Appendix B:
Shute, Mihaly & Weinberger LLP Letter Exhibits

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Congressional Research Service

California Drought: Hydrological and Regulatory Water Supply Issues

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CRS Report for Congress
Prepared for Members and Committees of Congress

Summary

California experienced severe water supply shortages in 2009, which led to economic disruption across the state, including concentrated losses in agricultural areas in the western portion of the Central Valley—areas already experiencing declines in the housing industry and the economic downturn in general. At the same time, several fish species whose habitat lie at the heart of California's water supply system and throughout its northern rivers are in decline and some face the possibility of extinction. This situation too has had economic implications, resulting in job and income losses in northern California. The short-term issue for Congress is how to evaluate demands for increasing water supplies that may help some users but may jeopardize the continued existence of several fish species. A longer-term issue for Congress is how to evaluate management alternatives that will protect species, but also help water users and economies that depend on reliable water supplies and healthy ecosystems.

While three years of hydrological drought conditions have created a fundamental shortage of water supply in California, many water users have questioned the extent to which regulatory and court-imposed restrictions on water removed from the Sacramento and San Joaquin Rivers Delta, in order to protect fish habitat, have contributed to water shortages in 2009. Conversely, fishermen and others question to what degree increased Delta pumping in 2004 contributed to fish declines.

Current observations of below-average runoff, reservoir levels, and groundwater levels are broadly comparable to those observed during previous episodes of drought in California. At the end of water year 2008-2009 (October through September), statewide precipitation stood at 76% of average, and water levels in key reservoirs in the state were 69% of average. Groundwater levels from selected wells in the Central Valley are also broadly similar to groundwater levels during two previous historic drought periods. The below-average precipitation, below-average water content of the Sierra snowpack in consecutive winters, and similarity of groundwater levels compared across different periods of California drought support the contention that a multiyear hydrological drought underlies the current water crisis that faces California.

Depending on what baseline is used, total reductions in water exported from the Delta in 2009 are estimated to range from 37% to 42%. Restrictions on water deliveries resulting directly from federal and state regulations, or imposed by courts' interpretation of those rules, are estimated to range roughly from 20% to 25% of the total export reductions for 2009. The remaining 75%-80% of 2009 export reductions, according to the Department of the Interior, are due to "lack of run-off" (i.e., drought) and other factors. The system of state water rights also has a profound effect on who gets how much water and when, particularly in times of drought or other shortages. Water shortages due to drought and regulatory export restrictions have resulted in unequal impacts on Central Valley Project (CVP) and State Water Project water contractors because of differences in priority of water rights underlying different water contracts. Although combined Delta exports have increased on average since the 1980s and early 1990s, even with implementation of several regulatory restrictions, CVP water allocations for some contractors have been significantly reduced.

This report discusses California's current hydrological situation and provides background on regulatory restrictions affecting California water deliveries, as well as on the long-established state water rights system, which also results in uneven water deliveries in times of shortages.

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Introduction

This report analyzes California's current hydrological situation and addresses whether California is experiencing a hydrological drought and to what extent water delivery reductions are linked to regulatory restrictions. Some observers question the Administration's and the state's contention that drought conditions persist and that such conditions are largely to blame for significantly reduced water deliveries in 2009. It appears that three years of hydrological drought conditions have created a fundamental shortage of supply, and that regulatory and court-imposed restrictions, as well as the long established state water rights system, seem to have exacerbated the impacts of drought on water deliveries. An underlying question is not necessarily whether the drought is either hydrological or regulatory, but rather to what extent each affects water deliveries.

The Department of the Interior (hereafter referred to as "Interior") has stated that California is experiencing a hydrological drought.[1] This also was briefly stated by Interior and other federal agencies in response to Member questions during a March 31, 2009, hearing on drought before the House Natural Resources Committee. Further, the governor of California declared a drought emergency in both January 2008 and January 2009. Earlier this year, USDA had designated two California counties as primary natural disaster areas, and most recently the U.S. Department of Agriculture on September 22 designated 21 counties in California as "primary natural disaster areas" because of losses caused by drought in 2009.[2]

CRS has analyzed a variety of data and information on hydrological and regulatory limits on California water resources, as well as restrictions due to water rights allocations. This report provides a summary of California's 2009 hydrological situation with comparisons, where applicable, to other drought years; a summary of the key regulatory requirements that at times limit water deliveries or "exports" from the San Joaquin and Sacramento Rivers Delta (hereafter referred to as the "Delta"); and a brief discussion of California water rights and how they relate to different types of federal contracts and their associated water allocations.

What Is Drought?

Droughts have affected the United States, particularly the American West, for centuries. Drought is defined in a number of ways; the simplest may be as a deficiency of precipitation over an extended period of time, usually a season or more.[3] The deficiency is usually evaluated relative to some long-term average condition, or balance, between precipitation, evaporation, and transpiration by plants. Drought, which has a beginning and an end, is distinguished from aridity, which is restricted to low-rainfall regions and is a relatively permanent feature of climate (e.g., deserts are regions of relatively permanent aridity).[4]

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[1] U.S. Dept. of the Interior and Office of Communications, *Reality Check: California's Water Crisis*, Washington, DC, September 17, 2009, p. 1, http://www.usbr.gov/main/docs/CA_Water_Reality_Check.pdf.

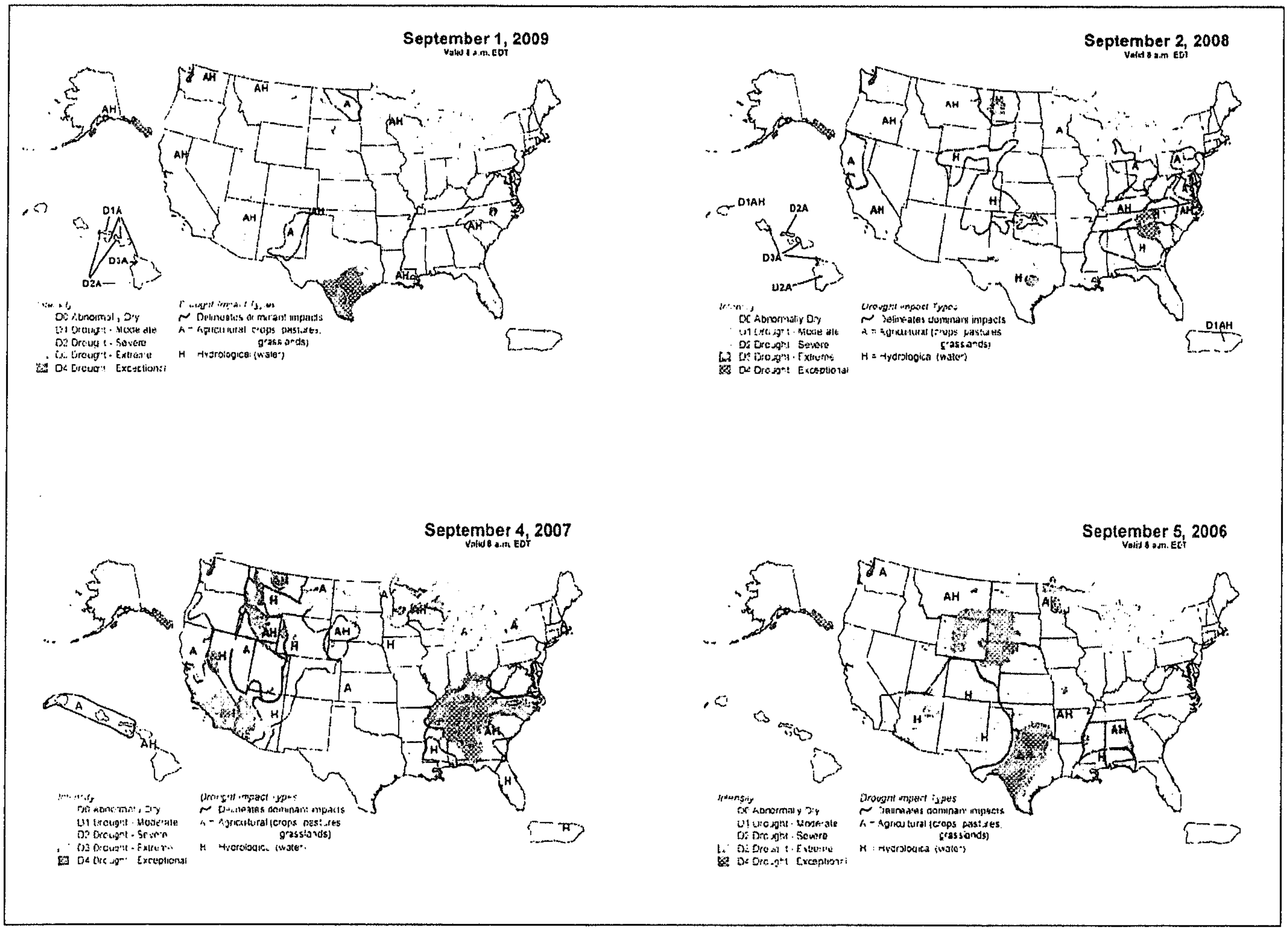
[2] U.S. Dept. of Agriculture, Farm Service Agency, *USDA Designates 21 Counties in California as Primary Natural Disaster Area*, News Release No. 1481.09, Sept. 22, 2009, http://www.fsa.usda.gov/FSA/newsReleases?area=newsroom&subject=landing&topic=edn&newstype=ednewsrel&type=detail&item=ed_20090922_rel_1481.html.

[3] National Drought Mitigation Center (NDMC), at http://www.drought.unl.edu/whatis/what.htm.

[4] NDMC, at http://www.drought.unl.edu/whatis/concept.htm.

At the national level, drought is monitored and reported in an index known as the U.S. Drought Monitor, which synthesizes various drought indices and impacts, and represents a consensus among academic and federal scientists of ongoing drought conditions. The U.S. Drought Monitor uses five key indicators, together with expert opinion, indices to account for conditions in the West where snowpack is relatively important, and other indices used mainly during the growing season. (The five key indicators include the Palmer Drought Index, the Climate Prediction Center soil moisture model, U.S. Geological Survey weekly streamflow data, the Standardized Precipitation Index, and short- and long-term drought indicator blends.)[5] Drought indices are typically used to assess and classify the intensity and type of drought. The classification of drought intensity, such as that shown in **Figure 1**, may depend on a single indicator or several indicators, often combined with expert opinion from the academic, public, and private sectors.

Figure 1. U.S. Drought Monitor Maps for Early September 2006-2009



Source: U.S. Drought Monitor, at http://drought.unl.edu/DM/MONITOR.html.

Notes: The U.S. Drought Monitor map for early September 2006 is shown for comparison, indicating that California was not experiencing drought conditions in 2006.

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[5] For a discussion of drought indices, see the NDMC, at http://www.drought.unl.edu/whatis/indices.htm. See also U.S. Drought Monitor, at http://www.drought.unl.edu/dm/classify.htm.

The "A" and "H" terms shown in **Figure 1** give additional information on the nature of the drought in the affected region. Agricultural drought ("A") can be defined as when there is insufficient moisture to meet the needs of a particular crop at a particular time.[6] Hydrological drought ("H") can be defined as deficiencies in water supplies, as measured by stream flows, lake or reservoir levels, or elevation of the ground water surface. Hydrological drought usually lags behind agricultural drought because it takes longer for deficiencies in precipitation to affect the broader hydrologic system. Lack of rainfall during a critical part of the growing season may have an immediate impact on farmers—an agricultural drought—but the deficiency may not affect reservoir or river levels for many months. Because a hydrological drought affects the broader hydrologic system, such as one or several river basins, a severe hydrological drought could exacerbate competition among water uses: irrigation, navigation, recreation, municipal and industrial supply, energy production, preservation of endangered species, and others.

Drought in California: Hydrological Conditions

The U.S. Drought Monitor in **Figure 1** shows persistent drought in California for 2007-2009. The map does not take into consideration any decisions on reductions in water delivery made by the state or federal government. It is strictly a representation of the hydrological status of California (from factors other than deliveries of water mandated or restricted by regulation). However, increases in 2009 precipitation levels in many California watershed basins and near-average and above-average reservoir levels in some areas of the state have caused some to question the drought determination by state and federal officials. Some parties have pointed in particular to environmental restrictions on Delta exports as causing a regulatory or "man-made" drought.[7] In response to this debate, the Bureau of Reclamation has noted that one-third less water—approximately 2.1 million acre-feet (AF)[8]—is available for export out of the Delta this year. Of that amount, the agency estimates that nearly 25% (500,000 AF) of this year's export reduction is due to recent Endangered Species Act (ESA) restrictions for the Delta smelt and the other 75% is due to dry conditions and other long-standing requirements such as Delta salinity standards. Another less frequently mentioned factor in water allocations is the state system of water rights, which has a large and direct effect on how much water the different state and federal water contractors receive north of the Delta versus south of the Delta, particularly in dry years. Under this system, some federal water contractors are receiving just 10% to 15% of their contracted supplies, while more senior contractors are receiving 100%. (For a summary of the different types of contractors, see "California Water Rights: Acquisitions and Allocations," below.)

The U.S. Drought Monitor map for September 1, 2009 (upper left map in **Figure 1**), includes California within its agricultural and hydrological drought impact classification (the AH symbol on the map), which means that the dry conditions have been severe enough to affect crops, pastures, grasslands, rivers, groundwater supplies, and reservoir levels. **Figure 1** also illustrates the persistent nature of the drought for 2007 through 2009. The figure shows that other parts of the country, such as Texas, the Southeast, and portions of the Great Plains have seen drought conditions come and go since 2006. In contrast, California has faced abnormally dry to extreme drought conditions continuously from 2007 to the present.

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[6] NASA Earth Observatory, at http://earthobservatory.nasa.gov/Library/DroughtFacts/.

[7] For example, see floor debate on motion to recommit H.R. 1145, the National Water Research and Development Initiative Act of 2009, *Congressional Record*, daily edition, vol. 155 (April 23, 2009), p. H4715.

[8] An acre-foot is equivalent to 325,851 gallons.

California has experienced years of consecutive drought in the past. Observations of below-average runoff, reservoir levels, and groundwater levels are broadly comparable to those observed during previous episodes of drought in California (e.g., 1977-1978 and 1987-1992).

Runoff and Storage

The California Department of Water Resources (DWR) evaluation (as of August 31, 2009) of the California drought identifies below-average runoff and reservoir storage:

> This water year will be the third dry year in a row for California. Runoff and reservoir storage entering Water Year 2009-2010 will be below average, with key reservoirs significantly lower than average. Emergency declarations are in place in four counties currently experiencing economic or supply difficulties. Drought conditions remain severe at this time, and the developing El Nino over the Pacific Ocean may not improve statewide water supply next year.[9]

Below-average runoff indicates an underlying deficit in precipitation, which would support a common definition of drought: less rain or snow than a region would receive compared to some long-term average (consistent with the description of hydrological drought, discussed above). The California DWR also points out that California has experienced three dry years in a row compared to the long-term average, a persistent and statewide condition that likely underlies much of the discussion and controversy over water allocations in the state. **Figure 2** shows reservoir storage at the end of the water year in California for seven "key" reservoirs identified by the California DWR for 2006-2009. The figure shows that the reservoirs have been at 78% or less of average levels for the last three years compared to 2006, which was 123% of average for the seven reservoirs. Reservoir levels for the seven key reservoirs shown in **Figure 2** were at 69% of historical average as of September 30, 2009, the end of the 2008-2009 water year.

A comparison of reservoir levels for 12 California reservoirs measured in April 2009 and in September 2009 indicates that individual reservoirs' conditions changed in the intervening five months, but that nine of the 12 reservoirs were below historically average levels in both April and September. (See **Appendix A** and **Appendix B** for the comparison between April and September for the 12 reservoirs.) According to the California DWR, statewide reservoir storage was at 79% of average levels at the end of September; however, the two largest reservoirs (Shasta and Lake Oroville) in the federal and state systems serving California remained at 63% and 59% of historical levels for September.[10] Also, comparing the *amount* of water held in storage at each of the 12 reservoirs versus the total amount of storage (i.e., the aggregate amount from the 12 reservoirs) historically held at the same time shows that reservoir levels were at approximately 70% of the historical total, not 79% as indicated by the California DWR.[11] This difference may reflect the way the California DWR calculated the statewide average value from the levels measured in the 12 reservoirs.[12] In addition, of the five reservoirs which historically average

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[9] As shown in **Appendix A**, some reservoirs are at or above historically average levels, but overall storage is below the historical average. California Department of Water Resources, "California's Drought Update," August 31, 2009, at http://www.water.ca.gov/drought/docs/DroughtUpdate-083109.pdf.

[10] California Department of Water Resources, "California's Drought Update" (Sept. 30, 2009), at http://www.water.ca.gov/drought/docs/DroughtUpdate_sept30.pdf.

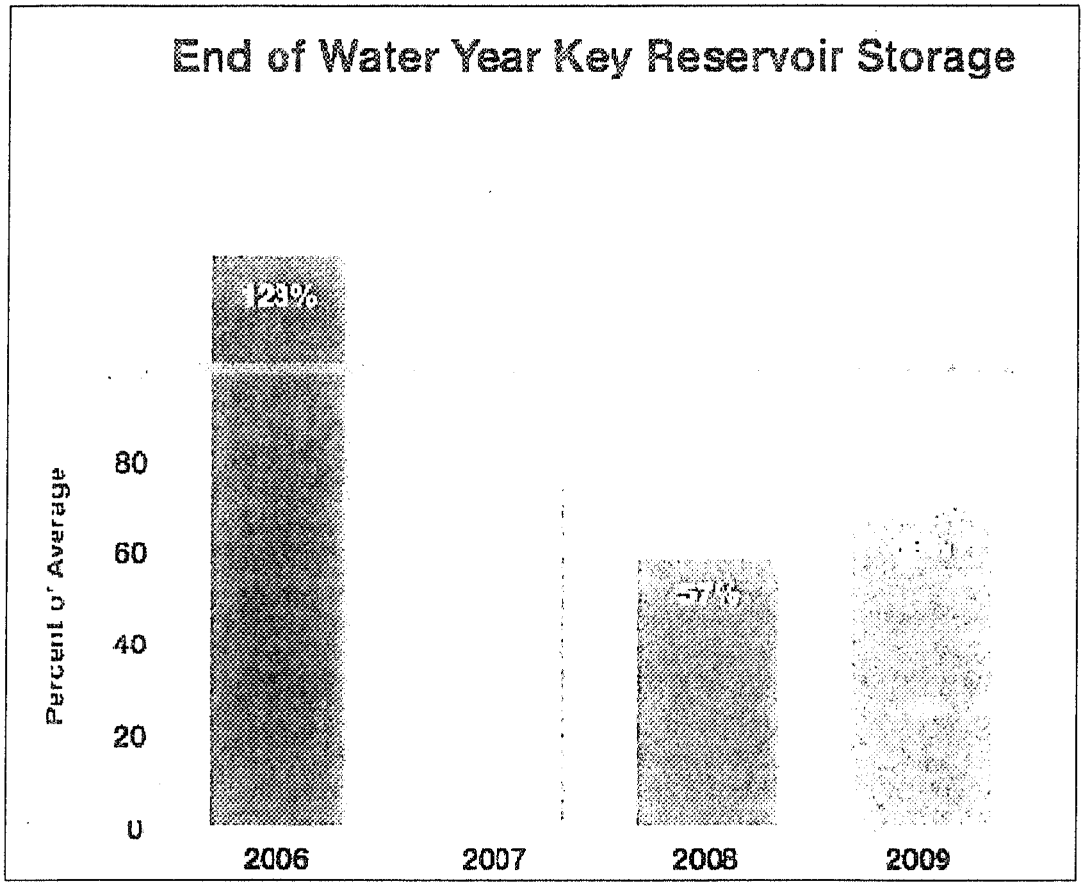
[11] California Department of Water Resources, California Data Exchange Center, *Current Conditions for Major Reservoirs* (as of September 29, 2009), at http://cdec.water.ca.gov/reservoir_map.html.

