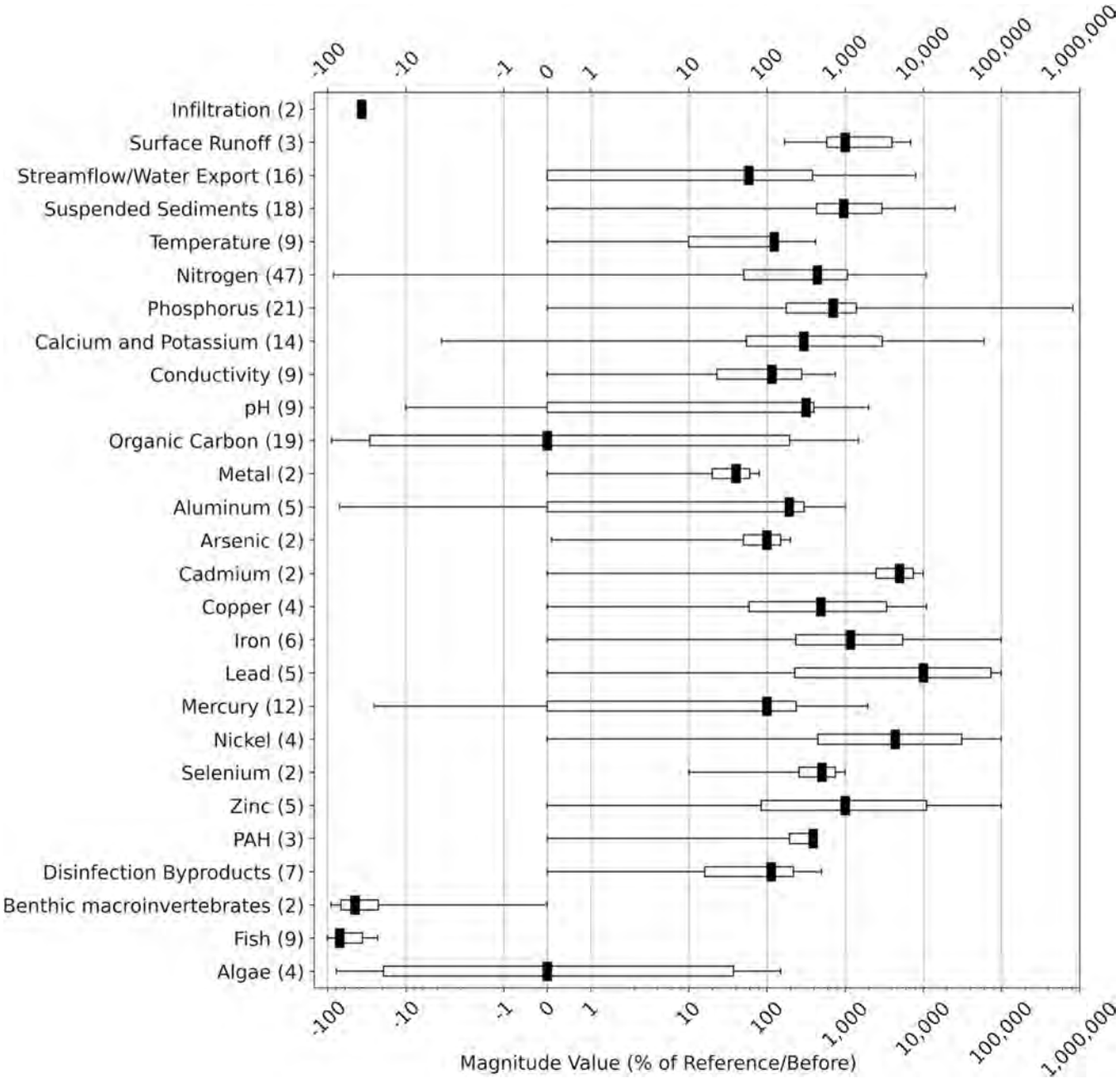


Figure 2.

Magnitude (percent change compared to reference or before fire condition) of observed water quality change after wildfire. The value in parentheses after the variable is the number of observations from the literature. Shown are minimum, maximum (whiskers), quartiles (boxes) and median (hash) values across studies. *Disinfection byproducts are the formation potential from precursors.

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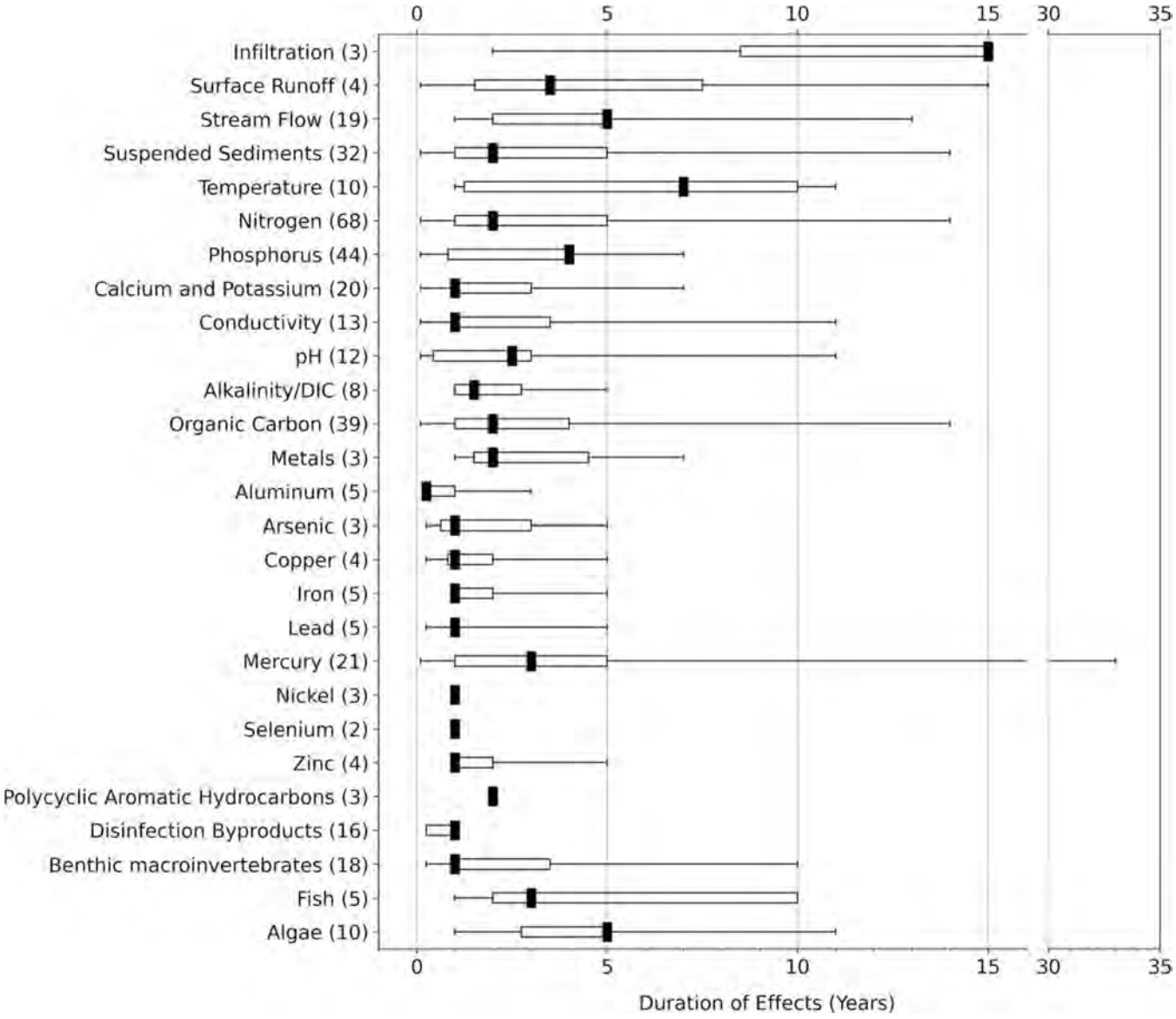


Figure 3.

Duration (years) of observed water quality responses after wildfire by endpoint as reported in studies. Figure elements as in Figure 2.

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Table 1

The Number of Studies Reporting Increases, Decreases, or No Change in Conceptual Model Endpoints After Wildfire, With Percentages Given in Parantheses

Response endpoints	Increase	Decrease	No change	Total
Physical responses				
Hydrologic characteristics	19 (66%)	3 (10%)	7 (24%)	29
Infiltration		3 (100%)		3
Surface runoff	6 (100%)			6
Streamflow/water export	11 (61%)		7 (39%)	18
Peak flows	2 (100%)			2
Suspended sediment [a]	31 (91%)	0 (0%)	3 (9%)	34
Temperature	11 (79%)	0 (0%)	3 (21%)	14
Chemical responses				
Nitrogen [a]	64 (77%)	6 (7%)	13 (16%)	83
Phosphorus	33 (65%)	14 (27%)	4 (8%)	51
Calcium and potassium	17 (77%)	4 (18%)	1 (5%)	22
Conductivity	11 (69%)	1 (6%)	4 (25%)	16
pH [b]	10 (45%)	5 (23%)	7 (32%)	22
Alkalinity/dissolved inorganic carbon	3 (33%)	5 (56%)	1 (11%)	9
Organic carbon	24 (48%)	13 (26%)	13 (26%)	50
Dissolved oxygen	2 (22%)	4 (44%)	3 (33%)	9
Disinfection byproduct formation potential [a]	4 (21%)	4 (21%)	11 (58%)	19
Metals [c]	53 (57%)	9 (10%)	31 (33%)	93
Aluminum [b]	4 (66%)	1 (17%)	1 (17%)	6
Arsenic [a]	4 (100%)	0 (0%)	0 (0%)	4
Cadmium [a]	1 (33%)	0 (0%)	2 (67%)	3
Chromium [a]	1 (100%)	0 (0%)	0 (0%)	1
Cobalt	0 (0%)	0 (0%)	2 (100%)	2
Copper [a, b]	5 (62%)	1 (13%)	2 (25%)	8
Iron [b]	5 (83%)	0 (0%)	1 (17%)	6
Lead [a]	6 (60%)	1 (10%)	3 (30%)	10
Mercury [a]	10 (40%)	6 (24%)	9 (36%)	25
Nickel	3 (60%)	0 (0%)	2 (40%)	5
Selenium [a]	2 (100%)	0 (0%)	0 (0%)	2
Vanadium	1 (50%)	0 (0%)	1 (50%)	2
Zinc [b]	4 (67%)	0 (0%)	2 (33%)	6
Polycyclic aromatic hydrocarbons [a, c]	24 (71%)	0 (0%)	10 (29%)	34
Acenaphthene	1 (100%)	0 (0%)	0 (0%)	1

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Response endpoints	Increase	Decrease	No change	Total
Acenaphthylene	1 (100%)	0 (0%)	0 (0%)	1
Anthracene	1 (100%)	0 (0%)	0 (0%)	1
Benzanthracene	0 (0%)	0 (0%)	1 (100%)	1
Benzofluoranthene	2 (100%)	0 (0%)	0 (0%)	2
Benzopyrene [a]	0 (0%)	0 (0%)	1 (100%)	1
Chrysene	1 (100%)	0 (0%)	0 (0%)	1
Dibenz-anthracene	1 (100%)	0 (0%)	0 (0%)	1
Fluoranthene	1 (100%)	0 (0%)	0 (0%)	1
Indenopyrene	1 (100%)	0 (0%)	0 (0%)	1
Naphthalene	3 (75%)	0 (0%)	1 (25%)	4
Phenanthrene	4 (100%)	0 (0%)	0 (0%)	4
Pyrene	1 (100%)	0 (0%)	0 (0%)	1
Biological responses [d]				
Macroinvertebrates	6 (20%)	17 (57%)	7 (23%)	30
Fish	2 (7%)	17 (63%)	8 (30%)	27
Algae	7 (28%)	6 (24%)	12 (48%)	25

Note. Single studies often reported on multiple endpoints, and therefore the overall number in the right-hand total column (578) is higher than the number of reviewed studies (184).

[a]Primary drinking water regulated contaminant.

[b]Secondary drinking water regulated contaminant.

[c]The category of total metals and polycyclic aromatic hydrocarbons (PAHs) are noted. Listed under each category are the directional changes for specific metals and PAHs. Some papers indicated changes in metals and PAHs generally without detailing which metal or PAH. Thus, the directional changes for individual metals and PAHs will not sum to the total for these water quality responses.

[d]Biological responses are primarily changes in diversity/richness, although a few include changes in abundance, especially for fish.

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Table 2

Maximum Literature Values Exceeding Magnitudes of U.S. EPA Drinking Water Standards or Ambient Human Health and Aquatic Life Recommended Criteria Values for Water Quality Endpoints in Wildfire Burned Watersheds

	Drinking water standards (mg/L)		Human health recommended criteria (USEPA, 2020e) (mg/L except arsenic as noted)		Aquatic life recommended criteria (USEPA, 2020c) (mg/L)		Max observed (mg/L)	
	Primary (USEPA, 2020a; 2020d)	Secondary (USEPA, 2020b)	Human health for the consumption of water + organism	Human health for the consumption of organism	Acute	Chronic		Citation
Nitrate[a]	10						14[b]; 180[c]	*d*
Aluminum		0.05–0.2					0.33	*e*
Arsenic	0.01		0.018 (μg/L)	0.14 (μ/L)			0.061	*d*
Cadmium[f]	0.005				0.0018	0.00072	0.1	*g*
Iron		0.3				1	100	*g, h*
Lead[f]	0.015				0.065	0.0025	1.0	*e, g, h*
Manganese			0.050	0.100			0.600	*h*
Nickel[f]					0.47	0.052	0.10	*g, h*
Selenium					0.0015–0.0031		0.01	*g*
Zinc[f]					0.12	0.12	1.0	*g, h*
Cyanide					0.022	0.0052	0.062	*i*
Benzene	0.005						1.25	*j*
HAA5	0.06						0.66	*d*
TTHMs	0.08						0.23	*d*

Note. Values are in mg/L unless otherwise noted, and HAA5 (5 haloacetic acids) and TTHMs (total trihalomethanes) are types of disinfection byproducts. Exceedances for drinking water standards were in source water except for nitrate, arsenic, and HAA5 and TTHMs, which were reported for finished drinking water.

[a] Concentrations for nitrate expressed in mg N/L.

[b] Surface water.

[c] Groundwater.

[d] Pennino et al. (2022).

[e] Lydersen et al. (2014).

[f] Aquatic criteria are hardness based; values shown for 100 mg/L $CaCO_3$ hardness.

[g] Burke et al. (2013).

[h] Burton et al. (2016).

[i] Gallaher and Koch (2004).

[j] Macler et al. (2020).

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Table 3

Common Water Quality Programs Potentially Affected by Wildfire, With Example Impacts Given for Each Program

Water program	Example impacts
Drinking water	• Stressors may adversely affect drinking water supplies, source water quality and treatment efficiency and costs • Drinking water infrastructure may be physically damaged
Water quality standards	• Standards programs may have increased requests for variances, allowing waterbodies to temporarily exceed criteria • Natural condition site specific criteria may need to incorporate fire effects • Aquatic life criteria setting based on reference condition may need to include wildfire effects on reference baselines
Wastewater	• Altered flows may influence low flows and reasonable potential analyses • Altered background pollutant concentrations may lead to an impact on permitting calculations • Water permitting programs may have increased requests for variances, allowing waterbodies to temporarily exceed limits • Wastewater infrastructure may be physically damaged
Assessment	• Assessment programs may see listings/delistings depending on fire impact magnitudes and durations • Exceedance frequencies may need to be adjusted for fire affected watersheds • Beach closures to swimming and to other recreation use may increase due to post-fire harmful algal blooms
TMDLs	• Reference targets for total maximum daily loads (TMDLs) using forested watersheds may need to consider fire effects • Upstream fire effects may need to be incorporated into load reduction scenarios
Non-point source control	• Increased need for watershed restoration post-fire to reduce sedimentation and other impacts

EXHIBIT V

This is a historical timeline of the Crestline-Lake Arrowhead Water Agency (Agency). The timeline encompasses the local forces driving the need for supplemental water in the San Bernardino Mountains, the legislation creating the Agency and the public perception of the Agency at that time, and bringing the Agency's history to present. The timeline will be followed by a brief look at the benefits the Agency currently provides to its customers (both wholesale and retail), as well as the mountain residents in general.

CLAWA was formed in large part due to the remarkable foresight of several local people that realized the lack of adequate ground water in a booming area. This foresight was namely due to two local Fire Chiefs, Francis Newcombe of Crestline and Bruce Horning of Running Springs, along with two Fire Commissioners, H. Fay Smith of Twin Peaks and Loyal Klopfenstein of Cedar Glen. These fears of inadequate local ground water were confirmed when an initial feasibility study confirmed that local well water supplies were deficient within the area. These men spread the word along with the managers of the local existing water companies, and in March 1962 they held a public meeting at Rim of the World High School regarding the legal and practical aspects of securing Feather River Water for the mountain community areas. At this meeting there were representatives from the Department of Water Resources, local water districts, fire departments, the County Surveyor, the U.S. Forest Service and California Division of Forestry, and the Registrar of Voters to answer questions.

The Crestline-Lake Arrowhead Water Agency (CLAWA), a governmental public agency, was created in 1962 by the California State Legislature Act 9099a of the California Water Code to provide supplemental water across the San Bernardino Mountains. CLAWA's boundaries span more than 50,000 acres and its revenues come from water sales, connection fees, standby charges and taxes. CLAWA provides both wholesale and retail treated water from

Silverwood Lake across the mountain to Green Valley. Within this area there are more than twenty water districts and camps depending on wholesale supplemental water from CLAWA, along with approximately 1,200 retail customers within lettered improvement districts, with a direct connection to CLAWA.

CLAWA is a State Water Contractor that provides water from the State Water Project (SWP) to its customers; this water is delivered from the Sacramento Bay-Delta via the California Aqueduct to Silverwood Lake and then pumped up approximately 3,000 feet to serve the San Bernardino Mountains. CLAWA treats the water at Silverwood Lake and then pumps it up the mountain through various booster stations and into several tanks for storage. Once the water is treated and pumped up the mountain, it can then be delivered to its wholesale purveyors and retail customers.

CLAWA is governed by an elected Board of Directors, which is comprised of five directorial divisions, within the Agency boundaries, for four year terms. The Board meets the first Thursday of each month, unless special meetings are necessary. A CLAWA employee is usually designated as the appointed Secretary of the Board. The General Manager is directly accountable to the Board of Directors. The Board sets CLAWA's policy, rules and regulations, and operating procedures, as well as approving the Annual Budget, Audit and Quarterly Statements, progress payments on contracts, and special adjustments of water bills.

CLAWA retains the services of an engineering firm (Albert A. Webb and Associates), legal counsel (Best, Best and Krieger), and a certified public accounting firm (Rogers, Anderson, Malody & Scott, LLP), along with other specialty consultants to help the staff comply with various regulations imposed by the California Department of Health Services, South Coast Air Quality Management District, and several other governmental agencies.

As one of the smallest State Water Contractors, CLAWA has successfully developed a state of the art water treatment plant, solid office staff, and exceedingly knowledgeable field staff, with relatively few job changes and loss of staff. This can be seen in the fact that CLAWA:

- Was one of the first to use remote/radio read water meters and computerized billing;
- Uses Granular Activated Carbon (GAC) to treat the water and remove Trihalomethanes (THMS) formed by naturally occurring organics with chlorine used for disinfection, along with other contaminants;
- Recently purchased and has put into use a state of the art Total Organic Chemicals (TOC) monitor;
- Is constantly contacted for the status of emerging data from the two above programs;

TIMELINE

1950s – Water was trucked up the mountain due to water shortages in wells, especially in the Valley of Enchantment area.

1957 – DWR releases the California Water Plan

1959 – The State legislature passed the Burns-Porter Act, authorizing $1.75 billion in bonds to construct an aqueduct from Sacramento to the Perris Reservoir in northern Riverside County.

1959 – The Feather River Project, later to be known as the State Water Project, establishes a 444-mile conveyance system to deliver State water to Southern California.

1960 – The California Water Resources Development Bond Act passed by the Legislature to finance the construction of the California Aqueduct.

In November an election was held to authorize the State Water Project and the $1.75 billion bond to build the State Water Project. The measure was approved by the State's electorate, and in the mountain areas voters approved by a count of 1,831 in favor of the project and bonds, 416 against.

1961 – A preliminary investigation of the Crestline-Lake Arrowhead Water Agency area was conducted by the Department of Water Resources and the results were published. This published report was titled: Feasibility of Serving the Crestline-Lake Arrowhead Water Agency Area from the State Water Facilities.

The Agency's boundaries originally included Lake Arrowhead. Due to a last minute change in the legislation requested by the developer of Lake Arrowhead that area was excluded from the Agency boundaries.

1962 – April – The bill authorizing creation of the Agency, upon approval by local voters, was signed by Governor Edmund "Pat" Brown. The legislation was effective 90 days later and the election was scheduled to follow 75 days after the legislation became effective. The legislation denoted one director for each division (there are five divisions).

During special session of the State legislature the Agency was set up and functioning before the December 1963 contract deadline with the Department of Water Resources.

According to the Crestline Courier Article dated 1962:

"Since existing local water agencies in the mountains are unable alone to develop an adequate water supply, and are unable legally and financially to contract with the State for imported water, it is the responsibility and function of the Crestline-Lake Arrowhead Water Agency to negotiate a contract with the State. It is essential that the contract be consummated prior to December 1963 as this is the deadline date set by the State, so that they may know the water requirements of all areas prior to construction of their facilities."

The Crestline-Lake Arrowhead Water Agency was one of the last three southern California agencies to join the State Water Project.

1963 – January 8th – A special election was conducted to activate the Crestline-Lake Arrowhead Water Agency and to authorize execution of a contract to participate in the State Water Project. This was also an election to elect the first Agency Board of Directors. The mountain voted: 917 for the activation of the Agency, and 39 against. The winning margin was 96.3%.

This election indebted all taxpayers within Agency boundaries for all financial burdens of the State Water Project in proportion to the annual allotment of water and the reach of the Project where water is withdrawn. Annually the Agency's Board of Directors sets a tax rate to be collected by the County on the tax bills. This rate is determined by the necessary indebtedness as billed by the Department of Water Resources.

The original Directors were:
Division 1 – Stanley Ziegler, 1963-1967
Division 2 – Frances D. Newcombe, 1963-1993
Division 3 – H. Fay Smith, 1963-1984
Division 4 – Loyal D. Klopfenstein, 1963-1988
Division 5 – Bruce Horning, 1963-1991

Sections 1.5 and 4 of the Agency's act (9099a), state that the representation is based on the number of registered voters and the Act specifies the boundaries of each district. Remember there are five divisions represented on the Agency's Board of Directors.

April 12th – The San Bernardino County Board of Supervisor's certified the election results for the Agency's Board of Directors.

June 22nd – The contract with the State and the Crestline-Lake Arrowhead Water Agency was signed. The contract called for the first water delivery to the Agency in 1972; however, the first delivery actually occurred in 1971.

This year also saw the condemnation of the town of Cedar Springs, which was located on the dam site. The town consisted of 45 residents, and had 24 registered voters. The town was condemned and bought out according to eminent domain, by the Department of Water Resources, to make way for the Cedar Springs Dam and Silverwood Lake.

1964 – July 16th – A letter from the Crestline-Lake Arrowhead Water Agency General Manager, Herman Diech, was published in 'The Timberline' newspaper. The letter was to local residents in the Arrowhead Woods, informing them of potential future regrets that access to supplemental water had been lost due to the decision by the Arrowhead Development Company to exclude Lake Arrowhead from the Agency's boundaries.

The letter stated the following:
"Because the governing board of the Agency does not wish to have you subsequently say, 'Why didn't we know about this?' or 'Why didn't you tell us?'"

This was seen as fair warning for the residents of the Arrowhead Woods. The response from Arrowhead Woods Property Owner's Association stated that they had not made a decision, but that they felt as follows: "However, we do not feel that it is equitable to have our district support a major portion of the cost while being represented on the Board in minor proportion; surely proportion of cost participation should be equal to proportion of Board representation!" Some residents of the Lake Arrowhead area also feared erroneously that their lake would become public if they opted to be included in the Crestline-Lake Arrowhead Water Agency boundaries.

1965 – February – Bulletin #119-19 was issued by the State of California, the Resources Agency, and the Department of Water Resources. The Bulletin was titled: The Feasibility of Serving the Crestline-Lake Arrowhead Water Agency Area from the State Water Project.

March 16th – An election was held to authorize a $7.5 million bond to acquire right of way, finance the treatment plant, the intake tower, and other supplemental water transmission infrastructure. This bond required a two-thirds majority to pass, it failed by two votes. Several newspaper articles and interviews stated that people were so sure it would pass that they didn't bother to vote in favor of the funding. The vote was: 820 for the bond, and 413 against. There was only a 30% turnout.

June 15th – A second election was held to authorize the $7.5 million bond. This time it passed by the required two-thirds majority. In fact it passed with 61 votes more than needed in favor. The return was: 1064 for the bond, and 501 against.

Some residents dissatisfied with the bond results sued to withdraw from the Agency. This was especially seen in the San Moritz area of Crestline, which has since been taken over by another water district and currently receives supplemental water from the Agency.

Also in this year, the State relocated Highway 2 to run west of the Cedar Springs Dam site. This is the current Highway 138. This was necessary as construction of the dam was scheduled to begin in 1968.

Along with the scheduled dam construction was the construction of a tunnel leading directly from Silverwood Lake, south under Job's Peak to Devils Canyon in San Bernardino (north-west of the CSUSB campus). This tunnel was scheduled to be 15 feet in diameter, and to be completed in 1966. The purpose of the tunnel was to accommodate facilities to move imported water further south.

1967 – Oroville Dam was completed, with a capacity of 3.5 million acre feet. Oroville Lake is the first storage reservoir in the State Water Project system.

Also in this year work began on the north portal of the tunnel to San Bernardino.

Prior to supplemental water being available in Silverwood Lake, the Agency negotiated an agreement with the Department of Water Resources to provide desert well water to the mountain in conjunction with the Department's drilling of the tunnel. Also by means of the State of California participation, the Agency built a Phase 1 Regulating Reservoir, water transmission mains, and valves. Additionally, the Department of Water Resources paid the interest on the early sale of the Agency's bonds, facilitating the early construction of portions of the Agency's permanent transmission system facilities. This early construction allowed for replacement of possible local water lost due to State tunnel drilling in the Crestline area, and provided early use of Agency pipelines and a storage reservoir in the Running Springs area to store local water before imported water from the State Water Project was ever available to the Agency.

1968 – Prior to water arriving to the Agency, the 2.0 million gallon Nob Hill Storage Reservoir and the 0.5 million gallon Green Valley Storage Reservoir were constructed.

November 9th – Groundbreaking ceremony held at the Cedar Springs Dam site, commencing the construction of the dam and Silverwood Lake.

1969 – February 9th – The northern portal of the tunnel flooded, causing a delay in construction, but the project did proceed on schedule.

This year also saw the construction of the Crestline-Lake Arrowhead Water Agency's high-pressure test facility for the development of special pressure-reduction equipment and high-pressure valves.

1971 – March 5th – The last load of rock was placed on the Cedar Springs Dam, an earthen dam.

June 1st – The boat ramp, for the recreation portion of Silverwood Lake, was completed.

August 29th – The Department of Water Resources accepted the completed Cedar Springs Dam.

This was also the year that the Agency's initial transmission system construction was completed, at which time the Agency began delivering water from Silverwood Lake. The Intake Tower and Bridge, as well as the Treatment Plant Complex were completed.

1972 – In this year the first State Project water was delivered over the Tehachipi's to Pearblossom. The Project was expected to reach Lake Perris in 1973 and the San Bernardino Valley Municipal Water District around August of 1972.

January 21st – The first northern water from the State Water Project was delivered into Silverwood Lake.

May 9th – Silverwood Lake is filled to operating level.

May 25th – Dedication of the Cedar Springs Dam and Silverwood Lake; following the dedication of the dam, the interim recreational facilities opened.

July 1st – Fishing season is opened for its inaugural year at Silverwood Lake.

In this year the State Water Project was more than 99% completed including: 18 reservoirs, 15 pumping plants, and 580 miles of aqueducts. Portions of the Project had been in operation since 1962.

1978 – The Crestline-Lake Arrowhead Water Agency submitted an application to the State Water Resources Control Board to appropriate local water from Houston Creek. Houston Creek is a tributary to Silverwood Lake.

1980 – November – The Panorama Fire was fought with approximately 4 million gallons of water provided by the Agency transmission lines.

1991 – The State Water Resources Control Board issued two diversion permits which allow the Agency appropriations of up to 1,302 acre feet per year from Houston Creek.

1999 – The Department of Water Resources completed construction of a new intake structure in Silverwood Lake. The Crestline-Lake Arrowhead Water Agency installed two 100 horse-power pumps in the Department of Water Resources new lake-outlet structure.

2003 – January – The Agency began installing Granular Activated Carbon (GAC) vessels, and brought them into service at its treatment plant to reduce THM (trihalomethane) levels. Trihalomethanes are disinfection by-products created by organics' reaction to chlorine used for disinfection purposes.

October 25th – The Old Fire (fought into November) was fought with approximately 20 million gallons of Agency water.

2007 – October 22nd – The Grass Valley and the Slide Fires were fought with approximately 12 million gallons of Agency water.

Benefits of the Crestline-Lake Arrowhead Water Agency

Fire Fighting

The Crestline-Lake Arrowhead Water Agency has approximately 250 fire hydrants across its boundaries. Many of the hydrants are on land otherwise inaccessible by water (USFS land, etc…). As a result of these hydrants the Agency provides the mountain communities with an added source of fire protection. As mentioned, in 1980 the Panorama Fire consumed the San Bernardino Mountains from Northpark in San Bernardino to Horseshoe Bend in Crestline. The Agency provided fire fighters with added capability to fight the fire with approximately four million gallons of water. Additionally, in 2003 the Old Fire burnt across the mountain from the Cajon Pass to Running Springs and from San Bernardino to Silverwood Lake. The Agency provided fire fighters with approximately 20 million gallons of water to fight this fire. In addition to providing water for fire fighting, which the Agency is not reimbursed for, the Agency has helped to lower homeowner's insurance premiums for mountain residents given the added fire protection allowed with State water.

Reliability

Given the mountainous terrain within the Agency, elevations vary from 3,300 feet to over 7,300 feet above sea level, requiring special high-pressure water pumping units to boost the water at four main booster stations up to as much as 1,800 feet vertically each lift. The Agency uses both natural gas engine-driven pumps and electric motor-driven pumps, which have been installed or are proposed at each main booster station for system reliability and to maximize readiness in the event of fire, earthquake or other emergency. The Agency has also installed emergency generators at all pump stations, as well as the Treatment Plant.

Lake Arrowhead[i]

During 2005, the Agency completed negotiations and executed agreements with San Bernardino Valley Municipal Water District (SBVMWD) and with the Lake Arrowhead Community Services District (LACSD) to address water shortage concerns in Lake Arrowhead while also strengthening the reliability of the Agency's supply to its own customers. A main significant element of the arrangement is that the Agency has pre-purchased 7,600 acre-feet of water from SBVMWD, which will be taken from SBVMWD's future allocations of imported water from the State Water Project.

This arrangement negotiated between the Agency, SBVMWD, and the LACSD results in significant benefits for all parties involved. It takes water which the SBVMWD currently does not need, and instead applies it for use in an area which has a water shortage crisis compounded by a regulatory decision which limits the quantity of water which the LACSD can take from Lake Arrowhead for delivery to its customers. It makes use of available capacity in the Agency's water treatment and delivery facilities, for a charge which is fair and which will produce additional revenue to help hold down the Agency's charges to its own customers and property owners. And the arrangement also makes an additional source of water available to the Agency for temporary use by the Agency in the event of a drought. It is a classic case of public agencies working together cooperatively to produce benefits for all involved. However, the arrangement has produced only a temporary solution to the water supply issues confronting the Lake Arrowhead area. The LACSD has now requested permission to discuss possible arrangements with the Agency to address water supply issues in Lake Arrowhead on a long-term basis. The Agency's Board of Directors has authorized staff to engage in those discussions provided that such arrangements result in financial and/or water supply benefits to the Agency's

existing customers and property owners, and do not adversely affect existing customers or property owners in any way.

Snow Valley Annexation

The Agency has also completed proceedings to annex the Snow Valley Ski Resort area into the Agency. The annexation will allow the ski resort to take Agency water for snow-making purposes during the ski season, provided the Agency has water in excess of the demands of other Agency customers. The ski resort may use the water only to make snow, not for domestic consumption, and the agreement provides that the Agency may deny water service to the ski resort whenever that water is needed to satisfy service demands elsewhere, save Lake Arrowhead. This annexation originated when Snow Valley contacted the Agency in 1988 regarding obtaining water from the Agency for snowmaking purposes. The inquiry was renewed in 1996, and the annexation and environmental impact report have been completed; however, no infrastructure has been completed to date.

Upon completion this agreement would be beneficial not only to the Agency, but to the mountain communities. The agreement would allow the Agency to use system capacity in the winter when demand is low (October through April) and produce additional revenue. The agreement would benefit the mountain because the capacity for snowmaking at the resort would increase, and potentially the ski season could increase in length; allowing for greater revenue in the community.

Bibliography

Crestline-Lake Arrowhead Water Agency documents:

- Fact Sheet
- Scrap Book
- Water Quality Report

Hanson, Fred H. Vice President, A.A. Webb & Associates. Interview May 31, 2007. Agency Engineer

Holmes, Roxanne M. Crestline-Lake Arrowhead Water Agency. Interviews May 2, 16, 30 and June 4, 2007. Agency General Manager.

Newell, Thomas C. Crestline-Lake Arrowhead Water Agency. Interviews May 21 and June 1, 2007. Assistant General Manager.

[i] This information is taken directly from the Agency's 2005 Water Quality Report and was reproduced in its entirety (as applicable) with authorization from the General Manager of the Agency.

EXHIBIT W

SAN BERNARDINO COUNTY | COUNTYWIDE PLAN

COUNTY POLICY PLAN
September 2022

HARD COPY VERSION. The following is a hard copy version that represents the legal general plan as recorded by the County Clerk of the Board. A web-based version of the Policy Plan, including maps, is provided at www.countwideplan.com for easier use, reference, and navigation.

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Table of Contents

Adoption & Amendment History iv

Land Use Element 1

Purpose 1
Principles 1
Goals & Policies 2
Goal LU-1 Fiscally Sustainable Growth 2
Goal LU-2 Land Use Mix and Compatibility 3
Goal LU-3 Annexations and Sphere Development 4
Goal LU-4 Community Design 5
Goal LU-5 Military Mission 6
Goal LU-6 Amendments to the Policy Plan 7
Tables 8
Table LU-1. Land Use Categories 9
Table LU-2. Land Use Category/Zoning Equivalency Matrix 11
Table LU-3. Community Character 12

Housing Element 13

Purpose 13
Principles 13
Goals & Policies 14
Goal H-1 Housing Production and Supply 14
Goal H-2 Development Regulations 15
Goal H-3 Housing and Neighborhood Quality 15
Goal H-4 Affordable Housing Assistance 16
Goal H-5 Equal housing opportunities 16

Infrastructure & Utilities Element 19

Purpose 19
Principles 19
Goals & Policies 20
Goal IU-1 Water Supply 20
Goal IU-2 Wastewater Treatment and Disposal 21
Goal IU-3 Stormwater Drainage 21
Goal IU-4 Solid Waste 22
Goal IU-5 Power and Communications 22

Transportation & Mobility Element 23

Purpose 23
Principles 23
Goals & Policies 24
Goal TM-1 Roadway Capacity 24
Goal TM-2 Road Design Standards 25
Goal TM-3 Vehicle Miles Traveled 25
Goal TM-4 Complete Streets, Transit, and Active Transportation 26
Goal TM-5 Goods Movement 27
Goal TM-6 Airports 28
Table 29
Table TM-1. County Roadway Designations 29

Natural Resources Element 31

Purpose 31
Principles 32
Goals & Policies 32
Goal NR-1 Air Quality 32
Goal NR-2 Water Quality 33
Goal NR-3 Open Space, Parks, and Recreation 34
Goal NR-4 Scenic Resources 35
Goal NR-5 Biological Resources 35
Goal NR-6 Mineral Resources 36
Goal NR-7 Agriculture and Soils 37

Renewable Energy and Conservation Element 39

(Placeholder for element adopted in 2017 and amended in February 2019)

Cultural Resources Element 41

Purpose 41
Principles 41
Goals & Policies 41
Goal CR-1 Tribal Cultural Resources 41
Goal CR-2 Historic and Paleontological Resources 42

Hazards Element 43

Purpose 43
Principles 43
Goals & Policies 44
Goal HZ-1 Natural Environmental Hazards 44
Goal HZ-2 Human-generated Hazards 46

Goal HZ-3 Environmental Justice 47
Tables 50
Table HZ-1. CalEnviroScreen Scores for Environmental Justice Focus Areas 50
Table HZ-2. EJ Assessment in the El Mirage Valley 52
Table HZ-3. EJ Assessment in the North High Desert 54
Table HZ-4. EJ Assessment in Bloomington and Muscoy 56
Table HZ-5. EJ Assessment in Valley Unincorporated Islands 58
Table HZ-6. Objectives for Unincorporated Environmental Justice Focus Areas 61
Personal & Property Protection Element 63
Purpose 63
Principles 64
Goal PP-1 Law Enforcement 64
Goal PP-2 Law & Justice 65
Goal PP-3 Fire and Emergency Medical 66
Goal PP-4 Emergency Preparedness and Recovery 67
Economic Development Element 69
Purpose 69
Principles 69
Goals & Policies 70
Goal ED-1 Unincorporated Land and Facilities 70
Goal ED-2 Labor Force 70
Goal ED-3 Countywide Business and Employment Growth 71
Health & Wellness Element 73
Purpose 73
Principles 73
Goals & Policies 74
Goal HW-1 Health and Social Wellness 74
Goal HW-2 Education 75
Goal HW-3 Community Development 76
Glossary of Terms 79

Adoption & Amendment History

Date	Resolution	Update / Amendment
October 27, 2020	Resolution No. 2020-197	Policy Plan, comprehensive update
September 27, 2022	Resolution No. 2022-185	Housing Element, comprehensive update
September 27, 2022	Resolution No. 2022-186	Hazards Element, technical update

Built Environment Section

Land Use Element

How we accommodate development and arrange land use is critical to achieving the Countywide Vision. While the county may appear to have a limitless supply of land, the County only has land use authority over approximately 12 percent of unincorporated lands (the balance is primarily under federal control). As the regional service provider and municipal government, the County must plan for uses and development that adds value to its communities and the overall county, in terms of function, design, and fiscal return.

The County can best serve our communities, businesses, institutions, and visitors by focusing new development in and around cities, towns, and communities with access to infrastructure and services, while preserving natural open spaces that define San Bernardino County and our way of life.

Purpose

The Land Use Element:

- Designates the distribution, location, intensity, and balance of land uses for the unincorporated areas of the county.
- Establishes goals for where, when, and how the county grows, which is also guided by policies in other elements.
- Provides direction for new development on community design, land use compatibility, and interagency coordination.
- Provides guidance for orderly expansion of incorporated areas.

Principles

We believe:

- The way land is used and developed will determine our revenue base and costs.
- Development that supports our Countywide Vision will strengthen the county's economy and quality of life.
- When growth occurs, it should do so in a manner that is fiscally sustainable and context-sensitive.
- New development should be focused in areas where there is potable water, wastewater treatment, roadways, and public services.

- New development should be focused in areas with low risks from natural and man-made hazards, and with fewer impacts on the natural environment.
- Rural and suburban patterns of development in unincorporated areas of the county complement the urban and suburban options found in incorporated cities and towns.
- Supporting our military institutions is critical to the mission of national defense and the military plays an integral role in the county's economic success.
- Collaboration with local, state, tribal, and federal agencies is essential to effectively manage land and land use in San Bernardino County.

Goals & Policies

Goal LU-1 Fiscally Sustainable Growth

Growth and development that builds thriving communities, contributes to our Complete County, and is fiscally sustainable.

Policy LU-1.1 **Growth.** We support growth and development that is fiscally sustainable for the County. We accommodate growth in the unincorporated county when it benefits existing communities, provides a regional housing option for rural lifestyles, or supports the regional economy.

Policy LU-1.2 **Infill development.** We prefer new development to take place on existing vacant and underutilized lots where public services and infrastructure are available.

Policy LU-1.3 **Fiscal sustainability.** When determining fiscal impacts, we consider initial capital investments, long-term operations and maintenance, desired levels of service for public facilities and services, capital reserves for replacement, and impacts to existing uses in incorporated and unincorporated areas.

Policy LU-1.4 **Funding and financing mechanisms.** We require the establishment of community facility districts, lighting and landscaping maintenance districts, and other types of funding and financing mechanisms for new development when the County determines that it may be necessary to maintain fiscal sustainability. We prefer the expansion of existing districts to the establishment of new districts.

Policy LU-1.5 **Development impact fees.** We require payment of development impact fees to ensure that all new development pays its fair share of public infrastructure.

Policy LU-1.6 **Tax sharing.** We may utilize tax sharing as a tool to extend public facilities and services from adjacent municipalities into unincorporated areas as an alternative to the County's direct provision of public facilities and services when it is fiscally sustainable for the County.

Goal LU-2 Land Use Mix and Compatibility

An arrangement of land uses that balances the lifestyle of existing residents, the needs of future generations, opportunities for commercial and industrial development, and the value of the natural environment.

Policy LU-2.1 **Compatibility with existing uses.** We require that new development is located, scaled, buffered, and designed to minimize negative impacts on existing conforming uses and adjacent neighborhoods. We also require that new residential developments are located, scaled, buffered, and designed so as to not hinder the viability and continuity of existing conforming nonresidential development.

Policy LU-2.2 **Compatibility with planned uses.** We require that new residential development is located, scaled, buffered, and designed to minimize negative impacts both on and from adjacent areas designated for nonresidential land uses.

Policy LU-2.3 **Compatibility with natural environment.** We require that new development is located, scaled, buffered, and designed for compatibility with the surrounding natural environment and biodiversity.

Policy LU-2.4 **Land Use Map consistency.** We consider proposed development that is consistent with the Land Use Map (i.e., it does not require a change in Land Use Category), to be generally compatible and consistent with surrounding land uses and a community's identity. Additional site, building, and landscape design treatment, per other policies in the Policy Plan and development standards in the Development Code, may be required to maximize compatibility with surrounding land uses and community identity.

Policy LU-2.5 **Hillside preservation.** We require that new development in sloping hillside areas preserve the natural character of the surrounding environment and does not further exacerbate natural hazards or erosion.

Policy LU-2.6 **Coordination with adjacent entities.** We require that new and amended development projects notify and coordinate with adjacent local, state, and federal entities to maximize land use compatibility, inform future planning and implementation, and realize mutually beneficial outcomes.

Policy LU-2.7 **Countywide jobs-housing balance.** We prioritize growth that furthers a countywide balance of jobs and housing to reduce vehicle miles traveled, increase job opportunities and household income, and improve quality of life. We also strive for growth that furthers a balance of jobs and housing in the North Desert region and the Valley region.

Policy LU-2.8 **Rural lifestyle in the Mountain/Desert regions.** We intend that new residential development in the unincorporated Mountain and Desert regions offer a lower intensity lifestyle that complements the suburban and urban densities in incorporated cities and towns to provide a range of lifestyle options. Master planned communities in unincorporated Mountain/Desert regions may provide a broader range of lifestyles and densities.

Policy LU-2.9 **Suburban lifestyles in the Valley region.** We intend that new residential development in the unincorporated Valley region offer a suburban lifestyle that is similar to that of adjacent cities.

