VOLUME 1 - THE STRATEGIC PLAN

CHAPTER 5

Managing an Uncertain Future

Sea level stake at Crissy Field, San Francisco. Over the last 100 years, sea level has risen by 8 inches at Crissy Field and continues to rise. Climate change is expected to raise the sea level, reduce snowpack, and bring fiercer droughts and floods. DWR is modeling potential future climates, potential future populations, and land use patterns to prepare for risks and plan for water needs out to a year 2050 horizon.

Contents

Chapter 5. Managing an Uncertain Future 5-7
About This Chapter 5-7
Recognizing and Planning for Risk and Uncertainty 5-7
Overview 5-7
Traditional Planning Approach — The Past Is a Model for the Future 5-8
New Planning Approach — Anticipate Change 5-9
Recognizing and Reducing Uncertainty 5-10
Water Scenarios 2050: Possible Futures 5-11
Growth Scenarios 5-13
Climate Scenarios 5-14
Future Environmental Requirements 5-17
Evaluating Vulnerabilities and Resource Management Strategies for Three Hydrologic Regions 5-18
Evaluation of Management Response Packages 5-26
Statewide 2050 Water Demands 5-34
Limitations of Future Water Management Analysis for Update 2013 5-37
Managing for Sustainability 5-38
Testing Sustainability Indicators with Pilot Studies 5-42
Summary 5-52
References 5-57
References Cited 5-57

Tables

Table 5-1 Conceptual Growth Scenarios 5-15
Table 5-2 Growth Scenarios (Urban) — Statewide Values 5-15
Table 5-3 Growth Scenarios (Agriculture) — Statewide Values 5-16
Table 5-4 Reliability Thresholds 5-26
Table 5-5 Resource Management Strategies Used in Plan of Study 5-32
Table 5-6 Water Sustainability Domains 5-45

Figures

Figure 5-1 Scenario Drivers and Water Demand 5-14
Figure 5-2 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Red Bluff 5-17
Figure 5-3 Variation in 30-Year Running Average precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Oroville 5-18
Figure 5-4 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Fresno 5-19

Figure 5-5 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Millerton....5-20
Figure 5-6 Change in Average Annual Temperature from Historical 1951-2005 Average and 12 Scenarios of Future Climate Years 2006-2100 for Sacramento Valley Floor 5-21
Figure 5-7 California's Hydrologic Regions Highlighting Three Central Valley Regions Used in Test Case....5-22
Figure 5-8 Robust Decision Making Steps Used in Water Plan Analysis 5-23
Figure 5-9 Single Simulation of Urban Supply, Demand, and Unmet Demand for the San Joaquin River Hydrologic Region....5-24
Figure 5-10 Single Simulation of Agricultural Supply, Demand, and Unmet Demand for the San Joaquin River Hydrologic Region....5-25
Figure 5-11 Range of Urban and Agricultural Reliability Results Across Futures....5-27
Figure 5-12 Range of Groundwater Storage Changes Across Futures 5-27
Figure 5-13 Range of Reliability for Environmental Flow Objectives Across Futures....5-28
Figure 5-14 Climate Conditions Leading to Low Agricultural Supply Reliability in the San Joaquin River Hydrologic Region 5-29
Figure 5-15 Climate Conditions Leading to Low Urban Supply Reliability in the Tulare Lake Hydrologic Region for the High-Population and Low-Density Land Use Scenario 5-30
Figure 5-16 Climate Conditions Leading to Low Agricultural Supply Reliability Results in the Tulare Lake Hydrologic Region....5-31
Figure 5-17 Change in Urban and Agricultural Supply Reliability as Additional Response Packages Are Implemented for the San Joaquin River Hydrologic Region (left panel) and Tulare Lake Hydrologic Region (right panel)....5-35
Figure 5-18 Percentage of Scenarios Showing Unacceptable Outcomes for Selected Performance Metrics Across Different Response Packages for the Sacramento River Hydrologic Region....5-36
Figure 5-19 Percentage of Scenarios Showing Unacceptable Outcomes for Selected Performance Metrics Across Different Response Packages for the San Joaquin River Hydrologic Region....5-37
Figure 5-20 Range of Reliability for Three Environmental Flow Objectives Across Futures for Currently Planned Management and Diversification Level 3 5-38
Figure 5-21 Percentage of Scenarios Showing Unacceptable Outcomes for Selected Performance Metrics Across Different Response Packages for the Tulare Lake Hydrologic Region....5-39
Figure 5-22 Change in Statewide Agricultural and Urban Water Demands for 117 Scenarios from 2006-2050 (million acre-feet per year)....5-40
Figure 5-23 Change in Regional Agricultural and Urban Water Demands for 117 Scenarios from 2006-2050 (million acre-feet per year)....5-41
Figure 5-24 Conceptual California Water Sustainability Indicators Framework....5-43
Figure 5-25 Details of the California Water Sustainability Indicators Framework 5-44
Figure 5-26 California's Blue and Green Water Footprint....5-46
Figure 5-27 California's Energy-Related Blue and Green Water Footprint 5-48

Figure 5-28 California's Energy-Related Internal and External Water Footprint.......................5-48
Figure 5-29 Water Quality Index Score for Hydrologic Regions 5-49
Figure 5-30 Geomorphic Process Score for Hydrologic Regions 5-50
Figure 5-31 California Stream Condition Index Score by Site and for Hydrologic Regions 5-51
Figure 5-32 Fish Community Score for Hydrologic Regions..5-53
Figure 5-33 Public Perception by Region of Threats to the Public Water Supply.....................5-54
Figure 5-34 Public Perception of Security of Future Water Supplies..5-54
Figure 5-35 Public Perception of Effects of Climate Change on Future Water Supply 5-55
Figure 5-36 Public Perception of Future Water Management Strategies to Maintain
Water Supply...5-55
Figure 5-37 Public Favor for Improving Conditions for Fish, Including Payment Strategies ...5-56
Figure 5-38 Groundwater and Drinking Water Contamination Score for
Hydrologic Regions 5-57

Boxes

Box 5-1 Uncertainty, Risk, and Sustainability...5-8
Box 5-2 Sources of Future Change and Uncertainty 5-12
Box 5-3 Managing Floods versus Managing Flood Risk 5-13
Box 5-4 Central Valley WEAP Model..5-24
Box 5-5 Analyzing Surface Storage and Delta Conveyance as Management Responses 5-34
Box 5-6 U.S. EPA California Footprint Sustainability Indicators Suite 5-42
Box 5-7 Water Footprint as an Index of Sustainability...5-47

Chapter 5. Managing an Uncertain Future

About This Chapter

Chapter 5, "Managing an Uncertain Future," emphasizes the need for decision-makers, water and resource managers, and land use planners to use a range of considerations in planning for California's water future in the face of many uncertainties and risks. It provides examples of uncertainties and discusses the need to assess risks in planning for actions with more sustainable outcomes. An approach is presented for evaluating resource management strategies for robustness by using multiple future scenarios. Water management vulnerabilities identified during preparation of *California Water Plan Update 2013* (Update 2013) are presented. A framework is provided to measure the sustainability of water management policies and projects. This chapter describes the following topics:

- Recognizing and Planning for Risk and Uncertainty.
- Water Scenarios 2050: Possible Futures.
- Managing for Sustainability.
- Summary.

Recognizing and Planning for Risk and Uncertainty

Overview

On January 27, 2014, the California Natural Resources Agency, the California Environmental Protection Agency, and the California Department of Food and Agriculture released a detailed California Water Action Plan to help guide state efforts and resources with regard to improving the reliability of water supply, providing the ecosystem restoration needed to bring the water system back into balance, and strengthening the resilience of the state's infrastructure. The Water Action Plan recognizes that the challenges facing California are many: uncertain water supplies, water scarcity and drought, declining groundwater basins, poor water quality, declining native fish species and loss of wildlife habitat, flood risks, and supply disruptions. Similarly, the California Water Plan (CWP) acknowledges that planning for the future is uncertain and that change will continue to occur (see Box 5-1). Update 2013 builds on three key considerations in the planning approach for future management of regional and statewide water resources. The planning approach should (1) recognize and reduce uncertainties inherent in the system, (2) define and assess the risks that can hamper successful system management and select management practices that reduce the risks to acceptable levels, and (3) keep an eye toward approaches that help implement and maintain water and flood management systems that have more sustainable outcomes.

Box 5-1 Uncertainty, Risk, and Sustainability

Uncertainty. Uncertainty is what we do not know about the system. For example, engineers do not know the foundation conditions under all California levees. Uncertainty can be decreased by reducing data gaps to increase knowledge.

Risk. Most risks originate from such hazards as floods, earthquakes, and droughts that would occur even if all uncertainty could be eliminated. Reducing uncertainty provides a clearer view of what the risks to the system are.

Risk is the probability of the occurrence (multiplied by) consequences of the occurrence over a range of potential events.

Sustainability. A sustainable system or process has longevity and resilience. A sustainable system manages risk but cannot eliminate it. A sustainable system generally provides for the economy, the ecosystem, and social equity. Water sustainability is the dynamic state of water use and supply that meets today's needs without compromising the long-term capacity of the natural and human aspects of the water system to meet the needs of future generations. For example, planning ways to eventually eliminate drafting more groundwater than can be recharged over the long term is one approach for improving sustainability.

Traditional Planning Approach — The Past Is a Model for the Future

Water managers recognize the variable nature of water flow in California's streams and rivers during wet and dry periods spanning from seasons to multiple years. Having too little water or too much water — droughts or floods — were often primary reasons that Californians built early water projects. Early in California's water development history, personal observations and experience were often used to help size water facilities because of the limited availability of recorded data.

A system to record water flow conditions over time gradually improved information available to water managers. However, the main assumption governing water planning and management for much of California's history has been that past records were a good indication of the frequency, duration, and severity of future floods and droughts, and these records were used as predictors of potential future conditions. In addition, historical records were generally used to establish trends, such as population growth, which were assumed to continue into the future.

This static view of the range of possible future conditions based on past records worked fairly well when the demands on the resources were considerably lower than now. Early designers of water facilities may have understood the variability of storm events and the range of streamflows that could occur, as well as the likelihood that a reservoir would refill in a given year, but generally they did not fully understand or consider the interrelationships among ecosystem functions, flood management, water availability, water use, and water quality.

The past approach to flood planning focused on flood damage reduction and public safety. Projects were designed to control and capture flood flows by using such facilities as dams, levee systems, bypasses, and channel enlargements. Although these projects provided significant flood protection benefits, some of these early structural projects caused unintended or redirected consequences of higher peak flows, conflicts with environmental resources, and increased flood risks. These experiences have prompted flood planners to look more comprehensively at flood systems to gain a better understanding of floodplains, related water supply, and environmental systems to provide multiple benefits.

In addition, risks posed by earthquakes, extreme floods, and extreme droughts were generally underestimated. Without a complete acknowledgment of the uncertainties inherent in the system and the risks that the system actually faced, management was relatively simple compared with today's standards. Conditions appeared more certain and less risky than they actually were, and water managers were more focused on meeting shorter term objectives. Although understanding the past is still an important part of managing for the future, it is becoming increasingly apparent that continued management under this traditional approach will not provide for sustainable water resources into the future.

New Planning Approach — Anticipate Change

Today, as part of integrated water management (IWM), California's water and resource managers must recognize that conditions are changing and will continue to change. Traditional approaches for predicting the future based solely on projecting past trends will no longer work. Today, there is better recognition that strategies for future water management must be dynamic, adaptive, and durable. In addition, the strategies must be comprehensive and integrate physical, biological, and social sciences, as well as consider risk and uncertainty.

California's water management system is large and complex, with decentralized water governance that requires a great deal of cooperation and collaboration among decision-makers at the State, federal, tribal, regional, and local level. California lacks a common analytical framework and approach to understand and manage the system, especially when management actions may compete for the same resources. Given today's uncertainties and those that may occur in the future, water managers must make sound investments that balance risk with reward. Update 2013 works to strengthen alignment between water managers while considering investment in innovation and infrastructure with multiple benefits.

As described in more detail in Chapter 6, "Integrated Data and Analysis: Informed and Transparent Decision Making," the CWP promotes ways to develop a common approach for data standards and understanding, evaluating, and improving regional and statewide water-management systems, and for common ways to evaluate and select from alternative management strategies and projects. To these ends, the California Department of Water Resources (DWR) has initiated work on the Water Planning Information Exchange (Water PIE). This system for accessing and sharing data across existing networked databases will use Web services and geographic information system (GIS) software to improve analytical capabilities, develop timely surveys of statewide land use and water use, and estimate future implementation of resource management strategies. Ultimately, Water PIE will build on, complement, and connect several existing data-sharing sites managed by DWR, including the Water Data Library, California Data Exchange Center, and the California Irrigation Management Information System.

Update 2013 acknowledges that planning for the future is uncertain and that change will continue to occur. It is not possible to know for certain how population growth, land use decisions, water demand patterns, environmental conditions, climate, and many other factors that affect water use, supply, and flood management may change by 2050. To anticipate change, water management and planning for the future need to consider and quantify uncertainty, risk, and sustainability.

- **Uncertainty.** How water demands will change in the future, how ecosystem health will respond to human use of water resources, what disasters may disrupt the water system, and how climate change may affect water availability, water use, water quality, flooding, and the ecosystem are just a few uncertainties that must be considered. The goal is to anticipate and reduce future uncertainties, and to develop water management strategies that will perform well despite uncertainty about the future.

  Uncertainties will never be eliminated, but better data and improved analytical tools will allow water and resource managers to better understand risks within the system. Many water agencies in California have begun incorporating climate change information into their operation and planning processes to reduce uncertainty of how climate may affect California's water resources in the future. Additional efforts are needed to develop the accurate climate data needed to reduce uncertainty and risk in California water management in the future. To read more about the development of DWR's Climate Science program, see in Volume 4, *Reference Guide*, the article "The State of Climate Change Science for Water Resources Operation, Planning, and Management," and visit http://www.water.ca.gov/climatechange.

- **Risk.** Uncertainties about future conditions contribute to water-related risks. Each future event has a certain, but unknown, chance of occurring and a set of consequences should it occur. Combining the likelihoods with consequences yields estimates of risk. For example, a chance of a levee failure with a certain-size flood event can be estimated with associated economic and human consequences. Likewise, one can estimate the likelihood of a drought of a specific severity and combine this with estimates of the consequences.

  By reducing the uncertainties described above, the "true" risks can be reduced. Many water managers are performing risk assessments that can be used in future planning to balance risk with reward when implementing new management actions. Risk assessments are also a way to quantitatively consider the uncertainties that relate to events of interest, such as the performance of levees, the consequences of flooding, and the impact of events on the environment.

- **Sustainability.** Given the uncertainties and risks in the water system, one set of resource management strategies may provide for more sustainable water supply, flood management, and ecosystems than another set of resource management strategies. IWM must be dynamic, adaptive, and durable. As described later in this chapter, DWR has developed a draft framework for quantifying indicators of water sustainability and has begun testing the indicators in regional pilot studies.

Recognizing and Reducing Uncertainty

It is important to consider two broad types of uncertainty while striving to improve data collection and analytical tools.

1. The first type of uncertainty comes from the inherent randomness of events in nature, such as the occurrence of an earthquake or a flood. However, additional data may allow better quantification of this uncertainty.

2. The second type of uncertainty can be attributed to lack of knowledge or scientific understanding. In principle, this uncertainty can be reduced with improved knowledge that comes from collection of additional information.

California's water and resource managers must deal with a broad range of uncertainty. Uncertainty is inherent in the existing system and in all changes that may occur in the future. For example, although water managers can be certain that the flows in California's rivers will be different next year compared with this year, they do not know the exact magnitude or timing of those changes. The threat of a chemical spill that may disrupt water diversion presents uncertainty. Future protections for endangered species may require modifications in water operation procedures that are unknown today. Scientists are trying to understand the reasons for the pelagic fish decline in the Sacramento-San Joaquin Delta (Delta), the condition of levees throughout the state, and the extent of groundwater recharge and overdraft, to name just a few of the uncertainties that need to be addressed in planning for the future.

For the purposes of considering potential changes and their inherent uncertainties, it is useful to consider and estimate how change may occur. Gradual changes can include such factors as variation in population by region, shifts in the types and amount of crops grown in an area, or changes in precipitation patterns or sea level rise. Sudden changes can include episodic events, such as earthquakes, floods, droughts, equipment failures, chemical spills, or intentional acts of destruction. The nature of these changes, the uncertainties about their occurrence, and their potential impacts on water management systems can greatly influence the response to the changes. Box 5-2 shows some sources of future change and uncertainty.

With improved understanding of uncertainties, risks facing future operation of the system can be better assessed. Most risks originate from such hazards as floods, earthquakes, and droughts. But risks can also result from other issues, such as water demands growing faster than anticipated, salt water intrusion, or land subsidence caused by groundwater overdraft. *Risk* can be defined as the probability that a range of undesirable events will occur, which is usually linked with a description of the corresponding consequences of those events. Box 5-3 describes how risk management is an integral part of flood management. A range of tools is available for assessing and accounting for risk (see in Volume 4, *Reference Guide*, the article "Accounting for Risk").

There is no way of predicting the future with absolute certainty, but scenarios of possible future conditions can be constructed. Update 2013 considers many alternative, plausible, yet very different future scenarios as a way of considering uncertainty and risk and improving resource sustainability. For example, three alternative population growth rates and three alternative assumptions about future land-use development density are considered, thus yielding nine alternative growth scenarios. Many alternative scenarios of future climate are considered in order to represent extended droughts and climate change. The concept is not to plan for any one given future, but to identify strategies that are robust across many scenarios. Certain combinations of management strategies may prove to be robust regardless of future conditions. This is especially true if the strategies have a degree of adaptability to differing conditions that may develop. A general description of the scenarios can be found in the next section.

Water Scenarios 2050: Possible Futures

Since *California Water Plan Update 2005* (Update 2005), the CWP has used the concept of multiple future scenarios to capture a broad range of uncertain factors that affect water management, but over which water managers have little control. Scenarios are used to test the robustness of strategies by evaluating how well strategies perform across a wide range of possible future conditions. The CWP organizes scenarios around themes of population growth, land use patterns, and climate change. Growth scenarios characterize a range of uncertainty surrounding

Box 5-2 Sources of Future Change and Uncertainty

Sources of Gradual or Long-term Change and Uncertainty

Urban Land Use (population). Projecting future changes in population, development patterns, changes in runoff and infiltration with increased impervious area, and changes in water quality impacts becomes more uncertain with the time frame of the projection.

Agricultural Land Use. Agricultural water use is influenced by land conversions to urban or ecosystem uses, but also depends on cropping patterns driven by water availability and the world economy.

Other Land Use. Conversions of land to ecosystem or other uses can change water use, water quality, ecosystem health, and many other factors. Some ecosystem uses consume more water per acre than agricultural and urban uses.

Climate Change. The changing climate presents many uncertainties in the magnitude, pattern, and the rate of potential change:

- **Snowpack.** California's snowpack, a major part of annual water storage, is decreasing with increasing winter temperatures.
- **Hydrologic Pattern.** Warmer temperatures and decreasing snowpack cause more winter runoff and less spring/summer runoff.
- **Rainfall Intensity.** Regional precipitation changes remain difficult to determine, but larger precipitation events could be expected with warmer temperatures in some regions.
- **Sea Level Rise.** Sea level rise is increasing the threat of coastal flooding, salt water intrusion, and even disruption of water exports from the Sacramento-San Joaquin Delta (Delta) should levees fail on key islands and tracts.
- **Water Demand.** Plant evapotranspiration increases with increased temperature.
- **Aquatic Life.** Higher water temperatures are expected to have a negative effect on some species and may benefit species that compete with native species.
- **Greenhouse Gas Emissions — Carbon Intensity or Carbon Footprint.** Storage, transport, and treatment of water involves substantial amounts of energy, which in most cases result in the release of greenhouse gas emissions that contribute to climate change. Each water management strategy should be evaluated for its contribution to the accumulation of greenhouse gasses in our atmosphere.

Sources of Sudden or Short-term Change and Uncertainty

Delta Vulnerabilities. The Delta is highly susceptible to flooding and to disruption of significant water supply to many areas of the state.

Droughts. The severity, timing, and frequency of future droughts are uncertain.