[12] CRS calculated the 70% value by summing the total amount of water held in storage for the 12 reservoirs and dividing by the total amount of water historically held in storage during the same time period for all 12 reservoirs. The (continued...)

greater than 1 million AF of storage at the end of September, only Don Pedro reservoir was above its historical average (106%); the other four reservoirs ranged from 83% (New Melones) to 54% (Trinity). The three largest reservoirs (Shasta, Oroville, Trinity), which historically contain over 50% of the total storage in September for the 12 reservoirs shown in **Appendix A**, were all well below average historical levels at the end of September 2009, ranging from 54% (Trinity) to 63% (Shasta).

Figure 2. Reservoir Storage at the End of the Water Year, as a Percent of Average, for Seven Reservoirs in California

(2009 levels as of September 30, 2009)



Source: California Department of Water Resources, "California's Drought Update," Figure 2 (Nov. 30, 2009), at http://www.water.ca.gov/drought/docs/DroughtUpdate-113009.pdf.

Notes: The seven reservoirs identified as "key" by the California DWR are Trinity, Shasta, Oroville, Folsom, Don Pedro, New Melones, and San Luis.

(...continued)

CRS calculation thus accounts for the different amount of water held in each reservoir. In contrast, calculating the percent of storage held in each individual reservoir, summing the percentages for all 12 reservoirs, and then taking the average of summed percentages yields a value of 81.5% for September 29, 2009. The latter calculation would give greater weight to smaller reservoirs, rather than reflect the status of total storage compared to a total historical average for all reservoirs.

Timing

Persistent drought conditions in California since 2007 do not necessarily mean that all locations throughout California experienced the same degree of drought at all times. Drought conditions have changed over time and by location, so that despite below-average precipitation and lower-than-average reservoir levels generally, conditions have differed from month to month. For example, January is normally the wettest month for California, averaging 4.35 inches of precipitation in the state.[13] In January 2009, however, California only received 1.25 inches, or 29% of average precipitation for the month. From October through April, a seven-month period, California receives most of its precipitation, an average of approximately 20 inches, or more than 90% of the yearly total. For 2008-2009, only February received above-average precipitation over that seven-month period (**Table 1**). Despite a relatively wet February (138% of average), and a wet May and June (169% and 134% of average, respectively), California had received 76% of its average annual precipitation as of September 30, 2009.[14] The state had received 77% at the end of March and 73% at the end of April 2009[15]—critical times for water delivery decisions (see **Table 1**). The California DWR reported that reservoir storage was 80% of average at the end of August; however, much of that storage was located in smaller reservoirs south of the Delta.[16]

Table 1. Average and Observed Statewide Precipitation, by Month

(shows % of average by month and cumulatively for water year 2008-2009, through September 30, 2009)

Month	**Average Precipitation Statewide (inches)**	**Water Year 2008-2009 Observed Precipitation**	**% of Average (by month)**	**% of Average (cumulative)**
October	1.22	0.73	60%	60%
November	2.80	2.49	89%	80%
December	3.91	3.05	78%	79%
January	4.35	1.25	29%	61%
February	3.66	5.06	138%	79%
March	3.12	2.13	68%	77%
April	1.64	0.59	36%	73%
May	0.89	1.50	169%	77%
June	0.35	0.47	134%	79%
July	0.18	0.03	17%	78%
August	0.28	0.06	21%	78%
September	0.48	0.09	19%	76%
Total	**22.34**	**17.39**		**76%**

Source: California Department of Water Resources, "California's Drought Update," (Nov. 30, 2009), Table 1, at http://www.water.ca.gov/drought/docs/DroughtUpdate-113009.pdf. CRS provided the last column showing the cumulative % of average precipitation.

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[13] California Department of Water Resources, "California's Drought Update" (Nov. 30, 2009), Table 1, at http://www.water.ca.gov/drought/docs/DroughtUpdate-113009.pdf.

[14] Ibid.

[15] Ibid.

[16] California Department of Water Resources Data Exchange Center, "Executive Update" (September 1, 2009), at http://cdec.water.ca.gov/cgi-progs/reports/EXECSUM. Also, see footnote 12 for another explanation for the how the 80% value may have been calculated.

When, where, and how precipitation occurs (e.g., snow versus rain) are critical to water allocation decisions typically made in the late spring. The timing of precipitation and runoff critically influences allocation decisions for the State Water Project (SWP) and the Central Valley Project (CVP). For example, both projects rely on precipitation data, including data indicating the water content of snowpack and projected runoff, to decide how much water to allocate to water users early in the water year (February-May). Typically, DWR and the Bureau of Reclamation (hereafter referred to as "Reclamation") announce water allocations for the coming growing season in mid-February of each year. This announcement is generally followed by monthly allocation announcements (through May) based on updated precipitation data and runoff projections. In February 2009, the California DWR (responsible for the SWP) and Reclamation (responsible for the CVP) announced that water allocations would be significantly restricted for all contract categories and severely restricted for some (some CVP contractors were to receive no CVP water). DWR stated that its May allocation for the water year was its last allocation, based on reservoir levels and other factors up to that date. Although early May rain and snow allowed the DWR to increase its allocation of the SWP from 30% to 40%, below-normal precipitation and runoff for six of the preceding seven months kept the allocation low: "This small increase in SWP deliveries does not mean California has overcome the effects of three consecutive dry years. In fact, 2007 to 2009 will likely rank in the top 10 driest three-year periods in the last century."[17] Similarly, Reclamation was able to increase its CVP allocations in April and May; however, south-of-Delta CVP *water service* contractors were still allocated just 10% of their maximum contract amount, while senior north-of-Delta *water rights* contractors and south-of-the-Delta *water rights* contractors were allocated 100% of their contract amounts.[18]

Because the Sierra Nevada snowpack is such a critical component of the California water supply, the amount, timing, and water content of the snowpack influences decisions about water distribution for the rest of the year. For example, January 2009 was the ninth-driest January on record for the state, and the Sierra snowpack contained only 60% of its average water content, prompting the California governor to declare a statewide emergency due to drought on February 27, despite a relatively wet February.[19] The Sierra snowpack was also at 60% of its average water content in January 2008, and the driest spring on record in 2008 also prompted the governor to declare a statewide drought and a state of emergency for nine counties in June 2008,[20] despite improvements in the snowpack in February 2008.

Prospects for a Continuing Hydrologic Drought

California receives the bulk of its precipitation in the late fall and winter months, and it is difficult to predict with any certainty what the precipitation patterns will be for the 2009-2010 water year. Greater than average precipitation fell during October 2009 (2.29 inches received versus 1.22 inches average);[21] however, precipitation in October typically represents only about 5% of the

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[17] California Department of Water Resources Director Lester Snow, May 20, 2009 press release, at http://www.water.ca.gov/news/archive/index.cfm.

[18] Maximum contract quantities are not the same as deliveries. A variety of factors influence actual deliveries in any given year and in some cases actual deliveries are often well below a contractor's maximum contracted supply.

[19] California Department of Water Resources, "Drought Timeline," at http://www.water.ca.gov/drought/docs/timeline-present.pdf.

[20] Ibid.

[21] California Department of Water Resources, "California's Drought Update" (Nov. 30, 2009), Table 1, at http://www.water.ca.gov/drought/docs/DroughtUpdate-113009.pdf.

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WATER AVAILABILITY ANALYSIS
Policy Report
August 2007

Introduction:

At the height of the 1990 drought in Napa County, the Napa County Board of Supervisors and the Napa County Planning Commission became very concerned with the approval of use permits and parcel division that would cause an increased demand on groundwater supplies within Napa County. During several Commission hearings, conflicting testimony was entered as to the impact of such groundwater extraction on water levels in neighboring wells. The Commission asked the Department of Public Works to evaluate what potential impact an approval might have on neighboring wells and on the basin as a whole. In order to simplify a very complex analysis, the Department developed a three phase water availability analysis to provide a cost-effective answer to the question.

On March 6, 1991, an interim policy was presented and approved by the Commission which requires the applicants for use permits and parcel divisions to submit a water availability analysis with their proposal. The staff report that provides the procedure to follow for compliance with the Commission policy was intended to be an interim one. With the passage on August 3, 1999 by the Board of Supervisors of Napa County Ordinance #1162 (the Groundwater Conservation Ordinance) it became apparent that the interim policy required updating and formalization. The purpose of the revised report is to provide the procedure for preparation of water availability analysis and to restate the purpose and functionality of the analysis as related to the revised Groundwater Ordinance (Napa County Ordinance # 1162).

Water Availability Analysis:

The Water Availability Analysis (WAA) sets up guidelines to determine if a proposed project will have an adverse impact on the groundwater basin as a whole or on the water levels of neighboring wells with the overriding benefit of helping to manage groundwater resources. An important sidelight to the process is public education and awareness. WAA's are comprised of potentially three phases; phase one, phase two and phase three.

A **phase one analysis** is a reconnaissance level report that may be prepared by the applicant or their agent. **It must be signed by the applicant. If prepared by the applicant's agent, it must contain the letterhead of the agent, the name of the agent, and the agent's signature.** The phase one WAA contains the following information:

1. The name and contact information of the property owner and the person preparing the phase one report.

2. Site map of the project parcel and adjoining parcels. The map should include: Assessor's Parcel Number (APN), parcel size in acres, location of project well(s) and other water sources, general layout of structures on the subject parcel, location of agricultural development and general location within the county.

3. Narrative on the nature of the proposed project including: all land uses on the subject parcel, potential for future water uses, details of operations related to water use, description of interconnecting plumbing between the various water sources and any other pertinent information.

4. Tabulation of existing water use compared to projected water use for all land uses contained on the parcel. Should the water use extend to other parcels, they should be included in the analysis (see Appendix E for additional information on determining fair share estimates when multiple parcels are involved). **These estimates should reflect the specific requirements of the applicant's operations.** The applicant should use the guidelines attached in Appendix A

The Department will review the analysis for completeness and reasonableness (based on the guidelines outlined in Appendix A) and then compare the analysis to a threshold level of groundwater use for the subject parcel. The threshold is based upon several factors including annual rainfall, topography, soil types, proximity to recharge zones and available groundwater information. In general, parcels located on the Valley Floor or in strong alluvial areas will be assigned a threshold of 1 acre-foot per acre of land (an acre-foot of water is the amount of water it takes to cover one acre of land to a depth of one foot, or 325,851 gallons). Therefore, a 40-acre parcel will have an acceptable level of groundwater use of 40 acre-feet per year. The threshold for Hillside parcels (primarily located in volcanic rock and soils) is 0.5 acre-feet per acre or 20 acre-feet per year for a 40-acre parcel. Areas designated as "Groundwater Deficient Areas" as defined in the Groundwater Conservation Ordinance will have threshold established for that specific area. For example, the Milliken-Sarco-Tulocay Basin (M-S-T) is currently the only "groundwater deficient area" and has an established threshold of 0.3 acre-feet per acre per year. Thus, the same 40-acre parcel has an acceptable level of water use of 12 acre-feet per year (see Appendix B).

If the Phase I analysis shows a water use above the parcel threshold then further analysis may be required in the form of a Phase II or Phase III analysis.

In instances where the applicant is in the M-S-T basin and their estimated future water usage will be significantly less than the values listed in Appendix A, or if the estimate is within 50% of the estimated threshold, the County may require the applicant to install a water meter to verify actual groundwater usage. If the actual usage exceeds the parcel's threshold, applicant may be required to reduce groundwater consumption and/or find alternate water sources to ensure that no more groundwater is consumed than the threshold for the parcel(s) (See Appendix D).

In the M-S-T basin a phase one analysis examines only the estimated quantity of groundwater water usage as compared to the established water usage threshold. It is assumed that if all consumers within the MST basin were to limit their consumption to 0.3 acre-feet per acre per year* there will be sufficient groundwater for all properties within that area.

* Does not apply to the Ministerial Exemption as outlined in the Groundwater Conservation Ordinance

Any new project within the M-S-T Basin whose estimated use exceeds the threshold use will likely be recommended for denial to the County Department requesting review of the application.

For projects in all other areas within Napa County whose estimated water use exceeds the threshold, the applicant will be required to conduct either a **phase two or a phase three analysis (or both).**

The phase two analysis is commonly called an acquifer test or well test. It requires the pumping of the project well(s) at the maximum rate needed to meet project water demands and at the same time requires the monitoring of the immediate effects of groundwater pumping on a neighboring or monitoring well(s). The following requirements must be met when performing a phase two analysis:

- An approved hydrogeologist, a list of which is on file with the Department of Public Works, must develop the test procedure. Upon approval of test procedures, the hydrologist will supervise the test and submit a report to the Department evaluating impacts to neighboring static water levels.
- A licensed well drilling contractor must perform the actual testing and monitor static and dynamic water levels of the project well and monitoring wells during the duration of the test, including the recovery phase of the project well and monitoring wells.
- The test must be conducted long enough to stabilize the dynamic water level of the project well or include an analysis of what the impact* of continued pumping would have.
- The applicant or agent must notify the Department at least 48 hours prior to conducting the test.

* Impact is unique to each project and will be evaluated on a case by case basis by the department of public works.

Any projects requiring a phase two analysis may also be required to install water meters to measure the actual amount of water consumed, and be required to find alternate water sources if their actual groundwater usage exceeds the threshold for their property (see Appendix D).

The Department will review the phase two analysis and determine if the impacts to static water levels of neighboring wells are within acceptable limits. If the phase two is unacceptable, **a phase three analysis** is required. The phase three analysis may include many measures aimed at reducing water consumption and/or the maximum pumping rate. The Department will require periodic monitoring of static water levels with annual submittals of well production and static water level reports.

The phase three analysis only determines possible actions which could be taken to moderate the immediate effects of groundwater pumping to neighboring wells. These mitigation measures will be designed to reduce, but may not eliminate, the immediate effects of groundwater pumping to neighboring wells.

The preparation and submittal of WAA's for all use permits and parcel divisions, as well as for all Groundwater Conservation Ordinance permits must be submitted through the normal procedures for the Conservation, Development and Planning Department (CDPD) and the Department of Environmental management (DEM) respectively. All subsequent communication should likewise pass through CDPD or DEM. Any mitigation measures identified in the phase three analysis will become either project modifications to, or conditions of approval for, the proposed project.

Details of the use permit or land division can be obtained from CDPD and details of the Groundwater Ordinance and related permit process can be obtained from the Department of Environmental Management. Mapping of "Groundwater Deficient Areas" is available at all three Departments with final determination being supplied by the Department of Public Works.

Conclusions:

The Napa County Board of Supervisors has long been committed to the preservation of groundwater for agriculture and rural residential uses within the County. It is their belief that through proper management, the excellent groundwater resources found within the county can be sustained for future generations.

Since 1991, several conclusions can be drawn from application of the water availability analysis process:

- In the process of conducting the analysis, applicants become much more aware of water use for their project, providing a higher level of awareness and potentially leading to more efficient use of the resource.

- Information submitted by applicants has lead to a broader database for future study and management.

- Groundwater use can vary widely depending upon its availability.

- The current practice of evaluating an applicant's Phase I WAA to determine if additional analysis is needed has been the accepted method for making groundwater determinations. Due to the limited information available on Napa County groundwater basins in general (with the exception of the MST basin), the Phase 1 WAA has been the most reasonable approach to the process and has not been shown to be inaccurate or inadequate. As such, the established WAA procedures for making groundwater determinations as outlined above and throughout the Appendices will continue to be the accepted method of making groundwater determinations and findings.

The water availability analysis is based upon the basic premise that each landowner has equal right to the groundwater resource below his or her property. By attempting to limit the extraction to a threshold amount, it is believed that sufficient groundwater will be available for both current and future property owners.

APPENDIX A: Estimated Water Use for Specified Land Use

Guidelines for Estimating Residential Water Use-For use with the Phase I Form

The typical water use associated with residential buildings is as follows:

Primary Residence	0.5 to 0.75 acre-feet per year (includes minor to moderate landscaping)
Secondary Residence	0.20 to 0.50 acre-feet per year
Farm Labor Dwelling	0.06 to 0.10 acre-feet per person per year

Additional Usage to Be Added

1. Add an additional 0.1 acre-feet of water for each additional 1000 square feet of drought tolerant lawn or 2000 square feet of non-xeriscape landscaping above the first 1000 square feet.
2. Add an additional 0.05 acre-feet of water for a pool with a pool cover.
3. Add an additional 0.1 acre-feet of water for a pool without a cover.

Residential water use can be estimated using the typical water uses above. All typical uses are dependant on the type of fixtures and appliances, the amount and type of landscaping, and the number of people living onsite. If a residence uses low-flow fixtures and has appliances installed, is using xeriscape landscaping, and is occupied by two people, the water use estimates will be on the low side of the ranges listed above.

Examples of Residential Water Usage:

Residential water use can vary dramatically from house to house depending on the number of occupants, the number and type of appliances and water fixtures, the amount and types of lawn and landscaping. Two homes sitting side by side on the same block can consume dramatically different quantities of water.

Example1:

Home #1 is 2500 square feet. Outside the house there is an extensive bluegrass lawn, a lot of water loving landscaping, a swimming pool with no pool cover. Inside the house all the appliances and fixtures, including toilets and shower-heads, are old and have not been upgraded or replaced by water saving types. The owners wash their cars weekly but they don't have nozzles or sprayers on the hose. They do not shut off the water while they are soaping up the vehicles, allowing the water to run across the ground instead. Water is commonly used as a broom to wash off the driveways, walkways, patio, and other areas. The estimated water usage for Home #1 is 1.2 acre-feet of water per year.

Example2:

Home #2 is also 2500 square feet. Outside of the house there is a small lawn of drought tolerant turf, extensive usage of xeriscape landscaping, and no swimming pool. Inside the house all of the appliances and fixtures, including toilets and showerheads, are of the low flow water saving types. The owners wash their cars weekly, but have nozzles or sprayers on the hose to shut off the water while they are soaping up the vehicles. Driveways, walkways, patios, and other areas are swept with brooms instead of washed down with water. Estimated water usage for Home #2 is 0.5 acre-feet of water per year.

The above are only examples of unique situations. The estimated water use for each project will vary depending on existing parcel conditions.

Guidelines For Estimating Non-Residential Water Usage:

Agricultural:	
Vineyards	
Irrigation only	0.2 to 0.5 acre-feet per acre per year
Heat Protection	0.25 acre feet per acre per year
Frost Protection	0.25 acre feet per acre per year
Farm Labor Dwelling	0.06 to 0.10 acre-feet per person per year
Irrigated Pasture	4.0 acre-feet per acre per year
Orchards	4.0 acre-feet per acre per year
Livestock (sheep or cows)	0.01 acre-feet per acre per year
Winery:	
Process Water	2.15 acre-feet per 100,000 gal. of wine
Domestic and Landscaping	0.50 acre-feet per 100,000 gal. of wine
Industrial:	
Food Processing	31.0 acre-feet per employee per year
Printing/Publishing	0.60 acre-feet per employee per year
Commercial:	
Office Space	0.01 acre-feet per employee per year
Warehouse	0.05 acre-feet per employee per year

Parcel Location Factors:

The Fair share allotment of water is based on the location of your parcel. There are 3 different location classifications. Valley Floor, Hillside and Groundwater Deficient Areas. Valley Floor areas include all locations that are within the Napa Valley and the Carneros Region except for areas specified as groundwater deficient areas. Groundwater Deficient areas are areas that have been determined by the Department of Public Works as having a history of problems with groundwater. The only Groundwater Deficient Basin in Napa County is the MST basin. All other areas are classified as Hillside Areas. Public Works can assist you in determining your classification.