Policy LU-2.10 **Unincorporated commercial development.** We intend that new commercial development in the unincorporated areas serve unincorporated residential areas, tourists, and/or freeway travelers. We encourage new commercial development to be concentrated to enhance pedestrian circulation and reduce vehicular congestion and vehicle miles traveled, with new development directed into existing centralized areas when possible.

Policy LU-2.11 **Office and industrial development in the Mountain/Desert regions.** We allow new office and industrial uses in unincorporated Mountain/Desert regions in order to meet the service, employment, and support needs of the unincorporated areas.

Policy LU-2.12 **Office and industrial development in the Valley region.** We encourage office and industrial uses in the unincorporated Valley region in order to promote a countywide jobs-housing balance.

Policy LU-2.13 **Short-term private home rentals.** We enforce appropriate operation standards, maintenance standards, and permitting procedures for the establishment and maintenance of short-term private home rentals in the unincorporated areas.

Policy LU-2.14 **Contiguous land administration.** We support the consolidation of disconnected land areas under public ownership or administration to increase financial and environmental value, streamline the management of land and resources, and establish more complete and effective transition areas or buffers. Such consolidation may include transfer of title of property among public entities and the purchase or swapping of private property voluntarily sold when the consolidation is fiscally neutral or beneficial to the County.

Goal LU-3 Annexations and Sphere Development

Annexations and development in spheres of influence that improve the provision of public services to incorporated and unincorporated residents and businesses.

Policy LU-3.1 **Annexation of unincorporated areas.** We support the annexation of unincorporated areas when it will result in a more effective and efficient provision of public services and a net fiscal benefit to the County.

Policy LU-3.2 **Annexations with planned incompatible land uses.** We oppose annexations when future planned land uses for the proposed annexation area would be incompatible with the remaining adjacent unincorporated lands.

Policy LU-3.3 **City/town standards in SOIs.** Upon negotiation with individual jurisdictions, we may require new development in unincorporated municipal sphere of influence areas to apply the improvement standards for roads and sidewalks of the incorporated jurisdiction.

Policy LU-3.4 **Development project annexations.** When a property owner proposes annexation to facilitate new development adjacent to an unincorporated residential area, we prefer that the annexation includes the adjacent residential area.

Goal LU-4 Community Design

Preservation and enhancement of unique community identities and their relationship with the natural environment.

Policy LU-4.1 **Context-sensitive design in the Mountain/Desert regions.** We require new development to employ site and building design techniques and use building materials that reflect the natural mountain or desert environment and preserve scenic resources.

Policy LU-4.2 **Fire-adapted communities.** We require new development in high or very high fire hazard severity zones to apply fire-resistant design techniques, including fuel modification areas, fire resistant landscaping, and fire-resistant building materials.

Policy LU-4.3 **Native or drought-tolerant landscaping.** We require new development, when outside of high and very high fire hazard severity zones, to install and maintain drought-tolerant landscaping and encourage the use of native species.

Policy LU-4.4 **Natural topography in the Mountain region.** We require new development in the Mountain region to retain natural topography and minimize grading unless it is necessary to reduce exposure to natural hazards.

Policy LU-4.5 **Community identity.** We require that new development be consistent with and reinforce the physical and historical character and identity of our unincorporated communities, as described in Table LU-3 and in the values section of Community Action Guides. In addition, we consider the aspirations section of Community Action Guides in our review of new development.

Policy LU-4.6 **Adaptive reuse.** We encourage the rehabilitation, adaptive reuse, and revitalization of existing structures to preserve and celebrate the unique sense of place, identity, and history of our communities.

Policy LU-4.7 **Dark skies.** We minimize light pollution and glare to preserve views of the night sky, particularly in the Mountain and Desert regions where dark skies are fundamentally connected to community identities and local economies. We also promote the preservation of dark skies to assist the military in testing, training, and operations.

Policy LU-4.8 **Public gathering spaces.** We require the development of safe and attractive public gathering spaces that facilitate social interaction, community events, and physical activity in master planned communities, large residential developments, and large commercial developments.

Policy LU-4.9 **CPTED.** We require public gathering spaces to use CPTED (crime prevention through environmental design) principles and ensure sufficient access for public safety services.

Policy LU-4.10 **Entry monumentation, signage, and public art.** We encourage the installation of durable signage, entry monumentation, and/or works of public art in commercial areas of unincorporated Community Planning Areas as a means of reinforcing a community's character, culture, heritage, or other unique features.

Policy LU-4.11 **Businesses in Joshua Tree.** We prohibit the establishment of franchise businesses in the commercial focus area/franchise-restricted in Joshua Tree to preserve the unique community character and its value as a year-round, world renowned tourist destination.

Goal LU-5 Military Mission

The federal government maintains and invests in military facilities and operations in the county to further the mission of national defense, thereby generating employment opportunities for residents and commercial opportunities for businesses in the county.

Policy LU-5.1 **Military land use compatibility.** We coordinate with military stakeholders to ensure compatible land uses in areas where military operations on or off installations could affect public health and safety, or where civilian activities could have an impact on current or future military operations. We will coordinate with military stakeholders to resolve existing land use conflicts and protect public safety in the Military Influence Overlay.

Policy LU-5.2 **Military Influence Overlay.** We require conditional use permits for projects within the Military Influence Overlay that could penetrate the defined floor elevation of the military airspace, or that could encroach upon military operations. We consider how development of roads and infrastructure within the Military Influence Overlay will promote growth that might lead to incompatible land use.

Policy LU-5.3 **Open space for military activity and buffering.** We engage with military installations to preserve open space areas to facilitate military training and operations and to buffer civilian areas from military activity.

Policy LU-5.4 **Ranged activities and projects.** We require activities and projects that can exert impacts beyond project boundaries, such as renewable energy facilities, wireless communication systems, and unmanned aircraft systems, to coordinate with military installations in preliminary planning and throughout the project's construction stages and long-term operation.

Policy LU-5.5 **Transportation and infrastructure.** We consider military needs for operations and training when planning and improving local and regional transportation and infrastructure systems.

Policy LU-5.6 **Military partnerships.** We maintain effective partnerships among military and community stakeholders and pursue joint projects that provide long-term mutual benefits for the military, County, and general public.

Policy LU-5.7 **Economic development opportunities with the military.** We leverage our relationship and increased coordination with the military to expand employment and commercial opportunities with military agencies.

Goal LU-6 Amendments to the Policy Plan

Growth and development in the unincorporated county in a manner that requires few and infrequent amendments to the Policy Plan.

Policy LU-6.1 **Residential amendments that increase density in the Desert and Mountain regions.** We discourage policy plan amendments that would permit new development on lots smaller than 2.5 acres in the Desert regions and lots smaller than one-half acre in the Mountain region. We approve general plan amendments that would increase residential density only if:

- The proposed change is determined to be compatible in accordance with policies LU-2.1, 2.2, 2.3, and 4.5.
- Adequate infrastructure and services are available concurrently.
- The increase in density would not degrade existing levels of service for fire protection, sheriff, water, or wastewater service in the area.

Policy LU-6.2 **Large residential development in the Desert and Mountain regions.** We require a specific plan or Planned Development process for proposed residential development in the:

- North or East Desert regions: when the proposed development would include one or more lots that is 2.5 acres or smaller and the overall development would cover 40 or more acres.
- Mountain region: when the proposed development would include one or more lots that is 1 acre or smaller and the overall development would cover 40 or more acres.

Policy LU-6.3 **Commercial amendments.** We will only approve Land Use Plan amendments that would introduce new commercial areas in the context of a comprehensive Land Use Plan amendment. We may waive this requirement when the proposed amended area abuts an existing or designated commercial area and the amount of land available for new commercial uses falls below 15 percent of the total commercially-designated land in the area.

Policy LU-6.4 **Industrial amendments near schools and parks.** We approve Land Use Plan amendments for new industrial development only if they are at least one-half mile from an existing or planned public primary or secondary school or public park. We may waive this requirement for obsolete school or park sites or for industrial amendments submitted through a specific plan.

Tables

Land Use Categories and Zoning

The County plans and regulates land uses using a two-map system for the unincorporated land in San Bernardino County. In the Policy Plan, a set of broad Land Use Categories provide long-term guidance and direction for the overall distribution, intensity, and compatibility of development in the unincorporated county areas.

The Policy Plan provides the basis for and is implemented by the County's Development Code, which includes a set of Land Use Zoning Districts that establishes detailed land use districts, intensities, requirements, and standards. The Land Use Zoning Districts must be consistent with the Land Use Categories.

While unincorporated areas administered and/or controlled by federal, tribal, and state governments are generally outside of the County's land use authority, the two-map system is applied to these areas to convey the long-term land use plans of said entities and provide complete coverage of the unincorporated lands. The Land Use Categories and Zoning Districts would also directly govern land use if the federal, tribal, or state governments relinquished control over any of these lands in the future.

Table LU-1 summarizes the Policy Plan Land Use Categories, including the permitted density/intensity range, the primary purpose of each category, and a list of typical permitted uses. Table LU-2 depicts the implementing Land Use Zoning Districts for each Land Use Category.

Community Character

The county contains dozens of unincorporated communities, each presenting their own unique history, setting, and way of life. These places will continue to attract those seeking to live, work, or benefit from the amenities and/or quality of life found only in unincorporated community planning areas. In the evaluation of proposed development, the County will use standards and guidance in the Development Code and goals and policies from the Policy Plan to determine whether a proposed development would positively reinforce or negatively affect the desired community character and identity of an unincorporated community. Although the goals and policies throughout the entire Policy Plan may apply, those contained in the Land Use Element will commonly be the initial reference points.

In particular, Policy LU-4.5 directs the County to ensure that new development is consistent with the physical and historical character and identity of an unincorporated community planning area. This policy also directs the County to ensure consistency with the values and aspirations as defined by each community in their Community Action Guides. To further assist the County in determining the consistency of new development with a community's character, Table LU-3 identifies key characteristics and features that new development should reinforce and/or not detract from in order to maintain and protect the identity and character of the community planning areas.

Table LU-1. Land Use Categories

Land Use Category		Density / Intensity Range	Primary Purpose	Description of Typical Uses [2, 3]
RESIDENTIAL LAND USES				
RL	**Rural Living**	1 unit per 2.5 acres max	▪ Allow for rural residential development set in expansive areas of open space that reinforce the rural lifestyle while preserving the county's natural areas ▪ Minimize development footprint and maximize undeveloped areas ▪ Allow for cluster-type development to provide and preserve open space	▪ Rural residential ▪ Small-scale, non-water-intensive, and incidental agricultural (commercial-scale agriculture permitted in Oak Glen and Mentone community planning areas) ▪ Public and quasi-public facilities such as parks, religious facilities, schools, sheriff's stations, and fire stations
VLDR	**Very Low Density Residential**	2 units per acre max	▪ Allow for very low density residential uses when developed as single family neighborhoods that can share common infrastructure, public facilities, and services	▪ Single-family residential uses ▪ Incidental agriculture ▪ Public and quasi-public facilities such as parks, religious facilities, schools, sheriff's stations, and fire stations
LDR	**Low Density Residential**	2 to 5 units per acre [1]	▪ Promote conventional suburban residential neighborhoods that support and are served by common infrastructure, public facilities, and services	▪ Single-family residential uses ▪ Public and quasi-public facilities such as parks, religious facilities, schools, sheriff's stations, and fire stations
MDR	**Medium Density Residential**	5 to 20 units per acre [1]	▪ Provide areas for a wide range of densities and housing types ▪ Promote efficient location of higher density residential development and neighborhoods in relation to infrastructure and transit systems, as well as employment opportunities, retail and service businesses, and community services and facilities	▪ Single-family and multiple residential uses (or any mix thereof) ▪ Public and quasi-public facilities such as parks, religious facilities, schools, sheriff's stations, and fire stations
EMPLOYMENT GENERATING LAND USES				
C	**Commercial**	0.75 FAR max 5 units per acre max	▪ Provide suitable locations for retail, office, and service commercial businesses that serve the needs of local residents, regional markets, and visitors/tourists ▪ Provide employment opportunities for residents in the surrounding area ▪ Allow for a mix of commercial and lower density residential uses in rural areas (when residential is permitted in the underlying zoning district)	▪ Retail stores and personal services ▪ Office and professional services ▪ Lodging, recreation, and entertainment ▪ Heavy commercial with adequate buffering for surrounding residential uses ▪ In rural areas: agriculture and lower density residential
LI	**Limited Industrial**	0.50 FAR max	▪ Provide suitable locations for light or limited industrial activities where operations are totally enclosed in a structure and limited exterior storage is fully screened from public view ▪ Provide suitable locations for employee-intensive uses, such as research and development, technology centers, corporate offices, clean industry, and supporting retail uses ▪ Provide employment opportunities for residents in the surrounding area	▪ Light industrial and manufacturing ▪ Wholesale, warehouse, and distribution ▪ Transportation services ▪ Agricultural support services ▪ Neighborhood-scale and community-scale energy facilities (see note 3 on limitations)
GI	**General Industrial**	0.75 FAR max	▪ Provide suitable locations for general or heavy industrial activities where all or part of operations take place outside of enclosed structures, exterior storage is not fully screened from public view, or involve large equipment ▪ Provide areas for industrial activity that generates substantial odors, noise, vibration, or truck traffic ▪ Provide employment opportunities for residents in the surrounding area	▪ General or heavy industrial, manufacturing, and processing ▪ Recycling and salvage operations ▪ Wholesale, warehouse, and distribution, including rail facilities ▪ Mineral extraction and associated processing ▪ Transportation services ▪ Agricultural support services ▪ Neighborhood-, community-, and utility-scale energy facilities (see note 3 on limitations)

Table LU-1. Land Use Categories

Land Use Category		Density / Intensity Range	Primary Purpose	Description of Typical Uses [2, 3]
PUBLIC AND SPECIAL LAND USES				
PF	**Public Facility**	n/a	▪ Provides areas for public and quasi-public uses and facilities to meet current and future needs ▪ Protect and ensure the continued operation of public facilities and systems during times of flooding, fire, or other hazardous events ▪ Prevent the loss of life or property caused by flooding by preserving areas and capacity to carry/discharge flood flow ▪ Protect floodways from encroachment by land uses that could be endangered during times of flooding; prohibit occupancy or encroachment of any improvement that would unduly affect the capacity of floodways	▪ Civic and educational buildings and facilities ▪ Utility systems, facilities, and corridors ▪ Neighborhood, community, and utility-scale energy facilities (see note 3 on limitations) ▪ Channels, drainage areas, and other floodways ▪ Transportation corridors and facilities ▪ Cemeteries and landfills ▪ Commercial agriculture/grazing
RLM	**Resource/Land Management**	1 unit per 40 acres max	▪ Manage, preserve, and protect natural resources such as agricultural/grazing lands, watersheds, minerals, and wildlife habitat areas, as well as open space areas not otherwise protected or preserved ▪ Provide areas for military operations and training while minimizing impacts on and from surrounding civilian uses ▪ Allow for limited rural development while minimizing the expansion of development outside of existing communities	▪ Natural resource conservation, such as watersheds, habitat areas and corridors, wilderness study areas, areas of critical environmental concern, and national conservation lands ▪ Mineral resource extraction and processing, commercial agriculture and grazing ▪ Military facilities, operations, and training areas ▪ Recreation areas ▪ Renewable energy facilities consistent with the Renewable Energy and Conservation Element (see note 3 on limitations) ▪ Single family homes on very large parcels ▪ Limited and low density commercial development ▪ Lands under the control of the state or federal government or tribal entities
OS	**Open Space**	n/a	▪ Provide and preserve publicly-owned land for parks and open space ▪ Manage, preserve, and protect natural areas, habitats, and wildlife corridors	▪ Local, regional, and state parks and recreation areas ▪ National forests, monuments, parks, preserves, and wilderness areas ▪ Locally conserved lands for the purposes of resource management, mitigation, land banking, or similar purpose ▪ Public facilities in an open space setting ▪ Privately-owned land treated as RLM designated lands, unless otherwise restricted by government regulations ▪ Mineral extraction, timbering, or similar activities as permitted by federal or state regulations ▪ Commercial-scale agriculture in the Oak Glen and Mentone community planning areas and in the Crafton Hills
SD	**Special Development**	With a Specific Plan: 30 units per acre max 2.0 FAR max Without a Specific Plan: 4 units per acre max 0.25 FAR max	▪ Allow for a combination of residential, commercial, and/or manufacturing activities that maximizes the utilization of natural and human-generated resources ▪ Identify areas suitable for large-scale, master planned developments ▪ Promote cluster-type development to provide and preserve open space ▪ Allow for a mix of residential, commercial, and public/quasi-public uses in rural areas ▪ Facilitate joint planning efforts among adjacent land owners and jurisdictions	▪ Specific plans and master planned development ▪ Mixed use development in rural areas

1. For a parcel designated LDR or MDR, property owners can build one residential unit on an existing lot even if the resulting density would be below the minimum density. Additionally, if a parcel is adjacent to a lower density Land Use Category and is not required to connect to sewer, property owners can subdivide/develop below the minimum density.
2. The list of typical uses is not exhaustive and is intended to further clarify the purpose of each land use category. The exact uses permitted in each land use category is subject to the regulations of the underlying Zoning District as described in the Development Code.
3. The list of typical uses is also subject to and limited by policies in every element of the County Policy Plan. Policy 4.10 of the Renewable Energy and Conservation Element, for example, prohibits utility-oriented renewable energy projects in the Rural Living land use category and any land use category within the boundaries of multiple community planning areas.

Table LU-2. Land Use Category/Zoning Equivalency Matrix

Land Use Category		Implementing Zoning Districts	
Rural Living	RL	RL RL-5 RL-10 RL-20 RL-40	Rural Living
Very Low Density Residential	VLDR	RS-1 RS-20M	Single Residential
Low Density Residential	LDR	RS-14M RS-10M RS	Single Residential
Medium Density Residential	MDR	RM	Multiple Residential
Commercial	C	CG CH CN CO CR CS	General Commercial Highway Commercial Neighborhood Commercial Office Commercial Rural Commercial Service Commercial
Limited Industrial	LI	IC CS	Community Industrial Service Commercial
General Industrial	GI	IR	Regional Industrial
Special Development	SD	SD SP	Special Development [1] Specific Plan [1]
Public Facility	PF	FW IN	Floodway Institutional
Resource/Land Management	RLM	AG RC	Agriculture Resource Conservation
Open Space	OS	OS RC	Open Space Resource Conservation

Note:

1. Although the Special Development (SD) and Specific Plan (SP) Land Use Zoning Districts are generally intended to implement the SD Land Use Category, the SD and SP Land Use Zoning Districts can act as an implementing district for any Land Use Category.

Table LU-3. Community Character

Community Category	Key Characteristics and Features
Valley Communities Bloomington, Mentone, Muscoy, San Antonio Heights	▪ A suburban lifestyle characterized by a mix of lot sizes and/or land uses in proximity to urban services and facilities. ▪ Views of canyons and hills within the community planning area (Mentone and San Antonio Heights). ▪ Economic activity that benefits local residents and/or serves the local economy.
Mountain Communities Angelus Oaks, Bear Valley [1], Crest Forest [2], Hilltop [3], Lake Arrowhead [4], Lytle Creek, Mt Baldy, Oak Glen, Wrightwood	▪ A rural lifestyle characterized by low density neighborhoods oriented around commercial or recreational nodes, and the prevalence of the forest and mountain landscapes and natural resources. ▪ Abundant views of open spaces, natural features, and dark skies. ▪ Scenic, natural, and recreational features that serve as the foundation of the community's local economy and attract tourists. ▪ Small businesses that serve local residents and visitors, compatible with the natural environment and surrounding uses.
Rural Desert Communities Baker, El Mirage, Homestead Valley [5], Lucerne Valley, Morongo Valley, Newberry Springs, Oak Hills, Pioneertown [6], Phelan/Pinon Hills	▪ A rural lifestyle characterized by the predominance of large lots, limited commercial development, and the prevalence of the desert landscape and natural resources. ▪ Abundant views of open spaces, natural features, and dark skies. ▪ Scenic, natural, and/or recreational features that serve as the foundation of the community's local economy and attract tourists. ▪ Small businesses that serve local residents and visitors, compatible with the natural environment and surrounding uses. ▪ Mining of mineral resources with minimal negative impacts on local residents.
Desert Village Communities Daggett, Helendale, Joshua Tree, Oro Grande, Yermo	▪ A rural context with clusters of housing in proximity to commercial development and public facilities, and larger lots farther from the commercial core. ▪ Abundant views of open spaces, natural features, and dark skies especially outside of clustered development. ▪ Scenic, natural, and/or recreational features that serve as the foundation of the community's local economy and attract tourists. ▪ Small businesses that serve local residents and visitors, compatible with the natural environment and surrounding uses. ▪ Mining of mineral resources with minimal negative impacts on local residents (Oro Grande and Yermo).

Notes:

1. Bear Valley includes: Baldwin Lake, Big Bear City, Erwin Lake, Fawnskin/Northshore, Lake Williams, Moonridge, Sugarloaf.
2. Crest Forest includes: Cedarpines Park, Crestline, Lake Gregory, Valley of Enchantment.
3. Hilltop includes: Arrowbear, Green Valley Lake, Running Springs.
4. Lake Arrowhead includes: Agua Fria, Blue Jay, Cedar Glen, Crest Park, Deer Lodge Park, Lake Arrowhead, Rimforest, Skyforest, Twin Peaks.
5. Homestead Valley includes: Flamingo Heights, Johnson Valley, Landers, Yucca Mesa.
6. Pioneertown includes: Gamma Gulch, Pioneertown, Pipes Canyon, Rimrock.

Housing Element

An adequate supply of quality and affordable housing is fundamental to the economic and social well-being of the county. California cities and counties are required by state law to prepare a housing element to address existing local housing needs and an assigned share of the region's housing growth in eight-year cycles. State law also requires that the cities and counties identify and analyze existing and projected housing needs and prepare a series of goals, policies, and quantified objectives, financial resources, and programs to further the development, improvement, and preservation of housing.

The Housing Element contains goals, policies, and programs to address the state law requirements and the needs of our unincorporated communities. The County also provides housing services to the entire county through the Housing Authority and Community Development & Housing Agency.

NOTE: The Housing Element is updated every eight years and is subject to detailed statutory requirements and mandatory review by a State agency, the California Department of Housing and Community Development (HCD). This Housing Element is for the 2021–2029 planning period. The following presents the purpose, principles, goals, and policies, with the balance of the Element presented as a technical report under separate cover.

Purpose

The Housing Element:

- Identifies adequate sites to facilitate and encourage housing for households of all economic levels, including persons with disabilities.
- Removes governmental constraints to housing production, maintenance, and improvement as legally feasible and appropriate.
- Assists the development of adequate housing for low- and moderate-income households.
- Preserves publicly assisted multiple-family housing developments in each community.
- Conserves and improving conditions in existing housing and neighborhoods, including affordable housing.
- Promotes a range of housing opportunities for all individual and households consistent with fair and equal housing opportunity.

Principles

We believe:

- A range of housing for all income levels is essential to a complete county.
- The county's housing stock should match the type and price needed by current and future residents and workforce, including those with special needs.

- New housing development should be focused in areas where there is potable water, wastewater treatment, roadways, and public services.
- Affordable, moderately-priced, and higher density housing should be placed in areas served by public transportation.
- Preserving, maintaining, improving, and creating distinct neighborhoods and communities protects property values and provides a desirable place to live.
- Affordable, quality housing helps attract and retain a qualified workforce and supports a prosperous local economy.

Goals & Policies

Goal H-1 Housing Production and Supply

A broad range of housing types in sufficient quantity, location, and affordability levels that meet the lifestyle needs of current and future residents, including those with special needs.

Policy H-1.1 **Appropriate range of housing.** We encourage the production and location of a range of housing types, densities, and affordability levels in a manner that recognizes the unique characteristics, issues, and opportunities for each community.

Policy H-1.2 **Concurrent infrastructure.** We support the integrated planning and provision of appropriate infrastructure (including water, sewer, and roadways) concurrent with and as a condition of residential development to create more livable communities.

Policy H-1.3 **Income-restricted multifamily.** Where infrastructure and public services are available, we encourage the production of affordable multifamily housing by providing assistance and incentives for projects that include new affordable units reserved for lower income, moderate income, or special needs households.

Policy H-1.4 **Accessory dwelling units.** We Incentivize and encourage the construction of accessory dwelling units through various methods, including but not limited to public education, fee modification, and making necessary resources available.

Policy H-1.5 **RHNA transfers with annexation.** We work with the Southern California Association of Governments, Local Agency Formation Commission, and incorporated jurisdictions to develop agreements for the transfer of the regional housing need allocation as a precondition for annexations.

Policy H-1.6 **Life-cycle costs.** We encourage energy-conservation techniques and upgrades in both the construction and rehabilitation of residential units that will reduce the life-cycle costs of housing.

Goal H-2 Development Regulations

An efficient administrative process that recognizes the need for efficient and timely review of residential projects while also ensuring and valuing the need for quality design, environmental review, and planning.

Policy H-2.1 **Streamlining development regulations.** We review the County Development Code regularly for possible revisions that might unduly constrain the production or rehabilitation of residential development. We also advocate for changes in state law, state and federal tax codes, and funding vehicles that will make market rate and affordable housing more feasible.

Policy H-2.2 **Small lot sizes.** We continue to utilize Planned Development density bonus and density transfer provisions as described in the Development Code to allow the development of lot sizes less than that normally required by residential land use districts.

Policy H-2.3 **Flexible standards and incentives.** We maintain development incentives and allow flexibility in the application of residential and mixed-use development standards to gain benefits such as exceptional design quality, economic advantages, sustainability, or other benefits that would not otherwise be realized.

Policy H-2.4 **Certain and transparent process.** We maintain a residential development review process that provides certainty and transparency for project stakeholders and the public, complies with streamlining provisions in state law, and provides sufficient review to ensure safe and high quality housing development.

Policy H-2.5 **Critical infrastructure.** We ensure that the efficient provision of critical infrastructure accompanies residential development and the building of complete communities, and ensure that the costs are fairly apportioned to the development community.

Goal H-3 Housing and Neighborhood Quality

Neighborhoods that protect the health, safety, and welfare of the community, and enhance public and private efforts in maintaining, reinvesting in, and upgrading the existing housing stock.

Policy H-3.1 **Public services, amenities, and safety.** We support the provision of adequate and fiscally sustainable public services, infrastructure, open space, nonmotorized transportation routes, and public safety for neighborhoods in the unincorporated area.

Policy H-3.2 **Code enforcement.** We support the timely removal of neighborhood blight through graffiti abatement, abandoned or inoperative automobile removal, trash and debris removal, housing repair, and other code enforcement efforts.

Policy H-3.3 **Housing maintenance.** We establish and enforce public health, safety, building, and zoning standards to ensure housing and property maintenance that yields safe, sound, and attractive residential properties.

Policy H-3.4 **Housing rehabilitation and improvement.** We seek funding to facilitate the rehabilitation, repair, and improvement of single family homes, multiple family housing,

and mobile homes and, if needed, the demolition of substandard housing through available loan and grant programs.

Policy H-3.5 **Inspection of subsidized housing.** We inspect or facilitate the inspection of assisted multifamily rental housing, contract shelters, voucher hotels, and other housing projects on a regular basis to ensure that properties are regularly repaired and maintained in good condition.

Policy H-3.6 **Neighborhood improvements.** We support comprehensive neighborhood efforts to address housing conditions, property maintenance, infrastructure repair, public safety, landscaping, and other issues affecting the livability of neighborhoods.

Goal H-4 Affordable Housing Assistance

The development, maintenance, modernization, and preservation of affordable housing; and the provision of assistance, where feasible, for residents to rent or purchase adequate housing in San Bernardino County.

Policy H-4.1 **At-risk units.** We seek funding to preserve income-restricted housing units that are at risk of converting to market rents within 10 years due to the expiration of affordability covenants or funding contracts. In establishing or extending affordability requirements, we prefer the preservation of affordability in perpetuity.

Policy H-4.2 **Rental assistance.** We support the provision of rental assistance to qualified extremely low, very low, and low income households and special needs households served by the County Housing Authority, Department of Behavioral Health, and other County entities.

Policy H-4.3 **Homeowner assistance.** We support the expansion of homeownership opportunities and preservation by offering financial assistance when available, working in collaboration with partners to increase funding, and supporting foreclosure prevention programs.

Policy H-4.4 **Modernize and replace multiple-family projects.** We support the Housing Authority's efforts to modernize and replace, where needed, existing multiple-family projects to provide safe, sound, and affordable housing options for qualified low income individuals and families.

Policy H-4.5 **Nonprofit partnerships.** We continue to form and strengthen partnerships with nonprofit organizations, public agencies, community-based organizations, and housing developers in order to increase housing opportunities for very low and low income and special needs households.

Goal H-5 Equal housing opportunities

Equal housing opportunities for all persons regardless of race, age, religion, sex, marital status, disability status, ancestry, national origin, or color.

Policy H-5.1 **Housing discrimination.** We further fair housing opportunities by prohibiting discrimination in the housing market; providing education, support, and enforcement services to address discriminatory practices; and removing potential impediments to equal housing opportunity.

Policy H-5.2 **Local organizations.** We utilize local organizations that provide fair housing services to the San Bernardino County area to better prevent, monitor, and resolve fair housing issues. We also utilize local organizations to provide housing information, counseling, and financial literacy to lower income households.

Policy H-5.3 **Higher resource areas.** In census tracts identified by the state as high/highest resource areas, we facilitate the production of new income-restricted housing and target rental assistance for lower income households overpaying for housing costs in high/highest resource areas.

Policy H-5.4 **Transitional, supportive, and emergency housing.** We encourage the production of transitional and permanent supportive housing to serve special needs groups in unincorporated communities. We promote access to emergency housing for individuals and families living throughout the county by coordinating with cities and incorporated towns to facilitate the production of emergency shelters and low barrier navigation centers in incorporated areas that are close to public services, transit, and food stores.

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Infrastructure & Utilities Element

The ability to live and prosper in the diverse physical setting of San Bernardino County is dependent on the effective provision and management of water, wastewater, stormwater, solid waste, power, and communication systems. The effective management of these systems helps fulfill the County's obligation to protect the lives and property of residents and businesses, while also protecting the natural environment from the impacts of human development.

The County maintains a regional flood control system for the entire county and coordinates local flood management for the unincorporated areas. The County has limited responsibilities for public water systems and public sewer systems in unincorporated areas, but the County is responsible for regulating small public water systems, permitting wells and septic systems countywide, and uses a significant amount of water at County facilities.

In collaboration with incorporated jurisdictions, the County operates regional landfills and maintains closed landfills to manage dispersion programs and solid waste disposal. Power and communication systems are predominantly provided and maintained by private companies and public utilities.

Purpose

The Infrastructure & Utilities Element:

- Provides guidance on where, when, and how infrastructure and utilities are improved and expanded.
- Establishes goals and policies to maintain an adequate supply of potable water and the safe disposal, treatment, and recycling of wastewater, and the recycling and safe disposal of solid waste.
- Provides direction on system integration, resource conservation, and the protection of the natural environment.

Principles

We believe:

- Reliable and cost-effective water, stormwater, wastewater, sanitary, power, and communications systems are critical for maintaining and improving our communities, institutions, and businesses.
- Groundwater recharge, water conservation, water reclamation, and supplemental water are key components of a resilient water supply strategy. The effective management of water resources can reduce carbon emissions, energy consumption, and utility costs.
- Reducing, treating, and safely disposing solid and liquid waste will protect public and environmental health and preserve our natural resources.
- Flood control facilities are important for reducing the risks of flooding, contributing to groundwater recharge, and providing open space and habitat area.
- Collaborative efforts between government agencies and other stakeholders are necessary in order to effectively plan and efficiently provide infrastructure.

Goals & Policies

Goal IU-1 Water Supply

Water supply and infrastructure are sufficient for the needs of residents and businesses and resilient to drought.

Policy IU-1.1 **Water supply.** We require that new development be connected to a public water system or a County-approved well to ensure a clean and resilient supply of potable water, even during cases of prolonged drought.

Policy IU-1.2 **Water for military installations.** We collaborate with military installations to avoid impacts on military training and operations from groundwater contamination and inadequate groundwater supply.

Policy IU-1.3 **Recycled water.** We promote the use of recycled water for landscaping, groundwater recharge, direct potable reuse, and other applicable uses in order to supplement groundwater supplies.

Policy IU-1.4 **Greywater.** We support the use of greywater systems for non-potable purposes.

Policy IU-1.5 **Agricultural water use.** We encourage water-efficient irrigation and the use of non-potable and recycled water for agricultural uses.

Policy IU-1.6 **User fees.** For water systems operated by County Special Districts, we establish user fees that cover operation and maintenance costs and set aside adequate reserves for capital upgrades and improvements.

Policy IU-1.7 **Areas vital for groundwater recharge.** We allow new development on areas vital for groundwater recharge when stormwater management facilities are installed onsite and maintained to infiltrate predevelopment levels of stormwater into the ground.

Policy IU-1.8 **Groundwater management coordination.** We collaborate with watermasters, groundwater sustainability agencies, water purveyors, and other government agencies to ensure groundwater basins are being sustainably managed. We discourage new development when it would create or aggravate groundwater overdraft conditions, land subsidence, or other "undesirable results" as defined in the California Water Code. We require safe yields for groundwater sources covered by the Desert Groundwater Management Ordinance.

Policy IU-1.9 **Water conservation.** We encourage water conserving site design and the use of water conserving fixtures, and advocate for the adoption and implementation of water conservation strategies by water service agencies. For existing County-owned facilities, we incorporate design elements, building materials, fixtures, and landscaping that reduce water consumption, as funding is available.

Policy IU-1.10 **Connected systems.** We encourage local water distribution systems to interconnect with regional and other local systems, where feasible, to assist in the transfer of water resources during droughts and emergencies.

Policy IU-1.11 **Water storage and conveyance.** We assist in development of additional water storage and conveyance facilities to create a resilient regional water supply system, when it is cost effective for County-owned water and stormwater systems.

Goal IU-2 Wastewater Treatment and Disposal

Residents and businesses in unincorporated areas have safe and sanitary systems for wastewater collection, treatment, and disposal.

Policy IU-2.1 **Minimum parcel size.** We require new lots smaller than one-half acre to be served by a sewer system. We may require sewer service for larger lot sizes depending on local soil and groundwater conditions, and the County's Local Area Management Program.

Policy IU-2.2 **User fees.** For wastewater systems operated by County Special Districts, we establish user fees that cover operation and maintenance costs and set aside adequate reserves for capital upgrades and improvements.

Policy IU-2.3 **Shared wastewater facilities for recycled water.** We encourage an expansion of recycled water agreements between wastewater entities to share and/or create connections between wastewater systems to expand the use of recycled water.

Goal IU-3 Stormwater Drainage

A regional stormwater drainage backbone and local stormwater facilities in unincorporated areas that reduce the risk of flooding.

Policy IU-3.1 **Regional flood control.** We maintain a regional flood control system and regularly evaluate the need for and implement upgrades based on changing land coverage and hydrologic conditions in order to manage and reduce flood risk. We require any public and private projects proposed anywhere in the county to address and mitigate any adverse impacts on the carrying capacity and stormwater velocity of regional stormwater drainage systems.

Policy IU-3.2 **Local flood control.** We require new development to install and maintain stormwater management facilities that maintain predevelopment hydrology and hydraulic conditions.

Policy IU-3.3 **Recreational use.** We prefer that stormwater facilities be designed and maintained to allow for regional open space and safe recreation use without compromising the ability to provide flood risk reduction.

Policy IU-3.4 **Natural floodways.** We retain existing natural floodways and watercourses on County-controlled floodways, including natural channel bottoms, unless hardening and channelization is the only feasible way to manage flood risk. On floodways not controlled by the County, we encourage the retention of natural floodways and watercourses. Our priority is to reduce flood risk, but we also strive to protect wildlife corridors, prevent loss of critical habitat, and improve the amount and quality of surface water and groundwater resources.

Policy IU-3.5 **Fair share requirements.** We require new development to pay its fair share of capital costs to maintain adequate capacity of the County's regional flood control systems.

Goal IU-4 Solid Waste

Adequate regional landfill capacity that provides for the safe disposal of solid waste, and efficient waste diversion and collection for unincorporated areas.

Policy IU-4.1 **Landfill capacity.** We maintain a minimum ongoing landfill capacity of 15 years to serve unincorporated waste disposal needs.

Policy IU-4.2 **Transfer stations.** We locate and operate transfer stations based on overall system efficiency.

Policy IU-4.3 **Waste diversion.** We shall meet or exceed state waste diversion requirements, augment future landfill capacity, and reduce greenhouse gas emissions and use of natural resources through the reduction, reuse, or recycling of solid waste.

Policy IU-4.4 **Landfill funding.** We require sufficient fees for use of County landfills to cover capital costs; ongoing operation, maintenance, and closure costs of existing landfills; and the costs and liabilities associated with closed landfills.

Goal IU-5 Power and Communications

Unincorporated area residents and businesses have access to reliable power and communication systems.

Policy IU-5.1 **Electricity and natural gas service.** We partner with other public agencies and providers to improve the availability and stability of electricity and natural gas service in unincorporated communities.

Policy IU-5.2 **Expanded high-speed internet and wireless communication.** We encourage the expansion of expand affordable, high-speed internet access in underserved and unserved unincorporated communities. We encourage the expansion of advanced mobile and fixed wireless communication technologies that improve service, coverage, and reliability throughout the county.

Policy IU-5.3 **Underground facilities.** We encourage new and relocated power and communication facilities to be located underground when feasible, particularly in the Mountain and Desert regions.

Policy IU-5.4 **Electric transmission lines.** We support the maintenance of existing and development of new electric transmission lines along existing rights-of-way and easements to maintain the stability and capacity of the electric distribution system in southern California.

Policy IU-5.5 **Energy and fuel facilities.** We encourage the development and upgrade of energy and regional fuel facilities in areas that do not pose significant environmental or public health and safety hazards, and in a manner that is compatible with military operations and local community identity.

Policy IU-5.6 **Dig once approach.** We encourage infrastructure, telecommunication, and utility planning and projects to coordinate so that improvements are made concurrently or in such a manner that minimizes disruption to rights-of-way and reduces costs.

Transportation & Mobility Element

A large and diverse multimodal transportation network serves residents, businesses, and visitors throughout San Bernardino County. The efficiency of this transportation network is a key asset to businesses operating in the county and influences the quality of life experienced by residents.

While cars and trucks are expected to be the dominant mode of transportation throughout the lifetime of this plan, we recognize the need to invest in robust alternatives for residents, including complete streets, public transit systems, and off-street networks that promote walking and bicycling. With dozens of communities spread across 20,000 square miles and four subregions, we must also design transportation and mobility systems to be sensitive to the local and environmental context.

Purpose

The Transportation & Mobility Element:

- Establishes the location and operational conditions of the roadway network.
- Coordinates the transportation and mobility system with future land use patterns and projected growth.
- Provides guidance for the County's responsibility to satisfy the local and subregional mobility needs of residents, visitors and businesses in unincorporated areas.
- Addresses access and connectivity among the various communities, cities, towns, and regions, as well as the range and suitability of mobility options: vehicular, trucking, freight and passenger rail, air, pedestrian, bicycle, and transit.

Principles

We believe:

- An effective transportation and mobility network involves a fair share, collaborative effort between multiple local and regional agencies.
- The ongoing operations, maintenance of, and reinvestment in the transportation network must be matched with new and on-going funding.
- The pattern of land use and transportation systems should be designed to reduce the length and duration of trips traveled by vehicles.
- Pedestrian, cyclist, and other active transportation infrastructure in mobility focus areas should safely connect neighborhoods and communities to key destinations.
- Local roadways should be designed to serve projected travel demand and reflect the surrounding environmental and community context.
- Road, freight, and airport design and maintenance are essential for efficient movement of goods and people.
- The expansion of passenger, freight, and general aviation services at airports throughout the county is vital to the regional economy.

Goals & Policies

Goal TM-1 Roadway Capacity

Unincorporated areas served by roads with capacity that is adequate for residents, businesses, tourists, and emergency services.

Policy TM-1.1 **Roadway level of service (LOS).** We require our roadways to be built to achieve the following minimum level of service standards during peak commute periods (typically 7:00-9:00 AM and 4:00-6:00 PM on a weekday):

- LOS D in the Valley Region
- LOS D in the Mountain Region
- LOS C in the North and East Desert Regions

Policy TM-1.2 **Interjurisdictional roadway consistency.** We promote consistent cross-sections along roads traversing incorporated and unincorporated areas.

Policy TM-1.3 **Freeways and highways.** We coordinate with Caltrans and regional transportation agencies and support the use of state, federal, and other agency funds to improve freeways and highways.

Policy TM-1.4 **Unpaved roadways.** The County does not accept new unpaved roads into the County Maintained Road System, and we require all-weather treatment for all new unpaved roads.

Policy TM-1.5 **Upgrading unpaved roads.** We support the paving of unpaved roads when funding is contributed through a local area funding and financing mechanism.

Policy TM-1.6 **Paved roads.** For any new development for which paved roads are required, we require the developer to construct the roads and we require the establishment of a special funding and financing mechanism to pay for roadway operation, maintenance, and set-aside reserves.

Policy TM-1.7 **Fair share contributions.** We require new development to pay its fair share contribution toward off-site transportation improvements.

Policy TM-1.8 **Emergency access.** When considering new roadway improvement proposals for the CIP or RTP, we consider the provision of adequate emergency access routes along with capacity expansion in unincorporated areas. Among access route improvements, we prioritize those that contribute some funding through a local area funding and financing mechanism.

Policy TM-1.9 **New transportation options.** We support the use of transportation network companies, autonomous vehicles, micro transit, and other emerging transportation options that reduce congestion, minimize land area needed for roadways, create more pedestrian- and bicycle-friendly streets, reduce VMT, or reduce dependence on privately-owned vehicles.

Goal TM-2 Road Design Standards

Roads designed and built to standards in the unincorporated areas that reflect the rural, suburban, and urban context as well as the regional (valley, mountain, and desert) context.

Policy TM-2.1 **Context sensitive approach.** We maintain and periodically update required roadway cross sections that prioritize multi-modal systems inside mobility focus areas (based on community context), and vehicular capacity on roadways outside of mobility focus areas (based on regional context).

Policy TM-2.2 **Roadway improvements.** We require roadway improvements that reinforce the character of the area, such as curbs and gutters, sidewalks, landscaping, street lighting, and pedestrian and bicycle facilities. We require fewer improvements in rural areas and more improvements in urbanized areas, consistent with the Development Code. Additional standards may be required in municipal spheres of influence.

Policy TM-2.3 **Concurrent improvements.** We require new development to mitigate project transportation impacts no later than prior to occupancy of the development to ensure transportation improvements are delivered concurrent with future development.

Policy TM-2.4 **Atypical intersection controls.** We allow the use of atypical intersection concepts such as roundabouts when they improve traffic flow and safety compared to conventional intersection controls.

Policy TM-2.5 **Context-based features.** When making road improvements, we provide feasible, context-based transportation features such as:

- Chain installation and inspection areas in the Mountain Region
- Slow-vehicle turnouts on roadways with steep grades
- Limited on-street parking areas to serve snow-plow or emergency services
- Passing lanes in rural areas
- Vista areas along scenic routes

Policy TM-2.6 **Access control.** We promote shared/central access points for direct access to roads in unincorporated areas to minimize vehicle conflict points and improve safety, especially access points for commercial uses on adjacent properties.

Goal TM-3 Vehicle Miles Traveled

A pattern of development and transportation system that minimizes vehicle miles traveled.

Policy TM-3.1 **VMT Reduction.** We promote new development that will reduce household and employment VMT relative to existing conditions.

