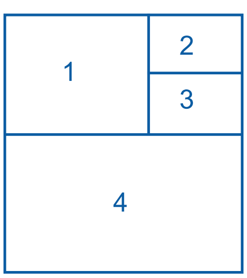
Managing an Uncertain Future



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1. ***Levee break.***
2. ***Salmon***
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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. The chapter presents an approach using multiple future scenarios for making these evaluations and examples of what was learned during preparation of this Water Plan update.

- Planning Approach
- Recognizing and Reducing Uncertainty
- Assessing Risk
- Managing for Sustainability
- Water Scenarios 2050 – Factors That Shape Our Future
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Planning Approach

Overview

Update 2005 included a framework for improving water reliability through two initiatives. One initiative placed emphasis on integrated regional water management to make better use of local water sources by integrating multiple aspects of managing water and related resources such as water quality, local and imported water supplies, watershed protection, wastewater treatment and water recycling, and protection of local ecosystems. The second initiative placed emphasis on maintaining and improving statewide water management systems.

These two initiatives are still at the root of the strategic plan in Update 2009 to secure reliable and clean water supplies through 2050. As with Water Plan Update 2005, this update acknowledges that planning for the future is uncertain and that change will continue to occur (see Box 5-1). Update 2009 enhances the effectiveness of the two initiatives by incorporating three key considerations into 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 sustainability of the resources and water and flood systems.

Box 5-1 Uncertainty, Risk, and Sustainability

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

Risk. Most risks originate from hazards like floods, earthquakes, and droughts that would still occur even if all uncertainty could be removed. We want to reduce uncertainty so we have a clearer view of what the risks to the system are.

Risk = probability of the occurrence (times) consequences of the occurrence

Sustainability. A system or process that is sustainable has longevity and resilience. A sustainable system manages risk, but cannot eliminate risk. A sustainable system generally provides for the economy, the ecosystem, and social equity. For Update 2009, sustainability is not a specific desired result, but is more of an approach or way of seeking longevity and resilience that will continue to be developed in future water plans. For example, planning ways to eventually eliminate drafting more groundwater than can be recharged over the long-term is one approach for improving sustainability.

This chapter provides a general description of this planning approach. Chapter 6, Integrated Data and Analysis, provides more detail on needed data and analytical tools for integrated water management.

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

Water managers have always recognized the variable waterflow 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 the main reasons that Californians built early water projects. Early in California's water development history, personal observations, and experience were often the best data available to help size water facilities because recorded data did not exist.

A system to record waterflow conditions over time gradually improved information available to water managers. **However, the main assumption governing water 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 were used as models of potential future conditions.** In addition, historical records were generally used to establish trends, such as population growth, that were assumed to continue into the future.

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

Box 5-2 Abbreviations and Acronyms Used in this Chapter

ACWA	Association of California Water Agencies
B/C	benefit/cost ratio
CAT	Climate Action Team
CLD	California Levee Database
DRMS	Delta Risk Management Strategy
DWR	California Department of Water Resources
HEC-FDA	USACE Flood Damage Assessment software
IEUA	Inland Empire Utilities Agency
LCPSIM	Least-Cost Planning Simulation Model
LGC	Local Government Commission
RDM	Robust Decision-making
SGC	(Governor's) Strategic Growth Council
SWRR	Sustainable Water Resources Roundtable
USACE	US Army Corps of Engineer
Water PIE	Water Planning Information Exchange

The early approach to flood planning focused on flood damage reduction and public safety. These projects were designed to control and capture floodflows using structural measures such as dams, levee systems, bypasses, and channel enlargements. Although these projects provided significant flood protection benefits, some of these early structural projects caused unintended consequences of larger 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 fuller acknowledgement of the uncertainties inherent in the system and the risks that the system actually faced, the system management was relatively simple compared with today's standards. Conditions appeared more certain and less risky than they actually were. 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

Traditional approaches for predicting the future based solely on projecting trends will no longer work.

Today, as part of integrated regional water management and integrated flood management, California's water and resource managers must recognize that conditions are changing and that they will continue to change. Traditional approaches for predicting the future based solely on projecting trends will no longer work. Today, there is better understanding 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.

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 Water Plan Update 2005 stressed the importance of a common analytical approach for these entities to understand and manage the system, especially when management actions may compete for the same resources. The entities must make sound investments that balance risk with reward, given today's uncertainties and those that may occur in the future. Update 2005 also emphasized the benefits of integrated regional water management. Now, Update 2009 adds integrated flood management into this framework.

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The California Water Plan promotes ways to develop a common approach for data standards and for understanding, evaluating, and improving regional and statewide water management systems, and for common ways to evaluate and select from alternative management strategies and projects. The Department of Water Resources (DWR) is developing the Water Planning Information Exchange (Water PIE) for accessing and sharing data and networking existing databases using GIS software to improve analytical capabilities and developing timely surveys of statewide land use, water use, and estimates of future implementation of resource management strategies.

To anticipate change, our approach to water management and planning for the future needs to incorporate consideration of uncertainty, risk, and sustainability.

The California Water Plan 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, land use and development patterns, environmental conditions, the climate, and many other factors that affect water use and supply may change by 2050. To anticipate change, our approach to water management and planning for the future needs to incorporate consideration of uncertainty, risk, and sustainability.

1. **Uncertainty.** There are enormous uncertainties facing water managers in planning for the future. 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, 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 collection and management and improved analytical tools will allow water and resource managers to better understand risks within the system. DWR has begun the process of incorporating climate change information into its operation and planning process in order to reduce uncertainty of how climate may impact California's water resources in the future. Additional efforts will be needed in order 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 the Volume 4 article, "The State of Climate Change Science for Water Resources Operation, Planning, and Management". Chapter 6, Integrated Data and Analysis, provides a description of how uncertainty is being quantified in Update 2009.

2. **Risks.** Uncertainties about future conditions result in water-related risks. Each undesirable 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 sized 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 economic consequences.

   By reducing the uncertainties described above, the "true" risks can be reduced. State government and other entities are performing more risk assessments that can be used in future planning to balance risk with reward from 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. More information on these risk assessments can be found in later in this chapter.

3. **Sustainability.** Given the uncertainties and risks in the water system, some management strategies may provide for more sustainable water supply and flood management systems and ecosystems than another set of management strategies. Recognizing that change will continue to occur and that additional uncertainties and risks are likely to surface in the future, water management must be dynamic, adaptive, and durable.

We have no way of predicting the future, but we can construct scenarios. Future scenarios can be used to help us better understand the implications of future conditions on water management. This Water Plan considers three plausible, yet very different, future scenarios as a way to consider uncertainty and risk and to improve resource sustainability. One scenario is a projection of current trends. Another scenario considers lower population growth and other factors that may require less intensive use of resources. A third scenario covers the possibility of more expansive population growth and other factors that would result in more intensive use of resources.

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The concept is to not plan for any one given future as in past water plan updates, but to look at how each future scenario could be managed. Certain combinations of management strategies, or response packages, may prove to be appropriate regardless of the future conditions. This is especially true if the response packages have a degree of adaptability to differing conditions that may develop. A general description of the scenarios can be found later in this chapter. More details on the approach used to quantify the scenarios can be found in Chapter 6 Integrated Data and Analysis.

Recognizing and Reducing Uncertainty

There are two broad types of uncertainty:

- The first type of uncertainty is from the inherent randomness of events in nature such as the occurrence of an earthquake or a flood. This type of uncertainty is known as *aleatory* uncertainty and cannot be reduced by collection of additional data. However, additional data may allow better quantification of uncertainty.
- The second type of uncertainty can be attributed to lack of knowledge or scientific understanding. This type of uncertainty is known as *epistemic* (knowledge-based) uncertainty. In principle, epistemic uncertainty can be reduced with improved knowledge that comes from collection of additional information.

Although it is not necessary to categorize uncertainty for the Water Plan update into these two types of uncertainty, it is important to improve data collection and analytical tools.

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. It is useful to consider how change may occur: gradual changes over the long-term or more rapid or sudden changes over the short-term.

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 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 River Delta (the Delta), the condition of levee foundations, and the extent of groundwater recharge and overdraft to name a few.

For the purposes of considering potential future changes and their inherent uncertainties, it is useful to consider how change may occur: gradual changes over the long-term or more rapid or sudden changes over the short-term. Gradual changes can include things like 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 how to respond to the changes. Box 5-3 shows some sources of future change and uncertainty.

Assessing Risk

With improved understanding of uncertainties, risks facing future operation of the system can be better assessed. Most risks originate from hazards like floods, earthquakes, and droughts. But risks can also be due to other issues like water demands growing faster than anticipated, salt water intrusion, or land subsidence caused by

Box 5-3 Sources of Future Change and Uncertainty

Sources of Gradual 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 Delta water exports 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 affect 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 the use of 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 Sacramento-San Joaquin River 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.** Even though more is known about earthquakes, their location, timing, magnitudes can cause 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 cause disruption of surface and groundwater supplies.
- **Intentional Disruption.** Vandalism, terrorist acts, and even cyber threats pose serious potential impacts to the operational capability of water delivery and treatment systems.
- **Fire.** Wildfire in local watersheds can change the runoff characteristics and 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 listings of endangered species can require significant changes to the operation of the water system and the distribution of water supplies between agricultural, urban and environmental uses.
  - **Plumbing Codes.** Future changes in plumbing codes, like the one for installing ultralow flush toilets, could allow use of innovative water fixtures to conserve water.
  - **Emerging Contaminants.** The nature and impact of contaminants may be changing in the future, especially as new health and ecological risk information is obtained.