Parcel Location Factors

Valley Floor	1.0 acre feet per acre per year
Hillside Areas	0.5 acre feet per acre per year
MST Groundwater Deficient Area	0.3 acre feet per acre per year*

* Does not apply to the Ministerial Exemption as outlined in the Groundwater Conservation Ordinance

The threshold for the Valley Floor Area was determined in 1991 in the form of a Staff Report to the Board of Supervisors. The value of 1.0 AF/A/Year was established as the expected demand an average vineyard would have. It was noted that the Valley Floor threshold would have relatively little effect on neighboring wells.

The threshold for the Mountain Area was established due to the uncertainty of the geology, and the increasingly fractured aquifer in the mountainous and non Napa Valley areas.

The threshold for the Groundwater Deficient Areas was determined using data from the 1977 USGS report on the Hydrology of the Milliken Sarco Tulocay region. The value is calculated by dividing the "safe annual yield" (as determined by the USGS study of 1977) by the total acreage of the affected area (10,000 acres).

APPENDIX B: Values Used to Establish Thresholds

Average Annual Rainfall (Source: Napa County Road & Streets Standards):

American Canyon	1.5 feet per year
City of Napa	2.0 feet per year
Yountville	2.5 feet per year
Oakville	2.5 feet per year
Rutherford	2.67 feet per year
St. Helena	2.75 feet per year
Calistoga	3.0 feet per year
Western Hills	increase by 20%
Eastern Hills	increase by 10%

Threshold Factors of Acceptable Water Use:

Valley Floor	1.0 acre-foot per acre
Hillsides	0.5 acre-foot per acre
MST Groundwater Deficient Areas	0.3 acre-foot per acre*

* Does not apply to the Ministerial Exemption as outlined in the Groundwater Conservation Ordinance

APPENDIX C: Guidance for M-S-T Basin Permit Applications

Data collected from the monitoring of wells within the M-S-T Basin over the last forty years indicate that it may be in overdraft, leading to the conclusion that the existing water users within the basin are pumping more water from the ground than is being naturally replaced each winter season. The only way to end the overdraft trend is to cease all water extraction from the basin. However, as no other reasonable water resources exist in the M-S-T, the Department, to avoid a ban on all new construction, has assumed that each property owner should be able to develop their property to a "reasonable" level of water use while reducing the rate at which the groundwater levels are being lowered.

Within the near future, the U.S.G.S. will release a report on a recent study of the M-S-T Basin. From the U.S.G.S. report we will be able to determine to what extent the overdraft condition may exist and infer what problems may occur from the continued extraction of groundwater from the Basin. Results of the study will be used to plan for alternatives to address these problems. Until the report is available, and alternative measures can be implemented, the Department will use the following analysis to evaluate impacts from proposed projects in the M-S-T Basin:

Single Family Dwellings on Small Parcels In the M-S-T Basin: The average, single family dwelling will likely use between 0.5 and 0.75 acre-feet of groundwater per year. Using a threshold of 0.3 acre-ft/year/acre, the minimum parcel size able to support the above range is between 1.5 to 2.5 acres. Therefore, if an existing residence that uses 0.5 acre-feet per year of groundwater is located on a one-acre parcel, it already exceeds the acceptable level of water use for the property. Applications for the construction of a single family home in these instances can be approved ministerially if the owner agrees to the conditions outlined in the Groundwater Ordinance. If the conditions are not agreed upon, or if the project involves a secondary dwelling or other groundwater uses not consistent with a single family dwelling, then the project would be subject to the complete groundwater permit process including but not limited to the submittal of a Phase 1 analysis detailing all water use, existing and proposed, on the project parcel.

Agricultural Development In the M-S-T Basin: Agriculture in the M-S-T Basin is not exempt from the groundwater permit process. In these cases, such development will require an application for a groundwater permit including a phase one analysis detailing the existing and proposed water use(s) on the project parcel(s). It is likely that all agricultural development in the M-S-T will be required to meter all wells supplying water to the property with periodic reports to the Department.

Existing Vineyard, New Primary or Secondary Residence In the M-S-T Basin: On an application related to a new residence on a parcel with an existing vineyard or residence, the Phase 1 WAA shall include all water use on the property, both existing and proposed. Projects on parcels with an established vineyard will likely be required to meter all wells supplying water to the property with periodic reports to the Department.

Wineries and Other Use Permits In the M-S-T Basin: On an application for a use permit, the applicant is required to provide a phase one analysis. Should the application be approved, a specific condition of approval will be required to meter all wells supplying groundwater to the property with periodic reports to the Department. It is also possible that water conservation measures will be a condition of approval. All new use permits must meet the threshold water use for the project parcel.

APPENDIX D: Water Meters

If required, water meters shall measure all groundwater used on the parcel. Additional meters may also be required for monitoring the water use of individual facilities or operations, such as a winery, residence, or vineyard located on the same parcel. If a meter(s) is installed, the applicant shall read the meter(s) and provide the readings to the County Engineer at a frequency determined by the County Engineer. The applicant shall also convey to the County Engineer, or his designated representative, the right to access and verify the operation and reading of the meter(s) at any time.

If the meters indicate that the water consumption of a parcel in the M-S-T basin exceeds the fair share amount, the applicant will be required to submit a plan which will be approved by the Director of Public Works to reduce water usage. The applicant may be required to find additional sources of water to reduce their groundwater usage. Additional sources may include using water provided by the City of Napa, the installation of water tanks which are filled by water trucks, or other means which will ensure that the groundwater usage will not exceed the fair share amounts.

The readings from water meters may also be used to assist the County in determining trends in groundwater usage, adjusting baseline water use estimates, and estimating overall groundwater usage in the M-S-T basin.

Appendix E: Determining water use numbers with multiple parcels

The water availability analysis is based on the premise that each landowner has equal right to the groundwater resource below his or her property. There will be cases where one person or entity owns multiple parcels and requests that the total water allotment below all of his or her parcels be considered in the Phase I water availability analysis. Determining the total threshold based on multiple parcels is acceptable, however to protect future property owners, certain safeguards must be in place to ensure that the water allotment and transfer between parcels is clearly documented and recorded, especially in cases where the water from more than one parcel will ultimately serve a use on a single parcel.

When multiple parcels are involved, the parcels for which the total threshold is being based on must be clearly identified on a site plan with assessors parcel numbers noted. The transfer of water from these parcels to the parcel on which the requested use is located must be documented using the form provided by the department of public works. The form must be approved by the County and subsequently recorded by the applicant prior to commencement of any activity authorized by the groundwater permit or other county permit or approval. A condition requiring such will be placed on the use permit, groundwater permit or other permit for approval.

C

Autumn DeWoody
Programs Director
Inland Empire WATERKEEPER
3741 Merced Drive, Unit F2
Riverside, CA 92503

February 2, 2008

Dear Autumn,

As you requested, I have reviewed the document titled *Focused Geohydrologic Evaluation of the Maximum Perennial Yield of the North Shore and Grout Creek Hydrologic Subunit Tributary Subareas*, dated December 2, 2003, prepared by Geoscience Support Services, Inc., for the City of Big Bear Lake Department of Water and Power. The review comments are numbered sequentially as noted:

1. The report presents minimum background information about the purpose and context of the study performed. The report is a follow-up study to a 2001 yield estimate for the watershed. Section 3.2 (page 13) states: "*Previous perennial yield estimates (GEOSCIENCE, 2001) have been based on the assumption that production of water from the bedrock aquifer is not as economically feasible as production of water from the alluvial aquifer.*" Section 5.3.1 (page 28) states: "*For the purposes of this study, however, the bedrock aquifer in the Grout Creek and North Shore Subunits is considered a viable ground water production source and is included in the total perennial yield estimate for the respective subunits.*" Groundwater production from the fractured bedrock will be considerably more expensive because of the higher cost of well installation and likely lower well capacity compared to wells screened in alluvium. The viability of groundwater production from bedrock must be further questioned in the context of existing domestic well construction. If increased production results in water table decline, the yield of existing domestic wells will drop and wells may become dry. Lowering of the water table may also impact the ecosystem in the area; this issue was not addressed in the study and should be part of an ecological impact assessment.
2. The following is the key statement in the report (Executive Summary, Page 6, last paragraph): "*The ground water recharge analysis is based on long-term precipitation records. However, short-term periods (5 to 10 years) of relatively low precipitation have been observed throughout the period of record. These short-term periods of low precipitation are anticipated to have a significant impact on the ground water levels in the North Shore and Grout Creek Hydrologic Subunits because the storage capacity of the ground water reservoir is relatively small. For this reason, future ground water production, and development, in each tributary*

subunit should rely more on established ground water level thresholds than the perennial yield estimates." The groundwater levels will indeed be the decisive indicator of sustainable groundwater use in the tributary areas. Measured groundwater levels throughout the watershed represent the "hard data" that should be used for management decisions. The watershed yield calculations presented in this study are rough estimates that can be useful for comparative ranking of watersheds or their sub-areas, but they should not be depended on for quantitative determination of water availability.

3. The estimate of the potential water yield is based on a model that uses 20 parameters. Of these, only two were site-specific and 18 were taken from the literature (i.e., nation-wide studies by the U.S. Environmental Protection Agency). For these 18 parameters, the study used the means of the ranges of "*typical*" and "*possible*" parameter values. The choice of parameters should be location-appropriate (i.e., elimination of values typical for other climatic settings, etc.). It would be more appropriate to use, for the most sensitive parameters, the maximum and minimum values instead of the mean, and to generate a range of model results.
4. Water management decisions should account for increased runoff and reduced perennial watershed yield resulting from future development (as recognized on page 33).
5. The calculation of outflow (Section 3.2, page 12) was based on aquifer properties estimated from pumping tests and lithologic data. The transmissivity values given on page 27 and saturated thickness values (page 26) correspond to hydraulic conductivity between 0.5 and 2.5 feet per day, indicative of a relatively low permeability aquifer material. The aquifer test analysis was not available for review. Review of these data and conducting aquifer tests to obtain representative estimates of aquifer properties that would allow more accurate calculation of outflow is recommended.

The opinions expressed are my own. I have no financial interest in the subject matter and I have not received any compensation for the review.

Regards,

Tom Perina

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D

Review Comments on Maximum Perennial Yield of the North Shore and Grout Creek Hydrologic Subunit Tributary Subareas

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DATE: January 29, 2008

Preface

On December 2, 2003, Geoscience Support Services, Inc. submitted a report entitled " Maximum Perennial Yield of the North Shore and Grout Creek Hydrologic Subunit Tributary Subareas". This report presents the use of an EPA Hydrological Simulation Progran Fortran (HSPF) watershed model with updated geohydrologic database to evaluate the maximum perennial yield of both the North Shore and Grout Creek Subunits that extend across most of the northern portion of the Big Bear Lake Watershed in the San Bernardino Mountains of western San Bernardino County, California. My review on this report is based on my previous experiences on various hydrology related studies.

Background

Generally, this report has addressed the objective, methodology, and various water budget components for the study of the maximum perennial yield; however, verification of the data adopted for the study area, details of numerical calculations, and calibration of watershed model are not well presented. Accordingly, results derived from this study are subject to large uncertainty and unreliable. Nine (9) comments from the review of this report are listed below.

Comments

1. The EPA HSPF watershed model is adopted in this report for numerical calculation; however, there is no discussion on model calibration. This is a serious problem in the application of any numerical model.
2. The 3rd paragraph in page 2 mentions the boundaries of surface water drainage divides also represent groundwater flow divides. Are there physical evidences or data to support this indecipherable statement?
3. The first paragraph in page 3 mentions that the input parameters are either estimated or assumed because measured field data are not available. Chapter 3.3.2.4 in page 18 further mentions that 18 of the 20 required model input parameters are estimated from EPA published data. I do not see any discussion on the confidence of using these estimated data in the report. In addition, how well these estimated data represent the local-scale spatial variability?

4. This is related to comment 3. This report also mentions that Geoscience did a similar study in 2001. There are some degrees of differences in estimated annual groundwater recharge from both reports, mainly, due to different set of data used. Since many data are assumed in the current report and there is no summary of the 2001 Geoscience report, which report is more representative to the study area?
5. The last paragraph in page 6 mentions future groundwater production and development in each tributary subunit should rely more on established groundwater thresholds due to small storage capacity of the groundwater reservoir. Since there is not reference cited to support this statement, are there hydrogeological data to support this statement?
6. Chapter 3.2 in page 12 describes the estimation of groundwater underflow for an estimate of groundwater recharge. Is this calculation performed by a commercial program? An appendix to detail the underflow calculation in the Grout Creek subunit will help to clarify any question that may arise.
7. I would suggest add a brief discussion on the calculation of annual groundwater recharge using the HSPF model and a summary table of all annual budget terms for the calculation of yields.
8. Chapter 3.3.2.2, the 2nd paragraph in page 17 discusses the estimation of daily precipitation and adjustment factor. How many precipitation stations and data records are available in study area? In addition, the 3rd paragraph in the same page demonstrates the calculation of daily precipitation in Grout Creek Tributary Subarea A. Does that imply a constant daily precipitation applies to the whole Subarea A? In addition, a map showing all weather stations and a table listing precipitation periods of all weather stations are strongly recommended.
9. Chapter 4.3 in page 23 mentions few pumping tests in production wells at various places. I would suggest add a summary table of these pumping tests and hydraulic properties derived from these tests. By the way, a description of the spatial distribution of these hydraulic properties in the study area is also needed.

E

Climate Change Primer

CCRC Home > Climate Change Primer

The Natural Climate System

Natural Climate Cycles

In addition to the familiar daily, seasonal, and yearly fluctuations in weather, there are longer term natural variations in the Earth's clim
defined as the "average weather," or more specifically, as "the statistical description in terms of the mean and variability of relevant qua
time ranging from months to thousands or millions of years" (IPCC 2007). Past variation in the Earth's climate has been cyclical, as opp
following linear trends (fig. 1). It is important to understand this natural cyclical variability in climate when considering and evaluating h
change.

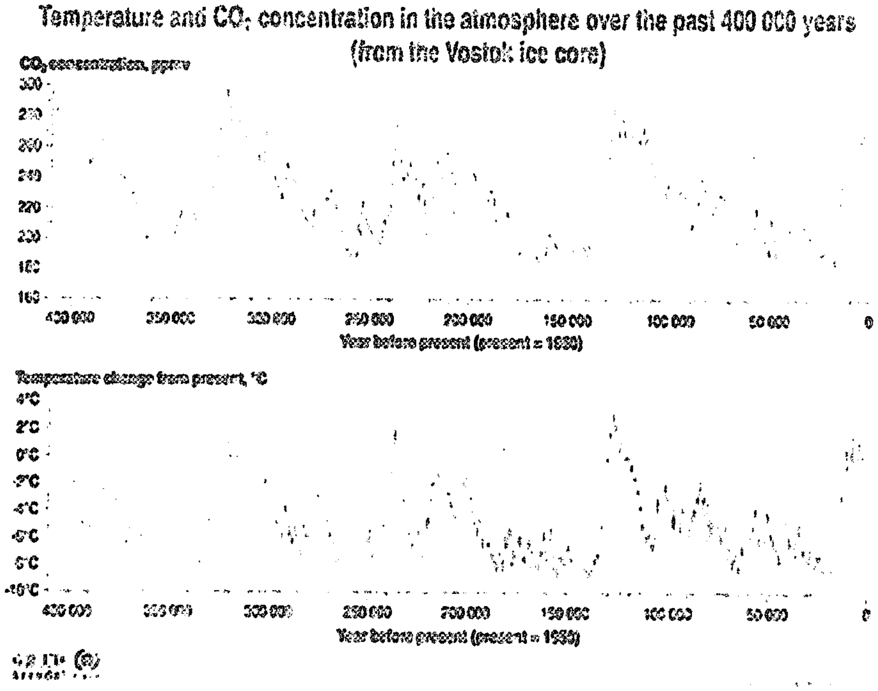

Figure 1—Variation in temperature and CO2 over the past 400,000 years. Source: Petit et al. 1999.

Cycles in the Earth's climate are nested and on multiple time scales, from year to year (interannual) to decades, centuries, and millenni
caused by independent physical mechanisms. Thus, for example, there are major glacial (cold) and interglacial (warm) periods on multi
caused by changes in the Earth's orbit around the Sun. Other cycles in the Sun's activity drive climate variations at the century scale. Cy
circulation of the oceans and atmosphere lead to decadal (30 to 40 year) patterns, such as the Pacific Decadal Oscillation (PDO), which a
North America. Cycles in the ocean-atmosphere system also lead to interannual variations in climate, such as the El-Niño/La Niña cycle (
Southern Oscillation). Climate at any one time is an expression of all of these nested mechanisms and cycles operating together.

Multimillennial climate cycles—

Long-term climatic change is driven primarily by changes in solar radiation and atmospheric composition of gases such as CO2. Variation
influence the amount of solar radiation received at the surface. Several parameters of the Earth's orbit change over time, including 1) ec
elliptical (versus circular) the Earth's orbit is around the sun; (2) tilt, or the angle of the Earth's tilt on its axis; and (3) precession, a "w
rotation, resulting in variation in the time of year when the Earth is closest to the sun. The eccentricity, tilt, and precession of the Earth's
of approximately 100,000, 41,000, and 23,000 years, respectively (Chapin et al. 2002) (fig. 2). Together, these variations in the Earth's
Milankovitch cycles of solar input. These cycles are strongly associated with the glacial and interglacial cycles over the last 800,000 years
from analysis of ocean sediments and ice cores.

The patterns of historical temperature changes associated with the glacial-interglacial cycles are also correlated with changes in atmosph
carbon dioxide and methane, two greenhouse gases. Concentrations of carbon dioxide were relatively higher during warm interglacial pe
decreased during cold glacial periods (fig. 1). The strong relationship between temperature and greenhouse gases suggests a mechanisti
estimated that about half of the glacial-interglacial temperature change is due to greenhouse gas feedbacks (Petit et al. 1999). The pote
through the 21st century may be sufficient (at the upper end of the uncertainty bounds) to produce a temperature increase on the magn
interglacial cycle (IPCC 2001).

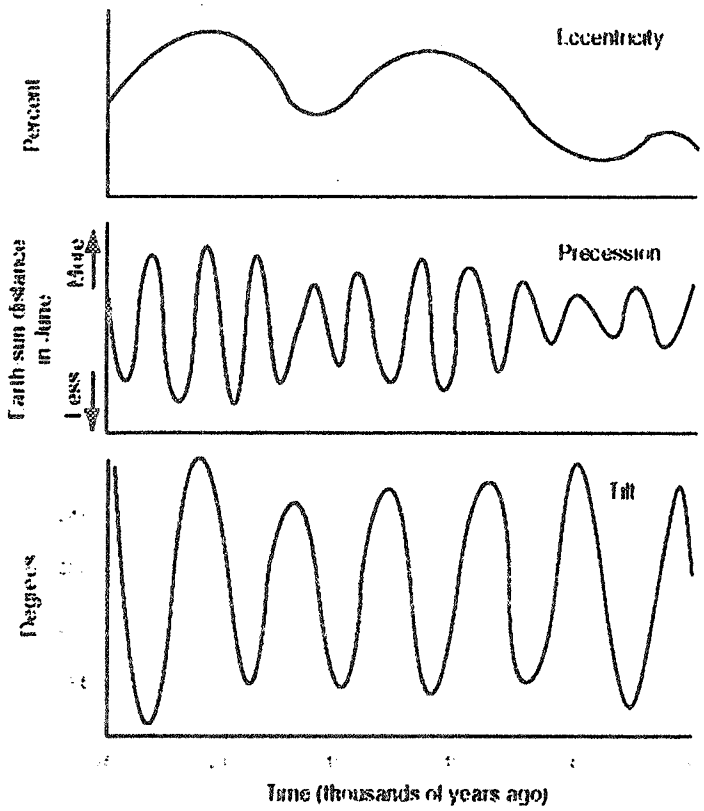

Figure 2—Variation in parameters of the Earth's orbit over the last 250,000 years. Source: Chapin et al. 2001.