Floods. The severity, timing, and frequency of future floods are uncertain.

Earthquakes. Though more is known about earthquakes, their location, timing, and magnitudes can have various effects on water systems.

Facility Malfunction. Deferred maintenance and aging infrastructure can cause unexpected outages in portions of the system.

Chemical Spills. Chemical spills are unpredictable, but can disrupt surface water and groundwater supplies.

Intentional Disruption. Vandalism, terrorist acts, and even cyber threats can have serious potential impacts on the operational capability of water delivery and treatment systems.

Fire. Wildfire in local watersheds can change runoff characteristics and affect water quality for decades.

Economic disruption. Sudden changes in the economy influence the ability to pay for improvements to the water management system.

Changing Policies/Regulations/Laws/Social Attitudes. Some changes in policies, regulations, laws, and social attitudes may be gradual, but some may be sudden:

- **Endangered species.** New endangered species listings can require significant changes to water system operations and water supply distribution for agricultural, urban, and environmental uses.
- **Plumbing Codes.** Future changes in plumbing codes, such as installing ultralow-flow toilets, could allow use of innovative water fixtures to conserve water.
- **Emerging Contaminants.** The nature and impact of contaminants may change in the future, especially with new health and ecological risk information.

Box 5-3 Managing Floods versus Managing Flood Risk

Managing floods means building and operating facilities, such as dams, weirs, levees, and pump stations, to safely store and convey flood flows within designated channels to reduce the chance of flooding. Although such improvements can greatly reduce flood risk, they cannot entirely eliminate it. Subsequently, floodplains are often developed because of the perception that the chance of flooding has been eliminated. As a result, the overall flood risk (paradoxically) can increase following construction of flood control facilities. Flood risk is the combined effect of the chance of flooding and the property that would be damaged if flooded. Managing flood risk means either reducing the chance of flooding or the population and property exposed to flooding, or a combination of both. Thus, managing flood risk can include flood control facilities, as well as limiting floodplain development; elevating structures above flood elevations; creating natural flood storage and groundwater recharge areas; and using flood risk notification, flood insurance, and flood preparedness.

Source: California Department of Water Resources 2012

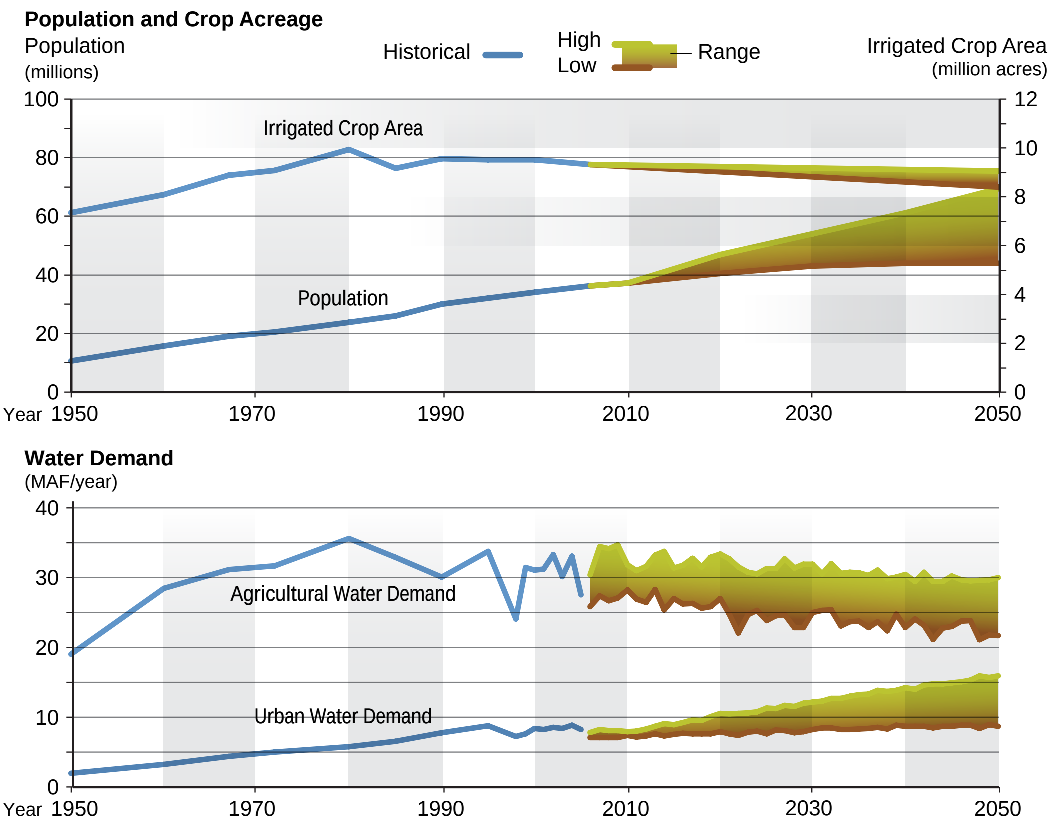
how cities and other land managers will accommodate future population growth through infill development or expansion into areas of existing open space and agriculture. Climate scenarios explore how future climate change might influence timing; distribution; and amount of precipitation, storm runoff, and water supply. Figure 5-1 shows how population growth, irrigated crop area, and water demand have changed historically and how the CWP scenarios suggest these factors may change in the future.

Growth Scenarios

Future water demand is affected by a number of growth and land use factors, such as population growth, planting decisions by farmers, and size and type of urban landscapes. The CWP quantifies several factors that together provide a description of future growth and how growth could affect water demand for the urban, agricultural, and environmental sectors. Growth factors are varied among the scenarios to describe some of the uncertainty faced by water managers. For example, it is impossible to predict future population growth accurately, so the CWP uses three different but plausible population-growth estimates when determining future urban water demands. In addition, the CWP considers up to three alternative views of future development density. Population growth and development density will reflect how large the urban landscape will have become by 2050 and are used by the CWP to quantify encroachment into agricultural lands by 2050. Table 5-1 identifies the growth scenarios relative to current trends by using information from the California Department of Finance and the Public Policy Institute of California.

For Update 2013, DWR worked with researchers at the University of California, Davis, to quantify how California might grow through 2050. The UPlan model was used to estimate a year 2050 urban footprint under the scenarios of alternative population growth and development density listed in Table 5-1 (see http://ice.ucdavis.edu/project/uplan for information on the UPlan model). UPlan is a simple, rule-based urban growth model intended for regional or county-level modeling. The needed space for each land use type is calculated from simple demographics and is assigned based on the net attractiveness of locations to that land use (based on user input), locations unsuitable for any development, and a general plan that determines where specific types of development are permitted. Table 5-2 describes the amount of land devoted to urban use for 2006 and 2050, and the change in the urban footprint for California under each scenario. Table 5-3 describes how future urban growth could affect the land devoted to agriculture in 2050.

Figure 5-1 Scenario Drivers and Water Demand



Irrigated land area is the total agricultural footprint. Irrigated crop area is the cumulative area of agriculture, including multi-crop area, where more than one crop is planted and harvested each year. Each of the growth scenarios shows a decline in irrigated acreage over existing conditions, but to varying degrees.

Climate Scenarios

A significant improvement to the CWP scenarios in Update 2013 is a quantitative look at the uncertainty surrounding future climate change when evaluating the performance of new resource management strategies. After consultation with its Climate Change Technical Advisory Group, DWR chose to include 22 alternative climate scenarios in the evaluation of future strategies. These include 12 climate scenarios identified by the Governor's Climate Action Team (CAT) for future climate change, five scenarios repeating historical climate with a severe 3-year drought, and five scenarios repeating historical climate with a warming temperature trend. Each of the climate scenarios has separate estimates of future precipitation and temperature. Collectively these estimates provide planners with a range of precipitation and temperature that might be experienced in the future, and they are used with other factors to estimate future water demands. Refer to Volume 4, *Reference Guide,* the article "Overview of Climate-Change Scenarios Being Analyzed," for additional information on the CAT climate scenarios.

Table 5-1 Conceptual Growth Scenarios

Scenario	Population Growth	Development Density
LOP-HID	Lower than Current Trends	Higher than Current Trends
LOP-CTD	Lower than Current Trends	Current Trends
LOP-LOD	Lower than Current Trends	Lower than Current Trends
CTP-HID	Current Trends	Higher than Current Trends
CTP-CTD	Current Trends	Current Trends
CTP-LOD	Current Trends	Lower than Current Trends
HIP-HID	Higher than Current Trends	Higher than Current Trends
HIP-CTD	Higher than Current Trends	Current Trends
HIP-LOD	Higher than Current Trends	Lower than Current Trends

Table 5-2 Growth Scenarios (Urban) — Statewide Values

Scenario	2050 Population (millions)	Population Change (millions) 2006[a] to 2050	Development Density	2050 Urban Footprint (million acres)	Urban Footprint Increase (million acres) 2006[b] to 2050
LOP-HID	43.9[c]	7.8	High	5.6	0.3
LOP-CTD	43.9	7.8	Current Trends	6.2	1.0
LOP-LOD	43.9	7.8	Low	6.5	1.2
CTP-HID	51.0[d]	14.9	High	6.3	1.1
CTP-CTD	51.0	14.9	Current Trends	6.7	1.5
CTP-LOD	51.0	14.9	Low	7.1	1.9
HIP-HID	69.4[e]	33.3	High	6.8	1.6
HIP-CTD	69.4	33.3	Current Trends	7.6	2.4
HIP-LOD	69.4	33.3	Low	8.3	3.1

Notes:

[a] 2006 population was 36.1 million.

[b] 2006 urban footprint was 5.2 million acres.

c Values modified by the California Department of Water Resources (DWR) from the Public Policy Institute of California.

[d] Values provided by the California Department of Finance.

[e] Values modified by DWR from the Public Policy Institute of California.

Table 5-3 Growth Scenarios (Agriculture) — Statewide Values

Scenario	2050 Irrigated Land Area[a] (million acres)	2050 Irrigated Crop Area[b] (million acres)	2050 Multiple Crop Area[c] (million acres)	Reduction in Irrigated Crop Area (million acres) 2006 to 2050
LOP-HID	8.6	9.2	0.65	0.1
LOP-CTD	8.4	9.0	0.63	0.3
LOP-LOD	8.3	8.9	0.63	0.4
CTP-HID	8.4	9.0	0.63	0.3
CTP-CTD	8.2	8.9	0.62	0.4
CTP-LOD	8.1	8.7	0.61	0.6
HIP-HID	8.2	8.9	0.62	0.4
HIP-CTD	8.0	8.6	0.60	0.7
HIP-LOD	7.8	8.4	0.58	0.9

Notes:

[a] 2006 Irrigated land area was estimated by the California Department of Water Resources (DWR) to be 8.7 million acres.

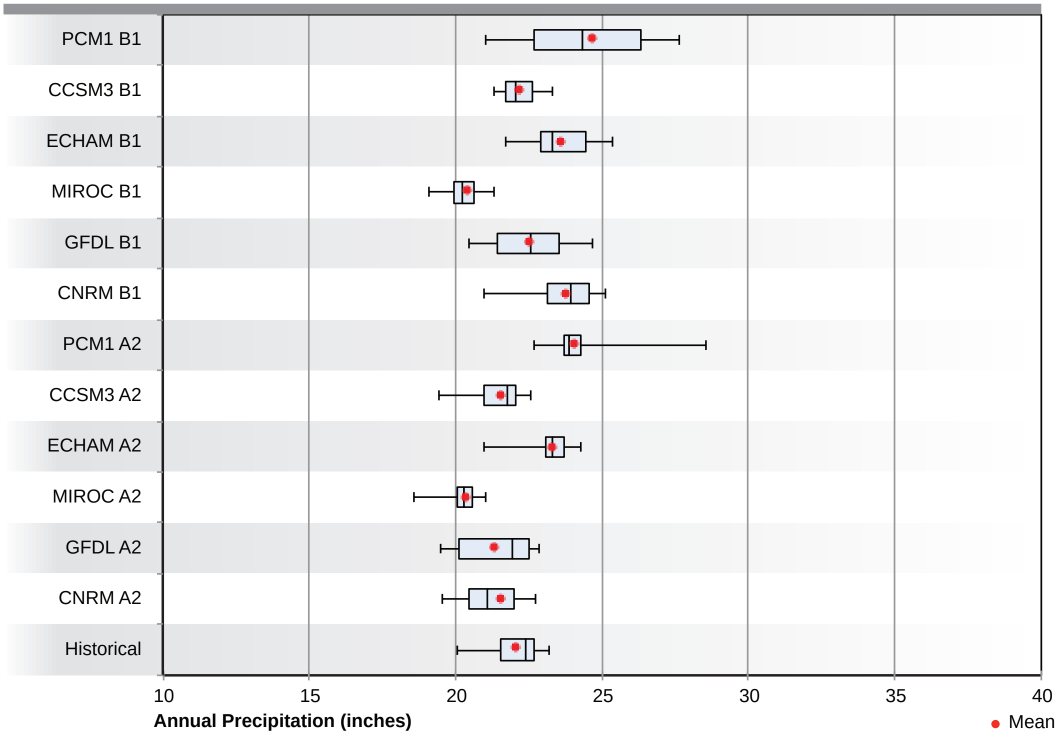
[b] 2006 Irrigated crop area was estimated by DWR to be 9.3 million acres.

[c] 2006 multiple crop area was estimated by DWR to be 0.65 million acres.

Figures 5-2, 5-3, 5-4, and 5-5 show the variation in 30-year running average annual precipitation for locations in the Central Valley and Sierra Nevada foothill regions for the 1915-2003 historical period, as well as 2011-2099 for the 12 CAT scenarios of future climate. The variation in the 30-year running average precipitation is represented as a box plot (also known as a box-and-whisker diagram or plot), which is a convenient way of graphically summarizing groups of numerical data by using five numbers (the smallest observation, lower quartile [Q1], median [Q2], upper quartile [Q3], and largest observation). For example, for the historical period, the box plot for Red Bluff shows a minimum value of about 20 inches in the driest 30-year period and a maximum value of slightly over 23 inches in the wettest 30-year period. The precipitation values used to generate the box plots are from a specific location (i.e., Red Bluff, Oroville, Fresno, and Millerton).

Figure 5-6 shows the trend in the change in average annual temperature for the Sacramento Valley floor for each climate sequence compared with the 1951-2005 historical average. A distinct upward trend in temperature change is shown in each climate scenario. Nonetheless, there is considerable year-to-year fluctuation and different expectations for the long-term magnitude of temperature change. While the absolute change in temperature varies from region to region, the relative change in average annual temperature follows a pattern similar in all regions to that shown for the Sacramento River Hydrologic Region in Figure 5-6.

Figure 5-2 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Red Bluff



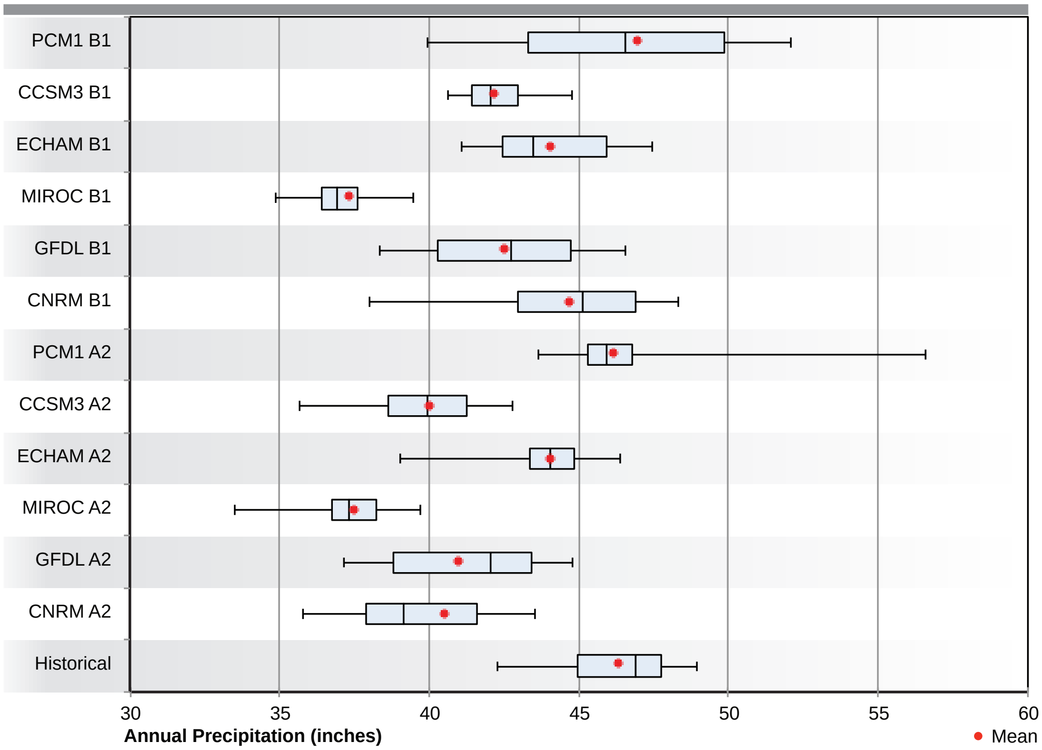
Future Environmental Requirements

The CWP uses currently unmet environmental objectives as a surrogate to estimate new requirements that may be enacted in the future to protect the environment or new ecosystem restoration actions implemented, for example, under an integrated regional water management (IRWM) plan. These unmet objectives are instream flow needs or additional deliveries to managed wetlands that have been identified by regulatory agencies or by pending court decisions, but which are not yet required by law. For Update 2013, the CWP has identified the following unmet objectives:

- American (Nimbus) Department of Fish and Wildlife Values.
- Stanislaus (Goodwin).
- Ecosystem Restoration Program #1, Delta Flow Objective.
- Ecosystem Restoration Program #2, Delta Flow Objective.
- Ecosystem Restoration Program #4, Freeport.
- Trinity below Lewiston.
- Ecosystem Restoration Program #3 San Joaquin River at Vernalis.
- San Joaquin River below Friant.
- Level 4 Water Deliveries to Wildlife Refuges.

The analysis of Response Packages, described below, includes assessments of these additional objectives. These are only some of the unmet objectives in the state. In particular, they do not

Figure 5-3 Variation in 30-Year Running Average precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Oroville



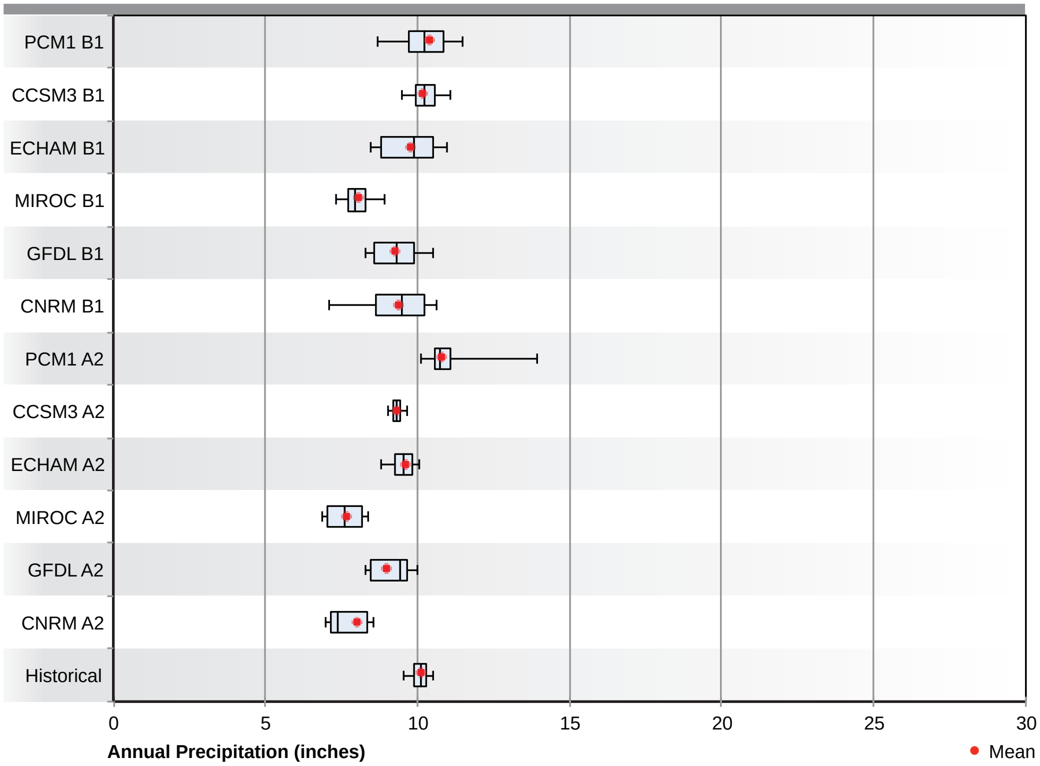
include additional water to protect species in the Delta, as recommended in the December 2008 Delta Smelt Biological Opinion issued by the U.S. Fish and Wildlife Service, or to protect salmon and several other species, as recommended in the June 2009 Biological Opinion on the Central Valley Water Project by the National Marine Fisheries Service.