"To stave off water crises in an age of climate change, humans are going to have to manage water, energy and ecosystems together in a system, undeveloped as yet, that takes into account their complex interconnection."
Peter Friederici
The Next Market Crunch: Water,
July 2008

groundwater overdraft. DWR defines risk as the probability that some undesirable event will occur, which is usually linked with a description of the corresponding consequences of that event, or:

Risk = the probability of the occurrence (times) the consequences of the occurrence

For example, the risk for a flooding hazard is determined as follows:

- Probability equals the frequency of the storm event that causes a levee to fail, say 1 percent chance each year.
- Consequences equal the effects of the floodwater from the levee failure upon the human and natural environment; say $100 million in damages.
- The annual risk would be 0.01 X $100 million, or $1 million per year.

Figure 5-1 further demonstrates risk for flooding from a levee failure.

Accounting for Risk

Although it is impossible to account for all sorts of uncertainty and risk in a planning study, techniques can be used to acknowledge their existence and to assign some quantitative importance to them in the analysis. These techniques include direct enumeration, sensitivity analysis, scenario analysis, probability analysis, game theory, robust decision methods, stochastic simulation. Planners may combine analyses, such as performing scenario analysis supported by probability analysis.

- **Direct enumeration.** With this technique, all possible outcomes are listed. Although this would provide decision-makers an idea of the possible outcomes of an action, it does not provide any clue to the probability of one event happening over another. Also, given the complex relationships that are involved in most water resource-related studies, all possible outcomes are not likely to be known.
- **Sensitivity analysis.** In sensitivity analysis, the values of important factors can be varied to test their effects upon the system being analyzed. These factors can be tested one at a time to find ones that have a significant impact on the results and those that do not. An example of this would be to vary the assumption about future energy costs. If different energy costs do not have a significant effect upon the relative ranking of the proposed project relative to its alternatives, the analyst may feel more comfortable with the project. Although sensitivity analysis is relatively easy to do, it has drawbacks: (a) it frequently assumes that the appropriate range of values is identified and that all values are equally likely to occur, and (b) the results of the analysis are often reported as a single, most likely value that is considered precise.
- **Scenario analysis.** Scenario analysis is similar to sensitivity analysis except groups of factors are tested to together in a methodical way. Each scenario includes factors that support a given theme or story. For example, one scenario could include factors that imply high growth in demand for water and another could include factors that support low growth in demand for water. In this way, scenarios can be compared. Water Plan Update 2009 uses scenario analysis to consider possible future conditions.

Figure 5-1 Understanding flood risks

Flood risk is generally accepted to include both the probability of flooding and the consequences that would result from flooding. Flood risk is commonly calculated as:

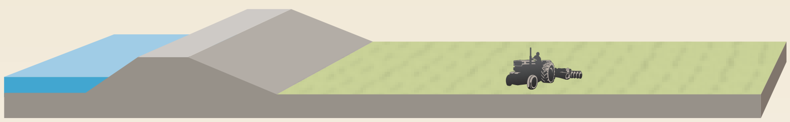
(Probability) x (Consequence) = FLOOD RISK

So, for a predominantly agricultural area that currently floods about once every 50 years causing about $10 million worth of damage, the risk for this area is:

1/50 x $10 million = $200,000 per year

If we improve the levee protection so that it floods about once every 100 years, the risk is cut in half and reduced to:

1/100 x $10 million = $100,000 per year



However, if the area begins to be urbanized with new homes, businesses, and infrastructure being added, the consequences resulting from flooding become much greater. So, if the consequences of flooding as a result of urbanization rise from $10 million to $100 million, the flood risk is greatly increased:

1/100 x $100 million = $1,000,000 per year

So, even when we significantly improve the level of flood protection, we can still end up having higher flood risks if at the same time we increase the consequences by putting more people and infrastructure in the floodplain. A long term goal should be to reduce flood risk.

DWR defines risk as the probability that some undesirable event will occur, which is usually linked with a description of the corresponding consequences of that event

- **Probability analysis.** Although it is recognized that the “true” values of planning and design variables and parameters are not known with certainty and can take on a range of values, it may be possible to describe a variable or parameter in terms of a probability distribution. For example, for a normally distributed variable or parameter, indicators such as mean and variance can be identified which would allow confidence intervals to be placed around point estimates. In other words, instead of saying the benefit/cost (B/C) ratio for a project is 1.20, we might be able to say that we are 90 percent confident that the B/C ratio exceeds the value of 1.15, which gives the decision-makers more information to consider.

- **Robust decision methods.** Robust decision methods are designed to help decision-makers identify solutions (or resource management strategies) that are robust across a wide range of plausible future conditions. These methods are particularly useful when uncertainties cannot easily be characterized using probability distributions. Many argue, for example, that we do not know enough about how the climate may change in response to greenhouse gas emissions and other natural changes, to assign meaningful probabilities to individual climate scenarios. Robust Decision-making (RDM) is a specific robust decision method that systematically identifies the key vulnerabilities of promising water management strategies and then guides the development of more robust options.
- **Stochastic simulation.** This is also known as Monte Carlo simulation or model sampling. An example of this type of analysis is the US Army Corps of Engineer's (USACE) software program, HEC-FDA (Flood Damage Assessment) that directly incorporates uncertainties into a flood damage analysis. For example, direct inputs into this program include frequency/discharge, stage/discharge, and structural inventories for which stage/damage curves are determined within the program. FDA statistically assigns error bands around all of these relationships, and then through a Monte Carlo analysis, samples within the various relationships' error bands in order to determine expected annual damage. Although this program is still subject to the same fundamental sources of uncertainty (model specification and data collection/measurement), at least it explicitly attempts to incorporate uncertainty into the flood damage analysis.

Risk Assessment Examples

The Water Plan encourages all resource planners to incorporate risk assessments into their planning for integrated regional water management, which includes integrated flood management.

As mentioned, risk assessments provide a way to quantitatively consider the uncertainties that relate to events of interest. DWR and others are beginning to conduct more risk assessments as part of planning for the future. The Water Plan encourages all resource planners to incorporate risk assessments into their planning for integrated water management, which includes integrated flood management. This provides the basis for balancing risks with rewards in planning for more sustainable outcomes. Some examples of ongoing risk assessments are given here.

Delta Risk Management Strategy. The Delta Risk Management Strategy (DRMS) recently completed a study evaluating Delta issues from the perspective of the risks from levee failures and ways to reduce those risks (URS 2009).

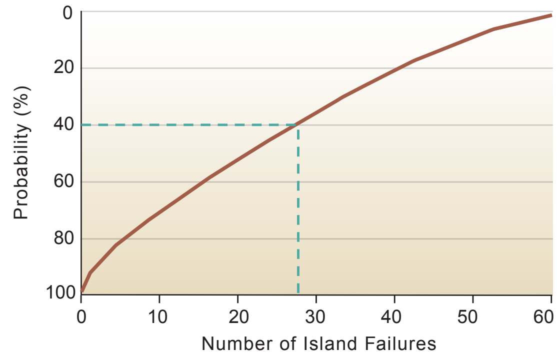
DRMS provides a framework for evaluating major threats to the Delta levee system and the impacts that levee failure can have on the Delta ecosystem and economy, the State's water delivery system and other infrastructure, and those who rely on the exports of fresh water from the Delta. The purpose of DRMS is to:

- Evaluate the risk and consequences to the state (e.g., water export disruption and economic impact) and the Delta (e.g., levees, infrastructure, and ecosystem) associated with the failure of Delta levees and other assets considering their exposure to all hazards (seismic, flood, subsidence, seepage, sea level rise, etc.) under present as well as foreseeable future conditions. The evaluation

assesses the total risk as well as breaking the risk down for individual islands.
- Propose risk criteria for consideration of alternative risk management strategies and for use in management of the Delta and the implementation of risk-informed policies.
- Develop a management strategy, including a prioritized list of actions to reduce and manage the risks of consequences associated with Delta levee failure.

For more information on DRMS, visit the Web site at www.drms.water.ca.gov/.

Figure 5-2 Probability of a number of simultaneous levee failures from a seismic event during a 25-year exposure period (2005-2030)



Source: Adapted from DRMS Risk Report (URS/JBA 2008c), Figure 13-4

The DRMS assessment provides preliminary estimates of the probability that multiple islands will flood simultaneously during a 25-year exposure period due to a seismic event as shown in Figure 5-2. For example, there is a 40 percent probability of a major earthquake causing 27 or more islands to flood at the same time in the 25-year period from 2005 to 2030. DRMS estimated that if 20 islands were flooded as a result of a major earthquake, the export of fresh water from the Delta could be interrupted for about a year and a half. Water supply losses of up to 8 million acre-feet would be incurred by State and federal water contractors and local water districts.

There is a 40 percent probability of a major earthquake causing 27 or more islands to flood at the same time in the 25-year period from 2005 to 2030.

