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In Hot Water

Water Management Strategies to Weather the Effects of Global Warming

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Foreword

The effects of global warming on the health of the planet has been a topic of discussion for decades. However, only recently have the potential impacts of climate change on Western communities become a focus for water resource scientists, planners, and managers. In the American southwest, the severe drought on the Colorado River that began in 2000 served as a wakeup call to water utility managers regarding the possible implications of global warming. Those implications are sobering.

During the last century, long-range forecasts of population growth and water demands in the West have often been underestimated. Add to this fact the reality that stable and reliable water supplies in the West are, for the most part, already allocated. In this age of scarce water supplies, the prospect of climate change should serve as a catalyst for paradigm shifts in the way we manage water. Long-term climate change is adding even more uncertainty to the already difficult task of water resource planning and management.

To respond to the challenges posed by climate change, water managers will need to reevaluate their assumptions concerning storage and use of existing supplies, the amount of water expected to be available in the future, and how scarce or limited supplies should be shared among competing interests. Continued scientific study and dialogue will be of paramount importance to this effort, not only in terms of providing data to help individual utilities manage their respective situations, but also to facilitate the development of practical local, regional, and national policies.

With this in mind, the Natural Resources Defense Council, Desert Research Institute, and Southern Nevada Water Authority co-sponsored a 2005 conference entitled "Urban Water Supplies and Climate Change in the West." The objectives of the conference were threefold: to educate participants about the most recent studies of climate change and potential water supply impacts; to increase understanding and facilitate dialogue between water scientists and water managers; and to discuss options for addressing the potential impacts of climate change on water supplies. The presentations and discussion at that conference led to this report.

It is clear that global warming is occurring, particularly in the West. In general, temperatures are increasing. Scientists predict that this will likely lead to more runoff from rain, less alpine snow pack, larger winter streamflows, and hotter, drier summers. Communities are likely

to face more flooding and more frequent drought. As the West experiences earlier snowmelts and warmer, rainier winters, rivers and streams will be altered. Natural recharge to groundwater basins could decrease.

To cope with these changes effectively, water utilities will need to act quickly to develop diverse and flexible water resource portfolios that will allow them to reduce demands and adapt their supplies to changing climatic and hydrological conditions. However, from a regional and national perspective, perhaps the most important goal for water utilities will be to pursue increased cooperation and collaboration. In the past, models of water resource planning have emphasized competition for water resources. However, as communities throughout the West become more dependent upon each other to manage available resources, and as these resources prove to be interconnected in a myriad of ways, this competitive model of resource allocation is no longer prudent. Without open, collaborative dialogue among utilities and other stakeholders, competition for scarce water resources will only result in conflict, stalemate, and shortages.

The accompanying report and recommendations, and the conference that led to them, represent a first step toward addressing some of these difficult long-term issues. This report summarizes the broad potential water management impacts of climate change, the many existing climate-related activities of water managers around the West, and a full range of recommendations for water managers and staff to consider as they incorporate global warming into the planning and management of their agencies.

As the drought on the Colorado River has shown us in the West, even seemingly "permanent" water resources are susceptible to climatic variability. The time to prepare is now.

Patricia Mulroy
General Manager
Southern Nevada Water Authority

Executive Summary

The world's climate is warming—by an average of 1.3 degrees Fahrenheit in the past century. Unless current trends are reversed, global warming pollution is projected to keep increasing rapidly, raising temperatures by as much as 11.5 degrees Fahrenheit by the end of this century and compromising our water supply, flood management systems, and aquatic ecosystems. Experts predict that rising temperatures will lead to less alpine snowpack, earlier and larger peak streamflows, potential reductions in total streamflows, greater evaporative losses, declining ecosystem health, sea level rise, more extreme weather events—including both floods and droughts—and hotter, drier summers. We're already seeing evidence of these trends around the West.

Water managers—including water districts and local, state, and federal agencies with water-related resource management responsibilities—play a key role in Western communities by identifying potential water-related problems and pointing the way to solutions. As stewards of one of the West's most valuable —and scarce—resources, water managers can lead the response to ongoing climate changes and help stave off further damage.

WATER MANAGEMENT IN A CHANGING CLIMATE

Global warming presents challenges regarding water supply, water quality, ecosystem protection, and flood management—issues that water managers face every day. NRDC has created a blueprint for action, including a set of specific strategies water managers and other decision makers can use as they incorporate climate change issues into management decisions.

Action 1: Evaluate the Vulnerability of Water Systems to Global Warming Impacts

• ***Conduct agency assessments of climate change impacts on water supply.*** Assessments should analyze water supply and other impacts from projected climate change effects, including reductions of snow pack and earlier

peak streamflows, as well as from projected increases in temperature, which may result in greater environmental protection requirements and higher urban and agricultural water demand.

• ***Work with other water managers to evaluate regional vulnerability.*** Regional analyses can help water managers understand the common challenges they face and lay the groundwork for cooperative responses. They are especially important for water agencies in large watersheds and regions facing similar climate change–related challenges.

Action 2: Develop Response Strategies to Reduce Future Impacts of Global Warming

■ ***Consider the impact of climate change on future water management tools.*** Water management tools will be affected significantly—but not equally—by climate change. In general, climate change will make increases in efficiency more effective and reduce the yields from traditional surface storage and diversion projects. The table on the next page shows which water management tools will be most helpful in a climate-altered world.

■ ***Put conservation first.*** Increased investments in water efficiency represent a sound and basic "no regrets" water management approach to future climate change impacts. Cost-effective water conservation investments can generate significant benefits for water supplies and aquatic ecosystems, as well as reduced energy consumption and greenhouse gas emissions.

■ ***Incorporate climate and energy issues into statewide water planning.*** State-level planning efforts should incorporate climate change vulnerability analyses, global warming impacts on management tools, and the energy implications of water management decisions.

■ ***Consider integrated regional water management strategies.*** Water managers should carefully consider an integrated regional water management approach to climate change response. A robust climate change response strategy should include:

• Analysis of potential climate impacts on existing systems, as well as future water supply strategies

• Multiple benefits (e.g., supply, water quality, energy, flood management, and ecosystem benefits)

• An examination of unique regional conditions

• Potential partners to assist in financing and implementation (e.g., energy, stormwater, wastewater, and land use agencies)

• Institutional strengths and responsibilities

The Impacts of Climate Change on Water Management

Global warming is not an issue that we can afford to address with a "wait and see" approach. We must take action immediately or we are at risk of irreversibly damaging some of the West's precious water resources:

• For every rise of one degree Celsius (1.8 degrees Fahrenheit) in the West, researchers predict that snow levels will retreat upward by 500 feet in elevation.

• Extreme weather events such as floods and large storms could increase in size and frequency, straining the limits of flood control systems and exposing some floodplains and low-lying coastal regions to damage reminiscent of Hurricane Katrina.

• The IPCC projects that sea level will rise by 7 to 23 inches by 2100, affecting water supplies, eroding wetlands, diminishing coastal protection from storms, and exposing residents to severe flood damage. This projection assumes no acceleration of ice melt in Greenland or Antarctica. A new study, published after the deadline for consideration by the IPCC, projects that sea levels will rise by 20 to 55 inches this century based on recent observations.

• The stability of levees in the San Francisco Bay-Delta, which provides a portion of the water supply for more than 20 million Californians, will be threatened by rising sea levels.

• Higher temperatures will decrease salmon, trout, and other fish habitat, thereby increasing conflicts over water resources. Scientists estimate that up to 38 percent of locations currently suitable for coldwater fish could become too warm to provide habitat by 2090.

• A full range of potential water supply and demand strategies

• A full range of flood management options

• "Efficiency first" investments

• A clear "with and without" project analysis for major infrastructure investments

• Stronger, enforceable environmental protections, such as flow and temperature requirements for protected species

• Economic analysis and "beneficiary pays" financing

• Clear objectives and performance standards

• Educating the public and decision makers about climate change

■ ***Collaborate with energy utilities.*** Water conservation generates substantial water and energy savings, and thus reductions in greenhouse gas emissions. Water agencies should work with local energy utilities to develop joint programs, such as rebate offers, to encourage customers to conserve water and energy.

■ ***Consider climate change when making commitments about future water deliveries.*** In particular, agencies should avoid promising increased water deliveries based solely on current hydrology, without consideration of future climatic conditions.

■ ***Factor in flood management.*** For agencies with flood management responsibilities, an awareness of climate change should be integrated into future management decisions. Managers should investigate opportunities such as the reoperation of existing facilities, floodplain restoration, groundwater recharge, and flood-compatible agriculture. To reduce future damage, floodplains should be managed with an awareness that they will be inundated more frequently. This suggests placing an increased emphasis on land use issues.

■ ***Protect and restore aquatic ecosystems.*** Degraded aquatic ecosystems result in the loss of species and create endangered species conflicts. Healthy aquatic ecosystems will be more resistant to climate impacts, help reduce conflicts, and provide other benefits to water quality, recreation, and flood protection.

Action 3: Prevent Future Impacts by Reducing Greenhouse Gas Emissions

■ ***Support policies including mandatory caps on emissions.*** The IPCC found with at least 90 percent certainty that the current global warming trend is caused primarily by greenhouse gas emissions—particularly carbon dioxide—released through the burning of fossil fuels. Enforcing a mandatory national cap on the pollution that causes global warming is the single most important step in controlling and reducing the future impacts of global warming. While caps would be most effective at the federal level, local, state, and regional initiatives are also important tools in the face of federal inaction.

Table ES-1: Performance of Water Management Strategies After Considering Global Warming Effects

More effective	Not affected	Less effective
• Landscape conservation • Conservation rate structures • Agricultural water conservation • Water marketing • Urban stormwater management • Saltwater groundwater intrusion barriers to protect coastal aquifers • Water system reoperation • Interagency collaboration and integrated water management strategies • Floodplain management • Watershed restoration	• Wastewater recycling • Interior water conservation • Groundwater cleanup	• Traditional river diversions • Traditional groundwater pumping • Traditional surface storage facilities • Ocean water desalination*

*Given existing energy requirements.

■ ***Take action at the district level.*** Water agencies should develop programs to reduce their energy consumption and greenhouse gas emissions. A thorough understanding of the energy implications of water management decisions can lead to a range of options for achieving this goal. (NRDC's 2004 report *Energy Down the Drain* explores this relationship in detail.)

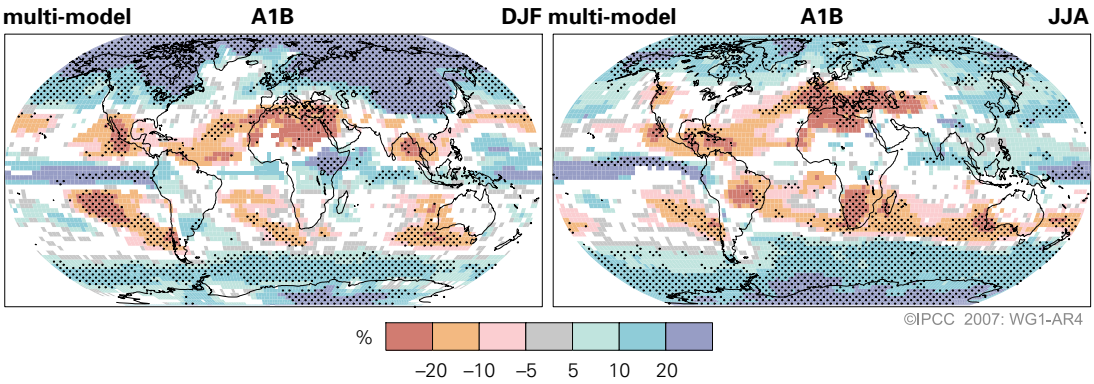
Action 4: Increase Awareness of Global Warming and Water Impacts

■ ***Educate customers and decision makers.*** Global warming is not just an environmental concern—it affects the future of all Western communities, particularly through water-related issues. Addressing the impacts of climate change on water management will require increased awareness and involvement by water district customers and decision makers, including elected officials.

■ ***Raise public awareness.*** Given the global nature of climate change and the need for far-reaching actions to address its causes, raising public awareness is essential to encouraging effective action. Water managers can play an important role in increasing awareness of global warming and the need to take action. Outreach can take the form of advertisements, media outreach, discussions with business groups, conferences, community forums, and more.

Western communities look to water managers for leadership on water issues. With global warming changing

Figure ES-1: Projected Patterns of Precipitation Changes for Period 2090-2099, relative to 1980-1999



Source: IPCC 2007:: WG1-AR4

the way we think about water in the American West and around the globe, water managers and other decision makers must lead the way in ensuring that our drinking water supply is safe, that our communities are protected from floods, and that our aquatic ecosystems support healthy fish and wildlife populations. The time to prepare is now.

HIGHLIGHTS OF EFFORTS TO INCORPORATE CLIMATE CHANGE INTO WATER MANAGEMENT

Across the West, water agencies and other water managers have begun taking action to address the challenges presented by climate change. Here are a few highlights of those efforts.

Evaluating the Vulnerability of Water Systems to Global Warming Impacts

• Many Western communities, including Seattle, Portland, Denver, the San Francisco Bay Area, and water districts in the Sierra Nevada foothills have undertaken analyses of potential impacts to their existing water systems.

• New Mexico and California have released statewide vulnerability analyses.

• In 2005, the American Water Works Association Research Foundation released *Climate Change and Water Resources: A Primer for Municipal Water Providers*.

Implementing Response Strategies to Reduce Future Impacts

• Denver Water has decided to dramatically accelerate its long-range water conservation program, partially in response to potential impacts from global warming.

• California's Department of Water Resources has issued multiple reports regarding climate impacts, including *Progress on Incorporating Climate Change into Management of California's Water Resources*.

• Southern California's Santa Ana Watershed Project Authority has created a national model for integrated regional water management, producing far-reaching water supply, water quality, energy, and climate benefits.

Preventing Future Impacts by Reducing Greenhouse Gas Emissions

• In California, three water agencies—the Santa Clara Valley Water District, the East Bay Municipal Utility District, and the Marin Municipal Water District—supported AB 32, which Governor Schwarzenegger signed into law in September 2006, creating the nation's first state-level mandatory cap on greenhouse gas emissions.

• The Santa Clara County Water District has helped to create a public/private partnership called Sustainable Silicon Valley, which is working to reduce the emission of global warming gases and other pollutants.

• The Bay Area's East Bay Municipal Utility District (EBMUD) has joined the California Climate Action Registry to report its greenhouse gas emissions, earning the district a "Green Power Leadership" award from the Environmental Protection Agency. Since EBMUD joined the registry, more than a dozen California water agencies have joined as well as Seattle Public Utilities and the Salt River Project.

• The Marin Municipal Water District has joined the Cities for Climate Protection campaign, uniting with dozens of other Western cities that run municipal water utilities to create a strategic agenda to reduce global warming.

Increasing Public and Decision Maker Awareness

• The Santa Clara Valley Water District has added a discussion of global warming to its website, stating that "The reality of global warming and climate change is the most significant long-term threat to water resources management in Silicon Valley."

• In January 2007, the San Francisco Public Utilities Commission convened a Water Utility Climate Change Summit attended by more than 150 water managers and other stakeholders. The conference received significant media coverage.

Chapter 1

An Overview of Major Scientific Findings on Climate Change

All elements of water systems, from watershed catchment areas to reservoirs and conveyance systems to wastewater treatment, will likely be affected by climate change and variability.[1] Rising temperatures, a greater proportion of annual precipitation falling in the form of rain instead of snow, altered streamflow timing, reduced snowpack, increased evaporation and transpiration, greater risk of fires, and a sea level rise—all effects of climate change—will require changes in how our current water systems are managed. And with virtually every major water supply source in the West already overallocated beyond its physical and/or legal capacity to be sustained, the consequences could be significant for Western water supply, water quality, and aquatic ecosystems.

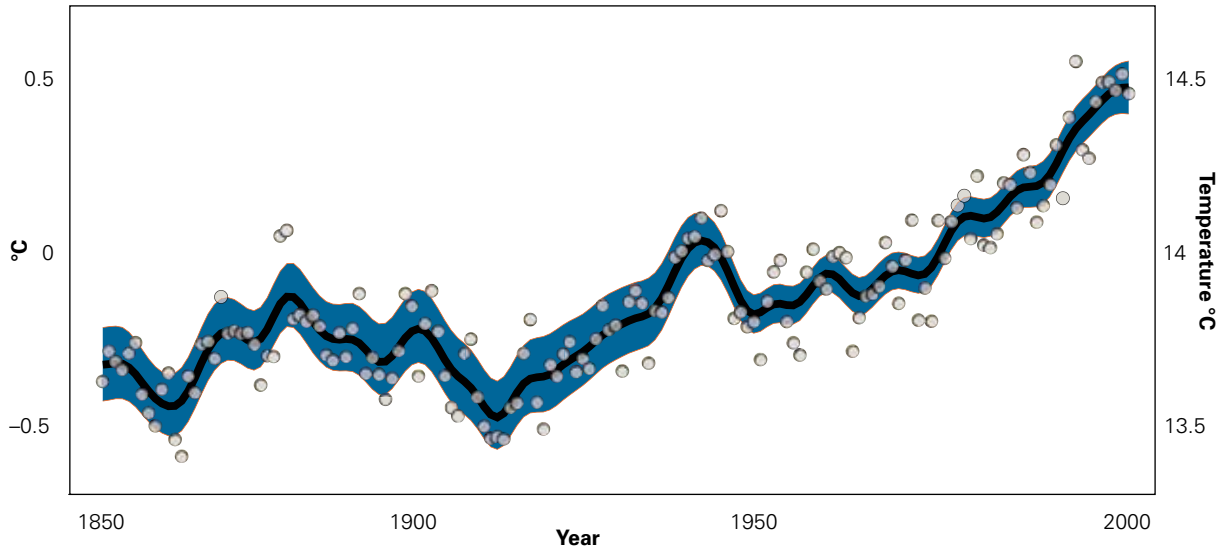
There is broad scientific agreement that climate change is occurring, that emissions of heat-trapping pollution are the primary cause, and that the resulting climate change and variability pose significant dangers to our environment, our health, and our economy.

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report released in 2007 found, with at least 90 percent certainty, that human activities are causing global warming.[2] This comprehensive review confirms and lends even greater confidence to the conclusions of the U.S. National Research Council's (NRC) Committee on the Science of Climate Change 2001 report, *Climate Change Science: An Analysis of Some Key Questions,* which found that greenhouse gases are accumulating in the earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising.[3] It also found that the combustion of fossil fuels (coal, oil, and natural gas) is the major source of greenhouse gas emissions (see Figures 1-1 and 1-2).

The IPCC in 2007 projected that the rate of warming over the 21st century—up to 11.5 degrees Fahrenheit—would be much greater than the changes observed during the 20th century. The IPCC projects the following changes as a result of increased temperatures:

- more frequent hot extremes, heat waves, and heavy precipitation events
- more intense hurricanes and typhoons
- decreases in snow cover, glaciers, ice caps, and sea ice

Figure 1-1: Changes in Global Average Temperatures, 1850-2000



Source: IPCC 2007: WG1-AR4

Global Warming Basics

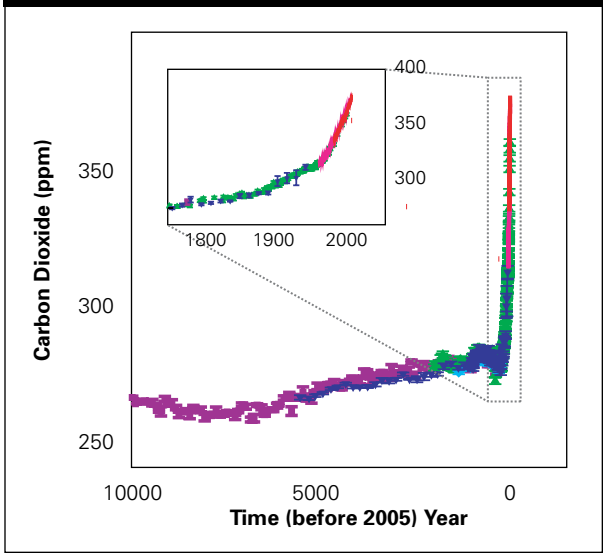
The basic dynamic of global warming is that the earth's temperature is largely regulated by gases that trap heat in the earth's atmosphere. This so-called greenhouse effect allows the earth's temperature to be in the range at which all life on earth has evolved. Increased concentrations of specific gases increase the heat-trapping ability of the atmosphere and are responsible for increasing temperatures. The composition of the earth's atmosphere is particularly important, because certain gases (including water vapor, carbon dioxide, methane, halocarbons, ozone, and nitrous oxide) absorb heat radiated from the earth's surface. Changes in the composition of the atmosphere alter the intensity of the greenhouse effect.

Although natural variability in climate occurs, it is now clear that human activities have been causing most of the global warming since the mid-20th century. We are exerting a major and growing influence on some of the key factors that govern climate by changing the composition of the atmosphere and by modifying the land surface. The concentration of carbon dioxide (CO_2) has risen about 30 percent since the late 1800s. The concentration of CO_2 is now higher than it has been in for at least the last 650,000 years. This increase is the result of the burning of coal, oil, and natural gas and the destruction of forests around the world to provide space for agriculture and other human activities. Rising concentrations of CO_2 and other greenhouse gases are intensifying earth's natural greenhouse effect. Projections of population growth and energy use indicate that, on our current course, the CO_2 concentration will continue to rise, likely reaching between two and three times late-19th-century levels by 2100. This dramatic doubling or tripling will have occured in the space of about 200 years.

Sources: National Assessment Synthesis Team, 2001. *Climate Change Impacts on the United States, report for the United States* Global Change Research Program. Cambridge University Press, p.12. http://prod.gcrio.org/nationalassessment/.

Climate Change 2007: The Physical Science Basis: Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, p.4.

Figure 1-2: Changes in Atmospheric Concentrations of Carbon Dioxide from Ice Core and Modern Data



Source: IPCC 4 Summary for Policy Makers, p. 3

• a rise in global mean sea level of 7 to 23 inches (this projection does not include accelerated ice-sheet melting and other factors)[4]

Recent studies indicate that the range of possible sea level rise may be even greater. A report in *Science* magazine projects a 20- to 55-inch rise in sea levels over the 21st century, based upon recent observations.[5] This study was published after the deadline for consideration for the IPCC's Fourth Assessment Report.

Changes caused by a warming climate will not necessarily occur in a steady and predictable fashion. A recent report from the NRC, *Abrupt Climate Change: Inevitable Surprises*, shows that some major and widespread climatic changes have occurred with startling speed. The study notes that abrupt changes were most common when the earth's climate was being heated most rapidly, concluding that "greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events."[6]

Although difficult to predict or plan for, climatic shifts—gradual or dramatic—are among the scenarios that water managers must consider in future modeling and planning. Fortunately, some in the water management community are actively engaged in the analysis of climate change impacts and are undertaking analyses of water system vulnerabilities to future climate change effects. For example, in 2005, the American Water Works Association Research Foundation (AWWARF) and the National Center for Atmospheric Research (NCAR) released a report entitled *Climate Change and Water Resources: A Primer for Municipal Water Providers,* and in July 2006 the California Department of Water Resources released *Progress on Incorporating Climate Change into Management of California's Water Resources.*[7,8] It is clear that water managers will have to adapt to changing climate conditions.

> **"The water supply for any utility will depend on the quantity and timing of local and regional precipitation, both of which may change with global climate change… Climate change is an additional source of uncertainty that will become increasingly relevant to water resource managers in the 21st century. Just as with any other source of uncertainty, best practice requires understanding as much as possible about the changes that can occur and their implications for operation and management of the utility."**
>
> Source: Kathleen Miller and David Yates, Climate Change and Water Resources: A Primer for Municipal Water Providers (AWWARF 2006).

Chapter 2

How Climate Change Will Affect Western Water Supply and Management

The snow and ice of western mountain ranges are the lifeblood of water supply and storage in the western United States; their melting snowpack feeds rivers that provide that area of the country with as much as 75 percent of its water supply.[1] An elaborate system of reservoirs, aqueducts, pumping plants, treatment facilities, and other engineered facilities moves the West's water supply from two principal sources: (1) surface water, which is often stored in reservoirs and (2) groundwater.

This water supply infrastructure, matched by an even more elaborate set of laws and policies that govern water use and rights, was designed and engineered for timing and magnitudes of runoff based on our understanding of past hydrological conditions, including temperature, precipitation, and snowmelt patterns.

Climate change and variability will affect the timing, amounts, and form of precipitation, in turn, affecting all elements of water systems from watershed catchment areas to reservoirs, conveyance systems, and wastewater treatment plants.[2] These systems are already stressed today. Overdraft and contamination of groundwater sources have reduced the availability of groundwater supplies in many areas. Saltwater intrusion in coastal aquifers is a problem in many areas. Climate change has the potential to exacerbate these situations, requiring increased attention from water managers. Extreme events such as droughts and major flood events are particularly challenging for water managers. Climate modeling indicates that these kinds of extreme events are likely to become more frequent and intense in the future. In fact, there is strong evidence that wildfires, precipitation patterns, and

Figure 2-1: Total Surface and Groundwater Withdrawals by U.S. County

The Western United States withdraws more water than any other region in the nation. The changes to hydrology and water supply that are likely to be caused by global warming threaten to have serious implications for western water management. Source: USGS 2004

> **"Climate change has the potential of affecting a wide variety of water resource elements. These range from water supply, hydroelectric power, sea level rise, more intense precipitation events, water use, and a number of miscellaneous items which include water temperature changes."**
>
> Source: Maurice Roos, California's state hydrologist in draft materials prepared for the California Energy Commission for the Public Interest Research Program (PIER) on Climate Change.

snowmelt are already being influenced by anthropogenic climate change.[3]

CLIMATE CHANGE EFFECTS WILL RESHAPE WATER SUPPLY IN THE WEST

As the U.S. National Assessment water sector report summarizes, "More than 20 years of research and more than 1,000 peer-reviewed scientific papers have firmly established that a greenhouse warming will alter the supply and demand for water, the quality of water, and the health and functioning of aquatic ecosystems."[4] The most significant impacts of global warming on water management—rising temperatures, increasing proportions of annual precipitation in the form of rainfall, disrupted streamflow timing, altered snowpack conditions, increased evaporation and transpiration, greater risk of fires, and sea level rise—are discussed in more detail in the following sections.