Policy TM-3.2 **Trip reduction strategies.** We support the implementation of transportation demand management techniques, mixed use strategies, and the placement of development in proximity to job and activity centers to reduce the number and length of vehicular trips.

Policy TM-3.3 **First mile/last mile connectivity.** We support strategies that strengthen first/last mile connectivity to enhance the viability and expand the utility of public transit in unincorporated areas and countywide.

Goal TM-4 Complete Streets, Transit, and Active Transportation

On- and off-street improvements that provide functional alternatives to private car usage and promote active transportation in mobility focus areas.

Policy TM-4.1 **Complete streets network.** We maintain a network of complete streets within mobility focus areas that provide for the mobility of all users of all ages and all abilities, while reflecting the local context.

Policy TM-4.2 **Complete streets improvements.** We evaluate the feasibility of installing elements of complete street improvements when planning roadway improvements in mobility focus areas, and we require new development to contribute to complete street improvements in mobility focus areas. In evaluating complete street improvements, we prioritize those in mobility focus areas that are within unincorporated environmental justice focus areas.

Policy TM-4.3 **Funding.** We partner with SBCTA, Caltrans, and local agencies to fund active transportation systems in the county. We encourage unincorporated communities to apply for funding and cooperate with them in their funding applications for active transportation improvements that are identified in a non-motorized transportation plan that is accepted or adopted by the County.

Policy TM-4.4 **Transit access for residents in unincorporated areas.** We support and work with local transit agencies to generate a public transportation system, with fixed routes and on-demand service, that provide residents of unincorporated areas with access to jobs, public services, shopping, and entertainment throughout the county.

Policy TM-4.5 **Transit access to job centers and tourist destinations.** We support and work with local transit agencies to generate public transportation systems that provide access to job centers and reduce congestion in tourist destinations in unincorporated areas.

Policy TM-4.6 **Transit access to public service, health, and wellness.** In unincorporated areas where public transit is available, we prefer new public and behavioral health facilities, other public facilities and services, education facilities, grocery stores, and pharmacies to be located within one-half mile of a public transit stop. We encourage and plan to locate new County health and wellness facilities within one-half mile of a public transit stop in incorporated jurisdictions. We encourage public K-12 education and court facilities to be located within one-half mile of public transit.

Policy TM-4.7 **Regional bicycle network.** We work with SBCTA and other local agencies to develop and maintain a regional backbone bicycle network.

Policy TM-4.8 **Local bicycle and pedestrian networks.** We support local bike and pedestrian facilities that serve unincorporated areas, connect to facilities in adjacent incorporated areas, and connect to regional trails. We prioritize bicycle and pedestrian network improvements

that provide safe and continuous pedestrian and bicycle access to mobility focus areas, schools, parks, and major transit stops.

Policy TM-4.9 **Bike and pedestrian safety.** We promote pedestrian and bicyclist safety by providing separated pedestrian and bike crossings when we construct or improve bridges over highways, freeways, rail facilities, and flood control areas. We monitor pedestrian and bicycle traffic accidents and promote safety improvements in unincorporated high-accident areas.

Policy TM-4.10 **Shared parking.** We support the use of shared parking facilities that provide safe and convenient pedestrian connectivity between adjacent uses.

Policy TM-4.11 **Parking areas.** We require publicly accessible parking areas to ensure that pedestrians and bicyclists can safely access the site and onsite businesses from the public right-of-way.

Goal TM-5 Goods Movement

A road, rail, and air transportation system that supports the logistics industry and minimizes congestion in unincorporated areas.

Policy TM-5.1 **Efficient and sustainable goods movement network.** We advocate for the maintenance of a goods movement system in southern California that is efficient and sustainable and that prioritizes public health through the use of zero-emission equipment and infrastructure.

Policy TM-5.2 **Intermodal facility.** We support the development of an intermodal facility in connection with the Southern California Logistics Airport.

Policy TM-5.3 **High Desert Corridor.** We support the development of the High Desert Corridor to improve the regional goods movement network and foster economic development in the North Desert region.

Policy TM-5.4 **Grade separations.** We support grade separations to reduce conflicts between rail facilities and roadways, subject to available funding.

Policy TM-5.5 **Countywide truck routes.** We support SBCTA's establishment of regional truck routes that efficiently distribute regional truck traffic while minimizing impacts on residents. We support funding through the RTP to build adequate truck route infrastructure.

Policy TM-5.6 **Unincorporated truck routes.** We establish local truck routes in unincorporated areas to efficiently funnel truck traffic to freeways while minimizing impacts on residents. We establish routes where trucks are prohibited in unincorporated environmental justice focus areas and to avoid overlaps or conflicts with safe routes to schools.

Policy TM-5.7 **Trucking-intensive businesses.** We require trucking-intensive businesses to pay their fair share of costs to build and maintain adequate roads.

Goal TM-6 Airports

A network of local and regional airports that meet regional and local aviation needs.

Policy TM-6.1 **Local airports.** We maintain County airports and coordinate with other local airports to provide general aviation services to residents and businesses throughout the county.

Policy TM-6.2 **Economic potential.** We seek to maximize the economic development potential of County airports.

Policy TM-6.3 **Regional airports.** We advocate for expanded passenger and cargo service at regional airports.

Policy TM-6.4 **Airport land use compatibility.** We require proposed development in unincorporated areas to be consistent with applicable airport master plans, airport safety review areas, and military air installation compatible use zones. We may support proposed development in the influence area of County airports only when they are consistent with applicable airport master plans.

Policy TM-6.5 **Coordination on airport planning.** We collaborate with FAA, military installations, Caltrans Division of Aeronautics, airport owners, neighboring jurisdictions, and other stakeholders in the preparation, update, and maintenance of airport-related plans.

Table

The County applies designations to roadways throughout the county to depict and evaluate how the roadway system and individual roads accommodates two characteristics: the movement of vehicular traffic and the level of access provided to adjacent properties. Based on these generalized characteristics, roadways often vary in terms of right-of-way, roadway width, number of lanes, intersection and traffic signal spacing, speed, and other factors. Table TM-1 identifies the roadway designations for the County of San Bernardino and provides the general geometric mid-block cross sectional characteristics of each.

The County also maps these roadway designations onto adjacent incorporated roads to depict a more comprehensive diagram of the overall roadway system. While the County's roadway designations are generally consistent with the designations of incorporated cities and towns, the County's roadway designations do not officially apply within incorporated boundaries. The designation, design, construction, maintenance, and improvement of roadways in incorporated areas are the responsibility of the incorporated city or town.

Additionally, the County may apply roadway designations to freeways and state highways, but the design, construction, maintenance, and improvement of freeways and state highways is under the jurisdiction and responsibility of Caltrans, unless the roadway has been relinquished to a local jurisdiction.

Table TM-1. County Roadway Designations

Roadway Designation	Typical Street Cross Section Characteristics			
	Divided	Right-of-Way	Curb-to-Curb	Lanes
Major Divided Highway	Yes	120'	94'	4 to 6
Major Arterial Highway	No	120'	94'	4 to 6
Major Highway	At times	104'	80'	2 to 4
Secondary Highway	At times	88'	64'	2 to 4
Controlled/Limited Access Collector	Usually	66'	44'	2
Mountain Major Highway	No	80'	64'	2 to 4
Mountain Secondary Highway	No	60'	44'	2
State Highway/Special Conditions or Special Standards	Determined by Caltrans			
Freeway				

Notes:

1. Characteristics listed in this table are provided for general guidance on a typical mid-block street cross section. Intersection configurations will vary by location as necessary. The County may approve or construct mid-block street sections that vary from these figures based on physical or environmental constraints.

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Resources & Conservation Section

Natural Resources Element

The county's abundant natural resources are integral to our quality of life, community identities, and economic success. Natural resources include agricultural/grazing lands, watersheds, minerals, native plants and wildlife, and plant and wildlife habitat areas. Appropriately managed, they provide safe air and water for our people and the environment, improve the health of our residents and workers, attract visitors from around the world, and sustain the productivity of our local and national economies.

The County maintains a regional system of parks and trails for the entire county. In the unincorporated areas, the County maintains some local park facilities with special district funding, and self-governing community service districts maintain other local park facilities. The County also sets standards and applies designations to preserve the varied scenic resources across the unincorporated lands.

While air and water quality are largely regulated by regional, state, and federal agencies, the County applies standards set by and coordinates with such agencies, manages small public water systems, and provides permits for wells and septic systems. Similarly, the protection and conservation of biological resources is primarily regulated and controlled by state and federal agencies, with the County enforcing state and federal laws and participating in local and countywide efforts to promote biodiversity and healthy ecosystems.

The County is the lead agency for mining activity on all private and public lands in unincorporated areas and facilitates the extraction of mineral resources while minimizing adverse effects on the environment and communities. Although the rich agricultural lands of the Valley region were long ago urbanized, the County promotes the preservation and continued viability of remaining agricultural resources and farming operations.

Purpose

The Natural Resources Element:

- Establishes policies that preserve and enhance the beauty and resiliency of our natural resources.
- Provides guidance on coordinating with others to manage, conserve, and protect natural resources such as watersheds, wildlife habitat areas and corridors, and other natural and open space areas.
- Promotes clean air and a supply of water for human consumption and the natural environment.
- Supports the maintenance and enhancement of a countywide system of open space, parks, and recreation assets.
- Provides guidance and support for mining operations and the preservation of viable agricultural and grazing lands.
- Provides guidance on the location and distribution of new development to protect natural resources.

Principles

We believe:

- Effective preservation, management, and enhancement of natural resources will ensure their environmental and economical sustainability and resiliency.
- Access to open space and vibrant natural resources improves public health and contributes significantly to the county's overall economic vitality.
- Improving air quality and ensuring access to clean and affordable drinking water will enhance the quality of life for our residents and attract continuing investment in residences and businesses.
- The County's primary role is to govern land use and establish development standards to ensure that new development has minimal impact on the natural environment in the unincorporated areas of the county.
- The County has a responsibility to maintain and make available information on natural resources to enable property owners to be better stewards of the land and natural resources.

Goals & Policies

Goal NR-1 Air Quality

Air quality that promotes health and wellness of residents in San Bernardino County through improvements in locally-generated emissions.

Policy NR-1.1 **Land use.** We promote compact and transit-oriented development countywide and regulate the types and locations of development in unincorporated areas to minimize vehicle miles traveled and greenhouse gas emissions.

Policy NR-1.2 **Indoor air quality.** We promote the improvement of indoor air quality through the California Building and Energy Codes and through the provision of public health programs and services.

Policy NR-1.3 **Coordination on air pollution.** We collaborate with air quality management districts and other local agencies to monitor and reduce major pollutants affecting the county at the emission source.

Policy NR-1.4 **Military coordination on air quality.** We collaborate with the military to avoid or minimize impacts on military training and operations from air pollution and haze.

Policy NR-1.5 **Sensitive land uses.** We consider recommendations from the California Air Resources Board on the siting of new sensitive land uses and exposure to specific source categories.

Policy NR-1.6 **Fugitive dust emissions.** We coordinate with air quality management districts on requirements for dust control plans, revegetation, and soil compaction to prevent fugitive dust emissions.

Policy NR-1.7 **Greenhouse gas reduction targets.** We strive to meet the 2040 and 2050 greenhouse gas emission reduction targets in accordance with state law.

Policy NR-1.8 **Construction and operations.** We invest in County facilities and fleet vehicles to improve energy efficiency and reduce emissions. We encourage County contractors and other builders and developers to use low-emission construction vehicles and equipment to improve air quality and reduce emissions.

Policy NR-1.9 **Building design and upgrades.** We use the CALGreen Code to meet energy efficiency standards for new buildings and encourage the upgrading of existing buildings to incorporate design elements, building materials, and fixtures that improve environmental sustainability and reduce emissions.

Goal NR-2 Water Quality

Clean and safe water for human consumption and the natural environment.

Policy NR-2.1 **Coordination on water quality.** We collaborate with the state, regional water quality control boards, watermasters, water purveyors, and government agencies at all levels to ensure a safe supply of drinking water and a healthy environment.

Policy NR-2.2 **Water management plans.** We support the development, update, and implementation of ground and surface water quality management plans emphasizing the protection of water quality from point and non-point source pollution.

Policy NR-2.3 **Military coordination on water quality.** We collaborate with the military to avoid or minimize impacts on military training and operations from groundwater contamination and inadequate groundwater supply.

Policy NR-2.4 **Wastewater discharge.** We apply federal and state water quality standards for wastewater discharge requirements in the review of development proposals that relate to type, location, and size of the proposed project in order to safeguard public health and shared water resources.

Policy NR-2.5 **Stormwater discharge.** We ensure compliance with the County's Municipal Stormwater NPDES (National Pollutant Discharge Elimination System) Permit by requiring new development and significant redevelopment to protect the quality of water and drainage systems through site design, source controls, stormwater treatment, runoff reduction measures, best management practices, low impact development strategies, and technological advances. For existing development, we monitor businesses and coordinate with municipalities.

Policy NR-2.6 **Agricultural waste and biosolids.** We coordinate with regional water quality control boards and other responsible agencies to regulate and control animal waste and biosolids in order to protect groundwater and the natural environment.

Goal NR-3 Open Space, Parks, and Recreation

A system of well-planned and maintained parks, trails, and open space that provides recreation opportunities for residents, attracts visitors from across the region and around the country, and preserves the natural environment.

Policy NR-3.1 **Open space preservation.** We regulate land use and coordinate with public and nongovernmental agencies to preserve open space areas that protect natural resources, function as a buffer against natural hazards or between land uses, serve as a recreation or tourist destination, or are central to the identity of an unincorporated community.

Policy NR-3.2 **Residential clustering.** We allow residential development to cluster housing units in order to reduce the consumption of undeveloped land, maximize the amount of open space, preserve natural resources, conform to natural topography/grade, and/or reduce exposure of structures to natural hazards.

Policy NR-3.3 **Management of designated areas.** We coordinate with public and nongovernmental agencies to sustainably manage and conserve land within or adjacent to locally-, state-, or federally-designated open space or resource conservation areas.

Policy NR-3.4 **Land exchange.** We coordinate with state and federal agencies to exchange publicly owned lands in order to provide additional areas for open space, recreation, and resource protection. We also request the right of first refusal on publicly owned lands made available for purchase to the public.

Policy NR-3.5 **Private conservation efforts.** We support nongovernmental organizations and private entities who purchase, own, maintain, and expand areas for conservation and preservation. We also support the voluntary transition of privately held lands within a larger boundary designated by the state or federal government for open space and resource conservation to public ownership.

Policy NR-3.6 **Regional park land.** We coordinate with other jurisdictions and agencies to provide regional park land. We prioritize the maintenance and improvement of existing County parks and trails over their expansion or creation of new facilities.

Policy NR-3.7 **Regional park revenue.** We generate revenues from County-owned parks and facilities to offset the costs of operation and maintenance. We may also coordinate with local jurisdictions and leverage other resources to support the maintenance and improvement of park and trail facilities.

Policy NR-3.8 **Regional trail system.** We coordinate with incorporated jurisdictions, state and federal agencies, and other regional and not-for-profit entities to maintain and improve a regional trail system. We prioritize the maintenance and improvement of the Santa Ana River Trail, followed by the creation of trails in unincorporated areas that connect to existing trails in incorporated areas and to state- and federally-maintained trails.

Policy NR-3.9 **Local parks, trails, and recreation.** We support the provision of local and community parks, trails, and recreational programs and facilities in unincorporated areas when a locally-approved funding and financing mechanism is established to pay for acquisition, construction, maintenance, and operations. We encourage unincorporated communities to apply for funding and cooperate with them in their funding applications for local trails that are identified in a non-motorized transportation plan that is accepted or adopted by the County. We also encourage, where feasible, local trails to be separated from vehicular traffic to improve the safety of trail users.

Policy NR-3.10 **Joint use facilities.** We promote the creation of joint use facilities for local parks and recreation programs through coordination with the County Flood Control District, local school districts, utilities, and other public agencies.

Policy NR-3.11 **Off-highway vehicle areas.** In areas under the County's land use authority, we require new or expansion of existing commercial off-highway vehicle (OHV) areas to be situated and buffered to minimize effects on nearby residential uses, military activity, and environmentally sensitive areas.

Policy NR-3.12 **Rights-of-way and easements.** We consider reserving portions of rights-of-way and easements found to be unnecessary for the ultimate buildout of roadways or flood control facilities for use as local pedestrian, bicycle, and/or equestrian trails.

Goal NR-4 Scenic Resources

Scenic resources that highlight the natural environment and reinforce the identity of local communities and the county.

Policy NR-4.1 **Preservation of scenic resources.** We consider the location and scale of development to preserve regionally significant scenic vistas and natural features, including prominent hillsides, ridgelines, dominant landforms, and reservoirs.

Policy NR-4.2 **Coordination with agencies.** We coordinate with adjacent federal, state, local, and tribal agencies to protect scenic resources that extend beyond the County's land use authority and are important to countywide residents, businesses, and tourists.

Policy NR-4.3 **Off-site signage.** We prohibit new off-site signage and encourage the removal of existing off-site signage along or within view of County Scenic Routes and State Scenic Highways.

Goal NR-5 Biological Resources

An interconnected landscape of open spaces and habitat areas that promotes biodiversity and healthy ecosystems, both for their intrinsic value and for the value placed on them by residents and visitors.

Policy NR-5.1 **Coordinated habitat planning.** We participate in landscape-scale habitat conservation planning and coordinate with existing or proposed habitat conservation and natural resource management plans for private and public lands to increase certainty for both the conservation of species, habitats, wildlife corridors, and other important biological resources and functions; and for land development and infrastructure permitting.

Policy NR-5.2 **Capacity for resource protection and management.** We coordinate with public and nongovernmental agencies to seek funding and other resources to protect, restore, and maintain open space, habitat, and wildlife corridors for threatened, endangered, and other sensitive species.

Policy NR-5.3 **Multiple-resource benefits.** We prioritize conservation actions that demonstrate multiple resource preservation benefits, such as biology, climate change adaptation and resiliency, hydrology, cultural, scenic, and community character.

Policy NR-5.4 **Off-base recovery efforts.** We coordinate with military installations to facilitate off-base recovery of threatened and endangered species and landscape-scale conservation.

Policy NR-5.5 **Mitigation and future responsibilities.** We require that new development satisfy habitat conservation responsibilities without shifting conservation responsibilities onto military property.

Policy NR-5.6 **Mitigation banking.** We support the proactive assemblage of lands to protect biological resources and facilitate development through private or public mitigation banking. We require public and private conservation lands or mitigation banks to ensure that easement and fee title agreements provide funding methods sufficient to manage the land in perpetuity.

Policy NR-5.7 **Development review, entitlement, and mitigation.** We comply with state and federal regulations regarding protected species of animals and vegetation through the development review, entitlement, and environmental clearance processes.

Policy NR-5.8 **Invasive species.** We require the use of non-invasive plant species with new development and encourage the management of existing invasive plant species that degrade ecological function.

Goal NR-6 Mineral Resources

Mineral resource zones that allow extraction industries to continue supporting the regional and national economy while minimizing negative impacts on the public and natural environment.

Policy NR-6.1 **Mineral resource areas.** We prioritize the conservation of land area with mineral resources by prohibiting or discouraging development of land that would substantially preclude the future development of mining facilities in areas classified as Mineral Resource Zone (MRZ) 2a, 2b, or 3a.

Policy NR-6.2 **Mining operations and reclamation.** We require and monitor mineral extraction activities to ensure that the operation and reclamation of mined lands is consistent with the State Surface Mining and Reclamation Act of 1975 (SMARA).

Policy NR-6.3 **Conservation of construction aggregate.** We encourage the continued operation of existing mining facilities and streamline the permitting of new mining facilities (consistent with the Policy Plan and other local, state, and federal regulations) to establish aggregate resources that are sufficient to satisfy 50 years of county demand.

Goal NR-7 Agriculture and Soils

The ability of property owners, farmers, and ranchers to conduct sustainable and economically viable agricultural operations.

Policy NR-7.1 **Protection of agricultural land.** We protect economically viable and productive agricultural lands from the adverse effects of urban encroachment, particularly increased erosion and sedimentation, trespass, and non-agricultural land development.

Policy NR-7.2 **Preservation of important farmlands.** We require project applicants seeking to develop 20 or more acres of farmland (classified as prime, of statewide importance, or unique farmland) to non-agricultural uses to prepare an agricultural resource evaluation prior to project approval. The evaluation shall use generally accepted methodologies to identify the potentially significant impact of the loss of agricultural land as well as the economic viability and sustainability of future agricultural use of the property, including long-term sustainability and economic viability of water resources. If the conversion is deemed significant, the County shall require mitigation at a 1:1 ratio of converted to preserved acreage through conservation easements, payment of its valuation equivalent if a fee mitigation program is established, or inclusion in a regional agricultural preservation program.

Policy NR-7.3 **Conservation and preservation incentives.** We support programs and policies that provide tax and economic incentives to conserve existing productive agricultural lands or preserve farmland classified as prime, of statewide importance, unique, or of local importance. We support land owners in establishing new and maintaining existing California Land Conservation (Williamson Act) contracts.

Policy NR-7.4 **Economic diversity of farm operations.** We encourage farm operations to strengthen their economic viability through diversifying potential sources of farm income and activity, including value added products, agricultural tourism, roadside stands, organic farming, and farmers markets.

Policy NR-7.5 **Agriculture on Rural Living and Open Space properties.** We permit small-scale, non-water-intensive, and incidental agricultural on properties designated for Rural Living. In the Oak Glen and Mentone community planning areas, we also permit commercial-scale agriculture on properties designated for Rural Living. In the Oak Glen and Mentone community planning areas and in the Crafton Hills, we also permit commercial-scale agriculture on privately-owned properties designated for Open Space.

Policy NR-7.6 **Sustainable grazing practices.** We require all grazing on open rangelands to be compatible with the conservation of threatened and endangered species.

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Renewable Energy and Conservation Element (placeholder for element adopted in 2017 and amended in February 2019)

This page is a placeholder for the Renewable Energy and Conservation Element (RECE), which was adopted in 2017 and amended in February 2019 and is not being updated through the Countywide Plan. The RECE will be incorporated in its entirety into the Countywide Plan upon its adoption.

On February 28, 2019, the Board of Supervisors voted to prohibit utility-oriented renewable energy development in the Rural Living land use district, currently adopted Community Plan areas, and other areas as determined in the Development Code update.

Additional policy amendments were adopted regarding a focus on using existing energy generation sites and greater collaboration to encourage development of utility-oriented renewable energy generation facilities on public lands, apart from unincorporated communities.

The adopted changes (see below) will be reflected in the Countywide Plan. This webpage will be updated with the updated element in the near future.

The amendments became effective immediately upon adoption of the resolution. Any application for development of a renewable energy generation project that had been accepted as complete in compliance with California Government Code Section 65943 before the effective date of the resolution is to be processed in compliance with the policies and regulations in effect at the time the application was accepted as complete. These applications may be relocated to other sites under the same policies and regulations.

AMENDMENTS: The text of the Renewable Energy and Conservation Element was amended to add RE Policy 4.10, replace RE Policy 5.2, and add RE Policy 5.9 to read as follows:

RE Policy 4.10: Prohibit utility-oriented RE project development on sites that would create adverse impacts on the quality of life or economic development opportunities in existing unincorporated communities. Any exceptions or revisions to the following policy direction would require approval by the Board of Supervisors.

> **RE 4.10.1:** Prohibit development of utility-oriented RE projects in the Rural Living land use districts throughout the County.
>
> **RE 4.10.2:** Prohibit development of utility-oriented RE projects within the boundaries of existing community plans, which at the time of adoption of this Element are the Bloomington, Muscoy, Bear Valley, Crest Forest, Hilltop, Lake Arrowhead, Lytle Creek, Oak Glen, Homestead Valley, Joshua Tree, Lucerne Valley, Morongo Valley, Oak Hills and Phelan/Pinon Hills Community Plans.
>
> **RE 4.10.3:** Establish exclusion areas in the Development Code regulations for renewable energy development, beginning with the prohibitions in Policies 4.10.1 and 4.10.2 and provide for additional exclusion areas, such as new community plan areas, to be designated by amendment to the Development Code.

RE Policy 5.2: Utility-oriented RE generation projects on private land in the unincorporated County will be limited to the site-types below, in addition to meeting criteria established herein and in the Development Code:

i. Private lands adjacent to the federal Development Focus Areas supported by the Board of Supervisors that meet siting criteria and development standards

ii. Waste disposal sites
iii. Mining sites (operating and reclaimed)
iv. Fallow, degraded and unviable agricultural lands
v. Airports (existing and abandoned or adaptively re-used)
vi. Brownfields
vii. California Department of Toxic Substance Control Cleanup Program sites
viii. Resource Conservation and Recovery Act sites
ix. Sites within or adjacent to electric transmission and utility distribution corridors
x. Existing energy generation sites
xi. Industrial zones proven to not conflict with economic development needs
xii. Other sites proven by a detailed suitability analysis to reflect the significantly disturbed nature or conditions of those listed above

RE Policy 5.9: Collaborate with utilities, the California Energy Commission (CEC) and the Bureau of Land Management (BLM) to plan for RE generation facilities to be located on public lands, apart from existing unincorporated communities.

Cultural Resources Element

Cultural resources provide both tangible and intangible links to the past. Such resources may include archaeological sites, sacred landscapes, historic buildings, and even culturally important plants and animals. These resources are valuable in that they can serve to recognize the diversity of our county's many previous, current, and future inhabitants. Not only can a resource be a memorial to historical events and individuals, but it can also be an important object/place of modern cultural significance, as well as be something that will contribute to the continuance of a community's cultural identity. Additionally, paleontological resources, which most commonly manifest as fossils related to animals, plants, and the ecosystem, provide great insight into our county's past prior to human habitation. As such, it is vital that we find and implement culturally appropriate ways to preserve and conserve these resources, while also continuing to grow and develop in the unincorporated parts of our county.

Purpose

The Cultural Resources Element:

- Establishes direction on notification, coordination, and partnerships to preserve and conserve cultural resources.
- Provides guidance on how new development can avoid or minimize impacts on cultural resources.
- Provides direction on increasing public awareness and education efforts about cultural resources.

Principles

We believe:

- Today's generations are stewards of the county's cultural history and are responsible for conserving it for future generations.
- Preserving and celebrating cultural resources enhances our understanding of the world in which we live.
- Cultural resources are valuable assets that attract visitors and support local businesses.

Goals & Policies

Goal CR-1 Tribal Cultural Resources

Tribal cultural resources that are preserved and celebrated out of respect for Native American beliefs and traditions.

Policy CR-1.1 **Tribal notification and coordination.** We notify and coordinate with tribal representatives in accordance with state and federal laws to strengthen our working relationship with area tribes, avoid inadvertent discoveries of Native American archaeological sites and burials, assist with the treatment and disposition of inadvertent discoveries, and explore options of avoidance of cultural resources early in the planning process.

Policy CR-1.2 **Tribal planning.** We will collaborate with local tribes on countywide planning efforts and, as permitted or required, planning efforts initiated by local tribes.

Policy CR-1.3 **Mitigation and avoidance.** We consult with local tribes to establish appropriate project-specific mitigation measures and resource-specific treatment of potential cultural resources. We require project applicants to design projects to avoid known tribal cultural resources, whenever possible. If avoidance is not possible, we require appropriate mitigation to minimize project impacts on tribal cultural resources.

Policy CR-1.4 **Resource monitoring.** We encourage coordination with and active participation by local tribes as monitors in surveys, testing, excavation, and grading phases of development projects with potential impacts on tribal resources.

Goal CR-2 Historic and Paleontological Resources

Historic resources (buildings, structures, or archaeological resources) and paleontological resources that are protected and preserved for their cultural importance to local communities as well as their research and educational potential.

Policy CR-2.1 **National and state historic resources.** We encourage the preservation of archaeological sites and structures of state or national significance in accordance with the Secretary of Interior's standards.

Policy CR-2.2 **Local historic resources.** We encourage property owners to maintain the historic integrity of resources on their property by (listed in order of preference): preservation, adaptive reuse, or memorialization.

Policy CR-2.3 **Paleontological and archaeological resources.** We strive to protect paleontological and archaeological resources from loss or destruction by requiring that new development include appropriate mitigation to preserve the quality and integrity of these resources. We require new development to avoid paleontological and archeological resources whenever possible. If avoidance is not possible, we require the salvage and preservation of paleontological and archeological resources.

Policy CR-2.4 **Partnerships.** We encourage partnerships to champion and financially support the preservation and restoration of historic sites, structures, and districts.

Policy CR-2.5 **Public awareness and education.** We increase public awareness and conduct education efforts about the unique historic, natural, tribal, and cultural resources in San Bernardino County through the County Museum and in collaboration with other entities.

Safety & Security Section

Hazards Element

The massive scale of the county's geography and the complexity of its economy and socioeconomics exposes people, buildings, and facilities to a wide range of natural (wildfires, flooding, geologic activity, and wind) and human-generated hazards (hazardous materials, airports, and noise). Reducing the risks associated with such hazards improves real and perceived senses of safety, providing the county with a higher quality of life and spurring continuous investment and improvement of the county's communities, businesses, and natural areas.

The County is committed to protecting life, property, and commerce from impacts associated with natural hazards, human-generated hazards, and increased risk due to climate change. The County also works to ensure that residents in unincorporated disadvantaged communities have a reduced risk of exposure to pollution and have equitable access to public facilities and services. Effectively reducing these risks requires the County and its partners to evaluate public safety threats, proactively plan and protect against potential hazards, and establish systems that will make the county and its people safer and more self-reliant.

Purpose

The Hazards Element:

- Identifies potential natural and human-generated hazards, including increased risk due to climate change.
- Provides direction to address risks to residents, businesses, workers, and visitors.
- Prioritizes resources and reduce pollution exposure in unincorporated disadvantaged communities.

Principles

We believe:

- A safe environment is necessary to build and maintain a sustainable and prosperous county.
- The County is proactive in lessening risks from natural and human-generated hazards.
- Reduction in the loss of life, injury, private property damage, infrastructure damage, economic losses, and social dislocation can be achieved through planning and preparedness.
- Emergency response and recovery efforts contribute to a resilient county, given unavoidable emergencies and natural disasters.
- Those who live in unincorporated disadvantaged communities should not be burdened with elevated exposure to pollution risks and reduced access to public facilities and services.

Goals & Policies

Goal HZ-1 Natural Environmental Hazards

Minimized risk of injury, loss of life, property damage, and economic and social disruption caused by natural environmental hazards and adaptation to potential changes in climate.

Policy HZ-1.1 **New subdivisions in environmental hazard areas.** We require all lots and parcels created through new subdivisions to have sufficient buildable area outside of the following environmental hazard areas:

- Flood: 100-year flood zone, dam/basin inundation area
- Geologic: Alquist Priolo earthquake fault zone; County-identified fault zone; rockfall/debris-flow hazard area, existing and County-identified landslide area

Policy HZ-1.2 **New development in environmental hazard areas.** We require all new development to be located outside of the environmental hazard areas listed below. For any lot or parcel that does not have sufficient buildable area outside of such hazard areas, we require adequate mitigation, including designs that allow occupants to shelter in place and to have sufficient time to evacuate during times of extreme weather and natural disasters.

- Flood: 100-year flood zone, dam/basin inundation area
- Geologic: Alquist Priolo earthquake fault zone; County-identified fault zone; rockfall/debris-flow hazard area, medium or high liquefaction area (low to high and localized), existing and County-identified landslide area, moderate to high landslide susceptibility area)
- Fire: high or very high fire hazard severity zone

Policy HZ-1.3 **Floodplain mapping.** We require any new lots or subdivisions partially in, and any new development partially or entirely in 100-year flood zones or 100-year flood awareness areas to provide detail floodplain mapping for 100- and 200-year storm events as part of the development approval process.

Policy HZ-1.4 **500-year flood zone.** We may collaborate with property owners in the Valley region to establish funding and financing mechanisms to mitigate flood hazards in identified 500-year flood zones.

Policy HZ-1.5 **Existing properties in environmental hazard areas.** We encourage owners of existing properties in hazard areas to add design features that allow occupants to shelter in place and to have sufficient time to evacuate during times of extreme weather and natural disasters.

Policy HZ-1.6 **Critical and essential facility location.** We require new critical and essential facilities to be located outside of hazard areas, whenever feasible.

Policy HZ-1.7 **Underground utilities.** We require that underground utilities be designed to withstand seismic forces, accommodate ground settlement, and hardened to fire risk.

Policy HZ-1.8 **Wind erosion hazards.** We require new development in medium-high or high wind erosion hazard areas to minimize the effects of wind-blown soil through building and site design features such as fencing, surface treatment or pavement, attenuation or wind barriers, architectural features, building materials, and drought resistant landscaping.

Policy HZ-1.9 **Hazard areas maintained as open space.** We minimize risk associated with flood, geologic, and fire hazard zones or areas by encouraging such areas to be preserved and maintained as open space.

Policy HZ-1.10 **Energy independence.** We encourage new residential development to include rooftop solar energy systems and battery storage systems that can provide backup electrical service during temporary power outages.

Policy HZ-1.11 **Energy efficiency retrofits.** We encourage owners of existing residential and commercial properties to retrofit the walls, doors, windows, ceilings, roofs, ductwork, and other elements of their building envelopes, in order to improve energy efficiency and better protect occupants from extreme temperatures.

Policy HZ-1.12 **Local hazard mitigation plan implementation.** We require adherence to the goals, objectives and actions in the Multi-jurisdictional Hazard Mitigation Plan and subsequent amendments to reduce and mitigate damages from hazards in the county.

Policy HZ-1.13 **Fire protection planning.** We require that all new development in County-designated Fire Safety Overlay and/or CAL FIRE-designated Very High Fire Hazard Severity Zones meet the requirements of the California Fire Code and the California Building Code as amended by the County Fire Protection District, including Title 14 of the California Code of Regulations fire safety requirements for any new development within State Responsibility Areas, as well as provide and maintain a Fire Protection Plan or Defensible Space/Fuel Modification Plan and other pre-planning measures in accordance with the County Code of Ordinances.

Policy HZ-1.14 **Long-term fire hazard reduction and abatement.** We require proactive vegetation management/hazard abatement to reduce fire hazards on existing private properties, along roadsides of evacuation routes out of wildfire prone areas, and other private/public land where applicable, and we require new development to enter into a long-term maintenance agreement for vegetation management in defensible space, fuel modification, and roadside fuel reduction in the Fire Safety Overlay and/or Very High Fire Hazard Severity Zones.

Policy HZ-1.15 **Evacuation route adequacy.** We coordinate with CAL FIRE, California's Office of Emergency Services, and other local fire districts to identify strategies that ensure the maintenance and reliability of evacuation routes potentially compromised by wildfire, including emergency evacuation and supply transportation routes.

Goal HZ-2 Human-generated Hazards

People and the natural environment protected from exposure to hazardous materials, excessive noise, and other human-generated hazards.

Policy HZ-2.1 **Hazardous waste facilities.** We regulate and buffer hazardous waste facilities to protect public health and avoid impacts on the natural environment.

Policy HZ-2.2 **Database of hazardous materials.** We maintain up-to-date databases of the storage, use, and production of hazardous materials, based on federally- and state-required disclosure and notification, to appropriately respond to potential emergencies.

Policy HZ-2.3 **Safer alternatives.** We minimize the use of hazardous materials by choosing and by encouraging others to use non-toxic alternatives that do not pose a threat to the environment.

Policy HZ-2.4 **Truck routes for hazardous materials.** We designate truck routes for the transportation of hazardous materials through unincorporated areas and prohibit routes that pass through residential neighborhoods to the maximum extent feasible.

Policy HZ-2.5 **Community education.** We engage with residents and businesses to promote safe practices related to the use, storage, transportation, and disposal of hazardous materials.

Policy HZ-2.6 **Coordination with transportation authorities.** We collaborate with airport owners, FAA, Caltrans, SBCTA, SCAG, neighboring jurisdictions, and other transportation providers in the preparation and maintenance of, and updates to transportation-related plans and projects to minimize noise impacts and provide appropriate mitigation measures.

Policy HZ-2.7 **Truck delivery areas.** We encourage truck delivery areas to be located away from residential properties and require associated noise impacts to be mitigated.

Policy HZ-2.8 **Proximity to noise generating uses.** We limit or restrict new noise sensitive land uses in proximity to existing conforming noise generating uses and planned industrial areas.

Policy HZ-2.9 **Control sound at the source.** We prioritize noise mitigation measures that control sound at the source before buffers, soundwalls, and other perimeter measures.

Policy HZ-2.10 **Agricultural operations.** We require new development adjacent to existing conforming agricultural operations to provide adequate buffers to reduce the exposure of new development to operational noise, odor, and the storage or application of pesticides or other hazardous materials.

Policy HZ-2.11 **Legacy abandoned mine lands.** We inventory legacy abandoned mines and require private property owners to eliminate hazardous conditions that could threaten human life and environmental contamination. We pursue funding to address legacy abandoned mines on County-owned property.

Goal HZ-3 Environmental Justice

For unincorporated environmental justice focus areas, equitable levels of protection from environmental and health hazards; expanded opportunities for physical activity and meaningful civic engagement; and access to healthy food, public facilities, safe and sanitary housing.

Policy HZ-3.1 **Health risk assessment.** We require projects processed by the County to provide a health risk assessment when a project could potentially increase the incremental cancer risk by 10 in 1 million or more in unincorporated environmental justice focus areas, and we require such assessments to evaluate impacts of truck traffic from the project to freeways. We establish appropriate mitigation prior to the approval of new construction, rehabilitation, or expansion permits.

Policy HZ-3.2 **Studying and monitoring.** We coordinate with state and regional regulatory entities to monitor pollution exposure, publicize pollution data, and identify solutions in unincorporated environmental justice focus areas. We work with state and regional regulatory entities to pursue grant funding to study cumulative health risks affecting such areas.

Policy HZ-3.3 **Community emissions reduction plans.** We assist the air quality management districts in establishing community emissions reduction plans for unincorporated environmental justice focus areas and implement, as feasible, those parts of the plans, that are within the jurisdiction and authority of the County, with particular emphasis in addressing the types of pollution identified in the Hazard Element tables.

Policy HZ-3.4 **Residential improvements.** In directing discretionary housing improvements investments in unincorporated communities, we encourage and prioritize investments that also address environmental conditions identified in the Hazard Element tables. We utilize code enforcement activities to enhance structural safety and property maintenance in environmental justice focus areas.

Policy HZ-3.5 **Hazardous waste facilities.** We do not permit new hazardous waste facilities to be developed in unincorporated environmental justice focus areas.

Policy HZ-3.6 **Contaminated water and soils.** We advocate for and coordinate with local and regional agencies in efforts to remediate or treat contaminated surface water, groundwater, or soils in or affecting unincorporated environmental justice focus areas. We pursue grant funding and establish partnerships to implement the County's Site Remediation Program in unincorporated environmental justice focus areas, with particular emphasis in addressing the types of contamination identified in the Hazard Element tables.

Policy HZ-3.7 **Well water testing.** In unincorporated environmental justice focus areas that are not served by public water systems, we periodically test well water for contamination, identify potential funding sources, and, where feasible, provide technical assistance to implement necessary improvements, with particular emphasis in addressing the types of contamination identified in the Hazard Element tables.

Policy HZ-3.8 **Indoor air quality.** We educate and raise awareness in unincorporated environmental justice focus areas about indoor air quality, and we pursue grant funding to address asthma and other respiratory illnesses.

Policy HZ-3.9 **Public improvements and services.** In directing discretionary investments in County-provided public facilities, infrastructure, and services in unincorporated communities, we prioritize investments that also address environmental conditions identified in the Hazard Element tables.

Policy HZ-3.10 **Multi-use facilities.** We emphasize coordination efforts for joint use of public and private recreation facilities serving unincorporated environmental justice focus areas. We encourage that newly constructed or substantially remodeled public facilities serving unincorporated environmental justice focus areas be assessed and designed for features and spaces that improve the community's access to physical activity and/or healthy food options, as feasible and appropriate to the needs of the community.

Policy HZ-3.11 **Public Health.** We utilize County Department of Public Health experience, expertise, and staffing resources to expand and improve outreach, community engagement, analysis, and implementation efforts in unincorporated environmental justice focus areas, with particular emphasis in addressing the types of health concerns identified in the Hazard Element tables.

Policy HZ-3.12 **Barriers to physical activity.** We prioritize identification of appropriate remedies to improve and remove, where feasible, barriers to outdoor physical activity, such as inadequate infrastructure, when doing County projects in environmental justice focus areas, with particular emphasis in addressing the types of health and mobility issues identified in the Hazard Element tables.

Policy HZ-3.13 **Safe routes to school**. We work with our regional transportation authority, school districts and local law enforcement to ensure that schools have safe walking and bicycling routes to school. In applying for Safe Routes to School grants, we will prioritize schools that are either located in the environmental justice focus areas, or serve children residing in environmental justice focus areas.

Policy HZ-3.14 **Community-desired improvements.** We assist unincorporated environmental justice focus areas to identify ways in which they might establish special funding and financing mechanisms to provide community-desired public facilities and services, recreational facilities, sidewalks and bike trails, and access to fresh and healthy food.

Policy HZ-3.15 **Food access.** We increase access to healthy food in underserved areas by promoting local food production, community gardens, and urban farms in agricultural zoning districts or on vacant or underutilized lands. We also encourage existing and new small grocery or convenience stores to sell fresh foods in underserved areas. We require the County Healthy Communities Program to prioritize environmental justice communities for technical assistance and grant making, and ensure that residents of environmental justice communities are provided educational materials related to food assistance programs, healthy eating habits and food choices.

Policy HZ-3.16 **Notification.** We notify the public through the County website, mail, and other means when applications are accepted for conditional use permits, changes in zoning, and Policy Plan amendments in or adjacent to environmental justice focus areas. We prepare public notices in the predominant language(s) spoken in the communities containing environmental justice focus areas.

Policy HZ-3.17 **Community stakeholders.** We identify and coordinate with key community stakeholders through advisory committees or other methods to increase public awareness and obtain timely community input concerning potential funding opportunities, conditional use permits, changes in zoning, and amendments to the Policy Plan in or adjacent to environmental justice focus areas.

Policy HZ-3.18 **Application requirements.** In order for a Planning Project Application (excluding Minor Use Permits) to be deemed complete, we require applicants to indicate whether the project is within, adjacent to, or nearby an unincorporated environmental justice focus area and, if so, to:

- document to the County's satisfaction how an applicant will address environmental justice concerns potentially created by the project; and
- present a plan to conduct at least two public meetings for nearby residents, businesses, and property owners to obtain public input for applications involving a change in zoning or the Policy Plan. The County will require additional public outreach if the proposed project changes substantively in use, scale, or intensity from the proposed project presented at previous public outreach meeting(s).

Policy HZ-3.19 **Community education.** We make educational materials available to the public in unincorporated environmental justice focus areas so that they clearly understand the potential for adverse pollution, noise, odor, vibration, and lighting and glare, and the effects of toxic materials to promote civil engagement. We require that such educational materials be developed in accordance with Plain Language Guidelines. We require that this information be made available in public spaces such as libraries and community centers, as well as on County websites and other appropriate means.

Policy HZ-3.20 **Updating EJFAs.** We update the assessment of boundaries, issues, policies, objectives, and implementation strategies regarding environmental justice focus areas subsequent to updates in CalEnviroScreen, equivalent state tools, or as the County deems necessary.

Policy HZ-3.21 **Emerging pollutants.** For pollutants that do not yet have established regulatory thresholds, we coordinate with regulatory agencies to assist their efforts to monitor pollutant levels, establish thresholds, and identify funding and mitigation options, particularly for pollutants that are found in environmental justice focus areas.