California Statewide Levee Database. California has more than 13,000 miles of levees that protect residential and agricultural lands. The levee failures in New Orleans during hurricane Katrina prompted DWR to initiate development of a state-of-the-art levee database for the purpose of better understanding and managing levees. The California Levee Database (CLD) will support an efficient and effective approach for assessing levee reliability, risk assessment factors, and structural data impacting individual levee reaches. The CLD is being coordinated with a similar nationwide database being developed by the USACE.

DWR Economic Analysis for Flood Risk Management. DWR has prepared its Economic Analysis Guidebook (DWR 2008 www.water.ca.gov/economics/guidance.cfm) with procedures for consistent economic analysis for the large list of flood risk reduction studies and projects that are under way or will be started over the next several years. These include major analyses for the Central Valley Flood Protection Plan, the State Plan of Flood Control, regional flood management planning, and various grant programs.

Because of its considerable water management partnerships with the federal government, DWR has a policy that all economic analyses conducted for its internal use on programs and projects be fundamentally consistent with the federal Economics and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G), which was adopted by the US Water Resources Council on March 10, 1983, and is currently being revised for the first time in 25 years. In addition, The USACE requires that risk analysis be conducted for all of its flood damage reduction studies. For agencies seeking USACE funding and/or levee certification, approved risk analyses must be applied. USACE guidance on risk analysis can be found in:

- EM 1110-2-1619, Risk-Based Analysis for Flood Damage Reduction Studies, August 1996 and
- ER 1105-2-101, Risk Analysis for Flood Damage Reduction Studies, January 2006

Least-Cost Planning Simulation Model. DWR developed the Least-Cost Planning Simulation Model (LCPSIM) to evaluate risks of water supply shortages. It is a yearly time-step simulation/optimization model that assesses the economic benefits and costs of enhancing urban water service reliability at a regional level (www.water.ca.gov/economics/models.cfm). The LCPSIM output includes the economically efficient level of adoption of reliability enhancement measures by type, including the cost of those measures. The LCPSIM accounts for the ability of shortage event management (contingency) measures, including water transfers, to mitigate regional costs and losses associated with shortage events as well as the ability of long-run demand reduction and supply augmentation measures to reduce the frequency, magnitude, and duration of those shortage events. Forgone use is the difference between the quantity of water demanded and the supply available for use.

Presenting Uncertainty About Climate Change to Water-Resource Managers.
This report documents a series of three workshops conducted by RAND Corporation with the Inland Empire Utilities Agency (IEUA) in Southern California in fall 2006 (Groves et. al 2008b). The workshops were supported by modeling to explore how different descriptions of uncertainty about the effects of climate change and other key factors on IEUA's projected supply and demand might influence water managers' perceptions of risk and preferences for new infrastructure investments, changes in operational policies, and adoption of regulatory measures. RAND used RDM analysis, a new approach to decision support when conditions present deep uncertainty. RDM uses computational methods to identify scenarios likeliest to break assumptions embedded in a long-term resource-management plan.

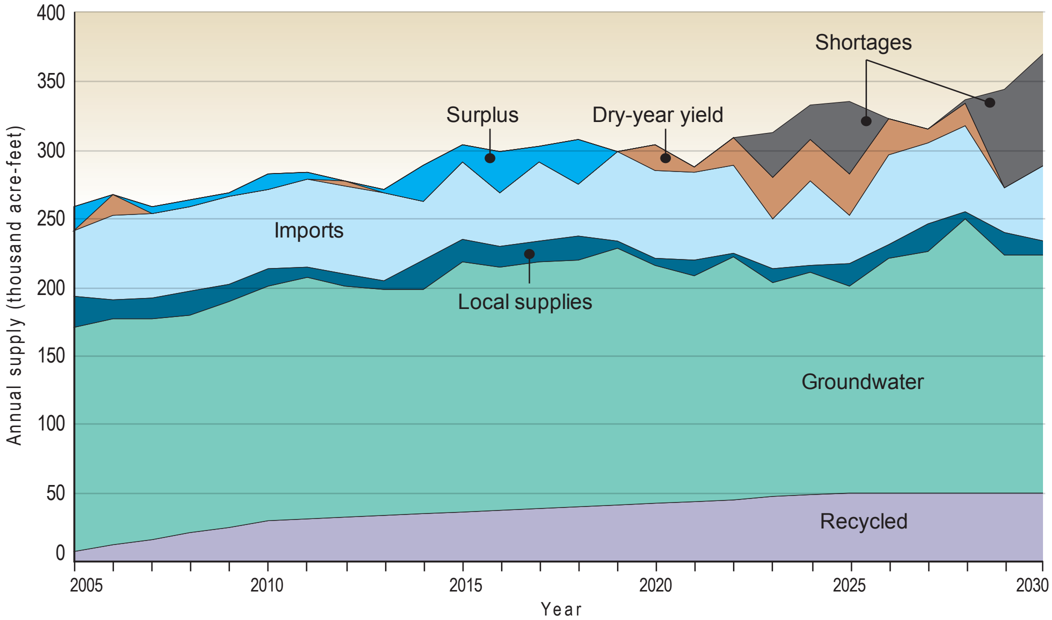
The report presents a decision analysis of potential IEUA-region water-planning responses using three different formulations of uncertainty: traditional scenarios; long-term, probabilistic forecasts; and policy-relevant scenarios. The modeling showed periods of water shortages under different scenarios. As one example, Figure 5-3 shows estimated supply conditions for one scenario.

California's water resources are finite and require managing—management that may be different than what has been practiced during the first 150 years of the state's history.

Managing for Sustainability

Over the past few decades, questions have been raised about how sustainable are our ecosystems and water use, land use, and other resources, given current management practices and expected future changes. California's water resources are finite and require managing—management that may be different than what has been practiced during the first 150 years of the state's history.

Figure 5-3 Delivered supply, surplus, and shortages for the Hotter and Drier, Miss Goals Scenario under the 2005 IEUA Urban Water Management Plan



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Results of one climate scenario show supplies, surplus, and shortages.

What is Sustainability?

The word "sustainability" has been widely used in recent years for a wide variety of planning activities, and often no definition is provided with its use. The need for "sustainable development" or "sustainable use of resources" may have somewhat different meanings depending on the perspective of the user. A system or process that is sustainable can generally continue indefinitely. The intent here is not to give a strict definition, but to portray the concepts of longevity and resilience. A system that is sustainable, should meet today's needs without compromising the ability of future generations to meet their own needs. A sustainable system generally provides for the economy, the ecosystem, and social equity.

For this Water Plan, incorporating the concept of resource sustainability into water planning is an ongoing process or approach that will continue to be developed in future water plan updates. The process includes broad principles for planning for sustainability rather than defining a specific desired outcome. See Volume 4 Reference Guide for copy of DWR's Sustainability Policy dated April 2009.

Since 2002, the Sustainable Water Resources Roundtable (SWRR) has brought together State, federal, corporate, nonprofit, and academic sectors to advance understanding of the nation's water resources and to help develop tools for understanding and ensuring their sustainability.

Since 2002, the Sustainable Water Resources Roundtable (SWRR) has brought together State, federal, corporate, nonprofit, and academic sectors to advance understanding of the nation's water resources and to help develop tools for understanding and ensuring their sustainability (acwi.gov/swrr/index.html). SWRR concluded that discussions of water sustainability offer the most promise when there is an understanding of major driving forces like population, income, land use, climate change, and energy use. SWRR identified a set of four sustainability principles for water resource management

Box 5-4 Sustainable Water Resources Roundtable Sustainability Principles

Discussions of water sustainability offer most promise when they take place with an understanding of major driving forces like population, income, land use, climate change, and energy use. To help it navigate within such a context, SWRR identified a set of four sustainability principles for water resources management:

1. **The value and limits of water.** Water supports all life and provides great value. While water is abundant, people need to understand and appreciate that it is limited in many regions, that there are environmental and economic costs of depleting or damaging water resources, and that unsustainable water and land use practices pose serious risks to people and ecosystems. A renewable natural resource is sustainable only if the rate of use does not exceed the rate of natural renewal.

2. **Shared responsibility.** Water does not respect political boundaries. Sustainable management of water requires consideration of the needs of people and ecosystems up- and down-stream and throughout the hydrologic cycle, and avoiding extreme situations that may deplete water in some regions to provide supplies elsewhere.

3. **Equitable access.** Sustainability suggests fair and equitable access to water, water dependent resources, and related infrastructure. Equitable access requires continuous monitoring to detect and address problems as they occur, and means to correct the problems.

4. **Stewardship.** Meeting today's water needs sustainably challenges us to continually address the implications of our water resources decisions on future generations and the ecosystems upon which they will rely. We must be prepared to correct policies and decisions if they create adverse unintended consequences.

The Sustainable Water Resources Roundtable, SWRR, November 2007

(see Box 5-4 SWRR Sustainable Principles and Volume 4 Reference Guide article "Sustainable Water Resources Roundtable Report").