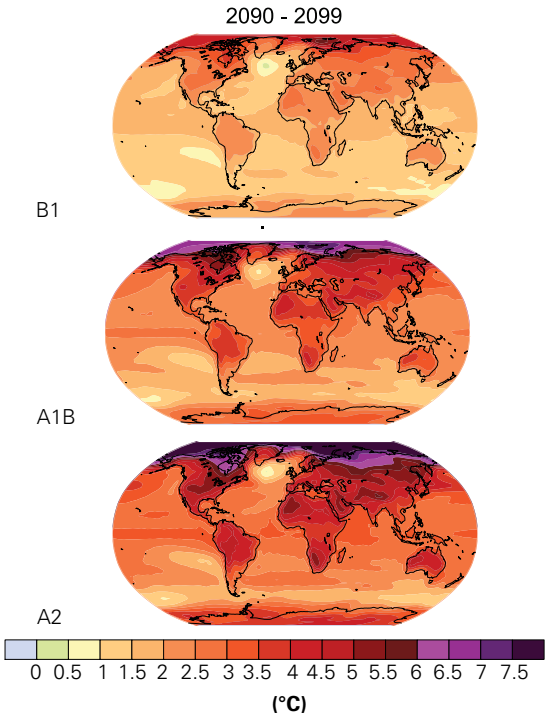
Rising Temperatures Could Mean Earlier Snowmelts and Outflows

The IPCC 2007 report found that "11 of the last 12 years (1995 to 2006) rank among the 12 warmest years... since 1850".[5] Climate models also consistently indicate a warmer future for the U.S. West (see Figure 2-2). Evidence of warming trends is already being seen in winter temperatures in the Sierra Nevada, which rose by almost 2 degrees Celsius (4 degrees Fahrenheit) during the second half of the 20th century. Trends toward earlier snowmelt and runoff to the San Francisco Bay-Delta over the same period have also been detected.[6] Water managers are particularly concerned with the mid-range elevation levels where snow shifts to rain under warmer conditions, thereby changing the snow storage. Research is also indicating earlier melting and spring flows, as described in more detail in a later section.

Greater Extremes in Precipitation Will Challenge Flood Control and Water Storage

Climatologists expect that global average precipitation will increase, however, some areas will become wetter while others will become drier. In addition, the timing, location, and form (rain versus snow) will likely differ from historical norms. Studies have found an average increase in precipitation in the continental United States of about 10 percent over the last century. The intensity of precipitation has increased for very heavy and extreme precipitation days, with most of the increase in the highest annual one-day precipitation events. Plots of global and U.S. precipitation changes over roughly the past century reveal considerable variation by region. Such findings have serious implications for flood control as well as water supply storage.[7]

Figure 2-2: Projections of Surface Temperature Changes for Late 21st Century



Source: *Climate Change 2007: The Physical Scientific Basis: Summary for Policymakers.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

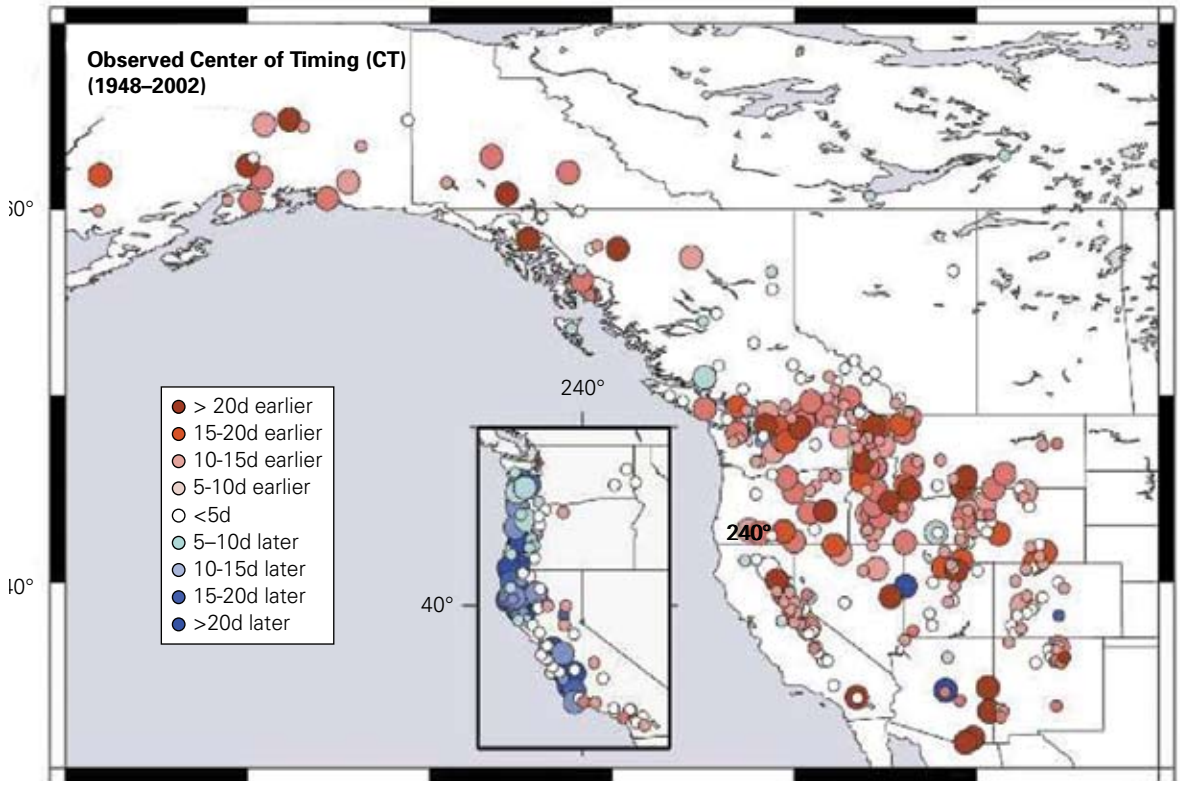
Although there is uncertainty regarding how climate change will affect regional precipitation patterns throughout the American West, several analyses indicate that the Southwest may be drier and that high latitudes may be wetter in the future. For example, a 2007 National Research Council report on Colorado River basin hydrology concluded, "Over the next 10–40 years, there is a tendency in the results of climate model super-ensembles to forecast slightly increased annual precipitation in the Northwestern United States by about ten percent above current values and to forecast slightly decreased annual precipitation in the Southwestern United States by less than ten percent below current values, with relatively little change in annual precipitation amounts forecast for the headwaters regions of the Colorado River."[8] Potential changes in precipitation patterns will have far reaching implications for water managers, particularly in oversubscribed river basins—which includes most rivers in the West.

Reduced Snowpack and Earlier Snowmelt Disrupt Streamflows

In the West, streamflow is often strongly influenced by runoff from melting winter snowpacks. Streamflow is characterized by timing, magnitude, frequency, and duration of water flows, all of which are affected by climate change. Water management strategies for supply and flood control are therefore highly attuned to streamflow timing, making any changes in streamflow timing a critical management issue.

Recent studies indicate that changes have already occurred in snowmelt and spring runoff throughout the western region of North America. The United States Geological Survey (USGS), which has been measuring

Figure 2-3: Accelerated Runoff in the West, 1948-2002



Spring runoff in the West, measured in terms of center of timing—the date at which 50% of annual runoff is reached—now occurs 1–4 weeks earlier than 50 years ago.

Source: Steward, Iris T., Daniel R. Cayan, Michael D. Dettinger, April 2005. "Changes toward Earlier Streamflow Timing across Western North America". Journal of Climate. http://meteora.ucsd.edu/cap/pdffiles/stewart_timing.pdf

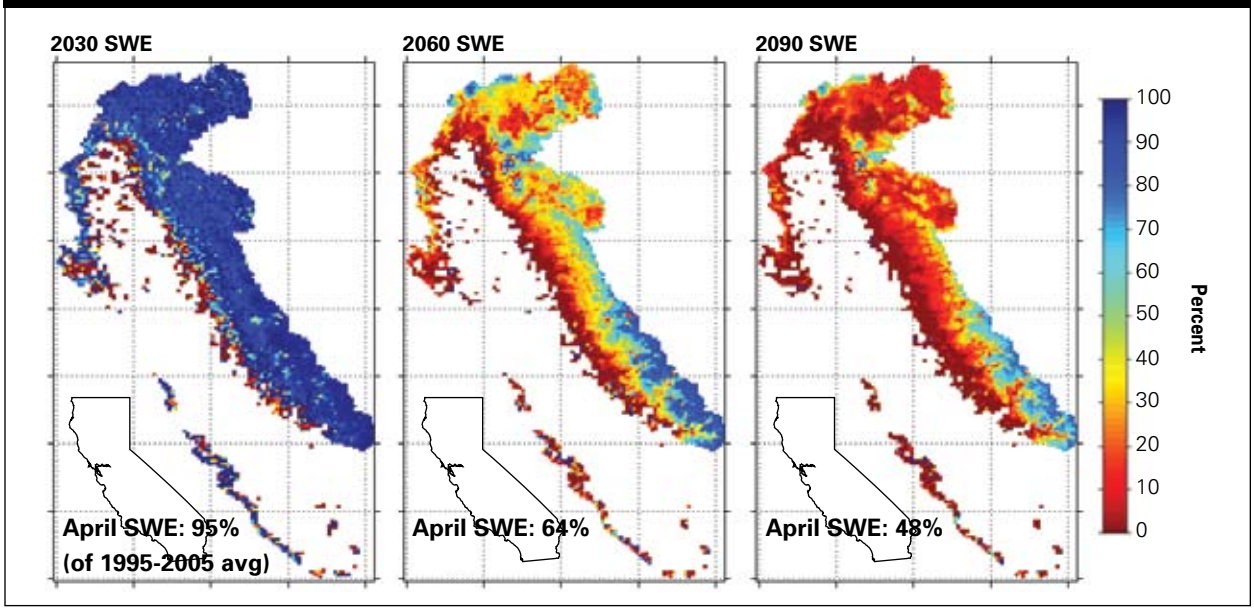
streamflows and spring runoff since the late 19th century, observes that "both measures indicate that flows in many western streams arrive a week to almost 3 weeks earlier now than they did in the middle of the 20th century. The largest changes have been identified in the Pacific Northwest, but the trends also are present in the Sierra Nevada of California, in the Rocky Mountains, and in parts of British Columbia and southern Alaska."[9] Figure 2-3 shows accelerated spring runoff across the West for the latter half of the 20th century.

Water agencies have found the same changes in streamflow when analyzing climate changes impacts upon their water systems. For example, Seattle Public Utilities sponsored a study by University of Washington's Climate Impact Group (CIG) to examine global warming's potential effects on Seattle's water system. Their modeling indicates an average decrease in combined inflow volumes to its two primary water sources, the Cedar and Tolt Reservoirs, of approximately 6 percent per decade through 2040—totaling about 5,000 acre-feet by 2040 when compared to historical record.[10]

Other recent studies indicate that both early snowmelt and diminished snowpack in the West may be related to increased temperatures due to global warming.[11] Runoff indexes for both the Sacramento and San Joaquin rivers in California, for example, show a marked decline in flows during the critical April to July period over the past century. And researchers have shown that for most of the second half of the 1900s, snowmelt-generated runoff came increasingly early in the water year in many basins in California.[12] A declining fraction of the annual runoff was occurring during the months of April to June in middle-elevation basins, while an increasing fraction was occurring earlier in the water year, particularly in March.[13] Other studies have reached similar findings of increasing winter and spring floods under conditions in which rain falls on snow.[14]

Future changes in snowpack are a cause for concern. One study projected that snow levels will retreat 500 feet in elevation in California for every rise of one degree Celsius.[15] Figure 2-4 shows projections for snowpack impacts in California through the 21st century. An analysis by Peter Gleick published in the journal *Water Resources Research* examined the potential for shifts in runoff in California due to increased temperature.[16] For the study, Gleick used a water-balance model developed for the Sacramento Basin. He based his climate change scenarios on increases in average monthly temperature of 2 and 4 degrees Celsius (4 and 7 degrees Fahrenheit) and changes in precipitation of +/–10 and 20 percent. The study found that summer runoff decreased in all scenarios, whereas winter runoff rose in all those scenarios in which precipitation was kept constant or increased. With an increase in temperature of 4 degrees Celsius (7 degrees

Figure 2-4: Evolution of Average Annual Snow Water Equivalent as a Percentage of Average 1995-2005 Values



Source: Knowles, N. and Dan Cayan. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. September 28, 2002. Geophysical Research Letters. Vol. 29, No. 18.

Fahrenheit) and an increase in precipitation of 20 percent, the winter runoff rose by 75 percent and the summer runoff decreased by 49 percent.

Increased Evapotranspiration Reduces Total Streamflows

Although there is still significant uncertainty regarding how climate change will affect precipitation patterns in the West, a significant body of analysis suggests that total streamflows in the future will be reduced in comparison with historical levels. This change has powerful implications for water managers.

Increased temperatures are expected to lead to increased evaporation and transpiration, which will increase water loss from standing water and decrease soil moisture levels. A seminal study by Gleick and Nash of the Colorado River basin demonstrated the crucial role evapotranspiration plays in water availability. The authors found that with no change in precipitation, a 2 degree Celsius increase in temperature would reduce mean annual runoff by 4 to 12 percent and that the reduction in runoff for a 4 degree Celsius increase would be between 9 and 21 percent. The authors concluded that if temperature rose by 4 degree Celsius, precipitation would need to jump by nearly 20 percent to maintain historical runoff levels.[17]

In 2007, the National Research Council reached similar conclusions in a review of the science regarding hydrologic variability in the Colorado River basin. The investigation included analyses of historical hydrology and likely future variability, as a result of climate change. The report projects that future reductions in total Colorado River streamflow are likely:

"This body of research collectively points to a future in which warmer conditions across the Colorado River region are likely to contribute to reductions in snowpack, an earlier peak in spring snowmelt, higher rates of evapotranspiration, reduced late spring and summer flows and a reduction in annual runoff and streamflow."[18]

This projected reduction in total runoff is anticipated as a result of increased losses to evapotranspiration. Specifically, "(h)igher temperatures will cause higher evaporative losses from snowpack, surface reservoirs, irrigated land and land cover surfaces across the river basin."[19]

The report discusses the significance of this change from a policy perspective. "Any future decreases in Colorado River streamflow, driven primarily by increasing temperatures, would be especially troubling because the quantity of water allocations under the Law of the River already exceeds the amount of mean annual Colorado River flows."[20]

Other efforts have also projected potential decreases in total streamflows. For example, analysis by the California Climate Change Center in 2006 found that climate change could lead to significant reductions in total reservoir inflows and total Delta inflows. Approximately two-thirds of model runs revealed likely reductions in total inflows for major northern California reservoirs, with maximum projected reductions of approximately 12 percent.[21] It is important to note that this analysis does not clearly separate the factors anticipated to cause this reduction.

Potential reductions in total streamflows have far-reaching implications for water managers. This is particularly true because, in many cases, additional water

Table 2-1: Predicted Changes in California's Reservoir and Delta Inflows in 2050 with Climate Change

	Lake Shasta			Folsom Lake			Total Delta Inflows		
	Annual Avg. Inflow (TAF)	Change From Base (TAF)	Change From Base (%)	Annual Avg. Inflow (TAF)	Change From Base (TAF)	Change From Base (%)	Annual Avg. Inflow (TAF)	Change From Base (TAF)	Change From Base (%)
Base	5492			2670			20850		
GFDL A2	5442	–51	–1%	2355	–315	–11.80%	20258	–592	–3%
PCM A2	5177	–315	–5.70%	2410	–260	–9.70%	19939	–911	–4%
GFDL B1	5601	109	2.00%	2368	–302	–11.30%	20071	–778	–4%
PCM B1	5854	362	6.60%	2829	159	6.00%	21789	939	5%

Data derived from Chapter 4 of California Department of Water Resources, Progress on Incorporating Climate Change into Management of California's Water Resources. Technical Memorandum Report. July 2006.

development could be designed to capture flows that are not captured by the current infrastructure. If future average streamflows are lower, it suggests that this infrastructure could be wasted—designed to capture flows that may not be there in the future.

A Warmer Climate Increases the Risk of Fires

Fire is already a serious concern in the West. Where wildlands meet development, fire poses a particular danger to life and property. But fire also provides important benefits and is a necessary process in the West's ecosystems. Many plants actually depend on periodic fire cycles to maintain health and some plants require fire for seed germination. Whether a benefit to the ecosystem or a threat to property, fire can have serious water supply impacts in terms of reduced downstream water quality and loss of reservoir storage capacity due to sedimentation.[22]

Studies show that earlier loss of snowpack will lead to increased stress on vegetation, reduced summer soil moisture, and, therefore, increased threat of fire, particularly in the arid West. There is strong evidence from research at Scripps Institute that this is already occurring in the western United States.[23] Two primary ways for climate change and variability to increase the threat of fire are: an oscillation between periods of increased precipitation and periods of drought—as projected in some climate scenarios—could increase fuel loads and create extreme fire conditions, and; warmer temperatures and consequent low moisture content in soils and fuel could create increased fire risk. Heat waves and high winds would exacerbate these conditions. Frank Davis at University of California Santa Barbara notes that "fire behavior models predict a sharp increase in both ignition and fire spread under warmer temperatures combined with lower humidities and drier fuels."[24]

A particularly interesting finding from the Southwest Regional Assessment is the relationship of climate to fire cycles evident in the tree-ring record.[25] Reconstruction from tree-ring data of wildfire occurrence in the Southwest reveals simultaneous changes occurring after 1700 that reflect climate impacts to wildfire patterns over interannual to centennial time scales.[26] Research by Swetnam et al. highlights the importance of understanding how lag times between climatic events and vegetation response influence subsequent fire patterns.[27] These lag times have important implications for long-range fire hazard forecasting and ecosystem management. For example, based on a 300-year record of climate and fire derived from tree-ring analysis, a pattern of one or more wetter-than-normal El Niño winters in the Southwest, followed by a drier-than-normal La Niña winter, establishes preconditions for unusually large and intense wildfires.[28] Further, certain kinds of episodic ecological disturbances, such as insect outbreaks, may be traceable to patterns in climatic variability.[29]

Sea Level Rise Threatens Water Supply, Water Quality and Wetlands

Global warming drives two primary mechanisms of sea level rise: thermal expansion of seawater as the oceans warm, and; melting of mountain glaciers and massive bodies of polar ice—particularly the Antarctic and Greenland ice sheets.

The Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report projects that sea levels will rise by 7 to 23 inches by the year 2100—a consequence that brings profound implications for water resources in the West.[30] This estimate does not account for the accelerated melting of the Antarctic and Greenland ice sheets.

The melting of ice sheets brings the largest potential rise in total sea levels, as their complete melting would result in a 70-meter increase in global sea levels.[31]

A great deal of uncertainty exists regarding ice sheet dynamics and the limitations of current modeling. For example, a NASA/University of Kansas study published in the March 24, 2006 issue of *Science* by Jonathan Overpeck and co-authors, estimated that the last time Arctic temperatures were as high as those projected for the 21st century (about 125,000 years ago), sea levels was 4 to 6 meters higher than it is today.[32] It is difficult to estimate how long it would take for sea level to rise this much, University of Texas researchers determined that the Greenland ice sheet is currently melting three times faster than during the previous five years, underscoring the already accelerating rates of ice sheet melting.[33] Although uncertainties exist in forecasting the rate of ice sheet melting, acceleration in sea level rise is real, bringing serious implications for coastal land and water supply.

On the West coast, sea level rise presents potentially severe impacts. For example, for the San Francisco Bay and the Sacramento-San Joaquin River Delta, global warming impacts will compromise ecosystem health, water supply, and water quality (see "The Rising Costs of Rising Sea Level"). Sea level rise could also affect water supply by causing wetland erosion and surface water and

The Rising Costs of Rising Sea Level

The predicted increase in physical damage to the coastal structures and coastal erosion associated with sea level rise inundation will have significant and far-reaching costs. The IPCC Third Assessment Report estimates that in the case of a 0.5-meter sea level rise, the financial costs of cumulative flooding impacts to U.S. coastal property would reach at least $20 billion to $150 billion. Storm surges and floods have the potential to breach levees, leading to massive economic and social costs—as seen in the aftermath of Hurricane Katrina in New Orleans. These costs must be considered when evaluating the reliability of future water supply projects, particularly those that include the building of storage facilities and physical ocean barriers, such as levees.

Source: Burkett, V., J.O. Codignotto, D.L Forbes, N. Mimura, R.J. Beamish, V. Ittekkot. "Coastal Zones and Marine Ecosystems" in *Climate Change 2001: Impacts, Adaption, and Vulnerability,* James J. McCarthy, Osvaldo F. Canziani, Neil A. Leary, David J. Dokken, Kasey S. White, eds. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. 881 p.

groundwater salination. The inundation of wetlands induced by climate change could weaken their critical role as a natural water filtration system.[34] In addition, inundation due to sea level rise will increase salinity intrusion into coastal aquifers.[35]

CLIMATE CHANGE WILL AFFECT FLOOD MANAGEMENT

Flood management has been the cause of growing concern—and cost—throughout the United States, particularly in the West as floodplains are urbanized. According to data from the National Weather Service, from 1955 to 2003 the average annual cost of flood damages combined for California, Washington, Oregon, Nevada, New Mexico, Utah, Colorado, Arizona, and Montana has been more than $332 million in today's dollars.[36] However, for the period between 1994 and 2003 the annual average was almost $930 million per year—an increase reflecting the growing severity of a situation that will only be made worse by the effects of climate change.

In the West, the majority of the annual precipitation occurs in the winter and early spring. That timing creates a tension between flood control and water supply. Most large reservoirs serve a dual purpose: providing flood protection during the wet months and water supply during the rest of the year. In order to provide flood protection, reservoirs must keep a percentage of their total storage capacity empty in the event that space is needed to capture high flows and prevent flooding downstream. But as the end of the wet season nears, water managers must balance the risk need to maintain sufficient storage space in their reservoirs for flood protection against the risk of leaving too much storage space and not filling reservoirs with water that will be needed during the dry season.

Scientists indicate that climate change will exacerbate the problem of flooding by increasing the frequency and magnitude of large storms, which in turn will cause an increase in the size and frequency of flood events. The increasing cost of flood damages and potential loss of life will put more pressure on water managers to provide greater flood protection. At the same time, changing climate conditions (decreased snowpack, earlier runoff, larger peak events, etc.) will make predicting and maximizing water supply more difficult. Water managers should be prepared to respond to these new challenges by improving floodplain management, and considering the reoperation of existing reservoirs and other water supply infrastructure.

Walking the Tightrope: Managing Dams for Water Supply and Flood Protection

Even under normal circumstances, maximizing water supplies is complicated by the inherent unpredictability of weather. To walk this tightrope, water managers work throughout the spring with snowpack data, and often aided

> **"Intensification of the hydrological cycle could make reservoir management more challenging, since there is often a tradeoff between storing water for dry-period use and evacuating reservoirs prior to the onset of the flood season to protect downstream communities. It may become more difficult to meet delivery requirements during prolonged periods between reservoir refilling without also increasing the risk of flooding."**
>
> Source: Climate Change and Water Resources, AWWARF

by computer models, to assess likely runoff into storage facilities. However this is an imprecise science at best because forecasting seasonal weather patterns for even a few weeks, let alone a month or two, is highly uncertain. The changes in snowpack and precipitation patterns related to global warming will make maximizing water supplies without increasing the risks of flooding even more challenging.

Despite some increases in winter precipitation, much of the mountainous West has experienced declines in spring snowpack over the past 50 years. According to two studies by climate scientists at the University of

The Other New Orleans: California's Delta and Sea Level Rise

Sea level rise has the potential to be among the most visible, harmful, and costly impacts of climate change. A rising sea level presents particular challenges for low-lying urban areas. California's San Francisco Bay-Delta provides an important example of the potential water supply impacts of climate-driven sea level rise.

The Delta represents the upper tidal reach of San Francisco Bay, the largest estuary on the western coast of the Americas. The Delta's watershed includes 40 percent of the state. The Delta is a significant surface water source and the state's largest riverine ecosystem—a resource of enormous environmental and economic value.

Farm flooding resulting from 2004 Jones Tract levee failure

More than 20 million people rely on it for a portion of their water supply; water for Central Valley farms, parts of the San Francisco Bay Area, and Southern California is diverted by massive water pumps in the Southern Delta. And although most of the 1,000-square-mile tule marsh that was once the Delta has been converted to farmland, the Delta still plays a critical role in supporting the biggest salmon run south of the Columbia River. Every winter its islands fill with swans, geese, and sandhill cranes. The hundreds of miles of channels that wind through dozens of leveed agricultural islands are a Mecca for boaters, windsurfers, and anglers. Four-hundred-thousand Californians live in Delta communities. The Delta is also crisscrossed by infrastructure, including power lines, and highways.

The Achilles heel of the San Francisco Bay-Delta may be the confluence of three factors: subsidence, sea level rise, and high levels of water diversions. When the Delta's light peat soils are farmed, they blow away, compact, and oxidize, causing the elevation of these farmlands to fall. Today, thousands of acres of Delta islands are 20 feet or more below sea level. It's not uncommon to stand on Delta farmland and look up at a boat 20 feet overhead as it sails by on the other side of a levee. In parts of the Delta, subsidence is continuing at 1 to 3 inches per year.

A recent study by Jeffrey Mount of the University of California at Davis and Bob Twiss of the University of California at Berkeley found that the Delta's future is threatened by several factors: ongoing subsidence, shaky century-old levees, floods, earthquakes, and sea level rise. Mount and Twiss estimated that the Delta has a 64 percent chance of a catastrophic failure of multiple Delta levees by 2050. Such a failure would threaten the Delta's residents, farms, and infrastructure.

If many islands were to flood simultaneously, particularly during the summer when less fresh water flows from the rivers that feed the Delta, it could draw salty San Francisco Bay water into the Delta, threatening important water supplies. The economic impacts of such a catastrophic failure could be widespread and long lasting. The failure of New Orleans' levees has awakened California water users and agencies to the long-term risks to stability of the Delta. Of all of the challenges facing the San Francisco Bay-Delta, sea level rise may be the most critical. There are more than 1,100 miles of Delta levees, many of which are in poor repair. Improving and raising all of these levees several feet may be financially infeasible.

Sources: U.S. Geological Survey, "Delta Subsidence in California," April 2000. http://science.calwater.ca.gov/pdf/fs00500.pdf.

Mount, Jeffrey, UC Davis, and Bob Twiss, UC Berkeley. "Subsidence, Sea Level Rise and Seismicity in the Sacramento-San Joaquin Delta." *San Francisco Estuary and Watershed Science,* Vol. 3, No. 1, March 2005.