Tables

The following tables provide more detailed information on the census tracts and community areas considered to be environmental justice focus areas (EJFAs). Table HZ-1 lists the percentile scores and major contributing factors for each EJFA. Tables HZ-2 through HZ-5 provide an expanded discussion of the contributing issues present in each EJFA by topical area, while Table HZ-6 lists high-level objectives for each topic.

Table HZ-1. CalEnviroScreen Scores for Environmental Justice Focus Areas

CES Rankings	Quartile 1 = Good	Quartile 2 = Moderate	Quartile 3 = Poor	Quartile 4 = Challenged

Variables/Factors in the CES model:

POLLUTION EXPOSURE	ENVIRONMENTAL EFFECTS	SENSITIVE POPULATION	SOCIOECONOMIC FACTORS
AQ = Air Quality	CS = Toxic Cleanup Sites	AS = Asthma	LI = Linguistic Isolation
PEST = Pesticides	GW: Groundwater Threats	LB = Low Birth Weight	POV = Poverty
DW = Drinking Water	HZ = Hazardous Waste	CVD = Heart Disease	UE = Unemployment
TR = Toxic Releases	IW = Impaired Waters		HB = Housing Burden
TD = Traffic Density	SW = Solid Waste Sites/Facilities		ED = Educational Attainment
LD = Lead from Housing			

Census Tract	Low Income	Percentile and Quartile Rank			Scores in the Upper Quartile	
		Composite Score	Pollution Score	Population Score	Pollution Factors	Population Factors
El Mirage Valley						
6071011700 Oro Grande	Yes	81	72	79	AQ, HZ, SW	LB, POV, UE
6071009117 El Mirage	Yes	89	65	95	AQ, CS, HZ	AS, CVD, ED, POV, UE, HB
North High Desert						
6071011900 Hinkley	No	78	59	83	AQ, CS, GW, HZ	AS, CVD, ED, UE
6071010300 Daggett/ Newberry Springs/Baker	Yes	75	62	77	AQ, DW, CS, GW, HZ, SW	LB, POV, UE
Bloomington-Colton						
6071003606	Yes	77	80	66	AQ, TD, DW	AS, CVD, ED, LI, POV
6071004001	Yes	94	88	89	AQ, TD, DW	AS, CVD, ED, LI, POV, UE
6071004003	Yes	95	91	89	AQ, DW, LD, GW, HZ, SW	AS, LB, CVD, ED
6071004004	Yes	96	99	76	AQ, TD, DW, CS, GW, HZ, SW	AS, LB, CVD, ED
6071003302	Yes	91	95	75	AQ, TR, TD, DW, SW	ED, LI, POV, UE
6071006601	Yes	78	83	65	AQ, TD, LD	AS, CVD

Table HZ-1. CalEnviroScreen Scores for Environmental Justice Focus Areas

CES Rankings	Quartile 1 = Good	Quartile 2 = Moderate	Quartile 3 = Poor	Quartile 4 = Challenged

Variables/Factors in the CES model:

POLLUTION EXPOSURE	ENVIRONMENTAL EFFECTS	SENSITIVE POPULATION	SOCIOECONOMIC FACTORS
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TR = Toxic Releases	IW = Impaired Waters		HB = Housing Burden
TD = Traffic Density	SW = Solid Waste Sites/Facilities		ED = Educational Attainment
LD = Lead from Housing			

Census Tract	Low Income	Percentile and Quartile Rank			Scores in the Upper Quartile	
		Composite Score	Pollution Score	Population Score	Pollution Factors	Population Factors
Muscoy-San Bernardino						
6071004104	Yes	95	77	99	AQ, LD, CS	AS, LB, CVD, ED, LI, POV, UE, HB
6071004101	Yes	86	63	93	AQ, LD, CS	AS, LB, CVD, ED, POV, UE
6071004103	Yes	92	77	94	AQ, LD, CS	AS, CVD, ED, POV, UE, HB
Valley Unincorporated Islands: Chino-Montclair						
6071000303	Yes	84	91	67	AQ, DW, CS, HZ, SW	ED, LI, POV
6071000304	No	84	78	79	AQ, DW, CS	LB, ED, LI
Valley Unincorporated Islands: Western Fontana						
6071002402	Yes	81	66	83	AQ, HZ	CVD, ED, LI, POV
6071002204	Yes	93	96	77	AQ, TR, CS, HZ, SW	CVD, ED, UE
6071002501	No	91	92	79	AQ, TR, TD, HZ, SW	CVD, ED, POV
6071002401	Yes	84	79	79	AQ, CS, HZ	CVD, ED, LI, POV
Valley Unincorporated Islands: San Bernardino						
6071006302	Yes	83	56	93	AQ, DW, LD	AS, CVD, ED, POV, UE, HB
6071006500	Yes	87	66	93	AQ, LD, CS	CVD, ED, POV, UE, HB
6071006100	Yes	78	48	91	AQ, DW, LD	AS, LB, CVD, HB

Source: OEHHA, CalEnviroScreen, version 4, 2021; latest data available.

Table HZ-2. EJ Assessment in the El Mirage Valley

Topic	Environmental Conditions
Reduction of pollution exposure and improving air quality	**Pollution Exposure** El Mirage has hazardous waste cleanup sites from past military and aerospace uses, groundwater threats, and a remediated/closed hazardous waste storage facility.
	Air Quality El Mirage and Oro Grande are in the Mojave Air Quality Management District. Like much of southern California, the region has air quality issues. The region does not meet federal standards for ozone and respirable particulate matter (PM10) or state standards for ozone and respirable and fine PM2.5.
Promoting public facilities (including infrastructure and community services)	**Water and Sewer** El Mirage has limited water infrastructure and relies on private wells that tap into the aquifer. El Mirage is also reliant on septic tanks and leach fields, with no ability to support the installation of a regional wastewater treatment plant due to the extremely low levels of population and density. Groundwater has been known to be vulnerable to contaminants. Oro Grande has sufficient water, but lacks adequate storage, is a high priority basin, and is susceptible to contaminants.
	Fire and Sheriff County Fire Station 311 serves El Mirage and responds in an average of 19 minutes. Station 322 serves Oro Grande at an average response time of 8 minutes due primarily to the extremely low levels of population and density. Police service is provided by the County Sheriff in Victorville and response time is not known.
Promoting health care Infrastructure	**Health Needs** Health needs for El Mirage and Oro Grande are significant—including a 39% adult obesity (13 points above the state average), 30% of working age adults in fair or poor health (50% higher than state averages), 14% diabetes rate (50% above the state average), and higher asthma rates among adults. Heart disease is also a significant concern in the area.
	Health Care Infrastructure Both El Mirage and Oro Grande are designated a HPSA for mental health and primary care services and is a medically underserved area. Both areas have limited medical infrastructure, and residents must travel some distance to access facilities in other communities

Table HZ-2. EJ Assessment in the El Mirage Valley

Topic	Environmental Conditions
Promoting food access	**Food Security** The poverty rate in El Mirage and Oro Grande is 30%, which is twice the state average. As a result, food insecurity is similarly high, affecting 16% of low income households, twice the state average. In El Mirage and Oro Grande schools, over 70% of children are eligible for free or reduced-price meals.
	Food Access El Mirage has limited grocery outlets, located in a cluster near SR-395 in Adelanto. There are no WIC (Women, Infants, and Children) vendors and only one Cal-Fresh-certified vendor in El Mirage. Due to the general lack of access to nearby stores, El Mirage is designated a food desert. Oro Grande also has limited food options, but is not considered a food desert due to its access to stores in Victorville.
Promoting safe and sanitary housing	**Housing** As part of the consolidated plan process, residents indicated a need to promote safe and sanitary housing. Although housing is relatively affordable in El Mirage and Oro Grande compared to other areas, concerns remain. Residents mentioned that abandoned homes should be demolished or rehabbed; code enforcement is understaffed; more is needed.
Promoting physical activity	**Level of Physical Activity** Among youth ages 5 to 17, 26% participated in at least of one hour of physical exercise regularly versus 24% in the county and 21% in the state. For adults, the percentages of adults who walked more than 150 minutes per week was lower in the area versus the county and state averages.
	Opportunities for Physical Activity Recreational outlets include trails and outdoor sports, including opportunities in state and federal parks. The unincorporated areas in the community plan areas have few developed parks. Road have limited pedestrian and bicycling facilities. This is not uncommon for desert roads.
Civil Engagement	**Community Participation** With daytime Planning Commission and Board of Supervisors meetings and a conventional notification process, it can be difficult for residents in this area to learn about and provide input on proposed development in a timely manner that substantively and effectively impacts the decision making process. Additionally, this area is far from public meeting sites, most households do not have good internet access, and approximately 11 percent of households do not speak English well.

Table HZ-3. EJ Assessment in the North High Desert

Topic	Environmental Conditions
Reduction of pollution exposure and improving air quality	**Pollution Exposure** The area's primary exposure to pollution is groundwater threats, hazardous wastes, and solid wastes. It should be noted, however, that this area extends 200 square miles to the Nevada border. Many of these pollutant sources are in unpopulated areas, far from Daggett, Newberry Springs, and Yermo.
	Air Quality This area is in the Mojave Air Quality Management District. Although the area has very high levels of ozone, there are few other appreciable air pollutants, except for a small area around the Barstow BNSF railyard, which has high levels of diesel particulate matter.
Promoting public facilities (including infrastructure and community services)	**Water and Sewer** LAFCO identified Daggett as a hotspot for insufficient water supply, water quality concerns, deficient infrastructure, and financial concerns. Unincorporated areas rely on individual septic systems. Drinking water is known to be at risk of contamination from nitrate, lead, and radioactive elements.
	Fire and Sheriff County Sheriff's Barstow Station serves this area; response times are not available. County Fire provides fire protection services from stations #52, #53, #56, and #4. Response times vary—from 20 to 50 minutes depending on staffing for the paid-call firefighter station.
Promoting health care Infrastructure	**Health Needs** Health issues include a 28% obesity rate and 10% diabetes rate—all close to state averages. Despite more modest income levels compared to other parts of the county, the health conditions of residents are better than many other areas of the county.
	Health Care Infrastructure Currently, the area is designated an HPSA for primary care, mental health, and dental services and a medically underserved area/population. There is a significant need for all the major medical services; residents must now travel to Barstow for service.
Promoting food access	**Food Security** The poverty rate in the area for adults is high (21%), far above the state average, and 11% of low income households are food insecure. Food insecurity affects children in the area as well. Approximately 78% of children in Barstow Unified School District were eligible for free/reduced-price meals in 2016.
	Food Access Except for small markets, these areas lack a full-service grocery store, and residents must drive to Barstow. There are no WIC vendors or Cal-Fresh–certified vendor closer than Barstow. Due to limited access to grocery stores, the entire area is designated a food desert by the USDA.

Table HZ-3. EJ Assessment in the North High Desert

Topic	Environmental Conditions
Promoting safe and sanitary housing	**Housing** Limited information is available about safe and sanitary housing in the area. Generally, the housing stock has a high proportion of mobile home units on septic service. Given the construction type and age of structures, there is a significant need to rehabilitate aging housing and demolish abandoned or dilapidated homes. Code enforcement issues may be concentrated in certain areas as well.
Promoting physical activity	**Level of Physical Activity** State physical fitness tests show one-third of students need improvement in aerobic capacity. However, the percentage of youth (age 5–17) getting regular physical activity is greater (31%) than in California (21%). The level of physical activity (measured by walking) among adults is lower than state averages.
	Opportunities for Physical Activity Recreational outlets include trails, hiking, and outdoor sports. Outside of Barstow and schools, formal park facilities are limited to Newberry Springs Park. Roadways have no pedestrian and bicycling facilities or other amenities. However, residents can walk and bicycle on public streets because traffic is very light.
Civil Engagement	**Community Participation** With daytime Planning Commission and Board of Supervisors meetings and a conventional notification process, it can be difficult for residents in this area to learn about and provide input on proposed development in a timely manner that substantively and effectively impacts the decision making process. Many parts of this area are far from public meeting sites. Additionally, the Daggett, Newberry Springs, and Baker communities do not have good internet access and approximately 10 percent of households do not speak English well.

Table HZ-4. EJ Assessment in Bloomington and Muscoy

Topic	Environmental Conditions
Reduction of pollution exposure and improving air quality	**Pollution Exposure** Nearly all census tracts (11 of 13) have high levels of air pollution and drinking water contamination concerns. Other pollution exposure issues include traffic density, toxic releases form industry, hazardous waste and cleanup sites from military and industrial land uses.
	Air Quality This area is in the South Coast Air Quality Management District and as a nonattainment status for ozone and particulate matter. Pollutant concentrations are high for particulate matter, including diesel particulate matter due to trucking routes in and around both communities.
Promoting public facilities (including infrastructure and community services)	**Water and Sewer** Water and sewer challenges are significant. For Muscoy, water service is provided by the Muscoy Mutual Water Company, and septic tanks and leach fields are used for its wastewater needs. For Bloomington, several water districts provide potable water for the community. For sewer, Bloomington was also developed with reliance on septic tanks and leach field systems.
	Fire and Sheriff San Bernardino County Fire Station #75 serves Muscoy, and response times are 4 to 6 minutes, which is generally with NFPA standards. Bloomington Fire Station #76 serves the community and response times are unknown but are assumed to be also within NFPA standards due to the size of the community. Both areas are served by County Sheriff and response times were not available.
Promoting health care Infrastructure	**Health Needs** Within this area, Muscoy has elevated levels of asthma and high levels of obesity (35%) versus statewide average of 26%, and emergency room admits for cardiovascular disease. For Bloomington, key health needs include diabetes, a 43% obesity rate, and high rate of emergency room admits for heart disease.
	Health Care Infrastructure Access to health-supporting land uses is mixed. While Bloomington is not defined as a HPSA, all areas south of I-10 are designated a medically underserved population/area. Muscoy is also not a HPSA, although utilization of existing clinics in the area is mixed.

Table HZ-4. EJ Assessment in Bloomington and Muscoy

Topic	Environmental Conditions
Promoting food access	**Food Security** The poverty rate in both Bloomington and Muscoy is high. Low income household food insecurity is high in Bloomington (13%) and Muscoy (10%) versus state averages (8%). County has designated both areas as an HPLA–high poverty low access food desert.
	Food Access Food access is generally poor. In Bloomington, the area south of I-10 is designated by the USDA as a food desert, bit other areas north of the I-10 have adequate access. Muscoy is also considered a food desert. There is a high preponderance of fast food outlets, liquor markets, and convenience stores.
Promoting safe and sanitary housing	**Housing** Limited information is available about safe and sanitary housing in the area. No code enforcement data are available. However, residents reported issues with the need for demolition and/or rehabilitation of homes, illegal dumping, junk and trash, and vacant homes in certain locations.
Promoting physical activity	**Level of Physical Activity** Among youth ages 5 to 17, 20% in Bloomington and 24% in Muscoy participated in at least of one hour of physical exercise regularly versus 24% in the county and 21% in the state. The percentage of adults who walked more than 150 minutes per week was lower in the area versus the county and state averages.
	Opportunities for Physical Activity Recreational outlets include bicycling, walking, and active recreation at parks. Roadways generally have limited pedestrian and bicycling facilities. Safety concerns (traffic and trucking) along streets makes active transportation uses generally not optimal.
Civil Engagement	**Community Participation** Despite the area's proximity to the primary County Government Center, daytime Planning Commission and Board of Supervisors meetings and a conventional notification process can make it difficult for residents in such areas to learn about and provide input on proposed development in a timely manner that substantively and effectively impacts the decision making process. Additionally, approximately 13 to 23 percent of households in Bloomington, 15 percent of households in the Colton SOI, and 5 to 13 percent of households in selected portions of Muscoy do not speak English well.

Table HZ-5. EJ Assessment in Valley Unincorporated Islands

Topic	Environmental Conditions
Reduction of pollution exposure and improving air quality	**Pollution Exposure** Pollution exposure is significant for valley unincorporated islands, particularly those located within or near to industrial land uses or transportation infrastructure. Locations and issues where the CES scores exceed the 75th percentile are as follows: Chino-Montclair: drinking water and toxic releases Western Fontana: toxic releases San Bernardino: toxic releases, lead from housing, drinking water, and cleanup sites
	Air Quality The San Bernardino Valley is in the South Coast Air Quality Management District and is designated as a nonattainment status for ozone and particulate matter. Pollutant concentrations are high for particulate matter, including diesel particulate matter due to trucking routes in these communities. Of concern, west Fontana and Chino-Montclair areas are near industrial centers. Toxic releases from industrial uses exceed the 75th percentile in every census tract within these two communities. None of the other census tracts in unincorporated San Bernardino or the Mentone area score high in toxic releases from industries.
Promoting public facilities (including infrastructure and community services)	**Water and Sewer** None of the four valley unincorporated islands were noted by the San Bernardino LAFCO as a hotspot for providing water. Wastewater service capacity is being studies by LAFCO. Based on technical reports for the countywide plan, infrastructure in all the unincorporated islands is able to provide water and sanitation services to support projected residential and nonresidential growth over the foreseeable future. However, it should be noted that drinking water contamination levels exceeded the 75th percentile in the Chino-Montclair and San Bernardino, unincorporated islands.
	Fire and Sheriff Chino-Montclair: Montclair FD and Chino Valley FD provides service; response times are unknown Western Fontana: County Station #72 serves west Fontana; response times are unknown San Bernardino: County Fire provides services to these areas; response times are unknown County Sheriff provides law enforcement services for all areas; response times are unknown

Table HZ-5. EJ Assessment in Valley Unincorporated Islands

Topic	Environmental Conditions
Promoting health care Infrastructure	**Health Needs** Chino-Montclair: high levels of diabetes (13%), obesity (37%), and emergency room visits for heart disease Western Fontana: high levels of diabetes (13%), obesity (41%), and emergency room visits for heart disease San Bernardino: high levels of diabetes (12%), obesity (40%), and emergency room visits for heart disease
	Health Infrastructure While the desert regions are known for a lack of health care infrastructure, most areas in the valley are fairly well-served with health care professionals, with a few exceptions by area. Chino-Montclair: not designated as a HPSA Western Fontana: not designated as a HPSA San Bernardino: designated as a HPSA for medically underserved area /population only
Promoting food access	**Food Security** A significant portion of children in these areas are eligible for free or reduced meals at local schools. With respect to household food insecurity, rates vary by community. Chino-Montclair: food insecurity similar to state (8%) and county averages (9%) Western Fontan: a-high levels of food insecurity among low income households (15%) San Bernardino: moderate levels of food insecurity among low income households (11%)
	Food Access Food access according to the USDA is generally good, with a few exceptions. Chino-Montclair: small portion along Mission Boulevard is a food desert Western Fontana: southeast quadrant is a food desert San Bernardino: selected unincorporated census tracts are food deserts
Promoting safe and sanitary housing	**Housing** There is no source of data documenting the condition of safe and sanitary housing in unincorporated islands. Most cities and the County do not track the data nor is this information included in consolidated plans or other mandated reports for individual areas. However, visual inspection indicates a need for housing rehabilitation, demolition of dilapidated structures, code enforcement concerns, property maintenance, and debris and vehicle clearance. While not all unincorporated islands display these issues, many of the lower income census tract areas have one or more of the above conditions affecting neighborhood quality.

Table HZ-5. EJ Assessment in Valley Unincorporated Islands

Topic	Environmental Conditions
Promoting physical activity	**Level of Physical Activity** Levels of physical activity are similar for most valley communities as follows. Chino-Montclair: 22% of youth exercised regularly and 30% of adults walked at least 150 minutes per week Western Fontana: 21% of youth exercised regularly and 31% of adults walked at least 150 minutes per week San Bernardino: 24% of youth exercised regularly and 30% of adults walked at least 150 minutes per week
	Opportunities for Physical Activity As the Valley is urbanized, there are ample opportunities for bicycling, walking, and active recreation at parks. Roadways generally have limited pedestrian and bicycling facilities. However, safety concerns (traffic and trucking) along streets makes active transportation uses generally not optimal. Certain neighborhoods may also have elevated levels of crime and vagrancy that may discourage use of physical activity opportunities.
Civil Engagement	**Community Participation** Despite the area's proximity to the primary County Government Center, daytime Planning Commission and Board of Supervisors meetings and a conventional notification process can make it difficult for residents in such areas to learn about and provide input on proposed development in a timely manner that substantively and effectively impacts the decision making process. Additionally, approximately 17 percent of households in the Montclair SOI, 14 to 17 percent of households in the western Fontana SOI, and 7 to 20 percent of households in the City of San Bernardino SOI do not speak English well.

Table HZ-6. Objectives for Unincorporated Environmental Justice Focus Areas

Topic	Objective
Reduction of pollution exposure and improving air quality	▪ **Contaminated soils.** Remediation of hazardous waste sites and other contaminated sites. ▪ **Water quality.** Improved water quality and elimination of groundwater threats**.** ▪ **Air quality.** Reduction of ozone emissions and particulate matter to levels that meet federal and state standards.
Promoting public facilities (including infrastructure and community services)	▪ **Fire and Sheriff.** Improved response times for public safety services. ▪ **Public facilities.** Improved access to existing and new public facilities that serve community needs for safety, health, and physical activity. ▪ **Water and wastewater infrastructure.** Adequate leach fields for onsite wastewater treatment systems and safe drinking water.
Promoting health care Infrastructure	▪ **Health needs and infrastructure.** Reduction in the number of residents that lack access to health care professionals.
Promoting food access	▪ **Food access.** Improved food security and access to fresh food.
Promoting safe and sanitary housing	▪ **Housing.** Improved housing conditions for homeowners and renters.
Promoting physical activity	▪ **Joint use facilities.** New joint use facilities that reduce barriers to exercise opportunities and increase access to physical fitness facilities. ▪ **Opportunities for physical activity.** New alternative transportation improvements in mobility focus areas.
Civil Engagement	▪ **Community participation.** Increased awareness and understanding of potential projects and more opportunities for meaningful public participation that can affect the decision making process.

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Personal & Property Protection Element

The benefits, public goods, and investments associated with a high quality of life in San Bernardino County—strong neighborhoods, economic prosperity, cradle-to-career education, a vibrant culture, and civic engagement—can only be achieved when people experience a real and perceived sense of safety. Public safety is also directly related to the County's resilience—its ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption or disasters.

The County provides law enforcement, including crime prevention, in unincorporated areas and under contract to some incorporated jurisdictions. It also provides some countywide law enforcement services, including the coroner, and when requested, special investigation assistance to incorporated jurisdictions. The County is also responsible for: the administration of justice, both prosecutions and public defenders, for crimes committed in the county; operation of County jails, including rehabilitation of inmates in its custody; holistically rehabilitate and assist the reentry and transition of parolees, probationers, and others living in the county engaged by the criminal justice system, and assistance to victims of and witnesses to crimes committed in the county.

The County Fire District provides fire prevention services, fire protection for wildfires and urban fires, and emergency medical response in unincorporated areas, portions of incorporated jurisdictions included in the district, and, under contract, in some incorporated jurisdictions. The County plans for and responds to emergencies and natural disasters countywide, and County Fire also provides regional urban search and rescue services.

The Sheriff is responsible for law enforcement and is elected by voters countywide. The Board of Supervisors appropriates funds to supplement state and federal funding for law enforcement. Achieving the Policy Plan's goals for law enforcement is, thus, a collaborative effort between the Board of Supervisors and the Sheriff. The Sheriff also provides countywide wilderness rescue services.

The County makes a maintenance of effort payment for courts, but the state is primarily responsible for funding courts and fully responsible for any expansion. However, the County funds the elected District Attorney's office, the Public Defender's office, and the Sheriff's department's court services. Thus, state decisions on court funding will influence the ability of the County to achieve this element's law and justice goal.

Purpose

The Personal and Property Protection Element:

- Promotes continuous improvement in the provision of public safety and administration of justice.
- Supports coordinated and effective interagency response to emergencies and natural disasters.
- Provides policy direction to engage communities and respond to identified needs.
- Fosters collaboration among the Board of Supervisors-directed agencies and departments and the elected Sheriff and District Attorney.
- Augments, rather than replaces, state- and federally-mandated goals and objectives.

Principles

We believe:

- Public safety and administration of justice is a fundamental responsibility of county government, and a key determinant of quality of life.
- Maintaining and improving a real and perceived sense of public safety is necessary to attract private investment in residences and businesses.
- A collaborative effort among County agencies and other organizations is required to prevent crime, assist victims of and witnesses to crime, and holistically rehabilitate and aid the reentry and transition of parolees, probationers, and others engaged in the criminal justice system.
- A regional approach to fire suppression and emergency response is effective and cost-efficient.
- Minimizing the loss of life and property during emergencies and natural disasters requires collaborative planning, preparation, and execution.

Goal PP-1 Law Enforcement

Effective crime prevention and law enforcement that leads to a real and perceived sense of public safety for residents, visitors, and businesses.

Policy PP-1.1 **Law enforcement services.** The Sheriff's Department provides law enforcement services for unincorporated areas and distributes resources geographically while balancing levels of service and financial resources with continuously changing needs for personal and property protection.

Policy PP-1.2 **Contract law enforcement.** When requested, the Sheriff's Department provide law enforcement services to incorporated jurisdictions by contract at the full cost of services as determined by the County, without direct subsidy by the County.

Policy PP-1.3 **Holistic approach to crime prevention.** We recognize that the roots of crime are found throughout a spectrum of psychological, social, economic, and environmental issues, and we coordinate proactive planning and activities among the Sheriff's Department and county and non-county agencies and organizations to intervene and effectively prevent crime.

Policy PP-1.4 **Crime prevention resource allocation.** The Sheriff's Department uses crime data analysis, professional expertise, and community input to allocate patrols and other crime prevention resources.

Policy PP-1.5 **Community-based crime prevention.** The Sheriff's Department provides a range of outreach, education, and training programs for community-based and school-based crime prevention.

Policy PP-1.6 **Agency partnerships.** The Sheriff's Department partners with other local, state, and federal law enforcement agencies and private security providers to enhance law enforcement service.

Policy PP-1.7 **Community partnerships.** The Sheriff's Department establishes and maintains partnerships to help identify public safety needs, strengthen community confidence, and improve service to our communities.

Policy PP-1.8 **Public awareness.** The Sheriff's Department engages the media and our communities to improve the public's perception and awareness of personal and property protection and safety.

Policy PP-1.9 **Periodic needs assessment.** The Sheriff's Department periodically assesses their facility, equipment, and staffing needs and use the assessment to allocate funding resources in the annual budget and capital improvement program.

Policy PP-1.10 **Qualified workforce.** The Sheriff's Department attracts and retains a qualified workforce of law enforcement and support personnel, reflective of the people they serve, and invest in training and ongoing education.

Goal PP-2 Law & Justice

An equitable justice system for violations of law in the county, adequate care and effective rehabilitation for inmates in the County's custody, and the holistic rehabilitation and aided reentry and transition of parolees, probationers, and others living in the county engaged by the criminal justice system.

Policy PP-2.1 **Equity.** We, in conjunction with the Sheriff's Department, monitor and improve our law and justice functions, including for those accused of violating state and local law, victims, and witnesses, to ensure that individuals and corporations are treated equitably.

Policy PP-2.2 **Capacity.** We advocate for and support sufficient capacity in the justice system, including the criminal and civil courts, District Attorney's office, and Public Defender's office, to effectively and efficiently adjudicate violations of law committed in the county.

Policy PP-2.3 **Information sharing.** We continually improve the sharing of non-privileged information from the time of arrest through trial, among the Sheriff's Department and city police departments, courts, District Attorney's office, Public Defender's office, and Probation Department.

Policy PP-2.4 **Housing and care of inmates.** We provide adequate care and effective rehabilitation for those incarcerated in County jails or housed in County juvenile detention facilities, consistent with state and federal law, and we advocate for adequate state funding.

Policy PP-2.5 **Support for victims and witnesses**. In conjunction with the District Attorney's office, we provide supportive services for victims of and witnesses to crime through a holistic approach considering physical, psychological, and basic needs.

Policy PP-2.6 **Recidivism.** To prevent recidivism, we provide holistic rehabilitation to those incarcerated and engaged in the reentry process, and provide coordinated services through the departments and agencies associated with law and justice, human services, economic development, and housing, as well as other agencies and nongovernmental organizations.

Goal PP-3 Fire and Emergency Medical

Reduced risk of death, injury, property damage, and economic loss due to fires and other natural disasters, accidents, and medical incidents through prompt and capable emergency response.

Policy PP-3.1 **Fire and emergency medical services.** We maintain a sufficient number and distribution of fire stations, up-to-date equipment, and fully-trained staff to respond effectively to emergencies.

Policy PP-3.2 **Fire District.** We support the expansion of the Fire District to serve additional incorporated jurisdictions, and the use of special funding and financing mechanisms to augment Fire District revenues to improve service and coverage.

Policy PP-3.3 **Search and rescue.** We maintain up-to-date equipment and fully-trained staff to provide urban search and rescue and swift water rescue emergency response.

Policy PP-3.4 **Fire prevention services.** We proactively mitigate or reduce the negative effects of fire, hazardous materials release, and structural collapse by implementing the California Fire Code, adopted with County amendments.

Policy PP-3.5 **Firefighting water supply and facilities.** We coordinate with water providers to maintain adequate water supply, pressure, and facilities to protect people and property from urban fires and wildfires.

Policy PP-3.6 **Concurrent protection services.** We require that fire department facilities, equipment, and staffing required to serve new development are operating prior to, or in conjunction with new development.

Policy PP-3.7 **Fire safe design.** We require new development in the Fire Safety Overlay to comply with additional site design, building, and access standards to provide enhanced resistance to fire hazards.

Policy PP-3.8 **Fire-adapted communities.** We inform and prepare our residents and businesses to collaboratively plan and take action to more safely coexist with the risk of wildfires.

Policy PP-3.9 **Street and premise signage.** We require adequate street signage and premise identification be provided and maintained to ensure emergency services can quickly and efficiently respond.

Policy PP-3.10 **Community outreach.** We engage with local schools, community groups, and businesses to increase awareness of fire risk, prevention, and evacuation.

Policy PP-3.11 **Post-burn risks.** In areas burned by wildfire, we require new and reconstructed development to adhere to current development standards, and may require additional study to evaluate increased flooding, debris flow, and mudslide risks.

Policy PP-3.12 **Fire protection and emergency medical resource allocation.** We use fire and emergency services data analysis and professional expertise to allocate resources, reduce fire risks, and improve emergency response.

Policy PP-3.13 **Periodic needs assessment.** We periodically assess our facility, equipment, and staffing needs and use the assessment to allocate funding resources in the annual budget and capital improvement program.

Policy PP-3.14 **Qualified workforce.** We attract and retain a qualified workforce of fire fighters, emergency medical technicians, and support personnel, and invest in training and ongoing education.

Goal PP-4 Emergency Preparedness and Recovery

A reduced risk of and impact from injury, loss of life, property damage, and economic and social disruption resulting from emergencies, natural disasters, and potential changes in climate.

Policy PP-4.1 **Emergency management plans.** We maintain, update, and adopt the Emergency Operations Plan, Continuity of Operations Plan, and the Multi-Jurisdictional Hazard Mitigation Plan. Plan updates are coordinated with wildfire hazard planning efforts of outside agencies, such as CALFIRE Strategic Fire Plan, Community Wildfire Protection Plans, U.S. Forest Service, military institutions, California Fire Safe Council and other non-profit stakeholder groups, and other applicable local, state, and federal agencies.

Policy PP-4.2 **Critical and essential facility operation.** We ensure that critical and essential County facilities remain operational during emergencies.

Policy PP-4.3 **Automatic and mutual aid.** We participate in agreements for automatic and mutual aid with other local, state, federal, and nongovernmental emergency service providers to improve protection services and emergency response throughout the county.

Policy PP-4.4 **Emergency shelters and routes.** We identify and publicize emergency shelters and sign and control evacuation routes for use during emergencies.

Policy PP-4.5 **Vulnerable populations.** We coordinate with and encourage the use of community-based networks to aid vulnerable populations prepare for emergencies and provide assistance with evacuation and recovery.

Policy PP-4.6 **Recovery.** We reestablish and expedite County services to assist affected residents and businesses in the short- and long-term recovery from emergencies and natural disasters.

Policy PP-4.7 **Public outreach and education.** We engage with the community to increase awareness of and preparedness for emergencies and natural disasters.

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Economy & Wellness Section

Economic Development Element

The economy of San Bernardino County is an integrated part of Southern California's regional economy. The skills and level of education of county residents, the provision of infrastructure, and the availability of sites and facilities influence which of the regional economy's businesses operate and are successful in the county. At the same time, the types of businesses that operate in the county determine the types of jobs and wages available to county residents. By increasing the number and quality of jobs, the County's economic development efforts are intended to attract private investment, reduce commute times, increase household wealth, and improve overall quality of life.

The County has a regional role in fostering economic and workforce development countywide and has a local role in bringing nonresidential development to targeted unincorporated communities. While economic development issues are addressed throughout the Policy Plan, this Element focuses on the County's major economic development responsibilities.

Purpose

The Economic Development Element:

- Provides direction for County efforts to attract private investment in nonresidential development in unincorporated areas of the county.
- Focuses countywide investments in workforce development on growing occupations and industries.
- Establishes the County's intent to invest in economic development in order to improve the countywide jobs-housing ratio.
- Identifies the means through which the County promotes countywide economic development.

Principles

We believe:

- Economic security is a necessary component of public safety and quality of life.
- Effective economic development requires collaboration among public agencies, not-for-profit organizations, and the private sector.
- Comprehensive and excellent labor force training and business assistance services are assets that help existing businesses grow and help attract new businesses.
- Tourism is important for its direct local economic impact, enhancing community identity, and improving the regional image of San Bernardino County.

Goals & Policies

Goal ED-1 Unincorporated Land and Facilities

Increased business investment in land and facilities and job growth in key unincorporated areas.

Policy ED-1.1 **Marketing focus areas.** In unincorporated areas, we actively market sites for business park and industrial development in employment focus areas, and we actively market sites for retail and commercial businesses in commercial focus areas.

Policy ED-1.2 **Infrastructure improvements.** We support and facilitate the establishment of special funding and financing mechanisms for road, water, sewer, and drainage infrastructure improvements in order to generate private investment in employment and commercial focus areas.

Policy ED-1.3 **Site aggregation.** We may assist in aggregating smaller lots and parcels to create more marketable and developable sites in employment focus areas.

Policy ED-1.4 **Planned business park and industrial areas.** We prefer master planned approaches through specific and area plans for business park and industrial development and redevelopment. We facilitate master planned approaches in order to discourage incremental general plan amendments that introduce or expand business park or industrial development.

Policy ED-1.5 **Mineral resources.** We support the extraction of mineral resources in unincorporated areas and the establishment and operation of supporting businesses throughout the county.

Policy ED-1.6 **Industrial redevelopment.** We facilitate and promote redevelopment in the industrial redevelopment focus areas to provide land and facilities for non-mining industrial development.

Goal ED-2 Labor Force

A skilled and educated labor force that helps businesses compete in the regional and global economy.

Policy ED-2.1 **Education pathways.** We collaborate with school systems and civic organizations to support countywide education pathways (P-14) to prepare students for jobs in high-skill, high-wage careers and/or to prepare for college.

Policy ED-2.2 **English proficiency.** We support local and countywide programs that improve adult proficiency in the English language.

Policy ED-2.3 **Industry-driven workforce training.** We support countywide education and workforce training programs with a demonstrated ability to expand skills and improve employment opportunities, and we also promote innovative approaches that address the diversity of education, job skills, geography, and socioeconomics of the countywide labor force.

Policy ED-2.4 **Business engagement.** We engage with businesses throughout the county to identify current and future skill and education needs. We assist businesses with recruitment, hiring, on-the-job training, and short-term training needs.

Policy ED-2.5 **Individual assistance.** We provide job search and application assistance to residents countywide, and we provide training and education assistance to eligible individuals.

Goal ED-3 Countywide Business and Employment Growth

Growth of new businesses, improved profitability of existing businesses, and an increased number and quality of jobs in the county.

Policy ED-3.1 **Countywide jobs-housing ratio.** We strive to achieve countywide job growth in excess of household growth to improve the jobs-housing ratio, reduce out-commuting, and enhance quality of life.

Policy ED-3.2 **Business assistance.** We collaborate with economic development service providers to offer training and other assistance to existing businesses and business startups countywide.

Policy ED-3.3 **Site selection assistance.** We coordinate with agencies, incorporated cities and towns, and service providers to assist existing and prospective businesses in identifying and selecting sites and facilities countywide. We also assist businesses with permitting, licensing, incentives, and other regulatory requirements.

Policy ED-3.4 **Site and facilities inventory.** We collaborate with real estate brokers, developers, municipalities, and building owners to maintain a countywide inventory of available sites and facilities for businesses.

Policy ED-3.5 **Countywide marketing.** We regularly analyze economic and market conditions and trends to identify target economic sectors and actively market sites and facilities countywide to prospective businesses.

Policy ED-3.6 **Countywide tourism.** We coordinate with a variety of partners to promote San Bernardino County as a regional, national, and international tourist destination and collaborate with tourism industry businesses to improve visitor experience.

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Health & Wellness Element

Maintaining and improving the health and wellness of individuals, families, and communities is one of society's most fundamental goals, similar in importance to public safety and providing adequate shelter. Creating healthier places and improving the health and education of people contribute to lower governmental costs for health care, enhances the capacity of the individual and collective workforce, and leads to a stronger economy and overall prosperity. Positive outcomes are not only the result of health-care treatment and the provision of a social safety net; they must also be achieved through preventive or upstream efforts that help avoid or reduce the occurrence of physiological, financial, and social instability.

The County is committed to improving the health and wellness of individuals, families, and communities through collaboration with public, private, and not-for-profit organizations. The County is also responsible, within the bounds of annual state and federal funding, for implementing the human health and social assistance responsibilities of the state and federal governments. Establishing a more complete county and stronger communities is achieved through the County's provision of or coordination with others to provide places, facilities, and programs for learning, arts and culture, entertainment, and social bonding.

In the context of this Element, the terms "health" or "health and wellness" are used broadly to reference physical health, behavioral health, and social well-being.

Purpose

The Health and Wellness Element:

- Provides guidance on addressing issues that by their nature require extensive coordination and collaboration within the County and with outside agencies and organizations.
- Establishes a holistic approach to the continuum of care.
- Identifies the County's policy focus regarding its use of state and federal funds to improve the physical and behavioral health of residents.
- Describes the County's priorities and roles in serving the health and social needs of vulnerable populations.

Principles

We believe:

- Human health and wellness are intrinsically valuable.
- Facets of health and wellness are often interrelated and should be addressed together, with a focus on preventative and proactive care.
- The health, well-being, education, and enrichment of residents are key components to the prosperity and quality of life in San Bernardino County.
- A diverse range of community and cultural resources, programs, and facilities help make the entire county and individual communities more complete and prosperous.

- Society has chosen to maintain a safety net that protects the most vulnerable and assists individuals and households in transitioning to self-sufficiency.
- Human health and social assistance services are state and federal responsibilities implemented, subject to available state and federal funding, by the County in partnership with service providers and not-for-profit organizations.

Goals & Policies

Goal HW-1 Health and Social Wellness

Supportive public facilities and services that assist and guide individuals to achieve and sustain self-sufficiency, social stability, and excellent physical and behavioral health and wellness.

Policy HW-1.1 **Coordinated holistic approach.** We invest in a holistic approach to individual health and wellness to improve the continuum of care, providing coordinated services through departments and agencies associated with human services, economic development, law and justice, and housing, as well as other agencies and nongovernmental organizations.

Policy HW-1.2 **Cultural humility and inclusion.** We guide the development and delivery of appropriate health care, health services, and social assistance by recognizing and continuously learning about the diverse values, cultures, languages, and behaviors found throughout the county, especially for those that are underserved or isolated.

Policy HW-1.3 **Monitoring health and social conditions.** We prioritize our resources to address the most pressing needs by continually engaging residents and monitoring health and social conditions, trends, and emerging needs across the county, while complying with federal and state mandates.

Policy HW-1.4 **Funding application coordination.** We coordinate the application for funding resources to maximize the long-term benefit of addressing multiple health and social issues, both within the County organization and between the County and other agencies and organizations.

Policy HW-1.5 **Partnerships and capacity building.** We leverage partnerships with other agencies and organizations to address health and wellness issues, and, as funding allows, assist in building the capacity of service providers and partner organizations to expand their service and effectiveness.

Policy HW-1.6 **Healthy behaviors.** We collaborate with other public agencies, not-for-profit organizations, and private service providers to offer education and training that enable individuals to make better health and wellness choices. We work to remove environmental and social barriers to healthy habits.

Policy HW-1.7 **Upstream issues.** We collaborate with partners to address upstream issues related to the social determinants of health and social stability (e.g., income, education, housing, neighborhood conditions, and job skills), and to reduce the occurrence of and costs associated with responding to acute and chronic conditions, while complying with federal, state, and local mandates.

Policy HW-1.8 **Assistance for veterans.** We invest in services to assist veterans and their families countywide connect with service providers and apply for benefits from federal, state, and local governmental agencies.

Policy HW-1.9 **Homelessness.** We address homelessness by coordinating a comprehensive countywide network of service delivery and by focusing on transitional and permanent supportive housing for the homeless, including the chronically homeless and near-homeless families and individuals.

Policy HW-1.10 **Safety net.** We use state and federal funding to provide a safety net of services that provides temporary, transitional, and ongoing assistance to protect those most vulnerable.

Policy HW-1.11 **Insurance and medical services.** We collaborate with other public agencies, non-profit organizations, and private health and wellness service providers to facilitate residents obtaining medical insurance, vaccines and preventative care, behavioral health, and treatments, through private service providers, County health and wellness facilities, and public programs.

Policy HW-1.12 **Equity.** We monitor and seek to achieve equitable access to County health and social services, with an emphasis on environmental justice focus areas countywide.

Policy HW-1.13 **Health care professional capacity.** We collaborate with other public agencies, non-profit organizations, and private health and wellness service providers to ensure that an adequate number of medical, behavioral, and dental health professionals serve residents countywide, with an emphasis on health care professional shortage areas.

Policy HW-1.14 **Arrowhead Regional Medical Center.** We provide quality general and specialty health care services, operate medical residency programs, conduct community outreach and wellness programs, and act as a safety-net hospital for the countywide under-insured and uninsured. We also leverage ARMC as an economic asset to stimulate the local economy and attract investment and professionals from outside the county.

Goal HW-2 Education

A common culture that values education and lifelong learning and a populace with the education to participate and compete in the global economy.

Policy HW-2.1 **Lifelong learning.** We collaborate with educators, the business community, students and families, recreation departments and other public agencies, and civic and not-for-profit organizations to foster lifelong learning including early childhood literacy, cradle to career education, English as a second language, career development, and adult enrichment. We encourage approaches to learning that embrace diverse modes of learning for all.

Policy HW-2.2 **Land use compatibility for schools.** We prioritize the safety and security of public schools in unincorporated areas by minimizing incompatible land uses near instructional facilities. We encourage school districts to place new schools where existing and planned land uses are compatible.

Policy HW-2.3 **Superintendent support.** We support the Superintendent of Schools in fulfilling the obligations for school district support, advocacy, and student services

Policy HW-2.4 **Health and enrichment programs.** We provide additional support for school districts for nutrition, physical activity, arts, and other enrichment programs, commensurate with the availability of grants and other funding resources.

Goal HW-3 Community Development

Assets that contribute to a complete county and healthy neighborhoods and communities.

Policy HW-3.1 **Healthy environments.** We collaborate with other public agencies, not-for-profit organizations, community groups, and private developers to improve the physical and built environment in which people live. We do so by improving such things as walkability, bicycle infrastructure, transit facilities, universal design, safe routes to school, indoor and outdoor air quality, gardens, green space and open space, and access to parks and recreation amenities.

Policy HW-3.2 **Building social capital.** In unincorporated communities, we support the provision of neighborhood and community gathering places for social activities, and the provision of meeting spaces and facilities for community organizations in order to build social capital, establish a sense of community, increase volunteerism, and expand civic engagement.