Sustainability Indicators

SWRR states, "Indicators represent a way to measure progress. They can provide a metric for understanding the extent to which water resources are managed to meet the long-term needs of our social, economic, and environmental systems. In essence, they can help us understand whether or not the nation is on a sustainable course in its management of water and related resources." SWRR has developed a set of 14 key sustainability indicators (see Box 5-5 SWRR Sustainability Indicators) that can be useful to other entities developing their own indicators. A more detailed list of indicators is included in the Volume 4 Reference Guide, "Draft Compendium of Feb. 5, 2008 Sustainable Water Resources Roundtable, National Indicators Draft Framework: Nov. 20, 2007."

Sustainability indicators may vary depending on the water agency or region of California. Defining indicators is an ongoing, iterative process for most entities. The CALFED Bay-Delta Program has been developing performance measures for water supply reliability, water quality, levee system integrity, and ecosystem restoration since its Record of Decision in 2000. The Water Plan team will develop indicators to accompany the various management actions selected for implementation.

Box 5-5 SWRR Sustainability Indicators

A. Water availability. People and ecosystems need sufficient quantities of water to support the benefits, services and functions they provide. These indicator categories refer to the total amount of water available to be allocated for human and ecosystem uses.

1. **Renewable water resources.** Measures of the amount of water provided over time by precipitation in a region and surface and groundwater flowing into the region from precipitation elsewhere. USGS considers renewable water resources to be the upper limit of water consumption that can occur in a region on a sustained basis.
2. **Water in the environment.** Measures of the amount of water remaining in the environment after withdrawals for human use.
3. **Water use sustainability.** Measures of the degree to which water use meets current needs while protecting ecosystems and the interests of future generations. This could include the ratio of water withdrawn to renewable supply.

B. Water quality. People and ecosystems need water of sufficient quality to support the benefits, services, and functions they provide. This indicator category is for composite measures of the suitability of water quality for human and ecosystem uses.

4. **Quality of water for human uses.** Measures of the quality of water used for drinking, recreation, industry, and agriculture.
5. **Quality of water in the environment.** Measures of the quality of water supporting flora and fauna and related ecosystem processes.
6. **Water quality sustainability.** Composite measures of the degree to which water quality satisfies human and ecosystem needs.

C. Human uses and health. People benefit from the use of water and water-dependent resources, and their health may be affected by environmental conditions.

7. **Withdrawal and use of water.** Measures of the amount of water withdrawn from the environment and the uses to which it is put.
8. **Human uses of water in the environment.** Measures of the extent to which people use water resources for waste assimilation, transportation, and recreation.
9. **Water-dependent resource use.** Measures of the extent to which people use resources like fish and shellfish that depend on water resources.
10. **Human health.** Measures of the extent to which human health may be affected by the use of water and related resources.

D. Environmental health. People use land, water and water-dependent resources in ways that affect the conditions of ecosystems.

11. **Indices of biological condition.** Measures of the health of ecosystems.
12. **Amounts and quality of living resources.** Measures of the productivity of ecosystems.

E. Infrastructure and institutions. The infrastructure and institutions communities build enable the sustainable use of land, water and water-dependent resources.

13. **Capacity and reliability of infrastructure.** Measures of the capacity and reliability of infrastructure to meet human and ecosystem needs.
14. **Efficacy of institutions.** Measures of the efficacy of legal and institutional frameworks in managing water and related resources sustainably.

The Sustainable Water Resources Roundtable (SWRR) November 2007

Examples of Managing for Sustainability

It is becoming increasingly evident to decision-makers, water managers, and planners of the need to manage for the long-term sustainability of resources. This is especially true in the face of climate change, population growth, and evolving environmental protections.

Water Plan Update 2005 was the first California Water Plan to emphasize integrated regional water management as a key component in managing for sustainability. To ensure that water use is sustainable, California water management must be based on three foundational actions: use water efficiently to get maximum utility from existing supplies, protect water quality to safeguard public and environmental health and secure the state's water supplies for their intended purposes, and expand environmental stewardship as part of water management responsibilities. These actions support two initiatives that water management must pursue to ensure reliable water supplies: first, expand integrated regional water management; and second, improve statewide water and flood management systems.

Integrated regional water management enables regions to implement strategies appropriate for their own needs and helps them become more self-sufficient. Regions must rely on a diversified portfolio of resource management strategies needed to cope with changing and uncertain future conditions.

Integrated regional water management enables regions to implement strategies appropriate for their own needs and helps them become more self-sufficient. Regions must rely on a diversified portfolio of resource management strategies. This diversification is essential to provide the flexibility needed to cope with changing and uncertain future conditions. To minimize the impacts of water management on natural environment and to ensure sustainable systems and uses, water and resource managers and planners must use water efficiently, protect water quality, and expand environmental stewardship. Sustainable development relies on policies, decisions, and actions that give full consideration to social, economic, and environmental issues.

Sustainable development relies on policies, decisions, and actions that give full consideration to social, economic, and environmental issues.

There are numerous examples of entities planning for more sustainable outcomes. Many of these are based on Integrated Regional Water Management plans, each relying on portfolios of management strategies that fit their specific needs. Following are a few examples of how different entities are approaching the need for sustainability.

Strategic Growth Council

A primary motivation for creating the SGC as described in the legislation is to improve coordination among State government agencies to promote more sustainable communities in California.

In September 2008 Governor Arnold Schwarzenegger signed SB 732, creating the Strategic Growth Council (SGC). A primary motivation for creating the SGC as described in the legislation is to improve coordination among State government agencies to promote more sustainable communities in California. The SGC is a cabinet level committee that is tasked with coordinating the activities of state agencies to:

- improve air and water quality,
- protect natural resource and agriculture lands,
- increase the availability of affordable housing,
- improve the transportation system,
- promote public health, and
- assist State and local entities in the planning of sustainable communities and meeting the goals of AB 32 (California Global Warming Solutions Act).

Association of California Water Agencies - Sustainability Principles

In 2008 the Association of California Water Agencies (ACWA) developed a set of policy principles for environmental and economic sustainability. According to ACWA, sustainable policies are those which provide levels of ecological and economic well-being that can persist over time. These principles were developed because ACWA member agencies believe that California's water policies today are unsustainable. See Volume 4 for the complete set of principles. The five overriding principles adopted by ACWA are listed here.

- Reliable, adequate water supplies and a healthy ecosystem must be primary co-equal goals for sustainable water management.
- Sustainable solutions will require comprehensive programs that combine substantial investments in ecosystem enhancement and water supply infrastructure.
- Providing reliable, high quality water supplies remains the primary mission of ACWA's public agency members.
- Water investment and management decisions must recognize that investing in an environmentally sustainable system serves the economic interests of water users statewide.
- New investments are required to progress toward sustainability and adapt to changing environmental conditions like climate change.

"The real prize today is a sustainable system. This may or may not result in increased water supply. The point is that a sustainable system by itself justifies billions in expenditures."
Timothy Quinn, Executive Director, Association of California Water Agencies

Local Government Commission

The Local Government Commission (LGC) is a nonprofit, nonpartisan, membership organization that provides inspiration, technical assistance, and networking to local elected officials and other community leaders dedicated to creating healthy, walkable, and resource-efficient communities. The LGC web portal (www.lgc.org/index.html) includes useful information on community planning and principles that form the basis for LGC's work on livable, sustainable communities.

Sustainability Symposium White Paper

The Sacramento Chapters of the American Society of Civil Engineers' Environmental & Water Resources Institute and Committee on Sustainability together with the Floodplain Management Association convened a symposium on July 23, 2009, to discuss the future of water resources management as a critical means of advancing and preserving sustainability of California's communities. The symposium brought together policymakers, community leaders, resource managers, regulators, land use planners, and environmental advocates. The outcomes of workshop are described in a white paper, "A Time for Changing Values, Ideas, and Solutions in Water Management: Addressing Sustainability of California's Communities" (2009). The paper is located in Volume 4 Reference Guide. The key recommendations summarized from the White Paper are:

- Establish a Water Sustainability Subcommittee within the Governor's Strategic Growth Council with the mandate to help develop, coordinate, and circulate key water resource management strategies and their associated sustainability challenges to various departments, agencies, and the general public.

The sustainability symposium brought together policymakers, community leaders, resource managers, regulators, land use planners, and environmental advocates.

- Encourage laws and policies that will better reflect the value of water resources to the State and its residents.
- Create a system that provides economic incentives to advance community sustainability through effective water management.
- Create statewide goals, policies and priorities for water management in California to support sustainable communities.
- Examine and address efficacy of current mechanisms used to govern beneficial use of water.

The Water Wiki

Sustainable Water Resources Roundable (SWRR)

SWRR serves as a forum to share information and perspectives that will promote better decision-making in the United States regarding the sustainable development of the nation's water resources. SWRR began a Web Wiki to support ongoing discussions on sustainability. Readers can view information already on the Wiki and contribute their own information and ideas for viewing by others. The Water Wiki can be found at waterwiki.wik.is/.

Water Scenarios 2050—Factors That Shape Our Future

What will California look like in 2050? Will the population growth keep pace with recent trends? Will the pattern of climate change continue? Will the protection of water quality and endangered species be driven mostly by lawsuits, creating a patchwork of legal requirements? We have no way of predicting the future, but we can construct some plausible scenarios. Future scenarios can be used to help us better understand the implications of future conditions on water management.