Evaluating Vulnerabilities and Resource Management Strategies for Three Hydrologic Regions

Throughout development of Update 2013, DWR has worked with the Statewide Water Analysis Network (SWAN) to develop methods to regionally evaluate and quantify the costs, benefits, and tradeoffs of different resource management strategies through the application of the Water Evaluation and Planning (WEAP) modeling platform. SWAN serves as the technical advisory committee for the CWP. The CWP is testing the evaluation methods by focusing on the three hydrologic regions in the Central Valley: the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions (see Figure 5-7). (For more information, refer to Volume 4, *Reference Guide*, the article "Evaluating Response Packages for the California Water Plan Update 2013, Plan of Study.")

This analysis of vulnerabilities and response packages uses Robust Decision Making (RDM), a quantitative decision-support methodology designed to facilitate decisions under conditions of deep uncertainty (Lempert et al. 2003; Groves and Lempert 2007). Deep uncertainty occurs when the parties to a decision do not know — or agree on — the best model for relating actions to

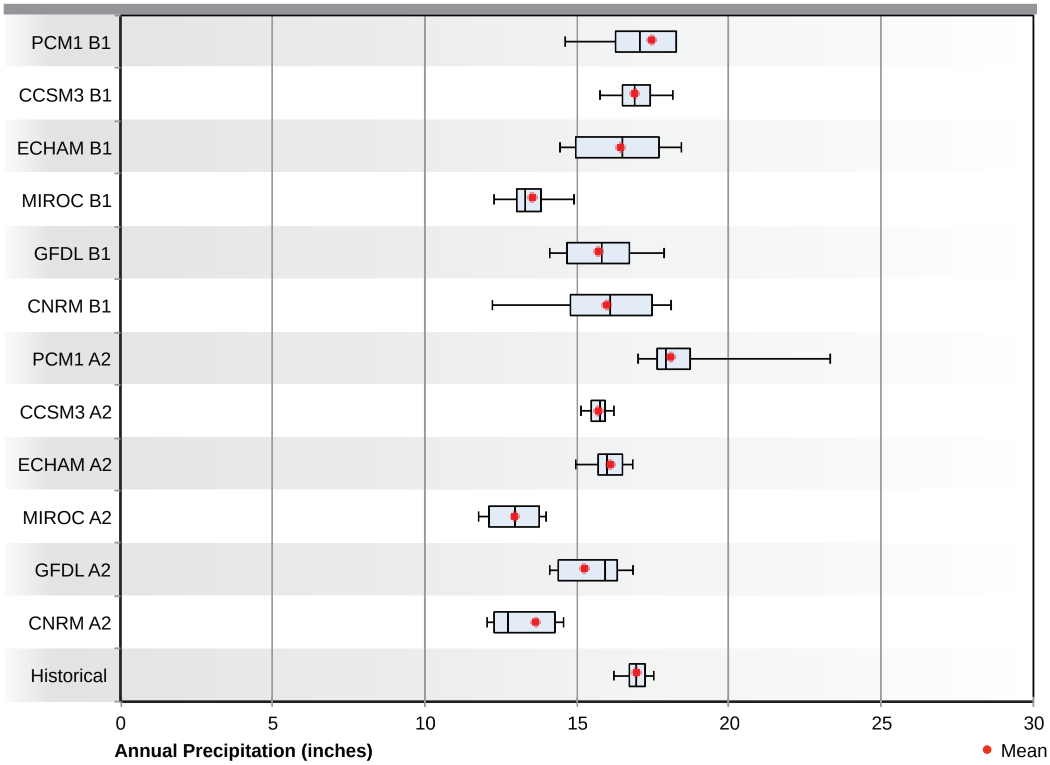
Figure 5-4 **Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Fresno**



consequences or the likelihood of future events. RDM rests on a simple concept: Rather than use models and data to predict the future and then plan for that prediction, RDM runs models over hundreds to thousands of different sets of assumptions to describe how plans perform in many plausible futures. This information is used as part of a vulnerability analysis to identify which future conditions could result in the management decisions not achieving their objectives. RDM then informs a tradeoff analysis, in which different decisions are compared based on their ability to reduce vulnerabilities, their costs, and other outcomes. (For more information about RDM and case studies, visit http://www.rand.org/methods/rdmlab.html.) Figure 5-8 shows the key steps of an RDM analysis.

The CWP is using this RDM framework to first evaluate the vulnerability of current water management in the Central Valley (Steps 1-3 in Figure 5-8) and then compare how various water management response packages could improve the resilience of the water management system (Steps 1-4 in Figure 5-8). Specifically, the vulnerability analysis explores how well the Central Valley water management system would perform under a wide range of futures defined by scenarios of urban growth and climate conditions. Urban growth scenarios reflect future population growth, density of housing, water use rates, and changes to irrigated land and cropping patterns. Climate scenarios describe different but plausible sequences of monthly temperatures and precipitation. Some scenarios reflect historical conditions, modified by an extended drought and climate warming. Others are derived from global climate model simulations. System performance is evaluated with respect to urban and agricultural supply reliability, reliability of meeting instream flow requirements and objectives, and changes in groundwater levels.

Figure 5-5 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Millerton

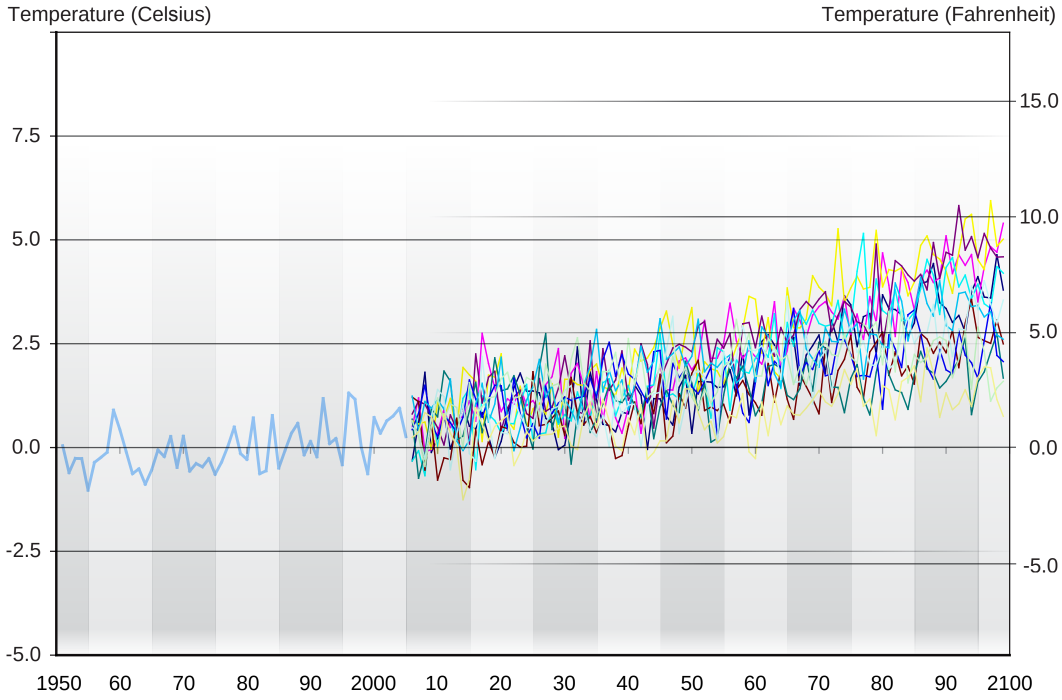


The CWP applied a model of the Central Valley water management system developed in the WEAP modeling platform to regionally quantify water management outcomes across a large number of growth and climate scenarios (see Box 5-4). For each scenario, an assessment was made of water supply, demand, and unmet demand in the urban and agricultural sectors; changes in groundwater; and how frequently instream flow requirements and objectives were met.

Figures 5-9 and 5-10 provide an example of information obtained from the Central Valley WEAP model and show urban and agricultural water supply, as well as demand and unmet demand results, for a single simulation (out of many) performed for the San Joaquin River Hydrologic Region. These simulations are based on historical supply conditions and Current Trends population and urban-density scenarios, and currently planned management. For the urban sector, demand gradually increases after the first 20 years of the simulation, and demand is completely met in all but one year (Figure 5-9). In the agricultural sector, water demand is more variable and declines slightly over time as urbanization reduces irrigated land area (Figure 5-10). Supply largely meets demand, except for simulated years 2023 and 2024, which corresponds to a repeat of 1976-1977 drought conditions. The model projects small but persistent unmet demands under a repeat of historical hydrologic conditions. Shortages are more acute under the dry conditions of 1977 and the early 1990s. These results are consistent with the greater water supply constraints present in these regions today.

The CWP evaluated numerous simulations under various future conditions to understand broadly how demand could change over time and to what extent supplies would be available to meet the demand. When reviewing results from numerous future simulations, the annual results for unmet

Figure 5-6 Change in Average Annual Temperature from Historical 1951-2005 Average and 12 Scenarios of Future Climate Years 2006-2100 for Sacramento Valley Floor



Note: In this figure, historical period shows actual demand (blue line). Each colored line represents 1 of 12 climate scenarios.

demand were summarized using a reliability metric. Reliability for this analysis is reported as the percentage of years in which water supply meets most of the water demand (e.g., 95 percent). Different reliability thresholds were defined for the urban and agricultural sectors in the Central Valley to reflect different historical levels of delivery (see Table 5-4).

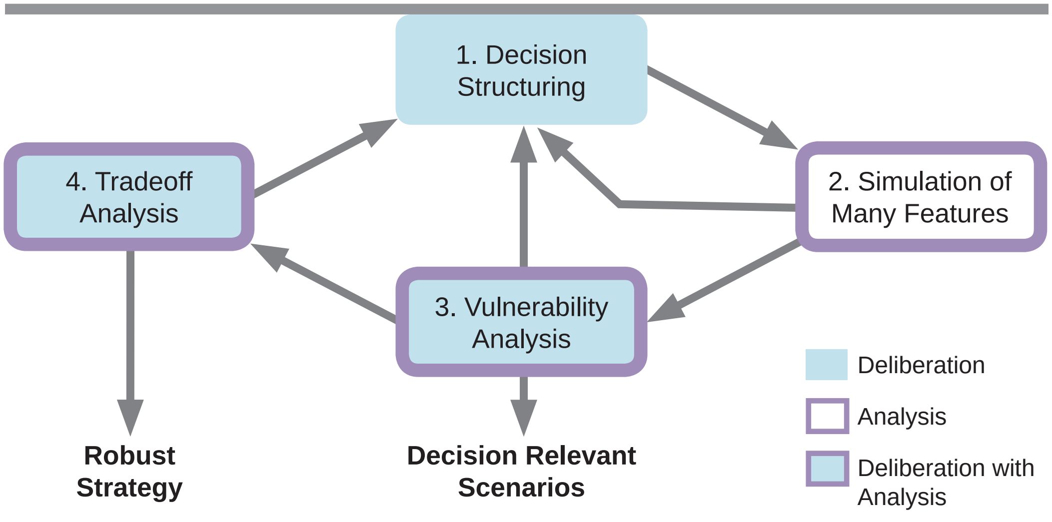
The CWP evaluated outcomes under currently planned management conditions for 198 futures representing combinations of climate and growth scenarios. Specifically, 22 climate scenarios — 10 different variations of historical climate with and without warming and 12 derived from global climate models — were evaluated for each of nine different growth scenarios. Reliability, defined as the percentage of years in which demand is sufficiently met by supply, is one of several different ways the CWP summarizes the projections of future urban and agricultural conditions. Groundwater conditions are summarized by the changes over the 45-year simulation period, and environmental flows are summarized by the reliability in which flow objectives are met. The analysis characterizes environmental flows as instream flow requirements (IFRs), which are flow objectives that are active in the baseline conditions and all response packages, and environmental flow targets (EFTs), which are flow objectives that are active in only some of the response packages, as described below.

Figure 5-11 shows the range of urban and agricultural reliability in the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions. In the figure, each symbol indicates the reliability for one of 198 simulations. The vertical lines indicate the median of each distribution, and

Figure 5-7 California's Hydrologic Regions Highlighting Three Central Valley Regions Used in Test Case

Original map and data points courtesy of University of California, Davis

Figure 5-8 **Robust Decision Making Steps Used in Water Plan Analysis**



Source: Groves and Bloom 2013

the shaded areas indicate the results that fall within the middle half of the distribution (between the 25th and 75th percentiles). The figure shows that both the urban and agricultural sectors in the Sacramento River Hydrologic Region, as well as the urban sector for the San Joaquin River Hydrologic Region, are projected to remain highly reliable across the futures evaluated. Reliability for the agricultural sector in the San Joaquin River Hydrologic Region and the urban sector in the Tulare Lake Hydrologic Region is lower, with about half the futures leading to reliability of less than 95 percent. For the agricultural sector in the Tulare Lake Hydrologic Region, reliability is broadly lower, with a median result of about 71 percent reliability. In some futures, reliability falls below 50 percent.

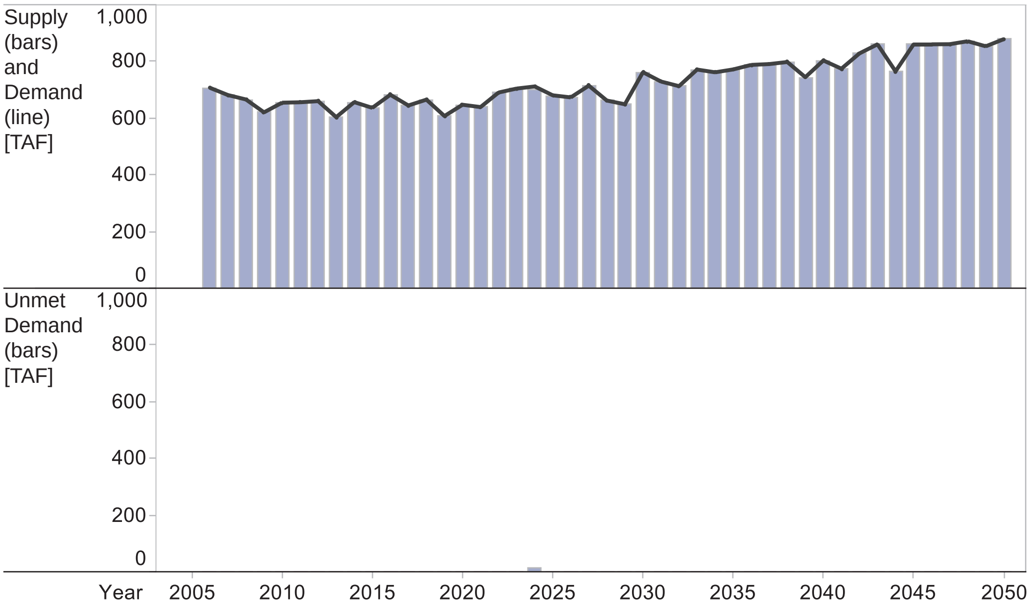
Figure 5-12 shows how groundwater storage would change in the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions for each of the 198 futures evaluated. In the Sacramento River Hydrologic Region, more than half the futures lead to increases in groundwater levels. This is caused by climate scenarios that are wetter than historical averages, combined with reduced agricultural water use resulting from projected urbanization of some agricultural lands. Groundwater in the San Joaquin River Hydrologic Region shows slight increases over the 45-year simulation period for most of the futures. Conversely, in the Tulare Lake Hydrologic Region, most futures lead to groundwater declines, with about half being greater than 10 percent.

The analysis focuses on five IFRs, three in the Sacramento River Hydrologic Region and two in the San Joaquin River Hydrologic Region, and four EFTs, three in the Sacramento River Hydrologic Region and one in the San Joaquin River Hydrologic Region. Figure 5-13 shows how the reliability for six IFRs varies across the futures. For the Sacramento River Hydrologic Region (blue symbols), performance for the IFRs is high, exceeding a reliability of more than 90 percent for all futures for Trinity below Lewiston and American (Nimbus). Flows relative to additional targets for Ecosystem Restoration Programs (ERPs) #1, #2, and #4 are high as well. Flows relative to additional targets at American (Nimbus) are significantly lower. For flows in the San Joaquin River Hydrologic Region (green symbols), reliability is high for each of the three IFRs — San Joaquin River at Vernalis, Stanislaus (Goodwin), and San Joaquin River below

Box 5-4 Central Valley WEAP Model

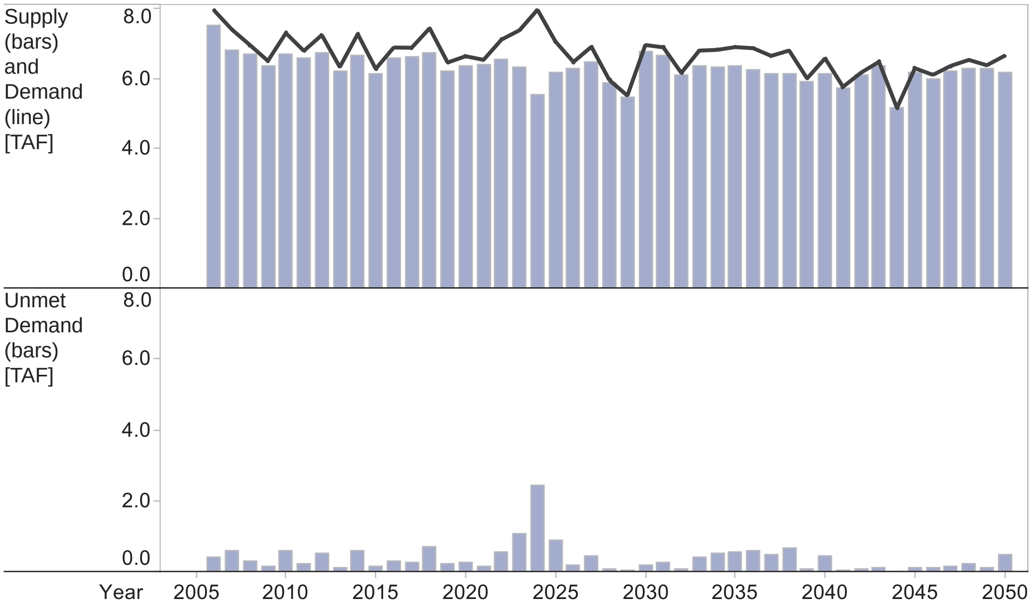
The California Water Plan supported the development of a model of the Central Valley by using the Water Evaluation and Planning (WEAP) system (see www.weap21.org). The WEAP system is a comprehensive, fully integrated river basin analysis tool. It is a simulation model that includes a robust and flexible representation of water demands from different sectors and the ability to program operating rules for infrastructure elements, such as reservoirs, canals, and hydropower projects (Purkey and Huber-Lee 2006; Purkey et al. 2007; Yates, Purkey et al. 2005; Yates, Sieber et al. 2005; Yates et al. 2008; and Yates et al. 2009). Additionally, it has watershed rainfall-runoff modeling capabilities that allow all portions of the water infrastructure and demand to be dynamically nested within the underlying hydrological processes. This functionality allows the analyses of how specific configurations of infrastructure, operating rules, and operational priorities will affect water uses as diverse as instream flows, irrigated agriculture, and municipal water supply under the umbrella of input weather data and physical watershed conditions. This integration of watershed hydrology with a water systems planning model makes WEAP ideally suited to study the potential impacts of climate change and other uncertainties internal to watersheds. The physical water-management system represented in WEAP is represented conceptually below.