Policy HW-3.3 **Public libraries.** We operate public libraries in unincorporated areas and contract cities/towns to provide programs and facilities that ensure equitable access to information and digital technology, provide places and activities for people to connect with other people, promote literacy and reading for pleasure for children and adults, and foster a culture of creativity, innovation, and collaboration. We invest in the modernization and expansion of public library facilities as adequate funding is available.

Policy HW-3.4 **Public museums.** We operate County museums to preserve and depict the history, culture, and natural science of San Bernardino County. We invest in facilities and technology and collaborate with other institutions, organizations, and businesses in order to increase public exposure to museum holdings.

Policy HW-3.5 **Arts and culture.** We increase awareness of the benefits of the arts throughout the county by recognizing and promoting the arts, artists, performing arts, and cultural organizations as valuable resources for community identity, economic vitality, and tourism. We encourage private and not-for-profit support of artistic and cultural activities through mutual programs and public-private partnerships.

Policy HW-3.6 **Multi-use facilities and integrated development.** We encourage those who build and/or operate community assets to accommodate multiple functions and programs. We encourage the development of new residential, commercial, and institutional uses and public facilities that incorporate one or more community assets.

Policy HW-3.7 **Attracting local-serving businesses.** We actively work across County departments and agencies to attract businesses that provide desired goods and services in unincorporated communities, especially in environmental justice focus areas, including but not limited to food stores with fresh produce, health care, child care, pharmacies, and other retailers. We balance community desires with comprehensive assessments of market demand to guide our business attraction efforts.

Policy HW-3.8 **Attracting leisure and entertainment.** We advocate for the establishment and retention of leisure and entertainment businesses and venues, countywide, that contribute to the complete county concept.

Policy HW-3.9 **Community-driven improvements.** We provide resources and information to assist unincorporated communities with the implementation of Community Action Guides.

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Glossary of Terms

The following is a glossary of terms to help users read and understand the Policy Plan and the meaning and intent of its goals and policies. Please note that this glossary is not intended to be comprehensive or define terms, acronyms, or abbreviations that are generally well understood or easily looked up using other resources. The focus is on terms that have multiple potential meanings (either in or out of the Policy Plan context), and to define the intended meaning of such terms to ensure the correct interpretation and implementation of the Policy Plan.

Some terms are used in multiple parts of the Policy Plan or other parts of the Countywide Plan. For these terms, additional words or document references are presented in italics and in parentheses *(e.g., Community Action Guide),* to indicate the specific context.

A

Accommodate. To make room for or provisions for something that is specifically intended to occur.

Action *(Community Action Guide)*. Suggested, measurable step to be taken to implement an Action Statement. Actions are found in the Action Plan of a Community Action Guide, along with potential leaders for each step and a timeline of when it should occur in the process. In the context of the Community Action Guide, the activity is typically to be undertaken by a member(s) of the community, although some activity by a broader public entity (such as the County) may also be involved.

Action *(Implementation Plan)*. A specific, measurable step that needs to be taken to meet stated objectives. An action is not mere compliance with the law or a commonly adopted or accepted practice or protocol. An action is short in duration and is meant to be updated and replaced once action has been taken. In the context of the County Implementation Plan, the activity is typically to be undertaken by the County or another public entity.

Action Plan *(Community Action Guide)*. A set of focus statements, action statements, and actions (detailed or suggested outline), intended for community members and stakeholders to use in improving their community.

Action Statement *(Community Action Guide)*. Measurable statements providing critical information on a program, initiative or project to complete.

Advocate. To openly support and promote an action, objective, or goal; also to speak on behalf of an individual or group.

Adaptive reuse. A method by which a building is adapted/modified to a different use from its original use, while its general physical form is retained. See also *historic rehabilitation* for historical buildings.

Agency. A governmental entity, department, office, or administrative unit responsible for carrying out regulations.

Agriculture. Use of land for the production of food and fiber, including the growing of crops and/or the grazing of animals on natural prime or improved pasture land.

Agricultural preserve. An agricultural preserve defines the boundary of an area within which a local government will enter into contracts with land owners. Only land located within an agricultural preserve is eligible for a Williamson Act contract. Preserves are regulated by rules and restrictions designated in the resolution to ensure that the land within the preserve is maintained for agricultural or open space use. See also *Williamson Act.*

Allow. To be open to something occurring but without any particular effort to make it happen.

Always. The action will apply to future decisions without exception.

Annexation. The means by which an incorporated city or town extends its corporate boundaries. Annexation of unincorporated land into an incorporated city or town is initiated by a petition of affected land owners or registered voters, or by resolution from the incorporated city or town. The process of annexation is overseen by the Local Agency Formation Commission (LAFCO).

Analyze. To methodically examine the desirability or feasibility of something, with a view toward letting the evidence determine the appropriate level of commitment.

Aspirations statement ***(Community Action Guide)***. A written narrative illustrating the community's desired look and function once the Community Focus Statements and Action Statements are fully implemented. This is a long term view of 10 to 20 years. The Aspirations Statement serves as a foundation for developing Community Focus Statements and Action Statements.

Aspire. To direct one's ambitions toward achieving something.

Augment. To add to something that is already in place to make it more desirable, functional, or beneficial.

Automatic aid. Automatic aid is assistance that is dispatched automatically by a contractual agreement between two emergency service departments, communities, or districts when an emergency occurs. It differs from mutual aid, which is arranged on an as-needed and requested basis.

Avoid. To not enable something that will lead to an undesirable outcome.

B

Bicycle facilities. On- and off-street spaces delineated for safe use by bicycles, designated in one of four classes:

- **Class I (shared use or bike path).** A bikeway physically separated from any street or highway. Shared Use Paths may also be used by pedestrians, skaters, wheelchair users, joggers, and other non-motorized users.
- **Class II (bike lane).** A portion of roadway that has been designated by striping, signaling, and pavement markings for the preferential or exclusive use of bicyclists.
- **Class III (bike route).** A generic term for any road, street, path, or way that in some manner is specifically designated for bicycle travel regardless of whether such facilities

are designated for the exclusive use of bicycles, or are to be shared with other transportation modes.

- Class IV (separated bikeway). A bikeway for the exclusive use of bicycles and includes a required separation between the bikeway and the through vehicular traffic. The separation may include, but is not limited to, grade separation, flexible posts, inflexible posts, inflexible barriers, or on-street parking.

Buffer / buffer zone. An area of land, structure, feature, or design treatment separating two uses that acts to soften or mitigate the effects of one use on the other.

C

California Environmental Quality Act (CEQA). A state law (California Public Resources Code Section 21000 et seq.), requiring state and local agencies to regulate activities with consideration for environmental protection. If a proposed activity has the potential for a significant adverse environmental impact, an environmental impact report (EIR) must be prepared and certified as to its adequacy before taking action on the proposed project.

California Native American Heritage Commission (NAHC). The governor-appointed nine-member commission charged with identifying and cataloging places of special religious or social significance to Native Americans and known graves and cemeteries of Native Americans on private lands. The NAHC also performs other duties regarding the preservation and accessibility of sacred sites and burials and the disposition of Native American human remains and burial items.

Capital Improvements Program (CIP). A program, administered by a city or county government that schedules permanent improvements, usually for a minimum of five years in the future, to fit the projected fiscal capability of the local jurisdiction. The CIP is generally reviewed annually for conformance to and consistency with the Policy Plan.

Capacity. The ability to provide a service or fulfill an obligation in the desired manner or at a desired level of service.

Cluster. Residential development in which a number of dwelling units are placed in closer proximity than usual, or are attached.

Collaborate. To intentionally, willingly work together toward a common objective or goal.

Community action guide. A set of potential actions community members (within a specific community planning area or CPA) can take to remain and become the type of community that current and future residents desire. The guides include action plans that place a focus on self-reliance, grass-roots action, and implementation, allowing the community to take the lead in moving actions forward.

Furthermore, the guides frame these potential actions in a set of community-driven values and aspirations generated based on public input from community members and stakeholders. While some actions will require coordination with, approval from, or assistance by the County, many others can be undertaken without County involvement. The guides may also be augmented by a set of generalized actions presented in a Community Development Toolkit.

Community assets. Public libraries, public museums, arts and cultural facilities, community/senior centers, and similar facilities open to and for the benefit of the public.

Community character / community identity. The history, culture(s), natural features, and human-built features that a community's residents value and wish to celebrate and maintain. Community character can also be defined as the sum of attributes and assets that make a community unique and establish a sense of place for its residents. Some attributes and assets are tangible, like a unique main street area, while others are intangible, like a general sense of tranquility associated with the natural environment.

Community facilities district (CFD). A special funding and financing mechanism that is formed when the property owners in a geographic area agree to impose a special property tax on the land to fund public improvements and services. Based on future tax revenue, CFDs (aka Mello-Roos) seek public financing through bonds. A Mello-Roos tax must be approved by 2/3 of the voters in a proposed district.

Community planning area (CPA). A planning area identified by the County of San Bernardino as an area where policies, standards, and guidelines may vary, based on local context and community character. A CPA is also used to define the boundaries for community action guides. See also *Community Planning Continuum* and the types of CPAs.

Community Planning Continuum (CPC). The CPC is a system of community planning activities and documents intended to guide local expectations for County services and set a clear direction for the future of unincorporated communities. The CPC is implemented by both County government (Policy Plan and Implementation Plan) and community residents and stakeholders (Community Action Guide and Community Development Toolkit). The resulting plans, guides, maps, and tools are web-based, living documents that will be updated periodically to reflect progress and change. The CPC includes a hierarchy of community planning areas (CPAs) that will ensure that planning details, tools, and resources match the conditions and needs of each community:

- Detailed CPAs. Includes communities that contain, or have the potential for, a variety of housing opportunities and supporting uses, such as commercial and industrial businesses, schools, a library, parks and recreation facilities, and religious and civic organizations.
- Framework CPAs. Includes communities that are primarily characterized by single-family residential properties and a limited number of supporting uses, such as a school, post office, and commercial businesses.
- Foundation CPAs. Includes communities that are primarily characterized by single-family residential properties. Residents of these communities typically drive to nearby towns or cities for employment, shopping, entertainment, education, and recreation opportunities.
- Fundamental CPAs. Includes communities that are primarily characterized by open space or agriculture with a scattering of residential homes and/or highway commercial uses, or an area where growth is constrained by adjacent land ownership, such as federal lands and state lands.

Community services district (CSD). A special funding and financing mechanism that is formed as an independent, self-governed entity that can provide locally adequate levels of public facilities

and services, an effective form of governance for combining two or more special districts that serve overlapping or adjacent territory into a multifunction special district, a form of governance that can serve as an alternative to the incorporation of a new city, and a transitional form of governance as the community approaches cityhood.

Community Wildfire Protection Plan (CWPP). A plan developed in the collaborative framework established by the Wildland Fire Leadership Council and agreed to by state, tribal, and local government, local fire department, other stakeholders, and federal land management agencies managing land in the vicinity of the planning area. A CWPP identifies and prioritizes areas for hazardous fuel reduction treatments and recommends the types and methods of treatment on Federal and non-Federal land that will protect one or more at-risk communities and essential infrastructure and recommends measures to reduce structural ignitability throughout the at-risk community. A CWPP may address issues such as wildfire response, hazard mitigation, community preparedness, or structure protection.

Compatible. In relation to use, the ability for two or more uses to coexist without conflict, with minimal conflict that can be mitigated, or in a beneficial manner. When used in relation to a structure, indicates that the structure is built so that its appearance is similar to that of the principal unit to which the structure is accessory or to the general character of the neighborhood or community with regards to color, materials, construction, lighting, signs, or the emission of sounds, noises and vibrations. See also *incompatible*.

Complete streets network. A system of on- and off-street facilities (e.g., sidewalks, bike lanes, and trails), that enable all users of all ages and abilities to navigate within or through a community area, with an emphasis on mobility focus areas. The system can consist of one or more facility type based on the intended users and access requirements. Individual facilities may overlap or not, serve all or just some users, and be contiguous or disconnected. Complete streets facilities and improvements are subject to physical constraints presented by the local context and financial feasibility limitations.

Comply with. To follow specified existing ordinances, regulations or procedures.

Complement / complementary. Combining or coexisting (e.g., two buildings or land uses) in such a way as to enhance or emphasize the qualities of each other.

Concurrent. Services, facilities, activities or other things that are provided or are occurring at the same time as something else.

Consider. To remain open to and evaluate a range of possible actions or outcomes as part of a decision.

Consistent. To be or act in harmony or aligned with something; see also *inconsistent*.

Consolidate. To bring together aspects, features, or components of a system or locale that can serve better in a consolidated form, compared to existing or provided separately.

Construct. To build something: buildings, roads, channels, etc.

Context. Local or regional environmental, social, and economic conditions.

Context-sensitive. An approach, design, standard, or practice that is sensitive to and varies according to the local or regional environmental, social, and economic conditions.

Contiguous land administration. Parcels that share a border and are under the ownership or administrative authority of a single entity, enabling more effective and efficient use, preservation, and/or management of the land and its resources and relationship to surrounding lands and resources.

Continue. To maintain and/or resume an action.

Cooperate. To work in a positive effort with another entity toward a mutually beneficial end. Such work may take the form of direct action, passive support, or even inaction.

Coordinate. To work in a positive effort with another entity in the process of conducting individual actions or initiatives that relate to each other and that can benefit from concurrent or cooperative activity.

County service area (CSA). Separate legal entities authorized by California laws and formed by the County Board of Supervisors to fund the County's provision of services, capital improvements and financial flexibility. They are formed and tailored to meet the specific needs of an area so that the property owners only pay for the services they that they want. Some of the unincorporated areas within San Bernardino County are exclusively serviced by these CSAs. CSAs in the County are generalized characterized by small and remote service areas with primary customers being single family residential parcels.

Critical and essential facilities. Public safety and services sites, structures and institutions that, if negatively impacted by an emergency, could exacerbate the problem, reduce a (generally public) entity's ability to respond, or present a significant secondary problem or a problem greater than the original emergency.

Cultural humility. An approach to public service (particularly medical and social services), where the professional service provider embraces a lifelong commitment to self-evaluation and lifelong learning about the cultures of their clients, working to learn with and from their clients to better serve individuals and defined populations.

D

Dedicate. To offer or set aside for a specific program, action, or use; when in the context of land dedication, the land is generally set aside for public ownership, use, and/or operation or maintenance.

Density (dwelling units per acre or du/ac). The number of residential units allowed per acre for a given area of the unincorporated county based on the Policy Plan land use category. The permitted Policy Plan density guides the maximum density for corresponding zoning designations as described in the Development Code and applied to a specific property.

Design. To conceive in advance the size, shape, qualities, appearance, open space and other attributes of a proposed development, building and related improvements, generally rendered in graphic forms that communicate the anticipated outcome.

Determine. To calculate in advance the nature or outcome of an anticipated action, situation, or proposal.

Development Code. Title 8 of the San Bernardino County Code, intended to implement the County Policy Plan by classifying and regulating the uses of land and structures within unincorporated San Bernardino County; by preserving and protecting the County's important agricultural, cultural, natural, open space and scenic resources; and by protecting and promoting the public health, safety, comfort, convenience, prosperity, and general welfare of residents and businesses in the County.

Discourage. To openly deter (or attempt to deter) an individual, group, or organization from doing something.

Discretionary. An action taken by a governmental agency that calls for the exercise of judgment in deciding whether to approve and/or how to carry out a project.

Dwelling Unit. A room or group of rooms (including sleeping, eating, cooking, and sanitation facilities, but not more than one kitchen), which constitutes an independent housekeeping unit, occupied or intended for occupancy by one household on a long term basis.

E

Earthquake fault zone / Alquist Priolo (AP) earthquake fault zone. Earthquake fault zones are regulatory zones around active faults. On the Earthquake Fault Zone Maps, the zones are shown as polygons that encompass mapped fault traces. The zones vary in width, but average about one-quarter mile wide.

Economic development service providers. State, federal, utility, education, and not-for-profit organization partners that help fund economic development activities; and public, private, and not-for-profit organizations that provide assistance to businesses such as small business development centers.

Economic value (mining). A mineral resource has economic value if it is financially feasible to extract and sell the mineral resource in the current market.

Encourage. To promote, support, or champion a concept or action; such support may be in terms of political support and coordination, staff resources, and/or financial resources.

Enhance. To improve existing conditions in quality, value, or characteristic.

Environmental Justice Focus Area. See focus area.

Equitable. A condition or treatment that is fair and impartial.

Establish. To bring something into being that does not currently exist.

Explore. To search for or examine the nature of a possibility before a commitment is made. See also *analyze*.

Expand. To increase in detail, extent, number, volume, or scope.

F

Facilitate. To make an action or process easier or to help bring about.

Fair share. An allocation of resources, costs, or fees considered equitable and proportional to the needs, impacts, or activity of an existing or proposed project.

Farmland, Important. Refers to four of the eight classifications of land mapped by the California Department of Conservation.

- Prime farmland. Land other has the best good combination of physical and chemical characteristics for the production of crops. It must have been used for the production of irrigated crops within the four years prior to the Important Farmland Map date produced by the State Farmland Mapping and Monitoring Program.
- Farmland of statewide importance. Land other than prime farmland that has a good combination of physical and chemical characteristics for the production of crops. It must have been used for the production of irrigated crops within the four years prior to the Important Farmland Map date produced by the State Farmland Mapping and Monitoring Program.
- Unique farmland. Land that does not meet the criteria for prime farmland or farmland of statewide Importance, that has been used for the production of specific high economic value crops at some time during the two update cycles prior to the Important Farmland Map date produced by the State Farmland Mapping and Monitoring Program. It has the special combination of soil quality, location, growing season, and moisture supply needed to produce sustained high quality and/or high yields of a specific crop when treated and managed according to current farming methods.
- Farmland of local importance. Farmlands that include areas of soils that meet all the characteristics of prime, statewide, or unique and which are not irrigated. It also includes farmlands not covered by above categories but of high economic importance to the community.

Fault / active fault. A fracture in the crust of the earth along which rocks on one side have moved relative to those on the other side. Most faults are the result of repeated displacements over a long period of time. A fault trace is the line on the earth's surface defining the fault. For the purposes of the Alquist Priolo Earthquake Fault Zoning Act, an active fault is one that has ruptured in the last 11,000 years. See *earthquake fault zone*.

Feasible. Capable of being done, executed, or managed successfully taking into consideration social, physical, environmental, and/or economic factors.

Feasible, technically. Capable of being implemented because the industrial, mechanical, or application technology exists.

Feature. A noticeable or important characteristic, attribute, or aspect of something.

Fire hazard severity zone. A designated area in which the type and condition of vegetation, topography, fire history, and other relevant factors demonstrate an increased possibility of uncontrollable wildland fire. As part of CAL FIRE's responsibilities, it assigns fire severity—moderate, high, and very high—to areas in California for fire planning and suppression purposes.

Fire responsibility areas. California's wildlands have been divided into three zones or responsibility areas, depending on the agency with primary financial responsibility for addressing the prevention, suppression, and postfire recovery of fire. These include local responsibility area (LRA), state responsibility area (SRA), and federal responsibility area (FRA).

- Local responsibility areas (LRAs). The areas of California where local jurisdictions (e.g., county or city/town fire departments, fire protection districts, and by CAL FIRE under contract to local government) are responsible for the prevention and suppression of wildfires.
- State Responsibility Areas (SRAs). The areas of California where the State of California is financially responsible for the prevention and suppression of wildfires. SRA does not include lands within incorporated city/town boundaries or in federal ownership.
- Federal Responsibility Areas (FRAs). The areas of California where the federal government has the primary financial responsibility for preventing and suppressing fires. These lands are generally protected by a variety of federal agencies.

Finding(s). The result(s) of an investigation and the basis upon which decisions are made. Findings are used by government agents and bodies to justify action taken or a decision made by the entity.

Fiscal sustainability. The County's capacity to operate and maintain public facilities and to provide public services with a reasonable level of service using the revenue generated for the service or facility or revenue generated by the users or beneficiaries of the service or facility. Fiscal sustainability exists when the County has the financial capacity to operate and maintain public facilities and to provide public services in the short term and over the long term.

Determination of the fiscal impacts of a project, program, policy, or other decision must account for:

- Initial capital investments and startup costs;
- Ongoing operations and maintenance over the long term;
- Reasonable levels of service and expected or desired levels of service over the long-term;
- Set-aside capital reserves for replacement, maintenance, and upgrades; and
- Impacts to existing uses in incorporated and unincorporated areas, which may have secondary fiscal impacts.

Fiscal or financial resiliency is related to fiscal sustainability and refers to the County's capacity to continue providing reasonable levels of service for the operations and maintenance of public facilities and for the provision of public services during periods of economic and financial stress and during emergencies. Fiscal resiliency is typically achieved by minimizing the use of debt, maintaining adequate dedicated reserves, maintaining an appropriate level of unrestricted fund balance, long-term financial planning, disaster planning, and comprehensive risk management.

Flood. Refers to the rising and overflowing of a body of water onto normally dry land that is often caused by storm events or breaches of flood control infrastructure. While there are many different types of flooding that are recognized for communities, the three common types of flooding in the county are alluvial fan, riverine, and urban flood:

- Alluvial flood. Alluvial flooding occurs on the surface of an alluvial fan or similar landform that originates at the apex, and is characterized by high-velocity flows, active erosion, sediment transport, and deposition; and unpredictable flow paths. Alluvial fan flooding is depicted on a Flood Insurance Rate Map as Zone AO, with a flood depth and velocity.
- Riverine flood. Riverine flooding occurs when excessive rainfall or heavy snow melt causes water to rise and overflow the edges of a river, bank, or channel. Flash flooding, a type of riverine flood, is characterized by an intense, high velocity torrent of water, often accompanied by debris, which occurs in a river channel with little to no warning.
- Urban flooding. Urban flooding is caused when heavy rainfall creates a flood independent of an overflowing water body, such as when intense rain overwhelms the capacity of an urban drainage system. An urban flood is more common in areas that lack or have undersized drainage systems.

Flood zone / flood hazard area. The Policy Plan displays and/or refers to the following simplified categories on flood hazard maps and in policies:

- FEMA 100-year flood zone. An area mapped on a flood insurance rate map (FIRM) where a storm with a 1 percent chance of being equaled or exceeded in any given year can cause flood conditions. FIRMs are mapped under the Federal Agency Management Agency's (FEMA) National Flood Insurance Program (NFIP).
- DWR 100-year flood zone. An area mapped by the California Department of Water Resources (DWR) that identify 100-year flood hazard areas using approximate assessment procedures. These floodplains are identified simply as flood prone areas without specific depths and other flood hazard data; they are not FEMA regulatory floodplain maps. The state conducts an Awareness Floodplain Mapping project to identify all pertinent flood hazard areas for areas that are not mapped under FEMA's NFIP, and to provide the community and residents an additional tool in understanding potential flood hazards currently not mapped as a regulated floodplain.
- FEMA 200-year flood zone. An area mapped (currently in limited areas) by DWR where a storm with a 0.5 percent chance of being equaled or exceeded in any given year can cause flood conditions
- FEMA 500-year flood zone. An area mapped on a FIRM where a storm with a 0.2 percent chance of being equaled or exceeded in any given year can cause flood conditions. FIRMs are mapped under FEMA's NFIP.

Flood insurance rate map (FIRM). The official map on which FEMA has delineated both the areas of special flood hazards and the risk premium zones applicable to the community. Flood hazard areas identified on the FIRM are identified as a special flood hazard area (SFHA). SFHAs are defined

as the area that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood. SFHAs are labeled as Zone A, Zone AO, Zone AH, Zones A1-A30, Zone AE, Zone A99, Zone AR, Zone AR/AE, Zone AR/AO, Zone AR/A1-A30, Zone AR/A, Zone V, Zone VE, and Zones V1-V30.

Moderate flood hazard areas, labeled Zone B or Zone X (shaded) are also shown on the FIRM, and are the areas between the limits of the base flood and the 0.2-percent-annual-chance (or 500-year) flood. The areas of minimal flood hazard, which are the areas outside the SFHA and higher than the elevation of the 0.2-percent-annual-chance flood, are labeled Zone C or Zone X (unshaded).

While the FIRM displays the above detailed flood hazard zones, the Policy Plan displays and refers to the following simplified categories from the FIRM on Policy Plan flood hazard maps and in policies: 100-year flood hazard and 500-year flood hazard.

Floodplain. The area, adjacent to a watercourse or other body of water, subject to recurring floods. Floodplains may change over time as a result of natural processes, the characteristics of a watershed, or the construction of bridges or channels. Floodplain can also serve as a reference to areas subject to flooding and mapped under FEMA's NFIP.

Floor-area-ratio (FAR). The ratio of floor area to total net parcel area. FAR restrictions are used to limit the maximum floor area allowed on a site (including all structures on the site, except as excluded by the Development Code). The maximum floor area of all structures (measured from exterior wall to exterior wall) permitted on a site (excluding carports) shall be determined by multiplying the FAR by the total net parcel area of the site: FAR x total net parcel area = maximum allowable floor area.

Focus area. A location where the County seeks to encourage and facilitate public improvements and private investment that lead to one of the following: increased mobility, community- and/or tourist-serving shops and services, employment opportunities, or the reuse and/or intensification of industrial development. The boundary of a focus area (excluding commercial focus area/franchise-restricted and environmental justice focus areas), is intended to convey the general location, but the actual boundary may be somewhat larger or smaller as determined during implementation efforts.

- Commercial focus area. An area where the County seeks to encourage and facilitate public improvements and private investment that lead to increased community- and/or tourist-serving shops and services.
- Commercial focus area/franchise-restricted. A defined commercial focus area where franchise businesses are not permitted. See *franchise business*.
- Employment focus area. An area where the County seeks to encourage and facilitate public improvements and private investment that lead to increased commercial, office, or industrial employment opportunities (consistent with the Policy Plan and as permitted by the adopted Land Use Categories).

- Environmental justice focus area. An area that is disproportionately affected by environmental pollution and other hazards that can lead to negative health effects, exposure, or environmental degradation. Such areas are determined by CalEnviroScreen composite scores in the upper quartile (census tracts with composite scores ranking above the 75th percentile). The term "environmental justice focus area" or "EJFA" is to be interpreted the same as the term "disadvantaged community" and is understood in the context of Senate Bill 1000 (2016).

  Consistent with CalEPA's criteria for SB 535, the County uses the following criteria to define an EJFA as any portion of a census tract:

  - Within the County's land use authority; and
  - Within a community planning area or unincorporated sphere of influence; and
  - A CES composite score in the 75th percentile (upper quartile)

  The County excludes areas outside of a community planning area or unincorporated sphere of influence from EJFAs as such lands are typically unpopulated, surrounded by state or federally owned land, and planned for open space, and resource and land management.

- Industrial redevelopment focus area. An area where the County seeks to encourage and facilitate public improvements and private investment that increase reuse, redevelopment, and/or intensification of industrial development (consistent with the Policy Plan and as permitted by the adopted Land Use Categories).
- Mobility focus area. An area where the County seeks to encourage and facilitate public improvements and private investment that lead to increased non-motorized accessibility and public safety. Mobility focus areas have a core with a high concentration (typically along corridors and/or at nodes), of two or more of the following: pedestrians; bicyclists; transit; retail, service, and office businesses; or medium density residential or higher.

Focus statement *(Community Action Guide)*. General direction towards realizing a community's aspirations; a focus statement also helps to organize the Action Plan.

Food insecurity. The state of being without reliable access to sufficient quantity of affordable, nutritious food.

Franchise business. All businesses in the retail trade, accommodation and food services, and other services as defined in the North American Industrial Classification System (NAICS), that have 11 or more establishments worldwide under the same trademark, service mark, or company brand name, regardless of ownership. Such establishments maintain two or more of the following features: a standardized array of merchandise, a standardized facade, a standardized decor and color scheme, uniform apparel, standardized signage, a trademark or a service mark. See *commercial focus area/franchise-restricted*.

Fugitive dust. Small solid particles or liquid droplets (particulate matter with an aerodynamic diameter of 10 micrometers or less or PM_{10}), that come primarily from the earth's soil and are suspended in the air by wind action and human activities.

Fund. To make money available for a prescribed purpose; may be a one-time, periodic, or ongoing commitment.

Funding and financing mechanism. A legislatively authorized public revenue tool covering a distinct geographical area in which revenues may be generated by properties to fund various public facilities and services. Many of these mechanisms also allow for the issuance of debt. Examples of funding and financing mechanisms can include: assessment district, contractual assessment district, business improvement district, community facility district, community services district, multifamily housing district, lighting and landscaping maintenance district, parking district, community revitalization and investment authority, and enhanced infrastructure finance district.

The use of funding and financing mechanisms must be complemented with the establishment, collection, and use of development impact fees.

The term funding and financing mechanism does not include the use of county service areas as these divert property tax revenues that would otherwise go to the County General Fund. The term also does not include the use of home/property owners' associations.

G

Grazing land. Land on which the existing vegetation, whether grown naturally or through management, is suitable for grazing or browsing of livestock. This classification does not include land otherwise designated as prime farmland, farmland of statewide importance, unique farmland, or farmland of local importance; or heavily brushed, timbered, excessively steep, or rocky lands that restrict the access and movement of livestock.

Greenhouse gas (GHG). Any gas that absorbs infrared radiation in the atmosphere. State law identifies seven greenhouse gases for which the California Air Resources Board is responsible to monitor and regulate in order to reduce GHG emissions: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and nitrogen trifluoride (NF_3).

Goal. A statement of desired future conditions regarding a particular topic; a goal paints a picture of how something will be in the future. A goal in and of itself is not sufficient to understand its intent, extent, or context. A goal itself is kept simple, with policies, objectives, and implementation actions providing further definition.

Greywater / graywater. Wastewater that is generated in residential buildings, excluding sewage, such as gently used water from bathroom sinks, showers, tubs, and washing machines. The wastewater generated by toilets, kitchen sinks, and dishwashers is called blackwater due to its larger organic load (fecal or organic matter).

Groundwater. Water under the earth's surface, often mapped as basins and confined to aquifers capable of supplying wells and springs.

Groundwater recharge. The natural process of infiltration and percolation of rainwater from land areas or streams through permeable soils into water-holding rocks that provide underground storage in aquifers. This process can also be conducted artificially by capturing and injecting surface water or recycled water into aquifers.

H

Habitat linkages. Landscape-scale open space areas that provide a natural habitat connection between at least two larger adjacent open spaces or habitat areas. Habitat linkages provide a large enough area to support, at a minimum, a natural habitat mosaic and viable populations of smaller terrestrial species and allow for gene flow through diffusion of populations over a period of generations. Habitat linkages also allow for jump dispersal for some species between neighboring habitats. Habitat linkages may be large tracts of natural open space that serve as resident species habitat or habitat linkages may serve primarily as landscape connections (i.e., for dispersal movements or travel). See also *wildlife corridors*.

Harden. The use of site design and materials to make a building or site able to withstand the onset or severity of damage from an event such as a fire, earthquake, flood, or other similar event.

Hazardous materials. Materials or wastes that either cause or contribute to an increase in mortality, serious illness, or otherwise pose a substantial treat to human or environmental health when improperly managed; see Division 10 (Definitions) of the County Development Code.

Hazardous waste facilities. Carefully designed off-site facilities accepting hazardous wastes for storage or treatment; see Division 10 (Definitions) of the County Development Code.

Health professional shortage area (HSPA). A geographic area, population, or facility with a shortage of primary care, dental, or mental health providers and services. The US Health Resources and Services Administration and California Office of Statewide Health Planning and Development work together using public, private, and state-provided data to determine when such a shortage qualifies for designation as a HPSA.

Historic resources. Buildings, structures, sites, or districts that are considered of particular historical and/or cultural significance. Generally, such resources are listed on a local, state, or federal register.

Historic treatment. The memorialization, preservation, reconstruction, rehabilitation, or restoration of a historic resource.

- Historic memorialization. Permanent recognition of an important historical resource through such means as a physical plaque or official designation.
- Historic preservation. A treatment for a historic building or landscape that focuses on the maintenance and repair of existing historic materials and retention of a property's form as it has evolved over time.
- Historic reconstruction. A treatment for a historic building or landscape that re-creates vanished or non-surviving portions of a property for interpretive purposes.
- Historic rehabilitation. A treatment for a historic building or landscape that acknowledges the need to alter or add to a historic property to meet continuing or changing uses while retaining the property's historic character.
- Historic restoration. A treatment for a historic building or landscape that depicts a property at a particular period of time in its history, while removing evidence of other periods.

Holistic approach. An approach that addresses the factors that lead to a condition or behavior as well as the treatment of symptoms or enforcement of laws, in order to prevent a condition or behavior.

I

Impact. Generally, the result of an action or inaction; when the term is used in the context of an environmental analysis under the California Environmental Quality Act (CEQA), the term "impact" refers to how a proposed project may directly or indirectly effect specific environmental, infrastructure, and public service factors; a negative impact damages those environmental factors or increases burdens on selected facilities and services).

Identify. To determine characteristics or facts without any predetermination regarding future commitments; gather information only.

Include. To make a part of a consideration or issue under public scrutiny.

Incompatible. To be so opposed in character as to be incapable of existing together without causing conflicts or harm upon one or all parts; conflicting; see also *compatible*.

Incorporate. The same as *include*.

Inconsistent. Varying to the point of conflict or contradiction; see also *consistent.*

Infill development. Development that is constructed on land that has direct access to existing public services and infrastructure.

Innovative. Methods or approaches that are new and original, often (but not always) more advanced.

Install. To put in place at a specified time or place or in a particular sequence.

Integrate. To blend new and existing projects or activities together in a compatible fashion.

Intensity. For non-residential land uses (such as commercial or retail development) the amount of square footage built on a given site. Expressed typically as floor-to-area ratio (see FAR). The maximum intensity permitted in an area of the unincorporated county is determined by the Policy Plan land use category and corresponding zoning designation.

Inundation area. A defined area downstream from any dam, basin, or impounded body or source of water (including reservoirs, large above ground water tanks, lakes, etc.) that could be flooded in the event of a sudden or complete failure of the structure. The inundation area or zone can also include levees that are breached or compromised, causing water to flood adjacent areas.

Investigate. To examine the accuracy of information provided in support of a proposed project, process, or program.

J

[placeholder]

K

[placeholder]

L

Land use category. Reference term for the classification of generally permitted land use type and intensity as directed by the County Policy Plan; also commonly referred to in other jurisdictions as general plan land use designations. The land use categories are implemented by land use zoning districts, which contain more specific regulations on land use and building standards.

Land use zoning district. Reference for the classification and regulation of land use type and intensity in the County Development Code. The land use zoning districts implement the land use categories of the Policy Plan. See also *zoning*.

Land Use Map. Reference term for the Policy Plan Land Use Map showing the distribution of land use categories across the unincorporated county.

Land Use Plan. Reference term that consists of the Policy Plan Land Use Map and tables describing the nature and intensity of development allowed in each Policy Plan land use category.

Land Use Plan amendment. A proposed change by an applicant or the County in the land use category(ies) of a parcel or set of parcels. Such change requires approval by the County Board of Supervisors.

Land Use Plan amendment, comprehensive. An evaluation by the County of the appropriate quantity and distribution of that land use category in the entire area (community planning area, unincorporated sphere of influence, or, when outside of such boundaries, the local context defined by the County).

Landscape-scale conservation. A holistic approach to conservation, concerned with biodiversity and local economies, cultural heritage, agriculture, eco-tourism, geodiversity and the health and social benefits of the environment. Landscape-scale conservation contrasts with site-based conservation and is not merely large-scale conservation.

Legacy community. In accordance with state law and guidance provided by the Governor's Office of Planning and Research and San Bernardino County Local Area Formation Commission, the County used the following criteria to identify disadvantaged unincorporated legacy communities (consistent with Senate Bill 244, 2011):

- Located outside of city/town limits and spheres of influence of any city/town;
- Inhabited and has been for at least 50 years (also referred to as a legacy community);
- Consists of at least 10 dwelling units in close proximity (approximately 1-mile radius); and
- Median household income for the census tract less than 80% of the statewide median.

The County must conduct a high level evaluation of the potable water, wastewater treatment, stormwater drainage, and structural fire protection service needs and resources for legacy communities.

Level of service (LOS) *(standard)*. A qualitative measure describing the delivery of service based on the needs and/or desires of customers or users. A LOS standard also generally factors in financial constraints (e.g., amount of user fees or taxes), as well as physical constraints (e.g., topography or distance). In measuring traffic conditions, it is the measurement and categorization of traffic flow based on vehicle speed, density, congestion, and other elements.

Limit. To confine a project or activity within prescribed specifications or performance criteria.

Link. To connect a project, area, function, or activity to another feature or features that would be mutually beneficial and reinforce desired functions.

Local park. Publicly-owned land designed and maintained to serve the recreation needs of people living or working in close proximity to the park. Neighborhood parks are small (~1 to 15 acres) and offer developed and programmed space and facilities such as playgrounds, picnic areas, fields, community centers, and sports fields for those within approximately one-half mile radius of the park. Community parks are larger (~16 to 99 acres) and are intended to provide recreation opportunities beyond those supplied by neighborhood parks, serving residents from throughout a community or jurisdiction.

Local trail. A trail typically built, operated, and maintained by a single jurisdiction, district, or agency for access by residents and visitors within a single community or jurisdiction.

Locate. To place an improvement, function, or use in a particular locale, on property with certain characteristics, or in proximity to specified features to bring about benefits and/or efficiency.

M

Master planned communities. A residential development that also includes recreational and commercial amenities, and can also include local retail stores, businesses, and other employment opportunities. Master planned communities are typically built in phases with coordinated transportation and infrastructure improvements, a variety of housing types, and long-term public and private funding mechanisms.

Maintain. To keep a system, facility, area, or activity in continuously sound condition, as defined by approved standards.

May. To offer the possibility but not the probability or promise of a certain commitment of resources or support; associated with action or activity that is often desirable and allowed, but implementation of such action or activity is often conditional.

Military activity / operations. Testing, training, or other activities conducted by the military (personnel or equipment) within or outside of a military installation.

Military installation. The land and facilities within a specific boundary identified by the US Department of Defense. The five military installations in (wholly or partially) San Bernardino County are: Marine Corps Air Ground Combat Center/Marine Corps Air Ground Task Force Training Command (MCAGCC/MAGTFTC), Edwards Air Force Base (AFB), Fort Irwin National Training Center (NTC), Naval Air Weapons Station (NAWS) China Lake, and Marine Corps Logistics Base (MCLB) Barstow.

Mines, legacy abandoned. Mines that ceased operation before state and federal laws required reclamation of mined land.

Minimize. To reduce something to the smallest amount or degree feasible.

Ministerial. An action taken by a governmental agency that follows established procedures and rules and does not call for the exercise of judgment in deciding whether to approve a project.

Mitigation bank. A wetland, stream, or other aquatic resource area that has been restored, established, enhanced, or (in certain circumstances) preserved for the purpose of providing compensation for unavoidable impacts to aquatic resources permitted under Section 404 of the Clean Water Act or a similar state or local wetland regulation. A mitigation bank may be created when a government agency, corporation, nonprofit organization, or other entity undertakes these activities under a formal agreement with a regulatory agency.

Monitor. To track the performance of a particular physical condition, activity accomplishment or aspect of change, with a view toward using the results to inform County determination of its appropriate commitments.

Mutual aid. Mutual aid is assistance that, based on a contractual agreement, is dispatched on an as-needed and requested basis between two emergency service departments, communities, or districts when an emergency occurs. It differs from automatic aid, which is dispatched automatically.

N

Never. Something (e.g., action or land use) will not take place or occur under any circumstance.

New development. On land in the unincorporated area, any construction of new buildings or construction of new structures that are the primary use, and any subdivision or change in zoning classification.

New lot. On land in the unincorporated area, any lot that is created (recorded) after the adoption date of the Policy Plan. The term applies to lots created through a parcel map or subdivision map.

Notify. To advise a specified party or parties regarding an event or change for which there is an obligation to inform or need to know.

O

Objective (*Business Plan*). Something that an individual's, group's, or organization's efforts are intended to attain; something designed to achieve specific results.

Overdraft. The condition of a groundwater supply in which the average annual amount of water withdrawn by pumping exceeds the average annual amount of water replenishing the aquifer in any ten year period, considering all sources of recharge and withdrawal.

Overdraft, critical. A groundwater basin is subject to critical conditions of overdraft when continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts. Groundwater basins "subject to

critical conditions of overdraft that are assigned a high or medium priority by the State Department of Water Resources must be managed under a groundwater sustainability plan by January 31, 2020. Groundwater sustainability plans, or their equivalent, must be established for all other high and medium-priority basins by January 31, 2022.

P

Partner. To join with another entity in conducting an activity or building a facility that would be mutually beneficial and add value more efficiently than if pursued independently; does not necessarily require financial commitments. See also *cooperate.*

Periodically. The action will take place or apply to future decisions at specified intervals or times.

Policy. A statement that guides decision-making and specifies public commitment. A policy defines and directs how the County intends to achieve goals.

Policy Plan. A compendium of long-term goals and policies intended to guide decision making regarding the improvement and planning of the county unincorporated areas, as well as the provision of regional and local services and facilities. The Policy Plan also provides the high-level direction for implementing programs and ordinances, such as the County Development Code.

The Policy Plan legally functions as the County's general plan. A general plan is a legal document required of each local agency by the State of California (see Government Code Section 65300 et seq.). In California, a general plan must address at least eight mandatory topics (land use, circulation, housing, conservation, noise, open space, safety, and environmental justice), and may include any number of optional topics (such as air quality, economic development, and health and wellness).

There is no requirement that the County refer to the document as a general plan, and other jurisdictions may refer to their general plan as a comprehensive plan. The County opted to refer to its general plan as the County Policy Plan to reflect its expanded topical and geographic coverage.

Prevent. To keep a particular use, condition, activity, or circumstance from occurring; it does not imply complete (100 percent) avoidance or elimination.

Preserve. To maintain something in its original or existing state *(verb)*. An area dedicated to the protection and conservation of biological resources and/or landscapes *(noun)*.

Prioritize. To intentionally direct discretionary investments or actions to one area ahead of other areas. The act of prioritizing is an ad-hoc process that considers a variety of relevant factors. State and federal law and agency requirements, court orders, and County-declared emergencies take precedent over the prioritization direction in the Policy Plan

Principle. An assumption, fundamental rule, or doctrine that guides Policy Plan policies, proposals, standards, and implementation measures.

Prohibit. To absolutely disallow something from happening or being built.

Promote. To actively stimulate the likelihood and desirability of something happening; does not require investing public resources in its direct development.

Protect. To shield from damage to people or property.

Provide. To make something available, typically to a community, organization, or business; it does not imply that the thing is being made available at no cost.

Public infrastructure. Capital facilities that are owned and maintained by public entities, including but not limited to: flood control, water, sewer, transportation, parks, law and justice, fire prevention and protection, public health, and facilities for parks, recreation, and other community services.

Public water system. A system for the provision of water for human consumption through pipes or other constructed conveyances that has 15 or more service connections or regularly serves at least 25 individuals daily at least 60 days out of the year, or as otherwise defined in the California Health and Safety Code. The three main types of public water systems are: community, transient-noncommunity, and nontransient, noncommunity.

Pursue. To strive to obtain or to seek to accomplish something, often through direct actions, partnerships, or indirect assistance. See also *support*.

Q

[placeholder]

R

Ranged activities or projects. Civilian activities or projects that can exert impacts beyond a project's boundaries and create compatibility issues with military activity.

Recidivism. A person's relapse into criminal behavior; a subsequent criminal adjudication or conviction while on probation supervision.