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> **"Models project that increasing atmospheric concentrations of greenhouse gases result in changes in frequency, intensity and duration of extreme events, such as more hot days, heat waves, heavy precipitation events and fewer cold days. Many of these projected changes would lead to increased risks of floods and droughts in many regions..."**
>
> Source: Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2001: Synthesis Report, Summary for Policymakers*

Washington and the University of Colorado, snowpack has decreased by 15 to 75 percent in parts of Oregon, western Washington, northern California and the northern Rockies, mainly because of climate change.[37] Increased temperatures cause a greater percentage of wintertime precipitation to fall as rain instead of snow.[38] The resulting reduction in snowpack causes a drop in the total amount of spring snowmelt runoff. The snowpack that does form is melting earlier in the year, further exacerbating changes in stream hydrology.[39]

The magnitude and frequency of larger high flow events are predicted to increase under climate change for two primary reasons. The first is related to the decrease in snowpack. Several 2002 climate change studies found that in California, peak streamflow occurred up to two months earlier in the year due to a decrease in the number of freezing days in the season, a drop in snowpack, and an increase in early snow melt.[40] The studies also showed that such changes "suggest that 50 percent of the season runoff will have occurred early in the year for many snow melt driven watersheds in the West, and the resulting early snow melt implies higher streamflow increases and an increased likelihood of more flood events in future years."[41]

A second factor causing higher peak flows is the basic relationship among temperature, evaporation rates, and the amount of moisture in the atmosphere. Climate models show that the warming of the earth's surface increases evaporation and the amount of water vapor in the atmosphere. Increases in water vapor, a primary factor in providing moisture for rain, will mean heavier precipitation during storm events. The USGS modeled the effects of climate change on increased storm intensity and found that the risk of a 100-year flood event will grow larger in the 21st century. Instead of a 1 percent chance that in any year there will be a 100-year flood event, the likelihood in a single year could become as high as one in seventeen.[42]

CLIMATE CHANGE WILL AFFECT WATER QUALITY

Changes in precipitation, flow, and temperature associated with climate change will likely exacerbate water quality problems. Changes in precipitation affect water quantity, flow rates, and flow timing.[43] Decreased flows can exacerbate the effect of temperature increases, raise the concentration of pollutants, increase residence time of pollutants, and heighten salinity levels in arid regions.[44]

On the one hand, higher water flows can dilute point-source pollutants, drive up loadings from non-point source pollutants, and reduce the residence time for contaminants. Higher flows can also increase the export of pollutants to coastal wetlands and deltas.[45] In addition, higher flows can cause higher turbidity in lakes, which reduces the light penetration crucial to the health of aquatic life.[46] On the other hand, where surface flows decline, erosion rates and sediment transport may drop, and lake clarity may improve but this may increase the concentration of pollutants.

The effect of climate change on water quality will also be felt at our beaches, as the rate of beach closures will likely go up. In recent years, beaches have been closed repeatedly because of unhealthy levels of bacteria and other contaminants in the water.[47] The primary cause of these high bacterial levels is runoff from storms. Rain that is channeled into storm drains and backed up into sewage systems flushes bacteria, feces, pesticides and pollutants such as motor oil and trash into coastal waters. The increase in severe storm events predicted by global warming models is likely to mean more polluted runoff in a climate-altered future.

Finally, as discussed earlier, climate change is likely to increase fire risks in much of the West. This increase in burning in western watersheds has the potential to increase downstream fire-related sedimentation and other water quality problems. For example, heavy rainfall in Colorado in 1996, following the 12,000-acre Buffalo Creek fire, deposited 600,000 cubic yards of sediment into a Denver Water storage facility in the Upper South Platte River basin.[48] This amounted to more than 13 years of average siltation in just a few days. Such events may be larger and more frequent with climate change.

> **"Aquatic and wetland ecosystems are very vulnerable to climate change. The metabolic rates of organisms and the overall productivity of ecosystems are directly regulated by temperature. Projected increases in temperature are expected to disrupt present patterns of plant and animal distribution in aquatic ecosystems. Changes in precipitation and runoff modify the amount and quality of habitat for aquatic organisms, and thus, they indirectly influence ecosystem productivity and diversity."**
>
> Source: Pew Center on Global Climate Change, *Aquatic Ecosystems and Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States,* 2002.

CLIMATE CHANGE WILL AFFECT AQUATIC ECOSYSTEMS

The United States is home to more than 800 fish species and thousands of aquatic invertebrates and insects found nowhere else.[49] The extinction rate for freshwater species in this country equals or exceeds that of other ecosystems.[50] The aquatic ecosystems found within our streams, lakes, and wetlands have been negatively affected for decades by changes in the environment such as dam construction and flow diversions, loss of habitat associated with development, decreased water quality, and now, climate change. Climate change will further exacerbate the current challenges faced by aquatic ecosystems. Understanding how climate change impacts aquatic ecosystems will allow water managers to implement appropriate strategies that support long-term aquatic ecosystem health, reduce endangered species related conflicts, and minimize impacts on water supplies. There are two major ways that climate change will impact ecosystems: increased temperatures and altered hydrology.

Increased Temperatures

Water temperature influences aquatic ecosystems primarily in terms of ecological and biological factors such as dissolved oxygen levels and the ability of a species to exist within the range of temperatures. Climate change will increase air temperatures, and hotter air will translate into warmer water temperatures in streams and rivers.[51,52] Warmer water will cause increased stress on aquatic species that may already be near their limit of temperature tolerance because they inhabit low-elevation areas or are near the southern edge of their distribution.

In response to climate change, many species will need to expand their range northward, or into cooler, higher elevations upstream, otherwise they will disappear from the watershed. Studies have found that a 4 degree Celsius increase would require some species to move approximately 420 miles northward to find temperature conditions similar to that of their original habitat.[53] The ability of species to adjust their range depends on its ability to move and find suitable habitat. Although avian species may be more mobile, resident fish and plants are less likely to be able to disperse to new locations, even over several generations. Migration barriers and the highly fragmented nature of most of our remaining riverine ecosystems pose many challenges to such geographic shifts.

Even if species can move within a watershed, new conditions at higher elevations may not be suitable for the displaced species. Fish that need deep pools or the lower flow velocities conditions typical of lower elevations within a watershed may be unable to find such conditions in the steeper reaches upstream. Dams and other infrastructure may also prevent access to portions of the river upstream. Overcoming these challenges is made all the more difficult by the fact that the current rapid rate of climate change will pressure species to adapt over decades, not the centuries normally needed to adapt to historic climate change.

Increased water temperatures and seasonally reduced streamflows will alter many ecosystem processes, with potential direct societal costs.[54] In addition to negatively impacting species, higher water temperatures will decrease water quality. As water temperatures rise, the amount of dissolved oxygen in water drops.

On the lower San Joaquin River in California, reduced dissolved oxygen levels have caused fish kills and created temporary seasonal barriers to the migration of salmon. Upstream dams and diversions have lowered streamflows. Lower flows have in turn led to increased water temperatures, concentrated nutrient loading from agriculture runoff and wastewater discharge.[55]

When higher water temperatures promote the growth of algae, this can further cut the amount of dissolved oxygen in the water, creating stressful or fatal conditions for fish. Higher water temperatures can also negatively impact ecosystem dynamics, including predator-prey relationships. On the Columbia River in Washington, for instance, warmer temperatures have created a thermal

Fish at Risk: Salmon in the Klamath River and Silvery Minnow in the Rio Grande

In recent years, the West has seen numerous water resource conflicts pitting protection of threatened and endangered species against the need for water supplies. The salmon kills on the Klamath River and the near extinction of the silvery minnow on the Rio Grande are the kinds of conflicts likely to become more common due to climate change impacts on already impaired aquatic water ecosystems.

A series of dams and diversions provide water for agriculture on the Klamath River in the northern California. At the same time, these dams and diversions significantly reduce in-streamflows. In 2002, low flows contributed to high water temperatures, which impeded migration and caused the death of more than 35,000 adult salmon. As a result of the adult fish kills in 2002 and the severely reduced population of juveniles the following year, salmon fisheries were heavily restricted in 2006 in California to protect the few returning Klamath adults, even though strong runs of salmon were returning on other rivers along the coast and in the Central Valley. The fishing restrictions hit the already struggling fishing industry hard.

Similarily, the Rio Grande silvery minnow was listed under the Endangered Species Act in 1994; it faced possible because of loss of habitat and the effects of dams and diversions constructed for municipal and agricultural use. Continued declines in the silvery minnow population lead to lawsuits against the Bureau of Reclamation and the Army Corps of Engineers. Today, this species is found in less than 5 percent of its historic range and is heavily managed to prevent its extinction.

Climate change will add new stresses to those associated with water supply diversions. As a result, aquatic ecosystems and sensitive species may be pushed to the point of collapse, thereby increasing the likelihood of even greater conflicts and the need to reduce water supply diversions to meet regulatory protections.

Source: Ikenson, B., 2002. "Rio Grand Silvery Minnow." *Endangered Species Bulletin,* March/June 2002, Vol. XXVII, No. 2.

barrier to migration for Coho salmon and have resulted in increased predation on juveniles by predator species.[56]

Not all impacts of warming will be harmful. For species that are limited in range due to cold temperatures, particularly in the northern latitudes, a warmer climate may have benefits. However, the benefits to relatively few species are vastly outweighed by the negative impacts that climate change will have on other species and ecosystems in the western states.

Altered Hydrology

The effects of climate change on seasonal variations in streamflows may have significant impacts on fish species, regardless of changes in water temperature. The hydrology of streams—including the timing, magnitude, frequency, and duration of flows—significantly influences the nature of stream ecosystems, particularly the physical characteristics such as the shape of the channel. Many species time their movements up or downstream or out to sea to take advantage of often temporary in-streamflow conditions. Regional shifts in climate that substantially and permanently alter the timing and magnitude of flows can further impact habitat suitability for many species.[57] As a result, alterations in timing and amount of rainfall can significantly impact their ability to reproduce and cause decreases in population numbers.

In the West, the typical snowmelt-driven stream hydrology entails high spring flows followed by lower summer, fall and winter base flows. But global warming is causing earlier snowmelt by increasing winter and springtime temperatures. Earlier snow melt changes the timing of high flows that are important to aquatic species for reproduction and predator avoidance.[58] In many western streams, spring runoff is critical to the rearing of

juvenile fish and the downstream migration for salmon on their way to the sea.

Earlier runoff can also result in lower streamflows in the summer and fall. Lower flows may result in warmer and shallower stream conditions that make it more difficult for migratory fish. Similar impacts of reduced in-streamflows already occur on many major rivers due to impoundment or flow diversion. Climate change could exacerbate this problem by shifting seasonal patterns of precipitation and in-streamflow.

Increased frequency and magnitude of peak flows have been observed and they are predicted by a number of climate models.[59,60] In the West, models show that an increased percentage of precipitation falling as rain instead of snow will mean higher peak flows even if total precipitation stays the same. The resulting increase in peak flows has implications for public safety as discussed earlier in this report and can also negatively impact aquatic ecosystems. Increased intensity of precipitation will lead to more runoff, which in turn can cause more sediment and pollution from the contributing watershed to make their way into water bodies. Higher flows can increase the rate at which beneficial nutrients are flushed out of the watershed and can displace species downstream to potentially less suitable habitat. The cumulative effects of higher peak flows can also cause significant shifts in species composition and may change some habitats so much that some species are eliminated from affected areas.[61]

For many species that are already struggling, the relatively rapid change in seasonal hydrology combined with increasing water temperatures will further degrade important habitats, increasing the need for environmental protection measures, such as flow and temperature requirements. The extent to which water supplies are affected by management actions requiring decreased flow diversion will largely depend on whether there are other management options to mitigate the impacts related to climate change. Adequate flows are essential to sustain aquatic ecosystems and sensitive species. But nonflow actions such as removing migration barriers, improving water quality, and restoring habitat can significantly reduce the need for additional flows.

Cold-Water Fish Such as Trout and Salmon Threatened by Warmer Waters

Cold-water species such as trout and salmon will be particularly vulnerable to warming waters. A study by Eaton and Scheller found that higher maximum temperatures in streams across the continental United States caused by an average air temperature increase of about 4 degrees Celsius would result in a decline of about 50 percent in thermally suitable habitat for 57 species that require cold or cool water—including game fish such as trout, salmon, and perch. Other researchers have predicted that an increase in air temperature of 3 degrees Celsius in streams of the Rocky Mountain region would reduce suitable stream habitat for trout by up to 54 percent.

Of particular concern is the number of streams that will cease to support a wide range of trout and salmon species due to increased temperatures. An analysis based on emission scenarios provided by the Intergovernmental Panel on Climate Change (IPCC) found that up to 38 percent of locations currently suitable for cold-water fish will become too warm to provide habitat by 2090.

Sources: Eaton, J.G., and R.M. Scheller, 1996. "Effects of Climate Warming on Fish Thermal Habitat in Streams of the United States." *Limnology & Oceanography* 41:1,109-1,115.

Keleher, C.J., and F.J. Rahel, 1996. "Thermal Limits to Salmonid Distributions in the Rocky Mountain Region and Potential Habitat Loss Due to Global Warming: A Geographic Information System (GIS) Approach." *Transactions of the American Fisheries Society* 125:1-13.

Rahel, F.J., C.J. Keleher, and J.L. Anderson, 1996. "Habitat Loss and Population Fragmentation for Coldwater Fishes in the Rocky Mountain Region in Response to Climate Warming." *Limnology & Oceanography* 41:1116-1123.

O'Neal, K., 2002. *The Effects of Global Warming on Trout and Salmon in U.S. Streams*. Natural Resources Defense Council and Defenders of Wildlife.

HOW CLIMATE CHANGE WILL AFFECT WESTERN HYDROPOWER

The West relies on dams, in addition to water supply and flood control, for hydropower generation. In California, for example, hydropower provides an annual average of 15 percent of California's electricity production.[62] But hydropower production is heavily influenced by variations in weather. In 2001, low snowpack in the Pacific Northwest diminished hydropower generation and contributed to energy shortages along the West Coast, illustrating just how vulnerable hydropower in the West is to climate change.[63]

Global warming could have a detrimental effect on the relationship between hydropower production and energy

demand. As discussed in earlier sections, scientists anticipate a shift in hydrology that includes in reduced winter snowpack, higher peak flows, earlier snowmelt runoffs in spring, and decreased summer streamflows. This shift would likely increase hydropower production supply in winter and spring, but decrease it during summer when less water is available as inflows. However demand for power, intensified by climate change, is likely to follow an opposite trajectory. An overall increase in temperatures could lead to lower winter demand for heating and greater summer demand for air conditioning. Thus, when energy is needed in summer to meet the greater demand for air conditioning, hydropower's energy production will likely be hindered, given the predicted decrease in summer flows. Another vulnerability of higher peak streamflows is an elevated risk of reservoir spills, are a key vulnerability of higher peak streamflows, which would contribute to an overall reduction of net generation.

The Portland Water Bureau (PWB) sponsored a study by Richard Palmer and Margaret Hahn of the University of Washington. The study concluded that a change in runoff timing would create problems for both water supply reliability and hydropower capacity. In Palmer and Hahn's analysis of future climate change scenarios, they found that the PWB system's winter flows could increase by as much as 15 percent and that late spring flows could decrease by 30 percent.[64] These changes, combined with an summertime increases in water and electricity use, present serious challenges for PWB. Simply put, early runoff results in water being less available when demand is highest for both water supply and hydropower energy production. Further, the Palmer and Hahn study found that global warming could exacerbate this water and energy supply problem because one of its key effects is an increased possibility of flooding. As fewer freezing days may raise runoff levels, the need intensifies to manage hydroelectric dams for greater flood protection at the expense of hydropower production and water supplies.[65]

For more information regarding the Palmer and Hahn study, please see the Portland Water Bureau Case Study in Appendix A.

Chapter 3

The Water and Energy Connection

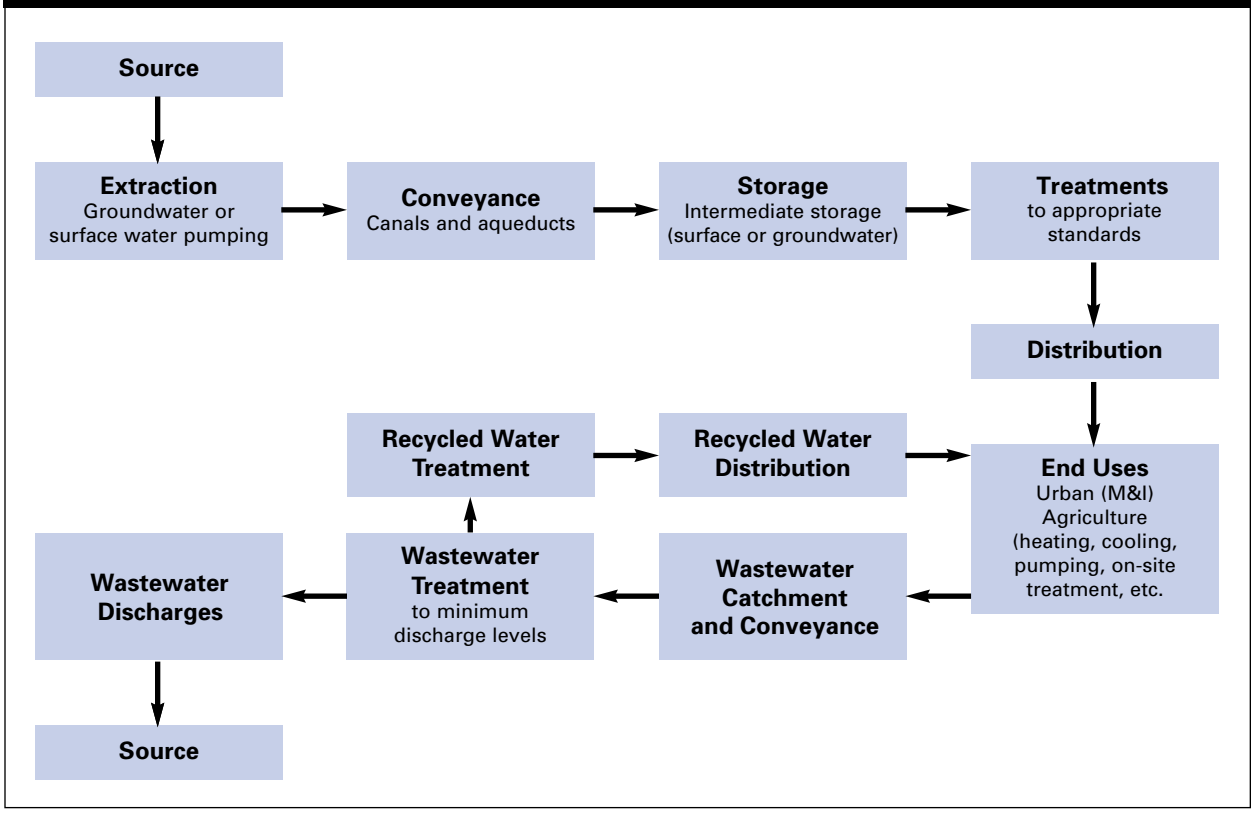
The strong connection between energy use and water management is often overlooked. Because the energy implications of water supply decisions can be so large,[1] the water/energy nexus will be increasingly important to future efforts to reduce greenhouse gas emissions. The California Energy Commission estimates that 19 percent of the state's electricity use, more than 30 percent of the natural gas use (aside from what is consumed by power plants), and 88 million gallons of annual diesel fuel consumption, are associated with water use.[2] In fact, the California State Water Project (SWP) is the single largest energy user in the state. The water and energy connection is discussed in greater detail in the report *Energy Down the Drain*, by NRDC and The Pacific Institute.

Water use efficiency and water recycling, along with groundwater recharge and stormwater management options, can provide significant opportunities for water managers to simultaneously improve water supply reliability, cut costs, save energy and reduce greenhouse gas emissions. An improved understanding of the relationship between energy and water will assist water managers incorporating climate change into management plans (see Figure 3-1).

The four principal elements of water systems use energy are: (1) water extraction, conveyance, and storage; (2) water treatment and distribution within service areas; (3) end use, including on-site water pumping, treatment, and thermal inputs (heating and cooling); and (4) wastewater collection, treatment, and discharge. Energy intensity, or embedded energy, is the total amount of energy calculated on a whole-system basis that is required for the use of a given amount of water in a specific location (see Figure 3-1).

Energy inputs to water systems, and related greenhouse gas emissions, vary considerably by energy sources and geographic location of both end users and water sources and end users. Water use in certain areas is highly energy intensive due to the combined requirements of extraction, conveyance, local treatment and distribution, and wastewater collection and treatment processes. In areas where a large percentage of power is provided by coal-fired plants, the greenhouse gas intensity of water use is particularly high.

Figure 3-1: Flow Diagram of Energy Inputs to Water Systems



Source: This schematic and method is based on Wilkinson (2000) with refinements by Gary Klein, California Energy Commission; Gary Wolff, Pacific Institute; and others. It is available as a simple spreadsheet tool from Wilkinson at Wilkinson@es.ucsb.edu.

Source and Conveyance of Water

Significant amounts of energy are often required to extract a source of water usable and to move the water to where it will be treated and used. Most water used in the United States is diverted from surface sources, such as rivers, streams and lakes, or pumped from groundwater aquifers. Conveying water often requires pumps to lift the water over hills and mountains, a process that can require large amounts of energy. In California, the State Water Project lifts water 2,000 feet over the Tehachapi Mountains—the highest lift of any major water system in the world. Where water is stored in intermediate facilities, additional energy may be required to store and then recover it. Smaller amounts of freshwater are produced from saltwater, brackish water, or wastewater using desalination or recycling technologies. Desalination requires energy to remove salts from water through reverse osmosis or other processes. Water recycling also requires energy to remove pollutants from wastewater.

Treatment and Distribution

Water treatment facilities use energy to pump and process water. The amount of energy required for treatment depends on source water quality. The energy required nationally for water treatment is expected to increase over the next decade as treatment capacity expands, new water quality standards are put in place, and new treatments are developed to improve drinking water quality, including taste and color. After water is treated, additional energy is typically required for local pumping and pressurization, but gravity pressurization and distribution is also possible when reservoirs are sufficiently higher than residences and businesses. Agricultural water generally is not treated before use.

End Uses

Water users require energy to further treat water supplies (e.g., softeners and filters), circulate and pressurize water supplies (e.g., building circulation pumps), and heat and cool water for various purposes. End use energy comprises

a major portion of water-related energy use. For example, water heating for one inefficient showerhead can use up to 2,800 kilowatt hours per year—almost as much energy as it takes to pump the annual water supply for two Southern California homes over the Tehachapi Mountains.[3]

Wastewater Collection and Treatment

Wastewater is collected and treated by a wastewater system (unless a septic system or other alternative is being used) and discharged. Wastewater is often pumped to treatment facilities where gravity flow is not possible and standard treatments requires energy for pumping, aeration, and other processes.

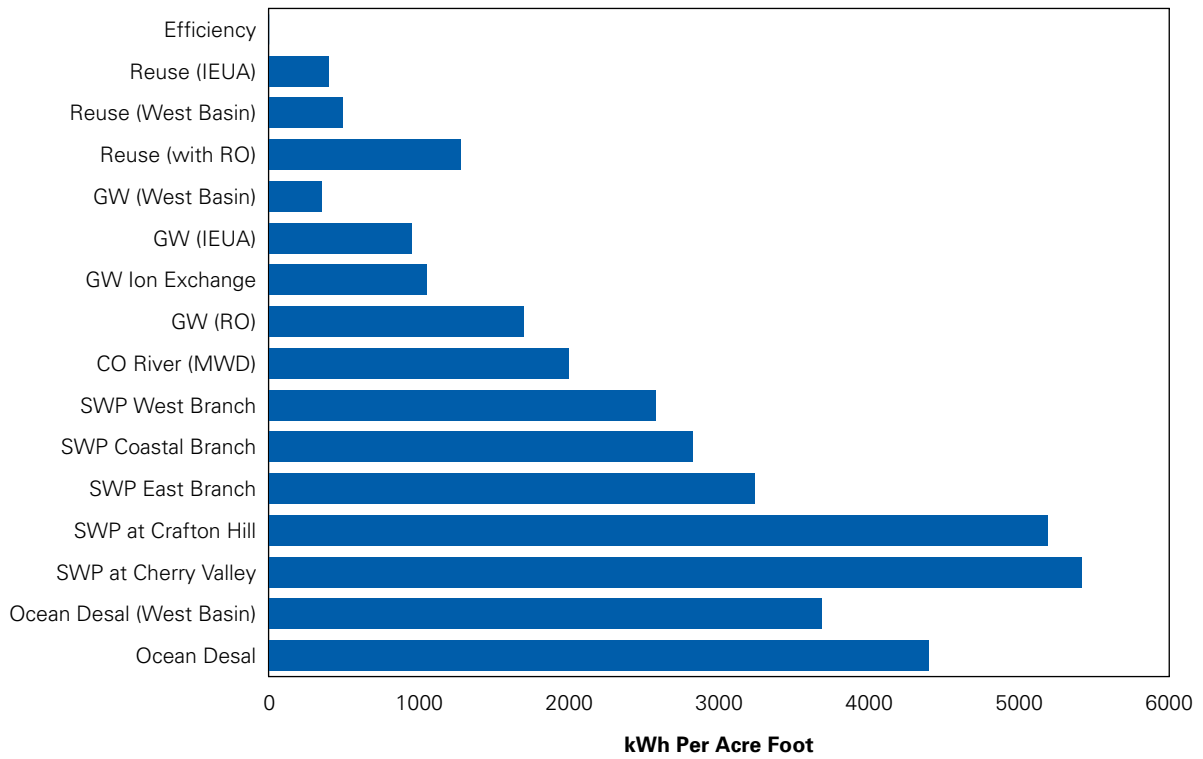
Reducing Water-Related Energy Use

Water use efficiency is the single best way to reduce water-related energy use. As noted above, the energy required for end uses of water (e.g., washing machines, cooling towers) is a major component of energy use in the urban water supply cycle. Water use efficiency saves end use energy, as well as the upstream energy needed to convey, treat, and distribute that water and the downstream energy needed to treat and dispose of wastewater. Therefore, improving water use efficiency, particularly for energy intensive uses of water, is important regardless of the source of the water or location of its use.

An analysis of water management options for the San Diego County Water Authority found that the total energy savings from relying on improved water use efficiency instead of additional State Water Project deliveries to provide the next 100,000 acre-feet of supply would be approximately 770 million kWh, This would be enough to supply electricity to 118,000 households—25 percent of the homes in San Diego—for a year.[4]

Most local sources are more energy efficient than imported water supplies. Figure 3-2 shows the energy intensity of water supply options for two southern California water agencies:

Figure 3-2: Energy Intensity of Alternative Supply Sources in Two Southern California Water Agencies



Source: Wilkinson based on data from Inland Empire Utilities Agency (IEUA), West Basin Municipal Water District, and California Department of Water Resources.

the Inland Empire Utilities Agency and the West Basin Municipal Utility District. The analysis indicates that water use efficiency is the least energy intensive option and that recycled water and local groundwater sources are a relative energy bargain compared with imported supplies. Even the Chino desalter, a reverse osmosis (RO) process for contaminated groundwater that includes groundwater pumping and RO filtration, is far less energy intensive than any of the imported sources of water. From an energy standpoint, local sources of reclaimed water and groundwater—including contaminated sources requiring advanced treatment—are remarkably efficient. Similar findings were made for the Central Basin Municipal Water District.

The energy intensity of many water supply sources may increase in the future due to regulatory requirements for water quality.[5] Advanced treatment systems such as reverse osmosis (RO) are being used to treat groundwater, reclaimed supplies, and ocean water. They can produce very high quality water. As a result, they are likely to face fewer energy impacts from more stringent water quality regulations. By contrast, some of the raw water supplies, such as Colorado river and Delta water, may require larger incremental energy inputs for treatment, due to high salinity, including arsenic and perchlorate. This may further increase the advantage of obtaining water from local sources.