Figure 5-9 Single Simulation of Urban Supply, Demand, and Unmet Demand for the San Joaquin River Hydrologic Region



Note: TAF = thousand acre-feet. In the upper part of the figure, the black line indicates demand, and vertical bars indicate annual supply (top) and annual unmet demand (bottom). This simulation is for the historical climate and CTP-CTD land use scenario.

Figure 5-10 Single Simulation of Agricultural Supply, Demand, and Unmet Demand for the San Joaquin River Hydrologic Region



Note: TAF = thousand acre-feet. In the upper part of the figure, the black line indicates demand, and vertical bars indicate annual supply (top) and unmet demand (bottom). This simulation is for the historical climate and CTP-CTD land use scenario.

Friant. The additional targeted flows are met in less than half of all months at Stanislaus (Goodwin) across all futures.

The CWP examined the urban and agricultural sectors that were the most vulnerable across the future scenarios by evaluating which future conditions would lead to low agricultural reliability in the San Joaquin Hydrologic Region and low urban and agricultural reliability in the Tulare Lake Hydrologic Region. This analysis considered less than 95-percent reliability as representative of a management vulnerability. For San Joaquin River agriculture, reliability is less than 95 percent in about 36 percent of the futures. Tulare Lake's urban and agricultural sectors are less than 95 percent reliable in 30 percent and 95 percent of futures evaluated, respectively. Using statistical analysis, the CWP identified that the two most important factors driving low-reliability outcomes are futures with high temperature and low precipitation in future decades. The specific growth scenarios (variations in population and land use density) are of secondary importance. Figures 5-14, 5-15, and 5-16 show reliability results graphed against the temperature trend (vertical axis) and change from historical precipitation levels (horizontal axis) of each simulation. In these graphs, X's are those results that are less than 95 percent reliable and O's are those that are more than 95 percent reliable. For the agricultural sector in the San Joaquin Hydrologic Region, low-reliability results correspond to the climate scenarios in which temperature is greater than 62.9 degrees and precipitation declines more than 5 percent from historical levels (Figure 5-14).

For the urban sector in the Tulare Lake Hydrologic Region, population growth partially explains the conditions that lead to low reliability. In Figure 5-15, the X's and O's show reliability results for the high-population/low-density growth scenario — one that leads to higher urban demand. For this growth scenario, 8 of 10 low-reliability outcomes correspond to conditions that are equal

Table 5-4 Reliability Thresholds

Hydrologic Region	Urban Sector	Agricultural Sector
Sacramento River	98%	90%
San Joaquin River	98%	85%
Tulare Lake	98%	80%

to or warmer than historical conditions and are more than 4 percent drier (colored region of the figure). Under a growth scenario in which urban demands are lower — the low-population/high-density growth scenario — there are only five low-reliability outcomes, and four of the five occur when conditions are much warmer and drier (up and to the left of the dashed lines in figure).

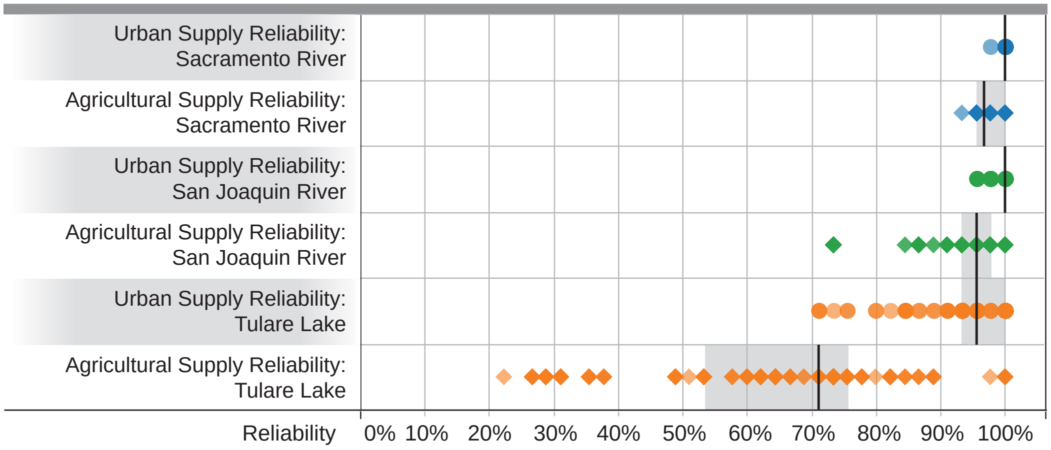
In the agricultural sector for the Tulare Lake Hydrologic Region, almost all futures are low reliability (less than 95 percent). Figure 5-16 shows results for the current trends in population and density land-use scenarios. In this graphic, each symbol averages the reliability results for each climate scenario across the nine growth scenarios. All but one climate scenario leads to low reliability, and reliability generally declines for warmer and dryer climate conditions (upper left). The warmest and driest climate conditions lead to reliability below 50 percent. These results clearly indicate that the agricultural sector within the Tulare Lake Hydrologic Region will likely continue to experience low-supply reliability, and perhaps extreme reliability problems, without additional water management strategies.

In summary, the Sacramento River Hydrologic Region is projected to remain highly reliable, with stable groundwater storage levels in most futures evaluated — even under alternative climate change projections. For the San Joaquin River Hydrologic Region, however, significant shortages would occur in the agricultural sector under climate conditions that are modestly warmer and slightly drier than experienced historically. For the Tulare Lake Hydrologic Region, urban supply reliability is below 95 percent in many futures, particularly those with warmer and drier conditions, and where high population growth is combined with low land-use density. For the agricultural sector, reliability is consistently below 95 percent and dips lower than 50 percent in the hottest and driest climate scenarios.

Evaluation of Management Response Packages

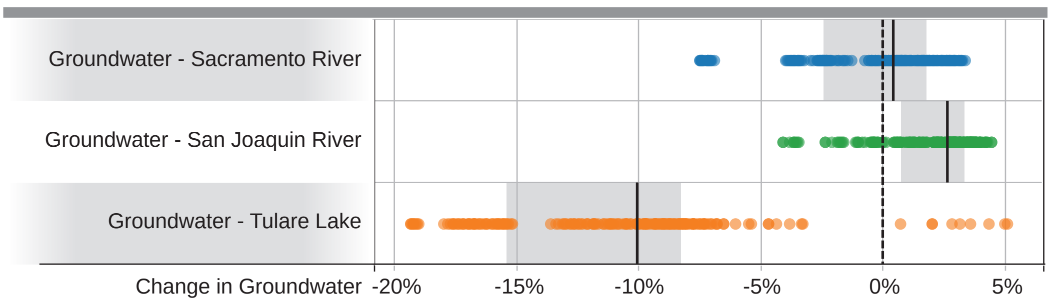
The CWP evaluated how implementing alternative mixes of resource management strategies could reduce the Central Valley vulnerabilities described above. The focus of this analysis was on the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions. Management response packages are each comprised of a mix of resource management strategies selected from Volume 3 and implemented at different investment levels and locations. These response packages do not represent a definitive set of alternatives; instead, they illustrate different levels of strategy diversification that could be taken to address water management challenges. Table 5-5 describes the currently planned management baseline and five response packages that were evaluated. They are designed to incrementally increase in diversification in each subsequent diversification level. The first two add strategies that can be implemented locally, such as water use efficiency, and that require some regional coordination and infrastructure investment, such as conjunctive management and recycled municipal water. Diversification Levels 3-5 all include additional

Figure 5-11 **Range of Urban and Agricultural Reliability Results Across Futures**



Note: Circles indicate urban reliability results, and diamonds indicate agricultural reliability results. Blue, green, and orange symbols correspond to results for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, respectively.

Figure 5-12 **Range of Groundwater Storage Changes Across Futures**



Note: Blue, green, and orange symbols correspond to results for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, respectively.

strategies designed to meet new environmental flow targets, increase water use efficiency and lead to the recovery of the region's groundwater basins. Box 5-5 provides a discussion on including new surface storage as part of the response packages.

Figure 5-17 summarizes changes in urban and agricultural reliability among diversification levels as additional management response packages are implemented. These additional response packages are shown from one diversification level to the next:

- Currently Planned Management to Diversification Level 2 — increasing urban and agricultural efficiency, water reuse, and conjunctive management.
- Diversification Level 2 to Diversification Level 3 — adding additional environmental flow and groundwater recovery targets.
- Diversification Level 3 to Diversification Level 5 — adding even more efficiency and conjunctive management.

In the graphics contained in Figure 5-17, each symbol represents a pair of results for one of 66 futures, those for three growth scenarios and 22 climate scenarios. The narrower, lighter end

Figure 5-13 Range of Reliability for Environmental Flow Objectives Across Futures

Note: Circles correspond to IRFs and diamonds correspond to EFTs. The color of the symbols indicates the hydrologic region — Sacramento River (blue) and San Joaquin River (green). The Trinity River (brown) below Lewiston is located in the North Coast Hydrologic Region and is included in the Central Valley WEAP model in relation to imports to the Sacramento River Hydrologic Region.

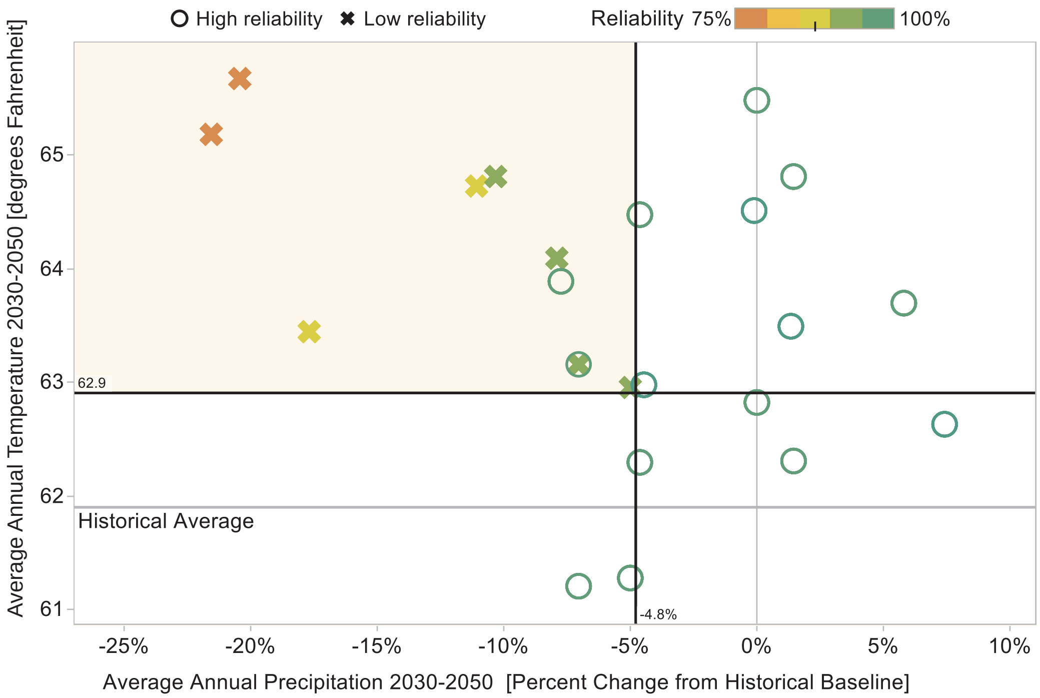
marks the result for the first response package and the thicker, darker end marks the result for the second response package. The horizontal position indicates urban supply reliability and the vertical position indicates agricultural supply reliability. The dashed lines mark the 95-percent reliability threshold, below which any percentage of reliability is considered low.

Across all response package comparisons, bigger changes are observed in the Tulare Lake Hydrologic Region than in the San Joaquin River Hydrologic Region, reflecting lower baseline reliability in the Tulare Lake Hydrologic Region. The efficiency increases in Diversification Level 2 significantly improve reliability in both the urban and agricultural sectors in the Tulare Lake Hydrologic Region. The additional environmental and groundwater flow targets in Diversification Level 3, however, reverse some of these improvements and lead to lower reliability for many futures. As described below, concurrent improvements are seen in groundwater storage and environmental flows with Diversification Level 3. Lastly, the additional efficiency and conjunctive management in Diversification Level 5 once again improve reliability across both sectors, close to the levels achieved with Diversification Level 3.

To summarize results across the 66 futures evaluated (three bounding growth scenarios multiplied by 22 climate scenarios), the following summary metrics are used:

- Percentage of futures in which urban supply reliability exceeds 95 percent.
- Percentage of futures in which agricultural supply reliability exceeds 95 percent.

Figure 5-14 Climate Conditions Leading to Low Agricultural Supply Reliability in the San Joaquin River Hydrologic Region

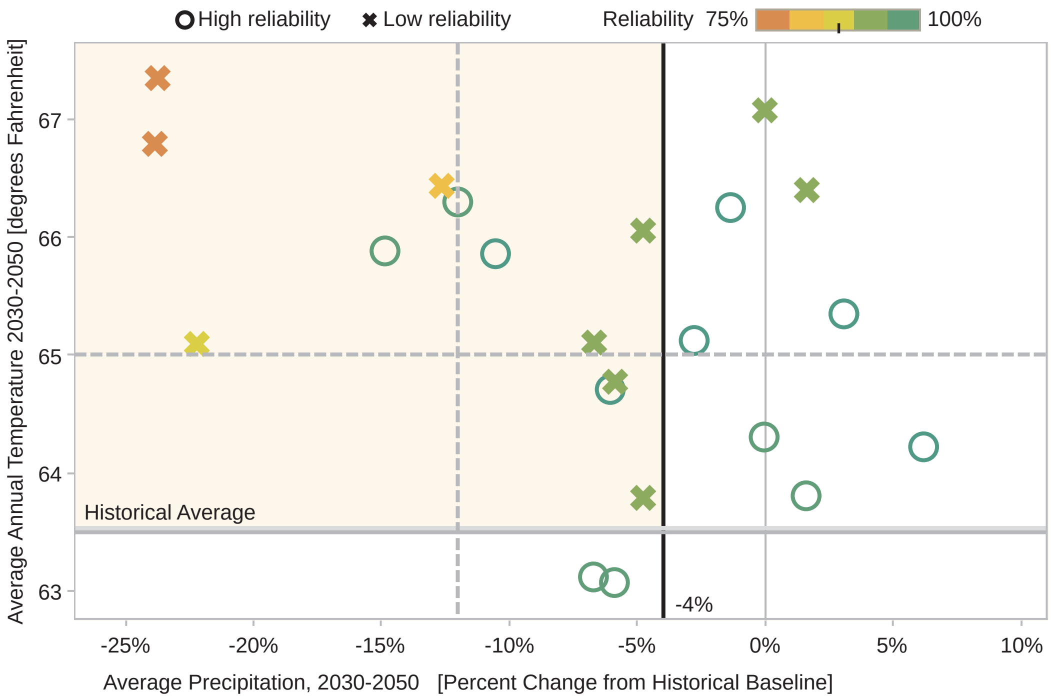


Note: Each point represents one future under the current management baseline strategy. The X's represent futures in which policy objectives are not met, and O's represent futures in which policy objectives are met. The color of the symbols indicates their reliability. The shaded area indicates the climate conditions that generally lead to low reliability. Because there are only 12 unique climate sequences used to generate 36 futures, each combination of temperature trend and change in precipitation represents three results.

- Percentage of futures in which groundwater storage in the last decade of simulation (2041-2050) is less than the starting year.
- Percentage of futures in which flow objective reliability exceeds 95 percent.

Figures 5-18, 5-19, and 5-20 summarize results for each of the diversification levels for these five metrics for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, respectively. The number and color within each square indicates the percentage of futures in which performance is low. For the Sacramento River Hydrologic Region (Figure 5-18), urban supply reliability is high for all futures across all diversification levels. Agricultural reliability declines below the 95-percent vulnerability threshold in about a third of all futures, when additional environmental flow and groundwater recovery targets are implemented (Diversification Level 3). Reliability in about half of these futures recovers with the implementation of strategies in Diversification Level 5. The number of futures with reductions in groundwater storage is reduced from 43 percent to 36 percent with Diversification Level 3. The additional flow targets improve ERPs #1 and #2 — completely eliminating any vulnerability — but the targets do not improve the number of futures in which the additional American (Nimbus) target is reliably met. Implementation costs increase with the significant conservation and recycling implemented in Diversification Level 2 and higher. Note that the cost of adding environmental flow requirements and groundwater reduction targets in Diversification Level 3 are not accounted for in the figure.

Figure 5-15 Climate Conditions Leading to Low Urban Supply Reliability in the Tulare Lake Hydrologic Region for the High-Population and Low-Density Land Use Scenario



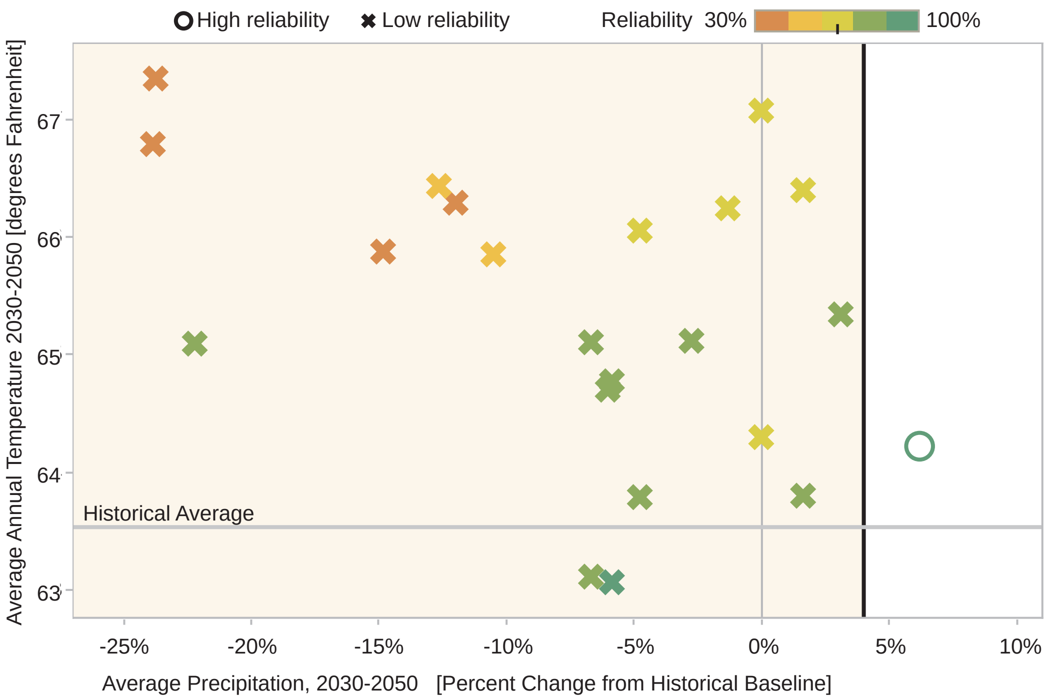
Note: Each point represents one future under the current management baseline strategy. The X's represent futures in which policy objectives are not met, and O's represent futures in which policy objectives are met. The color of the symbols indicates their reliability. The shaded area indicates the climate conditions that generally lead to low reliability. The dotted lines indicate the vulnerable region for the subset of futures based on the low-population/high-density growth scenario.

For the San Joaquin River Hydrologic Region (Figure 5-19), similar patterns are seen across the performance metrics. The management strategies included in the first two diversification levels — efficiency, conjunctive use, and recycling — lead to marked improvements in the percentage of futures in which agricultural supply is reliable and groundwater storage does not decline. The addition of environmental flow and groundwater recovery targets in Diversification Level 3 leads to improvement in groundwater storage and achieves targeted flows at Stanislaus (Goodwin) for all futures. These improvements in groundwater and environmental flows come at the expense of agricultural supply reliability and, to a lesser extent, urban supply reliability. The additional conservation and conjunctive use in Diversification Levels 4 and 5 partially mitigate these effects.

While the inclusion of environmental flow targets in Diversification Levels 3-5 does not reduce the number of futures in which reliability is low for the American (Nimbus) EFT, it does significantly increase the reliability — just not to the 95-percent reliability threshold (see Figure 5-20). By comparison, Diversification Level 3 leads to high reliability for all futures for ERPs #1 and #2 and Stanislaus (Goodwin) targets.