Recycled water. Water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur and is therefore considered a valuable resource. A form of water reuse that includes primary, secondary and tertiary treatment of wastewater to produce water suitable for a variety of non-potable applications, most notably for landscaping irrigation and industrial uses. Recycled water is synonymous with "reclaimed water," "Title 22 Water" (water that conforms to the Uniform Statewide Recycling Criteria), and "treated wastewater."

Redevelopment, significant. The addition or replacement of 5,000 or more square feet of impervious surface on an already developed site, including, but not limited to: expansion of a building footprint; addition of a building or structure; addition of an impervious surface, such as construction of a new parking lot that is not part of a routine maintenance activity; and replacement of imperious surfaces, buildings or structures when 5,000 or more square feet of soil is exposed during replacement construction. It does not include routine maintenance activities conducted to maintain original line and grade, hydraulic capacity, or the original purpose of a facility.

Reflect. To embody or represent (something) in a faithful or appropriate way.

Region / regional. A geographic area; or pertaining to activities or economies at a scale greater than that of a single jurisdiction, and affecting a broad geographic area. In the Countywide Plan, the term may refer to the Inland Empire (generally considered San Bernardino and Riverside counties), Southern California, or to San Bernardino County subareas with similar features or characteristics (e.g., Valley, Mountain, North Desert, and East Desert regions).

Regional park. A park typically 100 acres or larger focusing on activities and natural features not included in most other types of parks and often based on a specific scenic or recreational opportunity. A regional park may have any combination of developed, undeveloped, programmed, and unprogrammed space. A regional park is primarily intended to serve residents within an hour's drive, although it may also serve the entire county in some capacity.

Regional trail. A trail typically extending for very long distances across multiple jurisdictions, with operation and maintenance often coordinated and funded by multiple jurisdictions and/or agencies.

Report. To provide public information on a subject or condition.

Require. To absolutely impose an obligation or standard.

Resiliency. The ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption or disasters.

Respect. To give due regard for something or to hold something in high regard.

Rural. Development patterns characterized predominantly by very low density housing development and limited amounts of low intensity commercial buildings in proximity to large natural areas or open space. Rural development often has limited infrastructure (e.g., onsite septic, onsite wells, unpaved roads, etc.).

S

Safe yield. The maximum quantity of water that can be annually withdrawn from a groundwater aquifer without resulting in overdraft, without adversely affecting aquifer health, and without adversely affecting the health of associated lakes, streams, springs and seeps or their biological resources. The safe yield of an aquifer can be increased by management actions such as artificial recharge, including infiltration and other similar actions.

Sensitive land uses. Types of facilities that the California Air Resources Board recommends being protected from sources of air pollution. Sensitive land uses include residences, childcare centers, educational institutions, medical facilities, senior care facilities, and parks and recreation facilities.

Shall. Will always be carried out or required; no exceptions.

Shared parking. A land use strategy that optimizes parking capacity, reduces the amount of land developed, and promotes connectivity by allowing complementary land uses to share parking spaces, rather than producing or requiring separate spaces for separate uses.

Should. Will be carried out or required most of the time, unless a very good reason is identified why an exception is acceptable.

Social capital. An intangible resource that community members can draw upon to solve collective problems. It consists of social trusts, norms, and networks that can alleviate societal problems. Civic engagement encourages feelings of reciprocity between community members and facilitates coordination, communication, and collaboration. Social capital can also be understood by examining community events, organizations, facilities, and participants.

Sometimes. Will apply to future decisions under specified conditions or circumstances.

Specify. To establish distinct requirements.

Sphere of influence (SOI). The probable physical boundary and service area of a local agency, such as an incorporated city or town or a special district, as determined by the local agency formation commission (LAFCO). SOIs are planning tools used to provide guidance for individual proposals involving jurisdictional changes, and are intended to encourage the efficient provision of organized community services and prevent duplication of service delivery. A territory must also be within a city or district's sphere in order to be annexed.

While a city/town SOI can include both incorporated and unincorporated lands, the unincorporated lands remain within the jurisdictional control of the county until such time that the land is annexed into the city/town. A city/town is obligated to consider its unincorporated SOI in its general plan, although the county's planning authority remains in place.

Strive. To make great efforts or devote serious effort to achieve or obtain something.

Sufficient buildable area. Able to conform to current development standards and requirements from local, state, and federal agencies.

Suburban. Development patterns characterized predominantly by a mix of very low to medium density single family housing and multifamily housing development, interspersed with retail, office, industrial, and public or quasi-public facilities. Suburban development is often supported by investments in water, sewer, and roadway infrastructure.

Support. To provide assistance or promotion; see *encourage*.

Sustainable. Able to use a resource or conduct activity at a desired rate or level without depleting resources (e.g., financial or natural) to a point where others cannot rely upon or use them in the future; in some context the term can refer to the long-range viability of the environment, economy, and social equity (referred to as "the three E's of sustainability").

T

Truck traffic, truck trips, or trucking-intensive business. In the context of defining truck traffic or a trucking-intensive business, a truck is a vehicle identified by the Federal Highway Administration vehicle as Class 5 or higher, with the exception of dually trucks and recreational vehicles. A trucking-intensive business is a permitted use that includes the frequent use of trucks as part of its primary activities. Examples include truck yards, logistics facilities, hazardous materials or waste facilities, container storage, and container parking. Excluded from this definition is commercial vehicle storage in residential areas as permitted in the County Development Code.

U

Upstream issues. Conditions, such as food insecurity, that exist prior to and contribute to a person's undesirable medical, social, financial, or legal circumstance.

Urban. Development patterns characterized by higher density residential and/or nonresidential development served by frequent transit service and public infrastructure.

V

Value *(Community Action Guide)*. A shared asset, principle, standard, social more, and in the judgement of the community, what is important in the lives of its residents and businesses.

Vulnerable population or community. Populations or communities that experience heightened risk and increased sensitivity to natural disasters, emergencies, or severe weather events or conditions; and have less capacity and fewer resources to cope with, adapt to, or recover from such events or conditions.

W

Watermaster. A board or committee appointed by a court to oversee an adjudicated water basin, fulfilling the obligations set forth in a stipulated judgement containing a declaration of rights of the water users and other entities for a specific groundwater basin.

We *(Community Action Guide)*. The collective of community residents, business owners, property owners, service providers, and other stakeholders; distinct from the usage of "we" in the Policy Plan.

We *(Policy Plan)*. The County of San Bernardino government body; distinct from the usage of "we" in the Community Action Guides.

Wildlife corridor. A wildlife corridor can be defined as a linear landscape feature of sufficient width to allow animal movement between two comparatively undisturbed habitat fragments. Wildlife corridors are similar to linkages, but provide specific opportunities for animals to disperse or migrate between areas. Adequate cover is essential for a corridor to function as a wildlife movement area. It is possible for a habitat corridor to be adequate for one species yet, inadequate for others. Wildlife corridors are significant features for dispersal, seasonal migration, breeding, and foraging. Additionally, open space can provide a buffer against both human disturbance and natural fluctuations in resources.

Williamson Act (WA). Also known as the California Land Conservation Act of 1965, the WA creates an arrangement whereby private land owners contract with local governments to voluntarily restrict land to agricultural and open space uses. The vehicle for these agreements is a rolling term 10-year contract (i.e., unless either party files a "notice of nonrenewal" the contract is automatically renewed annually for an additional year). In return, restricted parcels are assessed for property tax purposes at a rate consistent with their actual use (which is typically very low based on agricultural or open space usage), rather than potential market value.

Contracts may be exited at the option of the land owner or local government by initiating the process of term nonrenewal. Contract cancellation involves a comprehensive review and approval process, as well as a fee equal to 12.5 percent of the full market value of the subject property. Other circumstances and processes may also apply. *See also agricultural preserve.*

Wind erosion hazard area. Wind erosion is the process of detachment, transport, and deposition of soil by wind. Wind erosion potential is determined based on the type of soil present in an area and the area's average wind speed. A wind erosion hazard area is an area where the potential for wind erosion is categorized as medium-high or high, and is therefore an area where wind-blown soil could be a hazard for buildings and other structures.

X

[placeholder]

Y

[placeholder]

Z

Zoning. The division of a jurisdiction by legislative regulations into areas (aka land use zoning districts), which specify allowable uses for real property and size restrictions for buildings within these areas; a program that implements policies and the land use categories of the Policy Plan.

EXHIBIT X

TRANSPORTATION IMPACT STUDY GUIDELINES

Date: July 9, 2019

Subject: Transportation Impact Study Guidelines

Senate Bill 743 (SB 743), signed by the Governor in 2013, is changing the way transportation impacts are identified. Specifically, the legislation has directed the Office of Planning and Research (OPR) to look at different metrics for identifying transportation as a CEQA impact. The Final OPR guidelines were released in December 2018 and has identified vehicle miles of travel (VMT) as the preferred metric moving forward. The Natural Resources Agency completed the rule making process to modify the CEQA guidelines in December of 2018 as well. Given the timing of this implementation with the County General Plan, it is prudent to address VMT and develop draft significance criteria to evaluate the General Plan related to VMT.

The County has identified that vehicle level of service (LOS) is still of value to the residents of San Bernardino County. As such, the General Plan includes policies that address LOS and identify LOS standards for which County infrastructure will strive to maintain. Therefore, County projects will also be required to complete a transportation impact study (TIS), in addition to VMT assessment, to demonstrate consistency with the General Plan. We recognize that the San Bernardino County Transportation Analysis Model (SBTAM) is currently the most appropriate travel demand model to use in San Bernardino County and our recommended methodologies reflect that. However, the recommended methodologies in this memorandum will continue to be applicable even if other traffic models supersede SBTAM in the future.

As such, the purpose of this memorandum is to provide recommendations related to VMT assessment (both thresholds of significance and methodology for identifying VMT related

impacts) and to refine the County's existing TIS guidelines to reflect state of the practice methodologies for identifying project impacts.

Finally, it should be noted that the County should update these guidelines on an as needed basis to reflect changes in CEQA requirements, new methodology development, or refinement of process moving forward. As such, the County should continually review these guidelines for applicability and consultants should contact the County to ensure that they are applying the most recent guidelines for project impact assessment.

The remainder of this memorandum is organized as follows. We have attempted to organize this memorandum to provide background information, assessment for congestion management/ General Plan Consistency (e.g. Level of Service analysis), and CEQA assessment (e.g. VMT analysis).

1. Introduction
2. Need for Transportation Impact Study
3. Level of Service Assessment for General Plan Consistency
4. CEQA Assessment - VMT Analysis
5. CEQA Assessment - Active Transportation and Public Transit Analysis
6. Transportation Impact Study Format

1. INTRODUCTION

The purpose of Transportation Impact Study (TIS) Guidelines is to provide a general guide in assessing the potential transportation impacts of proposed development projects, General Plan Amendments and changes in zoning in the County of San Bernardino. This memorandum presents the recommended format and methodology that should generally be utilized in the preparation of traffic studies. These recommendations are based on the County's most recent TIS Guidelines with updates provided to recommend state of the practice methodologies, address recent California Environmental Quality Act (CEQA) legislation such as Senate Bill 743 (SB 743), and provide consistency for future transportation studies in the County.

These recommendations are general guidelines for the preparation of a TIS Report. The Department of Public Works should reserve the right to modify the TIS requirements based on the unique characteristics of a particular project.

All TIS's shall be prepared by a registered Traffic Engineer (State of California) or a registered Civil Engineer with experience in traffic. The TIS must contain a Title Page that includes, at a minimum, the Tract or Parcel number of the project, the applicant's name and address and the Engineer's name, Engineer's signature, address, phone number and stamp.

To avoid unnecessary delays or revisions and to stream line the TIS preparation and review process, the County should require that the applicant submit and have approved, by the Department of Public Works Traffic Division, a scoping form prior to the preparation and submittal of a draft TIS. A version of this document in Word format is attached to this memo.

1.1 CEQA CHANGES

Since the last TIS Guidelines update, SB 743 was signed into law. A key element of this law is the elimination or deemphasizing of auto delay, level of service (LOS), and other similar measures of vehicular capacity or traffic congestion as a basis for determining significant impacts. This change can assist in balancing the needs of congestion management with statewide goals related to infill development, promotion of public health through active transportation, and reduction of greenhouse gas emissions.

SB 743 contains amendments to current congestion management law that allows cities and counties to effectively opt-out of the LOS standards that would otherwise apply in areas where Congestion Management Plans (CMPs) are still used. Further, SB 743 requires the Governor's Office of Planning and Research (OPR) to update the California Environmental Quality Act (CEQA)

Guidelines and establish criteria for determining the significance of transportation impacts. In December 2018, OPR released their final recommended guidelines based on feedback with the public, public agencies, and various organizations and individuals. OPR recommends Vehicle Miles Traveled (VMT) as the most appropriate measure of project transportation impacts. SB 743 does not prevent a city or county from continuing to analyze delay or LOS as part of other plans (i.e., the general plan), studies, congestion mitigation, or ongoing network monitoring; but these metrics may no longer constitute the sole basis for CEQA impacts.

In recognition of SB 743 and OPR's VMT recommendations, the recommendations in this memorandum include VMT thresholds and mitigation to ensure consistency with CEQA Guidelines. However, it should be noted that these recommendations are in advance of the County's General Plan Update, which will also include LOS standards since automobile level of service continues to be of importance to the County's unincorporated communities. Therefore, these TIS Guidelines also contain LOS analyses and threshold recommendations to maintain consistency with the General Plan.

2. NEED FOR TRANSPORTATION IMPACT STUDY

In order to ensure that projects are consistent with the Countywide General Plan, roadway facilities operate at an acceptable level of service, and region wide VMT is reduced, the County should require a study for any development if there are concerns over safety or operational issues such as congestion, VMT, etc. This can include development projects, Specific and Area Plans, or requests by an applicant for General Plan Amendments. Our recommendations, consistent with the most recent County TIS Guidelines, are provided below.

First, prior to the applicant filing an application with Land Use Services Department, the Traffic Division should determine both whether a TIS is required and what type of TIS should be prepared.

The requirement to prepare a TIS should be based upon, but not limited to, one or more of the following criteria:

- If a project generates 100 or more trips without consideration of pass-by trips during any peak hour.
- If a project is located within 300 feet of
    - The intersection of two streets designated as Collector or higher in the County's General Plan or the Department's Master Plan **or**
    - An impacted intersection as determined by the Traffic Division.
- If this project creates safety or operational concerns.
- The project has the potential to generate VMT that could result in a transportation impact as noted in the significance criteria presented later in this memorandum.
- If a project generates less than 100 trips without consideration of pass-by trips during any peak hour, a study maybe required if there are special concerns.

The Traffic Division should also reserve the right to require an applicant to prepare additional traffic analysis based on the project location, configuration, unique aspects of the project, proximity to major roadways, interchanges or intersections, evaluating corner site distance at the driveways or other requirements as determined by the Traffic Division, including after the scoping agreement is approved.

2.1 TYPES OF TRANSPORTATION IMPACT STUDIES

The type of study used should depend on the location of the project, the amount of project trips generated, the estimated VMT and whether the project falls within a fee plan area. As noted

previously, Traffic Division should determine the type of study to be submitted by the applicant. There are two types of TIS that can be requested by the Department of Public Works:

1. **Transportation Impact Study:** This type is required when thresholds are met and conducted based on these recommendations. Since these recommendations are in compliance with SBCTA guidelines, a TIS required by the County may be used to meet requirements for a TIS under the SBCTA Congestion Management Program.
2. **Letter Report:** A letter to address the significant impacts of the project in the immediate area. This type of report is primarily intended for specific concerns or small projects and thus limited to special situations. Letter reports may be sufficient when documenting potential VMT impacts and recommending mitigation measures to reduce VMT or when addressing a limited number of study locations.

2.2 COORDINATION WITH THE DEPARTMENT OF PUBLIC WORKS

Prior to filing an application with Land Use Services, the applicant should obtain a scoping form from Land Use Services or the Traffic Division and submit the completed form to Department of Public Works at Land Use Office or Traffic Division. Traffic Division can then make a determination regarding the need for and type of TIS.

If a TIS is needed, the applicant shall retain the services of a qualified registered Traffic or a registered Civil Engineer with experience in traffic engineering and initiate the process of finalizing a scoping agreement that will govern the conduct of the TIS. Studies submitted for review without an approved scoping agreement could be subject to significant revisions and could increase the cost for review that will be charged to the applicant by the Department. Additionally, the scoping agreement is an initial agreed-upon scope between the County and the engineer and the scope may need to be amended during the process based on potential changes to the project, input received during the project, or other items that may necessitate the need to expand or contract the scope of the study.

The TIS should be completed and submitted at the time an application is filed with Land Use Services. The applicant should obtain the approval of the submitted TIS prior to the approval of the proposed project.

3. LEVEL OF SERVICE ASSESSMENT FOR GENERAL PLAN CONSISTENCY

3.1 SCOPE OF TRANSPORTATION IMPACT STUDY

The locations and scenarios analyzed in a transportation impact study should insure that potential impacts are discussed and mitigated across a variety of possible facilities and horizon years. Our recommendations for study area and scenarios are given below.

3.1.2 Study Area Boundaries for LOS assessment

The area to be studied should include all intersections, which the proposed project will add 50 or more trips during any peak hour and roadway segments adjacent to the project if directed by the County. All key study facilities within this study area should be analyzed to identify impacts to capacity and Level of Service (LOS). The study facilities should be listed in the scoping form for review and approval by the Traffic Division.

At a minimum, the following subject/locations should be studied:

a) Site access driveways
b) On-site circulation
c) Roadway(s) adjacent to the project (if requested by County staff)
d) Intersections in the immediate vicinity of the project
e) Pedestrian and bicycle circulation
f) Consistency with County Plans and Policies
g) Transit (bus and light commuter rail) accessibility to project site
h) Any intersection on which the project will add 50 or more peak hour project trips

3.1.2 Study Scenarios for LOS Assessment

The following study scenarios should be included for intersection capacity analysis:

a) Existing Conditions
b) Background Conditions – Defined as Opening Year Conditions with ambient growth and traffic from approved projects
c) Background Plus Project Conditions – Defined as background conditions plus traffic from the proposed project

d) Cumulative No Project Conditions – Defined as ambient growth to the Cumulative Horizon (typically coinciding with the forecast horizon of the SBTAM travel demand forecasting model) plus traffic approved and pending projects in the area
e) Cumulative Plus Project Conditions – Defined as Cumulative No Project Conditions plus traffic from the proposed project

The purpose of Background Condition analyses is to document the potential near-term impacts of the Project on the County's transportation facilities. However, if the if the project opening year is more than five years beyond the Existing Conditions assessment, then an Existing Plus Project scenario should be analyzed as an additional scenario.

Phased projects could be evaluated in three ways. First, the analyst can identify which phase of a project triggers an impact based on the comparison of Background Conditions to Background Plus Project Conditions. Alternatively, they can provide a phased assessment looking at opening years of each phase. Finally, for large phased projects, the project as a whole could be evaluated initially; however, subsequent traffic studies would have to be completed for each proposed phase implementation to ensure that improvements are implemented when they are needed. The County should be consulted to identify which approach is most appropriate for a proposed project if phasing is proposed recognizing the County's desire to ensure that infrastructure is delivered concurrent with proposed development when needed.

Recommendations for developing Ambient Traffic and Cumulative Traffic are provided in the next section of this document.

3.2. DATA COLLECTION, PROJECT TRIP, AND FORECASTING METHODOLOGIES

The following recommendations pertaining to traffic count collection, project trip development, and traffic forecasting methodologies have been developed to maintain consistency across different transportation impact studies and reflect current state of the practice.

3.2.1 Traffic Counts

Data for existing traffic conditions should be collected for the project using the following guidelines:

- Peak period turning movement counts at all study intersections, roadway segments (if required) and/or driveways, including bicycle and pedestrian counts at intersections with high non-automotive use, should be collected. For intersections with high percentages of heavy vehicles, turning movement counts should count heavy vehicles separately.
- Average Daily Traffic (ADT) for all roadways within study area (if required) and vehicle classification counts in areas with a high percentage of heavy vehicle use.
- Traffic counts should not be used if more than one (1) year old without prior Traffic Division approval.
- Traffic data should not be collected on weeks that include a holiday and non-school session time periods unless approved by the Traffic Division.
- Traffic data should not be collected between Thanksgiving and the first week of the new year without prior Traffic Division approval.
- Traffic counts should be conducted on Tuesdays, Wednesdays, or Thursdays.

Unless directed otherwise by the Traffic Division, counts should be collected during the following time frames:

- Morning (7:00 a.m. to 9:00 a.m.)
- Afternoon/evening (4:00 p.m. to 6:00 p.m.)
- Midday and "School-Release" peak hours – As directed by the Traffic Division
- Other peak hours, off-peak, weekend or special event, may also be required depending on the project location and type of use

Count data should be included in the study appendices.

3.2.2 Trip Generation

The latest edition of the Institute of Transportation Engineers' (ITE) Trip Generation should be used for trip generation forecasts. Local data (if available) is preferred, but should be approved by

the County prior to application. Trip generation for high truck generating uses such as high cube warehouses, logistics space, etc. shall be determined with County input on a case-by-case basis. The proposed trip generation should be listed in the scoping form for review and approval by the Traffic Division.

Trip internalization for mixed use developments (if applicable) should be calculated using state of the practice methodologies. At the time of this memorandum, the EPA's mixed-use trip generation (or MXD) methodology is the state of the practice and should be approved by the Traffic Division prior to use in any studies. Trip internalization calculations (including gross trips, net trips after internalization, and MXD input assumptions (such as intersection density, TOD assumptions, acres, etc.)) should be documented in the TIS.

For projects that anticipate the generation of significant truck traffic, all truck trips should be converted into passenger car equivalents (PCE) for the capacity analysis or the analyst should adjust the heavy vehicle percentage in the capacity assessment appropriately.

3.2.3 Trip Distribution

A graphical representation of the proposed project trip distribution should be based on the relative location of population, commercial, recreational and employment centers; existing peak hour link and turning movement volumes; ADT volumes; proximity to regional transportation corridors knowledge of local and regional traffic circulation; and/or a select zone assignment from SBTAM. A preliminary trip distribution pattern should be submitted in the scoping form for review and approval by the Traffic Division.

The trip distribution may be further refined, after consultation with the Traffic Division, based on consideration of following factors:

- Type of proposed development
- Location and intensity of development
- Conditions on the roadway network in the vicinity
- Similar land use in the vicinity
- Truck route system
- As directed by Traffic Division

3.3 TRIP FORECASTS

For Cumulative Conditions, SBTAM should be used to develop future traffic volume forecasts. For all projects, the applicant should include cumulative development projects in the study. A list of proposed and approved developments can be obtained from the County's Land Use Services

Planning Division. For proposed projects that are in close proximity to incorporated cities, those cities should also be contacted to obtain a list of proposed and approved development projects in those jurisdictions. At a minimum, future projects located within two miles of the study area should be included. Projects outside that radius should be included if the traffic generated by that project can reasonably be expected to impact a study intersection and/or road segment.

3.4 INTERSECTION ANALYSIS

3.4.1 Analysis Methodology

Intersection analyses should be performed using the latest version of the Transportation Research Board, Highway Capacity Manual (the HCM 6th Edition) is the latest version at the time this memorandum was written methodology which reflects current state of the practice. The HCM methodology assigns an LOS grade to an intersection based on estimated delay at that intersection.

Level of service analysis based on the current Highway Capacity Manual shall be used in the analysis with the following assumptions:

- Existing signal timing for Existing Conditions; Optimized signal timing for non-coordinated intersections for all other analysis scenarios
- For coordinated intersections, the existing coordination timing plan should be obtained from the responsible agency.
- Four (4) seconds of lost time per critical phase should be assumed if signal timing data is not available
- Field-collected heavy vehicle factor if available; otherwise, 2% shall be assumed
- Field-collected peak hour factor (PHF) for existing and background conditions analyses; for cumulative assessment, 0.95 shall be assumed

Saturation flow rates should be used based on actual field measurements of particular intersections if possible and with approval from the Traffic Division. Otherwise, the following saturation flow rates can be used, consistent with the SBCTA CMP:

- For Existing and Background scenarios:
    - 1,800 vehicles per hour green per lane (vphgpl) for exclusive thru and exclusive right turn lanes
    - 1,700 vphgpl for exclusive left turn lanes
    - 1,600 vphgpl for exclusive dual left turn lanes
    - 1,500 vphgpl for exclusive triple left turn lanes

- For the Cumulative and General Plan Build-Out scenarios:
    - 1,900 vphgpl for exclusive thru and exclusive right turn lanes
    - 1,800 vphgpl for exclusive double right turn lanes
    - 1,800 vphgpl for exclusive left turn lanes
    - 1,700 vphgpl for exclusive dual left turn lanes
    - 1,600 vphgpl for exclusive triple left turn lanes

3.4.2 Signalized Intersection General Plan Consistency Requirements

Consistent with the acceptable LOS for the Desert, Valley, and Mountain regions as described in the General Plan[1], the County should consider the following signalized intersection criteria for application in a traffic study. Please note that this will be completed to demonstrate General Plan Consistency. Specific CEQA thresholds, which are based on VMT requirements, are described later in this memorandum.

- Any signalized study intersection in the Valley or Mountain regions that is operating at an acceptable LOS D or better without project traffic in which the addition of project traffic causes the intersection to degrade to an LOS E or F shall identify improvements to improve operations to LOS D or better.
- Any signalized study intersection in the Desert region that is operating at an LOS C or better without project traffic in which the addition of project traffic causes the intersection to degrade to an LOS D, E, or F shall identify improvements to improve operations to LOS C.
- Any signalized study intersection in the Valley or Mountain regions that is operating at LOS E or F without project traffic where the project increases delay by 5.0 or more seconds shall identify improvements to offset the increase in delay.
- Any signalized study intersection in the Desert region that is operating at LOS D, E, or F without project traffic where the project increases delay by 5.0 or more seconds shall identify improvements to offset the increase in delay.

3.4.3 Unsignalized Intersection General Plan Consistency Requirements

Consistent with the acceptable LOS for the Desert, Valley, and Mountain regions as described in the current General Plan, the County should consider the following unsignalized intersection criteria when identifying operational deficiencies:

[1] These standards are subject to change; please review the General Plan to ensure the most recent standards are utilized.

An operational improvement would be required if the study determines that either section a) or both sections b) and c) occur:

a) The addition of project related traffic causes the intersection to degrade from an LOS D or better to a LOS E or worse in the Valley and Mountain regions or from an LOS C or better to an LOS D or worse in the Desert region.

OR

b) The project adds 5.0 seconds or more of delay to an intersection that is already projected to operate without project traffic at an LOS E or F in the Valley and Mountain regions or at an LOS D, E, or F in the Desert region (per Section 10.5.2 b))

AND

c) One or both of the following conditions are met:
   1) The project adds ten (10) or more trips to any minor street approach
   2) The intersection meets the peak hour traffic signal warrant after the addition of project traffic (per Section 10.5.2 c)).

If the conditions above are satisfied, improvements should be identified that achieve the following:

- In the Valley and Mountain regions, improvements should be identified that would achieve LOS D or better for case a) above or to pre-project LOS and delay for case b) above.
- In the Desert region, improvements should be identified that would achieve LOS C or better for case a) above or to pre-project LOS and delay for case b) above

3.5 ROADWAY SEGMENT ANALYSIS

Intersections typically provide the transportation constraint on vehicle capacity. As such, these guidelines focus on the evaluation of intersections. However, in some instances, roadway segment assessment could be appropriate and may be requested by the County Transportation Department. The following sections describe the appropriate methodology for evaluating roadway segments in those situations where required by the department.

3.5.1 Analysis Methodology

Daily roadway segment analysis should be performed using thresholds from the latest version of the Transportation Research Board, Highway Capacity Manual 6th Edition methodology which

reflects current state of the practice. The HCM methodology assigns an LOS grade to a roadway segment based on whether the daily volumes surpass given thresholds.

3.5.2 General Plan Consistency Requirements

Consistent with the acceptable LOS for the Desert, Valley, and Mountain regions as described in the current General Plan, the County should consider the following roadway segment thresholds and improvement requirements:

- Any study roadway segment in the Valley or Mountain regions that is operating at an LOS D or better without project traffic in which the addition of project traffic causes the segment to degrade to an LOS E or F should identify improvements to achieve LOS D.
- Any study roadway segment in the Desert region that is operating at an LOS C or better without project traffic in which the addition of project traffic causes the segment to degrade to an LOS D, E, or F should identify improvements to achieve LOS D.
- Any roadway segment that operates unacceptably in the no project scenario where the project adds traffic in excess of 5% of the roadway capacity (e.g. a volume-to-capacity ratio increase of 0.05) should identify improvements to add capacity to the segment.

3.6 SITE ACCESS, SAFETY, AND OTHER ANALYSES

A project's TIS should analyze site access and safety around the project and on adjacent streets. The recommended analyses, based on the previous TIS Guidelines, are given below.

3.6.1 Site Access Analysis

The following analyses are recommended to improve the project access circulation and to limit driveways and local street access on arterial streets:

a) **Intersection Sight Distance –** All on-site intersections, project access driveways or streets to public roadways should provide adequate sight distance. Adequate intersection sight distance should be determined using the Caltrans Highway Design Manual.

b) **Driveway Length and Gated Entrance –** Primary project driveways should have a throat of sufficient length to allow vehicles to enter the project area without causing subsequent vehicles to back out onto the County street system. A turn around should be provided at all gated entrances.

c) **Limit Driveway Impacts –** Driveways and local streets access on arterial streets should be limited to minimize the impacts on arterial streets. Driveways should be located so as to maintain a reasonable distance from an adjacent intersection and/or driveway. Whenever possible, driveways shall be consolidated with adjacent properties.

d) **Corner Clearance –** A driveway should be a sufficient distance from a signalized intersection so that right-turn egress movements do not interfere with the right-turn queue at the intersection. In addition, every effort should be made to provide right-turn egress movements with sufficient distance to enter the left-turn pocket at the adjacent intersection.

e) **Right Turn Lanes at Driveways –** If the project right turn peak hour volume is 50 or more vehicles, a right-turn deceleration lane should be reviewed for appropriateness on all driveways accessing major arterial and secondary streets. The length of right turn lane should be sufficient to allow a vehicle traveling at the posted speed to decelerate before entering the driveway as outlined in the Caltrans Highway Design Manual.

f) Adequacy of pedestrian facilities

g) Bicycle accessibility

h) Accessibility from adjacent transit stops

3.7 SAFETY AND OPERATION IMPROVEMENT ANALYSIS

The TIS should analyze opening year roadway conditions to determine if safety and/or operational improvements are necessary due to an increase in traffic from the project or cumulative projects. The following improvements should be analyzed:

a) Addition of through lane(s), right turn lane(s) and left turn lane(s)

b) Left and/or right turn lane pocket length (queue length)

c) Bus Turnouts – Coordinate potential bus top locations on arterial streets adjacent to the proposed project site with local transit agencies. Review appropriateness of bus turnouts for each of the identified bus stop locations.

d) Intersection Geometrics – Projects that generate heavy vehicle traffic should also review intersections along the routes to/from the site to determine that the intersections have been designed appropriately to accommodate the addition of heavy vehicles (e.g. curb returns and geometrics can accommodate turning trucks).

e) Parking restrictions on adjacent streets

f) Free Right Turn Lane – Free right turn lane should be considered when right turn volumes exceed 300 vehicles per hour.

g) Traffic Signal Coordination – For new or modified traffic signals, the Traffic Division should consider requiring signal coordination timing plans and, under certain conditions, traffic simulation based on the latest Highway Capacity Manual. The traffic simulation and coordination timing plan should include signalized intersections as identified by the Traffic Division. A copy of any software program files to develop these plans should be available to the Traffic Division for review.

h) Bicycle Circulation – Identify and implement bike lane facilities adjacent to the project site in accordance with the County's Bicycle Master Plan.

3.8 TRAFFIC SIGNAL WARRANT ANALYSIS

A traffic signal warrant analysis should be performed for all unsignalized study intersections for the project opening year (if applicable) and build-out year conditions. Traffic signal warrant analysis should be performed using the latest edition of the California MUTCD. The warrant analysis should be included in the study appendices.

In determining the location of a new traffic signal on an arterial street or approaching an arterial street, traffic progression and simulation analysis may be required using Synchro/SimTraffic software or equivalent at the direction of the Traffic Division.

3.9 IMPROVEMENTS FOR TRANSPORTATION IMPACTS

Several options exist to improve identified impacts and are dependent on the specific identified impact. Potential measures are noted below.

As part of the final acceptance of a transportation impact study, the Traffic Division should review and approve any required improvements and/or fair share contributions necessary to mitigate the transportation related impacts from the development. These should be included as part of the conditions of approval and should be in addition to any improvements required by any other Divisions of Public Works and/or Departments. Any transportation improvements based on a transportation study will be in addition to any other fees related to the existing Transportation Facilities Plans or any fees required by other Divisions of Public Works and/or Departments.

Fair share contributions identified in the transportation impact study and subsequently listed in the conditions of approval shall be required before a building permit will be issued. Improvements required in a transportation impact study and subsequently listed in the conditions of approval shall be completed prior to occupancy.

3.9.1 Level of Service Improvements

Improvements for project level impacts should focus on providing operations that offset the project impact (e.g. achieve a "no project" level of service). Improvements could consist of signal timing improvements, lane restriping, or new lanes to study facilities.

Cumulative impacts should include a fair-share contribution toward achieving acceptable levels of service as noted below. Alternatively, if a cumulative location is included in an existing traffic impact fee program, payment of those fees would constitute an appropriate contribution.

Finally, the project applicant could revisit the project description in an effort to potential reduce the project impacts if viable.

3.10 COUNTY FEE PLANS

The study should state if the proposed project falls within any of the adopted fee plans in the County's unincorporated areas. Further information can be found on the following website: http://www.sbcounty.gov/dpw/transportation/transportation_planning.asp.

3.11 FAIR SHARE CONTRIBUTIONS

For improvements that are needed where the applicant is not solely responsible, a fair share computation should be computed and reported for each such mitigation. The fair share amount should be calculated using the following formula:

$$\text{Fair share} = \frac{\text{project trips}}{\text{project trips + future development trips}} \text{ X } 100\%$$

Trips noted above should correspond to the peak hour where the impact occurs for intersection assessment or daily trips for roadway segment impacts. If a project has impacts during both peak hours, then the analysis should identify the peak hour for fair share assessment that has the highest project burden for fair share contribution.

4. CEQA ASSESSMENT - VMT ANALYSIS

A key element of SB 743, signed in 2013, is the elimination of automobile delay and level of service as the sole basis of determining CEQA impacts. The most recent CEQA guidelines, released in December 2018, recommend VMT as the most appropriate measure of project transportation impacts. However, SB 743 does not prevent a city or county from continuing to analyze delay or LOS as part of other plans (i.e., the general plan), studies, or ongoing network monitoring.

The following recommendations assist in determining VMT impact thresholds and mitigation requirements for various land use projects' Transportation Impact Studies.

4.1 ANALYSIS METHODOLOGY

For purposes of SB 743 compliance, a VMT analysis should be conducted for land use projects as deemed necessary by the Traffic Division and would apply to projects that have the potential to increase the average VMT per person or employee. Normalizing to VMT per person/employee essentially provides a transportation efficiency metric that the analysis is based on. Using this efficiency metric allows the user to compare the project to the remainder of the unincorporated area for purposes of identifying transportation impacts.

Please note that SBCTA is leading a SB 743 Implementation Study which will further refine the methodology identified in this section and will create tools to assist in VMT screening. The analyst and County should monitor those efforts for applicability for VMT assessment for subsequent projects and update this section of the guidance accordingly as new information and tools become available for use in the County.

Projects which serve the local community and have the potential to reduce VMT should not be required to complete a VMT assessment. These projects are noted below:

- K-12 schools
- Local-serving retail less than 50,000 sq. ft.
- Local parks
- Day care centers
- Local serving gas stations
- Local serving banks
- Student housing projects
- Local serving community colleges that are consistent with the assumptions noted in the RTP/SCS

- Projects generating less than 110 daily vehicle trips[2]
    - This generally corresponds to the following "typical" development potentials:
        - 11 single family housing units
        - 16 multi-family, condominiums, or townhouse housing units
        - 10,000 sq. ft. of office
        - 15,000 sq. ft. of light industrial[3]
        - 63,000 sq. ft. of warehousing[3]
        - 79,000 sq. ft. of high cube transload and short-term storage warehouse[3]
        - 12 hotel rooms
- Projects located within a Transit Priority Area (TPA) as determined by the most recent SCAG RTP/SCS (map of HQTAs can be reviewed on SCAG's website currently located here and will further be refined through SBCTA's efforts: http://gisdata.scag.ca.gov/Pages/GISStaticMaps.aspx but should be verified by the analyst
- Projects located within a low VMT generating area as determined by the analyst (e.g. development in efficient areas of the County will reduce VMT per person/employee and is beneficial to the region)

For all remaining projects, VMT should be estimated by multiplying average trip length by the trip generation for the project. It is recommended that average trip length information be obtained for each trip purpose from the SBTAM model. We also recommend use trip generation rates from the SBTAM model. Using SBTAM to determine both trip generation and trip lengths allows the user to use an identical methodology when comparing project VMT per person/employee to the regional VMT per person/employee.

Consistent with the OPR guidelines, the following specific VMT components will be utilized to complete a VMT impact assessment:

- **Residential Projects** - VMT/Person for all home-based trips (productions)

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[2] This threshold ties directly to the OPR technical advisory and notes that CEQA provides a categorical exemption for existing facilities, including additions to existing structures of up to 10,000 square feet, so long as the project is in an area where public infrastructure is available to allow for maximum planned development and the project is not in an environmentally sensitive area. (CEQA Guidelines, § 15301, subd. (e)(2).) Typical project types for which trip generation increases relatively linearly with building footprint (i.e., general office building, single tenant office building, office park, and business park) generate or attract an additional 110-124 trips per 10,000 square feet. Therefore, absent substantial evidence otherwise, it is reasonable to conclude that the addition of 110 or fewer trips could be considered not to lead to a significant impact.

[3] Threshold may be higher depending on the tenant and the use of the site. This number was estimated using rates from ITE's Trip Generation Manual.

- **Employment Projects** – VMT/Employee for only the home-based-work trip purpose (attractions) and would apply to office, industrial, governmental, and institutional projects
- **Regional Retail** – VMT/(Employee + Visitors) for the Non-Home Based, Home-Based Work, and Home-Based Other *attraction* trips, which represent trips taken by both workers and visitors.
- **University (with on-campus housing)** – VMT/(Person + Employee + Student) for the Home-Based Work, Home-Based Other, and Non-Home Base trip purposes.
- **Mixed-Use:** Since a mixed-use project consists of the different project types listed above, the recommended analysis consists of Home-Based Work, Home-Based Other, and Non-Home Based.

The impact criteria, described later in this section, require the project to compare the VMT per person/employee to the VMT per person/employee for the unincorporated County. The VMT for the unincorporated County should also be derived from SBTAM for comparison and impact analysis purposes. The unincorporated County VMT per person/employee must be estimated consistent with the environmental baseline for the project; which typically is consistent with the notice of preparation released for the project or when technical studies are initiated. Since SBTAM base year land use and transportation network will likely not match the environmental baseline for the project, the user should use linear interpolation between the base year and future year model projection horizons to estimate VMT per person/employee for the region.

In addition to evaluating the project VMT per person/employee, the user must also evaluate the cumulative effects of the project on VMT. To complete this cumulative analysis, the user must compare the unincorporated VMT per person/employee with the project to the VMT per person/employee that would occur consistent with the RTP/SCS projections (if the project is already consistent with eh RTP/SCS, then no cumulative assessment would be required). If a project is not consistent with the RTP/SCS, then the user has two options of how to add the project to the model and extract VMT information:

- Add the proposed land uses to the travel demand model, complete a full model run, and determine if VMT per person/employee increases or decreases compared to the RTP/SCS assumptions; or
- Hold the regional land use control totals constant and determine where development would not occur if the proposed project were to occur. In this example, an economist could be utilized to provide this information, a land use allocation tool could be applied to provide this information, or the user can review future growth within a five to ten-mile

radius of the project and proportionately decrease development in those TAZs to match the level of development proposed by the project.

Finally, for projects that have the potential to increase congestion along major corridors, a network-based VMT assessment should be completed under the cumulative year (with and without the project) and countywide network VMT shall be evaluated to determine if increased congestion caused by the project displaces regional through trips that would increase VMT relative to the RTP/SCS. Total VMT can be used for this assessment (if the future land use is consistent between the no project and with project scenarios) or VMT per person/employee can be used for the assessment if the land use control totals are not consistent.

4.2 CEQA VMT IMPACT THRESHOLD AND MITIGATION

4.2.1 Project VMT Impacts

A project should be considered to have a significant impact if the project VMT per person/employee is greater than 4% below the existing VMT per person for the unincorporated County.

4% below existing was identified as an appropriate threshold through an exercise completed by Fehr & Peers as part of the General Plan process. The process focused on development in the growth areas of the County (where major development is expected to occur) and utilized the California Air Pollution Control Officers Association (CAPCOA) *Quantifying Greenhouse Gas Mitigation Measures* (August 2010) to estimate the maximum feasible VMT mitigation that could be achieved through TDM. The TDM effort identified that the ***maximum*** achievable TDM reduction associated with development in the identified growth areas would be just over 4% for both residential projects and for commute trips associated with employment uses. Utilizing the maximum achievable TDM reduction as the threshold provides an achievable threshold for County development to consider when processing applications.

Once a significant impact is identified, the project's VMT per person/employee should be mitigated to 4% below the baseline VMT per person. Mitigation should consist of Transportation Demand Management (TDM) measures analyzed under a VMT-reduction methodology consistent with Chapter 7 of the California Air Pollution Control Officers Association (CAPCOA) *Quantifying Greenhouse Gas Mitigation Measures* (August 2010) and approved by the Traffic Division and Land Use Services Department (if applicable); or the project description should be reviewed and modified to promote reduced VMT.

4.2.2 Cumulative VMT Impacts

Cumulative impacts should be evaluated for consistency with the adopted RTP/SCS. For example, if a project is included in the RTP/SCS, the project's cumulative impacts shall be less-than-significant. However, if the project is inconsistent with the adopted RTP/SCS, then the analysis should evaluate the project's effect on VMT and determine if the unincorporated Countywide VMT increases or decreases with the project relative to the VMT generated by the RTP/SCS. A significant impact would occur if the project increases the regional VMT per person/employee compared to the RTP/SCS assumptions.

4.2.3 VMT Mitigation Measures

To mitigate VMT impacts, the applicant can consider several factors noted below:

- Revisit project design features and or land use to reduce project trips or reduce trip length
- Consider development in a more efficient area
- Look for other measures to reduce trip lengths or the number of trips generated through the use of transportation demand management (TDM) measures

If a regional program is available to reduce VMT, a fair share payment toward that program would be deemed acceptable.

As part of the threshold setting exercise the following TDM measures were identified as feasible and should be considered for development in the County. However, the CAPCOA guidelines should be followed to quantify the VMT reduction associated with each considered measure (in addition to the land use TDM measures that are already accounted for in the travel demand forecasting):

- LUT-6 Integrate affordable and below market rate housing: 0.04% - 1.20%
  Amount of affordable housing would be project-specific
- LUT-9 Improve Design of Development: 3.0% - 21.3%
- SDT-1 Provide pedestrian network improvements
  Applicable for subdivisions connecting to other development, in areas identified for growth in the Countywide Plan, unincorporated Valley region areas, or unincorporated spheres of influence
- SDT-2 Provide Traffic Calming Measures: 0.25% - 1%
  Applicable for subdivisions connecting to other development, in areas identified for growth in the Countywide Plan, unincorporated Valley region areas, or unincorporated spheres of influence

- TRT-4 Implement Subsidized or Discounted Transit Passes: 0% - 16%
  Applicable to development within 1/2 mile of a transit system. As such, it would be applicable in the Valley region (but less applicable in other areas).
- TRT-6 Encourage Telecommuting and Alternative Work Schedules: 0.2% - 4.5%
  Applicable to the County as the County is and will continue to partner with internet providers to increase coverage within the County to facilitate this application.
- TRT-10 Implement a School Pool Program: 7.2% - 15.8% reduction in school VMT
  Applicable for large developments (approximately 300 households or more).