Recent State and National Actions to Address Energy-Water Issues

Recently, the link among water, energy, and climate has been getting increased attention. For example, the California Energy Commission (CEC) issued a report on the water/energy relationship and incorporated recommendations into its *Integrated Energy Policy Report* (IEPR) submitted to the state legislature in December 2005. According to the IEPR, investing in water conservation can achieve 95 percent of the energy and demand-reduction goals planned by the state's investor-owned energy utilities for the 2006–2008 program period at 58 percent of the cost of traditional energy efficiency measures.[6] The CEC report noted that "water agencies are seldom given credit, nor are they able to secure funding, for the electricity savings that result from water conservation and efficiency efforts."[7]

In the IEPR, the CEC recommended that "the California Public Utilities Commission (CPUC), Department of Water Resources, the Energy Commission, local water agencies and other stakeholders should assess efficiency improvements in hot and cold water use in homes and businesses and include these improvements in 2006–2008 programs."[8] To address this important implementation obstacle to integrated water and energy conservation programs, the CPUC has embarked upon a process for rulemaking on issues related to embedded energy, and is currently evaluating proposals for pilot programs that focus on saving embedded energy through improved water use efficiency.[9]

Building on the CEC work, California's Climate Action Team recently took the unprecedented step of identifying water use efficiency as a tool to reduce climate change emissions and the California State Legislature is considering legislation requiring water agencies to evaluate the energy impacts of its water management alternatives. As California implements AB 32, The Global Warming Solutions Act, water efficiency measures are among the suite of actions that will be evaluated for their ability to help the state meet its greenhouse gas emission reduction goals.

On the national level, the U.S. Department of Energy's Sandia National Laboratory is leading the National Energy/Water Roadmap Program initiated in 2005, as requested by Congress. The purpose of this integrated energy/water research and development program is "to assess the effectiveness of existing programs within the Department of Energy and other Federal agencies in addressing energy and water related issues, and to assist the DOE in defining the direction of research, development, demonstration, and commercialization efforts."[10]

These efforts represent the beginning of better-integrated water, energy, and climate policy. Information about the energy and climate implications of water use can help improve public policy and facilitate combined investment and management strategies among energy, water, and wastewater entities. Potential benefits include improved allocation of capital, avoided capital and operating costs, reduced burdens on ratepayers, emission reductions, and environmental benefits.

Chapter 4

A Guide for Water Managers: Designing a Comprehensive Response to Climate Change

Many water managers are already taking action to understand and address impacts related to climate change. This section is designed to summarize some of these actions and review "best management practice" approaches to these important challenges. Given the wide range of potential climate change impacts on water systems across the West, water managers have numerous options at their disposal to address the effects of climate change.

If well designed, these tools can provide a robust response, potential climate change impacts on water management, and a broad array of additional benefits. This chapter outlines four critical steps water managers can take to ensure a steady supply of quality water in the face of the challenges that climate change poses to the system. It sets forth strategies to make each step successful given the limited resources every water manager faces. Here are the four steps:

1. Vulnerability analysis: Evaluating the vulnerability of water supply systems, flood management systems, watersheds, and aquatic ecosystems to water-related climate impacts.

2. Response strategies: Implementing response strategies to reduce future impacts of climate change in two major areas: water supply and water management, including flood management and aquatic ecosystems.

3. Prevention: Taking immediate and sustained action to reduce greenhouse gas emissions in order to minimize future impacts.

4. Public outreach: Increasing public awareness of climate change and potential water-related impacts and opportunities.

VULNERABILITY ANALYSIS

An essential first step for water managers is to examine both local and regional effects of climate change. Given that a variety of factors can influence how climate change affects water resources, including the geographic location of sources, end uses, and the nature of the existing water supply infrastructure, each water resource agency should undertake an agency-level analysis to understand how climate change will impact their specific water-related resources and to lay the groundwork for the development of a response plan.

Agencies should also consider joining with other agencies to undertake analysis on a regional level because the impacts of climate change will affect agencies that derive water supplies from a larger shared resource (e.g., the

Colorado River, San Francisco Bay-Delta) and because some agencies in the same region may face similar challenges (e.g., the Sierra Nevada, the Rocky Mountains and the Northwest). Regional analysis will also facilitate cooperative responses and leverage limited resources to produce better results.

Elements that should be considered in conducting local and regional analyses of the effects of climate change on water supply are provided on the following pages. See Appendix A for detailed case studies illustrating how particular water agencies have tackled the challenge of climate change at the local, state and regional levels.

Assessing Water Supply System Vulnerabilities

Water supply systems are designed and operated to meet numerous objectives including water supply, flood protection, hydropower generation, and in-streamflow requirements—all of which are based on a retrospective view of hydrology. As climate change occurs, water infrastructure systems will face conditions different from those for which they were designed, presenting significant challenges for managers. Vulnerability analysis should be done to investigate how specific systems will react to climate-related changes. An analysis should examine a range of fundamental factors, including watershed characteristics, allocation, storage versus runoff ratio, diversity of water supply, flood management, shared regional water resources, water quality impacts, resource allocation and environmental water requirements.

Location and Watershed Characteristics

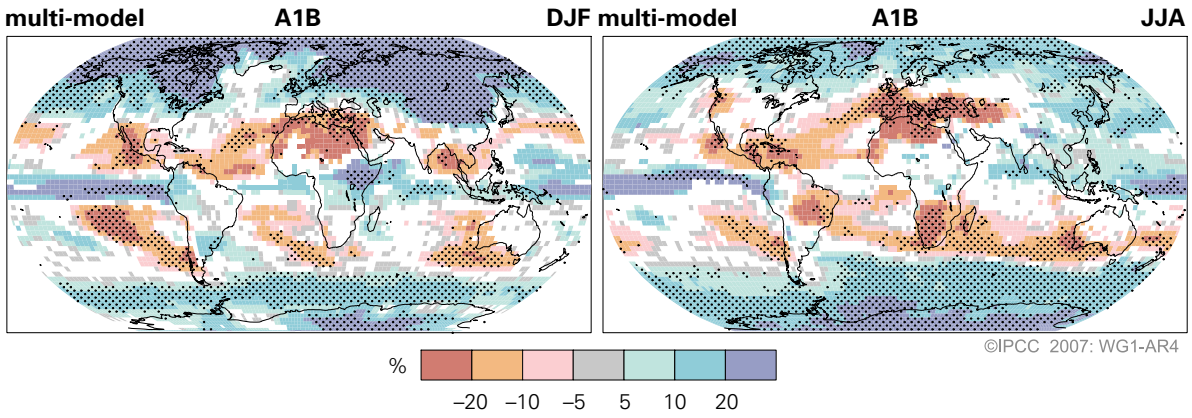
The geographic location and the watershed characteristics of the area being assessed are critical starting points. Although precipitation predictions are coarse, there are studies predicting regional changes related to climate change. Some analyses suggest that northern latitudes may become slightly wetter and drier regions, such as the Southwest, may receive even less precipitation.[1] As the science improves regarding regional impacts on precipitation patterns and total precipitation, water agencies will be increasingly able to identify regional or watershed-specific impacts. In addition, watersheds in the Southwest may be more significantly affected in the future by increases in evaporative losses within watersheds and from reservoirs.[2] Potential regional changes should be considered as a basis for further analysis.

Watershed characteristics are important. Elevations within the watershed will affect many attributes of a watershed's runoff characteristics including snowline, evaporation, dew point, and temperature. Other important characteristics are vegetation, slope aspect, and soils. A useful model focusing on the Sierra Nevada was developed by the American River Watershed Institute to examine these elements. Climate scenarios can be analyzed for specific watershed conditions to examine potential impacts.[3,4]

Allocation

Vulnerability analyses should include a determination of how much of the annual runoff is committed to use, including extraction for municipal, industrial, and agricultural uses; and in-stream, recreational, and

Figure 4-1: Projected Patterns of Precipitation Changes for Period 2090-2099, relative to 1980-1999



Source: IPCC 2007: WG1-AR4

environmental uses. If most, all, or more than all of the annual runoff is needed to meet existing uses, then the system is already stressed. Therefore, changes to the timing of hydrology from climate change, much less a change in natural inflow quantities, are likely to exacerbate the stress and result in negative impacts on the reliability of supplies. It is important to assess the reliability of water supplies to meet demands under both past and future climate variability.

Storage Versus Runoff Ratio

Vulnerability analyses should examine to what extent structural storage (dams) and non-structural storage (snowpack, groundwater) are relied on to meet demands. Although individual water supply systems vary in the degree to which they rely on storage, most of the West's water supplies depend on snowpack, reservoirs, and groundwater basins to provide annual and carryover storage. The amount of surface and groundwater storage in relation to the mean annual runoff diverted for beneficial use is one simple indicator of a water provider's reliance on snowpack. It is, however, important to recognize that each of these forms of storage has different operational characteristics. Climate change is expected to negatively affect water storage by reducing the snowpack and changing the timing and volume of runoff inflow, which may affect the yield of existing reservoirs. Climate change could also impact groundwater storage by reducing natural recharge and surface water supplies available for groundwater recharge.

Water managers have a wide range of tools to meet future needs. Some tools, such as water transfers, dam reoperation, floodplain management, and landscape conservation, can help conserve water in storage or provide "virtual" storage through cooperation with other agencies. Thus, water managers could respond to a potential future loss of supplies from existing storage by implementing a range of water management tools.

Diversity of Water Supply

Different water supply sources, including groundwater, surface supplies, transfers, and importation, have important water management implications. With climate change likely causing alterations in timing of precipitation and runoff, reduction of natural snowpack storage, and management of surface supplies, a portfolio of water supply alternatives can serve as a hedge strategy. Having a variety of alternatives available, such as wastewater recycling, increased groundwater, water conservation, and transfers among users, can reduce vulnerability of an individual system.

Water agencies seeking to diversify their existing water supplies should carefully consider potential pitfalls. For example, many river basins are already overcommitted and environmentally degraded. In some areas groundwater is overdrafted or contaminated. In many cases, increasing the diversity of supply for one agency could increase stress for other communities or environments (e.g. over allocated river systems). Moving from a reliance on vulnerable supplies (e.g. surface and groundwater sources) toward water use efficiency and reuse represent measures to diversify water supply portfolios that are appropriate in nearly all circumstances.

Flood Management

Water managers are constantly challenged with balancing flood safety and water supply. Surface storage operations are often designed to provide multiple benefits, including recreation, hydropower production, and flood safety. Flood management presents a particular challenge because when storage space within a multipurpose reservoir is set aside for attenuating flood flows, storage operating rules often can pit flood protection against operations that would maximize water supply.

Climate change is likely to complicate these operational choices. The earlier snowmelt brought on by a warming climate could increase the likelihood that snowmelt runoff will need to be released to maintain flood storage, but this may increase the risk that a given reservoir will not end the rainy season full. In some watersheds, an increase in storm intensity could directly increase peak flows and increase the likelihood of "rain on snow" events, which can result in dramatic increases in flows. If peak flows increase, the existing operating rules may no longer provide an appropriate level of protection. There will likely be a need to increase flood reservation capacity within existing storage facilities thereby exacerbating existing tensions with water supply. However, in some areas with limited existing snowpack, declining snowpack could decrease the likelihood of "rain on snow" events, providing an opportunity to reoperate existing facilities.

Shared Regional Water Resources

Dividing water resources among several water providers can result in shared risks and benefits. A relevant factor in assessing climate change impacts on water supply is whether a particular water supply is wholly appropriated

by local, regional, state, or federal entities. As illustrated by the Colorado River Compact, the effects of climate change may be addressed by increased coordination and planning among agencies and states.

Water Quality Impacts

Water supply could be threatened by water quality changes resulting from increased temperatures, increased peak runoff; decreased summer flows; and sea level rise with saltwater intrusion into coastal aquifers, streams, and estuaries. Where water quality standards are already an issue, climate change will likely exacerbate conditions. Watersheds may see an increase in sediment and non-point source pollution related to larger storm events. In California, for example, saltwater intrusion exacerbated by sea level rise could result in groundwater degradation. In the San Francisco Bay-Delta, saltwater intrusion could increase the salinity of Delta water. Increases in sedimentation due to climate change could result in lost storage capacity, degraded water quality, and increased treatment costs.

Assessing Water Demand Vulnerabilities

A critical consideration in evaluating the stresses and vulnerabilities of a water system is the current level of demand and the ability to manage increases in demand. Demand for water is as much a response to land use and resource management policies as it is a response to climate signals. Higher temperatures will push up demand for agricultural and landscape irrigation water. Those demands may be offset by conservation, changes in crop types, and irrigation practices for agriculture as well as increased use of xeriscaping and more efficient irrigation systems on the municipal side.

Conservation

Communities throughout the West have implemented a wide variety of water conservation measures to improve water use efficiency. Some of these efforts have produced striking results (see Appendix B). Per capita consumption gives a rough estimate of the degree to which a water provider can mitigate water supply impacts through increased investments in water conservation measures. For example, areas with large landscape water use have greater potential for benefits from landscape water conservation. Communities with high interior per capita use have the potential for significant savings from interior water conservation tools. It is important to note that because the technology of water conservation will improve over time. This water source will grow in the future.

Peak summer water use should also be considered when evaluating possible conservation opportunities. This factor takes into account the difference between summer and winter water use patterns. High peak summer water use in many municipal systems indicates a high degree of outdoor use, which can be reduced through landscape water conservation programs. Many providers have also developed effective indoor residential and industrial/commercial/institutional water user programs to reduce overall consumption.

Resource Allocation

The allocation of water to various sectors (agriculture, commercial, institutional, industrial, and residential) is an important consideration when analyzing the potential flexibility of a water provider to cope with dry years. Each sector has varying degrees of flexibility and requires different strategies for managing decreased water supplies, particularly in extremely dry years. For example, agricultural water users can fallow fields planted with annual crops during critical dry years. Different sectors will be affected differently by climate change. For example, outdoor residential and agricultural water consumption may increase with warmer temperatures. Industrial use may not.

Assessing Environmental and Water Quality Requirements

Rising temperatures, decreased summer streamflows, and increased evapotranspiration will likely increase the need for in-streamflow to meet ecosystem and water quality needs. Environmental requirements such as minimum in-streamflows and water quality standards are increasingly common for western rivers, wetlands, and lakes. Such requirements can significantly affect the operations of both large and small water systems. Most large dams must release water to maintain downstream water quality and provide benefits to aquatic ecosystems, including protected species. Often minimum flow requirements are based on meeting critical temperature and other standards that will require greater releases to maintain. Agencies should assess the degree to which climate change will alter existing environmental conditions with an eye on potential future environmental constraints on operations.

RESPONSE STRATEGIES FOR DEALING WITH WATER SUPPLY IMPACTS

Although prompt action to lessen greenhouse gas emissions can reduce the future impacts of climate change on western water supplies, it is clear that climate change will produce supply impacts for which water managers should be prepared. A vulnerability analysis can reveal the extent of the climate change-related risks to an existing system. This section discusses how climate change will affect the tools available to respond to these climate impacts and presents a framework for a robust, resilient, and flexible water management approach to handling the effects of climate change on water resources.

Seven Guiding Principles for Responding to Water Supply Impacts

The scope of the potential impacts of climate change makes this issue different from other challenges facing water managers. The following guiding principles are designed to assist forward-thinking water decision-makers in crafting strategies to respond to this challenge.

Strengthen Institutional Capacity. Responding to climate change will require a broad set of management and technical skills, including expertise that builds on traditional water management, such as:

- reoperating existing water systems
- understanding climate impacts
- evaluating opportunities to finance and implement integrated strategies for multiple benefits

Water managers should evaluate their institutional strengths and weaknesses, seek opportunities to improve institutional capacity, and reognize that responding to climate change will require new skills. As Roger Revelle and Paul Waggoner recommended in a 1990 American Association for the Advancement of Science publication, "Governments at all levels should reevaluate legal, technical, and economic procedures for managing water resources in the light of climate changes that are highly likely."[5]

Build In Flexibility. Climate change places managers in a difficult position. There is now a strong scientific consensus that climate change is happening and that it will result in significant impacts because preparing effectively will require investment of effort and time, water managers should begin such efforts immediately. However, there is still uncertainty regarding how rapidly these impacts will develop and how climate change will affect some water resource characteristics (e.g., total precipitation.)

The solution to this apparent paradox is to design flexible responses to climate change. Locking in large, long-term capital investments under conditions of uncertainty is a risky strategy. Whenever possible, flexibility is desirable as a management strategy. Specifically, strategies that allow for mid-course corrections and redirection of investments toward the most effective tools and that reduces the risk of stranded investments will increase the flexibility of water systems and the ability of water managers to adapt to changing conditions.

Increase Resilience. Even absent any change in climate, we can expect both wet and dry conditions. The relatively new science of paleoclimatology has revealed that the climate in the West has, historically, experienced significant variation, including extended drought periods. For example, the Colorado River basin has seen extended drought periods. In particular, the period used as the historical baseline for Colorado River water allocations was one of the wettest periods in five centuries, resulting in an overallocated river.[6] Climate change is likely to result in even greater divergence from the recent historical record. Scientists agree that we will see increased temperatures in coming years and we may see wetter wet periods and drier dry periods. Therefore, it makes sense to consider a range of water management options that build resilience through cost-effective strategies to meet future needs under conditions of greater variability and uncertainty.

Seek "No Regrets" and "Multiple Benefits" Strategies. Management strategies that cost-effectively improve a water system's ability to deal with existing stresses and problems (e.g., drought, population growth, land-use changes, and environmental impacts) are often characterized as no-regrets strategies because they make sense today, even before factoring in climate change. Where possible, water managers should seek to implement no-regrets strategies and secure multiple benefits (e.g., water, energy, and cost savings, emissions reductions and reduced environmental impacts) through well-designed policies, investments, and strategies. The focus of good policy is to build resilience in various systems ranging from whole water systems to local landscape conservation programs.

Multiple benefits strategies address more than one objective through a single targeted investment or policy measure. Some multiple benefit strategies that can enhance performance and build resilience through a single investment include:

• improving water use efficiency

• designing policies and management systems that provide better signals to consumers regarding the cost and scarcity of resources

• instituting flood plain management approaches that reduce damage from flooding, provide habitat, and increase groundwater recharge

Address Multiple Stresses. Climate change is just one of a number of factors putting pressure on water supply systems. Rapid population growth, land-use changes, contamination of surface and groundwater resources, and the need for ecosystem protection and restoration are all occurring simultaneously. Many water managers and users are effectively addressing these combined challenges through measures such as dramatically improving water use efficiency and restoring and protecting watersheds and groundwater sources. (See Appendix A.)

Invest in Cross-Agency Relationships. Many of the measures discussed in this chapter begin with developing relationships among agencies that can be partners in innovative approaches to water management. (Integrated approaches are discussed in more detail later in this section and Appendix A includes a number of case studies showing ways in which water managers across the West are developing their own integrated approaches.) Water managers seeking to position their agencies to best respond to climate challenges should begin by strengthening their relationships with potential partner agencies, including neighboring water agencies, as well as those with authority on energy, wastewater, stormwater, environmental quality, and land use issues.

Incorporate Climate Change into Ongoing Project Design. Water managers constantly face a wide range of design decisions regarding existing and new facilities. The design of those facilities should incorporate climate impacts. Managers should begin such work now, rather than waiting for the completion of a comprehensive response plan to address climate change. Several examples illustrate where climate issues are being incorporated into design decisions. For example, the California Department of Water Resources (DWR) is working to design operable barriers in the Sacramento-San Joaquin River Delta. Those barriers are designed to use tidal currents to control water levels and circulation in the south Delta. DWR recognizes that climate change is likely to produce significant sea level rise. Such changes could affect the operations and effectiveness of these Delta barriers. To reduce this risk, DWR decided to redesign these barriers so they could be retrofitted in the future to accommodate up to an additional foot of sea level rise. Given the probable useful life of these barriers, DWR believed that this was an appropriate design target. This decision required a redesign for a larger foundation, capable of accommodating larger gates in the future—and resulted in significant expense.[7]

The San Francisco Public Utilities Commission (SFPUC) is currently developing a long-term wastewater master plan designed, in part, to address climate change impacts. Perhaps the most significant climate change-related challenge for San Francisco is the potential for rising sea levels to result in seawater intruding through outfalls into waste treatment facilities.[8] Such saltwater intrusion could kill the microbes that serve as the foundation of secondary treatment. The SFPUC has already experienced these seawater intrusion events, even without storms, as the result of 7 inches of sea level rise in the past century. The SFPUC is currently designing valves to prevent such sea level rise-related inflows into the wastewater system. Seattle Public Utilities has made several significant design decisions to address potential climate change impacts.[9] Such water agencies are beginning to discuss how climate change could affect decisions such as the design of drinking water treatment facilities.

By incorporating climate change in ongoing design decisions, water managers can reduce risks and expenses in the future.

Expand Dialogue with the Scientific Community. The scientific community is an essential resource to water managers. Expanded dialogue with the scientific community can increase the effectiveness of measures designed to meet the challenges posed by climate change. A healthy dialogue with water managers will also help scientists develop a more realistic and accurate analysis of potential climate change impacts on water management. The September 2005 conference in Las Vegas, co-sponsored by the Natural Resources Defense Council, the Southern

Nevada Water Authority, and the Desert Research Institute represents an example of this kind of extended dialogue. Such conferences should be held with greater frequency.

The AWWARF Public Advisory Forum developed the following two recommendations regarding climate and science:

* Cooperation of water agencies with the leading scientific organizations can facilitate the exchange of information on state-of-the-art thinking about climate change and impacts on water resources.

• The timely flow of information from the scientific global change community to the public and the water-management community would be valuable. Such lines of communication need to be developed and expanded.[10]

Given the need discussed earlier to improve institutional capacity, a robust dialogue between water managers and scientists could be particularly valuable as water agencies move past vulnerability analyses to develop future response strategies that incorporate climate issues.

Determining the Best Mix of Water Management Tools

A century ago, water managers had a limited range of water management tools. Today, water managers have a much greater range of options to manage water in communities around the West:

• Technological advances have dramatically improved the water use efficiency of wide range of devices, including low-flow showerheads, low-flush toilets, water-efficient washing machines and dishwashers, and water-saving irrigation systems guided by satellite weather data.

• Wastewater recycling, groundwater cleanup, urban stormwater capture projects, water marketing, and active groundwater storage projects have also become proven water management tools.

• Pricing mechanisms, such as inclining block rates (the practice of increasing volumetric prices with increasing water use) and seasonal rates (which modify summer water rates to encourage landscape conservation), can encourage efficient water use.

• In some coastal areas, urban water agencies are beginning to explore desalination, previously dismissed as impractically expensive.

Given the impressive array of water management tools available, how should water managers determine the best mix of responses to climate change—particularly as the performance of water management tools will be affected in different ways as a result of climate change? This section is designed to help water managers answer this question. (See Table 4-1 for a summary of NRDC's findings.)

Water Management Tools that Will Perform Better as the Climate Changes

Some water management tools are likely to perform better in the future in the face of global warming. This effect is likely to be most significant for tools that reduce landscape water use.

Table 4-1: Performance of Water Management Strategies After Considering Global Warming Effects

More effective	Not affected	Less effective
• Landscape conservation • Conservation rate structures • Agricultural water conservation • Water marketing • Urban stormwater management • Saltwater groundwater intrusion barriers to protect coastal aquifers • Water system reoperation • Interagency collaboration and integrated water management strategies • Floodplain management • Watershed restoration	• Wastewater recycling • Interior water conservation • Groundwater cleanup	• Traditional river diversions • Traditional groundwater pumping • Traditional surface storage facilities • Ocean water desalination*

*Given existing energy requirements.

Landscape Irrigation Conservation. Urban water conservation programs often underemphasize the demands of urban landscaping. With climate change likely to increase evaporation and transpiration rates in planted landscapes, a lawn or landscape could consume more water in the future than it consumes today. One implication of this trend is that landscape irrigation conservation programs have the potential to save more water in a warmer future than they do today.

Landscape irrigation already represents a significant percentage of urban water use in the West. For example, it accounts for approximately half of urban water use in California, or about 10 percent of statewide water use.[11] Urban water agencies are increasingly turning to landscape irrigation to find new opportunities to increase urban water use efficiency.[12] For example:

• The Southern Nevada Water Agency offers customers a $1 per square foot rebate for all turf that is removed and replaced with drought-tolerant landscaping.[13]

• The Metropolitan Water District of Southern California has developed a website (www.bewaterwise.com) devoted to educating ratepayers about landscape conservation opportunities.[14]

• The East Bay Municipal Utility District (EBMUD) in California has published a comprehensive book aimed at encouraging appropriate landscape design. EBMUD also offers residential landscape conservation rebates of up to $1,000.[15]

• The Marin Municipal Water District, also in California, offers financial incentives to encourage the installation of weather-based irrigation controllers.[16]

As climate change reduces late season snowmelt, measures such as landscape conservation that reduce peak summer demands—often a key constraint on water systems—could be particularly effective. Water managers should incorporate such conservation measures in their plans to meet future water needs and respond to climate change impacts.

Conservation Water Rate Structures. Water rate structures are among the most effective tools to encourage water conservation because they give customers a price signal about the value of this resource. To maximize the effectiveness of this signal, agencies should strive to recover as much revenue as possible through volumetric charges, rather than high fixed charges. Increasing block, or tiered rate structures, offer an initial allocation at a base rate. Additional tiers or blocks of water increase in price. Some utilities offer a lifeline, or below cost rate, for low-income customers. University of California economists Hewitt and Hanemann found a significant positive response to block rate structures in California applications.[17] In addition, seasonal water rates, which increase prices during the warm irrigation season, can be particularly effective in encouraging landscape conservation and in reducing peak summer demands. Water managers seeking to encourage conservation in the future should pay particular attention to rate structures designed to encourage conservation.

> **"We have to attack both sides of the supply-demand equation when faced with more variable water supply due to global warming."**
>
> Source: Chips Barry, General Manager, Denver Water, 2006.

Agricultural Water Conservation. According to the U.S. Department of Agriculture, agricultural water represents 81 percent of all consumptive water use in the nation.[18] In the West, agriculture represents 90 percent of the consumptive use of the developed water supply.[19] Future agricultural water use is difficult to predict because of complex interactive impacts of climate change on international trade, crop selection, and yields. Nevertheless, as in the case of urban landscaping, rising temperatures may increase evapotranspiration rates-meaning that irrigating an acre of crops such as alfalfa or lettuce could take more water in the future than is currently required.[20] As a result, agricultural water conservation and fallowing could generate even more water savings in the future than they do today.

Even without considering potential climate change impacts, there is significant potential for agricultural water conservation around the West. For example, in much of the arid West, flood irrigation is still the predominant irrigation technology, and in states including Arizona, Montana, and Idaho, water application rates often exceed 5 feet per acre.[21] In agricultural areas working to cope with the impacts of climate change, conservation programs and related water transfers could provide valuable revenue.