For the Tulare Lake Hydrologic Region (Figure 5-21), the tradeoffs between urban and agricultural reliability and groundwater levels are also clearly evident. Improvements in urban and agricultural supply reliability are realized through Diversification Level 2. While groundwater storage

Figure 5-16 Climate Conditions Leading to Low Agricultural Supply Reliability Results in the Tulare Lake Hydrologic Region



Note: Each point represents the average reliability result for the nine growth scenarios for one climate scenario under the current management baseline strategy. The X's represent futures in which policy objectives are not met, and O's represent futures in which policy objectives are met. The color of the symbols indicates their reliability. The shaded area indicates the climate conditions that generally lead to low reliability.

improves considerably with the implementation of groundwater recovery targets and more efficiency in Diversification Levels 3-5, vulnerability in the agricultural sector remains high.

This first-of-its-kind CWP analysis of future vulnerabilities and responses provides several important insights relevant to California water management. First, there are many plausible futures in which the currently planned management strategy would lead to low-reliability outcomes, declining groundwater conditions, and lower-than-desired environmental flows. For the San Joaquin River agricultural sector, favorable climate conditions (i.e., cooler and wetter) would lead to improvements, but many plausible future climate conditions would further degrade conditions. In Tulare Lake, even more plausible future conditions lead to vulnerabilities, particularly for the agricultural sector.

Implementation of additional water management diversification through increased water-use efficiency, conjunctive use, and recycling can clearly hedge against future climate and demographic uncertainties. Balancing the additional goals of improvements in groundwater storage and environmental flows, however, requires additional investment in resource management strategies. Specifically, implementing groundwater and environmental flow targets improve some (but not all) groundwater and flow objectives, but requires even more additional conservation and conjunctive management to maintain urban and agricultural reliability. Lastly, the analysis shows that agricultural supply reliability in Tulare Lake will be unreliable in all but

Table 5-5 Resource Management Strategies Used in Plan of Study

Management Baseline or Response Package	Resource Management Strategy						
	URBAN WATER-USE EFFICIENCY	AG WATER-USE EFFICIENCY	RECYCLED MUNICIPAL WATER	CONJUNCTIVE MANAGEMENT AND GROUNDWATER		ECOSYSTEM RESTORATION	SURFACE STORAGE
				Groundwater Banking	Groundwater Recovery Targets	Environmental Flow Targets	
Currently Planned Management	20% by 2020	Current	Current	Current	Limit: Historical low	Flow requirements	**This strategy could not be evaluated as part of the Central Valley Vulnerability Assessment (See Box 5-5).**
Diversification Level 1	20% by 2020; 30% by 2030	10%, by 2020	Current	Current	Limit: Historical low	Flow requirements	
Diversification Level 2	20% by 2020; 30% by 2030	10%, by 2020	50% recycled water use, by 2030	Up to 20 taf/month/ planning area, beginning in 2020	Limit: Historical low	Flow requirements	
Diversification Level 3	20% by 2020; 30%, by 2030	10%, by 2020	50% recycled water use, by 2030	Up to 20 taf/month/ planning area in SOD, beginning in 2020	Limit: Average of historical low and initial levels in WMM, beginning in 2015	Flow requirements plus additional targets, beginning in 2015	
Diversification Level 4	30% by 2030 30% by 2030; 35% by 2040	10%, by 2020; 15%, by 2030	50% recycled water use, by 2030	Up to 40 taf/month/ planning area in SOD, beginning in 2020	Limit: Average of historical low and initial levels in WMM, beginning in 2015	Flow requirements plus additional targets, beginning in 2015	

Management Baseline or Response Package	Resource Management Strategy						
	URBAN WATER-USE EFFICIENCY	AG WATER-USE EFFICIENCY	RECYCLED MUNICIPAL WATER	CONJUNCTIVE MANAGEMENT AND GROUNDWATER		ECOSYSTEM RESTORATION	SURFACE STORAGE
				Groundwater Banking	Groundwater Recovery Targets	Environmental Flow Targets	
Diversification Level 5	30% by 2030; 30% by 2030; 40% by 2040	10% by 2020; 20% by 2030	50% recycled water use, by 2030	Up to 40 taf/month/ planning area in SOD, beginning in 2020	Limit: Average of historical low and initial levels in WMM, beginning in 2015	Flow requirements plus additional targets, beginning in 2015	

Notes:

taf = thousand acre-feet, SOD = South of Delta, WMM = water management model

Shading denotes relative levels of effort for each strategy.

Box 5-5 Analyzing Surface Storage and Delta Conveyance as Management Responses

There is a high level of interest by many stakeholders in evaluating new surface storage and conveyance improvements in the Sacramento-San Joaquin Delta (Delta) to help address California's water management problems. The limitations of the Central Valley Application of the Water Evaluation and Planning (WEAP) model precluded the evaluation of new surface storage or Delta conveyance options as part of the vulnerability and response package analysis performed for the California Water Plan (CWP). Additional improvements to the Central Valley WEAP application are needed to fully reflect operations of the Delta, reflect demands occurring in Delta export areas located outside the Central Valley, and accurately represent ecosystem performance metrics. New storage and conveyance may be highly complementary to the resource management strategies that were ready for the analysis performed for CWP Update 2013. The potential benefits, costs, and issues for new surface storage are described in Chapters 13 and 14 of Volume 3, *Resource Management Strategies*, and for new conveyance in Chapters 5 and 6 of that volume.

the most optimistic climate conditions, even with full implementation of the strategies included here. The addition of strategies not included in this analysis, such as surface storage, may be required to reduce these vulnerabilities.

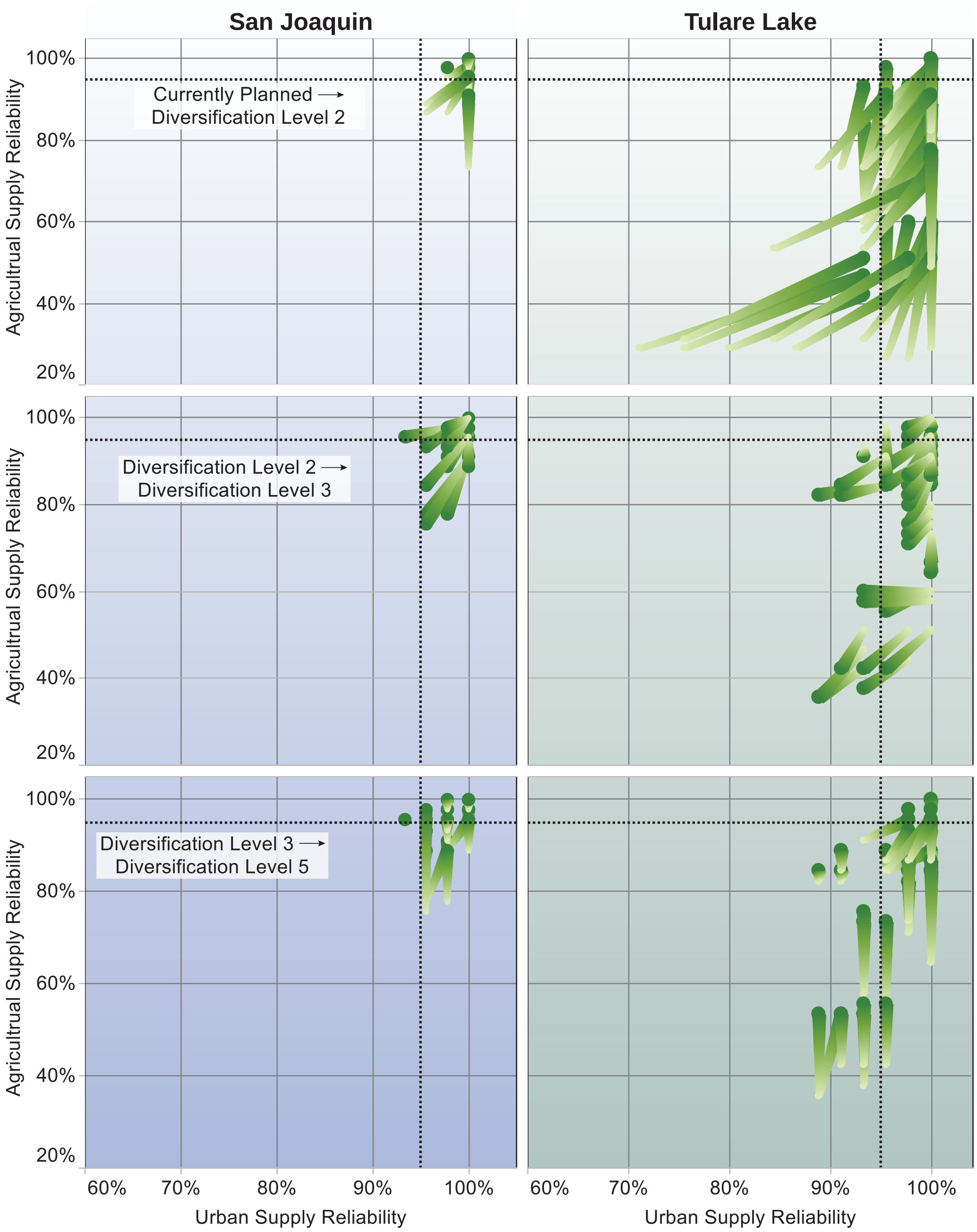
Statewide 2050 Water Demands

The section above describes a vulnerability assessment for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, which was conducted to demonstrate application of RDM techniques. In this section, a description is provided for how future statewide water demands might change under scenarios organized around themes of growth and climate change described earlier in this chapter. The change in water demand from 2006 to 2050 is estimated for each hydrologic region for agriculture and urban sectors under nine growth scenarios and 13 scenarios of future climate change. The climate change scenarios included the 12 CAT scenarios described earlier in this chapter and a thirteenth scenario representing a repeat of the historical climate (1962-2006) to evaluate a "without climate change" condition.

Figure 5-22 shows the change in statewide water demands for the urban and agricultural sectors under nine growth scenarios, with variation shown across 13 climate scenarios. The nine growth scenarios include three alternative population growth projections and three alternative urban-land development densities, as shown in Table 5-1. The change in water demand is the difference between the historical average for 1998 to 2005 and future average for 2043 to 2050. Urban demand is the sum of indoor and outdoor water demand, where indoor demand is assumed not to be affected by climate. Outdoor demand, however, depends on such climate factors as the amount of precipitation falling and the average air temperature. Figure 5-22 shows the change in water demand under a repeat of historical climate and a range representing 12 scenarios of future climate change. The net change in water demand for the sum of the urban and agricultural sectors is shown at the top of the figure.

Urban demand increased under all nine growth scenarios, consistent with population growth. On average, urban demand increased by about 1.3 million acre-feet (maf) under the three low-population scenarios, 2.9 maf under the three current-trend population scenarios, and about 6.1 maf under the three high-population scenarios, when compared with the historical average of 8.2

Figure 5-17 Change in Urban and Agricultural Supply Reliability as Additional Response Packages Are Implemented for the San Joaquin River Hydrologic Region (left panel) and Tulare Lake Hydrologic Region (right panel)



Note: Each line shows results corresponding to two different response packages, with the darker end corresponding to the second response package. The dotted lines indicate the vulnerability thresholds used to summarize results across the ensemble of futures.

Figure 5-18 Percentage of Scenarios Showing Unacceptable Outcomes for Selected Performance Metrics Across Different Response Packages for the Sacramento River Hydrologic Region

	Urban Supply Reliability	Agricultural Supply Reliability	Groundwater Change	Trinity below Lewston [IFR]	American (Nimbus) [IFR]	American (Nimbus) [EFT]	ERP #1 and #2 [EFT]	ERP #4, Freeport [EFT]	Average Annual Cost Above Current Plan
Currently Planned	0%	0%	42%	0%	0%	100%	14%	0%	$0.0M
Diversification Level 1	0%	0%	36%	0%	0%	100%	9%	0%	$106.6M
Diversification Level 2	0%	0%	36%	0%	0%	100%	9%	0%	$108.1M
Diversification Level 3	0%	36%	30%	0%	0%	100%	0%	0%	$108.1M
Diversification Level 4	0%	19%	27%	0%	0%	100%	0%	0%	$204.0M
Diversification Level 5	0%	15%	25%	0%	0%	100%	0%	0%	$304.0M

[IFR] = instream flow requirement [EFT] = environmental flow target

Note: Numbers and color indicate the percentage of 88 futures in which the currently planned management is vulnerable. The urban and agricultural sectors are vulnerable if they are less than 95 percent reliable. Groundwater change is vulnerable if it is negative. IFR and EFT metrics are vulnerable if they are less than 95 percent reliable.

maf. The results show that change in future urban water demands is less sensitive to housing density assumptions or climate change than to assumptions about future population growth.

Agricultural water demand decreases under all future scenarios owing to reduction in irrigated lands as a result of urbanization and background water conservation, when compared with historical average water demand of 30.2 maf. Under the three low-population scenarios, the average reduction in water demand was about 3.0 maf, while it was about 4.3 maf for the three high-population scenarios. For the three current trend population scenarios, this change was about 3.6 maf. The results show that low-density housing would result in more reduction in agricultural water demand because more agricultural lands are lost under low-density housing than high-density housing.

Figure 5-23 depicts the change in water demand for the agricultural and urban sectors for each of the 10 hydrologic regions. For each of the nine growth scenarios shown in Table 5-1, change in water demand was determined based on a repeat of a historical climate pattern and for 12 alternative scenarios of future climate change. It is evident from Figure 5-23 that future climate change presents a significant uncertainty with respect to future water demands. All regions show an increase in urban water demands and decrease in agricultural water demands. The South Coast is expected to have the greatest increase in urban water demands in response to population growth. Additional details about the regional water demands can be found in the Volume 2, *Regional Reports*.

Figure 5-19 Percentage of Scenarios Showing Unacceptable Outcomes for Selected Performance Metrics Across Different Response Packages for the San Joaquin River Hydrologic Region

	Urban Supply Reliability	Agricultural Supply Reliability	Groundwater Change	San Joaquin River at Vernalis [IFR]	San Joaquin River below Friant [IFR]	Stanislaus (Goodwin) [IFR]	Stanislaus (Goodwin) [EFT]	Average Annual Cost Above Current Plan
Currently Planned	0%	36%	19%	0%	0%	0%	100%	$0.0M
Diversification Level 1	0%	14%	11%	0%	0%	0%	100%	$103.3M
Diversification Level 2	0%	9%	9%	0%	0%	0%	100%	$146.8M
Diversification Level 3	5%	34%	6%	0%	0%	0%	0%	$147.0M
Diversification Level 4	5%	27%	6%	0%	0%	0%	0%	$227.7M
Diversification Level 5	5%	14%	1%	0%	0%	0%	0%	$396.6M

[IFR] = instream flow requirement [EFT] = environmental flow target

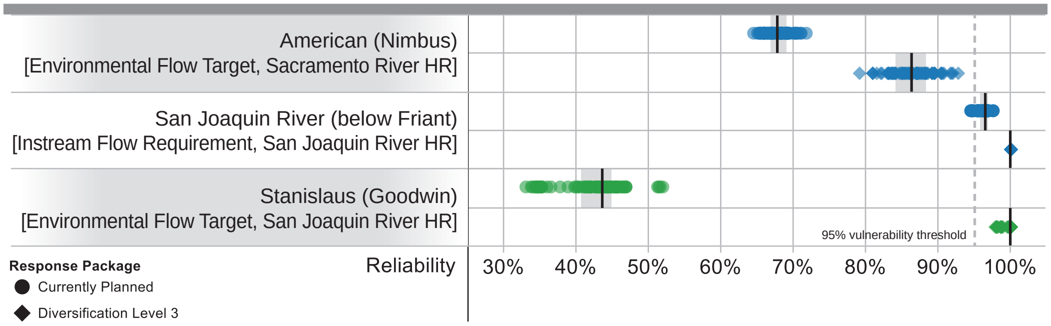
Note: Numbers and color indicate the percentage of 88 futures in which the currently planned management is vulnerable. The urban and agricultural sectors are vulnerable if they are less than 95 percent reliable. Groundwater change is vulnerable if it is negative. IFR and EFT metrics are vulnerable if they are less than 95 percent reliable.

Limitations of Future Water Management Analysis for Update 2013

The analysis of resource management strategies developed for Update 2013 can allow comprehensive analysis of strategy performance when conducted at a sufficient level of detail. However, all technical endeavors are subject to the limits of the particular technology being used and the financial resources available. The following are some of the important limitations the CWP team has identified for the analysis used for Update 2013.

- For Update 2013, DWR tested a vulnerability assessment for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, which included an assessment of water supply, demand, and unmet demand in the urban and agricultural sectors. The analysis for the remaining seven hydrologic regions in California was coarser and focused on quantifying future water demands under alternative future scenarios.
- Many of the resource management strategies identified in Volume 3 can be represented in the Update 2013 application of WEAP, particularly those related to the water management objectives to reduce water demand, improve operational efficiency and transfers, and increase water supply. However, the analysis for Update 2013 had limited ability to none at all with regard to quantifying strategies that improve flood management, improve water quality, and

Figure 5-20 Range of Reliability for Three Environmental Flow Objectives Across Futures for Currently Planned Management and Diversification Level 3



practice resource stewardship. These will be considered as part of future enhancements to the CWP.

- The analysis for Update 2013 quantified some of the resource-management-strategy benefits for providing a supply benefit, improving drought preparedness, providing environmental benefits, improving operational flexibility and efficiency, and reducing groundwater overdraft. There was limited to no ability to quantify benefits for improving water quality, reducing flood impacts, energy benefits, and recreational opportunities. Quantifying these other benefits will be considered as part of future enhancements to the analytical framework.
- The analysis to support the CWP is designed to represent the water management system at a sufficient level of detail to reflect important planning conditions, but not for detailed water project operations or to capture all detailed flows through the system. As a result, many system features, such as groundwater basins, are simplified to capture the broad regional behavior of groundwater recharge, groundwater storage, and hydrologic connection to rivers and lakes. Significant refinement in the analysis will be needed to support decisions by individual water districts.

Managing for Sustainability

With a growing recognition that California's water systems are over allocated — and faced with climate change, growing population, and more stringent environmental requirements — decision-makers, water managers, and planners are becoming increasingly aware of the need to sustainably manage water and respond to changing availability and constraints on water. In Updates 2005 and 2009, the State refocused attention on the sustainability of California's water systems and ecosystems in light of current water management practices and expected future changes. A number of concurrent efforts are underway at the regional, State, and federal levels to manage natural resources more sustainably (see in Volume 4, *Reference Guide*, the article "Managing for Sustainability," for more information). As an illustration, a significant, multi-agency collaborative effort — U.S. EPA California Footprint Sustainability Indicators Suite — is summarized in Box 5-6.

The California Water Sustainability Indicators Framework (CWSIF), developed as part of Update 2013, brings together water sustainability indicators that will provide information regarding water system conditions and their relationships to ecosystems, social systems, and economic systems. Figure 5-24 shows a conceptual representation of the CWSIF, as well as how communities interact to develop sustainability indicators, by using analytical information that ultimately is used to drive our water policy and to inform other end uses.

Figure 5-21 Percentage of Scenarios Showing Unacceptable Outcomes for Selected Performance Metrics Across Different Response Packages for the Tulare Lake Hydrologic Region

	Urban Supply Reliability	Agricultural Supply Reliability	Groundwater Change	Average Annual Cost Above Current Plan
Currently Planned	32%	95%	95%	$0.0M
Diversification Level 1	18%	89%	94%	$171.1M
Diversification Level 2	7%	68%	69%	$212.3M
Diversification Level 3	23%	89%	32%	$212.1M
Diversification Level 4	23%	86%	31%	$350.7M
Diversification Level 5	22%	78%	19%	$546.5M

Note: Numbers and color indicate the percentage of 88 futures in which the currently planned management is vulnerable. The urban and agricultural sectors are vulnerable if they are less than 95 percent reliable. Groundwater change is vulnerable if it is negative.