Century- to millennial-scale climate cycles—

In addition to multimillennial glacial and interglacial cycles, there are shorter cold-warm cycles that last from 100 to 1,000 years. These "Bond cycles," have been documented for at least the last 130,000 years. The average length of a Bond cycle is 1300 to 1500 years, witl phase of the cycle lasting for about 700 years. The Little Ice Age, a global cold period from 1450 to 1920, is an event that is thought to ɛ a Bond cycle (Grove 1988, Overpeck et al. 1997). Like the Milankovitch cycles, the Bond cycles are currently thought to be driven by cha al. 2001).

Interannual- to decadal-scale climate cycles—

The well-known El-Niño Southern Oscillation (ENSO) is a large-scale cyclical change in the atmosphere-ocean system that occurs on inte scales. ENSO events are part of a large-scale air-sea interaction that couples atmospheric pressure changes (the southern oscillation) wit temperature (El-Niño) over the equatorial Pacific Ocean (Chapin et al. 2002). Every few years, hemispheric trade winds that usually blow water in a westerly direction across the Pacific Ocean stall, resulting in warm water accumulating in the eastern Pacific Ocean. This leads temperatures off the shore of North and South America. Each year there is some degree of El Niño, or its opposite effect, La Niña. On ave every 4 to 7 years. El Niño events bring different conditions to different parts of the world. For example, El Niño events result in dry weal Northwest but wet weather in the Southwest U.S. (fig. 3). The reverse occurs during La Niña events.

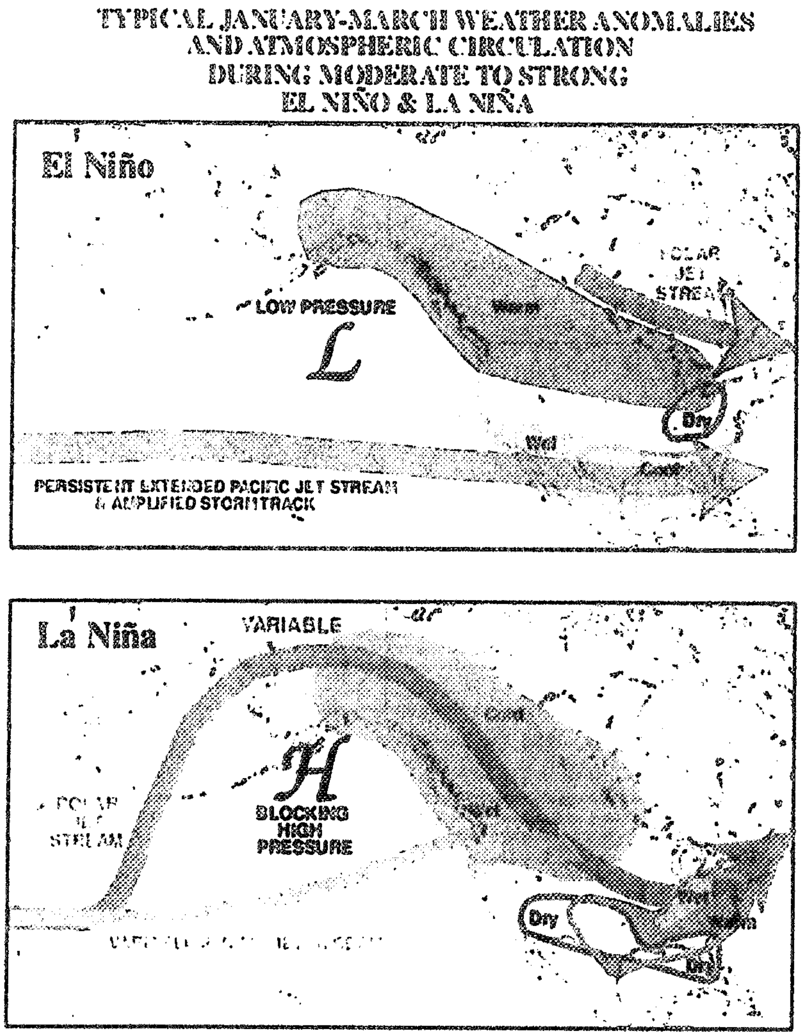

Figure 3—Typical winter conditions in North America during El Niño and La Niña years. Source: NOAA Climate Prediction Center (**http:// /products/analysis_monitoring/ensocycle/nawinter.shtml**)

Recently, climate cycles on multidecadal timescales have also been described. The Pacific Decadal Oscillation (PDO), which affects weste
to be regulated by decadal changes in ocean circulation patterns in the high-latitude Pacific Ocean. The effects of the PDO are similar to
1997), with warm (positive) phases and cool (negative) phases that last from 10 to 25 years (fig. 4). There are other decadal-scale ocea
affect other parts of the world, such as the North Atlantic Oscillation (NAO).

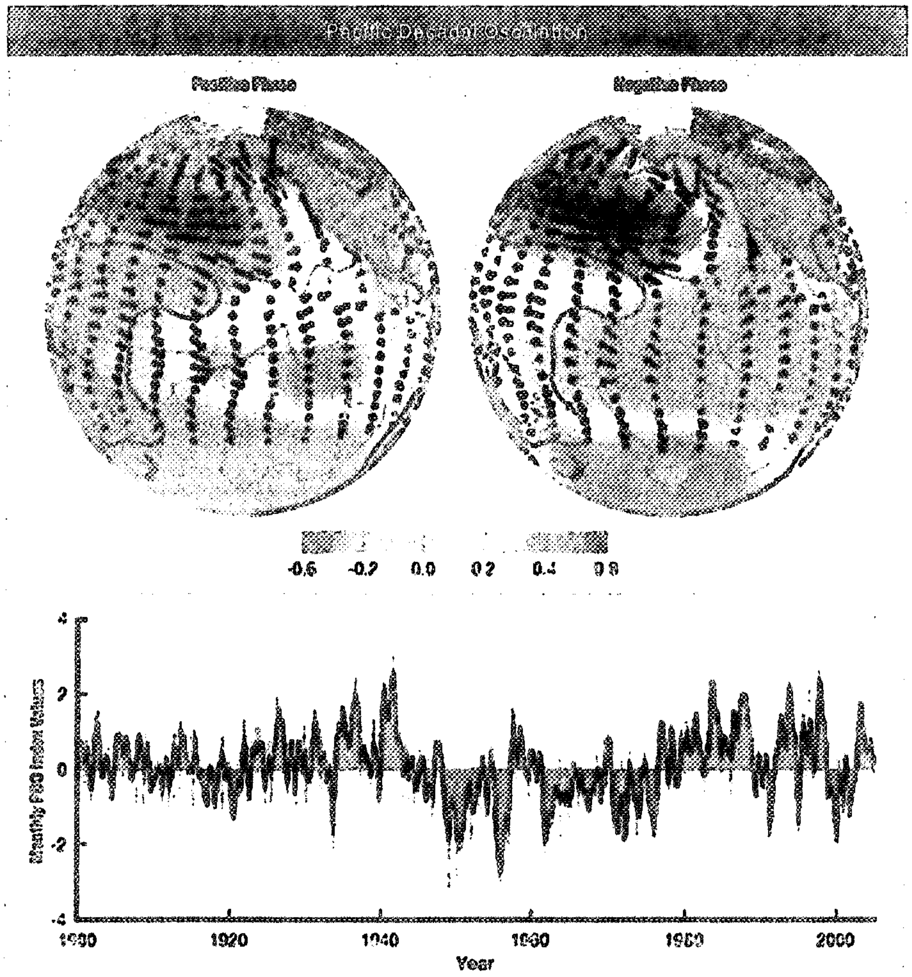

Figure 4—Top: Typical wintertime sea surface temperature (colors), sea level pressure (contours), and surface wind stress (arrows) anon positive and negative phases of the Pacific Decadal Oscillation (PDO). Temperature anomalies (colors) are in degrees Celsius. Bottom: Mc index, 1900-2004. Source: S. Hare and N. Mantua, Climate Impacts Group, Center for Science in the Earth System, Joint Institute for th Atmosphere and Ocean, University of Washington, Seattle.

Climate Mechanisms

Earth's energy budget—

The Earth's energy budget is the balance between incoming and outgoing radiation, which determines the amount of energy available to system (Chapin et al. 2002). About 30 percent of solar radiation that reaches Earth is reflected back into space by clouds, air molecules, Earth's surface. Another 20 percent of incoming solar radiation is absorbed by the atmosphere. The remaining solar radiation reaches the absorbed. The Earth's surface radiates this energy back to the atmosphere in the form of infrared radiation. Most (90 percent) of this infr in the atmosphere by greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The energy absorbed b reradiated in all directions. The energy that is directed back towards the Earth's surface contributes to the warming of the planet. This pł greenhouse effect (fig. 5).

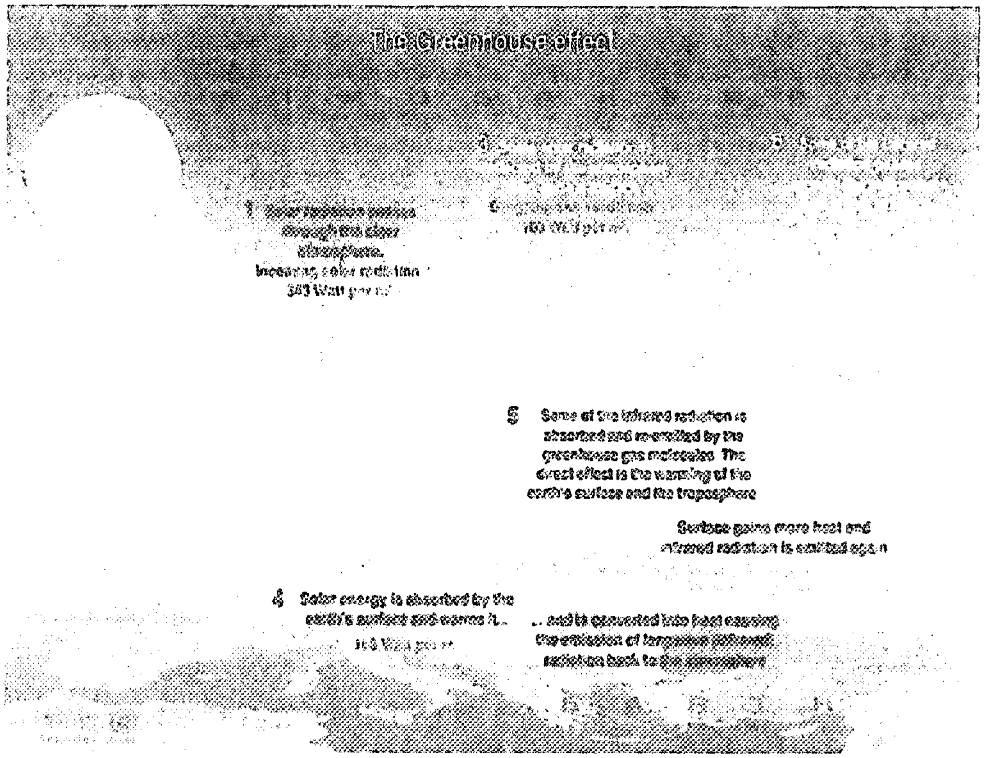

Figure 5—The greenhouse effect. Source: Climate Change 1995, The Science of Climate Change, contribution of working group 1 to the s of the Intergovernmental Panel on Climate Change.

Without the energy-absorbing greenhouse gases in the Earth's atmosphere, the mean temperature at Earth's surface would be about 33 and would probably not support life (Chapin et al. 2002). However, long-term records of the concentration of greenhouse gases in the at atmospheric measurements and ice core analysis) show steep increases in greenhouse gas concentrations since the beginning of the Ind years ago (fig. 6). These unprecedented increases in greenhouse gases are largely due to human activities, such as the burning of fossil activities. As concentrations of greenhouse gases increase, more radiation emitted by the Earth is trapped by the atmosphere, thus enha effect and leading to increased temperatures at the Earth's surface.

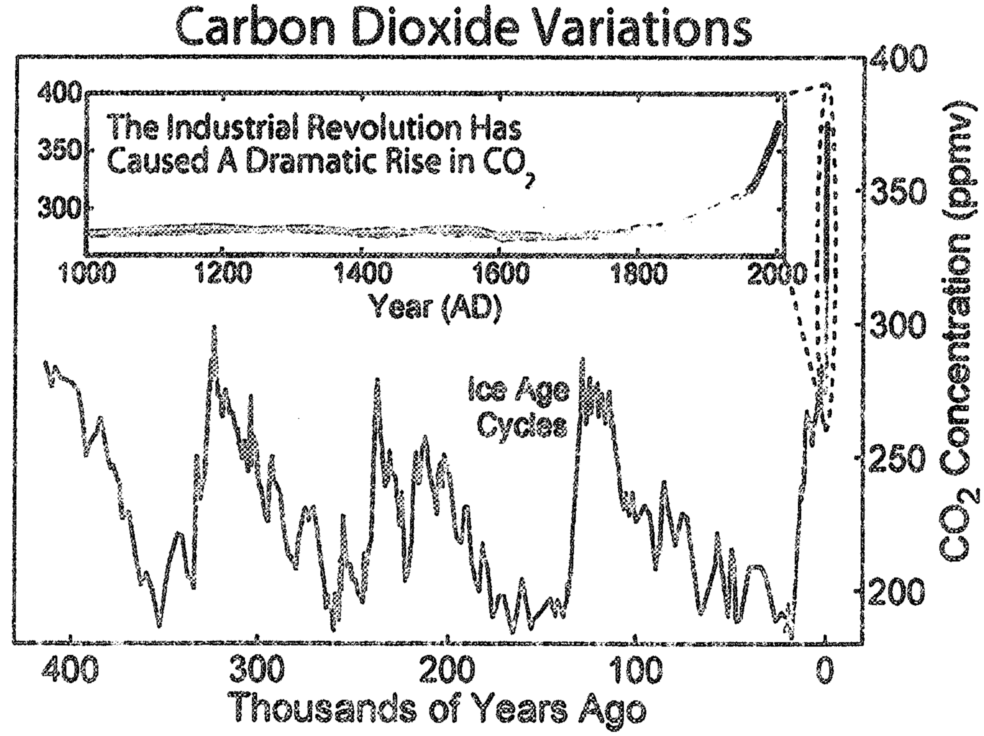

Figure 6—Variations in carbon dioxide concentrations in the Earth's atmosphere over the last 400,000 years. Source: Robert A. Rohde an (**http://www.globalwarmingart.com/wiki/Image:Carbon_Dioxide_400kyr_Rev_png**)

Human influence on climate—

Figure 7—Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoot decadal averaged values and circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive uncertainties (a and b) and from the time series (c). Source: IPCC 2007.

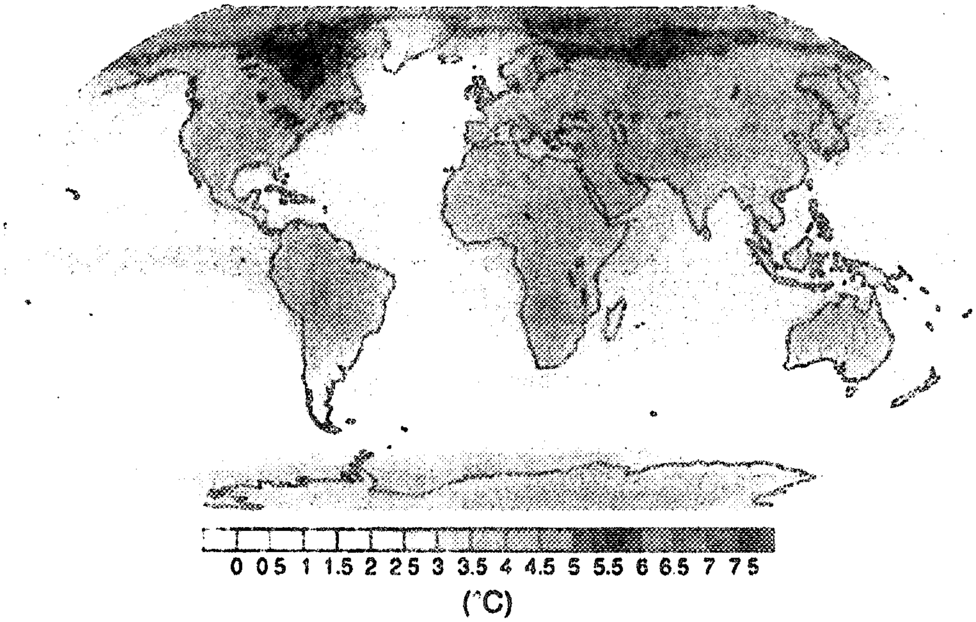

Figure 8—Projected surface temperature changes for the late 21st century (2090-2099). The map shows the multi-AOGCM average proje scenario. Temperatures are relative to the period 1980-1999. Source: IPCC Climate Change 2007.

Effects and Implications of Climate Change in the Western United States

Temperature and Precipitation

Over almost the entire Western United States, there have been increases in both cool season and warm season temperatures between 1 2005, Hamlet et al. 2007) (fig. 9). Although the rate of change varies with location and the time period examined, the warming has bee century over the 1916 to 2003 time period (Hamlet et al. 2007). The rate of increase from 1947 to 2003 is roughly double that of the lor 2003, and much of the observed warming has occurred from about 1975 to present.

Temperature increases in the west over the next century are expected to range from 2 to 3 °C at the low end of the uncertainty range to end of the uncertainty range (IPCC 2007, Miles et al. 2007). Beyond mid-century, future warming is dependent on greenhouse gas emis decades, which are dependent on human activities.

There have been increases in winter (November-March) precipitation since 1930 over much of the Western United States, although patte different regions (Mote et al. 2005) (fig. 9). Precipitation changes in the West over the next century are complex and more uncertain tha Expected changes in precipitation patterns differ by region. Summer rains in the Southwest may intensify and shift to the North. Winter the Southwest but increase in the northern half of the West (Salathé 2006). Interannual and interdecadal variability via El Niño-La Niña (Timmermann et al. 1999), producing extreme winter events in both the Southwest and the Northwest.