Market-Based Transfers, Sales of Water. With agricultural water conservation and fallowing programs increasing in effectiveness as temperatures rise, there also may be

Restoring the Wet Meadows of Sierra Nevada's Feather River Basin

A public/private partnership called the Feather River Coordinated River Management Group (CRM) has been working for more than a decade to implement wet meadow restoration projects in the Sierra Nevada's Feather River Basin. The Feather River is an important source of water for California's State Water Project, which provides a portion of the water supply for Southern California, the San Joaquin Valley, and Silicon Valley. There are 250,000 acres of high altitude meadows and valleys in the Feather River's Sierra Nevada watershed. These mountain meadows have been degraded by decades of grazing, road building, and other activities. Streams have eroded deep gullies in meadows, rapidly draining groundwater from these natural high-altitude reservoirs; and incised creek beds have dramatically reduced natural infiltration of runoff.

The Feather River CRM has used several techniques to help restore its degraded meadows. For example, creek beds have been regraded to restore natural drainage elevations by the replacement of incised gullies with barriers and pools. Subsequent monitoring has verified that such projects can significantly increase natural storage in these meadows, thus retaining additional winter rainfall and snowmelt. This additional stored water is naturally released later in the spring and summer. Analysis of the CRM Big Meadow Cottonwood Creek project found that groundwater levels were within 1 foot of the surface for an average of 8 days prior to restoration, and an average of 223 days after. As a result, the ephemeral stream in the meadow returned to nearly perennial flows, increasing from 214 to 344 days of flow.

This project creates additional active water storage, which could have increasingly important water supply and ecosystem benefits in the future. These projects can also decrease stream temperatures, addressing a key potential climate change impact on cold-water fisheries. As a result, the CRM estimates that large-scale restoration projects have the potential to create large amounts of increased natural groundwater storage.

Sources: http://www.feather-river-crm.org/.

Wilcox, Jim, January 2005. "Water Management Implications of Restoring Meso-Scale Watershed Features." http://www.feather-river-crm.org/publications/tech/IAHS%20Full%20Paper.htm.

a growing incentive for some farmers to sell a portion of their water supplies through voluntary, market-based transfers. Three factors suggest that incentives for water marketing that moves water from low-value agriculture to high-value urban uses are likely to increase as a result of global warming. First, as urban water agencies face reduced yields from existing water systems, they may be increasingly motivated to pursue, and increasingly willing to pay for, water transfers. Increasing scarcity could raise prices received by agriculture for marketed water. Second, climate change will create increasing uncertainty for agriculture. It may be a challenge for some farmers to cope with warming temperatures and more extreme weather events, increasing their interest in water transfers that could provide them with greater flexibility and revenue. And third, around the West, many agricultural water users have more senior water rights than their urban counterparts have. To a certain extent, this system will insulate the holders of senior water rights holders from the impacts of climate change—making their water supply more reliable than that of junior holders (including many growing urban areas). All of these factors suggest that the economic rationale for water marketing may increase.

It should be noted that water marketing does not create new water, it simply reallocates it. Various sources of water can potentially be transferred by market transactions, each constrained by legal, regulatory, market, and physical parameters. A California Legislative Analyst's Office report identifies the following sources:[22]

- Land fallowing and crop shifts to less water-intensive crops.
- Water recycling, such as recycling water from wastewater treatment plants for industrial and irrigation purposes.
- Groundwater pumping instead of using surface water rights, thereby freeing up surface water for transfer.
- Storing excess surface water from wet years in underground aquifers to be pumped in the future when surface supplies are low.
- Water conservation, in both the agricultural and urban sectors. This includes, for example, farmers using water-saving irrigation technologies and homes and businesses using water-efficient landscaping and bathroom fixtures.

FEATHER RIVER CRM.

Cottonwood Creek in California's Sierra Nevada, with Degraded Meadow. Before (left) and After (right) Restoration.

• Withdrawals from surface storage supplies that were not otherwise planned to be made.

If a water marketing system is to work optimally, care must be taken to design appropriate transfers and to avoid impacts to third parties and the environment. Efficient markets require that buyers and sellers bear the full costs and benefits of transfers. However, when water is transferred, third parties are likely to be affected. Where such externalities are ignored, the market transfers not only water, but also other benefits and costs from non-consenting third parties to the participants in the transfer.[23] Finally, the practice of "paper water" transfers—attempts to sell rights to water that exist only on paper—must be prevented.[24] Paper transfers can be highly disruptive, leading to environmental impacts and water management challenges.

Watershed Restoration. Watershed restoration has the potential, in some cases, to help mitigate impacts of climate change. As climate change reduces natural storage through a reduction of snowpack, watershed restoration efforts may be increasingly valuable to reduce peak flows, recharge groundwater, and delay spring runoff. Restoration projects may also decrease stream temperatures—reducing another impact of climate change—and provide additional environmental benefits such as riparian habitat. (See Restoring the Wet Meadows.)

Urban Stormwater Management. Throughout the West, there are abundant opportunities to manage urban stormwater to reduce runoff, flood damage, and pollution and to improve water supply availability and quality. As climate change affects rainfall volumes and storm intensity, the value of water supply tools that provide stormwater management benefits may increase.[25] Climate change will likely force urban communities to invest in additional flood management, creating willing partners for water agencies seeking to invest in integrated stormwater management and water supply strategies.

One approach is to direct stormwater runoff from impermeable surfaces, such as roofs and paved areas, to landscaped areas where the water can percolate into the soil, and recharge the groundwater. Impervious surfaces increase runoff during storm events. The first "flush" often collects and concentrates contaminants from those surfaces such as oils and sediment. When flows exceed the infiltration capacity of the soils, water flows into storm drains. By diverting a portion of the first flows, improved stormwater management reduces demands on storm drain systems. This strategy slows the rate of runoff and allows for recharge. Designs such as shallow depressions, or "swales" and the sloping of both the paved areas and the landscaped areas to follow normal drainage patterns facilitate the redirection of stormwater runoff to landscaped areas where it is intercepted and infiltrated into groundwater aquifers. Some of the most innovative work in this area has been done by Tree People, a non-profit organization in Los Angeles that is advocating the construction of a citywide system of cisterns, groundwater infiltration facilities and urban forestry in order to recharge groundwater and provide other benefits.[26]

Another stormwater management related strategy, called "daylighting," involves taking surface flows that are currently conveyed in underground culverts and restoring them to creeks. Daylighting can offer groundwater recharge and environmental benefits, as well as increase property values and recreation in adjacent communities.

Another strategy involves diverting water into groundwater infiltration basins from urban streams during high flow events.

Reoperation of Water Systems. Water agencies have extensive experience with water system management, particularly the operation of storage facilities to meet the different demands of flood management and water supply. As a result of climate change, it will likely be necessary in the future to reconsider operating rules for major water supply systems. The Intergovernmental Panel on Climate Change (IPCC) called for "a systematic reexamination of engineering design criteria, operating rules, contingency plans, and water allocation policies," noting that "water demand management and institutional adaptation are the primary components for increasing system flexibility to meet uncertainties of climate change."[27] Investigations of reoperation opportunities should be broadly conceived to reflect the interactions of the many elements of complex water systems.

For example, the Seattle Public Utilities (SPU) analysis of potential climate change impacts to the water supply system (see Appendix A) helped SPU identify potential future management challenges that could arise from climate change. SPU created a series of adaptive management strategies for reoperating the water system to improve day-to-day management and to provide greater flexibility. They now use a dynamic reservoir elevation rule curve to help guide the management of flood storage capacity and refill of mountain reservoirs, thereby adjusting reservoir level targets based on real-time snowpack measurements and soil moisture conditions. This information, coupled with simulation models, helps to set reservoir targets during the refill season. Using a dynamic rule curve allows SPU to be more adaptive than if they used a traditional fixed rule curve.

SPU's experience during the winter of 2005 demonstrates the operational flexibility that can be provided by utilizing the dynamic rule curve. Low snowpack in the winter reduced the probability of floods from snowmelt. Due to this reduced probability of flooding, SPU water managers captured more spring rains than in a normal year. This adaptation of operations to weather conditions provided Seattle with enough water to return to normal supply conditions by early summer, despite the lowest snowpack on record. It also demonstrated the flexibility in the water system to adjust operations for changing weather conditions, whether they are low snowpack or abnormal levels of precipitation. This system reoperation not only helps in managing the system for the variations in weather that occur now, but also can be used in the future to adjust to further climate change.[28]

The potential to reoperate reservoirs can also be increased by investments in groundwater storage, downstream channel conveyance capacity and integrated operations of operationally connected reservoir systems.

Saltwater Intrusion Barriers. In many coastal areas, increased seawater intrusion resulting from sea level rise threatens coastal aquifers. In some areas, high rates of groundwater pumping are already drawing saltwater into aquifers, threatening the utility of aquifers and wells. In order to prevent such intrusion, some water districts are injecting freshwater into aquifers to create a saltwater intrusion barrier. For example, Southern California's West Basin Municipal Water District is injecting highly treated wastewater into coastal aquifers. As sea level rise increases, such saltwater intrusion barriers may be increasingly important to protect coastal aquifers. These barriers may be given additional value in the future because of the importance of local groundwater storage as part of wastewater reclamation and stormwater management programs. As agencies expand their use of wastewater reclamation and stormwater management programs to respond to climate change, seawater intrusion barriers may become key tools.

Water Management Tools Relatively Unaffected by Climate Change

In general, the tools discussed in this section are more resistant to the effects of climate change because they do not rely on precipitation, snowpack or other climate-sensitive water sources. During the past several decades, these tools have proven themselves to be highly productive and cost-effective. For example, in California, these tools are expected to be the backbone of efforts to meet future water needs. They will likely become even more valuable in water management portfolios.

Water managers are starting to link major new investments in water conservation to their desire to prepare for potential climate change impacts. For example, Denver Water is addressing the potential effects of climate change by ramping up its water conservation efforts with its recent $400 million conservation plan. This plan is designed to cut annual water use by 22 percent, or 16.7 billion gallons per year, during the next 10 years. Although this plan was initially developed without regard to potential climate change effects upon its system, Denver Water is now seeking to reach this 22 percent reduction goal far

more rapidly in order to further protect water users from climate change impacts. The plan includes new strategies and increased investments in existing conservation programs, such as rebates for low-flow toilets and efficient clothes washers. The plan's new programs include:

• establishing a water efficiency rating program for new construction so that builders who do not meet new standards could find it more difficult to connect to the water system.

• installing water meters for landscape irrigation systems.

• initiating water audits of homes before they are sold, and requiring the replacement of leaking or inefficient plumbing fixtures.

• installing low-flow urinals in new commercial buildings.

The actions in the plan are expected to pay for themselves, through reduced water bills, within six years. Denver water users have already cut consumption by about 20 percent since local drought conditions began in 2002. The plan's first year has been approved by Denver Water's board and executive staff, with an initial $8 million.[29]

Interior Water Conservation. Although climate change is likely to improve the performance of landscape conservation programs, it will leave interior water conservation programs relatively unaffected. Interior water conservation technology, including water efficient showerheads, toilets, urinals, dishwashers and washing machines, will not perform significantly differently as a result of climate change. However, the value of the saved water may increase over time.

Water Recycling. Just as other forms of recycling have become commonplace, wastewater recycling has increased dramatically in recent decades. Today, for example, Southern California recycles approximately 500,000 acre-feet of water annually.[30] (This represents approximately 10 percent of total wastewater generated in this region.) The California Department of Water Resources projects that by 2030, an additional 0.9 million to 1.4 million acre-feet of water recycling will be developed. This still represents a small fraction of total wastewater. One of the advantages of this tool is its resistance to drought effects. Similarly, because the sourcewater supply for water recycling is municipal wastewater, it is far less susceptible to potential climate change impacts than traditional water supply projects.

Groundwater Cleanup and Protection. Although traditional groundwater pumping may be negatively affected by climate change (discussed in more detail in the next section), water projects, such as those in the Santa Ana watershed that are designed to clean up contaminated groundwater, may be less affected (see Integrated Regional Management Case Study: Santa Ana). The relative stability of groundwater cleanup, in the context of global warming, comes from the fact that the purpose of many of these projects is not simply to withdraw water but to comply with regulatory requirements and to create more usable, uncontaminated groundwater storage capacity. Where groundwater cleanup is intended to provide opportunities for conjunctive use, water managers should pay careful attention to the potential impacts of climate change on the source of water to be stored.

Water Management Tools That May Perform Poorly in the Future

The water management tools that are most likely to be negatively affected by climate change are those that rely primarily on historical precipitation, runoff, and recharge patterns, including both groundwater and surface water sources.

Traditional Groundwater Extraction. As discussed above, some analyses suggest that climate change may lead to significant reductions in groundwater. Shorter periods of high streamflows may decrease percolation, while longer, hotter summers are likely to decrease soil moisture. Therefore, projects that rely on traditional pumping of natural infiltration of precipitation could suffer a loss of yield in the future. In already overdrafted areas, this impact could increase competition for groundwater resources. We have not identified conjunctive use, the combined use of surface and groundwater systems, including active groundwater recharge, as a separate category in this report. Climate change impacts on conjunctive use projects will be determined in significant part by the source of stored water. Conjunctive use projects designed to rely on current snowpack or traditional river diversions may be negatively affected by climate change; however, conjunctive use projects using recycled wastewater may not be affected. Conjunctive use projects in low elevation coastal areas may be negatively affected by sea level rise.

The Conservation Technology Edge: A Water Management Tool That Will Be Increasingly Important in the Face of Climate Change

Conservation will remain a highly effective water management tool in a climate-altered world. Because climate change may make snowpack-based supplies and diversions less reliable over time, the advantages of new supplies produced by technological innovation should increase. The water sector analysis of the National Assessment of the Potential Consequences of Climate Variability and Change confirms this finding: "Evidence is accumulating that such improvements can be made more quickly and more economically, with fewer environmental and ecological impacts, than future investments in new supplies." Conservation tools have been central to the significant progress made in Los Angeles, the San Francisco Bay Area, Seattle, and Denver to meet the needs of growth without increasing water use (see Appendix B).

Innovation and technology development in the areas of end-use water applications have progressed rapidly in the past few decades. Techniques and technologies from laser leveling of fields and high-efficiency irrigation systems to the design of toilets, urinals, and showerheads have changed the demand side of the equation. Efficiency standards and code requirements have been particularly effective in promoting widespread application of these water saving technologies. End-use applications of water now require much less volume than before to provide equivalent or superior services, and uses of these new technologies often provide immediate economic savings.

These analyses of conservation potential are based on existing technology. Despite significant investments in conservation already, considerable potential remains. In California, 2.5 million toilets have been replaced with high-efficiency models since 1992. There's still room for expansion, with approximately 10 million low-efficiency toilets remaining to be replaced.

The impetus for technological development and innovation in efficient use comes from both price signals and policy. As water gets more expensive and because legal requirements are enacted prohibiting waste and limiting extraction from natural systems, technology has provided a wide range of options for expanding the benefits derived from a given amount of water. Broader application of these techniques will yield significant new supplies and innovations are likely to create improved water conservation technologies. The waterless urinal represents an example of such a relatively recent innovation. It is reasonable to anticipate that ongoing technological innovation will continue to expand the potential benefits of water conservation. In addition, collaborations among agencies with different missions (e.g., water and energy) are expanding water conservation efforts. In short, water use efficiency programs have several significant advantages that are likely to grow over time as a result of collaborations among agencies, technological innovation, and the direct and indirect effects of climate change.

Sources: California State Water Plan, Department of Water Resources, Vol. 2, p.16.1. http://www.waterplan.water.ca.gov/docs/cwpu2005/

Gleick, Peter H. et al., 2000. *Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States.* The report of the Water Sector Assessment Team of the National Assessment of the Potential Consequences of Climate Variability and Change, U.S. Global Change Research Program, Pacific Institute for Studies in Development, Environment, and Security.

Gleick, Peter H., Dana Haasz, Christine Henges-Jeck, Veena Srinivasan, Gary Wolff, Katherine Kao Cushing, and Amardip Mann, November 2003. *Waste Not, Want Not: The Potential for Urban Water Conservation in California.* Pacific Institute.

Finally, conjunctive use projects designed to take advantage of floodplain restoration, storing and infiltrating high flows, may be an increasingly important tool in the future. Water managers should evaluate local conditions to understand the implications of climate change on local groundwater resources.

Traditional River Diversions. Declining snowpack, receding glaciers, increased evaporation, flood control requirements, more frequent droughts, reduced dry-season runoff, and potential reductions in total runoff could render surface water diversion projects less reliable in the future. For example, the Canadian city of Calgary has concluded that the melting of glaciers as a result of climate change could reduce the long-term yield of its surface water supply.[31] Colorado River water users are increasingly concerned about reduced flows and loss of stored supplies to evaporation, due to climate change.[32]

Changes in river hydrography expected as a result of global warming will likely result in alterations in stream-

flows and a direct reduction in water supply reliability. The most obvious impact in this regard is the increase in peak flows and the reduction of dry season streamflows.

The environmental impacts of climate change could exacerbate impacts on the reliability of surface water diversions. As discussed in Chapter 2, climate change could lead to environmental impacts including increased stream temperatures, exacerbated water quality problems and damage to sensitive and listed species—impacts likely to result in more requirements to protect aquatic resources, and greater competition for and conflict over surface water resources.

In addition, as rivers approach the ocean, climate change-driven sea level rise could result in a serious reduction in the reliability and cost-effectiveness of traditional river diversion projects. This has serious implications for coastal communities that rely on low-elevation surface water diversions or on groundwater diversions with a direct connection to surface waters. The Sacramento–San Joaquin Delta is an example of an area vulnerable to these potential effects.

Traditional Surface Storage. Although dams are central to water supply in the West, they have often led to high-profile, protracted policy conflicts. This is true of proposed dams on the Colorado, Yellowstone, Green, Missouri, Platt, Tuolumne, Stanislaus, and American rivers. There are cases in which new surface storage projects have generated significantly less conflict, particularly when the surface storage system is well designed, such as in the case of the existing Los Vaqueros Reservoir in the eastern San Francisco Bay Area. This off-stream project was designed to improve water quality and provide emergency supplies and was seen by many as having fewer environmental impacts than traditional surface storage development.[33,34] However, most dam sites have high financial and environmental costs, with low potential water supply yields. Given the high capital cost of surface storage projects, water managers should consider how climate change will affect this water management option.

> **"Immediate prospects for major new water supply reservoirs or inter-basin transfers are limited. Consequently, new water project prototypes that emphasize conservation, landscaping, new technologies, and other measures are being promoted across the West."**
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> Source: Committee on the Scientific Bases of Colorado River Basin Water Management, February 2007. *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability.* National Research Council, p.96.

Western dam operators could face increased challenges from seven potential climate-related impacts: reductions in reservoir inflows, increases in the percentage of precipitation falling as rain, rather than snow (and related increases in flood control requirements), decreased snowpack, more severe weather events (both droughts and floods), greater environmental requirements, increased evaporative losses from reservoirs and increased spills from existing reservoirs.

Potential climate change impacts have been cited by some agricultural water agencies as justification for more surface storage facilities.[35] Some new surface or groundwater storage may be developed in the West to cope with the challenges presented by climate change. However, it is important for water managers to recognize that, just as climate change can reduce the yield of existing reservoirs, it can also reduce the potential water yield of new dams.

Although site-specific analyses will be required to evaluate potential climate change impacts on proposed new storage facilities, particularly in highly engineered watersheds, some general conclusions are clear. In relatively undeveloped watersheds, a shift toward more rainfall and less snowpack is likely to reduce the yield of most new proposed dams. With shorter high-flow periods, the window for filling off-stream storage facilities could be shorter in the future. Potential reductions in total streamflows as a result of climate change could have profound implications for new surface storage projects. Frequently, new surface storage facilities utilize junior water rights in a river basin. If climate change reduces average total runoff in a basin, water managers could find themselves in a position where they have constructed a new surface storage facility to capture runoff that may be lost in the future as a result of climate change impacts.

In highly engineered watersheds, the potential interactions of existing and proposed facilities can be complex. For example, the climate change effects listed earlier could reduce potential yield from a proposed new storage facility but at the same time, increased climate-driven spills from existing dams could increase the amount of water that could be captured by a new facility.

Finally, surface storage projects in some river systems could face increased operating restrictions to mitigate for the environmental impacts of climate change. The most likely additional operating restrictions include flow

Summary of Potential Climate Change Impacts on Potential New Traditional Surface Storage Facilities

Climate Change Impacts that Could Reduce Potential Yields from New Traditional Surface Storage

- potential decreases in total annual runoff
- decreased late-season runoff, as a result of reduced snowpack
- increased winter runoff, as a result of greater rainfall, increasing spills and flood control storage requirements
- more extreme weather events (droughts and storms)
- increased evaporative losses from reservoirs.
- potential new environmental requirements regarding flow and temperature

Climate Change Impacts that Could Increase Potential Yields

- increased uncaptured spills from existing storage facilities

and temperature requirements. Such requirements could decrease the expected water supply yield of existing and proposed surface storage facilities.

The authors of this report are not aware of any proposed new surface storage facilities that have undergone a comprehensive analysis mentioning the seven factors addressed above. It is likely in many cases that estimates of potential yields from proposed new surface storage projects will be reduced when climate impacts are considered. As a result, these projects, already expensive today, could be more expensive per acre-foot of yield, when future climate change impacts are considered. The potential impact of climate change on new surface storage facilities should be carefully evaluated.

This report is not the first to suggest diminishing prospects for traditional surface storage development in the West and an increase in alternative approaches. For example, the National Research Council's 2007 report on Colorado River basin hydrology observed that "(t)he declining prospects for traditional water supply projects are perhaps more correctly seen not as an end to 'water projects', but as part of a shift toward non traditional means for enhancing water supplies and better managing water demands."[36] The report went on to state that "(i)mmediate prospects for major new water supply reservoirs or inter-basin transfers are limited. Consequently, new water project prototypes that emphasize conservation, landscaping, new technologies, and other measures are being promoted across the West."[37]

Desalination. Evaluating the performance of desalination in the context of climate change raises issues different from those raised by other water management tools and some of these emerging issues support different conclusions. Ocean water, the source for many proposed desalination projects will be far less affected than freshwater sources by climate change. However, water managers making decisions on siting and design for coastal desalination facilities should carefully consider the likelihood of significant sea level rise as a result of climate change. For water managers in coastal areas with existing water systems that could be negatively affected by climate change (e.g. those that rely on snowpack and rivers), the reliability of seawater desalination could be an important consideration.

However, desalination raises another significant issue in the context of climate change. As discussed in Chapter 3, ocean water desalination is a very energy intensive water supply option. Indeed, energy is the primary operating cost of ocean water desalination facilities. Climate change prevention efforts are likely to result in a dramatic increase in efforts to reduce energy consumption, in order to decrease greenhouse gas emissions. Thus, a dramatic increase in energy-intensive seawater desalination facilities raises significant issues in the context of climate change. In addition, because of its high energy requirements, seawater desalination is also particularly vulnerable to any future energy price fluctuations.

Although climate change will not have the same impact on this tool as it is likely to have on water management tools that rely on rivers, historical groundwater recharge and snowpack, consideration of climate change raises serious concerns regarding the energy implications of desalination. Energy requirements of desalination have declined significantly in the past decade, largely as a result of the improvement of membrane technology for reverse osmosis plants and improvements in pressure recovery.[38] In addition, desalination of less saline sources, such as brackish and contaminated groundwater, requires significantly less energy. Efforts to reduce greenhouse gas emissions will raise additional issues regarding desalination. This climate change-related implication for desalination is less direct than the impacts affecting the other tools discussed in this section. As technology improves, this con-

cern will lessen. In fact, if the energy required for ocean desalination declines by a relatively small amount, some Southern California water agencies could save energy by substituting ocean water desalination for diversions from the Bay-Delta estuary.

Integrated Regional Water Management Planning

Many of the tools discussed above—water conservation, wastewater reclamation, and stormwater management—offer potential benefits to other public entities, including wastewater and stormwater agencies, energy utilities, and

Six Concerns Regarding Surface Storage Analyses

In some cases, project evaluation methodologies have exacerbated controversies around proposed surface storage projects. Future evaluations of surface storage projects should address these issues. Problematic approaches in past dam feasibility studies include:

1. Projections based on historical hydrology: Traditional water development has not considered the potential impacts of global warming on future hydrology. The case of the Colorado River shows how important assumptions regarding future hydrology can be. On the Colorado River, a relatively short hydrologic record led water managers to conclude that the river's long-term average flow would be higher than it has proven to be. As a result, the Colorado River Compact assumed that river flows would average 17 million acre-feet. In fact, average flows have proven to be less than 15 million acre-feet.This discrepancy has significantly increased conflicts on the river. With additional climate change impacts, reliance on historic hydrology will be even riskier.

2. Lack of demand side analysis: The supply side approach has traditionally focused on increasing supply through dams and diversions. Demand management and alternative approaches, which can be less expensive and environmentally damaging, have often been overlooked or their potential underestimated. Addressing both supply and demand side strategies—and comparing all available tools on a level playing field—is a key feature of an integrated approach to water management planning.

3. Flawed economic analysis: Some surface storage studies, particularly those undertaken by the federal government, have failed to include credible economic analysis. For example, the U.S. Bureau of Reclamation is currently studying a potential surface storage project in California's upper San Joaquin River basin to provide additional supply for agricultural water users. Water from this facility is likely to cost far more than the new water supply would be worth to the agricultural community. When the Bureau of Reclamation last studied a surface storage project in this region, the agency concluded that raising Friant Dam would produce water costing approximately $3,000 per acre-foot-twice the cost of desalinated seawater and approximately 100 times the cost of water provided by federal water contracts in the region. Recent analysis of Auburn Dam by the Bureau of Reclamation revealed lower water yields and a significantly higher cost than had been previously estimated.

4. Subsidies that encourage waste: In many water projects, a reliance on subsidies and artificially low water prices encourage under-investment in efficiency and over-use of water resources. Supply-side subsidies skew water management plans against conservation programs. These subsidies have, historically, been focused primarily on dramatically lowering costs for agricultural water users.

5. Underestimates of environmental damage: There is a long history of promises regarding environmental benefits from dams. However, dam building has a clear record of negative impacts on the environment. For example, 60 years ago, Friant Dam in California was authorized, in part, due to claimed benefits to the San Francisco Bay-Delta. In practice, Friant Dam has resulted in severe degradation of water quality and fisheries.

6. Unrealistic anticipated benefits: For many dam projects, a portion of the cost has been written off (i.e. paid by taxpayers rather than water users) because of claimed environmental, recreation, or other benefits. These benefits have frequently proven to be illusory.

Sources:

http://www.sciencedaily.com/releases/2006/05/060529082300.htm.

Committee on the Scientific Bases of Colorado River Basin Water Management, February 2007.

Department of the Interior, Bureau of Reclamation Mid-Pacific Region, Fish and Wildlife Service, October 1995. "Least-Cost CVP Yield Increase Plan," pp.III-41, III-51.