Sustainability indicators are qualitative or quantitative parameters from monitoring programs (e.g., streamflow) selected to represent parts of ecological, social, or economic systems. (See in Volume 4, *Reference Guide*, the article "California Water Sustainability Indicators Framework.") The evaluation of the sustainability indicators reveals how our actions or inaction can degrade or improve conditions that lead to water sustainability. The CWSIF is built around statements of intent (e.g., objectives) and domains (e.g., water quality). Reporting indicator condition is based on the principle of measuring how far a current condition is from a desired condition. The CWSIF is intended to support reporting of conditions to a wide array of water and environmental stakeholders, the public, and decision-makers to build knowledge and to enhance adaptive decision-making and policy change. A detailed representation of the CWSIF is depicted in Figure 5-25, showing several steps involved with linking sustainability goals and objectives into public policy by using reliable data and scientific information. Both the conceptual and detailed descriptions of the CWSIF (Figures 5-24 and 5-25) highlight the adaptive and collaborative nature of efforts to develop sustainable policies.

Goals and objectives are just one way to organize our thinking about an evaluation of sustainability. Another common approach is to evaluate progress within areas of concern or domains (e.g., ecosystem health). Five domains of natural and human systems are defined for the CWSIF (Table 5-6), which capture most of the environmental, social, and economic concerns about water sustainability: water supply reliability, water quality, ecosystem health, adaptive and sustainable management, and social benefits and equity.

Explicit criteria must be used to select indicators to ensure that the resulting evaluation is robust and usable in decision-making. For Update 2013, about 80 candidate indicators were selected on the basis of the indicator selection criteria, from an extensive review of sustainability and water system indicators around the world and in California. This exercise resulted in a set of candidate indicators that efficiently covered the sustainability objectives, while also covering the five

Figure 5-22 Change in Statewide Agricultural and Urban Water Demands for 117 Scenarios from 2006-2050 (million acre-feet per year)

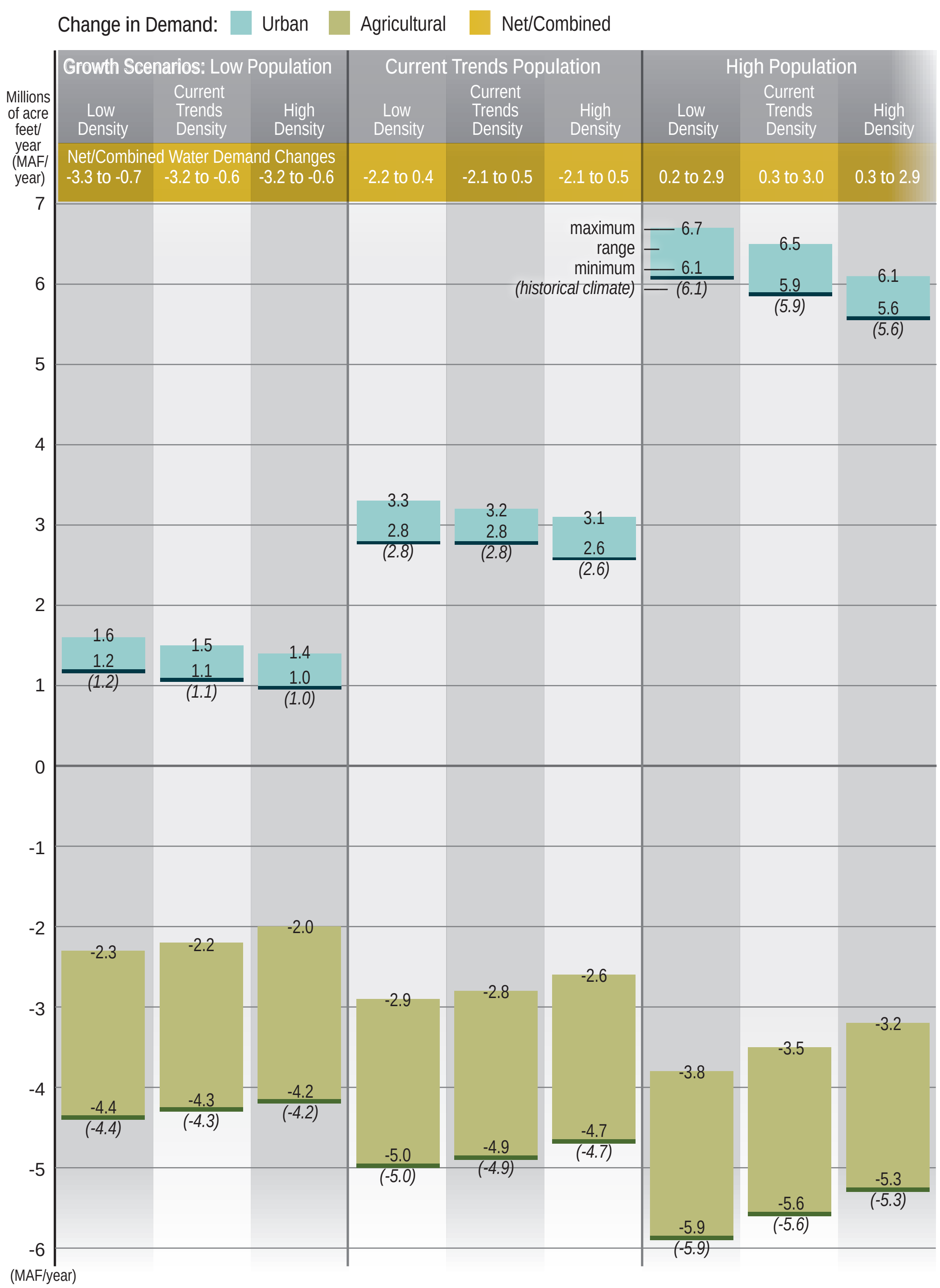
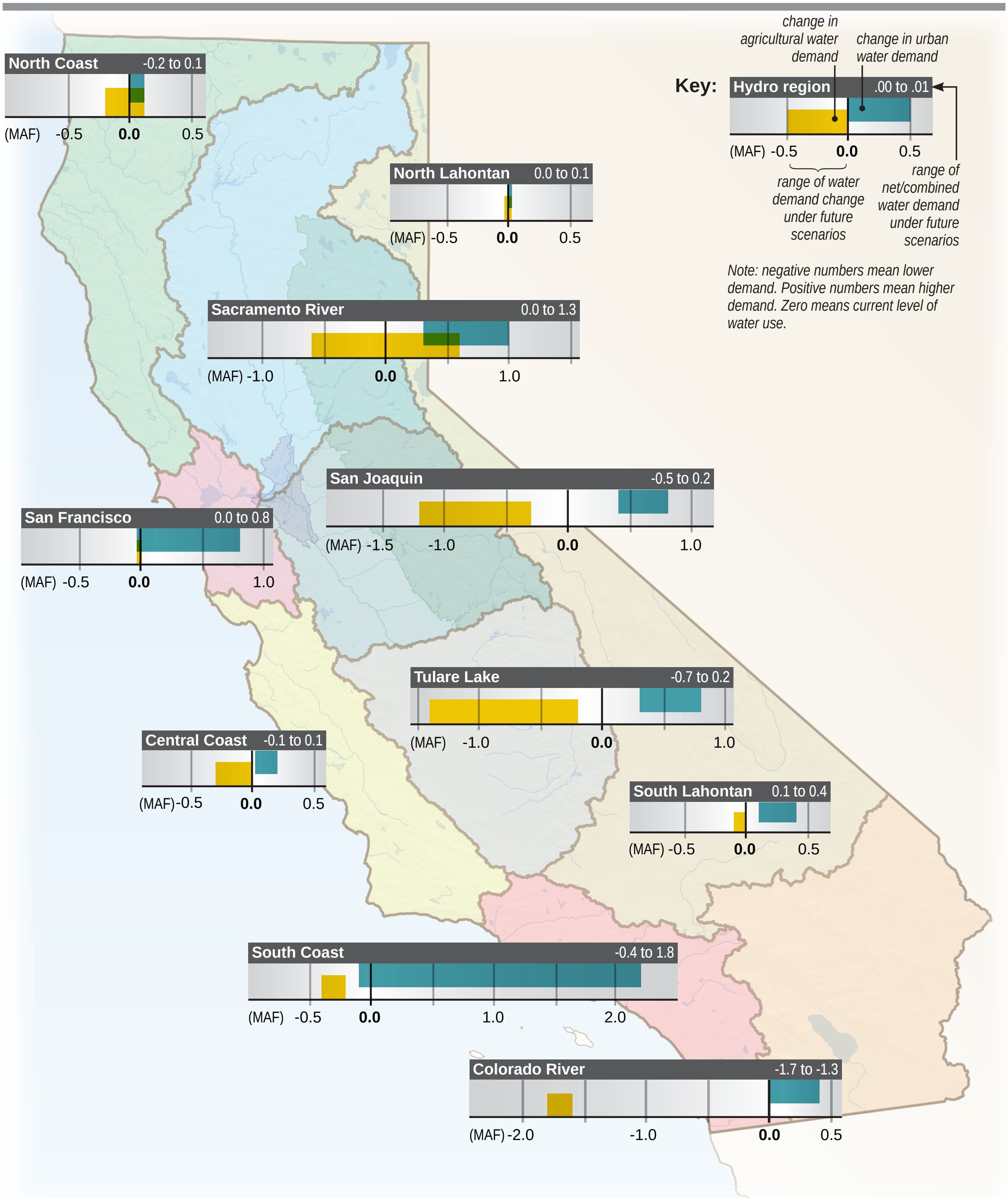


Figure 5-23 Change in Regional Agricultural and Urban Water Demands for 117 Scenarios from 2006-2050 (million acre-feet per year)



Box 5-6 U.S. EPA California Footprint Sustainability Indicators Suite

U.S. Environmental Protection Agency (EPA) Region 9 undertook the California Footprint Sustainability Indicators Suite to document such challenges as increasing population, aging infrastructure, depleting groundwater, degraded ecosystems, and a changing climate. The product includes the California Water Sustainability Indicators Framework, which involves the development of water sustainability indicators, water footprint, and a decision-support tool. A water footprint and an ecological footprint at a state scale have been developed for the first time to pilot the Decision Support Tool as a Global Earth Observation System of Systems project. The indicators suite also includes statewide indicators derived from satellite remote-sensing data -— a plant growth index and a total water and groundwater flux indicator with supporting data from the National Aeronautics and Space Administration's (NASA's) Gravity Recovery and Climate Experiment (GRACE). The project was funded by the EPA's Advance Monitoring Initiative and the California Department of Water Resources (DWR). Collaborators include the EPA's Office of Research and Development, DWR, University of California, Davis, the Pacific Institute, NASA's Jet Propulsion Laboratory, California State University, Monterey Bay, and the U.S. Geological Survey.

domains (e.g., water quality). The selected indicators are listed in Volume 4, *Reference Guide*, in Appendix D of the article "California Water Sustainability Indicators Framework."

Testing Sustainability Indicators with Pilot Studies

To assess the usefulness of the CWSIF for measuring water sustainability, it was tested at the state and regional scales. Draft sustainability goals and objectives were developed, based on Update 2009 objectives and resource management strategies. Indicators corresponding to the goals and objectives were chosen from the global literature and previous guidance in the CWP and other State planning documents. In the case of the State pilot, the sustainability goals and objectives, as well as the candidate indicators, were presented to various Update 2013 stakeholder forums, including the sustainability indicators interagency workgroup, State Agency Steering Committee, Public Advisory Committee, and Tribal Advisory Committee. The background, methods, results, and data downloads for the state and regional scale analyses are available at http://indicators.ucdavis.edu.

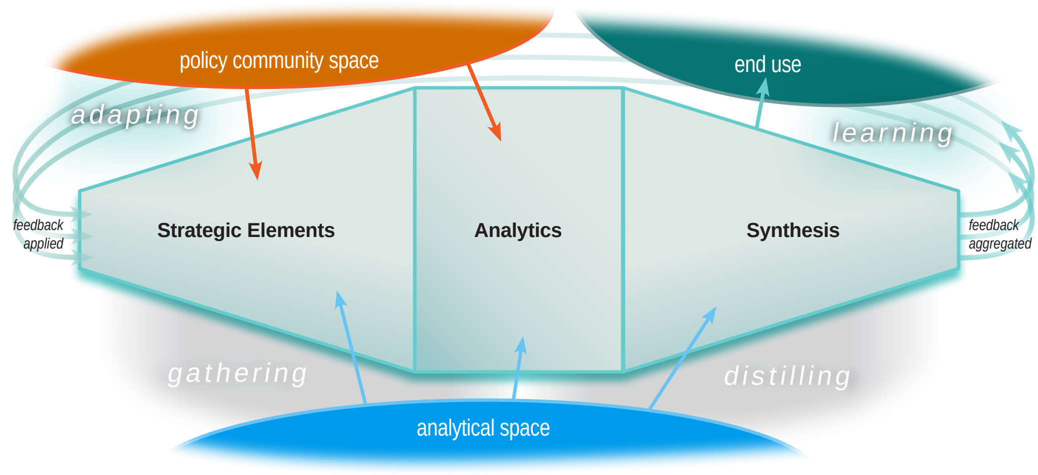
Statewide Pilot

Water sustainability indicators were evaluated at varying levels of specificity across the state, with the unit area of analysis depending on the specific indicator and data availability. For example, the water footprint and public perceptions of water management are measured at the state scale, whereas groundwater quality is measured at the well scale. Indicator evaluation included a conversion of the data to an equivalent sustainability score. The scores were calculated at the unit area of analysis, as well as being aggregated to each of the 10 hydrologic regions. The sections that follow include discussion of this analysis organized around the five water sustainability domains (see Table 5-6).

Water Footprint

A preliminary assessment has been conducted for California's Water Footprint. The Water Footprint can help identify water-related risks associated with California's consumption patterns.

Figure 5-24 **Conceptual California Water Sustainability Indicators Framework**

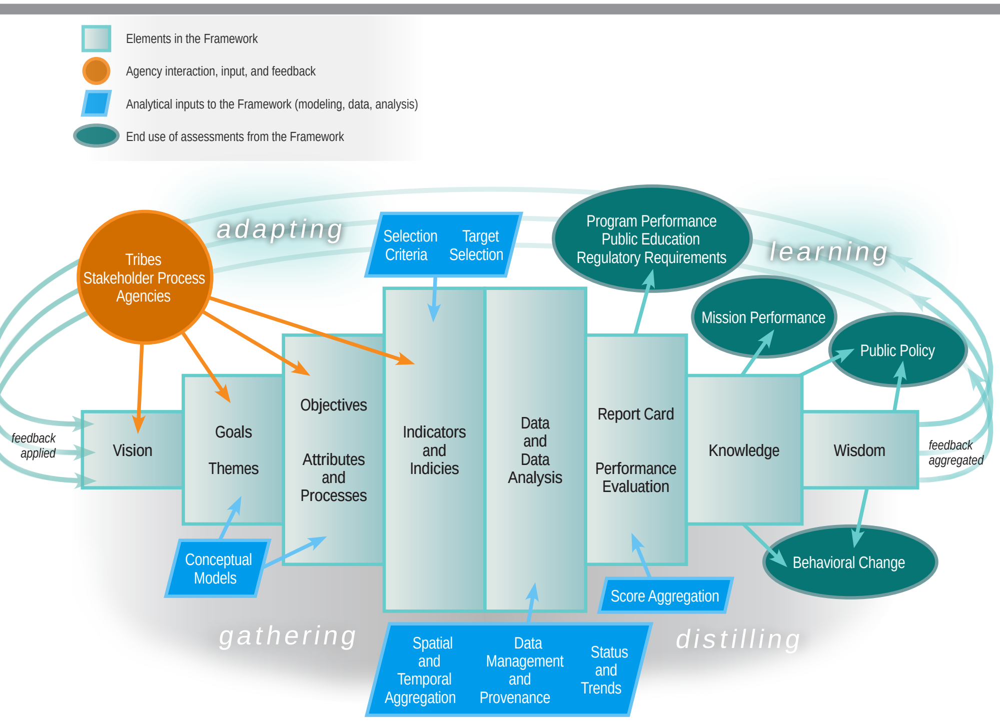


This risk results in part from the energy and hydraulic systems that distribute water, but also from changing hydrologic and ecologic conditions in California and in places that produce goods and services consumed in the state. By demonstrating the degree to which our state has externalized its Water Footprint by importing water-intensive goods, the Water Footprint analysis may encourage State and regional water strategic plans to consider the vulnerability associated with water-import dependency. The Water Footprint comprises three functions of water, each labeled by color: green water, blue water, and grey water. Green water is the amount of precipitation and soil moisture that is directly consumed in an activity, such as in growing crops. Blue water is the amount of surface or groundwater that is applied and consumed in an activity, such as in growing crops or manufacturing an industrial good. Finally, grey water is the amount of water needed to assimilate pollutants from a production process back into water bodies at levels that meet governing standards, regardless of whether those standards are actually met.

The current assessment estimates that California's overall Water Footprint — a measure of the total volume of freshwater that is used to produce the goods and services consumed by Californians — is 100 maf per year (Figure 5-26). This estimate represents the total amount of water used to support California's population and includes water for producing agricultural and industrial goods and energy products, as well as for residential, commercial, and institutional purposes. Nearly 20 percent of the total Water Footprint, or 20 maf, is associated with goods produced and consumed in California, which is referred to as California's Internal Water Footprint. About 80 percent of California's Water Footprint (80 maf) is associated with goods that are consumed in California but are produced outside of the state, and this is referred to as California's External Water Footprint. The majority of California's External Water Footprint relates to goods imported from other states and to a lesser degree from California's major foreign trading partners (e.g., Mexico, Canada, China). (See Box 5-7 for additional information about the Water Footprint as an index of sustainability.)

California's Water Footprint pertaining to the consumption of energy products within the state (herein "Energy Water Footprint") was also assessed. Figure 5-27 shows the amount of water required to produce the energy consumed in California between 1990 and 2008. As shown in Figure 5-27, before 2003, California's Energy Water Footprint was about 1.5 maf. During this

Figure 5-25 Details of the California Water Sustainability Indicators Framework



period, methyl tertiary butyl ether (MTBE) was added as an oxygenate to automotive gasoline to reduce air pollution, especially ground-level ozone and smog. By the end of 2002, however, MTBE was banned in California because it was detected in groundwater aquifers around the state. MTBE was replaced with ethanol in 2003. This change, as shown in Figure 5-27, led to a four-fold increase in California's Energy Water Footprint.

In 2008, the most recent year of analysis, the total Energy Water Footprint was 5.6 maf. More than two-thirds of this amount (4.0 maf) was green water, and the remainder (1.6 maf) was blue water. The green water portion of California's Energy Water Footprint is entirely attributable to bioethanol, most of which is blended with gasoline. The blue water portion of bioethanol adds a smaller, yet still significant, amount to California's Energy Water Footprint (0.4 maf). The process of increased blending of bioethanol in California's gasoline has also accelerated an externalization of the state's Energy Water Footprint. Figure 5-28 shows that, from 1990 to 2002, about half of California's Energy Water Footprint was external. In 2008, nearly 90 percent was external. The import of bioethanol from the U.S. Midwest is the primary driver of this phenomenon, though increased imports of other fuels, such as oil and natural gas, have also played a minor role.

Water Quality

Water Quality Index. There are many ways to measure water quality, including physical (e.g., temperature), chemical (e.g., pesticides), and biological (e.g., healthy algal communities) attributes. Water quality is affected by land and water development, as well as by natural processes. Land development leads to runoff of pollutants into local waterways and contributes to the degradation of water quality. One indicator of potential water quality is "impervious cover," which is the proportion of a watershed that has been covered by structures and related

Table 5-6 **Water Sustainability Domains**

Domain Name	Description
Water Supply Reliability	The availability or provision of water of sufficient quantity and quality to meet water needs for health and economic well-being and functioning
Water Quality	The chemical and physical quality of water to meet ecosystem and drinking water standards and requirements
Ecosystem Health	The condition of a natural system, including terrestrial systems interacting with aquatic systems through runoff pathways
Adaptive and Sustainable Management	A management system that can nimbly and appropriately respond to changing conditions and is equitable and representative of the various needs for water in California
Social Benefits and Equity	The health, economic, and equity benefits realized from a well-managed water system, including management of water withdrawal and water renewal

development. Our assessment shows that streams in most hydrologic regions appear to have good water quality (Figure 5-29). Streams in more urbanized regions are more likely to have moderate water quality scores. Averages at the hydrologic regions scale do not reflect local conditions, which may vary from exceptionally good to very degraded. In addition, specific point sources of impacts on water quality from agricultural drainage, for example, are not captured in this approach.