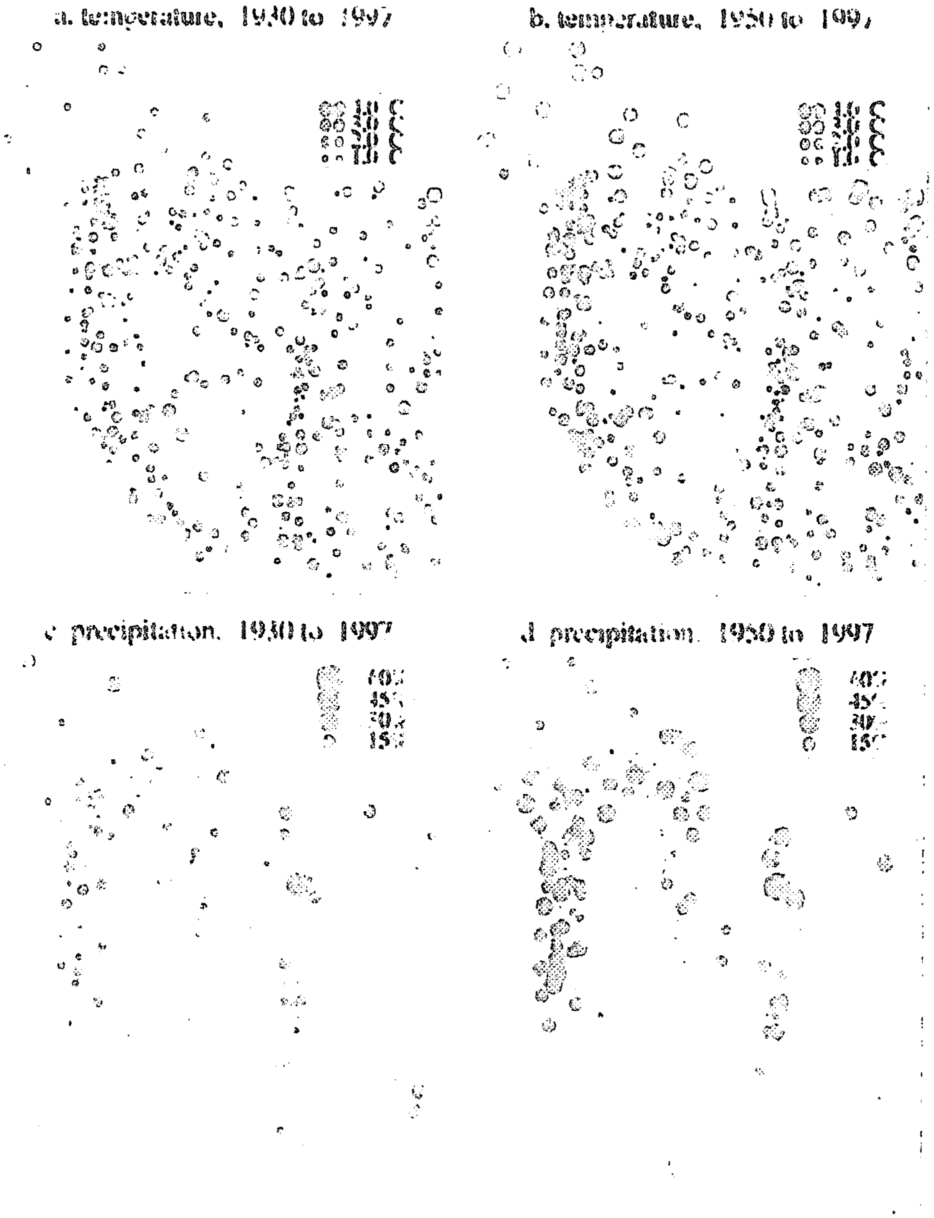

Figure 9—Linear trends in November-March (a), (b) temperature and (c), (d) total precipitation of the period indicated for the Western U For temperature, negative trends are indicated by blue circles, and positive trends are indicated by red circles; values are given in degre For precipitation, trends are given as a percentage of the starting value (1930 or 1950), and positive trends are shown as blue circles. Sc

The Hydrologic Cycle

In the Western United States, increased temperatures have led to more precipitation falling as rain rather than snow, earlier snowmelt a streamflow (Stewart et al. 2005, Hamlet et al. 2007), and reduced spring snowpack (Mote 2003, Mote et al. 2005, Barnett et al. 2008) (mountainous regions of the Western United States, snowmelt provides approximately 70 percent of annual streamflow (Mote et al. 2008 rain (as opposed to snow) and shifts to earlier spring snowmelt result in greater winter and spring streamflows and reduced summer stre dominated and transient (rain/snow) watersheds (fig. 11). This reduction in summer streamflow could have major implications for fisher and agriculture, particularly in drier regions. The current and expected future trends in hydrology suggest a coming crisis in water suppl States (Barnett et al. 2008).

Increased temperatures may also result in decreased soil moisture in arid regions of the Western United States (Miles et al. 2007). Chan expected to differ by region. In the Pacific Northwest, it is expected that mountainous regions will have 80 percent or less of historical a while arid regions will have 90 to 95 percent of historical soil moisture (Miles et al. 2007).

Warmer temperatures and higher rates of evapotranspiration with climate change in some areas, such as the Southwest United States, w drought frequency and severity. Overall, drought-affected areas are projected to increase in extent (IPCC 2007). Although increased tem to decreased runoff in some areas, increased frequency of heavy precipitation events will likely lead to increased flood risk in many regio snowmelt and runoff owing to increased temperatures could also lead to increased winter and spring flooding.

Figure 10—Changes in April 1 snow water equivalent in the Western United States. Linear trends in April 1 snow water equivalent (SWE) snow course locations in the Western United States and Canada for the period 1950-1997. Negative trends are shown by red circles and SWE is a common measurement for the amount of water contained in snowpack if it were melted instantaneously. Sources: Mote et al. 2

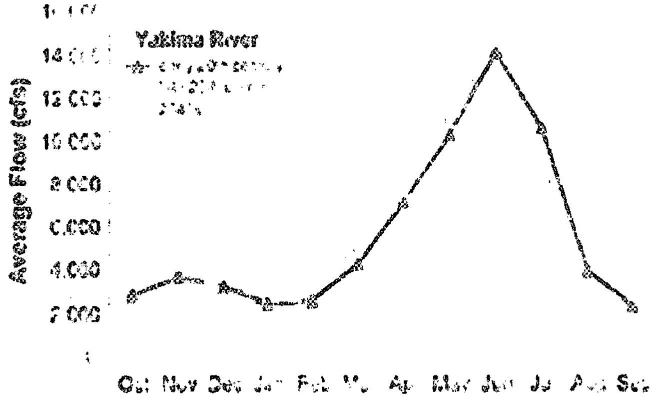

Figure 11—Winter precipitation sensitivity and projected changes in monthly streamflow for the Yakima River basin in Washington State. 2005.

Ecosystem Function and Process

Climate controls ecosystem structure and processes such as species distribution and abundance, regeneration, vegetation productivity ar disturbance, including insects, and fire. Increasing temperatures and changes in precipitation with climate change will impact both ecos) ecosystem processes. This section highlights some of potential effects of climate change on vegetation, wildlife and ecosystem disturban

Vegetation—

Abundance and distribution of plant species shift individualistically in response to climate fluctuations. Plant species respond according t constraints and water constraints. For example, regeneration of tree species increases with changes in limiting factors, such as snowpack season, and summer soil moisture levels. Thus, with increasing temperature, regeneration of species in high-snow environments will like regeneration of species in drier, lower elevation environments will likely decrease.

Tree growth and productivity will also change with increasing temperatures. Lower snowpacks, and longer growing seasons may result in productivity in subalpine forests. However, forest productivity may decrease in lower elevation forests owing to water limitations.

With increased temperatures in the Western United States, the highest and coldest alpine (tundra) zones will likely contract significantly temperate forest zones (primarily conifer dominated) will likely shift up in elevation helping to squeeze the high-elevation zones into sm sensitive vegetation of the subtropical zone, including oaks and other woody and ephemeral species, will also likely expand up in elevatic expansion of southern species could result in a contraction of the Great Basin shrublands.

Water constraints will have complex effects on vegetation distribution in the Western United States. Although precipitation may increase evapotranspiration with increased temperatures may lead to increased water stress. However, higher concentrations of carbon dioxide in reduce water stress. Changes in frequency and severity of fire may also influence vegetation distribution. Model simulations of western v

future climate change show a shifting of the water-limited boundaries, such as between closed forest and open tree-savanna, further do
northern half of the West (north of the Oregon-California border) (Bachelet et al. 2001) (fig. 12). Other water-limited vegetation in these
pine and juniper woodlands, is expected to expand (Bachelet et al. 2001) (fig. 12). In the Southwest, winter precipitation may decrease,
precipitation might increase. With the benefit of increased water use efficiency from elevated CO_2 concentrations, lower ecotones might
At the lower elevations, the reduction in winter precipitation may limit woody vegetation. Increased summer precipitation would benefit
grasslands.

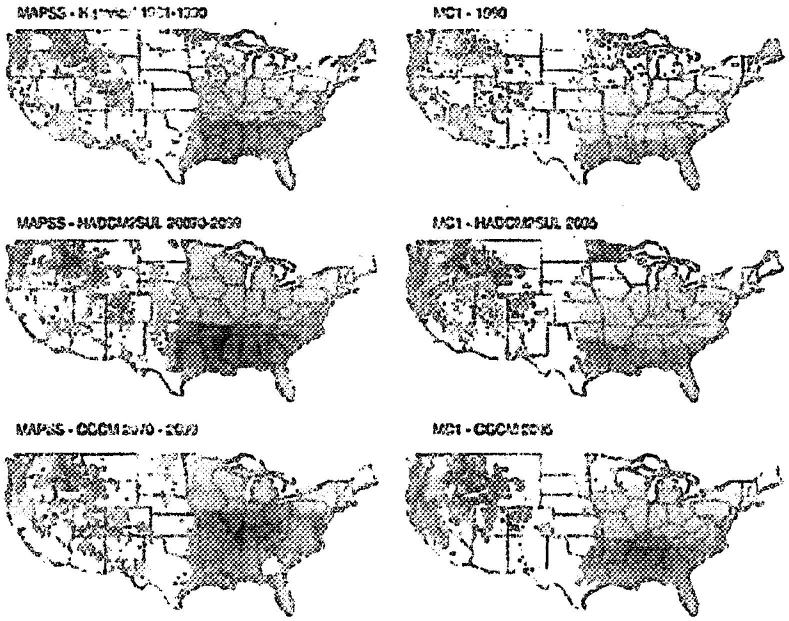

Figure 12—Potential vegetation distribution simulated by the Mapped Atmosphere-Plant-Soil System (MAPSS) model and a dynamic mo
conditions (historical for MAPSS and 1990 for MC1) and for future conditions (2070-99 for MAPSS and 2095 for MC1) under two future s
CGCM1. Source: Bachelet et al. 2001.

Wildlife—

Viability of a species is dependent on the availability of suitable habitat. Animal species respond to climate variability in the short term t
geographic range (migration) when suitable habitat is not available in the former range. Mortality and population extirpation in parts of
often occur. Over time, extirpation and colonization events cumulatively result in shifts of the species' distribution range (Davis and Sha
Delcourt 1991).

Species distributions have already changed in response to climate change in the Western United States. For example, the northern boun
skipper butterfly (*Atalopedes campestris*) has moved from California to Washington State (420 miles) over a 35-year period (Crozier 200
Studies show that winter cold extremes determine the northern range limit (Crozier 2003, 2004).

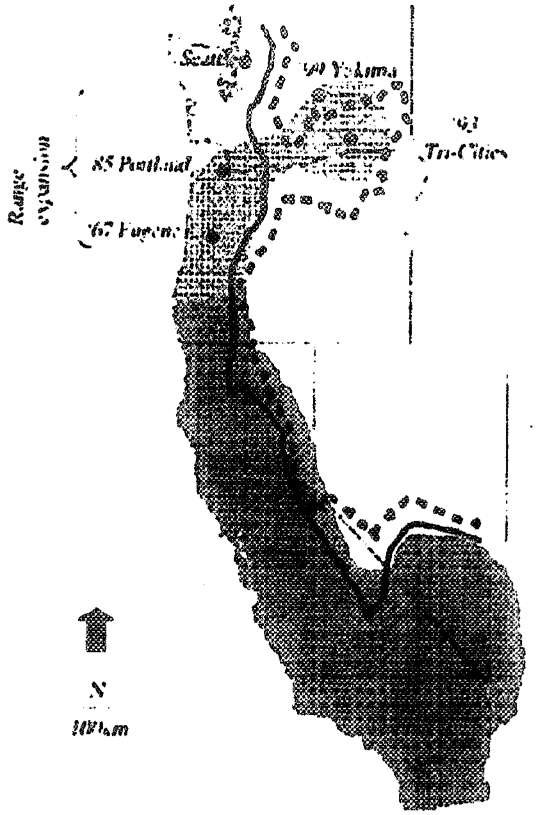

Figure 13—Overwintering range of the sachem skipper butterfly (shaded) in Washington, Oregon, California, and Nevada from Opler (19 the western range expansion (lighter shading). Colonization by the sachem skipper butterfly in four cities in Oregon and Washington sho range expansion. Contour lines represent the January average minimum -4 ºC isotherm 1950-1999 (solid) and 1990-1998 (dotted) (NC 2003.

Changes in phenology, or timing of life history events, of both plant and animal species with climate change could influence wildlife. For 1.4 ºC rise in local temperatures at the Rocky Mountain Biological Laboratory in Colorado between 1975 and 1999, yellow-bellied marmo emerged from hibernation 23 days earlier. However, the flowering plant phenology did not shift in that time period. Thus, the change in the relative phenology of marmots and their food plants (Inouye et al. 2000). Shifts in prey behavior could similarly influence predator s

Population extinctions have occurred in the Western United States in response to increasing temperatures over the last few decades. In t being recorded in the 1930's, 7 out of 25 recensused populations of the pika (Ochotona princeps) were extinct (Beever et al. 2003). The disturbance in the high-elevation pika habitat. It was observed that extinct populations were those that had been at significantly lower e populations still present (Parmesan and Galbraith 2004). Experiments show that adult pikas are sensitive to high temperatures (Smith 1

Land-use changes, urban development, and introduction of invasive species often impede the ability of species to respond to climate cha instance, many land-use changes impose barriers to species' migration to favorable new environments; small population sizes and isolat result of landuse impede gene flow, and landscape fragmentation reduces corridors for movement (Joyce et al., in press).

Fire—

Widespread fire years and fire extent are associated with warmer and drier spring and summer conditions in the Western United States (Westerling et al. 2006, Heyerdahl et al. 2008, Taylor et al. 2008). Warmer spring and summer conditions lead to relatively early snowme and fuel moisture, and thus longer fire seasons (Westerling et al. 2006). Increased temperatures and drought occurrence in some locatic warming will likely lead to increased fire frequency and extent. Intensity of fires may also increase in some areas if higher temperatures characteristics to increase fire intensity.

Insects—

Insect outbreaks may become more frequent and widespread because warmer temperatures may accelerate insect life cycles. Winter mi temperatures are forecasted to increase faster than maximum temperatures through the 21st century. This release of winter constraints increasing survival rates for insect larva and accelerating adult reproduction rates, thus leading to increased insect outbreaks. For examp beetle (Dendroctonus ponderosae) has invaded higher elevations and latitudes and significantly expanded its range in British Columbia c constraints (fig. 14). Thus, many forests that have historically never experienced these infestations are now being severely threatened a threatened in the future.

In addition to effects of increased temperatures on insect life cycles, increased temperatures will also increase drought stress of some fo making some forests more susceptible to insect infestation. In addition, insect infestations can interact with fire. Recently burned forests susceptible to insect damage. In turn, dead and weakened trees that have been infested with insects increase fire risk.

Figure 14—Mountain pine beetle damage in British Columbia. Photo taken by Lorraine Maclauchlan, Ministry of Forests, Southern Interior (**http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/bbphotos.htm**)

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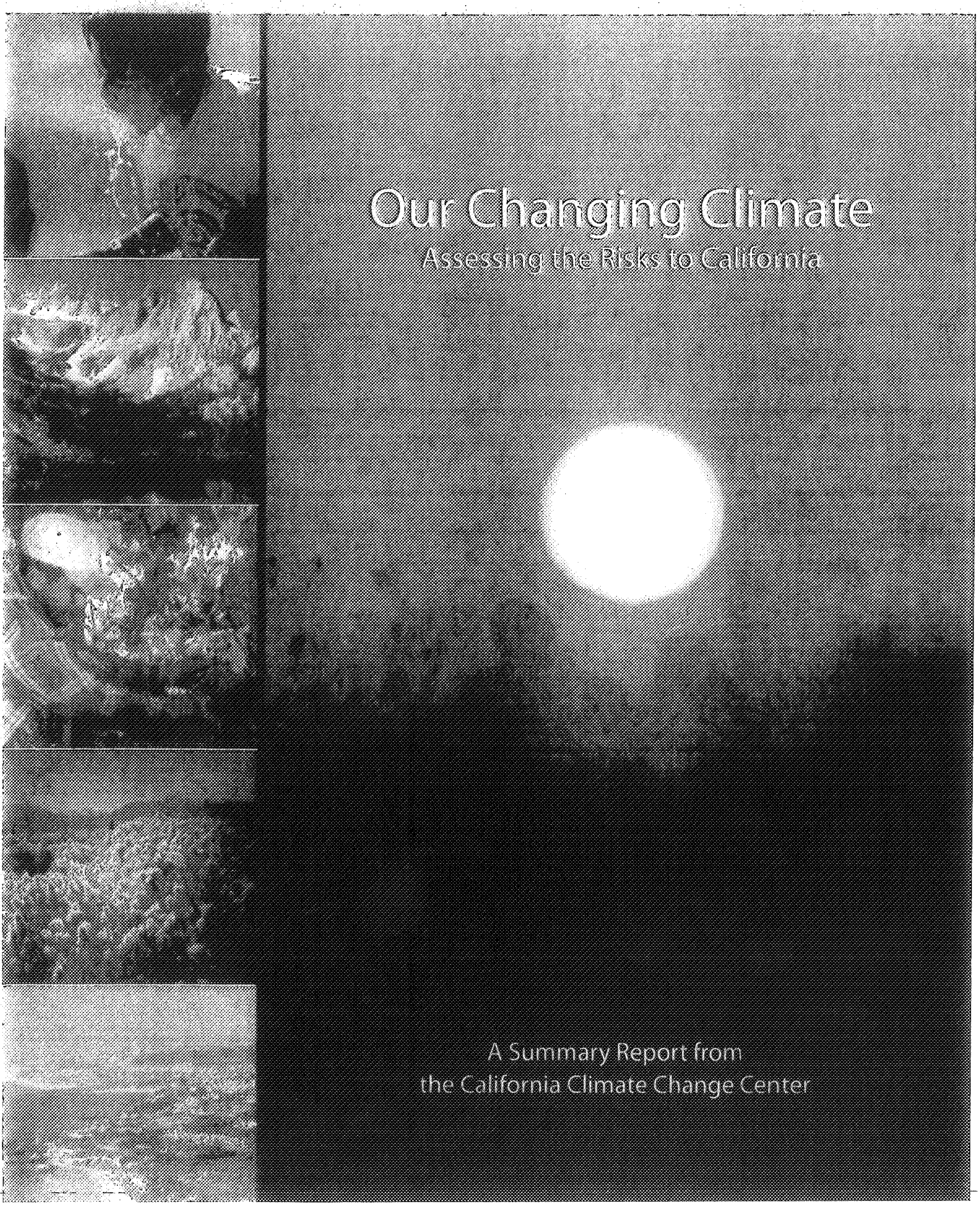


Our Changing Climate

Assessing the Risks to California

A Summary Report from
the California Climate Change Center

Because most global warming emissions remain in the atmosphere for decades or centuries, the choices we make today greatly influence the climate our children and grandchildren inherit. The quality of life they experience will depend on if and how rapidly California and the rest of the world reduce these emissions.

In California and throughout western North America, signs of a changing climate are evident. During the last 50 years, winter and spring temperatures have been warmer, spring snow levels in lower- and mid-elevation mountains have dropped, snowpack has been melting one to four weeks earlier, and flowers are blooming one to two weeks earlier.

These regional changes are consistent with global trends. During the past 100 years, average temperatures have risen more than one degree Fahrenheit worldwide. Research indicates that much of this warming is due to human activities, primarily burning fossil fuels and clearing forests, that release carbon dioxide (CO_2) and other gases into the atmosphere, trapping in heat that would otherwise escape into space. Once in the atmosphere, these heat-trapping emissions remain there for many years—CO_2, for example, lasts about 100 years. As a result, atmospheric concentration of CO_2 has increased more than 30 percent above pre-industrial levels. If left unchecked, by the end of the century CO_2 concentrations could reach levels three times higher than pre-industrial times, leading to dangerous global warming that threatens our public health, economy, and environment.