For Update 2009, we evaluated different ways of managing water in California depending on different future conditions for different regions of the state. The ultimate goal is to evaluate how alternative regional response packages, or combinations of resource management strategies from Volume 2, perform under different future conditions. The different future conditions are described as future scenarios. Together the response packages and future scenarios show what management options could provide for sustainability of resources and ways to manage uncertainty and risk at a regional level.

In Update 2009, the Water Plan has made significant improvements to the scenarios by considering the potential effect of long-term climate change on future water demands. More work will be required in the next Water Plan update to refine this information based on the differing conditions and opportunities in the various regions. The following subsections summarize the scenarios and show how they were used in estimating future water demands for meeting those demands.

Water Plan Baseline Scenario Descriptions

Before Water Plan Update 2005, water plan updates based planning assumptions on a single "likely future." Now, the use of multiple future scenarios provides decision-makers, water managers, and planners more information about how different management actions might perform under a range of possible future conditions.

Update 2009 has three future scenarios through the year 2050 to which the water community would need to respond regionally by implementing a mix of resource management strategies. The scenarios are referred to as baseline because they represent changes that are plausible and could occur without additional management intervention beyond those currently planned. Each scenario affects water demands and supplies differently. Each scenario includes assumptions about how different factors, like population or irrigated farmland, would describe its future. The title of each scenario—Current Trends, Slow & Strategic Growth, and Expansive Growth—tells us something about how different factors, like population, irrigated farmland, or background water conservation (plumbing codes, natural replacement, actions water users implement on their own, etc.) are assumed to change over time. These are factors of uncertainty over which the water community has little control yet affect future water demand for the urban, agricultural, and environmental sectors.

- **Scenario 1 – Current Trends.** For this scenario, recent trends are assumed to continue into the future. In 2050, nearly 60 million people live in California. Affordable housing has drawn families to the interior valleys. Commuters take longer trips in distance and time. In some areas where urban development and natural resources restoration has increased, irrigated crop land has decreased. The state faces lawsuits on a regular basis: from flood damages to water quality and endangered species protections. Regulations are not comprehensive or coordinated, creating uncertainty for local planners and water managers.
- **Scenario 2 – Slow & Strategic Growth.** Private, public, and governmental institutions form alliances to provide for more efficient planning and development that is less resources intensive than current conditions. Population growth is slower than currently projected—about 45 million people live here. Compact urban development has eased commuter travel. Californians embrace water and energy conservation. Conversion of agricultural land to urban development has slowed and occurs mostly for environmental restoration and flood protection. State government implements comprehensive and coordinated regulatory programs to improve water quality, protect fish and wildlife, and protect communities from flooding.
- **Scenario 3 – Expansive Growth.** Future conditions are more resource intensive than existing conditions. Population growth is faster than currently projected with 70 million people living in California in 2050. Families prefer low-density housing, and many seek rural residential properties, expanding urban areas. Some water and energy conservation programs are offered but at a slower rate than trends in the early century. Irrigated crop land has decreased significantly where urban development and natural restoration have increased. Protection of water quality and endangered species is driven mostly by lawsuits, creating uncertainty.

On the following pages are narrative descriptions of the three scenarios including factors of uncertainty that can be used in the modeling analysis.

Scenario 1 – Current Tends

Economic and Financial

Population and land use. In 2050, nearly 60 million people live in California. The state's metropolitan areas have continued to grow and past development patterns continue, spreading boundaries and absorbing once-rural areas like the Sierra Nevada foothills.

Agriculture. Irrigated crop land has decreased in some areas where urban development and natural resource restoration have increased. Some agricultural lands remain in production with land conservation agreements. Through a combination of advanced agricultural practices (e.g., multicropping) and technology, the agriculture industry has been able to increase the intensity of production as it also shifts to higher value permanent crops.

Institutional and Political

California continues to face lawsuits on a regular basis to protect water quality and endangered species. In addition the state has been held liable for billions of dollars in damages from a series of flood events. Response to these lawsuits largely has been on a case-by-case basis, which has created a lot of uncertainty for cities and water managers about future regulatory requirements. Many groundwater basins lack active management. Regulations are not comprehensive or coordinated, creating uncertainty for local planners and water managers.

Natural Systems

Climate change has affected California's natural systems. Sea level rise has begun to disrupt ecosystems and communities in coastal areas and ongoing tidal wetland restoration. The biggest impact is in the Delta where levees protect low-lying lands, many which were already below sea level. Air temperatures have increased throughout the state, and precipitation patterns have become more variable. Loss of mountain snowpack is significant, and peak river flows occur earlier in the spring.

Technological

Water and energy are inherently linked, especially in California. Technology has modestly decreased energy use in water treatment and distribution. Water treatment technology allows more cost-effective clean up of groundwater and brackish water. Meanwhile, some advancement in residential appliances and irrigation technology has increased water use efficiency.

Social Practices

Land use. Limited and expensive land forces families to look for affordable homes in the state's interior valleys. Commuters spend more time getting to and from work. Still, Californians have not abandoned the mild-temperature coastal areas. The state's population growth in inland areas has been more than twice that of any other state.

Water and energy conservation. Californians have continued to take advantage of existing rebate incentive programs to improve water and energy conservation.

Scenario 2 – Slow & Strategic Growth

Economic and Financial

Population and land use. Population growth has slowed substantially relative to Department of Finance forecasts. In 2050, nearly 45 million people live in California. Californians still locate to the Central Valley as well as the coastal counties. However, growth patterns have become more compact. Clustered urban development patterns have reduced the need for conversion of rural lands that currently provide opportunities for open space, habitat restoration, and refuges that harbor protected and endangered species.

Agriculture. Compact urban development and economic incentives have slowed the conversion of agricultural land to urban development. Most agricultural land conversion occurs for environmental restoration and flood protection purposes rather than residential development. Today, strong policies are in place to preserve prime agricultural lands.

Institutional and Political

Inspired by a series of legal decisions, California's legislature has worked with private, nonprofit, and local agencies to successfully implement comprehensive and coordinated programs to protect and improve water quality, protect fish and wildlife, and protect communities from flooding. These new programs include both regulatory controls and economic incentives. Increased institutional cooperation and agreements among groundwater users facilitate more sustainable use of groundwater basins and increase opportunities for conjunctive use.

Natural Systems

(Same as Current Trends) Climate change has affected California's natural systems. Sea level rise has begun to disrupt ecosystems and communities in coastal areas and ongoing tidal wetland restoration. The biggest impact is in the Delta where levees protect low-lying lands, many which were already below sea level. Air temperatures have increased throughout the state, and precipitation patterns have become more variable. Loss of mountain snowpack is significant, and peak river flows occur earlier in the spring.

Technological

The West Coast was an early adopter of green technology. Fifty years ago, venture capitalists backed innovated technology as the industry realized that there was money to be made in clean energy. Water treatment technology allows more cost-effective clean up of groundwater and brackish water. New advancement in residential appliances and irrigation technology has significantly increased water use efficiency.

Social Practices

Land use. Compact development patterns have eased commuter travel as families now find work where they live, and more people are using mass transit. For the coastal communities, compact development has made some housing more affordable and lessened impacts on sensitive coastal habitat.

Water and energy conservation. Californians have embraced aggressive water and energy conservation measures, significantly more than Current Trends, by upgrading residential appliances, installing water efficient landscapes, and investing in renewable energy sources even when utility rebates are not available.

Scenario 3 – Expansive Growth

Economic and Financial

Population and land use. California's population has grown at a faster rate than projected by the Department of Finance. We have 70 million people living here in 2050. To accommodate those growing numbers, California urban areas have spread and moved into areas that were once rural and in areas susceptible to flooding and fire.

Agriculture. Irrigated crop land has decreased significantly in some areas where urban development and natural resource restoration have increased. Some agricultural lands remain in production with land conservation agreements. Through a combination of advanced agricultural practices (e.g., multicropping) and technology, the agriculture industry has been able to increase the intensity of production as it also shifts to higher value permanent crops.

Institutional and Political

(Same as Current Trends) California continues to face lawsuits on a regular basis to protect water quality and endangered species. In addition the state has been held liable for billions of dollars in damages from a series of flood events. Response to these lawsuits largely has been on a case-by-case basis, which has created a lot of uncertainty for cities and water managers about future regulatory requirements. Many groundwater basins lack active management.

Natural Systems

(Same as Current Trends) Climate change has affected California's natural systems. Sea level rise has begun to disrupt ecosystems and communities in coastal areas and ongoing tidal wetland restoration. The biggest impact is in the Delta where levees protect low-lying lands, many which were already below sea level. Air temperatures have increased throughout the state, and precipitation patterns have become more variable. Loss of mountain snowpack is significant, and peak river flows occur earlier in the spring.

Technological

(Same as Current Trends) Water and energy are inherently linked, especially in California. Technology has modestly decreased energy use in water treatment and distribution. Water treatment technology allows more cost-effective clean up of groundwater and brackish water. Meanwhile, some advancement in residential appliances and irrigation technology has increased water use efficiency.

Social Practices

Land use. Families prefer low density housing and many seek rural residential properties. These development patterns have expanded urban areas away from existing infrastructure. Mass transit usage is the same as under Current Trends, but the annual miles driven has increased as due to farther commute distances.

Water and energy conservation. Californians have continued to take advantage of existing rebate incentive programs to improve water and energy conservation, but at a slower rate than Current Trends.