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local governments. These approaches are also often less centralized and less capital-intensive than traditional water development. Integrated regional water management offers the potential to maximize the benefits from these new tools.

Wastewater, stormwater, and conservation programs are often best implemented through collaborations among agencies. Where a water supply agency does not have wastewater or stormwater responsibilities, designing and implementing climate change response strategies in these areas will require interagency collaboration. In addition, water conservation offers significant energy benefits, inviting the participation of energy utilities and state agencies with energy regulatory and planning responsibilities. Finally, water conservation and stormwater management programs can benefit greatly through the participation of local governments with land-use authority.

Agencies with different missions do not always share identical service boundaries, creating a potential obstacle to interagency efforts. In many cases, this obstacle can be overcome by bringing together multiple agencies on a regional basis. Such an integrated regional approach can offer broad benefits. Integrated regional water management is emerging as a particularly important strategy. The 2005 California State Water Plan identifies integrated regional water management as an initiative co-equal with statewide water management planning efforts.[39]

California's Proposition 50, The Water Security, Clean Drinking Water, Coastal and Beach Protection Act, and Proposition 84, which were approved by the voters in November of 2002 and 2006 respectively, provided a total of $1.5 billion in general obligation bond financing for integrated regional water management efforts across the state. This new direction represents a decreased reliance on large traditional water projects and on state and federal agencies to guide planning and decision making. Increasingly, innovative thinking is showing how integrated regional strategies can supplement traditional statewide and federal planning.

Integrated regional planning has several advantages. It encourages collaboration among the diverse agencies in a particular region. As in the case of the projects in the Santa Ana watershed to clean up contaminated groundwater and generate electricity through "cow-power" (see Integrated Regional Management Case Study: Santa Ana), an integrated approach can reveal opportunities that cannot be implemented without cooperation among stakeholders and agencies. It tailors strategies to meet unique local needs. It can maximize the potential for multiple funding partners and multiple benefits, including reduced dependence on water supplies vulnerable to climate change impacts, reduced urban runoff pollution, groundwater cleanup and improved groundwater management, flood damage reduction, ecosystem restoration, energy conservation, and public education. And integrated regional planning offers the potential for water managers to address, in one program, multiple stresses facing current water supplies. These include population growth, land-use changes, contamination of surface and groundwater resources, and the need for ecosystem protection and restoration.

Moreover, an integrated approach can increase system flexibility. The massive investment required for a traditional water project can be highly inflexible because, if the construction cost of such a water project proves to be higher than expected, water managers with a partially constructed project cannot redirect investments, without losing the yield of the entire project. These large projects create a significant sunk cost risk. By contrast, investments in an integrated portfolio of conservation, reclamation, and stormwater projects, all of which can be scalable and less capital-intensive, can be more easily redirected to respond to changing conditions or to adjust for an underperforming water management tool.

Effective integrated planning can require the use of many water management tools, with varying potential benefits in different regions. For example, without debating the merits of desalination in general, we can examine how desalination might fit into an integrated regional strategy. In Southern California's Chino Basin, desalination is being used to clean up contaminated groundwater, thus fixing an existing problem and generating water supply reliability and wetland restoration benefits. In San Diego, desalination, although energy intensive and expensive, could provide high quality water that could be blended with existing supplies, facilitating energy-conserving wastewater reclamation programs. In contrast, on California's Central Coast, seawater desalination could be highly growth-inducing, leading to urban sprawl, with potentially serious environmental impacts. The implications of this technology and the case for public funding can be very different in different regional settings.

Integrated Water and Energy Management

Integrated water management efforts should pay particular attention to energy issues. Managing and using water more efficiently can reduce related energy requirements and greenhouse gas emissions. Efficiency as used here

Integrated Regional Management Case Study: The Santa Ana River Watershed

Water managers in Southern California's Santa Ana River watershed are leaders in designing integrated regional water management strategies, relying on an array of tools to produce a wide range of water management and environmental benefits.

The Santa Ana River drains 2650 square miles and runs 100 miles from the peaks of the San Bernardino Mountains to the beaches of Orange County. Five million people live within this "Inland Empire" watershed, a population that is expected to double within 50 years.The watershed is also home to the world's densest populations of cows, a fact that surprises most outsiders. At its peak, the basin held more than 300 dairies, with up to 400,000 head of cattle, operated in less than 220 square miles of the upper part of the watershed—the Chino Basin. These cows produce 1 million tons of manure per year and another 2 million tons of manure currently sit on dairy lands. Runoff from these dairies has contaminated one of Southern California's largest groundwater sources with salts, dissolved solids and nitrates.

Urbanization, dairy operations, habitat destruction and other activities have taken a toll on the Santa Ana River's ecosystem. Today, some of the river's residents, including the Santa Ana sucker, the Least Bell's vireo and the southwestern willow flycatcher, are listed under the Endangered Species Act.

In 1968, local water agencies formed the Santa Ana Watershed Project Authority (SAWPA) in order to develop an integrated approach to address the challenges discussed above. After decades of effort, this integrated approach includes strategies such as water conservation, wastewater reclamation, and storm water infiltration. What makes the SAWPA case study so interesting is that it shows how multiple problems can be addressed simultaneously.

The juxtaposition of the local dairy industry with growing cities has created challenges—and opportunities—for local leaders. The Inland Empire Utility Agency (IEUA) is diverting dairy waste for composting and marketing to agricultural users. The methane derived from anaerobic digestion of this waste is used to generate renewable electricity. Thus, by diverting dairy waste and reducing ongoing groundwater contamination, IEUA has created a new energy source and a marketable compost product.

The value of new water sources, as well as regulatory and legal pressure to clean up groundwater contamination have also led IEUA to construct two groundwater desalters, which use desalination technology to clean up contaminated groundwater. (Desalting groundwater requires far less energy than desalinating seawater.) The two desalters have a combined capacity of more than 23 million gallons per day.These facilities provide usable water supply and help remediate contaminated groundwater basins. Agencies in the watershed are also recharging the basin's aquifers using storm water runoff and recycled wastewater.

The energy and climate benefits of this integrated approach are also notable. By reducing reliance on energy-intensive imported water (see discussion in Chapter 3), IEUA is able to reduce the electricity consumed to meet water supply needs. In addition to avoiding energy and other costs associated with imported water supplies, increasing local supplies reduces pressure on stressed ecosystems such as the San Francisco Bay-Delta. IEUA has also built a new energy-efficient headquarter building that has received a platinum certification from the U.S. Green Building Council's LEED program. The building uses waste heat to reduce heating and cooling costs, and photovoltaic cells to generate electricity.

The benefits of SAWPA's integrated approach are impressive, including:

- creation of local drought-proof water supplies.
- reduced reliance on imported water supplies that are vulnerable to environmental constraints and climate impacts.
- reductions in groundwater contamination
- flood management improvements
- enhanced wetlands
- marketable organic composed dairy waste
- improved air quality
- renewable energy generation
- reduced energy use and greenhouse gas emissions
- marketable greenhouse gas credits

The roots of this effort are more than three decades old. Climate considerations did not lead SAWPA and IEUA to launch this integrated regional effort. However, the energy and climate benefits of their approach are significant. The integrated approach reduces the vulnerability of the region to water supply impacts from climate change. It also shows how water utilities can make cost-effective contributions to efforts to reduce greenhouse gas emissions, through water and energy conservation, wastewater reclamation, better groundwater management and renewable electricity generation.

This integrated approach demonstrates how far water management has come from the days when dams and increased water diversions were the all-purpose solutions to meeting water supply needs. In California, the SAWPA effort has become a model for other integrated efforts around the state.

Sources: Santa Anna Integrated Watershed Plan, 2005 Update, Santa Anna Water shed Project Authority, Riverside, CA, June 2005.

Atwater, Rich and Paul Sellew. "Organics management, clean water and renewable energy: Focus on California." *BioCycle: The Journal of Composting & Organics Recycling*, February 2002.

http://www.ieua.org/desalter.html.

The LEED program itself reflects an integrated approach to green building. IEUA was able to use its institutional strengths to design on-site stormwater recharge facilities and to locate the headquarters building adjacent to a wastewater treatment plant, in order to provide renewable energy from its digesters and reclaimed water for use on site. The design reduced potable water demand by 73 percent and energy use by 90 percent.

describes the useful work or service provided by a given amount of water. Significant economic and environmental benefits can be cost-effectively achieved through improving water system efficiency. The energy/water nexus will make water conservation programs more attractive to agencies planning a response to climate change. In particular, as greenhouse gas emission reduction programs increasingly emphasize energy conservation, water agencies are likely to find additional benefits from more fully integrating energy and water management. Taking both

12 Elements to Consider When Designing an Integrated Response to Climate Change

When evaluating options for responding to the water management challenges presented by climate change, water agencies should consider the benefits of comprehensive integrated regional water management planning (IRWMP). Such strategies should incorporate the following elements:

1. Climate Impacts on Existing Systems and Future Strategies. Water agencies should analyze the potential impacts of climate change on existing facilities and on the tools under consideration to meet future demands.

2. Unique Regional Conditions. A careful examination of regional conditions will reveal challenges and suggest unique opportunities for future strategies to produce multiple benefits.

3. Evaluation of Multiple-Benefits and Funding Partners. IRWMP can provide potential multiple benefits and attract new funding partners to address water, energy, and environmental challenges.

4. Efficiency First. In most cases, greater investments in water-use efficiency are cost-effective and environmentally preferable—and result in significant energy savings. California electricity utilities recently adopted a "loading order" that requires investments in efficiency as a first priority before additional supply-oriented power strategies are pursued.[54] Water utilities should consider adopting a similar approach in response to anticipated climate change impacts.

5. A Full Range of Water Supply and Demand Options. All of the many supply and demand-side water management options should be considered in designing an effective response to climate change.

6. A Full Range of Flood Management Options. Land use controls, setback levees, floodways, and other floodplain management techniques are likely to become increasingly important flood management tools in the future. Given the high cost of new surface storage facilities and levees, and the residual flood risk for communities behind levees (e.g., pre-Katrina New Orleans), decision makers should encourage appropriate land use in floodplains to reduce risk to life and property.

7. Clear Objectives and Performance Standards. In order to evaluate the costs and benefits of alternative strategies, water managers should include clear objectives and performance standards to evaluate all tools on a level playing field.

8. "With-and-Without Project" Baseline Analysis. Analysis of proposed surface storage projects and other large infrastructure investments should include an accurate baseline and a clear "with and without project" analysis. Such analysis can help avoid stranded investments.

9. Economics and Cost-Based Financing. IRWMP should include careful evaluation of the economic costs and benefits of alternative strategies. Financing plans in which beneficiaries, rather than taxpayers, pay for the benefits they receive will provide incentives to ensure cost-effective investments.

10. Enforceable Environmental Protections. IRWMP efforts to restore and enhance the aquatic environment should take the form of specific, enforceable commitments.

11. Institutional Capacity. IRWMP will benefit from efforts to strengthen particular disciplines, including economics, climate-related expertise, and designing interagency partnerships.

12. Outreach to the Public and Decision Makers. IRWMP efforts to educate the public will increase public acceptance of investments to address climate-related problems. Agencies preparing plans to respond to climate change should also encourage decision makers to take prompt action to lessen future climate change-related impacts by reducing greenhouse gas emissions.

Together, the above recommendations represent a new approach to the foreseeable water management impacts of climate change. Though this approach is a dramatic departure from historic water project planning efforts, it is based on the experiences of water agencies around the West. This integrated regional approach can produce water supply, water quality, environmental, and other water management benefits, as well as greenhouse gas reduction and other societal benefits.

resources into account will improve the cost-effectiveness of water use efficiency programs, allowing, for example, higher rebates that should result in greater participation. Eventually, greenhouse gas reduction programs are likely to generate new opportunities for funding and revenue for water agencies that master the connections between energy and water.

The energy intensity of water varies considerably by source, geographic location and end use. A number of water management entities, government agencies, professional associations, private-sector users, and non-governmental organizations have already demonstrated potential savings in the area of combined end-use efficiency strategies:

• *Water-efficiency improvements:* Implementing cost-effective water efficiency improvements can generate significant energy savings. For example, in some areas, water, and energy utilities have designed joint rebate programs for appliances that save water and energy (e.g. washing machines). Some efficiency improvements can result in direct energy savings for water districts. For example, most of the electricity use in water and wastewater treatment plants is for pumping. Programs that reduce the volume of wastewater can result in significant energy savings for agencies with treatment plants. In addition, water conservation efforts that reduce peak water use can also reduce energy consumption, thus reducing peak energy demands as well.

• *Operations-efficiency improvements:* Energy management benefits can also be obtained by improving pumping equipment and operational control systems at existing facilities, including the use of high-efficiency motors and adjustable-speed drives, efficient pumps, and effective instrumentation and controls. In many applications, these measures can be implemented with payback periods of three years or less.[40]

Response Strategies for Addressing Other Water Resource Impacts

Climate change will have direct effects on water supply resources as discussed in the sections above. However, impacts to water supplies will be compounded by indirect effects that climate change will have on other water resources including aquatic ecosystems and flood management. It is essential to understand and address these important water resource in order to formulate an effective response plan to minimize water supply impacts.

Goods and Services of Aquatic Ecosystems

Water supply
Drinking, cooking, washing and other household uses
Manufacturing, thermoelectric power generation and other industrial uses
Irrigation of crops, parks, golf courses, etc.
Aquaculture

Supply of goods other than water
Fish
Waterfowl
Clams, mussels, other shellfish, crayfish
Timber products

Nonextractive benefits
Biodiversity
Transportation
Recreational swimming, boating, etc.
Pollution dilution and water quality protection
Hydroelectric generation
Bird and wildlife habitat
Enhanced property values
Coastal shore protection

Source: Pew Report on the Climate Effects on Aquatic Ecosystems.

Aquatic Ecosystems

Climate change will likely have significant impacts on riverine and estuarine ecosystems throughout the West, diminishing the wide array of societal benefits these ecosystems provide. As water managers consider how to respond to climate change, they should evaluate the need to manage and protect aquatic systems to maintain these benefits. In the West, water supply has often been prioritized over competing concerns, resulting in a loss of other benefits—particularly environmental benefits. As a result, many western rivers have been degraded to the point where species have been listed as threatened or endangered.

Today, the public seeks—and environmental laws require—a better balance among beneficial uses, and water managers must help find that balance. Water resource managers and the public share a mutual interest in addressing the impacts of global warming on aquatic ecosystems, in order to reduce future conflicts such as

> **"The manner in which humans adapt to a changing climate will greatly influence the future status of inland freshwater and coastal wetland ecosystems. Minimizing the adverse impacts of human activities through policies that promote more science-based management of aquatic resources is the most successful path to continued health and sustainability of these ecosystems. Management priorities should include providing aquatic resources with adequate water quality and amounts at appropriate times, reducing nutrient loads, and limiting the spread of exotic species."**
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> Source: Pew Center on Global Climate Change, Aquatic Ecosystems and Global Climate Change: Potential Im*pacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States*, 2002.

those that have occurred on the Klamath, Rio Grande, and other rivers.

Around the West, many water managers have been leaders in implementing practices that can minimize the effects of climate change and help preserve the health of aquatic ecosystems. These practices include:

Protecting the Ability for Aquatic Species to Adapt to Changing Conditions. Species naturally seek out conditions favorable to their survival and success. In a warmer climate, some aquatic species experiencing increased stress will try to move higher within watersheds to find suitable habitat. Therefore, maintaining or improving conditions necessary for migration within a watershed is critical for the survival of species at the limits of their temperature tolerances. For example:

• Existing water infrastructure has, in many cases, reduced the ability of species to move throughout a watershed. Barriers such as dams and diversion structures should be assessed to determine the potential for improving movement of critical species. In some cases, particularly regarding antiquated infrastructure, retrofitting structures to enable passage, or removing barriers altogether, can allow species to utilize suitable habitat upstream.

• Maintaining free-flowing rivers allows natural migration to take place and helps maintain other physical processes such as sediment transports that are critical for functioning ecosystems. When developing new storage, seek to locate new storage off-stream or utilize groundwater resources.

Restoring aquatic ecosystems. Restoring in-stream, riparian and floodplain ecosystems will increase the resilience of ecosystems to the effects of climate change and other stressors. Aquatic ecosystems where the natural, physical (i.e., sediment transport) and biological processes (i.e., recruitment of new riparian trees) are largely intact will be healthier and better able to support aquatic species, reducing the challenges that managers will face as climate change impacts intensify. Specifically, managers should consider that:

• Restoration of riparian habitat can play a crucial role in mitigating the effects of increased temperatures. Shading from trees reduces water temperatures. Riparian vegetation provides nutrients critical to aquatic species and improves the stability of stream banks, reduces bank erosion, and creates important aquatic habitat. In addition, large trees that fall into streams provide important in-stream habitat, particularly for juvenile salmon and other small fish.

• In many systems, restoration of periodic high flows is vital for maintaining in-stream habitat. High flows, often in the spring, are needed to establish riparian vegetation. Mobilization of sediment in the channel during high flows is essential for maintaining spawning habitat for salmon and trout. High flows also help move out-migrating juvenile anadromous fish downstream. They can also inundate natural floodplains, which are critical for some species to reproduce.

• Restoration of floodplain ecosystems can provide increased flood protection, groundwater infiltration for water supply, and improved water quality by reducing runoff into streams.

Improving Water Quality by Reducing Runoff of Pollutants. Runoff from urban, agricultural and other managed landscapes into rivers and streams can severely impair water quality through discharges of excess nutrients, sediment, and toxic chemicals. Poor water quality can in turn reduce the biological productivity of rivers and stress aquatic species. Increased flows may be required to mitigate adverse water quality impacts, or meet water quality standards. Reductions in polluting runoff can be achieved through a variety of approaches:

• Support practices such as increased use of permeable surfaces that allow infiltration of rainwater. Impervious surfaces can produce up to 16 times the volume of urban runoff compared to natural, permeable surfaces, reducing natural groundwater recharge and moving pollution into waterways. These practices can not only directly support multiple benefits including water quantity and community aesthetics, but can be more cost effect water quality solutions compared to traditional storm water management which relies on wastewater treatment.

• Riparian and floodplain habitats act as buffers between surface water sources and adjacent land uses, by filtering runoff and reducing direct input of pollutants.

• Watershed education programs have been effective at informing people about actions they can take to protect their local rivers and lakes. Water supply and flood management districts have a unique ability to educate their customers about the need to protect the quality of their water supplies.

Managing Water Supply Systems to Meet the Temperature Needs of Sensitive Species. Maintaining the health of aquatic ecosystems while meeting water supply needs will require data collection, analysis and actions to mitigate or prevent temperature impacts on sensitive species. Such efforts include:

• Data collection and computer modeling of seasonal water temperatures downstream of reservoirs to enable water managers to identify potential temperature problems before a crisis occurs.

• Data collection and computer modeling of reservoir temperatures under different operations scenarios to help water managers identify opportunities to reoperate reservoirs in order to preserve cold water for release later in the year, and to minimize potential water supply impacts.

• Retrofitting existing surface storage with flow curtains or installing flow outlets at a range of elevations within the reservoir to help meet water temperature needs downstream.

• Managing local groundwater levels to preserve subsurface inflow of cold water that may be critical to maintaining cold-water habitat for fish. Local groundwater pumping can also harm riparian vegetation that provides temperature and other ecosystem benefits.[41]

Flood Control

The frequency and the size of flood events are expected to increase due to climate change. Water managers are considering the challenge of reoperating reservoirs that serve the dual purpose of flood control and water supply. Because there are competing operational elements between these two purposes, reoperation may result in reduced water supply yield. Flood protection actions downstream of reservoirs, such as levee setbacks, can in some cases reduce the tension that dam operators face in managing for water supply and flood protection.

The most common form of flood protection has been the construction of storage facilities, levees and flood bypasses, but today there are a number of options for improving flood protection that may be more cost effective and provide additional benefits. This section discusses a number of planning considerations as well as structural and nonstructural options for improving flood management in order to address the impacts of climate change. Emphasis has been placed on response measures that not only increase flood protection, but also benefit ecosystem health, water quality, and water supply. Many of these measures may be significantly more cost effective than traditional approaches—particularly over time—because they reduce the potential for flood damage.

Manage Floodplains Knowing that They Will Flood Eventually. Regardless of existing reservoirs or levees, most lands within the floodplain of a river will flood at some point, damaging property and resulting in the potential loss of life. It is not a question of *if*, but rather *when* such floods will happen. However, many local, state, and federal land-use and planning agencies only plan for the 100-year flood event. With climate change likely increasing the frequency and size of peak events, existing flood control systems may not be adequate. As such, the extent to which land uses within the floodplain can be limited to those compatible with periodic flooding will reduce the cost of flood damages and the need for increased levels of protection.

Many cities and counties currently use planning guidelines and zoning requirements to manage development within the floodplain to provide for public safety. Often only areas within the 100-year floodplain are subject to such regulations. Land that is adjacent to a river but protected by a levee built to withstand a 100-year flood event may not be considered to be within the floodplain. Areas deemed to have a 100-year level of protection may not be adequately protected in the future. The California

> **"A reasonably foreseeable flood is a flood event that is realistically probable for a particular area. In many cases, this event could exceed a predicted "100-year" flood... Sources of information on reasonably foreseeable floods may include historic floods, paleo-floods, hydrologic modeling using transposition, historical flood damage data, and hydrologic models."**
>
> Source: California Floodplain Management Report, 2002

Department of Water Resources notes that "during a typical 30 year mortgage period, a homeowner living behind a levee has a 26 percent chance of experiencing a flood larger than a 100 year event. This is almost twice the likelihood of a house fire."[42]

The single most effective flood management strategy is to avoid development in floodplains that is not compatible with occasional flooding.

Plan for More Extreme Flood Challenges. Current climate modeling does not yet provide precise estimates of the degree to which climate change will increase the frequency and magnitude of flood events in any given area. The need to prevent future flood damage and the time required to implement mitigation measures suggests the importance of immediate planning for increases in flood events. Because simply planning for the 100-year flood may not be adequate in the future, water resource managers should therefore plan for the "reasonably foreseeable flood", taking into consideration the hydrologic impacts of climate change among other factors.

Restore Floodplain Habitat. Traditional flood control projects have been designed to control flows without considering the importance of maintaining floodplains as part of a healthy riverine ecosystem. Floodplain ecosystems provide essential habitat for a multitude of plants, aquatic species, and other wildlife. Lands adjacent to rivers, particularly those subject to frequent or deep flooding should be strongly considered for preservation or restoration as floodplain habitat. In the last several decades, a growing number of flood management projects are incorporated floodplain protection and restoration as a strategy to reduce flood damage and increase ecosystem health.

Promote Flood-Compatible Agriculture. One of the best economic uses of floodplain lands is for agriculture compatible with periodic flooding. Not only does this encourage the preservation of productive agricultural lands, but periodic flooding also replenishes nutrients and soils, reducing the need for fertilizers. In addition, managed inundation of seasonal agricultural lands can provide valuable habitat for wildlife. The purchase of flood easements on private lands being used for flood control can also deliver financial benefits to farmers while creating a more cost effective way of meeting the need for improved flood management.

Build Flood-Resistant Infrastructure. In the valleys of large rivers such as the Sacramento, floodplain areas can extend great distances due to the low slope of the land. Making all of such land off-limits to development may not be necessary or feasible. Where construction occurs in an area that could be inundated to a shallow depth by a reasonably foreseeable flood event, structures should be built to withstand damage by requiring raised foundations or non-inhabited first floors. It is important for decision-makers to acknowledge and for residents to understand

Multi-beneficial Floodplains: The Yolo Bypass

The Yolo Bypass in California's Central Valley is a good example of incorporating agriculture and wildlife habitat into a local flood management plan. In the winter and spring months, the Bypass is employed as a flood control tool that plays a critical role in the Central Valley flood control system including protecting Sacramento and other neighboring cities. When flooded, the Bypass provides valuable habitat for native fish, and a resting stop for migratory birds. During the dry months of the year the Yolo Bypass is farmed with annual crops. Because of the important habitat the Yolo Bypass provides it is home to a national wildlife refuge.

The Yolo Bypass with downtown Sacramento in background.

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that this approach will not eliminate risk as climate change increases the frequency and magnitude of floods.

Expand Flood Insurance. The most common form of flood insurance is obtained through the National Flood Insurance Program (NFIP). NFIP makes flood insurance available to communities that have enacted ordinances requiring, among other things, that all new construction have its lowest floor elevated at or above 100-year flood elevation. Under federal law, flood insurance must be purchased when obtaining a federally backed loan for a home within the Flood Insurance Rate Maps 100-year floodplain. But it is well recognized that these maps are often out of date and do not include areas that are within the 100-year floodplain due to the existence of levees. Cities and counties should assess the adequacy of their flood mapping based on existing and likely future flood hydrology. Additionally, all homes and businesses in areas at risk of flooding in a reasonably foreseeable flood event should be required to have flood insurance, particularly if they would be at risk of flooding to significant depth in the event of a levee failure.

Floodplain Mapping: The Need for Further Information

The West is growing rapidly and millions of people will be living in areas with the potential to flood. Yet many communities do not have the necessary information to determine the risk or the type of flooding they face. Floodplain mapping involves analyzing the hydrology of flood events of varying sizes and then charting what areas are likely to flood given current flood protection. Programs such as the Flood Insurance Rate Maps are essential tools in enabling cities and counties to make informed management decisions. They also help ensure that development within floodplains is sufficiently protected. Cities and counties, in coordination with state and federal agencies, should ensure that floodplain mapping is adequate by using updated hydrological information that reflects reasonably foreseeable flood events. Development, especially the increase in impermeable surfaces, can significantly alter natural hydrology, increasing downstream risks. Therefore, mapping should also incorporate the flood impacts related to past and future development within the watershed.

Improve Monitoring, Forecasting, and Early Warning Systems. Collection of river and streamflow data is a critical component of water supply and flood management. To adequately manage rivers and meet ecosystem needs, water officials rely on streamflow data taken at all times of the year. Data collected during storm events is particularly relevant. Because every year is different, long records of data collection are extremely valuable in predicting future flows and rare high-flow events. Streamflow gauging is also an essential tool for developing early warning systems as part of evacuation plans that can both reduce flood damages and the loss of life. Unfortunately, recent cuts in federal spending have decreased the number of gauges throughout the West, undermining water resource managers and those responsible for public safety and ecosystem health. As climate change alters current hydrology, a robust stream gauge system will be essential to assist water managers and other decision makers.

Watershed and meteorological conditions vary greatly depending upon place, so no single strategy or suite of strategies will be appropriate for all locations. As a result, land-use planners and water resource managers should consider all options. They should also give priority to the response measures which are most cost effective, provide the most multiple benefits, and are easiest to implement given cost and political considerations.