The latest projections, based on state-of-the art climate models, indicate that if global heat-trapping emissions proceed at a medium to high rate, temperatures in California are expected to rise 4.7 to 10.5°F by the end of the century. In contrast, a lower emissions rate would keep the projected warming to 3 to 5.6°F. These temperature increases would have widespread consequences including substantial loss of snowpack, increased risk of large wildfires, and reductions in the quality and quantity of certain agricultural products. The state's vital resources and natural landscapes are already under increasing stress due to California's rapidly growing population, which is expected to grow from 35 million today to 55 million by 2050.

This document summarizes the recent findings of the California Climate Change Center's "Climate Scenarios" project, which analyzed a range of impacts that projected rising temperatures would likely have on California. The growing severity of the consequences as temperature rises underscores the importance of reducing emissions to minimize further warming. At the same time, it is essential to identify those consequences that may be unavoidable, for which we will need to develop coping and adaptation strategies.

In 2003, the California Energy Commission's Public Interest Energy Research (PIER) program established the California Climate Change Center to conduct climate change research relevant to the state. This Center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts as well as the efforts designed to reduce emissions.

Executive Order #S-3-05, signed by Governor Arnold Schwarzenegger on June 1, 2005, called for the California Environmental Protection Agency (CalEPA) to prepare biennial science reports on the potential impact of continued global warming on certain sectors of the California economy. CalEPA entrusted PIER and its California Climate Change Center to lead this effort. The "Climate Scenarios" analysis summarized here is the first of these biennial science reports, and is the product of a multi-institution collaboration among the California Air Resources Board, California Department of Water Resources, California Energy Commission, CalEPA, and the Union of Concerned Scientists.

Cover photos: (sunset) Photos.com; (from top to bottom) AP Photo/Paul Sakuma, iStockphoto, IndexStock, Picturequest, iStockphoto. Above: Bureau of Land Management. Background: IndexStock

California's Future Climate

alifornia's climate is expected to become considerably warmer during this century. How much warmer depends on the rate at which human activities, such as the burning of fossil fuels, continue. The projections presented here illustrate the climatic changes that are likely from three different heat-trapping emissions scenarios (see figure below).

Projected Warming

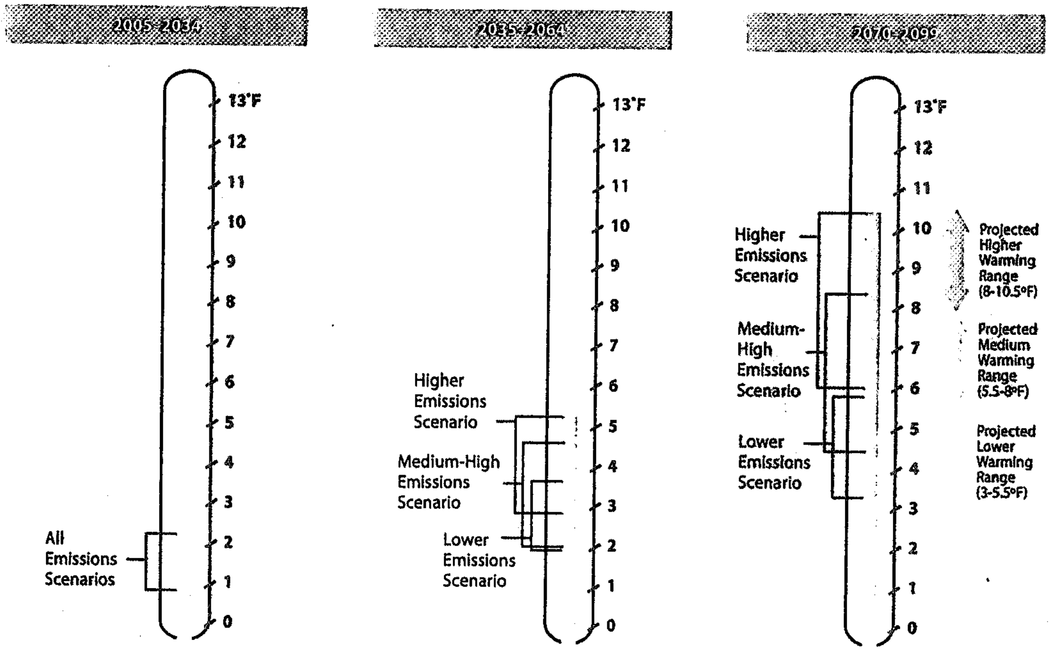
Temperatures are expected to rise substantially in all three emissions scenarios. During the next few decades, the three scenarios project average temperatures to rise between 1 and 2.3°F; however, the projected temperature increases begin to diverge at mid-century so that, by the end of the century, the temperature increases projected in the higher emissions scenario are approximately twice as high as those projected in the lower emissions scenario. Some climate models indicate that warming would be greater in summer than in winter, which would have widespread effects on ecosystem health, agricultural production, water use and availability, and energy demand.

Toward the end of the century, depending on future heat-trapping emissions, statewide average temperatures are expected to rise between 3 and 10.5°F. The analysis presented here examines the future climate under three projected warming ranges:[1]

- **Lower warming range:** projected temperature rises between 3 and 5.5°F
- **Medium warming range:** projected temperature rises between 5.5 and 8°F
- **Higher warming range:** projected temperature rises between 8 and 10.5°F

Precipitation

On average, the projections show little change in total annual precipitation in California. Furthermore, among several models, precipitation projections do not show a consistent trend during the next century. The Mediterranean seasonal precipitation pattern is expected to continue, with most precipitation falling during winter from North Pacific storms. One of the three climate models projects slightly wetter winters, and another projects slightly drier winters with a 10 to 20 percent decrease in total annual precipitation. 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.



California is expected to experience dramatically warmer temperatures during the 21st century. This figure shows projected increases in statewide annual temperatures for three 30-year periods. Ranges for each emissions scenario represent results from state-of-the-art climate models.

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[1] These warming ranges are for illustrative purposes only. These ranges were defined in the original Climate Scenarios analysis to capture the full range of projected temperature rise. The exact values for the warming ranges as presented in the original summary report are: lower warming range (3 to 5.4°F); medium warming range (5.5 to 7.9°F); and higher warming range (8 to 10.4°F).

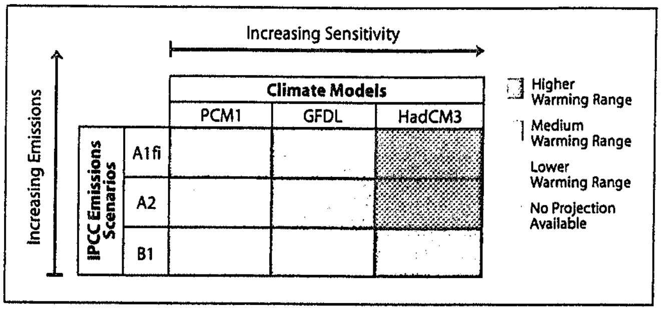
Projecting Future Climate

How much temperatures rise depends in large part on how much and how quickly heat-trapping emissions accumulate in the atmosphere and how the climate responds to these emissions. The projections presented in this report are based on three different heat-trapping emissions scenarios and three climate models.

Emissions Scenarios

The three global emissions scenarios used in this analysis were selected from a set of scenarios developed by the Intergovernmental Panel on Climate Change's (IPCC) *Special Report on Emissions Scenarios*, based on different assumptions about population growth and economic development (measured in gross domestic product).

- The **lower emissions scenario (B1)** characterizes a world with high economic growth and a global population that peaks by mid-century and then declines. There is a rapid shift toward less fossil fuel-intensive industries and introduction of clean and resource-efficient technologies. Heat-trapping emissions peak about mid-century and then decline; CO_2 concentration approximately doubles, relative to pre-industrial levels, by 2100.
- The **medium-high emissions scenario (A2)** projects continuous population growth and uneven economic and technological growth. The income gap between now-industrialized and developing parts of the world does not narrow. Heat-trapping emissions increase through the 21st century; atmospheric CO_2 concentration approximately triples, relative to pre-industrial levels, by 2100.
- The **higher emissions scenario (A1fi)** represents a world with high fossil fuel-intensive economic growth, and a global population that peaks mid-century then declines. New and more efficient technologies are introduced toward the end of the century. Heat-trapping emissions increase through the 21st century; CO_2 concentration more than triples, relative to pre-industrial levels, by 2100.



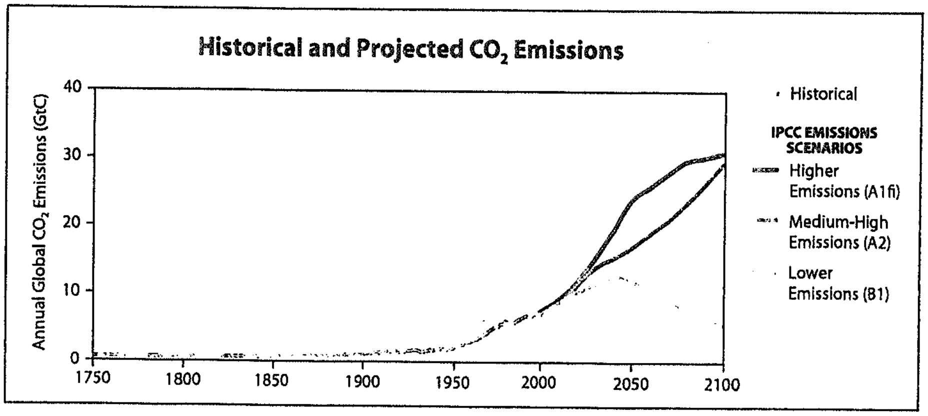
This matrix shows the temperature increases that result from the three climate models, assuming emission inputs indicated in the IPCC emissions scenarios. The resulting temperatures are grouped into three warming ranges defined in the "Climate Scenarios" analysis.

Climate Sensitivity

The three models used in this analysis represent different climate sensitivities, or the extent to which temperatures will rise as a result of increasing atmospheric concentrations of heat-trapping gases. Climate sensitivity depends on Earth's response to certain physical processes, including a number of "feedbacks" that might amplify or lessen warming. For example, as heat-trapping emissions cause temperatures to rise, the atmosphere can hold more water vapor, which traps heat and raises temperatures further—a positive feedback. Clouds created by this water vapor could absorb and re-radiate outgoing infrared radiation from Earth's surface (another positive feedback) or reflect more incoming shortwave radiation from the sun before it reaches Earth's surface (a negative feedback).

Because many of these processes and their feedbacks are not yet fully understood, they are represented somewhat differently in different global climate models. The three global climate models used in this analysis are:

- **National Center for Atmospheric Research Parallel Climate Model (PCM1):** low climate sensitivity
- **Geophysical Fluids Dynamic Laboratory (GFDL) CM2.1:** medium climate sensitivity
- **United Kingdom Met Office Hadley Centre Climate Model, version 3 (HadCM3):** medium-high climate sensitivity



As this figure shows, CO_2 emissions from human activities (such as the burning of fossil fuels) were negligible until around the so-called industrial age starting in the 1850s.

Public Health

Continued global warming will affect Californians' health by exacerbating air pollution, intensifying heat waves, and expanding the range of infectious diseases. The primary concern is not so much the change in *average* climate but the projected increase in *extreme* conditions, which pose the most serious health risks.

Poor Air Quality Made Worse

Californians currently experience the worst air quality in the nation, with more than 90 percent of the population living in areas that violate the state's air quality standard for either ground-level ozone or airborne particulate matter. These pollutants can cause or aggravate a wide range of health problems including asthma and other acute respiratory and cardiovascular diseases, and can decrease lung function in children. Combined, ozone and particulate matter contribute to 8,800 deaths and $71 billion in healthcare costs every year. If global background ozone levels increase as projected in some scenarios, it may become impossible to meet local air quality standards.

Higher temperatures are expected to increase the frequency, duration, and intensity of conditions conducive to air pollution formation. For example, if temperatures rise to the medium warming range, there will be 75 to 85 percent more days with weather conducive to ozone formation in Los Angeles and the San Joaquin Valley, relative to today's conditions. This is more than twice the increase expected if temperature rises are kept in the lower warming range.

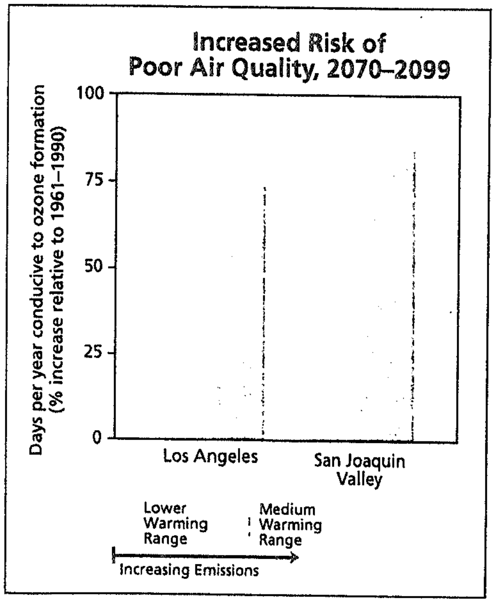
Air quality could be further compromised by increases in wildfires, which emit fine particulate matter that can travel long distances depending on wind conditions. The most recent analysis suggests that if heat-trapping gas emissions are not significantly reduced, large wildfires could become up to 55 percent more frequent toward the end of the century.

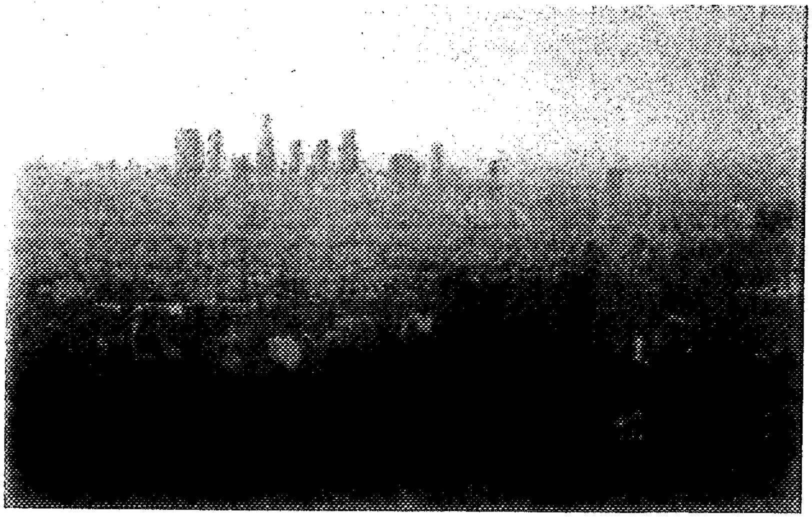
More Severe Heat

By 2100, if temperatures rise to the higher warming range, there could be up to 100 more days per year with temperatures above 90°F in Los Angeles and above 95°F in Sacramento. This is a striking increase over historical patterns (see chart on p. 6), and almost twice the increase projected if temperatures remain within or below the lower warming range.

As temperatures rise, Californians will face greater risk of death from dehydration, heat stroke/exhaustion, heart attack, stroke, and respiratory distress caused by extreme heat. By mid century, extreme heat events in urban centers such as Sacramento, Los Angeles, and San Bernardino could cause two to three times more heat-related deaths than occur today. The members of the population most vulnerable to the effects of extreme heat include people who are already ill; children; the elderly;

As temperatures rise, Californians will face greater risk of death from dehydration, heat stroke, heart attack, and other heat-related illnesses.

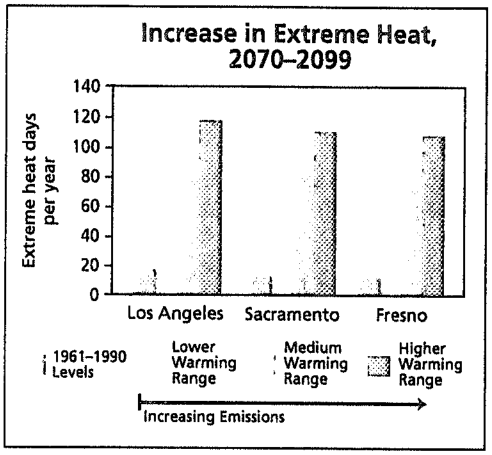




Cars and power plants emit pollutants that contribute to global warming and poor air quality. As temperatures increase, it will be increasingly difficult to meet air quality standards throughout the state.

and the poor, who may lack access to air conditioning and medical assistance.

More research is needed to better understand the potential effects of higher temperatures and the role that adaptation can play in minimizing these effects. For example, expanding air conditioner use can help people cope with extreme heat; however, it also increases energy consumption, which, using today's fossil fuel-heavy energy sources, would contribute to further global warming and air pollution.


Increase in Extreme Heat, 2070–2099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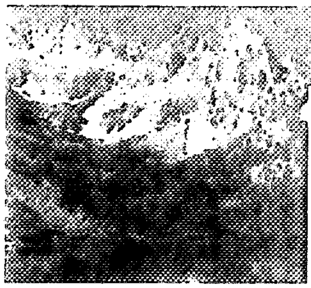


Water Resources


If global warming emissions continue unabated, Sierra Nevada snowpack could decline 70 to 90 percent, with cascading effects on winter recreation, water supply, and natural ecosystems.

Most of California's precipitation falls in the northern part of the state during the winter while the greatest demand for water comes from users in the southern part of the state during the spring and summer. A vast network of man-made reservoirs and aqueducts capture and transport water throughout the state from northern California rivers and the Colorado River. The current distribution system relies on Sierra Nevada mountain snowpack to supply water during the dry spring and summer months. Rising temperatures, potentially compounded by decreases in precipitation, could severely reduce spring snowpack, increasing the risk of summer water shortages.

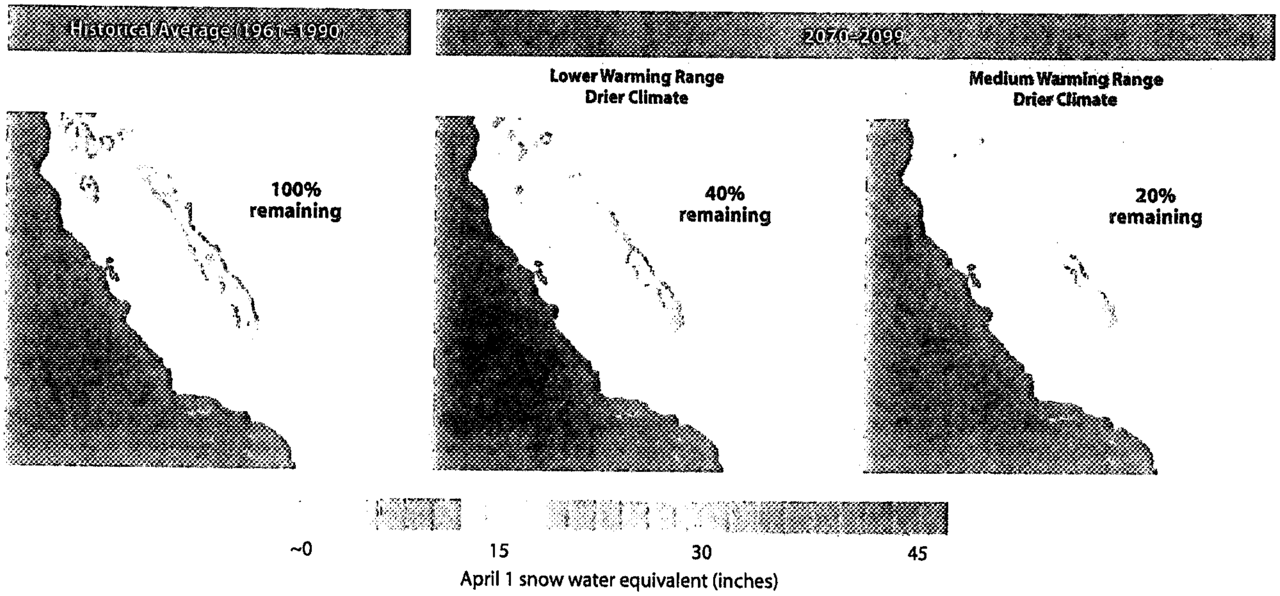
Decreasing Sierra Nevada Snowpack

If heat-trapping emissions continue unabated, more precipitation will fall as rain instead of snow, and the snow that does fall will melt earlier, reducing the Sierra Nevada spring snowpack by as much as 70 to 90 percent. How much snowpack will be lost depends in part on future precipitation patterns, the projections for which remain uncertain. However, even under wetter climate projections, the loss of snowpack would pose challenges to water managers, hamper hydropower generation, and nearly eliminate skiing and other snow-related recreational activities. If global warming emissions are significantly curbed and temperature increases are kept in the lower warming range, snowpack losses are expected to be only half as large as those expected if temperatures were to rise to the higher warming range.