5. CEQA ASSESSMENT - ACTIVE TRANSPORTATION AND PUBLIC TRANSIT ANALYSIS

The California Environmental Quality Act (CEQA) Guidelines set the following criteria for assessing significant impacts to non-automotive facilities:

- A significant impact occurs if the project conflicts with adopted policies, plans, or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decreases the performance or safety of such facilities.

Therefore, the TIS should include analysis of a project to examine if it is inconsistent with adopted policies, plans, or programs regarding active transportation or public transit facilities, or otherwise decreases the performance or safety of such facilities.

6. TRANSPORTATION IMPACT STUDY FORMAT

The recommended TIS format is as follows:

1. Executive Summary
    a. Table summarizing significant impacts and mitigation measures
2. Introduction
    a. Purpose of the TIS and study objective
    b. Project location and vicinity map (Exhibit)
    c. Project size and description
    d. Existing and proposed land use and zoning
    e. Site plan and proposed project (Exhibit)
    f. Proposed project opening year and phase opening
3. Methodology and Impact Thresholds
4. Existing Condition
    a. Existing roadway network
    b. Existing traffic control and intersection geometrics (Exhibit)
    c. Existing traffic volumes – AM and PM peak hour and ADT (Exhibit)
    d. Existing level of service (LOS) at intersections (Table)
    e. Existing bicycle facilities (Exhibit)
    f. Existing transit facilities (Exhibit)
    g. Existing pedestrian facilities
5. Project Traffic
    a. Trip generation (Table)
    b. Trip distribution and assignment (Exhibit)
    c. Project peak hour turning movements and ADT (Exhibit)
6. Existing Plus Project Analysis (if required)
    a. Peak turning movement and ADT (Exhibit)
    b. Intersection level of service (Table)
    c. Roadway segment level of service (Table)
    d. Identification of intersection and roadway segment impacts
7. Background Conditions (Opening Year) Analysis
    a. No Project analysis
        i. Committed (funded) roadway improvements
        ii. Pending and approved project trip generation (Table, if required)
        iii. Pending and approved project trip assignment and distribution (Exhibit, if required)

iv. Opening Year peak turning movement and ADT (Exhibit)
v. Intersection level of service (Table)
vi. Roadway segment level of service (Table)

b. Plus Project analysis
i. Plus Project peak turning movement and ADT (Exhibit)
ii. Intersection level of service (Table)
iii. Roadway segment level of service (Table)
iv. Identification of intersection and roadway segment deficiencies

8. Cumulative Year Analysis
a. No Project analysis
i. Committed (funded) roadway improvements
ii. Pending and approved project trip generation (Table, if required)
iii. Pending and approved project trip assignment and distribution (Table, if required)
iv. Cumulative Year peak turning movement and ADT (Exhibit)
v. Intersection level of service (Table)
vi. Roadway segment level of service (Table)

b. Plus Project Analysis
i. Plus Project peak turning movement and ADT (Exhibit)
ii. Intersection level of service (Table)
iii. Roadway segment level of service (Table)
iv. Identification of intersection and roadway segment deficiencies

9. Traffic Signal Warrant Analysis
10. Site Access Analysis
11. Safety and Operation Improvement Analysis
12. Active Transportation and Public Transit Analysis
13. Improvements and Recommendations
a. Proposed improvements at impacted intersections
b. Proposed improvements at impacted roadway segments
c. Recommended Improvements categorized by whether they are included in fee plan or not. (Identify if these improvements are included in an adopted fee program)
14. Vehicle Miles Traveled (VMT) Analysis
a. Project VMT per person/employee
b. Project effect on VMT
c. Identification of VMT impacts
d. Proposed VMT Mitigation Measures

15. Appendix
    a. Approved scope of work
    b. Traffic counts
    c. Intersection analysis worksheets
    d. VMT and TDM mitigation calculations
    e. Signal warrant worksheets

EXHIBIT Y

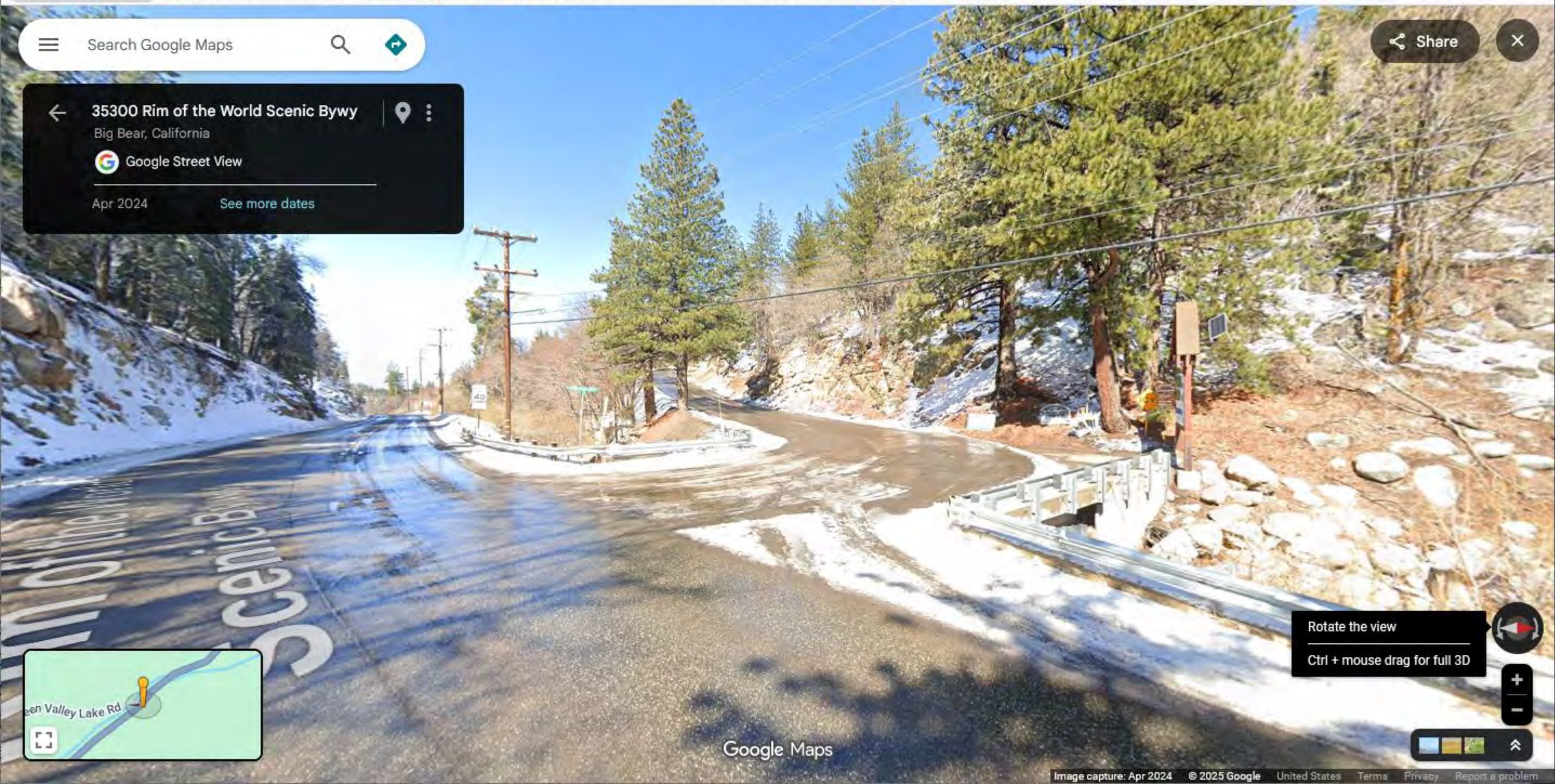

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EXHIBIT Z

TECHNICAL ADVISORY

ON EVALUATING TRANSPORTATION IMPACTS IN CEQA

December 2018

Contents

A. Introduction 1

B. Background 2

C. Technical Considerations in Assessing Vehicle Miles Traveled 4

1. Recommendations Regarding Methodology 4

D. General Principles to Guide Consideration of VMT 7

E. Recommendations Regarding Significance Thresholds 8

1. Screening Thresholds for Land Use Projects 12

2. Recommended Numeric Thresholds for Residential, Office, and Retail Projects 15

3. Recommendations Regarding Land Use Plans 18

4. Other Considerations 19

F. Considering the Effects of Transportation Projects on Vehicle Travel 19

1. Recommended Significance Threshold for Transportation Projects 22

2. Estimating VMT Impacts from Transportation Projects 23

G. Analyzing Other Impacts Related to Transportation 25

H. VMT Mitigation and Alternatives 26

Appendix 1. Considerations About Which VMT to Count 29

Appendix 2. Induced Travel: Mechanisms, Research, and Additional Assessment Approaches 32

A. Introduction

This technical advisory is one in a series of advisories provided by the Governor's Office of Planning and Research (OPR) as a service to professional planners, land use officials, and CEQA practitioners. OPR issues technical assistance on issues that broadly affect the practice of land use planning and the California Environmental Quality Act (CEQA) (Pub. Resources Code, § 21000 et seq.). (Gov. Code, § 65040, subds. (g), (l), (m).) The purpose of this document is to provide advice and recommendations, which agencies and other entities may use at their discretion. This document does not alter lead agency discretion in preparing environmental documents subject to CEQA. This document should not be construed as legal advice.

Senate Bill 743 (Steinberg, 2013), which was codified in Public Resources Code section 21099, required changes to the guidelines implementing CEQA (CEQA Guidelines) (Cal. Code Regs., Title 14, Div. 6, Ch. 3, § 15000 et seq.) regarding the analysis of transportation impacts. As one appellate court recently explained: "During the last 10 years, the Legislature has charted a course of long-term sustainability based on denser infill development, reduced reliance on individual vehicles and improved mass transit, all with the goal of reducing greenhouse gas emissions. Section 21099 is part of that strategy . . . ." (*Covina Residents for Responsible Development v. City of Covina* (2018) 21 Cal.App.5th 712, 729.) Pursuant to Section 21099, the criteria for determining the significance of transportation impacts must "promote the reduction of greenhouse gas emissions, the development of multimodal transportation networks, and a diversity of land uses." (*Id.*, subd. (b)(1); see generally, adopted CEQA Guidelines, § 15064.3, subd. (b) [Criteria for Analyzing Transportation Impacts].) To that end, in developing the criteria, OPR has proposed, and the California Natural Resources Agency (Agency) has certified and adopted, changes to the CEQA Guidelines that identify vehicle miles traveled (VMT) as the most appropriate metric to evaluate a project's transportation impacts. With the California Natural Resources Agency's certification and adoption of the changes to the CEQA Guidelines, automobile delay, as measured by "level of service" and other similar metrics, generally no longer constitutes a significant environmental effect under CEQA. (Pub. Resources Code, § 21099, subd. (b)(3).)

This advisory contains technical recommendations regarding assessment of VMT, thresholds of significance, and mitigation measures. Again, OPR provides this Technical Advisory as a resource for the public to use at their discretion. OPR is not enforcing or attempting to enforce any part of the recommendations contained herein. (Gov. Code, § 65035 ["It is not the intent of the Legislature to vest in the Office of Planning and Research any direct operating or regulatory powers over land use, public works, or other state, regional, or local projects or programs."].)

This December 2018 technical advisory is an update to the advisory it published in April 2018. OPR will continue to monitor implementation of these new provisions and may update or supplement this advisory in response to new information and advancements in modeling and methods.

B. Background

VMT and Greenhouse Gas Emissions Reduction. Senate Bill 32 (Pavley, 2016) requires California to reduce greenhouse gas (GHG) emissions 40 percent below 1990 levels by 2030, and Executive Order B-16-12 provides a target of 80 percent below 1990 emissions levels for the transportation sector by 2050. The transportation sector has three major means of reducing GHG emissions: increasing vehicle efficiency, reducing fuel carbon content, and reducing the amount of vehicle travel. The California Air Resources Board (CARB) has provided a path forward for achieving these emissions reductions from the transportation sector in its 2016 Mobile Source Strategy. CARB determined that it will not be possible to achieve the State's 2030 and post-2030 emissions goals without reducing VMT growth. Further, in its 2018 Progress Report on California's Sustainable Communities and Climate Protection Act, CARB found that despite the State meeting its 2020 climate goals, "emissions from statewide passenger vehicle travel per capita [have been] increasing and going in the wrong direction," and "California cannot meet its [long-term] climate goals without curbing growth in single-occupancy vehicle activity."[1] CARB also found that "[w]ith emissions from the transportation sector continuing to rise despite increases in fuel efficiency and decreases in the carbon content of fuel, California will not achieve the necessary greenhouse gas emissions reductions to meet mandates for 2030 and beyond without significant changes to how communities and transportation systems are planned, funded, and built."[2]

Thus, to achieve the State's long-term climate goals, California needs to reduce per capita VMT. This can occur under CEQA through VMT mitigation. Half of California's GHG emissions come from the transportation sector[3], therefore, reducing VMT is an effective climate strategy, which can also result in co-benefits.[4] Furthermore, without early VMT mitigation, the state may follow a path that meets GHG targets in the early years, but finds itself poorly positioned to meet more stringent targets later. For example, in absence of VMT analysis and mitigation in CEQA, lead agencies might rely upon verifiable offsets for GHG mitigation, ignoring the longer-term climate change impacts resulting from land use development and infrastructure investment decisions. As stated in CARB's 2017 Scoping Plan:

> "California's future climate strategy will require increased focus on integrated land use planning to support livable, transit-connected communities, and conservation of agricultural and other lands. Accommodating population and economic growth through travel- and energy-efficient land use provides GHG-efficient growth, reducing GHGs from both transportation and building energy use. GHGs can be further reduced at the project level through implementing energy-efficient construction and travel demand management approaches."[5] (*Id.* at p. 102.)

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[1] California Air Resources Board (Nov. 2018) *2018 Progress Report on California's Sustainable Communities and Climate Protection Act*, pp. 4, 5, available at https://ww2.arb.ca.gov/sites/default/files/2018-11/Final2018Report_SB150_112618_02_Report.pdf.
[2] *Id.*, p. 28.
[3] See https://ca50million.ca.gov/transportation/
[4] Fang et al. (2017) *Cutting Greenhouse Gas Emissions Is Only the Beginning: A Literature Review of the Co-Benefits of Reducing Vehicle Miles Traveled*.
[5] California Air Resources Board (Nov. 2017) *California's 2017 Climate Change Scoping Plan*, p. 102, available at https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf.

In light of this, the 2017 Scoping Plan describes and quantifies VMT reductions needed to achieve our long-term GHG emissions reduction goals, and specifically points to the need for statewide deployment of the VMT metric in CEQA:

> "Employing VMT as the metric of transportation impact statewide will help to ensure GHG reductions planned under SB 375 will be achieved through on-the-ground development, and will also play an important role in creating the additional GHG reductions needed beyond SB 375 across the State. Implementation of this change will rely, in part, on local land use decisions to reduce GHG emissions associated with the transportation sector, both at the project level, and in long-term plans (including general plans, climate action plans, specific plans, and transportation plans) and supporting sustainable community strategies developed under SB 375."[6]

VMT and Other Impacts to Health and Environment. VMT mitigation also creates substantial benefits (sometimes characterized as "co-benefits" to GHG reduction) in both in the near-term and the long-term. Beyond GHG emissions, increases in VMT also impact human health and the natural environment. Human health is impacted as increases in vehicle travel lead to more vehicle crashes, poorer air quality, increases in chronic diseases associated with reduced physical activity, and worse mental health. Increases in vehicle travel also negatively affect other road users, including pedestrians, cyclists, other motorists, and many transit users. The natural environment is impacted as higher VMT leads to more collisions with wildlife and fragments habitat. Additionally, development that leads to more vehicle travel also tends to consume more energy, water, and open space (including farmland and sensitive habitat). This increase in impermeable surfaces raises the flood risk and pollutant transport into waterways.[7]

VMT and Economic Growth. While it was previously believed that VMT growth was a necessary component of economic growth, data from the past two decades shows that economic growth is possible without a concomitant increase in VMT. (Figure 1.) Recent research shows that requiring development projects to mitigate LOS may actually reduce accessibility to destinations and impede economic growth.[8,9]

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[6] *Id.* at p. 76.

[7] Fang et al. (2017) *Cutting Greenhouse Gas Emissions Is Only the Beginning: A Literature Review of the Co-Benefits of Reducing Vehicle Miles Traveled*, available at https://ncst.ucdavis.edu/wp-content/uploads/2017/03/NCST-VMT-Co-Benefits-White-Paper_Fang_March-2017.pdf.

[8] Haynes et al. (Sept. 2015) *Congested Development: A Study of Traffic Delays, Access, and Economic Activity in Metropolitan Los Angeles*, available at http://www.its.ucla.edu/wp-content/uploads/sites/6/2015/11/Haynes_Congested-Development_1-Oct-2015_final.pdf.

[9] Osman et al. (Mar. 2016) *Not So Fast: A Study of Traffic Delays, Access, and Economic Activity in the San Francisco Bay Area*, available at http://www.its.ucla.edu/wp-content/uploads/sites/6/2016/08/Taylor-Not-so-Fast-04-01-2016_final.pdf.

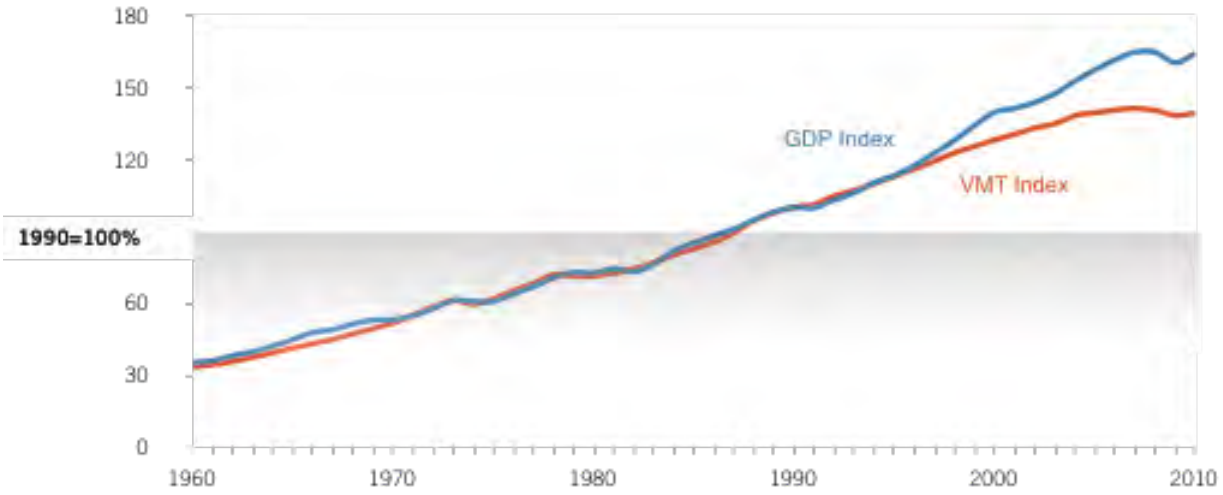


Figure 1. Kooshian and Winkelman (2011) *VMT and Gross Domestic Product (GDP), 1960-2010*.

C. Technical Considerations in Assessing Vehicle Miles Traveled

Many practitioners are familiar with accounting for VMT in connection with long-range planning, or as part of the CEQA analysis of a project's greenhouse gas emissions or energy impacts. This document provides technical information on how to assess VMT as part of a transportation impacts analysis under CEQA. Appendix 1 provides a description of which VMT to count and options on how to count it. Appendix 2 provides information on induced travel resulting from roadway capacity projects, including the mechanisms giving rise to induced travel, the research quantifying it, and information on additional approaches for assessing it.

1. Recommendations Regarding Methodology

Proposed Section 15064.3 explains that a "lead agency may use models to estimate a project's vehicle miles traveled . . . ." CEQA generally defers to lead agencies on the choice of methodology to analyze impacts. (*Santa Monica Baykeeper v. City of Malibu* (2011) 193 Cal.App.4th 1538, 1546; see *Laurel Heights Improvement Assn. v. Regents of University of California* (1988) 47 Cal.3d 376, 409 ["the issue is not whether the studies are irrefutable or whether they could have been better" … rather, the "relevant issue is only whether the studies are sufficiently credible to be considered" as part of the lead agency's overall evaluation].) This section provides suggestions to lead agencies regarding methodologies to analyze VMT associated with a project.

Vehicle Types. Proposed Section 15064.3, subdivision (a), states, "For the purposes of this section, 'vehicle miles traveled' refers to the amount and distance of automobile travel attributable to a project." Here, the term "automobile" refers to on-road passenger vehicles, specifically cars and light trucks. Heavy-duty truck VMT could be included for modeling convenience and ease of calculation (for example, where models or data provide combined auto and heavy truck VMT). For an apples-to-apples

comparison, vehicle types considered should be consistent across project assessment, significance thresholds, and mitigation.

Residential and Office Projects. Tour- and trip-based approaches[10] offer the best methods for assessing VMT from residential/office projects and for comparing those assessments to VMT thresholds. These approaches also offer the most straightforward methods for assessing VMT reductions from mitigation measures for residential/office projects. When available, tour-based assessment is ideal because it captures travel behavior more comprehensively. But where tour-based tools or data are not available for all components of an analysis, a trip-based assessment of VMT serves as a reasonable proxy.

Models and methodologies used to calculate thresholds, estimate project VMT, and estimate VMT reduction due to mitigation should be comparable. For example:

- A tour-based assessment of project VMT should be compared to a tour-based threshold, or a trip-based assessment to a trip-based VMT threshold.
- Where a travel demand model is used to determine thresholds, the same model should also be used to provide trip lengths as part of assessing project VMT.
- Where only trip-based estimates of VMT reduction from mitigation are available, a trip-based threshold should be used, and project VMT should be assessed in a trip-based manner.

When a trip-based method is used to analyze a residential project, the focus can be on home-based trips. Similarly, when a trip-based method is used to analyze an office project, the focus can be on home-based work trips.

When tour-based models are used to analyze an office project, either employee work tour VMT or VMT from all employee tours may be attributed to the project. This is because workplace location influences overall travel. For consistency, the significance threshold should be based on the same metric: either employee work tour VMT or VMT from all employee tours.

For office projects that feature a customer component, such as a government office that serves the public, a lead agency can analyze the customer VMT component of the project using the methodology for retail development (see below).

Retail Projects. Generally, lead agencies should analyze the effects of a retail project by assessing the change in total VMT[11] because retail projects typically re-route travel from other retail destinations. A retail project might lead to increases or decreases in VMT, depending on previously existing retail travel patterns.

[10] See Appendix 1, *Considerations About Which VMT to Count,* for a description of these approaches.
[11] See Appendix 1, *Considerations About Which VMT to Count, "*Assessing Change in Total VMT" section, for a description of this approach.

Considerations for All Projects. Lead agencies should not truncate any VMT analysis because of jurisdictional or other boundaries, for example, by failing to count the portion of a trip that falls outside the jurisdiction or by discounting the VMT from a trip that crosses a jurisdictional boundary. CEQA requires environmental analyses to reflect a "good faith effort at full disclosure." (CEQA Guidelines, § 15151.) Thus, where methodologies exist that can estimate the full extent of vehicle travel from a project, the lead agency should apply them to do so. Where those VMT effects will grow over time, analyses should consider both a project's short-term and long-term effects on VMT.

Combining land uses for VMT analysis is not recommended. Different land uses generate different amounts of VMT, so the outcome of such an analysis could depend more on the mix of uses than on their travel efficiency. As a result, it could be difficult or impossible for a lead agency to connect a significance threshold with an environmental policy objective (such as a target set by law), inhibiting the CEQA imperative of identifying a project's significant impacts and providing mitigation where feasible. Combining land uses for a VMT analysis could streamline certain mixes of uses in a manner disconnected from policy objectives or environmental outcomes. Instead, OPR recommends analyzing each use separately, or simply focusing analysis on the dominant use, and comparing each result to the appropriate threshold. Recommendations for methods of analysis and thresholds are provided below. In the analysis of each use, a mixed-use project should take credit for internal capture.

Any project that includes in its geographic bounds a portion of an existing or planned Transit Priority Area (i.e., the project is within a ½ mile of an existing or planned major transit stop or an existing stop along a high quality transit corridor) may employ VMT as its primary metric of transportation impact for the entire project. (See Pub. Resources Code, § 21099, subds. (a)(7), (b)(1).)

Cumulative Impacts. A project's cumulative impacts are based on an assessment of whether the "incremental effects of an individual project are considerable when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects." (Pub. Resources Code, § 21083, subd. (b)(2); see CEQA Guidelines, § 15064, subd. (h)(1).) When using an absolute VMT metric, i.e., total VMT (as recommended below for retail and transportation projects), analyzing the combined impacts for a cumulative impacts analysis may be appropriate. However, metrics such as VMT per capita or VMT per employee, i.e., metrics framed in terms of efficiency (as recommended below for use on residential and office projects), cannot be summed because they employ a denominator. A project that falls below an efficiency-based threshold that is aligned with long-term environmental goals and relevant plans would have no cumulative impact distinct from the project impact. Accordingly, a finding of a less-than-significant project impact would imply a less than significant cumulative impact, and vice versa. This is similar to the analysis typically conducted for greenhouse gas emissions, air quality impacts, and impacts that utilize plan compliance as a threshold of significance. (See *Center for Biological Diversity v. Department of Fish & Wildlife* (2015) 62 Cal.4th 204, 219, 223; CEQA Guidelines, § 15064, subd. (h)(3).)

D. General Principles to Guide Consideration of VMT

SB 743 directs OPR to establish specific "criteria for determining the significance of transportation impacts of projects[.]" (Pub. Resources Code, § 21099, subd. (b)(1).) In establishing this criterion, OPR was guided by the general principles contained within CEQA, the CEQA Guidelines, and applicable case law.

To assist in the determination of significance, many lead agencies rely on "thresholds of significance." The CEQA Guidelines define a "threshold of significance" to mean "an identifiable **quantitative, qualitative[12] or performance level** of a particular environmental effect, non-compliance with which means the effect will ***normally*** be determined to be significant by the agency and compliance with which means the effect ***normally*** will be determined to be less than significant." (CEQA Guidelines, § 15064.7, subd. (a) (emphasis added).) Lead agencies have discretion to develop and adopt their own, or rely on thresholds recommended by other agencies, "provided the decision of the lead agency to adopt such thresholds is supported by substantial evidence." (*Id*. at subd. (c); *Save Cuyama Valley v. County of Santa Barbara* (2013) 213 Cal.App.4th 1059, 1068.) Substantial evidence means "enough relevant information and reasonable inferences from this information that a fair argument can be made to support a conclusion, even though other conclusions might also be reached." (*Id*. at § 15384 (emphasis added); *Protect the Historic Amador Waterways v. Amador Water Agency* (2004) 116 Cal.App.4th 1099, 1108-1109.)

Additionally, the analysis leading to the determination of significance need not be perfect. The CEQA Guidelines describe the standard for adequacy of environmental analyses:

> An EIR should be prepared with a sufficient degree of analysis to provide decision makers with information which enables them to **make a decision which intelligently takes account of environmental consequences**. An evaluation of the environmental effects of a proposed project need not be exhaustive, but the sufficiency of an EIR is to be reviewed in the light of what is **reasonably feasible**. Disagreement among experts does not make an EIR inadequate, but the EIR should summarize the main points of disagreement among the experts. The **courts have looked not for perfection** but for **adequacy**, **completeness**, and a **good faith effort** at full disclosure.

(CEQA Guidelines, § 15151 (emphasis added).)

These general principles guide OPR's recommendations regarding thresholds of significance for VMT set forth below.

[12] Generally, qualitative analyses should only be conducted when methods do not exist for undertaking a quantitative analysis.

E. Recommendations Regarding Significance Thresholds

As noted above, lead agencies have the discretion to set or apply their own thresholds of significance. (*Center for Biological Diversity v. California Dept. of Fish & Wildlife* (2015) 62 Cal.4th 204, 218-223 [lead agency had discretion to use compliance with AB 32's emissions goals as a significance threshold]; *Save Cuyama Valley v. County of Santa Barbara* (2013) 213 Cal.App.4th at p. 1068.) However, Section 21099 of the Public Resources Code states that the criteria for determining the significance of transportation impacts must promote: (1) reduction of greenhouse gas emissions; (2) development of multimodal transportation networks; and (3) a diversity of land uses. It further directed OPR to prepare and develop criteria for determining significance. (Pub. Resources Code, § 21099, subd. (b)(1).) This section provides OPR's suggested thresholds, as well as considerations for lead agencies that choose to adopt their own

The VMT metric can support the three statutory goals: "the reduction of greenhouse gas emissions, the development of multimodal transportation networks, ***and*** a diversity of land uses." (Pub. Resources Code, § 21099, subd. (b)(1), emphasis added.) However, in order for it to promote and support all three, lead agencies should select a significance threshold that aligns with state law on all three. State law concerning the development of multimodal transportation networks and diversity of land uses requires planning for and prioritizing increases in complete streets and infill development, but does not mandate a particular depth of implementation that could translate into a particular threshold of significance. Meanwhile, the State has clear quantitative targets for GHG emissions reduction set forth in law and based on scientific consensus, and the depth of VMT reduction needed to achieve those targets has been quantified. Tying VMT thresholds to GHG reduction also supports the two other statutory goals. Therefore, to ensure adequate analysis of transportation impacts, OPR recommends using quantitative VMT thresholds linked to GHG reduction targets when methods exist to do so.

Various legislative mandates and state policies establish quantitative greenhouse gas emissions reduction targets. For example:

- Assembly Bill 32 (2006) requires statewide GHG emissions reductions to 1990 levels by 2020 and continued reductions beyond 2020.

- Senate Bill 32 (2016) requires at least a 40 percent reduction in GHG emissions from 1990 levels by 2030.

- Pursuant to Senate Bill 375 (2008), the California Air Resources Board GHG emissions reduction targets for metropolitan planning organizations (MPOs) to achieve based on land use patterns and transportation systems specified in Regional Transportation Plans and Sustainable Community Strategies (RTP/SCS). Current targets for the State's largest MPOs call for a 19 percent reduction in GHG emissions from cars and light trucks from 2005 emissions levels by 2035.

- Executive Order B-30-15 (2015) sets a GHG emissions reduction target of 40 percent below 1990 levels by 2030.

- Executive Order S-3-05 (2005) sets a GHG emissions reduction target of 80 percent below 1990 levels by 2050.

- Executive Order B-16-12 (2012) specifies a GHG emissions reduction target of 80 percent below 1990 levels by 2050 specifically for transportation.

- Executive Order B-55-18 (2018) established an additional statewide goal of achieving carbon neutrality as soon as possible, but no later than 2045, and maintaining net negative emissions thereafter. It states, "The California Air Resources Board shall work with relevant state agencies to develop a framework for implementation and accounting that tracks progress toward this goal."

- Senate Bill 391 requires the California Transportation Plan to support 80 percent reduction in GHGs below 1990 levels by 2050.

- The *California Air Resources Board Mobile Source Strategy* (2016) describes California's strategy for containing air pollutant emissions from vehicles, and quantifies VMT growth compatible with achieving state targets.

- The California Air Resources Board's *2017 Climate Change Scoping Plan Update: The Strategy for Achieving California's 2030 Greenhouse Gas Target* describes California's strategy for containing GHG emissions from vehicles, and quantifies VMT growth compatible with achieving state targets.

Considering these various targets, the California Supreme Court observed:

> Meeting our statewide reduction goals does not preclude all new development. Rather, the Scoping Plan … assumes continued growth and depends on increased efficiency and conservation in land use and transportation from all Californians.

(*Center for Biological Diversity v. California Dept. of Fish & Wildlife*, *supra*, 62 Cal.4th at p. 220.) Indeed, the Court noted that when a lead agency uses consistency with climate goals as a way to determine significance, particularly for long-term projects, the lead agency must consider the project's effect on meeting long-term reduction goals. (*Ibid*.) And more recently, the Supreme Court stated that "CEQA requires public agencies . . . to ensure that such analysis stay in step with evolving scientific knowledge and state regulatory schemes." (*Cleveland National Forest Foundation v. San Diego Assn. of Governments* (2017) 3 Cal.5th 497, 504.)

Meeting the targets described above will require substantial reductions in existing VMT per capita to curb GHG emissions and other pollutants. But targets for overall GHG emissions reduction do not translate directly into VMT thresholds for individual projects for many reasons, including:

- Some, but not all, of the emissions reductions needed to achieve those targets could be accomplished by other measures, including increased vehicle efficiency and decreased fuel carbon content. The CARB's *First Update to the Climate Change Scoping Plan* explains:

"Achieving California's long-term criteria pollutant and GHG emissions goals will require four strategies to be employed: (1) improve vehicle efficiency and develop zero emission technologies, (2) reduce the carbon content of fuels and provide market support to get these lower-carbon fuels into the marketplace, (3) **plan and build communities to reduce vehicular GHG emissions and provide more transportation options, and (4) improve the efficiency and throughput of existing transportation systems.**"[13] CARB's *2018 Progress Report on California's Sustainable Communities and Climate Protection Act* states on page 28 that "California cannot meet its climate goals without curbing growth in single-occupancy vehicle activity." In other words, vehicle efficiency and better fuels are necessary, but insufficient, to address the GHG emissions from the transportation system. Land use patterns and transportation options also will need to change to support reductions in vehicle travel/VMT.

- New land use projects alone will not sufficiently reduce per-capita VMT to achieve those targets, nor are they expected to be the sole source of VMT reduction.

- Interactions between land use projects, and also between land use and transportation projects, existing and future, together affect VMT.

- Because location within the region is the most important determinant of VMT, in some cases, streamlining CEQA review of projects in travel efficient locations may be the most effective means of reducing VMT.

- When assessing climate impacts of some types of land use projects, use of an efficiency metric (e.g., per capita, per employee) may provide a better measure of impact than an absolute numeric threshold. (*Center for Biological Diversity*, *supra*.)

Public Resources Code section 21099 directs OPR to propose criteria for determining the significance of transportation impacts. In this Technical Advisory, OPR provides its recommendations to assist lead agencies in selecting a significance threshold that may be appropriate for their particular projects. While OPR's Technical Advisory is not binding on public agencies, CEQA allows lead agencies to "consider thresholds of significance . . . recommended by other public agencies, provided the decision to adopt those thresholds is supported by substantial evidence." (CEQA Guidelines, § 15064.7, subd. (c).) Based on OPR's extensive review of the applicable research, and in light of an assessment by the California Air Resources Board quantifying the need for VMT reduction in order to meet the State's long-term climate goals, **OPR recommends that a per capita or per employee VMT that is fifteen percent below that of existing development may be a reasonable threshold**.

Fifteen percent reductions in VMT are achievable at the project level in a variety of place types.[14]

Moreover, a fifteen percent reduction is consistent with SB 743's direction to OPR to select a threshold that will help the State achieve its climate goals. As described above, section 21099 states that the

[13] California Air Resources Board (May 2014) *First Update to the Climate Change Scoping Plan*, p. 46 (emphasis added).
[14] CAPCOA (2010) *Quantifying Greenhouse Gas Mitigation Measures*, p. 55, available at http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf.

criteria for determining significance must "promote the reduction in greenhouse gas emissions." In its document *California Air Resources Board 2017 Scoping Plan-Identified VMT Reductions and Relationship to State Climate Goals*[15], CARB assesses VMT reduction per capita consistent with its evidence-based modeling scenario that would achieve State climate goals of 40 percent GHG emissions reduction from 1990 levels by 2030 and 80 percent GHG emissions reduction levels from 1990 by 2050. Applying California Department of Finance population forecasts, CARB finds per-capita light-duty vehicle travel would need to be approximately 16.8 percent lower than existing, and overall per-capita vehicle travel would need to be approximately 14.3 percent lower than existing levels under that scenario. Below these levels, a project could be considered low VMT and would, on that metric, be consistent with 2017 Scoping Plan Update assumptions that achieve climate state climate goals.

CARB finds per capita vehicle travel would need to be kept below what today's policies and plans would achieve.

CARB's assessment is based on data in the 2017 Scoping Plan Update and 2016 Mobile Source Strategy. In those documents, CARB previously examined the relationship between VMT and the state's GHG emissions reduction targets. The Scoping Plan finds:

> "While the State can do more to accelerate and incentivize these local decisions, local actions that reduce VMT are also necessary to meet transportation sector-specific goals and achieve the 2030 target under SB 32. Through developing the Scoping Plan, CARB staff is more convinced than ever that, in addition to achieving GHG reductions from cleaner fuels and vehicles, California must also reduce VMT. Stronger SB 375 GHG reduction targets will enable the State to make significant progress toward needed reductions, but alone will not provide the VMT growth reductions needed; there is a gap between what SB 375 can provide and what is needed to meet the State's 2030 and 2050 goals."[16]

Note that, at present, consistency with RTP/SCSs does not necessarily lead to a less-than-significant VMT impact.[17] As the Final 2017 Scoping Plan Update states,

> VMT reductions are necessary to achieve the 2030 target and must be part of any strategy evaluated in this Plan. Stronger SB 375 GHG reduction targets will enable the State to make significant progress toward this goal, but alone will not provide all of the VMT growth reductions that will be needed. There is a gap between what SB 375 can provide and what is needed to meet the State's 2030 and 2050 goals."[18]

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[15] California Air Resources Board (Jan. 2019) *California Air Resources Board 2017 Scoping Plan-Identified VMT Reductions and Relationship to State Climate Goals*, available at https://ww2.arb.ca.gov/resources/documents/carb-2017-scoping-plan-identified-vmt-reductions-and-relationship-state-climate.

[16] California Air Resources Board (Nov. 2017) *California's 2017 Climate Change Scoping Plan*, p. 101.

[17] California Air Resources Board (Feb. 2018) *Updated Final Staff Report: Proposed Update to the SB 375 Greenhouse Gas Emission Reduction Targets*, Figure 3, p. 35, available at https://www.arb.ca.gov/cc/sb375/sb375_target_update_final_staff_report_feb2018.pdf.

[18] California Air Resources Board (Nov. 2017) *California's 2017 Climate Change Scoping Plan*, p. 75.

Also, in order to capture the full effects of induced travel resulting from roadway capacity projects, an RTP/SCS would need to include an assessment of land use effects of those projects, and the effects of those land uses on VMT. (See section titled "*Estimating VMT Impacts from Transportation Projects"* below.) RTP/SCSs typically model VMT using a collaboratively-developed land use "vision" for the region's land use, rather than studying the effects on land use of the proposed transportation investments.

In summary, achieving 15 percent lower per capita (residential) or per employee (office) VMT than existing development is both generally achievable and is supported by evidence that connects this level of reduction to the State's emissions goals.

1. Screening Thresholds for Land Use Projects

Many agencies use "screening thresholds" to quickly identify when a project should be expected to cause a less-than-significant impact without conducting a detailed study. (See e.g., CEQA Guidelines, §§ 15063(c)(3)(C), 15128, and Appendix G.) As explained below, this technical advisory suggests that lead agencies may screen out VMT impacts using project size, maps, transit availability, and provision of affordable housing.

Screening Threshold for Small Projects

Many local agencies have developed screening thresholds to indicate when detailed analysis is needed. Absent substantial evidence indicating that a project would generate a potentially significant level of VMT, or inconsistency with a Sustainable Communities Strategy (SCS) or general plan, projects that generate or attract fewer than 110 trips per day[19] generally may be assumed to cause a less-than-significant transportation impact.

Map-Based Screening for Residential and Office Projects

Residential and office projects that locate in areas with low VMT, and that incorporate similar features (i.e., density, mix of uses, transit accessibility), will tend to exhibit similarly low VMT. Maps created with VMT data, for example from a travel survey or a travel demand model, can illustrate areas that are

[19] CEQA provides a categorical exemption for existing facilities, including additions to existing structures of up to 10,000 square feet, so long as the project is in an area where public infrastructure is available to allow for maximum planned development and the project is not in an environmentally sensitive area. (CEQA Guidelines, § 15301, subd. (e)(2).) Typical project types for which trip generation increases relatively linearly with building footprint (i.e., general office building, single tenant office building, office park, and business park) generate or attract an additional 110-124 trips per 10,000 square feet. Therefore, absent substantial evidence otherwise, it is reasonable to conclude that the addition of 110 or fewer trips could be considered not to lead to a significant impact.

currently below threshold VMT (see recommendations below). Because new development in such locations would likely result in a similar level of VMT, such maps can be used to screen out residential and office projects from needing to prepare a detailed VMT analysis.

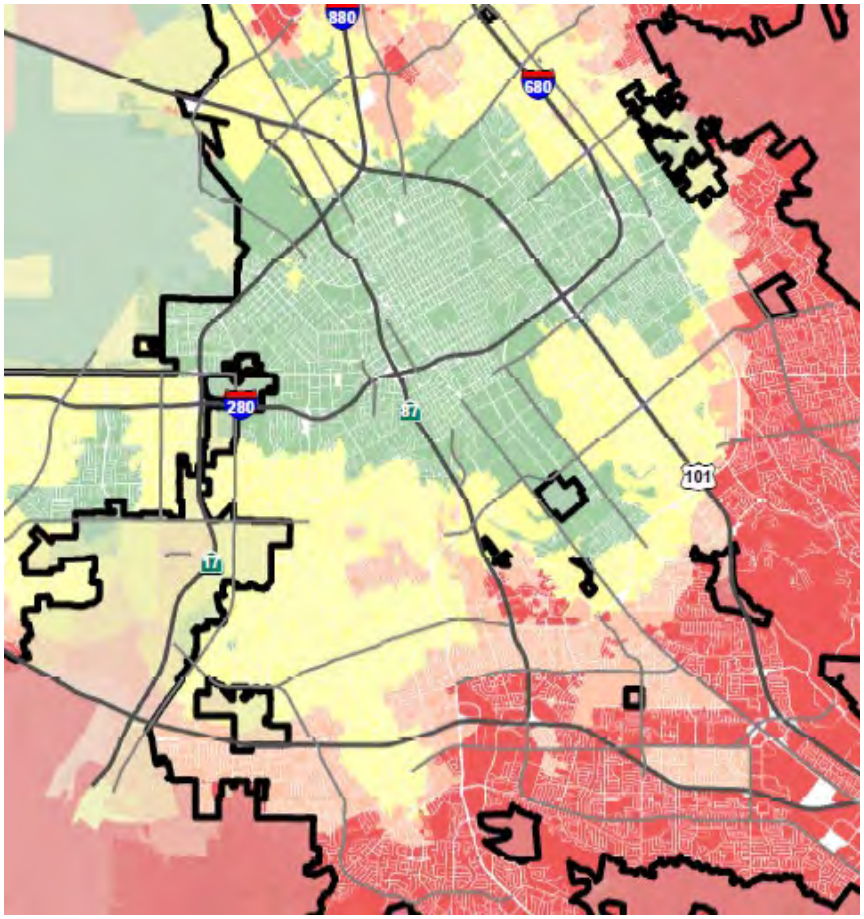


Figure 2. Example map of household VMT that could be used to delineate areas eligible to receive streamlining for VMT analysis. (Source: City of San José, Department of Transportation, draft output of City Transportation Model.)