Scenario Factors Affecting Future Water Demands

Future water demand is affected by a number of factors like population growth, planting decisions by farmers, size and type of urban landscapes, and background water conservation measures (like plumbing codes, natural replacement, actions water users implement on their own, etc.). Water Plan Update 2009 quantifies several factors that together provide a description of future water demand for the urban, agricultural, and environmental sectors. Each of these factors is varied between the three scenarios to describe some of the uncertainty faced by water managers. For example, no one can predict future population growth. The three scenarios use three different, but plausible values of future population when determining future urban water demands.

In this section we describe some of the key factors of uncertainty used to quantify urban, agricultural, and environmental water demands for Update 2009. Values for the key factors of uncertainty that affect urban demand (population, single-family homes, multi-family homes, commercial employees, and industrial employees) are reported in Table 5-1 for 2005 and 2050 under each of the three baseline scenarios. The 2050 population for the expansive growth scenario is about 60 percent higher than that for the Slow & Strategic growth scenario.

Key factors of uncertainty that affect urban demand are population, single-family homes, multi-family homes, commercial employees, and industrial employees.

Table 5-1 Scenario factors affecting urban water demand

Scenario factors for urban water demand	Year 2005	Future scenarios – Year 2050		
		Current Trends	Slow & Strategic Growth	Expansive Growth
Population (millions)	36.7	59.5	44.2	69.8
Single-family housing units (millions)	7.9	13.3	10.0	14.7
Multiple-family housing units (millions)	4.3	5.8	4.5	6.6
Commercial employees (millions)	19.0	36.5	28.0	40.4
Industrial employees (millions)	1.7	1.9	1.9	1.9

Table 5-2 Scenario factors affecting agricultural water demand

Scenario factors for agricultural water demand (area in millions of acres)	Year 2005	Future scenarios – Year 2050		
		Current Trends	Slow & Strategic Growth	Expansive Growth
Irrigated land area	8.7	8.0	8.4	7.6
Multicropped area	0.5	0.6	0.6	0.6
Irrigated crop area	9.2	8.6	9.0	8.3

Key factors of uncertainty that affect agricultural water demand are irrigated land area, multicrop area, and individual cropping patterns.

The 2005 and 2050 values for the key factors of uncertainty that affect agricultural water demand (irrigated land area, multicrop area, and individual cropping patterns) are reported in Table 5-2 under each of the three baseline scenarios. Each of the scenarios shows a decline in irrigated acreage over existing conditions. The amount of acres devoted to planting more than one crop per year on the same land (known as multicropping) increases in all scenarios.

In the Water Plan scenarios, currently unmet environmental objectives are used as a surrogate to estimate new requirements that may be enacted in the future to protect the environment. These are some of the major unmet objectives and do not include all environmental objectives in the state.

In the Water Plan scenarios, currently unmet environmental objectives are used as a surrogate to estimate new requirements that may be enacted in the future to protect the environment. These unmet objectives are instream flow needs or additional deliveries to managed wetlands that have been identified by regulatory agencies or pending court decisions, but are not yet required by law. An estimate of the ranges of unmet environmental water objectives for each water year from 1998 through 2007 are shown in Table 5-3 for 10 separate objectives. Table 5-3 also shows the range of unmet objectives used in the three Water Plan scenarios, which were varied from year to year based on hydrologic conditions. These are some of the major unmet objectives and do not include all environmental objectives in the state. In particular, they do not include additional water to protect species in the Delta resulting from the December 2008 Delta Smelt Biological Opinion issued by the US Fish and Wildlife Service or to protect salmon and several other species resulting from the June 2009 biological opinion by the National Marine Fisheries Service.

A significant improvement to the Water Plan scenarios in Update 2009 is a quantitative look at the uncertainty surrounding future climate change. Each of the three Water

Table 5-3 Unmet environmental water objectives by scenario

Unmet environmental water objectives (values in thousand acre-feet per year)	Historical[1] range 1998-2007	Future scenarios range (based on year type)		
		Current Trends	Slow & Strategic Growth	Expansive Growth
American River (Nimbus) DF&G Study	15-798	58-687	141-798	15-514
Stanislaus River (Goodwin)	0-137	10-93	20-137	0-34
ERP #1 Delta Flow Objective	0-293	0-98	0-293	0
ERP #2 Delta Flow Objective	0-76	0-34	0-76	0
ERP #3 San Joaquin River at Vernalis	0-148	43-83	62-148	0-18
ERP #4 Sacramento River at Freeport	0-242	0-149	0-242	0-41
Trinity River below Lewiston	5-344	47-180	99-344	5-34
San Joaquin River below Friant	56-356	155-318	251-356	56-277
Level 4 Refuges Sacramento Region	17-26	20-23	20-26	17-22
Level 4 Refuges San Joaquin Region	20-63	24-40	27-63	20-22

[1] This column represents the range of additional annual volume of water that would have been needed during 1998-2007 if the listed environmental objectives had been in place. These values are used as a surrogate to estimate new environmental requirements that may be enacted in the future.

Plan scenarios was evaluated against 12 separate climate scenarios identified by the Governor's Climate Action Team (CAT). Each of the 12 CAT 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 are used in the Water Plan scenarios with other factors to estimate future water demands. Refer to Chapter 6 Integrated Data and Analysis and the article in Volume 4 Reference Guide, "Overview of Climate-change Scenarios Being Analyzed" for additional information on the CAT climate scenarios.

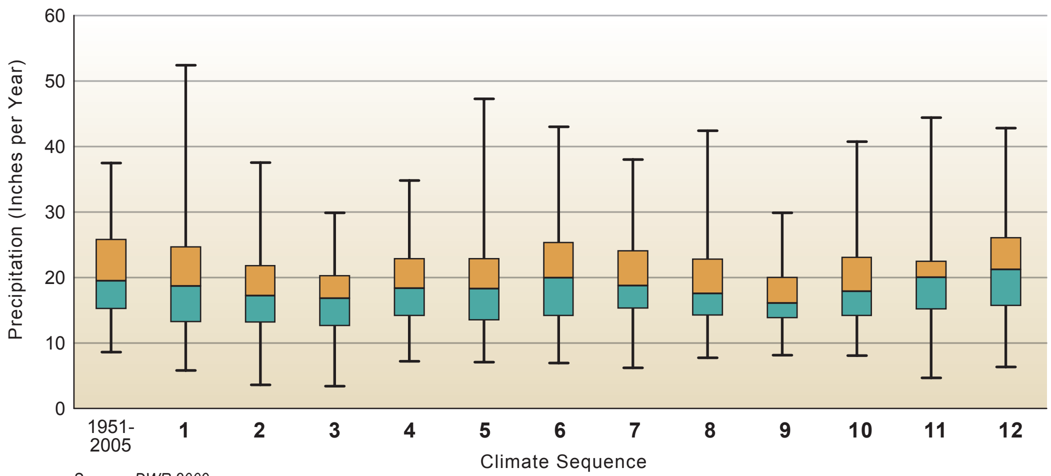
A significant improvement to the Water Plan scenarios in Update 2009 is a quantitative look at the uncertainty surrounding future climate change. Each of the three Water Plan scenarios was evaluated against 12 separate climate scenarios identified by the Governor's Climate Action Team (CAT).

Figure 5-4 shows the variation in average annual precipitation for the Sacramento Valley floor for both the 1951–2005 historical period and for the 12 CAT scenarios of future climate for the years 2006–2100. The variation in precipitation is represented as a boxplot (also known as a box-and-whisker diagram or plot), which is a convenient way of graphically summarizing a large data set with five numbers (the smallest observation, lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation). For example, for the 1951–2005 historical period, the boxplot shows a minimum value of about 8.5 inches in the driest year, a median value of 19.5 inches per year, and a maximum value of 37.5 inches in the wettest year. The precipitation values used to generate the boxplot are the spatial average over the valley floor within the Sacramento River Hydrologic Region. Similar boxplots were developed for the other nine hydrologic regions.