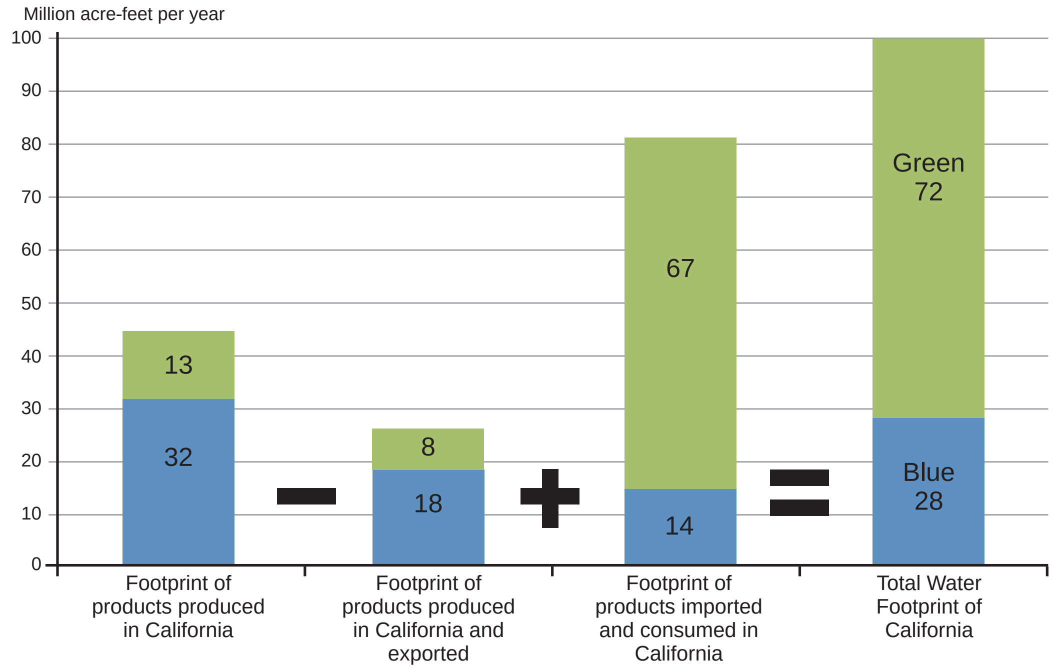
Ecosystem Health

Geomorphic Process. When land is developed, it changes stormwater runoff patterns and timing, constrains and modifies stream channels, and can exacerbate local and regional flooding. As is the case with the water quality index, impervious land cover is an indicator of land development that is useful for understanding modification of geomorphic processes. Streams in the urbanized San Francisco Bay and South Coast hydrologic regions are more likely to experience modified geomorphic processes than are rural and undeveloped areas (Figure 5-30).

California Stream Condition Index. Aquatic ecosystems have many varying attributes and processes that can be used to indicate the condition of the water body relative to standards of ecosystem health. One common attribute used as an index is the composition of fish and invertebrate communities, relative to historic or reference conditions. The California Stream Condition Index was developed by the State Water Resources Control Board (SWRCB) (Mazor et al., in prep.), as a way to estimate aquatic ecosystem health. The index is based on the presence of aquatic invertebrates, which are sensitive to stream disturbance and pollution. The analysis shows that ecosystem health in most regions appears to be good, except in the urbanized San Francisco Bay and South Coast hydrologic regions (Figure 5-31).

Native Fish Communities. Scientists have mapped the current and historic occurrence of most of California's native fish and many non-native fish (Moyle 2002; Santos et al. 2013). The ratio of current ranges to historic ranges was used to calculate a score for fish communities. The analysis shows that in the northern half of California, most fish communities have nearly all native species present. By contrast, in the agricultural Tulare Lake Basin, urban South Coast, and desert regions, many streams have few and sometimes no native fish species (Figure 5-32).

Figure 5-26 California's Blue and Green Water Footprint



Adaptive and Sustainable Management

Public Perception of Water Systems. The public expects clean and readily available water. Their expectation is usually that this public resource will be provided through State and local agencies, using public funds and based on policies that maintain the resource in trust. Measuring public understanding and support for water management and water policies is one proxy measure for how well State and local agencies are stewarding public trust resources. Three metrics were used to gauge public perceptions of current and future water supply management: (1) security of a region's water supply, (2) threat of climate change effects on water availability, and (3) appropriate management strategies to sustainably manage water systems in the future. The data is from surveys conducted by the Public Policy Institute of California (http://www.ppic.org/main/datadepot.asp).

Security of Water Supply. A little over one-third of respondents were very concerned about the current state of water supplies (Figure 5-33), and a similar proportion were concerned about water availability by 2019 (Figure 5-34), though these perceptions varied by region. A lower regional score is illustrative of a higher level of concern about water supply security for the region.

Threat of Climate Change Effects on Water Availability. At least half of the respondents have some level of concern about the effects on future water availability from droughts influenced by climate change (Figure 5-35). This perception varied only slightly by region. A lower regional score is illustrative of a higher level of concern about the threat of climate change in the region.

Future Sustainable Management of Water Systems. When asked about water management to meet future human needs, half of Californians favored managing and using existing supplies

Box 5-7 Water Footprint as an Index of Sustainability

The California Water Plan includes California's Water Footprint as a broad index of demand for water resources by the people of California. The State's water footprint is a measure of the total volume of freshwater that is used to produce the goods and services consumed by Californians. This water use is measured in terms of the volume of water consumed (i.e., evaporated or incorporated into a product) in a given year. The water footprint has an internal and external component. The internal water footprint is the water required to make the goods that are produced and consumed within California, as well as the direct use of water inside the state. The external water footprint includes the water required to make goods in other places that are then imported and consumed in the state.

Monitoring how California's Water Footprint has changed over time can help planners understand how the state's water resources are being used, as well as how its population is being supported by both internal and external water resources. As shown in Figure A, California's Water Footprint has changed dramatically over the past two decades. During this period, the water footprint has doubled, from about 55 million acre-feet (maf) in 1992 to 100 maf in 2010. During this period, California's internal water footprint has declined, while the external water footprint has grown dramatically, suggesting that the state has become increasingly reliant on external water resources. In addition, California's water resources have been increasingly devoted to products that are exported and consumed outside of the state.

Water footprint assessments address the complex ways in which humans interact with natural systems, such as the water cycle. Much of this complexity has to do with the global nature of California's economy, where goods and services are traded across regions, states, and among distant countries. So, for Californians, the goods and services we consume might be produced in many different places around the world. Thus, California affects and is affected by water resource conditions in other countries and other parts of the United States. A change in water availability elsewhere could affect not only California's economy, but also the way water is used here. Hence, the California Water Sustainability Indicators Framework definition of sustainability implies a need to recognize water use not only within California but also in locations where the products consumed in California are produced. The Water Footprint index helps address this complex task in a systematic way and may be used to address important issues related to sustainable water use in the state. For more information on California's Water Footprint, see in Volume 4, Reference Guide, the article and the 2012 report by the Pacific Institute, "Assessment of California's Water Footprint," at http://pacinst.org/publication/assessment-of-californias-water-footprint/.

Figure A California's Water Footprint

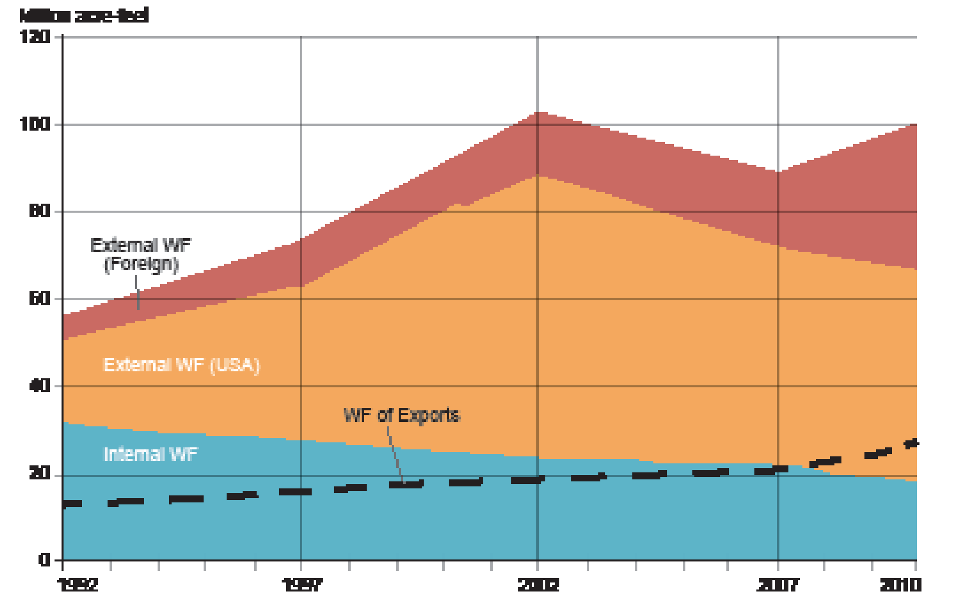


Figure 5-27 California's Energy-Related Blue and Green Water Footprint

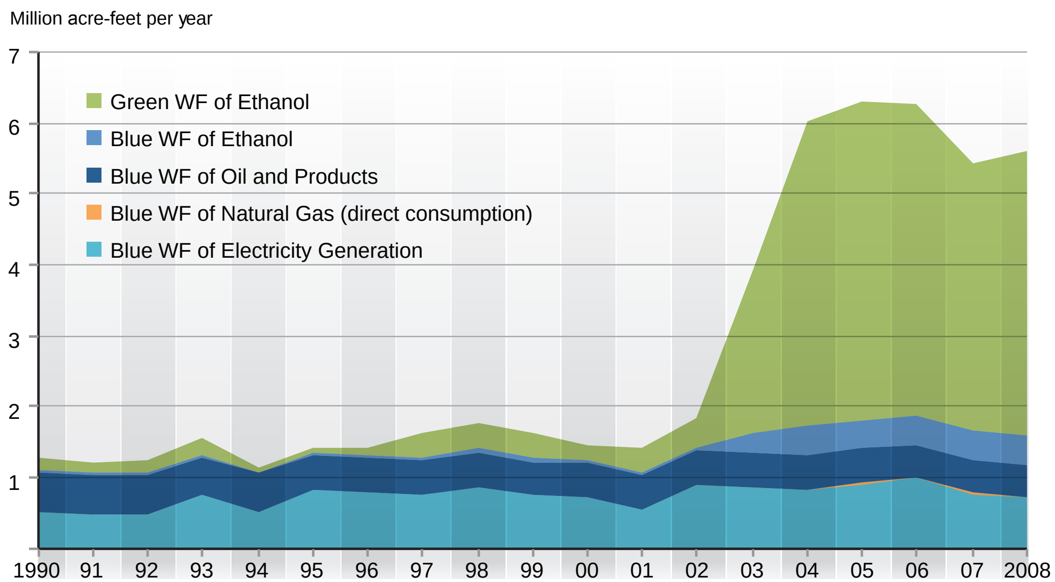
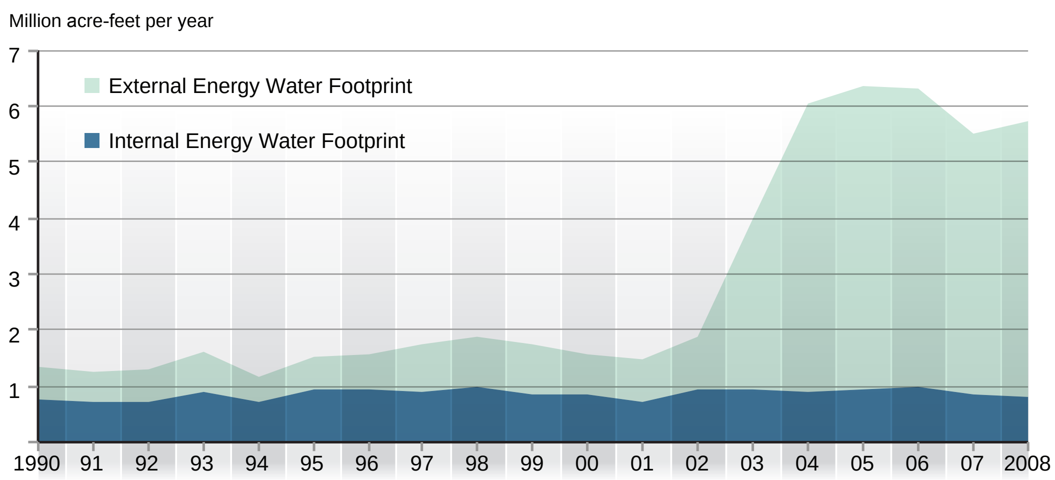


Figure 5-28 California's Energy-Related Internal and External Water Footprint



more efficiently (Figure 5-36). More than half of the people surveyed favored spending more money on improving conditions for native fish, with a third of the people favoring doing so even if their water bills went up (Figure 5-37).

Social Benefits and Equity

Groundwater and Drinking Water Contamination. Water sustainability rests on the principle that people have equitable access to such public-trust resources as water, and disparities in benefits and burdens are minimized. Accordingly, access to clean drinking water is a key component of water sustainability. In California, there are many contaminants that can and

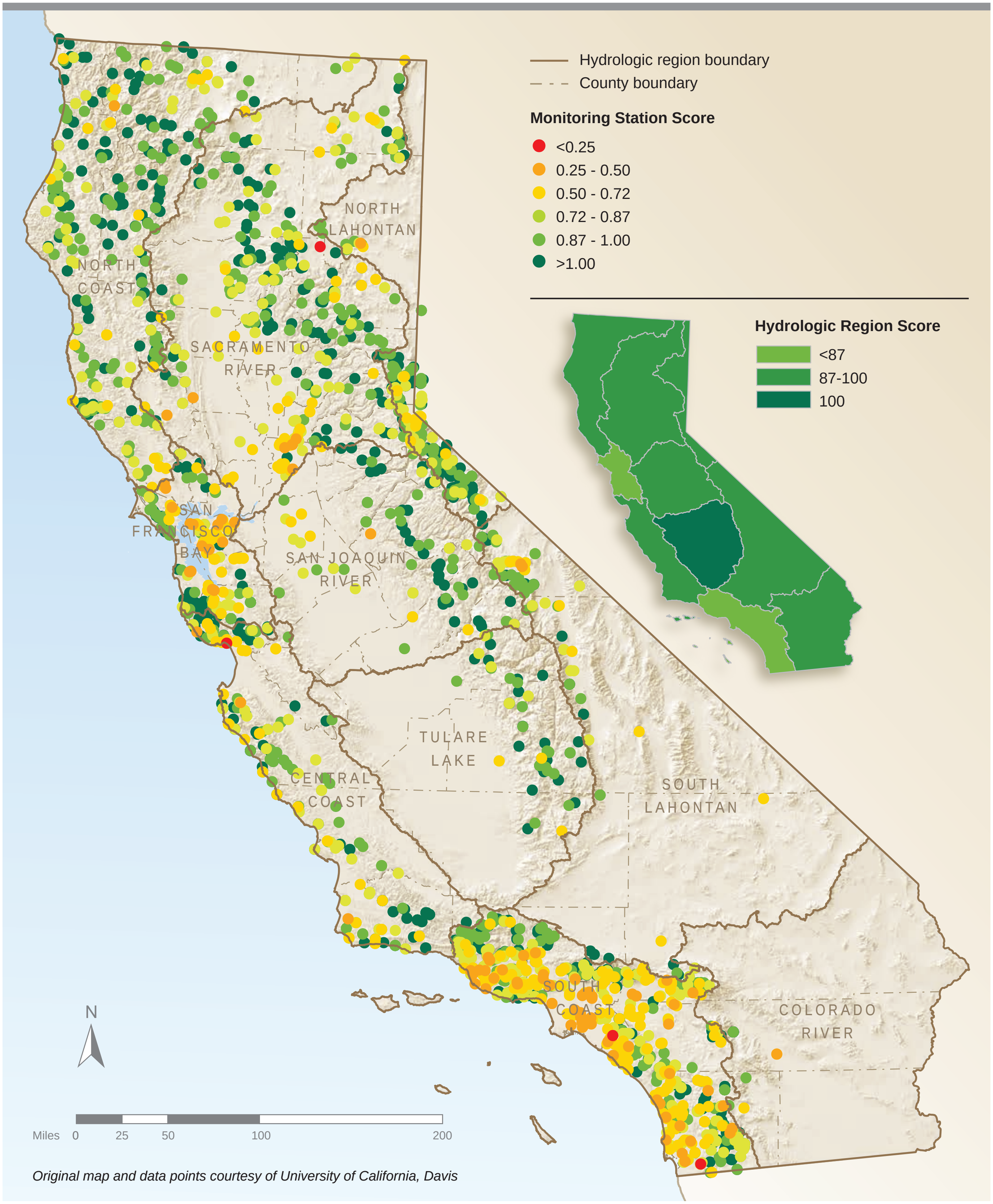
Figure 5-29 Water Quality Index Score for Hydrologic Regions

Original map and data points courtesy of University of California, Davis

Figure 5-30 Geomorphic Process Score for Hydrologic Regions

Original map and data points courtesy of University of California, Davis

Figure 5-31 **California Stream Condition Index Score by Site and for Hydrologic Regions**



Original map and data points courtesy of University of California, Davis

have made their way into groundwater, the primary drinking-water source for the majority of Californians (State Water Resources Control Board 2013). Because contaminant concentrations can be reduced to levels below legal thresholds through mixing with cleaner source-waters and through treatment, most people drink clean water most of the time in California. The California Legislature passed Assembly Bill 2222 in 2008, requiring the SWRCB to report to the Legislature on communities that rely on contaminated groundwater and the principal contaminants in groundwater. Nitrate was identified as the most common groundwater contaminant originating from human activities and was found to be second overall after arsenic. Certain community water services rely exclusively on groundwater and have exceeded maximum contaminant levels (MCLs) for various contaminants at some time during the last 10 years. The presence of nitrates and the reliance on contaminated groundwater are two indicators that can be used to understand where in California groundwater is affected by contaminants. Regions of California vary in both the concentration of nitrates in groundwater and community reliance on contaminated water (Figure 5-38). Inland and coastal agricultural regions have the highest number of communities reliant on contaminated groundwater exceeding the nitrate MCL of 45 milligrams per liter.