PREVENTION

Decision makers in the West have traditionally looked to water leaders, particularly those from rapidly growing urban areas, to inform them about problems related to water supply, and to develop solutions. The scope and extent of potential worst-case climate change impacts, ranging from lost snowpack to rising sea levels, could result in serious challenges for water managers. As in the case of the gasoline additive methyl tertiary-butyl ether MTBE (see The MTBE Story: Urban Water Agency Leadership) the wisest course for water managers is to be proactive, to reach out to decision makers and the public, and to encourage preventative action. Regarding climate change, prevention means comprehensive, ambitious, and prompt action to reduce greenhouse gas pollution. Such actions could have profound benefits for water management for decades to come.

The MTBE Story: Urban Water Agency Leadership

Perhaps the best example of proactive action by water managers in responding promptly to threats to urban water supplies is the effort to address the contamination of groundwater by the gasoline additive methyl tertiary butyl ether (MTBE). Water agencies were on the forefront of efforts regarding MTBE contamination long before regulatory agencies took action regarding this suspected carcinogen. A decade ago, urban water managers became aware of the threat posed by MTBE contamination to water supplies. MTBE threatened thousands of wells across the country in places where this gasoline additive had leached into groundwater.

Instead of waiting for regulators to assess the scope of the problem and design a response, water managers proactively educated the public and decision makers about MTBE's sources, potential health impacts, and potential costs to water agencies. They took the lead in urging regulatory agencies and legislators to address the threat posed by MTBE. Water agencies also opposed oil company efforts to obtain a congressional waiver of liability. The consensus regarding MTBE among water managers led to the involvement of the American Water Works Association (AWWA). Thanks to water managers, states began banning MTBE, reducing future contamination—and future costs—far more rapidly than would otherwise have been the case. The MTBE case illustrates the impact that proactive water managers can have on public education and prevention on critical water issues.

There were several reasons for this decision to take a leadership role in the MTBE debate. The scientific evidence regarding MTBE contamination was clear. The water management implications of MTBE were serious in terms of public health, the contamination of existing water supplies, and economic costs. Regulatory agencies were slow to respond to the problem when action by policymakers could have had a major impact. And finally, water managers are respected community leaders; decision makers and the public look to them for information about serious water-related problems. Each of these factors now applies in the case of climate change.

For many of the same reasons as the MTBE case, water managers should take the lead in advocating climate change prevention measures.

This would not be the first time that water managers have taken the lead on water management issues without waiting for intervention by regulatory agencies. In December 1991 in California, urban water agencies and environmental organizations signed a memorandum of understanding regarding urban water conservation. This landmark agreement included 14 best management practices for urban conservation. Membership in the California Urban Water Management Council has now grown to 354 members.[43] These urban water agencies could have waited for the state legislature or regulatory agencies to mandate conservation efforts. Although the state has raised significant concerns regarding the pace of implementation of the best management practices, this agreement remains a significant pro-active step.[44]

Western water agencies and other decision makers with water management responsibilities have already demonstrated a broad approach as they begin to reduce climate change impacts. The pace of action to prevent future damage from climate change is accelerating dramatically. Concerns about water impacts are a significant factor in these developments, and water managers are beginning to take clear, action to help prevent climate change. This section provides a brief survey of best practices regarding these actions at the local, state, regional, and national levels.

Action at the Local Level

Although reducing the future impacts of climate change will require action at all levels of government, steps taken at the local level can result in innovative approaches to prevention, and can point the way to broader action. Several examples of such local action are cited here.

Action by Individual Water Agencies

Some water agencies are laying the groundwork for programs to reduce their greenhouse gas emissions. For example, the East Bay Municipal Utilities District (EBMUD) is working to minimize the district's climate change footprint. EBMUD is the first water district to join the California Climate Action Registry. As a member of the registry, EBMUD pledges to annually track, report, and certify its greenhouse gas emissions. The district has also replaced nearly its entire passenger vehicle fleet

with electric-gas hybrids and installed microturbine and photovoltaic systems on the roofs of its two main offices to power business operations. EBMUD was recently awarded the Environmental Protection Agency's Green Power Leadership Club award for exemplary green power production—the first water/wastewater agency to receive this honor. (See Appendix A for a detailed discussion of EBMUD's approach to climate change.) Since EBMUD joined the registry, more than a dozen California water agencies have joined as well as Seattle Public Utilities and the Salt River Project.

Public/Private Partnerships

In some areas in the West, water agencies are collaborating with local businesses to address global warming. The Santa Clara Valley Water District's (SCVWD) partnership with Sustainable Silicon Valley is an excellent example. Formed in 2001, Sustainable Silicon Valley (SSV) is a collaboration of businesses, government agencies, and nongovernmental organizations aimed at addressing environmental and resource pressures in the San Francisco Bay Area's Silicon Valley.[45] SSV is working towards a goal of reducing regional carbon dioxide emissions to 20 percent below 1990 levels by 2010.

To meet the goal, the partnership is focusing on energy efficiency, fuel efficiency, and increased use of renewable energy. This partnership with high technology firms reveals an understanding of the need to take action to prevent climate change and of the opportunities for businesses pioneering. It also shows an understanding of effective new technologies that assist in achieving this goal. Many Silicon Valley entrepreneurs see climate change reduction efforts as a major growth industry. As part of this effort, SCVWD has installed high-efficiency photovoltaic cells above a parking area on its San Jose campus, reducing carbon dioxide emissions by an estimated 412,699 pounds per year and supplying 20 percent of the facility's energy needs with clean energy. (See Appendix A for a detailed discussion of how SCVWD is working to address climate change.)

Cities for Climate Protection

Local governments across the United States are beginning to address the challenge of reducing climate change emissions. More than 670 cities worldwide have joined the Cities for Climate Protection campaign. These include at least 150 in the United States, more than 45 of which are in the West.[46] These local governments include many with water management responsibilities. Of the western cities that are members of the campaign, more than 30 serve as direct municipal water providers. In addition, the Marin (California) Municipal Water District has signed on to the campaign as an individual water district—the first water district to do so. As part of the agreement, signatories analyze their greenhouse gas emissions, set emissions reduction goals, develop and implement local greenhouse actions plans, and monitor and report results. This campaign represents a major movement of cities to address climate change-related issues directly.

U.S. Mayors' Climate Protection Agreement

On June 13, 2005, the U.S. Conference of Mayors unanimously passed a resolution regarding global warming.[47] Remarkably, this measure received more support than any resolution in the organization's history.[48] Of the more than 410 mayors who had signed the agreement as of March 8, 2007, (representing more than 60 million people), at least 133 are mayors of western cities. At least 85 of those cities provide water services directly through municipal water agencies.[49] The agreement commits signatories to strive to meet or exceed Kyoto Protocol targets for reducing climate change pollution—a reduction of 5.2 percent below 1990 emissions levels by 2012.

Action at the State Level

Around the nation, a growing number of states are also taking action to address climate change. In the West, governors are stressing the potential impacts on water supplies as major reasons for taking comprehensive action. State-based strategies include gubernatorial initiatives, programs to reduce carbon pollution, and a move toward renewable portfolio standards.

Comprehensive Gubernatorial Initiatives

California. On June 1, 2005, Governor Arnold Schwarzenegger signed an executive order establishing greenhouse gas emissions targets for the state. The targets call for reducing California's emissions 11 percent below current levels by 2010, 25 percent by 2020, and 80 percent by 2050. Scientists agree that reductions of about 80 percent below current levels are needed to stave off the most serious effects of climate change.

In addition to highlighting potential impacts to water supply, the California initiative also emphasizes that water managers can be part of a comprehensive climate change strategy. The final March 2006 report from the

Governor's Climate Action Team underscores the fact that water conservation has the potential to generate significant energy savings, thus reducing greenhouse gas emissions. (See the discussion of energy and water issues in Chapter 3 for a more complete discussion of this issue.)

Three California urban water agencies have become directly involved in supporting the state's efforts to mandate cuts in climate change pollution. The East Bay Municipal Utility District, the Santa Clara Valley Water District, and the Marin Municipal Water District have all written to the governor, urging him to adopt an aggressive greenhouse gas pollution control strategy. For example, the Santa Clara Valley Water District stated in its letter to Governor Schwarzenegger, "(W)e are very concerned about the impacts of global warming on Sierra snow pack and on water quality in the Delta. The district has supported policies that would reduce the effects of greenhouse gases. We urge you to take the necessary next steps to further the goals and commitments made by your Administration to prevent and defer global warming in California."[50]

Arizona. On February 2, 2005, Governor Janet Napolitano signed an executive order creating a 36 person Climate Change Advisory Group. The group was charged with producing a Climate Change Action Plan that gives recommendations for reducing greenhouse gas emissions in Arizona.[51] The suite of recommendations issued by the task force would reduce emissions to 20 percent below 2006 levels, while saving the state approximately $6 billion, creating 300,000 new jobs, and saving 172,000 barrels of oil.

Oregon. On April 13, 2005, Governor Ted Kulongoski announced five new initiatives designed to curb climate change. These initiatives, based on the Governor's Advisory Group on Global Warming, include:

- establishing new greenhouse gas reduction goals
- developing a plan for stricter emission standards for vehicles, along the lines of California's program
- developing carbon dioxide reduction schedules for utilities and other large emitters
- reducing state agency energy use by 20 percent by 2025
- increasing renewable and bio-fuel production and use[52]

New Mexico. On June 9, 2005, Governor Bill Richardson signed an executive order setting greenhouse gas emis-

Western Leaders Speak Out About Climate—and Potential Water Impacts

"Global warming threatens California's water supply, public health, agriculture, coastlines and forests, our entire economy and way of life. We have no choice but to take action to reduce greenhouse gas emissions." (California Governor Arnold Schwarzenegger, July 3, 2005)

"Arizona and other Western States have particular concerns about the impacts of climate change and climate variability on our environment, including the potential for prolonged drought, severe forest fires, warmer temperatures, increased snowmelt, reduced snow pack and other effects." (Governor Janet Napolitano, Climate Change Executive Order, February 2, 2005)

"Coastal and river flooding, snowpack declines, lower summer river flows,... and increased pressure on many fish and wildlife species are some of the effects anticipated by scientists at Oregon and Washington universities." (Oregon Strategy for Greenhouse Gas Reductions, Governor's Advisory Group on Global Warming, p. i)

"The southwestern United States will likely suffer significant impacts from temperature changes, such as decreased annual precipitation, faster evaporation of surface water supplies, and increased runoff at the end of winter when snow will melt faster." (Governor Bill Richardson, Climate Change and Greenhouse Gas Reduction Executive Order, June 9, 2005)

"Montana has been locked in the grip of a drought for most of the past two decades...I am very concerned about the connection these conditions have to global climate change... I am intrigued by the fact that every city, state, corporation, province and country that has resolved to control its respective green house gas emissions has reaped substantial economic benefits from those efforts...I ask you to establish a Climate Change Advisory Group that will examine agriculture, forestry, energy, government and other sectors of our state. I want this broad-based group of Montana citizens to identify ways in which we can reduce our collective greenhouse gas emissions while saving money, conserving energy and bolstering our economy." (December 13, 2005 letter from Governor Brian Schweitzer to Richard Opper, director of the state Department of Environmental Quality)

sions reduction targets at 2000 emissions levels by 2012, 10 percent below 2000 levels by 2020, and 75 percent below 2000 levels by 2050. The order created the New Mexico Climate Change Advisory Group to write a plan to meet the targets.[53] New Mexico thus became the first major energy producing state to set targets for cutting global warming emissions.

Montana. On December 13, 2005, Governor Brian Schweitzer called for the creation of a Climate Change Advisory Group, charged with developing recommendations to help Montanans save energy and reduce greenhouse gas emissions. The effects of climate change on water were cited first in the governor's letter, quoted below:

State-Level Programs to Reduce Carbon Pollution

States are taking a wide range of individual actions to reduce the emissions that cause global warming. For example, several states are adopting renewable portfolio standards or California's pioneering legislation regulating automobile tailpipe emissions of greenhouse gases. However, these efforts represent only two possible state-level responses to address global warming. In addition to the broad gubernatorial initiatives discussed above, state-based programs include:

- Automobile tailpipe emissions standards
- Appliance efficiency standards
- Renewable energy generation requirements, known as renewable portfolio standards
- Incentives for renewable energy production and generation
- Green building standards, such as the U.S. Green Building Council's Leadership in Environmental Design (LEED) program
- Requiring utility energy plans to include the cost of carbon emissions

California's Global Warming Solutions Act. The Global Warming Solutions Act (AB 32) authored by Assembly Speaker Fabian Núñez (D-Los Angeles), was signed into law by Governor Arnold Schwarzenegger on September 27, 2006. This made California the first state in the nation to set limits on heat-trapping pollution by implementing the pollution reduction targets laid out by Governor Schwarzenegger in June 2005. It set limits to cut the state's global warming pollution 25 percent by 2020. In recognition of the water supply benefits of reducing global warming, AB32 was supported by three California urban water agencies: the East Bay Municipal Utilities District, the Marin Municipal Water District, and the Santa Clara Valley Water District. Water agency staff and board members lobbied in support of AB 32 and helped spread awareness of the potential water-related impacts of climate change, and contributed to the bill's passage.

California's Vehicle Tailpipe Greenhouse Gas Emissions Program. In 2002, California passed pioneering legislation to reduce global warming pollution from all new passenger cars and trucks sold in the state, the largest automobile market in the United States. The law takes effect with the 2009 model year. At least 10 states, including Arizona, Oregon, and Washington, and Canada have adopted or indicated their intention to adopt California's tailpipe pollution standards. Together, these states and Canada represent one-third of the North American automobile market, providing a significant incentive for automobile manufacturers to improve the emissions of their entire fleet.

Renewable Portfolio Standards. At least seven western states have adopted renewable portfolio standards, which require electric utilities to purchase specified percentages of their power from renewable energy sources by specific target dates.[54] There are many benefits of such standards, including reduced pollution from coal-fired power plants and lower greenhouse gas emissions.

- Arizona: Requires electricity retailers to purchase 15 percent of their power from renewable sources by 2025
- California: Requires 20 percent renewables by 2017
- Colorado: Requires 10 percent renewables by 2015
- Montana: Requires 15 percent renewables by 2015
- Nevada: Requires 20 percent renewables by 2015
- New Mexico: Requires 10 percent renewables by 2011
- Washington: Requires 15 percent renewables by 2020

Action at the Regional Level

Western Regional Climate Action Initiative

On February 26, 2007, the governors of Arizona, New Mexico, Oregon, Washington and California, launched

> **"In the Southwest, water is absolutely essential to our quality of life and our economy... Addressing climate change now, before it is too late, is the responsible thing to do to protect our water supplies for future generations."**
>
> Source: Governor Bill Richardson, February 28, 2006

a joint effort to reduce their emissions of global warming pollution. Through the Western Regional Climate Action Initiative, these states will create a regional system to promote clean energy and energy efficiency to slow emissions of carbon dioxide and other heat-trapping pollutants that are contributing to global warming. The new agreement is similar to the Regional Greenhouse Gas Initiative among 8 northeastern states and will include regulatory and market mechanisms.

West Coast Governors Global Warming Initiative

In September 2003, the governors of California, Oregon, and Washington launched a regional initiative designed to address climate change.[55] This effort includes setting emissions targets for state vehicle fleets, creating targets and incentives for renewable energy, and developing efficiency standards for appliances.

Southwest Climate Change Initiative

In February 2006, Governor Richardson of Arizona and Governor Napolitano of New Mexico announced the creation of the Southwest Climate Change Initiative, aimed at reducing global warming effects and cutting greenhouse gas emissions.

Regional Greenhouse Gas Initiative

The largest regional global warming effort, known as the Regional Greenhouse Gas Initiative (RGGI), has been launched among eight Northeast and mid-Atlantic states.[56] The initiative's goals include capping carbon dioxide emissions from power plants at current levels in 2009 and reducing them by 10 percent from current levels by 2019. RGGI may become the nation's first cap and trade carbon program. This market-based approach to emission reductions is expected to drive investments to the least cost strategies, encourage technological innovation, and bring net economic benefits to the region. State modeling has estimated that, along with expected investments in efficiency, RGGI will result in a net savings on consumer energy bills of more than $100 per household.

Sense of the Senate Resolution—Passed on June 22, 2005

On June 22, 2005, the United States Senate passed a resolution (54–43), which for the first time called for mandatory limits on U.S. global warming pollution. The bipartisan resolution was offered by Senators Bingaman (D-NM), Byrd (D-WV), and Domenici (R-NM). The passage of the resolution marked the first time that a majority of the Senate has voted in support of mandatory caps to limit global warming pollution. The resolution read: Congress finds that

(1) Greenhouse gases accumulating in the atmosphere are causing average temperatures to rise outside of the range of natural variability and are posing a substantial risk of rising sea levels, altered patterns of atmospheric and oceanic circulation, and increased frequency and severity of floods and droughts;

(2) There is a growing scientific consensus that human activity is a substantial cause of greenhouse gas accumulation in the atmosphere; and

(3) mandatory steps will be required to slow or stop the growth of greenhouse gas emissions into the atmosphere.

(b) Sense of the Senate—It is the sense of the Senate that Congress should enact a comprehensive and effective national program of mandatory market-based limits and incentives on emissions of greenhouse gases that slow, stop and reverse the growth of such emissions at a rate and in a manner that

(1) will not harm the United States economy; and

(2) will encourage comparable action by other nations that are major trading partners and key contributors to global emissions.

Action at the National Level

Progress on global warming can be made at the local, state, and regional level. However, the United States will not fully or adequately address climate change-related issues until it develops a mandatory national program to slow, stop, and reverse the emissions of pollutants that cause global warming. Though Congress has not passed

U.S. Climate Action Partnership: A Joint Business and Environmental Program

The business community is taking a leadership role in calling for an ambitious, effective national program to reduce greenhouse gas emissions. On January 22, 2007, the U.S. Climate Action Partnership, a diverse group of businesses and environmental organizations called on the federal government to quickly enact strong national legislation to achieve significant reductions of greenhouse gas emissions. It further stated:

"We, the members of the U.S. Climate Action Partnership, pledge to work with the President, the Congress, and all other stakeholders to enact an environmentally effective, economically sustainable, and fair climate change program consistent with our principles at the earliest practicable date."

This unprecedented alliance, called the U.S. Climate Action Partnership (USCAP), consists of businesses including Alcoa, BP America, Caterpillar, Duke Energy, DuPont, FPL Group, General Electric, Lehman Brothers, PG&E, and PNM Resources, along with four non-profit organizations, including NRDC. The USCAP document, "A Call for Action," includes a goal of reducing greenhouse gas concentrations to a level "that minimizes large-scale adverse climate change impacts to human populations and the natural environment." According to the group, "Each year we delay action to control emissions increases the risk of unavoidable consequences that could necessitate even steeper reductions in the future, at potentially greater economic cost and social disruption." The group supports "mandatory approaches" to reduce heat trapping pollutants, as well as flexible strategies to achieve these reductions. According to these business and environmental leaders, confronting this challenge "will create more economic opportunities than risks for the U.S. economy."

Source: United States Climate Action Partnership, January 2007. "A Call for Action." www.us-cap.org.

comprehensive legislation to this end, there has been some significant action at the federal level. The U.S. Senate has adopted a bipartisan resolution calling for mandatory limits on greenhouse gas emissions.

Mandatory Federal Limits on Global Warming Pollution

Recent scientific consensus has solidified around the need for decisive federal action to limit global warming pollution in order to stave off dangerous impacts on the earth's climate. Industry had recognized this urgency and called on Congress to act. Most significantly, in January of 2007, some of America's largest corporations called for mandatory limits on the pollution that causes global warming under a newly formed alliance called the United States Climate Action Partnership (USCAP). The group, which consists of such industry-leading companies as General Electric, Caterpillar, Duke Energy, Alcoa, Lehman Brothers and DuPont, noted in its report that "each year we delay actions to control emissions increases the risk of unavoidable consequences." USCAP went on to call for "prompt enactment of national legislation in the United States to slow, stop, and reverse the growth of greenhouse gas emissions over the shortest period of time reasonably achievable."[57]

Like USCAP, NRDC supports aggressive emissions reductions measures such as those outlined in Congressman Henry Waxman's *Safe Climate Act* (HR 5642), and in Senators' James Jeffords and Barbara Boxer's *Global Warming Pollution Reduction Act* (S. 3698). Both pieces of legislation call for reducing emissions to 1990 levels by 2020, and for further reductions to levels approximately 80 percent below 1990 levels by 2050. Such cuts are needed to avoid atmospheric concentrations of carbon dioxide that would lead to dangerously increased global temperatures and catastrophic changes in the earth's natural systems.

For up-to-date information, on federal global warming legislation, please visit the NRDC Global Warming web page at: http://www.nrdc.org/globalWarming/default.asp.

PUBLIC OUTREACH

As respected community leaders, water managers can have a significant impact in shaping public opinion and awareness. The role of water managers in shaping public awareness is particularly significant in the American West; where water is scarce, water leaders bear a greater burden in educating the public and decision makers regarding water-related issues. Some water officials are already beginning to educate the public about the connections between climate change and water management. Water districts use a wide range of educational tools: materials for children, billboards and other paid advertising, outreach and meetings with—and letters to—elected officials. These educational efforts can have a significant effect on the public debate when it comes to climate change.

How Water Managers Are Leading the Way

Today, some western urban water managers are meeting the challenge of calling for action on global warming. As early as 1998, the Water Education Foundation, a California nonprofit organization with many board members from water agencies, major water users, and water-related engineering firms, devoted an issue of its magazine to climate change, discussing the growing scientific evidence regarding climate change and potentially significant water-related impacts such as a reduction of snowpack.[58] In October 2001, the American Water Works Association's journal discussed some of the potential climate-related impacts on water supplies that are reviewed in this report.[59] These discussions, in turn, have helped water managers to begin to analyze how their systems are vulnerable to the impacts of climate change.

As public awareness about the threat posed by global warming has grown, so too has the awareness of water managers. In 2005 the American Water Works Association Research Foundation issued a seminal report entitled *Climate Change and Water Resources: A Primer for Municipal Water Providers.* Though written primarily for water managers, the report discusses the importance of public education about the water-related potential impacts of climate change. And there are more signs that awareness among water managers is continuing to build:

• The Santa Clara Valley Water District's website includes strong statements about climate change "The reality of global warming and climate change is the most significant long-term threat to water resources management in Silicon Valley."[60]

• Three San Francisco Bay Area urban water agencies wrote to Governor Schwarzenegger in early 2006, urging him to take prompt action to address climate change. These three urban water agencies have also supported state legislation that would create mandatory caps on greenhouse gas emissions.

• In January 2007, the San Francisco Public Utilities Commission convened a Water Utility Climate Change Summit attended by more than 150 water managers and other stakeholders. The conference received significant media coverage.

The message is beginning to get through to decision makers, as indicated by public comments made by governors around the West about the need to act to reduce climate change impacts. Nearly all of those comments (see Western Leaders Speak Out about Climate) highlight the effect global warming will have on water resources.

Chapter 5

Conclusions and Recommendations

The research, analysis, and best practices reviewed in this report suggest several broad conclusions related to climate change and water management. These conclusions, as well as the conclusions in the American Water Works Association Research Foundation (AWWARF) report, lead to a number of specific recommendations for water managers that fall into the four action areas outlined in the previous chapter: vulnerability analysis, response, prevention, and public awareness.

CONCLUSIONS

The Science Is Clear

The scientific community has provided clear and urgent evidence that global warming is already happening and that it is caused by the increase in greenhouse gas concentrations in the atmosphere, particularly carbon dioxide. This increase is largely human-caused, primarily through the burning of fossil fuels in power plants and cars.

Climate Change Will Affect Water Management

There are a variety of ways in which climate change will negatively affect water resources in the American West. Considered together, these changes could have a significant impact on water supply, water quality, aquatic ecosystems, and flood management. We are already experiencing serious impacts of climate change, including sea level rise, decreased snowpack and earlier peaks in spring runoff.

Immediate and Sustained Action Can Reduce Future Impacts

Broad and strong actions will slow, stop, and reverse rising emissions of greenhouse gases, reducing future impacts on water resources. Immediate action is required to reduce long-lasting climate effects. Cost-effective opportunities for emission reductions can provide immediate multiple benefits.

Water Managers are Taking Action on Climate Issues

Water managers need to provide leadership to address the impacts of climate change on water resources and lead by example by reducing greenhouse gas emissions. Around the West, some water managers have undertaken

a broad range of actions on issues related to all aspects of climate change.

RECOMMENDATIONS

Water managers work with their communities to meet future water needs. The comprehensive recommendations presented in this section are designed to assist managers in helping Western communities face the new challenges posed by climate change.

Vulnerability Analysis

Local, regional, state and national water resource managers should assess the vulnerability of water supplies, flood management and aquatic ecosystems to impacts from climate change.

■ *Conduct Local Analyses*

Water managers should analyze the potential effect of climate change on water supply systems, water demand, and environmental and water quality requirements.

■ *Assess Regional Impacts*

Water managers should undertake cooperative regional vulnerability analyses to develop an understanding of the common challenges they face and lay the groundwork for cooperative responses. Such regional efforts could also produce better results and reduce expenses for individual participating agencies.

■ *Undertake State- and Federal-Level Evaluations*

Agencies should undertake state level analyses of likely climate change impacts on a full range of water management issues. Federal agencies including the Bureau of Reclamation, the the U.S. Army Corps of Engineers, Fish and Wildlife Service, the Federal Emergency Management Agency, the Environmental Protection Agency, the National Oceanic and the Atmospheric Administration, Federal Energy Regulatory Commission and the United States Geologic Survey should undertake evaluations of the likely impacts of climate change on water resources, and federal facilities and on the communities they serve.

Response

The following recommendations are designed to help water managers respond effectively to likely climate change impacts.

■ *Guiding Principles for Water Resource Management Response*

The following general principles are designed to assist forward-thinking water decision makers in crafting strategies to respond to this challenge.

• *Strengthen Institutional Capacity.* Responding to climate change will require agencies to invest in inter-agency collaborations, stakeholder involvement and technical analysis.

• *Maximize Flexibility.* Develop strategies that allow for mid-course corrections and redirection of investments toward the most effective tools, and strategies that reduce the risk of stranded investments in order to increase the ability of water managers to adapt to changing conditions.

• *Increase Resilience.* Water managers should consider a range of water management options that increase their ability to meet future needs under conditions of greater variability and uncertainty.

• *Implement "No Regrets" and "Multiple Benefits" Strategies.* Choose cost-effective strategies providing multiple benefits that make sense both today, and in a world altered by climate change.

• *Address Multiple Stresses.* Climate change is intensifying the stress put on water resources by other factors (e.g., population growth, land-use changes, contamination of surface and groundwater resources, and the need for ecosystem protection.) Water managers should seek to address these combined challenges through measures such as improving water use efficiency and protecting surface and groundwater sources.

• *Invest in Inter-Agency Relationships.* Water managers should partner with neighboring water agencies, as well as with agencies managing energy, environmental resources, wastewater, stormwater, and land use .

• *Incorporate Climate Change into Ongoing Project Design.* Water managers should incorporate climate change impacts into the design of existing and new facilities now, rather than waiting for the completion of comprehensive response plans to address climate issues.