Figure 5-5 shows the trend in the change in average annual temperature for the Sacramento Valley floor for each climate sequence compared against the 1951–

Historical 1951-2005 period and 12 scenarios of future climate years 2006-2100

Figure 5-4 Variation in precipitation for Sacramento Valley floor

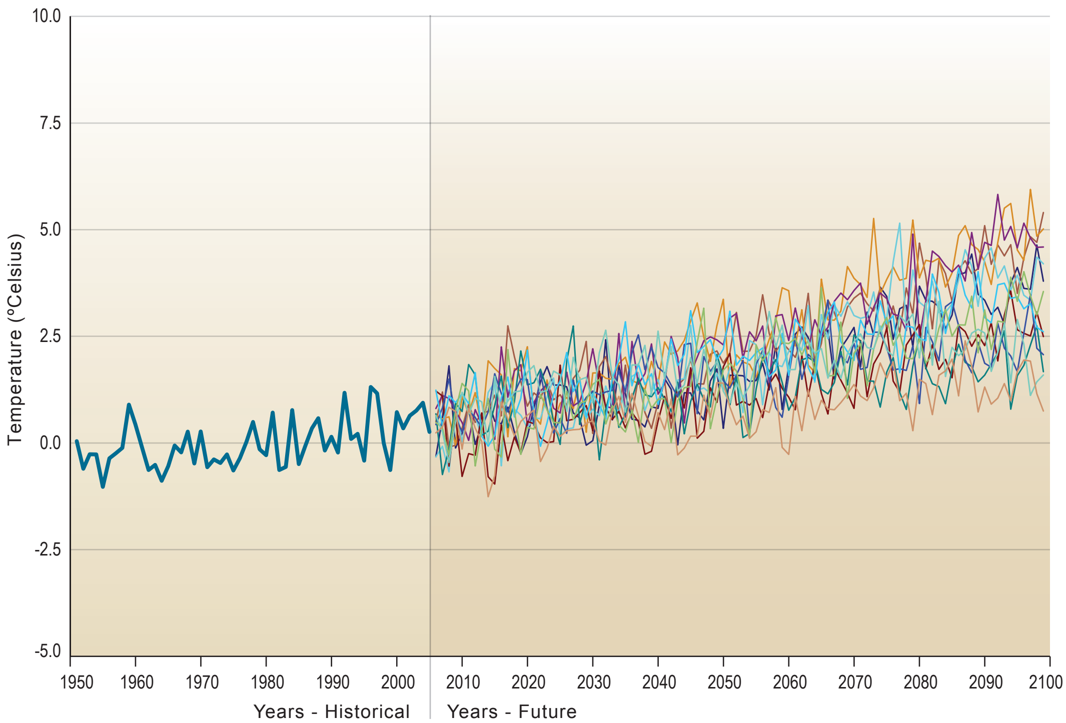


Source: DWR 2009

Historical 1951-2005 average for historical period and 12 scenarios of future climate years 2006-2100

Figure 5-5 Change in average annual temperature for Sacramento Valley floor

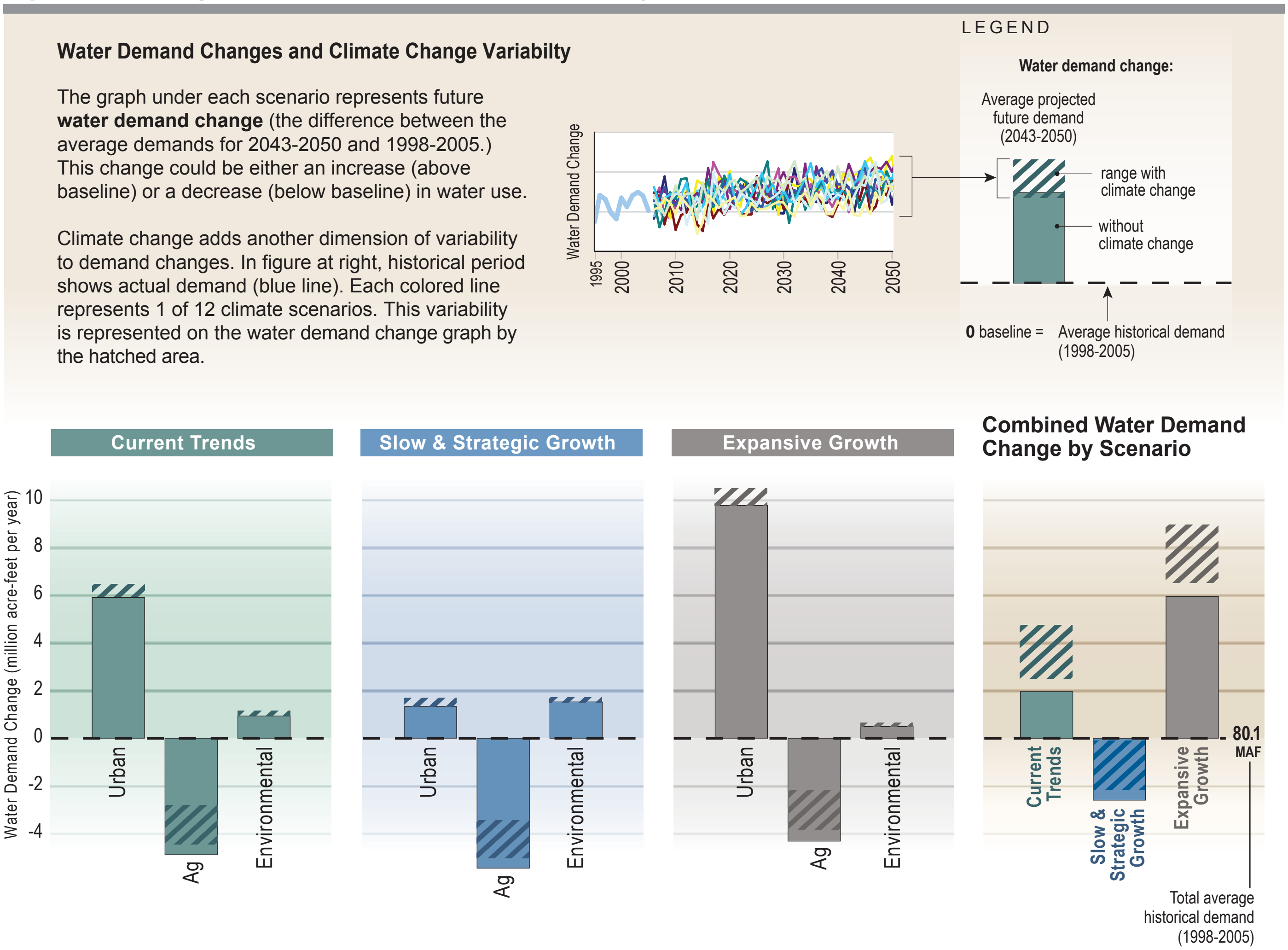
In this figure, historical period shows actual temperature (blue line). Each colored line represents 1 of 12 climate sequences.



Source: DWR 2009

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

Figure 5-6 Change in future statewide water demand by scenario



Looking to the Future—Statewide Scenario Water Demands

The change in water demand shown by the solid bar assumes a repeat of historical hydrology while the hatched bar shows the change in water demand when considering 12 different climate change scenarios.

Through the use of scenarios, the Water Plan quantified three different, but plausible estimates of future water demands. Future urban water demand was estimated individually for the residential, commercial, industrial, and public sectors. Irrigated agricultural water demand was estimated by using different plausible estimates of future irrigated crop acreage. Environmental water demand for each scenario was assumed to equal water dedicated to the ecosystem under current conditions plus an additional scenario-specific amount. See Chapter 6 Integrated Data and Analysis for a more detailed description of the analytical methods used to estimate future water demands for each California region.

Figure 5-6 shows the statewide change in water demand for each sector (urban, agricultural, and environmental) by scenario and summed across all sectors. The change in water demand shown is the difference between the average demands for 2043–2050 (projected future) and 1998–2005 (historical). The change in water demand shown by the solid bar assumes a repeat of historical hydrology while the hatched bar shows the change in water demand when considering 12 different climate change scenarios. These climate scenarios are based on recent scientific studies of future trends in precipitation and temperature as described in the previous section. Both of these factors heavily influence water demand for outdoor landscaping and irrigated agriculture.

Without considering climate change, annual combined statewide water demand shows a decrease of about 2.5 million acre-feet under the Slow & Strategic Growth scenario to an increase of about 6 million acre-feet per year under the Expansive Growth scenario. The Current Trends scenario falls in between these with an increase of about 2 million acre-feet per year. When climate change is factored in, all scenarios show higher annual water demands than under a repeat of historical climate.

Across the three scenarios, there is a wide potential range in future annual combined statewide water demands depending on the specific scenario assumptions of future population growth, acres of irrigated farmland, development densities, and background water conservation (like plumbing code changes, natural replacement, actions water users implement on their own, etc.). Without considering climate change, annual combined *statewide water demand* shows a decrease of about 2.5 million acre-feet under the Slow & Strategic Growth scenario to an increase of about 6 million acre-feet per year under the Expansive Growth scenario. The Current Trends scenario falls in between these with an increase of about 2 million acre-feet per year. When climate change is factored in, all scenarios show higher annual water demands than under a repeat of historical climate. For example, with climate change the range of annual water demand for the Expansive Growth scenario was from about 6.5 million to above 9 million acre-feet per year, between 0.5 and 3 million acre-feet higher than when considering a repeat of historical climate. This reflects changes in water demand for future climate scenarios that are either warmer or drier or both warmer and drier.

Climate change has a smaller impact on future annual urban water demands compared to the effects of future population growth.

The change in statewide annual *urban water demands* ranges from an increase of under 1.5 million acre-feet per year for the Slow & Strategic Growth scenario to an increase of about 10 million acre-feet per year under the Expansive Growth scenario. The Current Trend scenario falls in between with an increase of 6 million acre-feet per year. The demands for each scenario are heavily influenced by assumptions about future population growth shown in Figure 5-1 and background water conservation water savings assumed to be 5 percent, 10 percent, and 15 percent by 2050 for the Expansive Growth, Current Trends, and Slow & Strategic Growth scenarios, respectively. Climate change has a smaller impact on future annual urban water demands compared to the effects of future population growth, but could still result in increased annual water demands of up to 750 thousand acre-feet per year.

The observed effect of climate change is to dampen the reduction in future agricultural annual water demands.