Regional Pilot

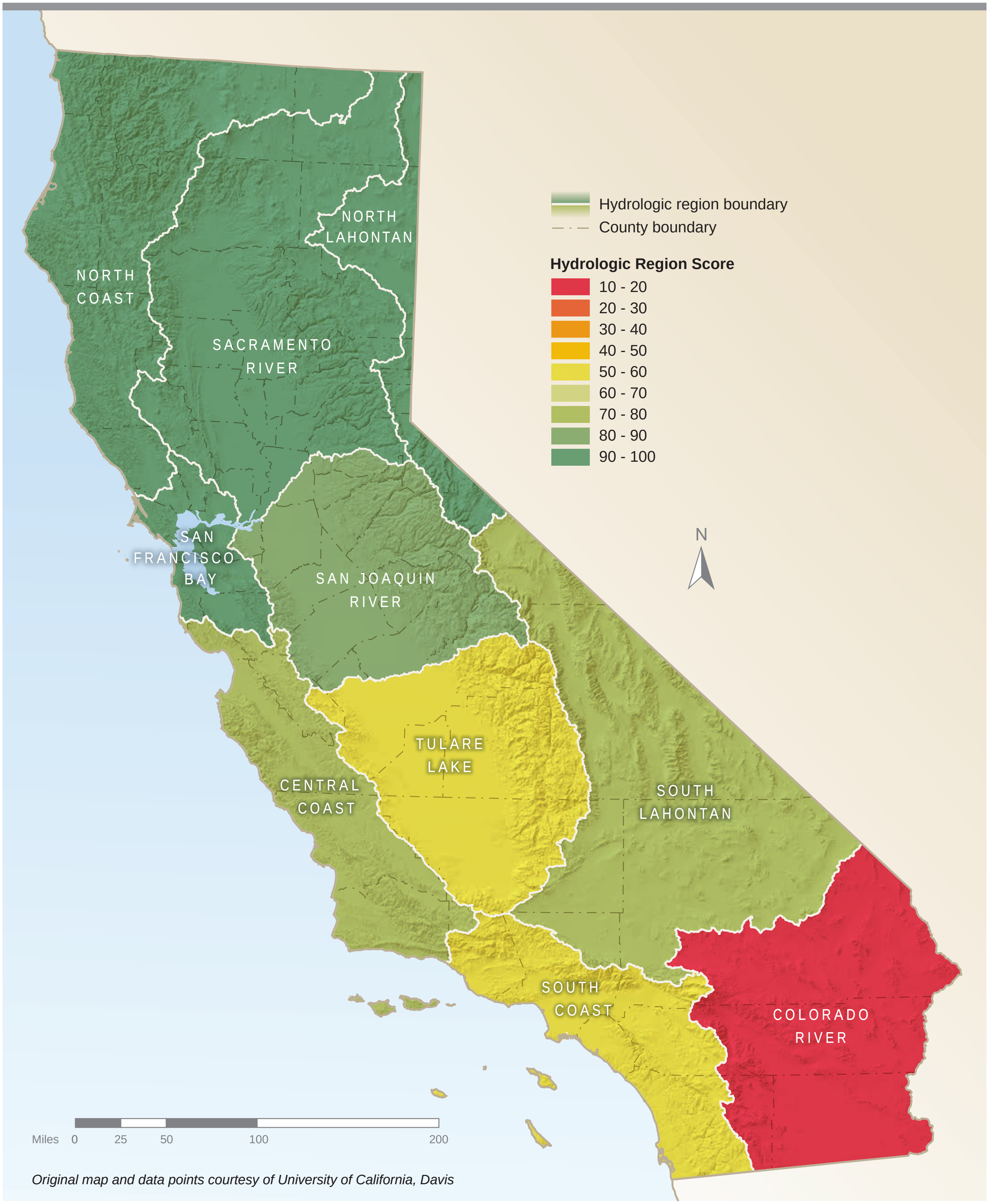
To test the CWSIF at the regional scale, the CWP considered a dozen potential pilot study areas. The Santa Ana Watershed Project Authority (SAWPA) was selected as a willing and able regional pilot partner because of their technical capacity and the fact that they were currently engaging a broad range of stakeholders in regional planning, through their One Water One Watershed 2.0 (OWOW2.0) process (visit http://www.sawpa.org/owow/). The OWOW2.0 process relies on "pillars," which are stakeholder groups focusing on particular issues of regional importance, as well as on advisory committees of member water agencies. In partnership with the SAWPA and the Council for Watershed Health (CWH), goals, objectives, and candidate indicators were developed to test the CWSIF and evaluate water sustainability for the regional pilot. Indicators were selected by the SAWPA and the CWH for the regional scale that had uniform data availability and that corresponded to the OWOW 2.0 goals and objectives. Indicator selection was vetted by the OWOW team and pillars at various stages of development. The findings for the regional pilot are available in Volume 4, *Reference Guide*, in Appendix B of the article "California Water Sustainability Indicators Framework – Final Report."

Summary

IWM is the basis for California's water planning. This umbrella approach recommends that California and its regions consider how a portfolio of resource management strategies, as described in Volume 3, might meet multiple water management objectives, in light of many risks and uncertainties, and ensure sustainable use of water resources. DWR and other entities are conducting various risk assessments so that risks can be better balanced with the rewards for improved management. Update 2013 introduced the CWSIF to ascertain how the objectives of the CWP, associated resource management strategies, and recommended actions would lead to sustainable water use and supply for the state and its 10 hydrologic regions.

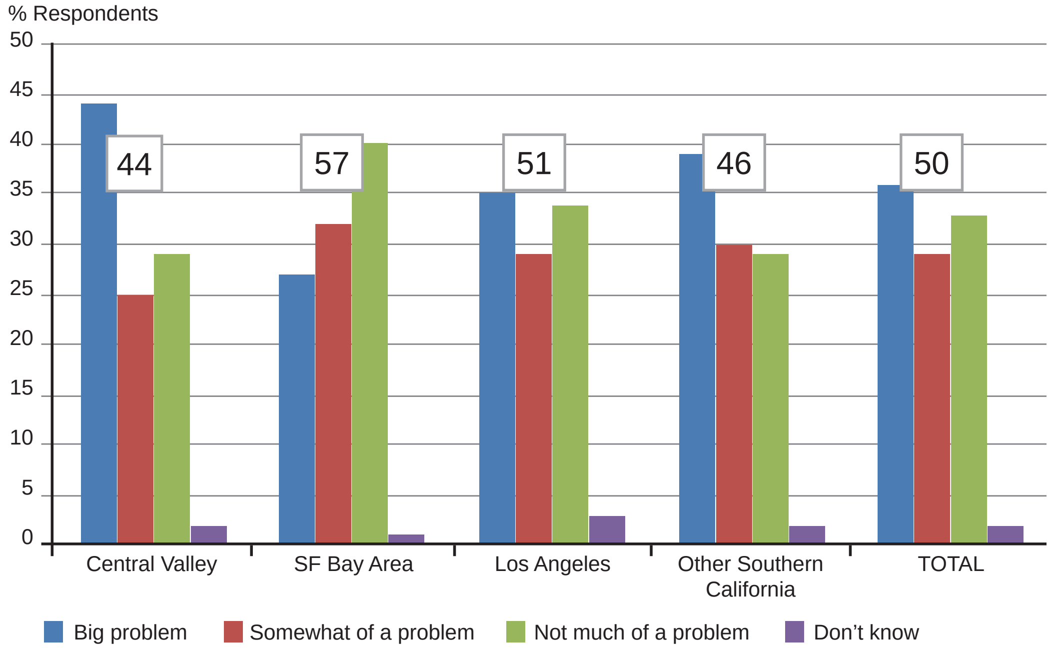
Update 2013 evaluated how statewide and regional water demands might change by 2050 in response to uncertainties surrounding future population growth, land use changes, future climate change, and other factors. These future uncertainties will play out quite differently across the regions of California, so each region will need to choose and implement a portfolio of resource

Figure 5-32 Fish Community Score for Hydrologic Regions



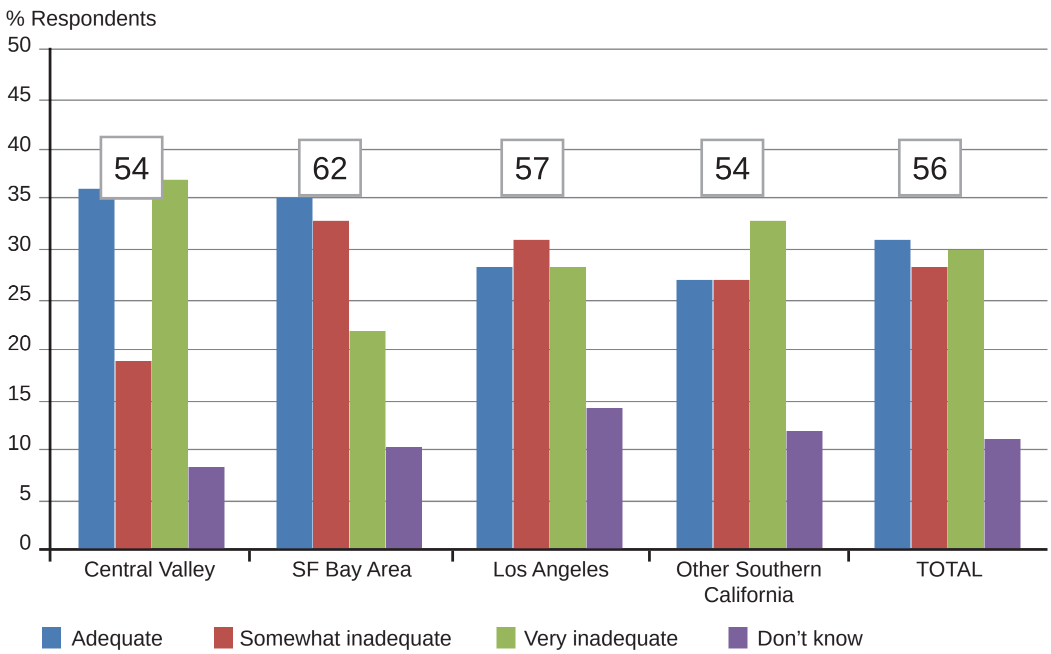
Original map and data points courtesy of University of California, Davis

Figure 5-33 Public Perception by Region of Threats to the Public Water Supply



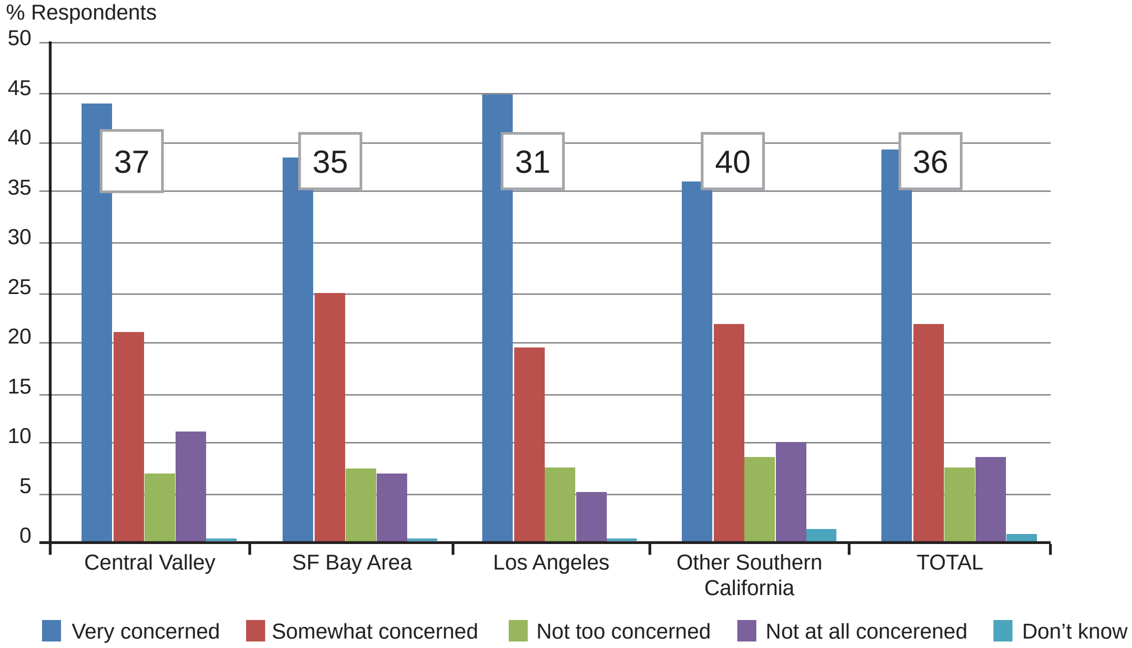
Notes: December, 2012; sample size = 7,315 respondents. Scores are shown in boxes above each regional summary.

Figure 5-34 Public Perception of Security of Future Water Supplies



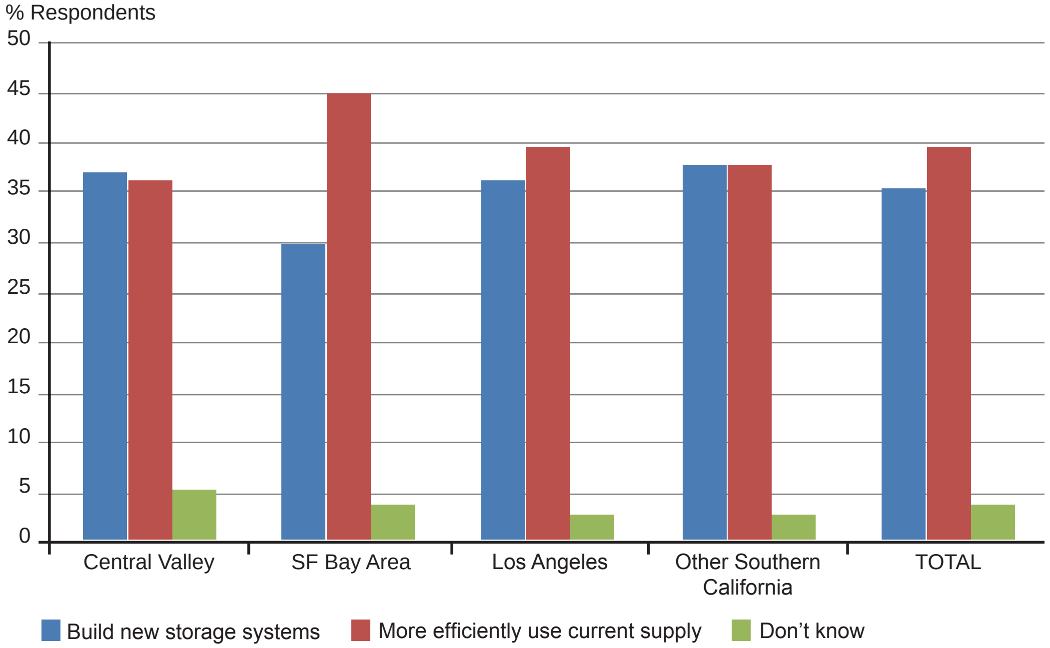
Notes: December 2009; sample size = 1,825 respondents. Scores are shown in boxes above each regional summary.

Figure 5-35 **Public Perception of Effects of Climate Change on Future Water Supply**



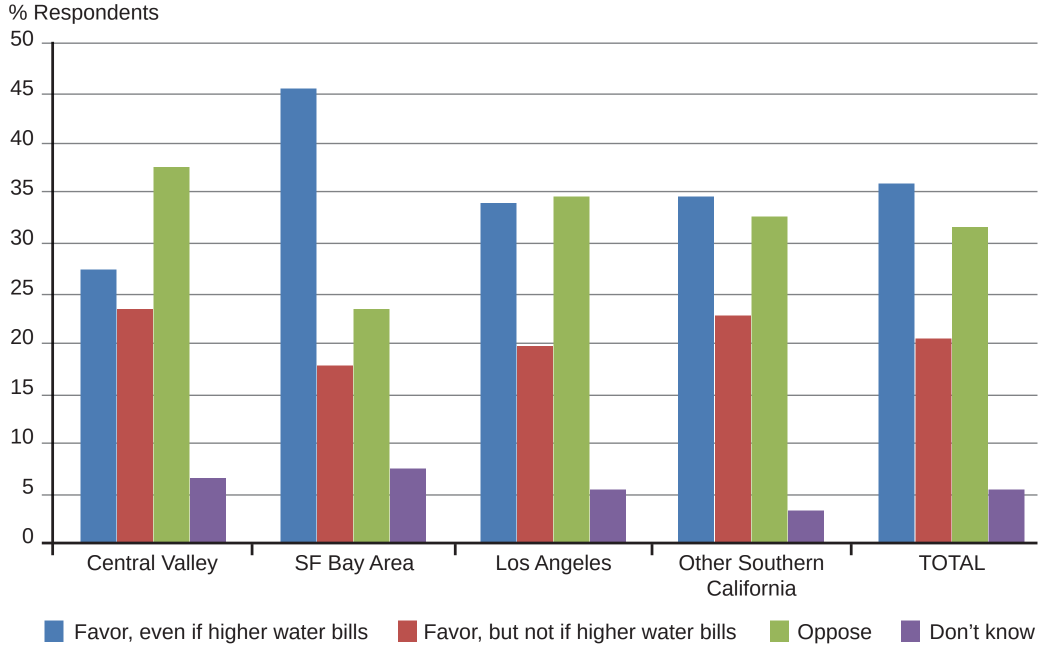
Notes: July 2011; sample size = 4,580 respondents. Scores are shown in boxes above each regional summary.

Figure 5-36 **Public Perception of Future Water Management Strategies to Maintain Water Supply**



Notes: December 2012; sample size = 3,904 respondents.

Figure 5-37 Public Favor for Improving Conditions for Fish, Including Payment Strategies



Note: December, 2012.

management strategies that consider regional water-management challenges. Update 2013 also conducted a more comprehensive vulnerability analysis for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions to test longer term analytical enhancements for the CWP. This analysis tested different response packages, or combinations of resource management strategies, under many future uncertainties. These response packages help decision-makers, water managers, and planners develop and evaluate IWM plans that invest in actions with more sustainable outcomes.

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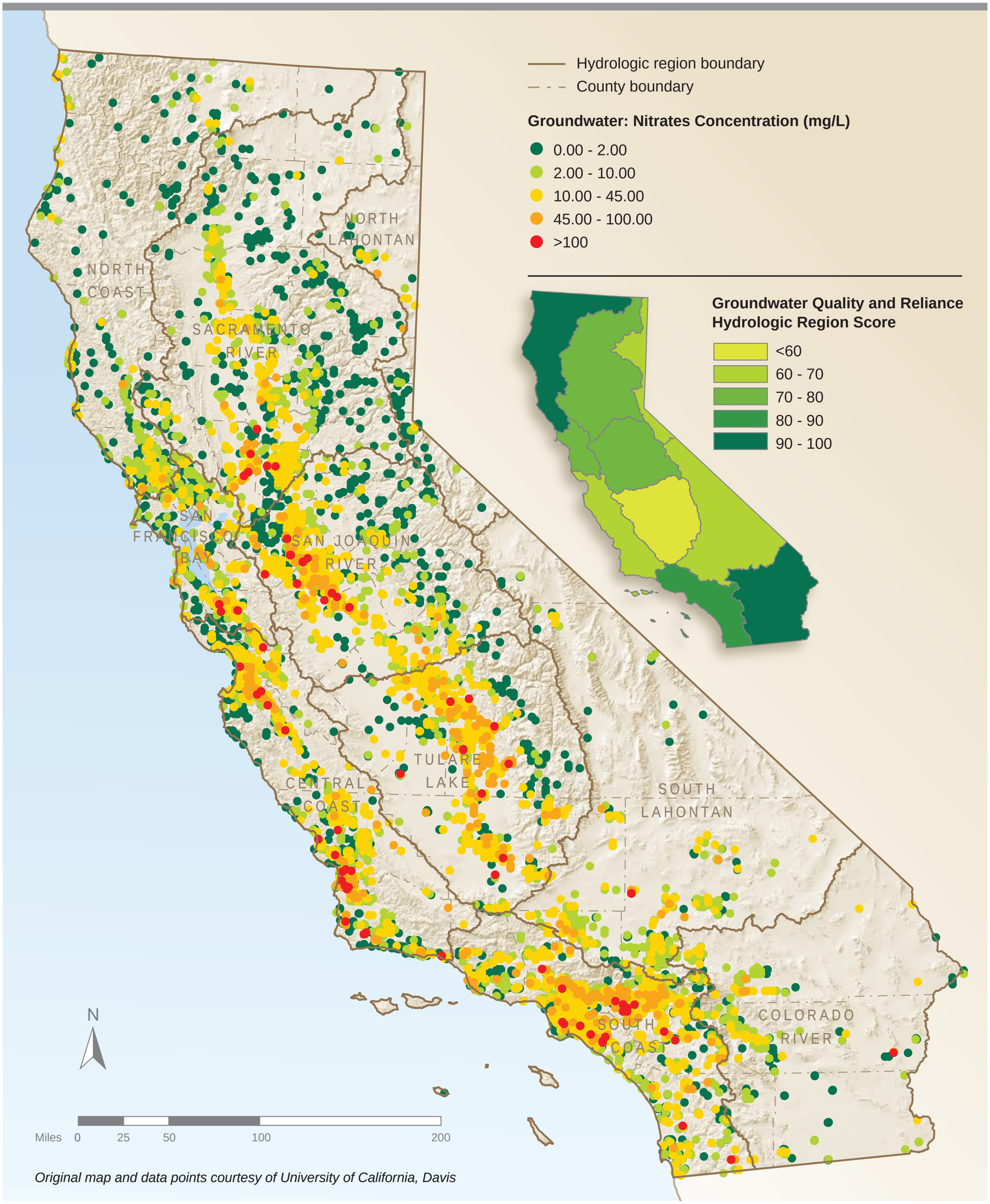
Figure 5-38 Groundwater and Drinking Water Contamination Score for Hydrologic Regions



Original map and data points courtesy of University of California, Davis

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