Challenges in Securing Adequate Water Supplies

Continued global warming will increase pressure on California's water resources, which are already over-stretched by the demands of a growing

Decreasing California Snowpack



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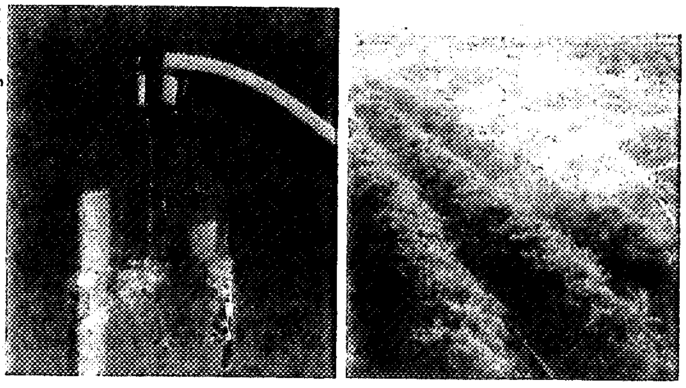
economy and population. Decreasing snowmelt and spring stream flows coupled with increasing demand for water resulting from both a growing population and hotter climate could lead to increasing water shortages. By the end of the century, if temperatures rise to the medium warming range and precipitation decreases, late spring stream flow could decline by up to 30 percent. Agricultural areas could be hard hit, with California farmers losing as much as 25 percent of the water supply they need.

Water supplies are also at risk from rising sea levels. An influx of saltwater would degrade California's estuaries, wetlands, and groundwater aquifers. In particular, saltwater intrusion would threaten the quality and reliability of the major state fresh water supply that is pumped from the southern edge of the Sacramento/San Joaquin River Delta.

Coping with the most severe consequences of global warming would require major changes in water management and allocation systems. As more winter precipitation falls as rain instead of snow, water managers will have to balance the need to fill constructed reservoirs for water supply and the need to maintain reservoir space for winter flood control. Some additional storage could be developed; however, the economic and environmental costs would be high.



Rising temperatures, potentially exacerbated by decreasing precipitation, could increase the risk of water shortages in urban and agricultural sectors.

Left: Photodisc. Right: Corbis

Potential Reduction in Hydropower

Higher temperatures will likely increase electricity demand due to higher air conditioning use. Even if the population remained unchanged, toward the end of the century annual electricity demand could increase by as much as 20 percent if temperatures rise into the higher warming range. (Implementing aggressive efficiency measures could lower this estimate.)

At the same time, diminished snow melt flowing through dams will decrease the potential for hydropower production, which now comprises about 15 percent of California's in-state electricity production. If temperatures rise to the medium warming range and precipitation decreases by 10 to 20 percent, hydropower production may be reduced by up to 30 percent. However, future precipitation projections are quite uncertain so it is possible that precipitation may increase and expand hydropower generation.

Loss of Winter Recreation

Continued global warming will have widespread implications for winter tourism. Declines in Sierra Nevada snowpack would lead to later starting and earlier closing dates of the ski season. Toward the end of the century, if temperatures rise to the lower warming range, the ski season at lower and middle elevations could shorten by as much as a month. If temperatures reach the higher warming range and precipitation declines, there might be many years with insufficient snow for skiing and snowboarding.

Stephen McMillan

Agriculture

California is home to a $30 billion agriculture industry that employs more than one million workers. It is the largest and most diverse agriculture industry in the nation, producing more than 300 commodities including half the country's fruits and vegetables. Increased heat-trapping emissions are expected to cause widespread changes to this industry, reducing the quantity and quality of agricultural products statewide.

Although higher carbon dioxide levels can stimulate plant production and increase plant water-use efficiency, California farmers will face greater water demand for crops and a less reliable water supply as temperatures rise. Crop growth and development will change, as will the intensity and frequency of pest and disease outbreaks. Rising temperatures will likely aggravate ozone pollution, which makes plants more susceptible to disease and pests and interferes with plant growth.

To prepare for these changes, and to adapt to changes already under way, major efforts will be needed to move crops to new locations, respond to climate variability, and develop new cultivars and agricultural technologies. With adequate research and advance preparation, some of the consequences could be reduced.

Increasing Temperature

Plant growth tends to be slow at low temperatures, increasing with rising temperatures up to a threshold. However, faster growth can result in less-than-optimal development for many crops, so rising temperatures are likely to worsen the quantity and quality of yield for a number of California's agricultural products. Crops that are likely to be hard hit include:

Wine Grapes

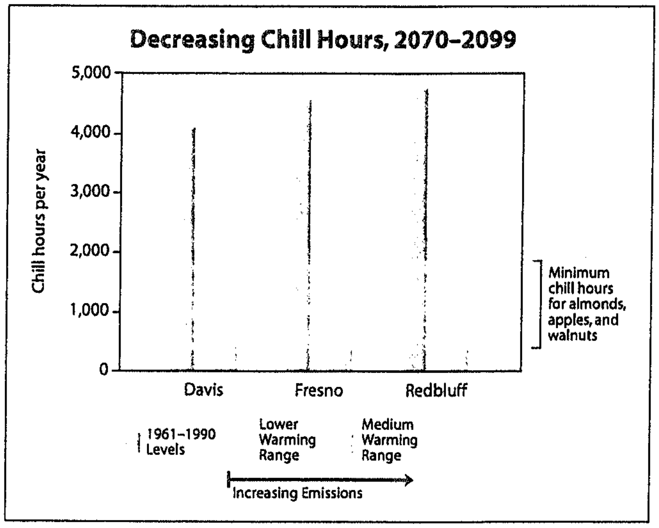
California is the nation's largest wine producer and the fourth-largest wine producer worldwide. High-quality wines produced throughout the Napa and Sonoma Valleys and along the northern and central coasts generate $3.2 billion in revenue each year. High temperatures during the growing season can cause premature ripening and reduce grape quality. Temperature increases are expected to have only modest effect on grape quality in most regions over the next few decades. However, toward the end of the century, wine grapes could ripen as much as one to two months earlier, which will affect grape quality in all but the coolest coastal locations (Mendocino and Monterey Counties).

IndexOpen

Fruits and Nuts

Many fruit and nut trees are particularly sensitive to temperature changes because of heat-accumulation limits and chill-hour requirements. Heat accumulation, which refers to the total hours during which temperatures reach between 45 and 95°F, is critical for fruit development. Rising temperatures could increase fruit development rates and decrease fruit size.

Decreasing Chill Hours, 2070–2099



For example, peaches and nectarines developed and were harvested early in 2004 because of warm spring temperatures. The fruits were smaller than normal, which placed them in a lower quality category.

A minimum number of chill hours (hours during which temperatures drop below 45°F) is required for proper bud setting; too few hours can cause late or irregular bloom, decreasing fruit quality and subsequent marketable yield. California is currently classified as a moderate to high chill-hour region, but chill hours are diminishing in many areas of the state. If temperatures rise to the medium warming range, the number of chill hours in the entire Central Valley is expected to approach a critical threshold for some fruit trees.

Milk

California's $3 billion dairy industry supplies nearly one-fifth of the nation's milk products. High temperatures can stress dairy cows, reducing milk production. Production begins to decline at temperatures as low as 77°F and can drop substantially as temperatures climb above 90°F. Toward the end of the century, if temperatures rise to the higher warming range, milk production is expected to decrease by up to 20 percent. This is more

Increasing temperatures will likely decrease the quantity and quality of some agricultural commodities, such as certain varieties of fruit trees, wine grapes, and dairy products.

than twice the reduction expected if temperatures stay within or below the lower warming range.

Expanding Ranges of Agricultural Weeds

Noxious and invasive weeds currently infest more than 20 million acres of California farmland, costing hundreds of millions of dollars annually in control measures and lost productivity. Continued climate change will likely shift the ranges of existing invasive plants and weeds and alter competition patterns with native plants. Range expansion is expected in many species while range contractions are less likely in rapidly evolving species with significant populations already established. Should range contractions occur, it is likely that new or different weed species will fill the emerging gaps.

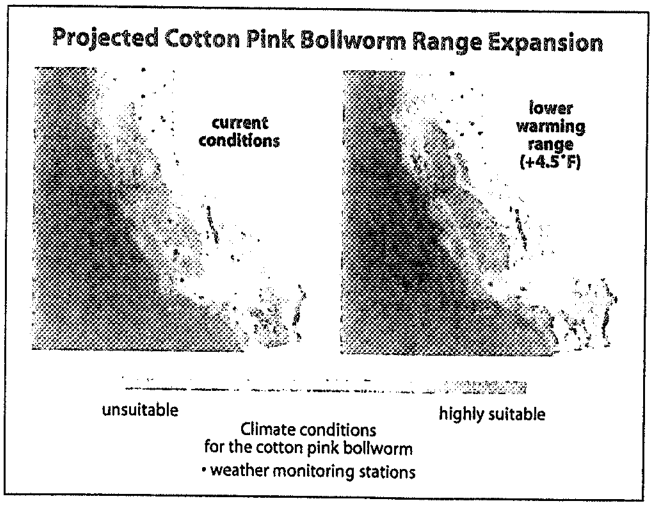
Increasing Threats from Pests and Pathogens

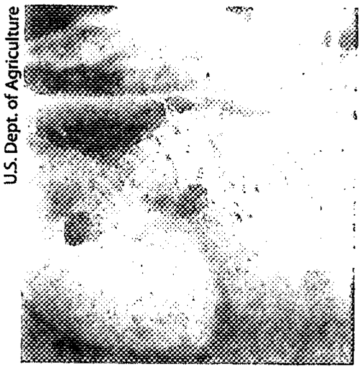
California farmers contend with a wide range of crop-damaging pests and pathogens. Continued climate change is likely to alter the abundance and types of many pests, lengthen pests' breeding season, and increase pathogen growth rates. For example, the pink bollworm, a common pest of cotton crops, is currently a problem only in southern desert valleys because it cannot survive winter frosts elsewhere in the state. However, if winter temperatures rise 3 to 4.5°F, the pink bollworm's range would likely expand northward, which could lead to substantial economic and ecological consequences for the state.

Temperature is not the only climatic influence on pests. For example, some insects are unable to cope in extreme drought, while others cannot survive in extremely wet conditions. Furthermore, while warming speeds up the lifecycles of many insects, suggesting that pest problems could increase, some insects may grow more slowly as elevated CO_2 levels decrease the protein content of the leaves on which they feed.

Multiple and Interacting Stresses

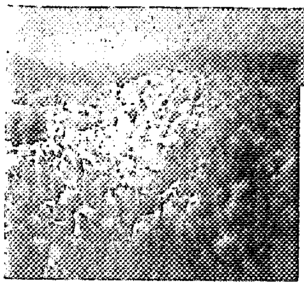
Although the effects on specific crops of individual factors (e.g., temperatures, pests, water supply) are increasingly well understood, trying to quantify interactions among these and other environmental factors is challenging. For example, the quality of certain grape varieties is expected to decline as temperatures rise. But the wine-grape industry also faces increasing risks from pests such as the glassy-winged sharpshooter, which transmits Pierce's disease. In 2002, this bacterial disease caused damage worth $13 million in Riverside County alone. The optimum temperature for growth of Pierce's disease is 82°F, so this disease is currently uncommon in the cooler northern and coastal regions of the state. However, with continued warming, these regions may face increased risk of the glassy-winged sharpshooter feeding on leaves and transmitting Pierce's disease.





U.S. Dept. of Agriculture

As temperatures rise, the climate is expected to become more favorable for the pink bollworm (above), a major cotton pest in southern California. The pink bollworm's geographic range is limited by winter frosts that kill over-wintering dormant larvae. As temperatures rise, winter frosts will decrease, greatly increasing the winter survival and subsequent spread of the pest throughout the state.



Forests and Landscapes

California is one of the most climatically and biologically diverse areas in the world, supporting thousands of plant and animal species. The state's burgeoning population and consequent impact on local landscapes is threatening much of this biological wealth. Global warming is expected to intensify this threat by increasing the risk of wildfire and altering the distribution and character of natural vegetation.

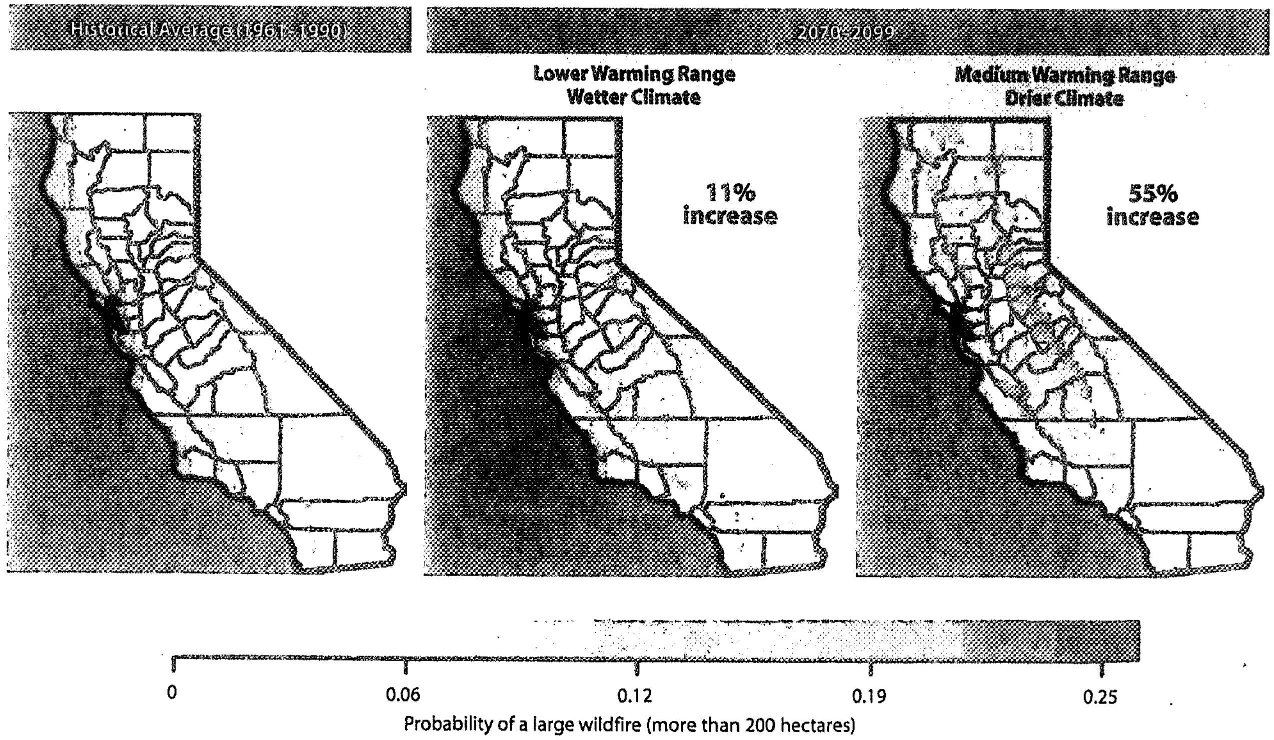
Global warming threatens alpine and subalpine ecosystems, which have no place to move as temperatures rise.

Increasing Wildfires

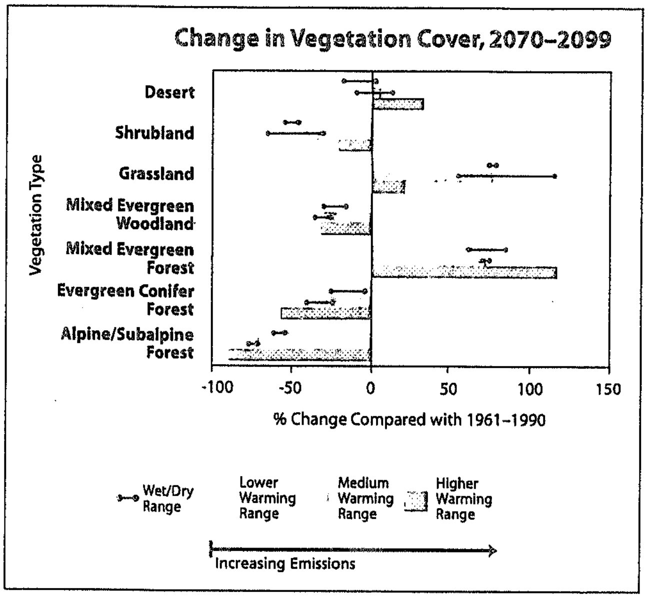
Fire is an important ecosystem disturbance. It promotes vegetation and wildlife diversity, releases nutrients into the soil, and eliminates heavy accumulation of underbrush that can fuel catastrophic fires. However, if temperatures rise into the medium warming range, the risk of large wildfires in California could increase by as much as 55 percent, which is almost twice the increase expected if temperatures stay in the lower warming range.

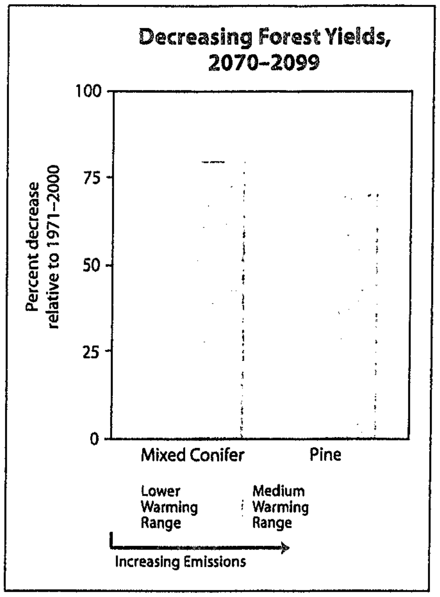
Because wildfire risk is determined by a combination of factors including precipitation, winds, temperature, and landscape and vegetation conditions, future risks will not be uniform throughout the state. In many regions, wildfire activity will depend critically on future precipitation patterns. For

Increasing Wildfire Frequency



Vegetation cover over the 21st century will depend on both temperature and precipitation. The lower and medium warming range bars reflect vegetation cover under a wetter climate (blue) and a drier climate (brown) projected in the different climate models. For the higher warming range, only a drier climate was considered.





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example, if precipitation increases as temperatures rise, wildfires in the grasslands and chaparral ecosystems of southern California are expected to increase by approximately 30 percent toward the end of the century because more winter rain will stimulate the growth of more plant "fuel" available to burn in the fall. In contrast, a hotter, drier climate could promote up to 90 percent more northern California fires by the end of the century by drying out and increasing the flammability of forest vegetation.

Shifting Vegetation

Land use and other changes resulting from economic development are altering natural habitats throughout the state. Continued global warming will intensify these pressures on the state's natural ecosystems and biological diversity. For example, in northern California, warmer temperatures are expected to shift dominant forest species from Douglas and White Fir to madrone and oaks. In inland regions, increases in fire frequency are expected to promote expansion of grasslands into current shrub and woodland areas. Alpine and subalpine ecosystems are among the most threatened in the state; plants suited to these regions have limited opportunity to migrate "up slope" and are expected to decline by as much as 60 to 80 percent by the end of the century as a result of increasing temperatures.