All scenarios show a decrease in *agricultural water demand* associated primarily with loss of farmland to development and increases in background water conservation. Similar to the urban sector, background water conservation savings by 2050 are assumed to be 5 percent, 10 percent, and 15 percent for the Expansive Growth, Current Trends, and Slow & Strategic Growth scenarios, respectively. Climate change may have significant effects on future agricultural water demands due to assumptions of future precipitation and temperature under different climate change scenarios. The observed effect of climate change is to dampen the reduction in future agricultural annual water demands (i.e., agricultural water demands would be higher). For example, in the Current Trends scenario statewide annual water demands for agriculture decline by about 5 million acre-feet per year without climate change. With climate change this decline ranges from 3 million to 4.5 million acre-feet per year.

As described in the previous section, the Water Plan scenarios use currently unmet environmental objectives as a surrogate to estimate new requirements that may be enacted in the future to protect the environment. The change in environmental water demand results are very coarse estimates and are not based on detailed hydrologic modeling of future instream flows. Under the three scenarios, the increase in annual water dedicated to environmental purposes is shown to increase between 0.5 million and 1.5 million acre-feet per year. Climate change may increase these amounts by approximately 10 percent in the drier climate scenarios.

Under the three scenarios, the increase in annual water dedicated to environmental purposes is shown to increase between 0.5 million and 1.5 million acre-feet per year. Climate change may increase these amounts by approximately 10 percent in the drier climate scenarios.

The three baseline scenarios for 2050 would play out differently in various hydrologic regions. This regional variability is illustrated in Figure 5-7, showing the combined urban, agriculture, and environmental water demand changes for each scenario in each region. The way scenario water demands change in each region reflects a number of things—the relative amount of water demand in the region for cities, farms, and environment; how the scenario factors (population, irrigated crop acreage, and water dedicated to the environment) increase or decrease in each area of the state; and how temperature and precipitation changed in the 12 climate change scenarios that were examined.

The three baseline scenarios for 2050 would play out differently in various hydrologic regions.

Hydrologic regions expecting higher population growth under the Current Trends and Expansive Growth scenarios, like the South Coast and the Sacramento River, show higher changes in water demands. Population growth also tends to drive urbanization of agricultural lands, reducing irrigated crop acreage. Precipitation and temperature heavily influence water demand for outdoor landscaping and irrigated agriculture. Less precipitation falling during the growing season increases the need to apply more irrigation water. Warmer temperatures increase crop evapotranspiration, which increases water demand.

Hydrologic regions expecting higher population growth show higher changes in water demands. Precipitation and temperature heavily influence water demand for outdoor landscaping and irrigated agriculture. Water demand changes in Central Valley agricultural areas were most sensitive to the warmer and drier climate change scenarios.

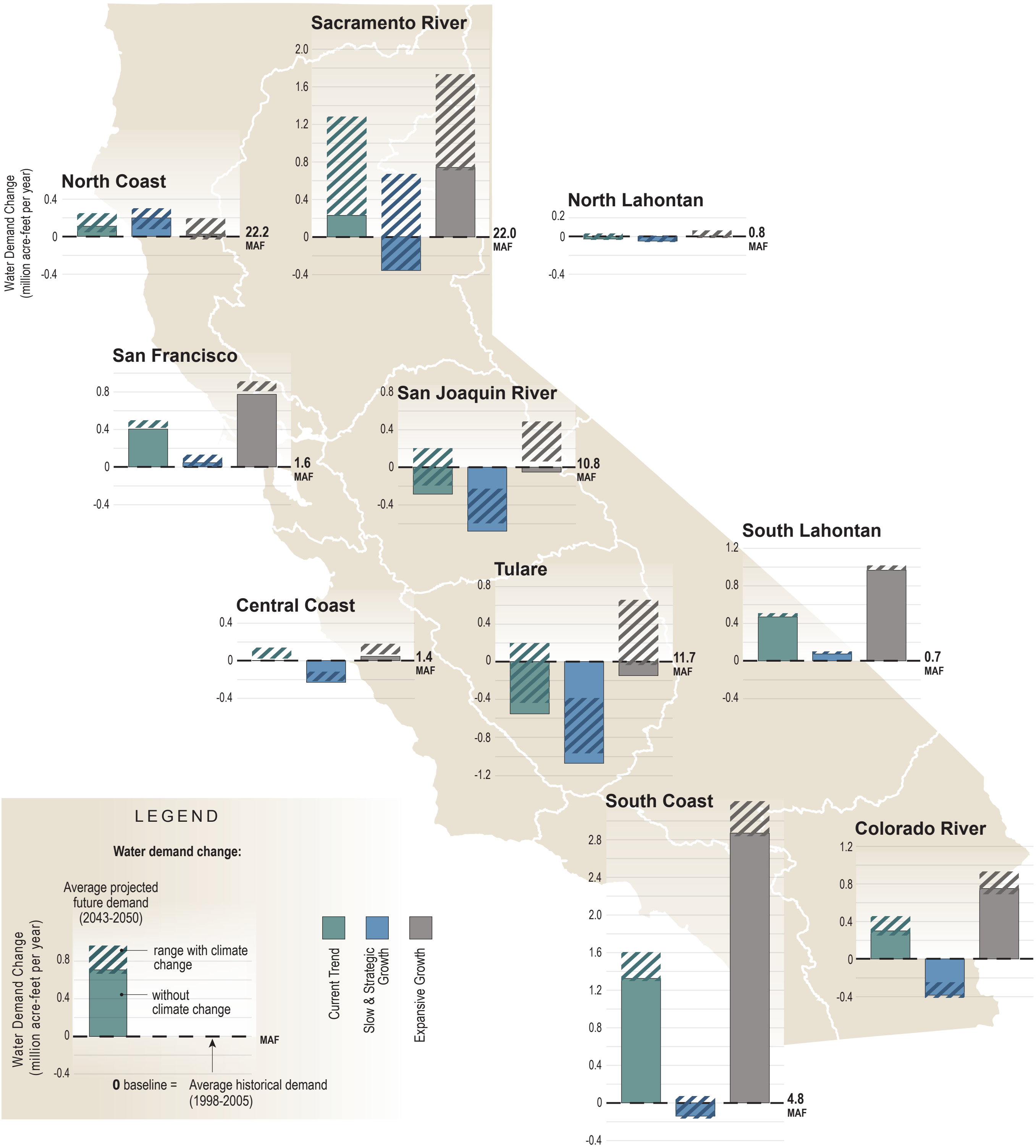
Water demand stays the same or decreases in the San Joaquin River and Tulare Lake regions when climate change was not considered because of less irrigated crop area from urbanization and more background water conservation. Water demand changes in Central Valley agricultural areas were most sensitive to the warmer and drier climate change scenarios. This is particularly evident in the Sacramento River Region where the variation in potential change in water demand is quite large across the 12 climate change scenarios.

Regional Responses

Each future scenario describes a different baseline for 2050 to which the water community would need to respond. A response package is a mix of resource management strategies from Volume 2 designed to provide benefits for a given future scenario. The performance of several different response packages can be compared for each scenario to determine high-performing packages. Having response packages for multiple future scenarios can help identify management responses that perform well across the array of possible future conditions.

Figure 5-7 Change in future regional water demand by scenario

Hydrologic regions expecting higher population growth show higher changes in water demands. Water demand changes in Central Valley agricultural areas were most sensitive to the warmer and drier climate change scenarios.



No single response package will work for all areas of California as each region has its own needs, constraints, and opportunities. Facing an uncertain future, regions need to invest in an appropriate mix of strategies based on integrated regional water management plans that are diversified, satisfy regional and state needs, meet multiple resource objectives, include public input, address environmental justice, mitigate impacts, protect public trust assets, and are affordable. (See Chapter 4 California Water Today in this volume or chapters in Volume 3 Regional Reports for examples of regional water projects throughout the state.)

Each future scenario describes a different baseline for 2050 to which the water community would need to respond. Having response packages for multiple future scenarios can help identify management responses that perform well across the array of possible future conditions. No single response package will work for all areas of California as each region has its own needs, constraints, and opportunities.

Summary

Integrated water management is becoming the basis for California's water planning. This umbrella approach comprises the principles and actions of integrated regional water management and integrated flood management (see Volume 1 Chapter 2 Imperative to Act for further discussion). It undertakes water and flood management at all fronts and on many levels—regionally and statewide; for multiple uses and benefits; for sustainable watersheds, water uses, and water and flood systems; and while weighing the risks of uncertain futures.

The California Water Plan recommends reducing uncertainty through improved data collection, data management, and development of analytical tools for integrated water management. DWR and other entities are conducting various risk assessments so risks can be better balanced with the rewards for improved management. Update 2009 used three different scenarios of future water demand based on alternative but plausible assumptions of future population growth, land use changes, background water conservation and other factors affecting water demands. These scenarios also considered the effect future climate change might have on future water demands. Future updates will test different response packages, or combinations of resource management strategies, for each future scenario. These response packages help decision-makers, water managers, and planners develop integrated water management plans, including integrated flood management plans, that provide for resources sustainability and investments in actions with more sustainable outcomes.

The California Water Plan recommends reducing uncertainty through improved data collection, data management, and development of analytical tools for integrated water management.

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