Presumption of Less Than Significant Impact Near Transit Stations

Proposed CEQA Guideline Section 15064.3, subdivision (b)(1), states that lead agencies generally should presume that certain projects (including residential, retail, and office projects, as well as projects that are a mix of these uses) proposed within ½ mile of an existing major transit stop[20] or an existing stop

[20] Pub. Resources Code, § 21064.3 ("'Major transit stop' means a site containing an existing rail transit station, a ferry terminal served by either a bus or rail transit service, or the intersection of two or more major bus routes with a frequency of service interval of 15 minutes or less during the morning and afternoon peak commute periods.").

along a high quality transit corridor[21] will have a less-than-significant impact on VMT. This presumption would not apply, however, if project-specific or location-specific information indicates that the project will still generate significant levels of VMT. For example, the presumption might not be appropriate if the project:

- Has a Floor Area Ratio (FAR) of less than 0.75
- Includes more parking for use by residents, customers, or employees of the project than required by the jurisdiction (if the jurisdiction requires the project to supply parking)
- Is inconsistent with the applicable Sustainable Communities Strategy (as determined by the lead agency, with input from the Metropolitan Planning Organization)
- Replaces affordable residential units with a smaller number of moderate- or high-income residential units

A project or plan near transit which replaces affordable residential units[22] with a smaller number of moderate- or high-income residential units may increase overall VMT because the increase in VMT of displaced residents could overwhelm the improvements in travel efficiency enjoyed by new residents.[23]

If any of these exceptions to the presumption might apply, the lead agency should conduct a detailed VMT analysis to determine whether the project would exceed VMT thresholds (see below).

Presumption of Less Than Significant Impact for Affordable Residential Development

Adding affordable housing to infill locations generally improves jobs-housing match, in turn shortening commutes and reducing VMT.[24,25] Further, "… low-wage workers in particular would be more likely to choose a residential location close to their workplace, if one is available."[26] In areas where existing jobs-housing match is closer to optimal, low income housing nevertheless generates less VMT than market-

[21] Pub. Resources Code, § 21155 ("For purposes of this section, a high-quality transit corridor means a corridor with fixed route bus service with service intervals no longer than 15 minutes during peak commute hours.").
[22] Including naturally-occurring affordable residential units.
[23] Chapple et al. (2017) *Developing a New Methodology for Analyzing Potential Displacement,* Chapter 4, pp. 159-160, available at https://www.arb.ca.gov/research/apr/past/13-310.pdf.
[24] Karner and Benner (2016) *The convergence of social equity and environmental sustainability: Jobs-housing fit and commute distance* ("[P]olicies that advance a more equitable distribution of jobs and housing by linking the affordability of locally available housing with local wage levels are likely to be associated with reduced commuting distances").
[25] Karner and Benner (2015) *Low-wage jobs-housing fit: identifying locations of affordable housing shortages.*
[26] Karner and Benner (2015) *Low-wage jobs-housing fit: identifying locations of affordable housing shortages.*

rate housing.[27,28] Therefore, a project consisting of a high percentage of affordable housing may be a basis for the lead agency to find a less-than-significant impact on VMT. Evidence supports a presumption of less than significant impact for a 100 percent affordable residential development (or the residential component of a mixed-use development) in infill locations. Lead agencies may develop their own presumption of less than significant impact for residential projects (or residential portions of mixed use projects) containing a particular amount of affordable housing, based on local circumstances and evidence. Furthermore, a project which includes any affordable residential units may factor the effect of the affordability on VMT into the assessment of VMT generated by those units.

2. Recommended Numeric Thresholds for Residential, Office, and Retail Projects

Recommended threshold for residential projects: A proposed project exceeding a level of 15 percent below existing VMT per capita may indicate a significant transportation impact. Existing VMT per capita may be measured as regional VMT per capita or as city VMT per capita. Proposed development referencing a threshold based on city VMT per capita (rather than regional VMT per capita) should not cumulatively exceed the number of units specified in the SCS for that city, and should be consistent with the SCS.

Residential development that would generate vehicle travel that is 15 or more percent below the existing residential VMT per capita, measured against the region or city, may indicate a less-than-significant transportation impact. In MPO areas, development measured against city VMT per capita (rather than regional VMT per capita) should not cumulatively exceed the population or number of units specified in the SCS for that city because greater-than-planned amounts of development in areas above the region-based threshold would undermine the VMT containment needed to achieve regional targets under SB 375.

For residential projects in unincorporated county areas, the local agency can compare a residential project's VMT to (1) the region's VMT per capita, or (2) the aggregate population-weighted VMT per capita of all cities in the region. In MPO areas, development in unincorporated areas measured against aggregate city VMT per capita (rather than regional VMT per capita) should not cumulatively exceed the population or number of units specified in the SCS for that city because greater-than-planned amounts of development in areas above the regional threshold would undermine achievement of regional targets under SB 375.

[27] Chapple et al. (2017) *Developing a New Methodology for Analyzing Potential Displacement*, available at https://www.arb.ca.gov/research/apr/past/13-310.pdf.
[28] CAPCOA (2010) *Quantifying Greenhouse Gas Mitigation Measures*, pp. 176-178, available at http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf.

These thresholds can be applied to either household (i.e., tour-based) VMT or home-based (i.e., trip-based) VMT assessments.[29] It is critical, however, that the agency be consistent in its VMT measurement approach throughout the analysis to maintain an "apples-to-apples" comparison. For example, if the agency uses a home-based VMT for the threshold, it should also be use home-based VMT for calculating project VMT and VMT reduction due to mitigation measures.

Recommended threshold for office projects: A proposed project exceeding a level of 15 percent below existing regional VMT per employee may indicate a significant transportation impact.

Office projects that would generate vehicle travel exceeding 15 percent below existing VMT per employee for the region may indicate a significant transportation impact. In cases where the region is substantially larger than the geography over which most workers would be expected to live, it might be appropriate to refer to a smaller geography, such as the county, that includes the area over which nearly all workers would be expected to live.

Office VMT screening maps can be developed using tour-based data, considering either total employee VMT or employee work tour VMT. Similarly, tour-based analysis of office project VMT could consider either total employee VMT or employee work tour VMT. Where tour-based information is unavailable for threshold determination, project assessment, or assessment of mitigation, home-based work trip VMT should be used throughout all steps of the analysis to maintain an "apples-to-apples" comparison.

Recommended threshold for retail projects: A net increase in total VMT may indicate a significant transportation impact.

Because new retail development typically redistributes shopping trips rather than creating new trips,[30] estimating the total change in VMT (i.e., the difference in total VMT in the area affected with and without the project) is the best way to analyze a retail project's transportation impacts.

By adding retail opportunities into the urban fabric and thereby improving retail destination proximity, local-serving retail development tends to shorten trips and reduce VMT. Thus, lead agencies generally may presume such development creates a less-than-significant transportation impact. Regional-serving retail development, on the other hand, which can lead to substitution of longer trips for shorter ones, may tend to have a significant impact. Where such development decreases VMT, lead agencies should consider the impact to be less-than-significant.

Many cities and counties define local-serving and regional-serving retail in their zoning codes. Lead agencies may refer to those local definitions when available, but should also consider any project-

[29] See Appendix 1 for a description of these approaches.
[30] Lovejoy, et al. (2013) *Measuring the impacts of local land-use policies on vehicle miles of travel: The case of the first big-box store in Davis, California, The Journal of Transport and Land Use*.

specific information, such as market studies or economic impacts analyses that might bear on customers' travel behavior. Because lead agencies will best understand their own communities and the likely travel behaviors of future project users, they are likely in the best position to decide when a project will likely be local-serving. Generally, however, retail development including stores larger than 50,000 square feet might be considered regional-serving, and so lead agencies should undertake an analysis to determine whether the project might increase or decrease VMT.

Mixed-Use Projects

Lead agencies can evaluate each component of a mixed-use project independently and apply the significance threshold for each project type included (e.g., residential and retail). Alternatively, a lead agency may consider only the project's dominant use. In the analysis of each use, a project should take credit for internal capture. Combining different land uses and applying one threshold to those land uses may result in an inaccurate impact assessment.

Other Project Types

Of land use projects, residential, office, and retail projects tend to have the greatest influence on VMT. For that reason, OPR recommends the quantified thresholds described above for purposes of analysis and mitigation. Lead agencies, using more location-specific information, may develop their own more specific thresholds, which may include other land use types. In developing thresholds for other project types, or thresholds different from those recommended here, lead agencies should consider the purposes described in section 21099 of the Public Resources Code and regulations in the CEQA Guidelines on the development of thresholds of significance (e.g., CEQA Guidelines, § 15064.7).

Strategies and projects that decrease local VMT but increase total VMT should be avoided. Agencies should consider whether their actions encourage development in a less travel-efficient location by limiting development in travel-efficient locations.

Redevelopment Projects

Where a project replaces existing VMT-generating land uses, if the replacement leads to a net overall decrease in VMT, the project would lead to a less-than-significant transportation impact. If the project leads to a net overall increase in VMT, then the thresholds described above should apply.

As described above, a project or plan near transit which replaces affordable[31] residential units with a smaller number of moderate- or high-income residential units may increase overall VMT, because

[31] Including naturally-occurring affordable residential units.

displaced residents' VMT may increase.[32] A lead agency should analyze VMT for such a project even if it otherwise would have been presumed less than significant. The assessment should incorporate an estimate of the aggregate VMT increase experienced by displaced residents. That additional VMT should be included in the numerator of the VMT per capita assessed for the project.

If a residential or office project leads to a net increase in VMT, then the project's VMT per capita (residential) or per employee (office) should be compared to thresholds recommended above. Per capita and per employee VMT are efficiency metrics, and, as such, apply only to the existing project without regard to the VMT generated by the previously existing land use.

If the project leads to a net increase in provision of locally-serving retail, transportation impacts from the retail portion of the development should be presumed to be less than significant. If the project consists of regionally-serving retail, and increases overall VMT compared to with existing uses, then the project would lead to a significant transportation impact.

RTP/SCS Consistency (All Land Use Projects)

Section 15125, subdivision (d), of the CEQA Guidelines provides that lead agencies should analyze impacts resulting from inconsistencies with regional plans, including regional transportation plans. For this reason, if a project is inconsistent with the Regional Transportation Plan and Sustainable Communities Strategy (RTP/SCS), the lead agency should evaluate whether that inconsistency indicates a significant impact on transportation. For example, a development may be inconsistent with an RTP/SCS if the development is outside the footprint of development or within an area specified as open space as shown in the SCS.

3. Recommendations Regarding Land Use Plans

As with projects, agencies should analyze VMT outcomes of land use plans across the full area over which the plan may substantively affect travel patterns, including beyond the boundary of the plan or jurisdiction's geography. And as with projects, VMT should be counted in full rather than split between origin and destination. (Emissions inventories have sometimes spit cross-boundary trips in order to sum to a regional total, but CEQA requires accounting for the full impact without truncation or discounting). Analysis of specific plans may employ the same thresholds described above for projects. A general plan, area plan, or community plan may have a significant impact on transportation if proposed new residential, office, or retail land uses would in aggregate exceed the respective thresholds recommended above. Where the lead agency tiers from a general plan EIR pursuant to CEQA Guidelines sections 15152 and 15166, the lead agency generally focuses on the environmental impacts that are specific to the later project and were not analyzed as significant impacts in the prior EIR. (Pub. Resources Code, § 21068.5; Guidelines, § 15152, subd. (a).) Thus, in analyzing the later project, the lead agency

[32] Chapple et al. (2017) *Developing a New Methodology for Analyzing Potential Displacement,* Chapter 4, pp. 159-160, available at https://www.arb.ca.gov/research/apr/past/13-310.pdf.

would focus on the VMT impacts that were not adequately addressed in the prior EIR. In the tiered document, the lead agency should continue to apply the thresholds recommended above.

Thresholds for plans in non-MPO areas may be determined on a case-by-case basis.

4. Other Considerations

Rural Projects Outside of MPOs

In rural areas of non-MPO counties (i.e., areas not near established or incorporated cities or towns), fewer options may be available for reducing VMT, and significance thresholds may be best determined on a case-by-case basis. Note, however, that clustered small towns and small town main streets may have substantial VMT benefits compared to isolated rural development, similar to the transit oriented development described above.

Impacts to Transit

Because criteria for determining the significance of transportation impacts must promote "the development of multimodal transportation networks" pursuant to Public Resources Code section 21099, subd. (b)(1), lead agencies should consider project impacts to transit systems and bicycle and pedestrian networks. For example, a project that blocks access to a transit stop or blocks a transit route itself may interfere with transit functions. Lead agencies should consult with transit agencies as early as possible in the development process, particularly for projects that are located within one half mile of transit stops.

When evaluating impacts to multimodal transportation networks, lead agencies generally should not treat the addition of new transit users as an adverse impact. An infill development may add riders to transit systems and the additional boarding and alighting may slow transit vehicles, but it also adds destinations, improving proximity and accessibility. Such development also improves regional vehicle flow by adding less vehicle travel onto the regional network.

Increased demand throughout a region may, however, cause a cumulative impact by requiring new or additional transit infrastructure. Such impacts may be adequately addressed through a fee program that fairly allocates the cost of improvements not just to projects that happen to locate near transit, but rather across a region to all projects that impose burdens on the entire transportation system, since transit can broadly improve the function of the transportation system.

F. Considering the Effects of Transportation Projects on Vehicle Travel

Many transportation projects change travel patterns. A transportation project which leads to additional vehicle travel on the roadway network, commonly referred to as "induced vehicle travel," would need to quantify the amount of additional vehicle travel in order to assess air quality impacts, greenhouse gas emissions impacts, energy impacts, and noise impacts. Transportation projects also are required to

examine induced growth impacts under CEQA. (See generally, Pub. Resources Code, §§ 21065 [defining "project" under CEQA as an activity as causing either a direct or reasonably foreseeable indirect physical change], 21065.3 [defining "project-specific effect" to mean all direct or indirect environmental effects], 21100, subd. (b) [required contents of an EIR].) For any project that increases vehicle travel, explicit assessment and quantitative reporting of the amount of additional vehicle travel should not be omitted from the document; such information may be useful and necessary for a full understanding of a project's environmental impacts. (See Pub. Resources Code, §§ 21000, 21001, 21001.1, 21002, 21002.1 [discussing the policies of CEQA].) A lead agency that uses the VMT metric to assess the transportation impacts of a transportation project may simply report that change in VMT as the impact. When the lead agency uses another metric to analyze the transportation impacts of a roadway project, changes in amount of vehicle travel added to the roadway network should still be analyzed and reported.[33]

While CEQA does not require perfection, it is important to make a reasonably accurate estimate of transportation projects' effects on vehicle travel in order to make reasonably accurate estimates of GHG emissions, air quality emissions, energy impacts, and noise impacts. (See, e.g., *California Clean Energy Com. v. City of Woodland* (2014) 225 Cal.App.4th 173, 210 [EIR failed to consider project's transportation energy impacts]; *Ukiah Citizens for Safety First v. City of Ukiah* (2016) 248 Cal.App.4th 256, 266.) Appendix 2 describes in detail the causes of induced vehicle travel, the robust empirical evidence of induced vehicle travel, and how models and research can be used in conjunction to quantitatively assess induced vehicle travel with reasonable accuracy.

If a project would likely lead to a measurable and substantial increase in vehicle travel, the lead agency should conduct an analysis assessing the amount of vehicle travel the project will induce. Project types that would likely lead to a measurable and substantial increase in vehicle travel generally include:

- Addition of through lanes on existing or new highways, including general purpose lanes, HOV lanes, peak period lanes, auxiliary lanes, or lanes through grade-separated interchanges

Projects that would not likely lead to a substantial or measurable increase in vehicle travel, and therefore generally should not require an induced travel analysis, include:

- Rehabilitation, maintenance, replacement, safety, and repair projects designed to improve the condition of existing transportation assets (e.g., highways; roadways; bridges; culverts; Transportation Management System field elements such as cameras, message signs, detection, or signals; tunnels; transit systems; and assets that serve bicycle and pedestrian facilities) and that do not add additional motor vehicle capacity
- Roadside safety devices or hardware installation such as median barriers and guardrails

[33] See, e.g., California Department of Transportation (2006) *Guidance for Preparers of Growth-related, Indirect Impact Analyses*, available at http://www.dot.ca.gov/ser/Growth-related_IndirectImpactAnalysis/GRI_guidance06May_files/gri_guidance.pdf.

- Roadway shoulder enhancements to provide “breakdown space,” dedicated space for use only by transit vehicles, to provide bicycle access, or to otherwise improve safety, but which will not be used as automobile vehicle travel lanes
- Addition of an auxiliary lane of less than one mile in length designed to improve roadway safety
- Installation, removal, or reconfiguration of traffic lanes that are not for through traffic, such as left, right, and U-turn pockets, two-way left turn lanes, or emergency breakdown lanes that are not utilized as through lanes
- Addition of roadway capacity on local or collector streets provided the project also substantially improves conditions for pedestrians, cyclists, and, if applicable, transit
- Conversion of existing general purpose lanes (including ramps) to managed lanes or transit lanes, or changing lane management in a manner that would not substantially increase vehicle travel
- Addition of a new lane that is permanently restricted to use only by transit vehicles
- Reduction in number of through lanes
- Grade separation to separate vehicles from rail, transit, pedestrians or bicycles, or to replace a lane in order to separate preferential vehicles (e.g., HOV, HOT, or trucks) from general vehicles
- Installation, removal, or reconfiguration of traffic control devices, including Transit Signal Priority (TSP) features
- Installation of traffic metering systems, detection systems, cameras, changeable message signs and other electronics designed to optimize vehicle, bicycle, or pedestrian flow
- Timing of signals to optimize vehicle, bicycle, or pedestrian flow
- Installation of roundabouts or traffic circles
- Installation or reconfiguration of traffic calming devices
- Adoption of or increase in tolls
- Addition of tolled lanes, where tolls are sufficient to mitigate VMT increase
- Initiation of new transit service
- Conversion of streets from one-way to two-way operation with no net increase in number of traffic lanes
- Removal or relocation of off-street or on-street parking spaces
- Adoption or modification of on-street parking or loading restrictions (including meters, time limits, accessible spaces, and preferential/reserved parking permit programs)
- Addition of traffic wayfinding signage
- Rehabilitation and maintenance projects that do not add motor vehicle capacity
- Addition of new or enhanced bike or pedestrian facilities on existing streets/highways or within existing public rights-of-way
- Addition of Class I bike paths, trails, multi-use paths, or other off-road facilities that serve non-motorized travel
- Installation of publicly available alternative fuel/charging infrastructure
- Addition of passing lanes, truck climbing lanes, or truck brake-check lanes in rural areas that do not increase overall vehicle capacity along the corridor

1. Recommended Significance Threshold for Transportation Projects

As noted in Section 15064.3 of the CEQA Guidelines, lead agencies for roadway capacity projects have discretion, consistent with CEQA and planning requirements, to choose which metric to use to evaluate transportation impacts. This section recommends considerations for evaluating impacts using vehicle miles traveled. Lead agencies have discretion to choose a threshold of significance for transportation projects as they do for other types of projects. As explained above, Public Resources Code section 21099, subdivision (b)(1), provides that criteria for determining the significance of transportation impacts must promote the reduction of greenhouse gas emissions, the development of multimodal transportation networks, and a diversity of land uses. (*Id.*; see generally, adopted CEQA Guidelines, § 15064.3, subd. (b) [Criteria for Analyzing Transportation Impacts].) With those goals in mind, OPR prepared and the Agency adopted an appropriate transportation metric.

Whether adopting a threshold of significance, or evaluating transportation impacts on a case-by-case basis, a lead agency should ensure that the analysis addresses:

- Direct, indirect and cumulative effects of the transportation project (CEQA Guidelines, § 15064, subds. (d), (h))
- Near-term and long-term effects of the transportation project (CEQA Guidelines, §§ 15063, subd. (a)(1), 15126.2, subd. (a))
- The transportation project's consistency with state greenhouse gas reduction goals (Pub. Resources Code, § 21099)[34]
- The impact of the transportation project on the development of multimodal transportation networks (Pub. Resources Code, § 21099)
- The impact of the transportation project on the development of a diversity of land uses (Pub. Resources Code, § 21099)

The CARB Scoping Plan and the CARB Mobile Source Strategy delineate VMT levels required to achieve legally mandated GHG emissions reduction targets. A lead agency should develop a project-level threshold based on those VMT levels, and may apply the following approach:

1. Propose a fair-share allocation of those budgets to their jurisdiction (e.g., by population);

[34] The California Air Resources Board has ascertained the limits of VMT growth compatible with California containing greenhouse gas emissions to levels research shows would allow for climate stabilization. (See *The 2017 Climate Change Scoping Plan: The Strategy for Achieving California's 2030 Greenhouse Gas Target* (p. 78, p. 101); *Mobile Source Strategy* (p. 37).) CARB's *Updated Final Staff Report on Proposed Update to the SB 375 Greenhouse Gas Emission Reduction Targets* illustrates that the current Regional Transportation Plans and Sustainable Communities Strategies will fall short of achieving the necessary on-road transportation-related GHG emissions reductions called for in the 2017 Scoping Plan (Figure 3, p. 35). Accordingly, OPR recommends not basing GHG emissions or transportation impact analysis for a transportation project solely on consistency with an RTP/SCS.

2. Determine the amount of VMT growth likely to result from background population growth, and subtract that from their "budget";
3. Allocate their jurisdiction's share between their various VMT-increasing transportation projects, using whatever criteria the lead agency prefers.

2. Estimating VMT Impacts from Transportation Projects

CEQA requires analysis of a project's potential growth-inducing impacts. (Pub. Resources Code, § 21100, subd. (b)(5); CEQA Guidelines, § 15126.2, subd. (d).) Many agencies are familiar with the analysis of growth inducing impacts associated with water, sewer, and other infrastructure. This technical advisory addresses growth that may be expected from roadway expansion projects.

Because a roadway expansion project can induce substantial VMT, incorporating quantitative estimates of induced VMT is critical to calculating both transportation and other impacts of these projects. Induced travel also has the potential to reduce or eliminate congestion relief benefits. An accurate estimate of induced travel is needed to accurately weigh costs and benefits of a highway capacity expansion project.

The effect of a transportation project on vehicle travel should be estimated using the "change in total VMT" method described in *Appendix 1*. This means that an assessment of total VMT without the project and an assessment with the project should be made; the difference between the two is the amount of VMT attributable to the project. The assessment should cover the full area in which driving patterns are expected to change. As with other types of projects, the VMT estimation should not be truncated at a modeling or jurisdictional boundary for convenience of analysis when travel behavior is substantially affected beyond that boundary.

Transit and Active Transportation Projects

Transit and active transportation projects generally reduce VMT and therefore are presumed to cause a less-than-significant impact on transportation. This presumption may apply to all passenger rail projects, bus and bus rapid transit projects, and bicycle and pedestrian infrastructure projects. Streamlining transit and active transportation projects aligns with each of the three statutory goals contained in SB 743 by reducing GHG emissions, increasing multimodal transportation networks, and facilitating mixed use development.

Roadway Projects

Reducing roadway capacity (for example, by removing or repurposing motor vehicle travel lanes) will generally reduce VMT and therefore is presumed to cause a less-than-significant impact on transportation. Generally, no transportation analysis is needed for such projects.

Building new roadways, adding roadway capacity in congested areas, or adding roadway capacity to areas where congestion is expected in the future, typically induces additional vehicle travel. For the types of projects previously indicated as likely to lead to additional vehicle travel, an estimate should be made of the change in vehicle travel resulting from the project.

For projects that increase roadway capacity, lead agencies can evaluate induced travel quantitatively by applying the results of existing studies that examine the magnitude of the increase of VMT resulting from a given increase in lane miles. These studies estimate the percent change in VMT for every percent change in miles to the roadway system (i.e., "elasticity").[35] Given that lead agencies have discretion in choosing their methodology, and the studies on induced travel reveal a range of elasticities, lead agencies may appropriately apply professional judgment in studying the transportation effects of a particular project. The most recent major study, estimates an elasticity of 1.0, meaning that every percent change in lane miles results in a one percent increase in VMT.[36]

To estimate VMT impacts from roadway expansion projects:

1. Determine the total lane-miles over an area that fully captures travel behavior changes resulting from the project (generally the region, but for projects affecting interregional travel look at all affected regions).
2. Determine the percent change in total lane miles that will result from the project.
3. Determine the total existing VMT over that same area.
4. Multiply the percent increase in lane miles by the existing VMT, and then multiply that by the elasticity from the induced travel literature:

[% increase in lane miles] x [existing VMT] x [elasticity] = [VMT resulting from the project]

A National Center for Sustainable Transportation tool can be used to apply this method: https://ncst.ucdavis.edu/research/tools

This method would not be suitable for rural (non-MPO) locations in the state which are neither congested nor projected to become congested. It also may not be suitable for a new road that provides new connectivity across a barrier (e.g., a bridge across a river) if it would be expected to substantially

[35] See U.C. Davis, Institute for Transportation Studies (Oct. 2015) *Increasing Highway Capacity Unlikely to Relieve Traffic Congestion*; Boarnet and Handy (Sept. 2014) *Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions*, California Air Resources Board Policy Brief, available at https://www.arb.ca.gov/cc/sb375/policies/hwycapacity/highway_capacity_brief.pdf.
[36] See Duranton and Turner (2011) *The Fundamental Law of Road Congestion: Evidence from US cities*, available at http://www.nber.org/papers/w15376.

shorten existing trips. If it is likely to be substantial, the trips-shortening effect should be examined explicitly.

The effects of roadway capacity on vehicle travel can also be applied at a programmatic level. For example, in a regional planning process the lead agency can use that program-level analysis to streamline later project-level analysis. (See CEQA Guidelines, § 15168.) A program-level analysis of VMT should include effects of the program on land use patterns, and the VMT that results from those land use effects. In order for a program-level document to adequately analyze potential induced demand from a project or program of roadway capacity expansion, lead agencies cannot assume a fixed land use pattern (i.e., a land use pattern that does not vary in response to the provision of roadway capacity). A proper analysis should account for land use investment and development pattern changes that react in a reasonable manner to changes in accessibility created by transportation infrastructure investments (whether at the project or program level).

Mitigation and Alternatives

Induced VMT has the potential to reduce or eliminate congestion relief benefits, increase VMT, and increase other environmental impacts that result from vehicle travel.[37] If those effects are significant, the lead agency will need to consider mitigation or alternatives. In the context of increased travel that is induced by capacity increases, appropriate mitigation and alternatives that a lead agency might consider include the following:

- Tolling new lanes to encourage carpools and fund transit improvements
- Converting existing general purpose lanes to HOV or HOT lanes
- Implementing or funding off-site travel demand management
- Implementing Intelligent Transportation Systems (ITS) strategies to improve passenger throughput on existing lanes

Tolling and other management strategies can have the additional benefit of preventing congestion and maintaining free-flow conditions, conferring substantial benefits to road users as discussed above.

G. Analyzing Other Impacts Related to Transportation

While requiring a change in the methodology of assessing transportation impacts, Public Resources Code section 21099 notes that this change "does not relieve a public agency of the requirement to analyze a project's potentially significant transportation impacts related to air quality, noise, safety, or any other impact associated with transportation." OPR expects that lead agencies will continue to

[37] See National Center for Sustainable Transportation (Oct. 2015) *Increasing Highway Capacity Unlikely to Relieve Traffic Congestion*, available at http://www.dot.ca.gov/newtech/researchreports/reports/2015/10-12-2015-NCST_Brief_InducedTravel_CS6_v3.pdf; see Duranton and Turner (2011) *The Fundamental Law of Road Congestion: Evidence from US cities*, available at http://www.nber.org/papers/w15376.

address mobile source emissions in the air quality and noise sections of an environmental document and the corresponding studies that support the analysis in those sections. Lead agencies should continue to address environmental impacts of a proposed project pursuant to CEQA's requirements, using a format that is appropriate for their particular project.

Because safety concerns result from many different factors, they are best addressed at a programmatic level (i.e., in a general plan or regional transportation plan) in cooperation with local governments, metropolitan planning organizations, and, where the state highway system is involved, the California Department of Transportation. In most cases, such an analysis would not be appropriate on a project-by-project basis. Increases in traffic volumes at a particular location resulting from a project typically cannot be estimated with sufficient accuracy or precision to provide useful information for an analysis of safety concerns. Moreover, an array of factors affect travel demand (e.g., strength of the local economy, price of gasoline), causing substantial additional uncertainty. Appendix B of OPR's General Plan Guidelines summarizes research which could be used to guide a programmatic analysis under CEQA. Lead agencies should note that automobile congestion or delay does not constitute a significant environmental impact (Pub. Resources Code, §21099(b)(2)), and safety should not be used as a proxy for road capacity.

H. VMT Mitigation and Alternatives

When a lead agency identifies a significant impact, it must identify feasible mitigation measures that could avoid or substantially reduce that impact. (Pub. Resources Code, § 21002.1, subd. (a).) Additionally, CEQA requires that an environmental impact report identify feasible alternatives that could avoid or substantially reduce a project's significant environmental impacts.

Indeed, the California Court of Appeal recently held that a long-term regional transportation plan was deficient for failing to discuss an alternative which could significantly reduce total vehicle miles traveled. In *Cleveland National Forest Foundation v. San Diego Association of Governments, et al.* (2017) 17 Cal.App.5th 413, the court found that omission "inexplicable" given the lead agency's "acknowledgment in its Climate Action Strategy that the state's efforts to reduce greenhouse gas emissions from on-road transportation will not succeed if the amount of driving, or vehicle miles traveled, is not significantly reduced." (*Cleveland National Forest Foundation*, *supra*, 17 Cal.App.5th at p. 436.) Additionally, the court noted that the project alternatives focused primarily on congestion relief even though "the [regional] transportation plan is a long-term and congestion relief is not necessarily an effective long-term strategy." (*Id.* at p. 437.) The court concluded its discussion of the alternatives analysis by stating: "Given the acknowledged long-term drawbacks of congestion relief alternatives, there is not substantial evidence to support the EIR's exclusion of an alternative focused primarily on significantly reducing vehicle trips." (*Ibid*.)

Several examples of potential mitigation measures and alternatives to reduce VMT are described below. However, the selection of particular mitigation measures and alternatives are left to the discretion of

the lead agency, and mitigation measures may vary, depending on the proposed project and significant impacts, if any. Further, OPR expects that agencies will continue to innovate and find new ways to reduce vehicular travel.

Potential measures to reduce vehicle miles traveled include, but are not limited to:

- Improve or increase access to transit.
- Increase access to common goods and services, such as groceries, schools, and daycare.
- Incorporate affordable housing into the project.
- Incorporate neighborhood electric vehicle network.
- Orient the project toward transit, bicycle and pedestrian facilities.
- Improve pedestrian or bicycle networks, or transit service.
- Provide traffic calming.
- Provide bicycle parking.
- Limit or eliminate parking supply.
- Unbundle parking costs.
- Provide parking cash-out programs.
- Implement roadway pricing.
- Implement or provide access to a commute reduction program.
- Provide car-sharing, bike sharing, and ride-sharing programs.
- Provide transit passes.
- Shifting single occupancy vehicle trips to carpooling or vanpooling, for example providing ride-matching services.
- Providing telework options.
- Providing incentives or subsidies that increase the use of modes other than single-occupancy vehicle.
- Providing on-site amenities at places of work, such as priority parking for carpools and vanpools, secure bike parking, and showers and locker rooms.
- Providing employee transportation coordinators at employment sites.
- Providing a guaranteed ride home service to users of non-auto modes.

Notably, because VMT is largely a regional impact, regional VMT-reduction programs may be an appropriate form of mitigation. In lieu fees have been found to be valid mitigation where there is both a commitment to pay fees and evidence that mitigation will actually occur. (*Save Our Peninsula Committee v. Monterey County Bd. of Supervisors* (2001) 87 Cal.App.4th 99, 140-141; *Gentry v. City of Murrieta* (1995) 36 Cal.App.4th 1359; *Kings County Farm Bureau v. City of Hanford* (1990) 221 Cal.App.3d 692, 727–728.) Fee programs are particularly useful to address cumulative impacts. (CEQA Guidelines, § 15130, subd. (a)(3) [a "project's incremental contribution is less than cumulatively considerable if the project is required to implement or fund its fair share of a mitigation measure or measures designed to alleviate the cumulative impact"].) The mitigation program must undergo CEQA evaluation, either on the program as a whole, or the in-lieu fees or other mitigation must be evaluated

on a project-specific basis. (*California Native Plant Society v. County of El Dorado* (2009) 170 Cal.App.4th 1026.) That CEQA evaluation could be part of a larger program, such as a regional transportation plan, analyzed in a Program EIR. (CEQA Guidelines, § 15168.)

Examples of project alternatives that may reduce vehicle miles traveled include, but are not limited to:

- Locate the project in an area of the region that already exhibits low VMT.
- Locate the project near transit.
- Increase project density.
- Increase the mix of uses within the project or within the project's surroundings.
- Increase connectivity and/or intersection density on the project site.
- Deploy management strategies (e.g., pricing, vehicle occupancy requirements) on roadways or roadway lanes.

Appendix 1. Considerations About Which VMT to Count

Consistent with the obligation to make a good faith effort to disclose the environmental consequences of a project, lead agencies have discretion to choose the most appropriate methodology to evaluate project impacts.[38] A lead agency can evaluate a project's effect on VMT in numerous ways. The purpose of this document is to provide technical considerations in determining which methodology may be most useful for various project types.

Background on Estimating Vehicle Miles Traveled

Before discussing specific methodological recommendations, this section provides a brief overview of modeling and counting VMT, including some key terminology.

Here is an illustrative example of some methods of estimating vehicle miles traveled. Consider the following hypothetical travel day (all by automobile):

1. Residence to Coffee Shop
2. Coffee Shop to Work
3. Work to Sandwich Shop
4. Sandwich Shop to Work
5. Work to Residence
6. Residence to Store
7. Store to Residence

Trip-based assessment of a project's effect on travel behavior counts VMT from individual trips to and from the project. It is the most basic, and traditionally the most common, method of counting VMT. A trip-based VMT assessment of the residence in the above example would consider segments 1, 5, 6 and 7. For residential projects, the sum of home-based trips is called *home-based* VMT.

A *tour-based* assessment counts the entire home-back-to-home tour that includes the project. A tour-based VMT assessment of the residence in the above example would consider segments 1, 2, 3, 4, and 5 in one tour, and 6 and 7 in a second tour. A tour-based assessment of the workplace would include segments 1, 2, 3, 4, and 5. Together, all tours comprise *household* VMT.

[38] The California Supreme Court has explained that when an agency has prepared an environmental impact report:

> [T]he issue is not whether the [lead agency's] studies are irrefutable or whether they could have been better. The relevant issue is only whether the studies are sufficiently credible to be considered as part of the total evidence that supports the [lead agency's] finding[.]

(*Laurel Heights Improvement Assn. v. Regents of the University of California* (1988) 47 Cal.3d 376, 409; see also *Eureka Citizens for Responsible Gov't v. City of Eureka* (2007) 147 Cal.App.4th 357, 372.)

Both trip- and tour-based assessments can be used as measures of transportation efficiency, using denominators such as per capita, per employee, or per person-trip.

Trip- and Tour-based Assessment of VMT

As illustrated above, a tour-based assessment of VMT is a more complete characterization of a project's effect on VMT. In many cases, a project affects travel behavior beyond the first destination. The location and characteristics of the home and workplace will often be the main drivers of VMT. For example, a residential or office development located near high quality transit will likely lead to some commute trips utilizing transit, affecting mode choice on the rest of the tour.

Characteristics of an office project can also affect an employee's VMT beyond the work tour. For example, a workplace located at the urban periphery, far from transit, can require an employee to own a car, which in turn affects the entirety of an employee's travel behavior and VMT. For this reason, when estimating the effect of an office development on VMT, it may be appropriate to consider total employee VMT if data and tools, such as tour-based models, are available. This is consistent with CEQA's requirement to evaluate both direct and *indirect* effects of a project. (See CEQA Guidelines, § 15064, subd. (d)(2).)

Assessing Change in Total VMT

A third method, estimating the *change in total VMT* with and without the project, can evaluate whether a project is likely to divert existing trips, and what the effect of those diversions will be on total VMT. This method answers the question, "What is the net effect of the project on area VMT?" As an illustration, assessing the total change in VMT for a grocery store built in a food desert that diverts trips from more distant stores could reveal a net VMT reduction. The analysis should address the full area over which the project affects travel behavior, even if the effect on travel behavior crosses political boundaries.

Using Models to Estimate VMT

Travel demand models, sketch models, spreadsheet models, research, and data can all be used to calculate and estimate VMT (see Appendix F of the preliminary discussion draft). To the extent possible, lead agencies should choose models that have sensitivity to features of the project that affect VMT. Those tools and resources can also assist in establishing thresholds of significance and estimating VMT reduction attributable to mitigation measures and project alternatives. When using models and tools for those various purposes, agencies should use comparable data and methods, in order to set up an "apples-to-apples" comparison between thresholds, VMT estimates, and VMT mitigation estimates.

Models can work together. For example, agencies can use travel demand models or survey data to estimate existing trip lengths and input those into sketch models such as CalEEMod to achieve more

accurate results. Whenever possible, agencies should input localized trip lengths into a sketch model to tailor the analysis to the project location. However, in doing so, agencies should be careful to avoid double counting if the sketch model includes other inputs or toggles that are proxies for trip length (e.g., distance to city center). Generally, if an agency changes any sketch model defaults, it should record and report those changes for transparency of analysis. Again, trip length data should come from the same source as data used to calculate thresholds to be sure of an "apples-to-apples" comparison.

Additional background information regarding travel demand models is available in the California Transportation Commission's "2010 Regional Transportation Plan Guidelines," beginning at page 35.

Appendix 2. Induced Travel: Mechanisms, Research, and Additional Assessment Approaches

Induced travel occurs where roadway capacity is expanded in an area of present or projected future congestion. The effect typically manifests over several years. Lower travel times make the modified facility more attractive to travelers, resulting in the following trip-making changes:

- **Longer trips.** The ability to travel a long distance in a shorter time increases the attractiveness of destinations that are farther away, increasing trip length and vehicle travel.
- **Changes in mode choice.** When transportation investments are devoted to reducing automobile travel time, travelers tend to shift toward automobile use from other modes, which increases vehicle travel.
- **Route changes.** Faster travel times on a route attract more drivers to that route from other routes, which can increase or decrease vehicle travel depending on whether it shortens or lengthens trips.
- **Newly generated trips.** Increasing travel speeds can induce additional trips, which increases vehicle travel. For example, an individual who previously telecommuted or purchased goods on the internet might choose to accomplish those tasks via automobile trips as a result of increased speeds.
- **Land Use Changes.** Faster travel times along a corridor lead to land development farther along that corridor; that new development generates and attracts longer trips, which increases vehicle travel. Over several years, this induced growth component of induced vehicle travel can be substantial, making it critical to include in analyses.

Each of these effects has implications for the total amount of vehicle travel. These effects operate over different time scales. For example, changes in mode choice might occur immediately, while land use changes typically take a few years or longer. CEQA requires lead agencies to analyze both short-term and long-term effects.

Evidence of Induced Vehicle Travel. A large number of peer reviewed studies[39] have demonstrated a causal link between highway capacity increases and VMT increases. Many provide quantitative estimates of the magnitude of the induced VMT phenomenon. Collectively, they provide high quality evidence of the existence and magnitude of the induced travel effect.

[39] See, e.g., Boarnet and Handy (Sept. 2014) Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions, California Air Resources Board Policy Brief, available at https://www.arb.ca.gov/cc/sb375/policies/hwycapacity/highway_capacity_brief.pdf; National Center for Sustainable Transportation (Oct. 2015) *Increasing Highway Capacity Unlikely to Relieve Traffic Congestion*, available at http://www.dot.ca.gov/research/researchreports/reports/2015/10-12-2015-NCST_Brief_InducedTravel_CS6_v3.pdf.

Most of these studies express the amount of induced vehicle travel as an "elasticity," which is a multiplier that describes the additional vehicle travel resulting from an additional lane mile of roadway capacity added. For example, an elasticity of 0.6 would signify an 0.6 percent increase in vehicle travel for every 1.0 percent increase in lane miles. Many of these studies distinguish "short run elasticity" (increase in vehicle travel in the first few years) from "long run elasticity" (increase in vehicle travel beyond the first few years). Long run elasticity is larger than short run elasticity, because as time passes, more of the components of induced vehicle travel materialize. Generally, short run elasticity can be thought of as excluding the effects of land use change, while long run elasticity includes them. Most studies find a long run elasticity between 0.6 and just over 1.0,[40] meaning that every increase in lanes miles of one percent leads to an increase in vehicle travel of 0.6 to 1.0 percent. The most recent major study finds the elasticity of vehicle travel by lanes miles added to be 1.03; in other words, each percent increase in lane miles results in a 1.03 percent increase in vehicle travel.[41] (An elasticity greater than 1.0 can occur because new lanes induce vehicle travel that spills beyond the project location.) In CEQA analysis, the long-run elasticity should be used, as it captures the full effect of the project rather than just the early-stage effect.

Quantifying Induced Vehicle Travel Using Models. Lead agencies can generally achieve the most accurate assessment of induced vehicle travel resulting from roadway capacity increasing projects by applying elasticities from the academic literature, because those estimates include vehicle travel resulting from induced land use. If a lead agency chooses to use a travel demand model, additional analysis would be needed to account for induced land use. This section describes some approaches to undertaking that additional analysis.

Proper use of a travel demand model can capture the following components of induced VMT:

- Trip length (generally increases VMT)
- Mode shift (generally shifts from other modes toward automobile use, increasing VMT)
- Route changes (can act to increase or decrease VMT)
- Newly generated trips (generally increases VMT)
    - Note that not all travel demand models have sensitivity to this factor, so an off-model estimate may be necessary if this effect could be substantial.

However, estimating long-run induced VMT also requires an estimate of the project's effects on land use. This component of the analysis is important because it has the potential to be a large component of

[40] See Boarnet and Handy (Sept. 2014) *Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions*, California Air Resources Board Policy Brief, p. 2, available at https://www.arb.ca.gov/cc/sb375/policies/hwycapacity/highway_capacity_brief.pdf.

[41] Duranton and Turner (2011) *The Fundamental Law of Road Congestion: Evidence from US cities*, available at http://www.nber.org/papers/w15376.

the overall induced travel effect. Options for estimating and incorporating the VMT effects that are caused by the subsequent land use changes include:

1. *Employ an expert panel.* An expert panel could assess changes to land use development that would likely result from the project. This assessment could then be analyzed by the travel demand model to assess effects on vehicle travel. Induced vehicle travel assessed via this approach should be verified using elasticities found in the academic literature.
2. *Adjust model results to align with the empirical research.* If the travel demand model analysis is performed without incorporating projected land use changes resulting from the project, the assessed vehicle travel should be adjusted upward to account for those land use changes. The assessed VMT after adjustment should fall within the range found in the academic literature.
3. *Employ a land use model, running it iteratively with a travel demand model.* A land use model can be used to estimate the land use effects of a roadway capacity increase, and the traffic patterns that result from the land use change can then be fed back into the travel demand model. The land use model and travel demand model can be iterated to produce an accurate result.

A project which provides new connectivity across a barrier, such as a new bridge across a river, may provide a shortened path between existing origins and destinations, thereby shortening existing trips. In rare cases, this trip-shortening effect might be substantial enough to reduce the amount of vehicle travel resulting from the project below the range found in the elasticities in the academic literature, or even lead a net reduction in vehicle travel overall. In such cases, the trip-shortening effect could be examined explicitly.

Whenever employing a travel demand model to assess induced vehicle travel, any limitation or known lack of sensitivity in the analysis that might cause substantial errors in the VMT estimate (for example, model insensitivity to one of the components of induced VMT described above) should be disclosed and characterized, and a description should be provided on how it could influence the analysis results. A discussion of the potential error or bias should be carried into analyses that rely on the VMT analysis, such as greenhouse gas emissions, air quality, energy, and noise.