Declining Forest Productivity

Forestlands cover 45 percent of the state; 35 percent of this is commercial forests such as pine plantations. Recent projections suggest that continued global warming could adversely affect the health and productivity of California's forests. If average statewide temperatures rise to the medium warming range, the productivity of mixed conifer forests is expected to diminish by as much as 18 percent by the end of the century. Yield reductions from pine plantations are expected to be even more severe, with up to a 30 percent decrease by the end of the century.

The risk of large wildfires in California could increase by as much as 55 percent.

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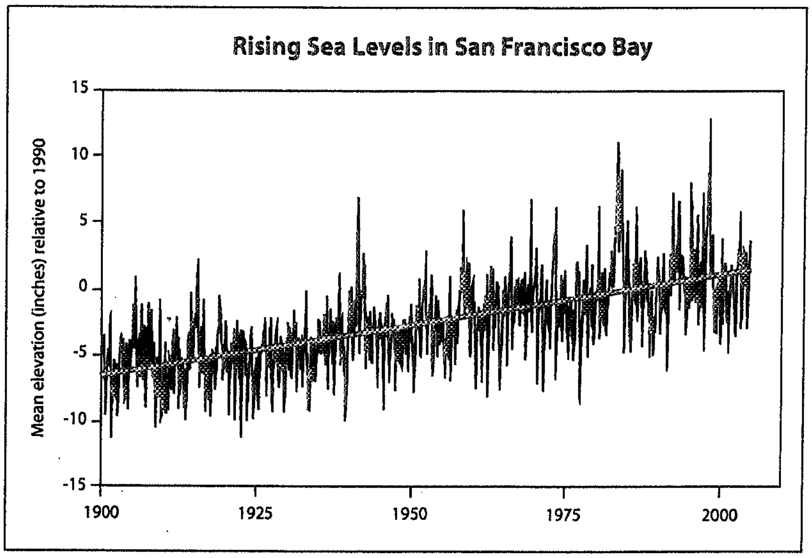
Rising Sea Levels

California's 1,100 miles of coastline are a major attraction for tourism, recreation, and other economic activity. The coast is also home to unique ecosystems that are among the world's most imperiled. As global warming continues, California's coastal regions will be increasingly threatened by rising sea levels, more intense coastal storms, and warmer water temperatures.

During the past century, sea levels along California's coast have risen about seven inches. If heat-trapping emissions continue unabated and temperatures rise into the higher warming range, sea level is expected to rise an additional 22 to 35 inches by the end of the century. Elevations of this magnitude would inundate coastal areas with salt water, accelerate coastal erosion, threaten vital levees and inland water systems, and disrupt wetlands and natural habitats.



Increasing Coastal Floods

The combination of increasingly severe winter storms, rising mean sea levels, and high tides is expected to cause more frequent and severe flooding, erosion, and damage to coastal structures. Many California coastal areas are at significant risk for flood damage. For example, the city of Santa Cruz is built on the 100-year floodplain and is only 20 feet above sea level. Although levees have been built to contain the 100-year flood, a 12-inch increase in sea levels (projected for the medium warming range of temperatures) would mean storm-surge-induced flood events at the 100-year level would likely occur once every 10 years.

Flooding can create significant damage and enormous financial losses. Despite extensive engineering efforts, major floods have repeatedly breached levees that protect freshwater supplies and islands in the San Francisco Bay Delta as well as fragile marine estuaries and wetlands throughout the

Robert A. Epplett/CA Governor's Office of Emergency Services

Rising sea levels and more intense storm surges could increase the risk for coastal flooding.

Sea levels could rise up to three feet by the end of the century, accelerating coastal erosion, threatening vital levees, and disrupting wetlands.

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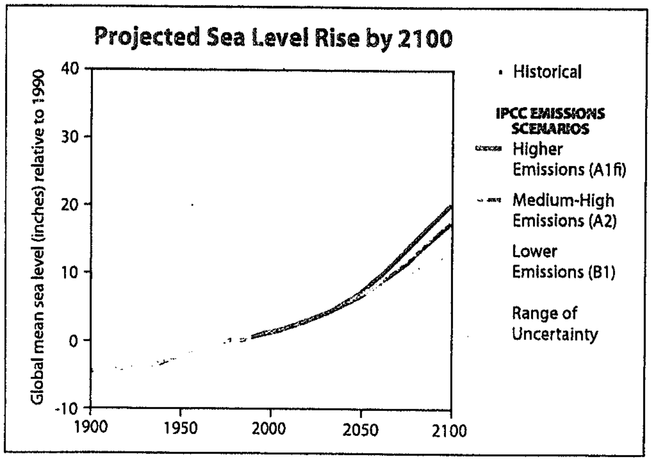
Many California beaches are threatened from rising sea levels and increased erosion, an expected consequence of continued global warming.

state. Continued sea level rise will further increase vulnerability to levee failures. Some of the most extreme flooding during the past few decades has occurred during El Niño winters, when warmer waters fuel more intense storms. During the winters of 1982–1983 and 1997–1998, for example, abnormally high seas and storm surges caused millions of dollars' worth of damage in the San Francisco Bay area. Highways were flooded as six-foot waves crashed over waterfront bulkheads, and valuable coastal real estate was destroyed.

Continued global warming will require major changes in flood management. In many regions such as the Central Valley, where urbanization and limited river channel capacity already exacerbate rising flood risks, flood damage and flood control costs could amount to several billion dollars.



Shrinking Beaches

Many of California's beaches may shrink in the future because of rising seas and increased erosion from winter storms. Currently, many beaches are protected from erosion through manmade sand replenishment (or "nourishment") programs, which bring in sand from outside sources to replace the diminishing supply of natural sand. In fact, many of the wide sandy beaches in southern California around Santa Monica, Venice, and Newport Beach were created and are maintained entirely by sand nourishment programs. As sea levels rise, increasing volumes of replacement sand will be needed to maintain current beach width and quality. California beach nourishment programs currently cost millions of dollars each year. As global warming continues, the costs of beach nourishment programs will rise, and in some regions beach replenishment may no longer be viable.

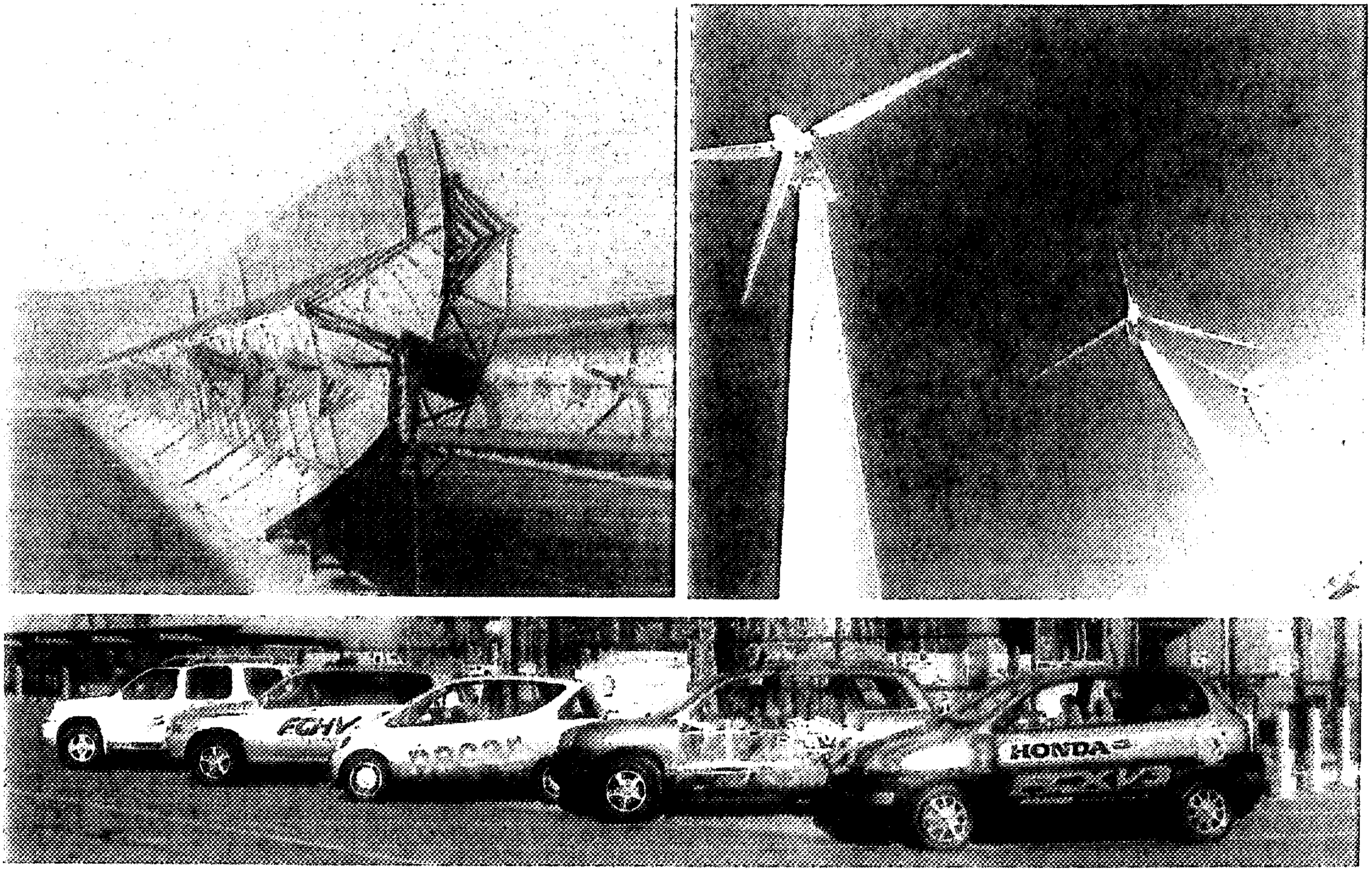
Multiple Causes of Coastal Flooding

Several factors play a role in sea level and coastal flooding, including tides, waves temperature, and storm activity. Sea levels fluctuate daily, monthly, and seasonally; the highest tides occur in winter and in summer, during new and full moons. Sea levels often rise even higher during El Niño winters, when the Eastern Pacific Ocean is warmer than usual and westerly wind patterns are strengthened.

Coastal flooding usually occurs during winter storms, which bring strong winds and high waves. Storm winds tend to raise water levels along the coast and produce high waves at the same time, compounding the risk of damaging waves—a doubling of wave height is equivalent to a four-fold increase in wave energy. When these factors coincide with high tides, the chances for coastal damage are greatly heightened.

As sea levels rise, flood stages in the Sacramento/San Joaquin Delta of the San Francisco Bay estuary may also rise, putting increasing pressure on Delta levees. This threat may be particularly significant because recent estimates indicate the additional force exerted upon the levees is equivalent to the square of the water level rise. Estimates using historical observations and climate model projections suggest that extreme high water levels in the Bay and Delta will increase markedly if sea level rises above its historical rate. These extremes are most likely to occur during storm events, leading to more severe damage from waves and floods.

Top left & right: Photos.com. Bottom: CA Fuel Cell Partnership



Cleaner energy and vehicle technologies can help California reduce global warming emissions, improve air quality, and protect public health.

Managing Global Warming

Continued global warming will have widespread and significant impacts on the Golden State. Solutions are available today to reduce emissions and minimize these impacts.

The projections presented in this analysis suggest that many of the most severe consequences that are expected from the medium and higher warming ranges could be avoided if heat-trapping emissions can be reduced to levels that will hold temperature increases at or below the lower warming range (i.e., an increase of no more than 5.5°F). However, even if emissions are substantially reduced, research indicates that some climatic changes are unavoidable. Although not the solution to global warming, plans to cope with these changes are essential.

California's actions can drive global progress to address global warming.

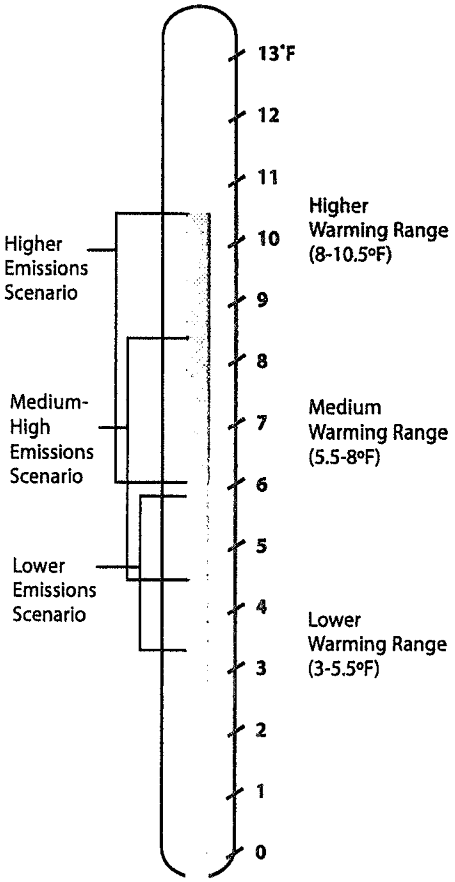
Reducing Heat-Trapping Emissions

Reducing heat-trapping emissions is the most important way to slow the rate of global warming. On June 1, 2005, Governor Arnold Schwarzenegger signed an executive order (#S-3-05) that sets goals for significantly lowering the state's share of global warming pollution. The executive order calls for a reduction in heat-trapping emissions to 1990 levels by 2020 and for an 80 percent emissions reduction below 1990 levels by 2050. These emission reduction targets will help stimulate technological innovation needed to help transition to more efficient and renewable transportation and energy systems.

Coping with Unavoidable Climatic Changes

Because global warming is already upon us, and some amount of additional warming is inevitable, we must prepare for the changes that are already under way.

Summary of Projected Global Warming Impact, 2070–2099
(as compared with 1961–1990)



- 90% loss in Sierra snowpack
- 22–30 inches of sea level rise
- 3–4 times as many heat wave days in major urban centers
- 4–6 times as many heat-related deaths in major urban centers
- 2.5 times more critically dry years
- 20% increase in energy demand

- 70–80% loss in Sierra snowpack
- 14–22 inches of sea level rise
- 2.5–4 times as many heat wave days in major urban centers
- 2–6 times as many heat-related deaths in major urban centers
- 75–85% increase in days conducive to ozone formation*
- 2–2.5 times more critically dry years
- 10% increase in electricity demand
- 30% decrease in forest yields (pine)
- 55% increase in the expected risk of large wildfires

- 30–60% loss in Sierra snowpack
- 6–14 inches of sea level rise
- 2–2.5 times as many heat wave days in major urban centers
- 2–3 times as many heat-related deaths in major urban centers
- 25–35% increase in days conducive to ozone formation*
- Up to 1.5 times more critically dry years
- 3–6 % increase in electricity demand
- 7–14% decrease in forest yields (pine)
- 10–35% increase in the risk of large wildfires

* For high ozone locations in Los Angeles (Riverside) and the San Joaquin Valley (Visalia)

Preparing for these unavoidable changes will require minimizing further stresses on sensitive ecosystems and implementing management practices that integrate climate risks into long-term planning strategies.

By reducing heat-trapping emissions, severe consequences can be avoided.

California's Leadership

California has been a leader in both the science of climate change and in identifying solutions. The California Climate Change Center is one of the first—and perhaps the only—state-sponsored research institution in the nation dedicated to climate change research, and other state agencies such as the Air Resources Board support similar research. Continuing this strong research agenda is critical for developing effective strategies for addressing global warming in California.

The state has also been at the forefront of efforts to reduce heat-trapping emissions, passing precedent-setting policies such as aggressive standards for tailpipe emissions, renewable energy, and energy efficiency. However, existing policies are not likely to be sufficient to meet the ambitious emission reduction goals set by the governor. To meet these ambitious goals California will need to build on its legacy of environmental leadership and develop new strategies and technologies to reduce emissions.

California alone cannot stabilize the climate. However, the state's actions can drive global progress. If the industrialized world were to follow the emission reduction targets established in California's executive order, and industrializing nations reduced emissions according to the lower emissions path (B1) presented in this analysis, we would be on track to keep temperatures from rising to the medium or higher (and possibly even the lower) warming ranges and thus avoid the most severe consequences of global warming.

The full text of the Climate Scenarios analysis overview report, and the core scientific papers that comprise this analysis, are online at *www.climatechange.ca.gov*. The scientists that participated in this effort are:

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CLIMATE CHANGE:

Stationarity Is Dead: Whither Water Management?

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Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity--the idea that natural systems fluctuate within an unchanging envelope of variability--is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual stream-flow or annual flood peak) has a time-invariant (or 1-year-periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S. $500 billion (1).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (2, 3). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

An uncertain future challenges water planners.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (4, 5) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (6). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (7).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (8), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (9) and water supply (10) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (11, 12). Accounting for the substantial uncertainties of climatic parameters estimated from short records (13) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (12, 14).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (15). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (16), although attempts to detect a recent change in global flood frequency have been equivocal (17, 18). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (19). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO_2 and the thermal inertia of the Earth system (4, 20).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (21, 22), the assumption of stationarity was combined with operations research, statistics, and welfare economics to formulate design problems as trade-offs of costs, risks, and benefits dependent on variables such as reservoir volume. These trade-offs were evaluated by optimizations or simulations using either long historical streamflow time series or stochastic simulations of streamflow based on properties of the historical time series.

This framework can be adapted to changing climate. Nonstationary hydrologic variables can be modeled stochastically to describe the temporal evolution of their pdfs, with estimates of uncertainty. Methods for estimating model parameters can be developed to combine historical and paleohydrologic measurements with projections of multiple climate models, driven by multiple climate-forcing scenarios.

Human influences. Dramatic changes in runoff volume from ice-free land are projected in many parts of the world by the middle of the 21st century (relative to historical conditions from the 1900 to 1970 period). Color denotes percentage change (median value from 12 climate models). Where a country or smaller political unit is colored, 8 or more of 12 models agreed on the direction (increase versus decrease) of runoff change under the Intergovernmental Panel on Climate Change's "SRES A1B" emissions scenario.

Rapid flow of such climate-change information from the scientific realm to water managers will be critical for planning, because the information base is likely to change rapidly as climate science advances during the coming decades. Optimal use of available climate information will require extensive training of (both current and future) hydrologists, engineers, and managers in nonstationarity and uncertainty. Reinvigorated development of methodology may require focused, interdisciplinary efforts in the spirit of the Harvard Water Program.

A stable institutional platform for climate predictions and climate-information delivery may help (23). Higher-resolution simulations of the physics of the global land-atmosphere system that focus on the next 25 to 50 years are crucial. Water managers who are developing plans for their local communities to adapt to climate change will not be best served by a model whose horizontal grid has divisions measured in hundreds of kilometers. To facilitate information transfer in both directions between climate science and water management, the climate models need to include more explicit and faithful representation of surface- and ground-water processes, water infrastructure, and water users, including the agricultural and energy sectors. Treatments of land-cover change and land-use management should be routinely included in climate models. Virtual construction of dams, irrigation of crops, and harvesting of forests within the framework of climate models can be explored in a collaboration between climate scientists and resource scientists and managers.

Modeling should be used to synthesize observations; it can never replace them. Assuming climatic stationarity, hydrologists have periodically relocated stream gages (24) so that they could acquire more perspectives on what was thought to be a fairly constant picture. In a nonstationary world, continuity of observations is critical.

The world today faces the enormous, dual challenges of renewing its decaying water infrastructure (25) and building new water infrastructure (26). Now is an opportune moment to update the analytic strategies used for planning such grand investments under an uncertain and changing climate.

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