• *Expand Dialogue with the Scientific Community.* Water managers and scientists should exchange information to increase the effectiveness of measures designed to meet the challenges posed by climate change and should develop a more accurate analysis of potential impacts on water resources.

■ *Restore and Protect Aquatic Ecosystems in Preparation for Climate Change*

In recent years, the West has seen numerous water resource conflicts pitting protection of threatened and endangered species against the demand for water supplies. To prevent future conflicts, to minimize impacts to water supplies and to protect our aquatic ecosystems, water managers should incorporate the following actions into their climate change strategies:

• Restore degraded rivers and floodplain habitats to buffer the impacts of climate change and provide critical habitat for sensitive species.

• Improve water quality by reducing runoff of pollutants through watershed management, increasing urban retention and infiltration of precipitation.

• Manage water supply systems to meet the temperature needs of sensitive species.

■ *Implement Water Management Tools That Are Effective in the Context of Climate Change*

Prior to making long-term investment decisions, water managers should carefully consider climate change effects on the tools available to meet future water needs. Climate change is likely to improve, or leave unchanged, the performance of tools such as water use efficiency and water recycling. Other tools that rely on historical hydrology (e.g., traditional river diversions, traditional groundwater pumping and traditional surface storage), are likely to perform less effectively in the future.

■ *Put Conservation First*

Water efficiency represent a sound and basic "no regrets" water management approach to future climate change impacts. Cost-effective water conservation investments can generate significant benefits on multiple fronts, including water supply, environmental, energy use, and greenhouse gas emissions reductions. Water managers should support conservation strategies that:

• *Transform markets through plumbing code changes and appliance standards.* These changes are the most successful and cost-effective way to save water. In California, a recent study found that between 50 percent and 85 percent of the conservation likely to occur under a variety of scenarios by 2030 will be attributable to changes in the plumbing code.[1]

• *Offer rebates for and make investments in interior water use efficiency.* Ultra-low flush or dual-flush toilets, low-flow showerheads and faucets, efficient appliances, and waterless urinals are proven cost-effective tools.

• *Promote landscape conservation.* Promote landscape water conservation including selection of drought-tolerant plants, landscape design that groups plants with similar water needs, efficient irrigation technology (including "smart-controllers" that automatically adjust to changes in weather), training for irrigation managers and maintenance personnel and seasonal rate structures

• *Use water metering and volumetric pricing to provide accurate price signals.* Water metering remains the single most effective water conservation tool. Measures such as submetering for multiple-unit residential and commercial buildings, and dedicated landscape meters, are particularly effective.

• *Price water to reflect its true cost and reduce existing water subsidies.* Water agencies should maximize the percentage of revenue recovered through volumetric charges rather than fixed charges, and should adopt tiered and seasonal water rate structures that encourage efficiency.

• *Support efficient product labeling.* The EPA has initiated the WaterSense program, comparable to the Energy Star™ program, to label products that meet its standards for water efficiency. Such a labeling program will help guide customers to the water-efficient choices already on the market and will encourage manufacturers to develop new, efficient products.

• *Use system leak detection to reduce unaccounted-for water.* In some systems these leaks can account for 30 percent or more of water use.

• *Implement commercial, industrial, and institutional conservation programs.* These can include programs targeted at individual measures, such as cooling towers, pre-rinse spray valves in restaurants, X-ray machines, and more customized initiatives designed to address industrial processes, and institutions, including universities and hospitals.

• *Create statewide and national programs for water conservation*. The California Urban Water Conservation Council is a good model for how to develop, implement, and monitor best management practices for water conservation. The new Alliance for Water Efficiency, which plans to bring together agencies, business interests

and environmental groups, should be an effective voice for advancing national water conservation standards and raising the profile of water conservation. [2]

• *Broaden public awareness.* Except in a handful of water-short regions, the public is generally unaware of the myriad benefits of water conservation. Regional campaigns to boost public awareness could generate substantial water savings.

■ *Incorporate Climate and Energy Issues in Water Planning*

By implementing tools ranging from efficiency improvements to reuse and recharge, there is an enormous opportunity to simultaneously save water and energy and to reduce greenhouse gas emissions. Water agencies should evaluate their energy consumption, particularly energy consumption driven by water use. Such an analysis should consider each phase of water use—storage and diversion, conveyance, treatment, local distribution, end use, wastewater treatment, and disposal.

■ *Collaborate with Energy Utilities.*

Water conservation generates substantial water and energy savings, and thus reductions in greenhouse gas emissions. Water agencies should work with local energy utilities to develop joint programs, such as rebates, to encourage water and energy conservation. Energy utilities should be appropriately credited for the embedded energy savings that accompany water conservation. Furthermore, water conservation activities that also save energy should qualify for public funding available for energy conservation.

■ *Integrate Regional Water Management*

Water managers should approach climate change response by utilizing an integrated regional water management approach, including a broad range of issues, multi-disciplinary analysis, stakeholders and agencies with multiple interests, and solutions tailored to local conditions. An integrated approach can produce broad benefits, including water supply, water quality, fish and wildlife, habitat improvements, recreational opportunities, flood damage reduction, energy supplies, greenhouse gas emissions, and regulatory compliance. Such integrated efforts should consider:

• potential climate change impacts on existing facilities and future water management tools

• unique regional conditions

• potential multiple benefits and potential funding and implementation partners (e.g. water supply, water quality, ecosystem management, recreation, land use and flood management)

• "efficiency first" investments

• a full range of potential demand and supply strategies

• a full range of potential flood management options

• clear objectives and performance standards for evaluating options

An Integrated New Vision for the San Francisco Bay-Delta Ecosystem

California recently created a new "Delta Vision" process to develop a plan to address the multiple crises currently facing the Bay-Delta estuary, including climate change-caused sea level rise and increased flood risks. This plan will be developed by state agencies, with input from a new blue ribbon panel and a stakeholder group, including urban and agricultural water interests. A new plan for the Bay-Delta should include prompt action in several areas:

• strengthening efforts to reduce future global warming, thus minimizing future risks to the Delta,

• implementing short-term actions to protect and restore endangered species, including, when necessary, reductions in Delta pumping

• reducing reliance on the Delta for water supplies (by investing in more reliable alternatives), thus reducing the economic risks associated with reliance on a vulnerable Delta

• stopping ongoing urbanization that is putting more Californians at risk of a Katrina-style disaster as they move into homes on vulnerable Delta islands

• maintaining the most important Delta levees and

• restoring other Delta islands to natural habitat, thus lessening the risk of a catastrophic failure, lowering levee maintenance costs, and helping to restore a healthy ecosystem.

Although a successful solution will cost billions of dollars, the price tag could be far higher if California fails to respond effectively to this challenge.

• "with and without project" baseline analysis for large infrastructure investments

• economic analysis and "beneficiary pays" financing

• enforceable environmental requirements

• strengthening institutional capacity

• educating the public and decision-makers about the need to reduce and prevent climate change

■ ***Evaluate Surface Storage***

Evaluations of any potential surface storage facilities should take place as part of a fully integrated approach, including the following specific actions

• base analyses on likely future hydrology

• give demand side approaches an emphasis at least equal to alternatives that would increase supply

• include a comprehensive economic analysis

• establish beneficiary pays pricing policies, rather than relying on subsidies

• fully incorporate potential environmental impacts

• avoid assigning costs to unrealistic potential benefits

■ ***Carefully Consider Commitments Regarding Future Water Deliveries***

Water agencies, including the Bureau of Reclamation, should consider climate change carefully when making commitments regarding future water deliveries. In particular, agencies should avoid promising increased water deliveries based on current hydrology.

■ ***Factor Climate Change into Flood Management Decisions***

For agencies with flood management responsibilities, an awareness of climate change should be integrated into future management decisions. For example:

• avoid development in floodplains that is not constructed to be compatible with occasional flooding

• dam operators should develop plans to reoperate surface storage facilities and other infrastructure in response to changing hydrology, caused by global warming

• managers should investigate floodplain management opportunities, such as floodplain, riparian and wetland restoration and the establishment of flood-compatible agricultural practices. These actions can generate public safety, flood damage-reduction, environmental and agricultural preservation benefits

• planners should incorporate climate change in analyses of future flood risk, including planning for the "reasonably foreseeable flood", which is larger than the 100-year flood

• support expansions in flood insurance

• improve mapping, monitoring, forecasting, and early warning systems

Prevention

Water managers can contribute to efforts designed to reduce greenhouse gas emissions to reduce future climate change impacts.

■ ***Support Mandatory Caps on Emissions***

Support the creation and enforcement of a mandatory national cap on the pollution that causes global warming (mainly carbon dioxide), as the single most important step in controlling and reducing the future impacts of global warming. The problem can be addressed most effectively addressed through federal caps, but local, state, and regional initiatives are also effective and important tools in the face of federal inaction.

■ ***Support Alternative Energy and Energy Efficiency Programs***

Energy efficiency and renewable energy programs are necessary elements for any plan to achieve a dramatic reduction in carbon emissions. The following programs can be implemented at the state and/or national levels:

• appliance efficiency standards

• renewable energy generation requirements

• incentives for renewable energy production and generation

• green building standards, such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) standards

• requiring utility energy plans to include the cost of carbon emissions

■ ***Take Action at the District Level***
Water agencies should develop programs to reduce their energy consumption and greenhouse gas emissions. Districts should consider joining the Cities for Climate Protection campaign.[3]

■ ***Develop Community Partnerships***
Partnerships with the business community and local governments can enable water districts to broaden participation in ambitious greenhouse gas emissions reductions programs.

Public Outreach

Given the global nature of climate change and the need for far-reaching actions to address its causes, raising public awareness is essential to encourage effective action.

■ ***Educate Ratepayers***
Ultimately, water district ratepayers could feel significant impacts and be forced to bear significant costs as a result of climate change. Water managers have a range of tools, such as newsletters, billboards, bill inserts, websites, and more, to educate ratepayers. An increased understanding of the challenges posed by climate change will promote ratepayer acceptance of programs designed to address this issue.

■ ***Educate Decision Makers***
The involvement of water managers is important to convince agency and legislative decision makers that climate change is more than simply an environmental issue. Water managers are in a unique position in the West to educate decision makers about the water supply and economic consequences of climate change and the need to prevent worst-case climate scenarios.

■ ***Educate the Media***
Water managers should strive to improve the media's understanding of these significant potential impacts and help raise awareness to reduce climate change impacts and risk.

■ ***Incorporate Climate Issues into Conferences and Publications***
Water community conferences on water issues regularly include a presentation or two regarding climate issues. Given the significance of the potential effects, climate-related water management issues should play a more central role in water agency conferences, newsletters, reports, and other publications. These efforts should be crafted to help water managers and users to take action.

ADDITIONAL RESEARCH NEEDS

The more we know about global warming and the effect it will have on our water resources, the better prepared water managers can be to prevent the most serious consequences of rising temperatures. Water agencies, academic institutions, and state and federal agencies should consider funding research designed to address the following areas:

- the potential groundwater impacts of climate change
- the impact of climate change on water demands.
- the impact of climate change on potential new surface storage facilities in highly engineered systems
- likely future changes in precipitation patterns (including totals and variability)
- potential future reductions in total streamflows
- improved maps and data showing flood risks and other flood-related information
- improved modeling of changes in the frequency and magnitude of peak flows
- potential impacts on water quality
- potential impacts on aquatic ecosystems
- downscale climate modeling for local and regional applications

Appendix A

Case Studies: Water Agency Action on Climate Change

Throughout the West, agencies of all sizes have conducted vulnerability analyses to evaluate the reliability of their water systems in the face of climate change. A number of agencies, such as the Santa Clara Valley Water District and Seattle Public Utilities have been studying potential climate change effects for years, while others have only recently begun to investigate these potential impacts. Each agency and utility's experience in analyzing potential climate change impacts has produced unique findings and has consistently given critical insight for water managers to prepare for the potential effects of climate change on their particular water systems.

Denver Water

Denver Water, a separate entity from the City of Denver, serves a total of 1,104,400 customers in the Denver Metro area, approximately one-fourth of Colorado's population. The agency uses one-third of the state's treated water supply. Its primary water sources are the Blue and South Platte rivers.

"We want to find out as much as we can about [climate change]," says Denver Water general manager Chips Barry.[1] To achieve that objective, Denver Water hired Stratus Consulting, an environmental and engineering research firm, to conduct an analysis of Denver's system in order to test the district's sensitivity to changes in temperature and precipitation as a result of climate change.[2] The findings of this analysis will be outlined in a general briefing paper presented to Denver Water on its completion. In the district's next Integrated Resources Plan (expected to be completed in 2007), Denver Water plans to include a scenario designed to produce a rough estimate of possible impacts on its supply and demand.[3] "Most of us operate on the premise that the future will be pretty much as it has been in the past," Barry points out. "Global warming has created greater doubt as to that proposition."[4] By reducing the uncertainty regarding the particular impacts of climate change on its system, Denver Water can effectively plan to mitigate its effects and increase supply reliability.

Denver Water is ramping up its water conservation efforts with a $400 million conservation plan designed to cut annual water use, over the next 10 years, to a level 22 percent below levels that prevailed prior to the 2002–2005 regional drought.[5] Although this conservation

CITY LEVEL
Denver Water at a Glance

- hired an environmental engineering and research firm to analyze the effects of global warming on its system, including changes in temperature and precipitation.
- plans to include in its next Integrated Resources Plan a sample scenario of the potential effect of climate change on its supply and demand.
- accelerated investments in conservation, in part as a response to potential global warming impacts.

plan was initially established without regard to potential climate change effects on the Denver Water system, the agency accelerated its implementation, in part because it provides Denver Water with the ability to use saved water to mitigate impacts from climate change. Denver Water's board and executive staff approved the plan with an initial allowance of $8 million for the first year. Moving forward, the plan's funding will be appropriated by the board and executive staff on an annual basis.[6]

Portland Water Bureau

The Portland Water Bureau supplies drinking water to more than 787,000 customers in the Portland region. The primary source of the bureau's water supply system is the Bull Run watershed, located in Mount Hood National Forest, 26 miles east of downtown Portland. Groundwater significantly supplements the agency's supply.

The Portland Water Bureau (PWB) incorporated climate change into its water supply planning analysis by commissioning a seminal study in 2002 by the University of Washington Climate Impacts Group.[7] The study used a series of four linked Global Circulation Models—the Department of Energy's Parallel Climate Model, the Max Planck Institute's ECHAM4 model, and the Hadley Centre's HasCM2 and HasCM3 models—to estimate climate change impacts upon its system. The studies focused particularly on the Bull Run watershed, the district's primary water source.

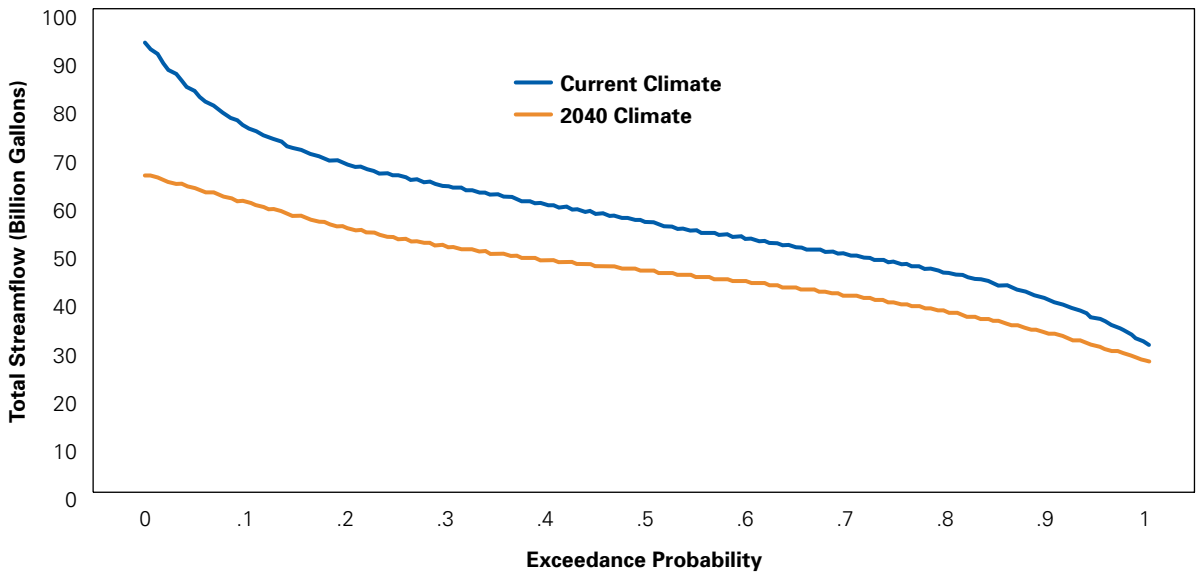
All four models were used to develop water demand forecasts and a hydrologic model for the Bull Run watershed. The output of these models were then applied to its Supply Transmission Model, which takes inputs of demand, weather, and water supplies to create different reliability scenarios. These model runs suggest that the Bull Run watershed will experience warmer and drier summers due to climate change, with an increase in general year-round temperature. The hydrologic models predict that precipitation will increase in the winter and decrease in the spring, with less snow melt remaining in the spring, making the Bull Run Watershed an increasingly rain-driven system with more years of lower summer streamflows into the storage reservoirs. This is particularly an issue in the Portland surface water storage system because the system's reservoirs are kept full during the winter, so an increase in earlier drawdown years with lower summer streamflows will affect overall system yield.[8]

Using the 60-year hydrological record, the study then evaluated the impacts of climate-altered streamflows and increased water demands on water supply performance with consideration given to three factors: (1) changes in water availability, (2) changes in water demand created by anticipated regional growth, and (3) changes in water demand as a result of hotter summer temperatures. The study estimated that the average impact of climate change alone on the current storage system could require approximately 1.3 billion gallons more water per year to meet demand. A change in runoff timing is PWB's supply threat, as it could reduce storage levels in comparison with historical record. This shift in runoff increases the number of years with longer drawdown periods due to lower flows and higher demand, requiring increased use of alterna-

CITY LEVEL
Portland Water Bureau at a Glance

- commissioned a study to analyze the potential effects of climate change on its system, with a particular focus on the district's primary water source.
- found that climate change will alter basic hydrology of the Bull Run watershed.
- projected that demand on the system will increase during the summer as a result of global warming, requiring an additional 1.3 billions gallons to meet demand.
- concluded that overburdening of the system will ultimately result in a reduction of Portland's surface water system safe yield during the summer, requiring additional conjunctive use of Portland's existing groundwater system.

Figure A-1: Portland Water Bureau's Projected Streamflow Shift Due to Climate Change



From the Powerpoint Presentation, "The Impacts of Climate Change on Portland's Water Supply." Portland Water Bureau and University of Washington Climate Impacts Group. 8/29/06

tive sources of supply, in addition to already anticipated reductions due to conservation measures. The study concludes that climate change will alter the basic hydrology of the Bull Run watershed as well as the system's demand, ultimately resulting in a reduction in the reliable yield of Portland's surface water system.

PWB is exploring the many alternatives to enhance its water supply reliability in the face of climate change, with an emphasis on flexibility in infrastructure development. Some of the strategies PWB is considering are conservation and conjunctive use that could be coordinated with reoperated existing surface and groundwater supplies. Other water suppliers in the Portland metropolitan area have conducted similar studies, in recognition of the need to collaboratively assess the impacts of climate change on regions with multiple water supplies.[9]

Santa Clara Valley Water District

The Santa Clara Water District (SCVWD) is the primary water agency for the residents of Santa Clara County, California. SCVWD provides water for the 1.7 million residents of the county, as well as serving as its flood protection agency and as the steward of the county's streams, creeks, underground aquifers, and reservoirs.

The Santa Clara Valley Water District (SCVWD) began incorporating the uncertainties posed by climate change in its water supply planning processes about a decade ago. The district is continuously updating its analyses

CITY LEVEL

Santa Clara Valley Water District at a Glance

- conducted a risk analysis in 2003 and determined that global warming could have serious implications for the district's water supply after 2020.
- concluded that the district's projects to meet water demand beyond 2020 must consider the effects of climate change on water quality, saltwater intrusion, imported and local water supplies, and the water transfer market.
- plans to complete a Water Supply Sustainability Plan in 2008, which will update its Integrated Water Resources Plan to include more detailed regional climate modeling and an analysis of local and regional impacts of future climate scenarios.
- is analyzing its climate footprint and has started tracking and reporting CO_2 emissions.

as more information about climate change emerges. In SCVWD's 2003 Integrated Water Resources Planning Study (IWRP), the district assessed global warming's threat to supply reliability. It applied vulnerability assessment models on five portfolios composed of various water supply options. These five hybrid portfolios were built to meet three planning objectives: high water quality, natural environment protection, and minimum cost impacts.

- SCVWD's "Extend" simulation model analyzed potential portfolio performance through 2040 based on historical hydrology
- The Economic Analysis Tool compared water supply options on equal economic footing
- The Risk Analysis Tool used statistical techniques and estimation of seven risk likelihoods to test the portfolios under a variety of possible future scenarios, including climate change

SCVWD considered its results over three time frames: Phase I (2003 through 2010), Phase II (2011–2020), and Phase III (2021–2040).[10]

In its risk analysis, SCVWD determined that global warming could have serious implications for the district's water supply after 2020. The analysis concluded that the district's projects designed to meet water demand beyond 2020 must consider the effects of climate change on water quality, saltwater intrusion, imported and local water supplies, and the water transfer market. SCVWD has concluded that its water supply is particularly vulnerable to certain climate change effects such as sea level rise, loss of snowpack, and a shift in runoff timing. Pursuant to its 2005 Urban Water Management Plan, SCVWD is assessing various options to address the impacts of climate change, including additional water recycling, additional water banking, and dry-year transfer options. Another option the agency is considering is employing additional treatment options to address water quality impacts such as increased salinity in the Delta, from which the district receives approximately 50 percent of its water supply.[11]

A key aim of the district is to increase the flexibility of its water supply portfolio in the face of potential water supply threats by securing baseline water supply programs, investing in "no regrets" actions, and focusing on the long term.[12] The district is moving forward by developing a robust framework for sustainability and investment decision making. It also plans to complete a Water Supply Sustainability Plan in 2008, which will update its IWRP analyses to include more detailed regional climate modeling and an analysis of both local and regional impacts of future climate scenarios. As a comprehensive water management agency, SCVWD is gearing up to both mitigate and adapt to global climate change. SCVWD is also analyzing its own climate change footprint and reporting its CO_2 emissions as a member of the Sustainable Silicon Valley Initiative (SSV).[13] See page 46 for more on the district's involvement with SSV.

Additionally, SCVWD is communicating its concern about the impacts of climate change to the community it serves and to state decision-makers. SCVWD wrote a letter in March 2006 supporting the governor's acknowledgement of global warming's effects on California industry in his 10-Year Strategic Growth Plan. The following month, the district wrote a letter of support for California Assembly Bill 32 (AB 32), which places a cap on greenhouse gas emissions from the electrical power, industrial, and commercial sectors, and establishes a program to track and report greenhouse gas emissions.

Seattle Public Utilities

Seattle Public Utilities provides water to a customer base of more than 1.3 million people in the metropolitan area of Seattle, Washington. The utility receives almost all of its water supply from two watersheds in the Cascade Mountains: the Cedar and Tolt River watersheds.

Seattle Public Utilities (SPU) has been actively involved in climate change as related to water supply issues for more than 15 years. Based on currently available information regarding the potential effects of climate change, the utility's analyses concluded that it is unlikely to need new water supply sources to meet water demand in the next 40 to 50 years, despite its region's

CITY LEVEL
Seattle Public Utilities (SPU) at a Glance:

- uses a dual approach to climate change vulnerability analysis process that incorporates both a bottom-up perspective (historical hydrology) and a top-down strategy (using modeling to assess local watershed levels).
- forming partnerships with other regional groups—including state agencies, county and city governments, water districts, and an Indian tribe—to better prepare the region for the effects of climate change.

growing population. However, SPU acknowledges the many uncertainties surrounding climate change's potential impacts on its water system. SPU's 2007 Water System Plan describes how the utility will continue to monitor its system vulnerabilities, engage in research, and employ scenario planning in order to make system investments and operational changes that will prepare the utility for possible impacts.[14]

SPU uses a two-pronged approach to investigate its system's vulnerabilities to climate change. To assess climate change from a bottom-up perspective, SPU began by examining its historical hydrology, using streamflow records to reconstruct inflows into its surface water supplies. The utility now has an inflow dataset for the past 76 years, from water year 1929 through 2004. SPU also uses a system stimulation model to estimate the firm yield of its supply in order to meet the utility's 98 percent reliability standard, while accounting for climate variability. This bottom-up approach has underscored that a key vulnerability of SPU's water supply system is the timing of the return of fall rains. SPU's reservoirs are operated on a single-year drawdown cycle, and delays in the fall rainy season can force SPU to draw down deeper into reservoir storage. When this occurs, SPU relies on emergency storage reserves to meet the needs of its customers and downstream habitat. Research on future climate change has not directly addressed the timing of fall rains, but SPU is taking steps to ensure that its emergency supplies can be relied on during times of extreme drought.[15]

Potential climate change-driven loss of snowpack represents another system vulnerability. To mitigate this threat, SPU routinely monitors snowpack conditions and uses a dynamic rule curve that adjusts reservoir refill targets according to actual snowpack and soil-moisture conditions. This approach utilizes real-time conditions to regulate reservoir management and increases the likelihood of a full reservoir refill prior to the summer drawdown period. The dynamic rule curve also assists in managing the utility's risk from increases in precipitation variability, another potential climate change impact. SPU does not have a sizeable reservoir capacity compared to many other water systems, and it therefore relies on the dynamic rule curve and other operational management strategies to make the most of current water supplies.

As mentioned earlier in this report, SPU worked with the University of Washington's Climate Impacts Group (CIG) to analyze its water system's susceptibility to climate change from a top-down perspective. CIG's analysis involved examining the SPU watershed's susceptibility by employing a statistical downscaling method to translate the average monthly meteorological data from the General Circulation Models (GCMs) at nearby grid points down to local weather station locations. This method used cumulative distribution curves and historic weather patterns to generate a time series of meteorological data representing future climate from the GCMs. These data were input into a hydrology model and then fed into Seattle Public Utilities' system simulation model using some simplifying assumptions, including the use of static reservoir operating rules. These loosely linked models complete the process of translating information from the GCMs to the local watershed level.[16]

This downscaling method reveals a series of potential climate change impacts that affect water supply. Although there is significant cumulative modeling uncertainty associated with this method, the modeling results are useful for water supply planning purposes and for reexamining existing and planned water management systems under a wider range of climatic conditions. This model examined several elements that affect water supply, including temperature, snowpack, yield and precipitation. The results show:

- an increase in temperature of 2.3 degrees Fahrenheit in the Seattle region by 2040
- a decrease in snowpack of 50 percent by 2040
- a 6 percent decrease in combined inflows from the Cedar and Tolt reservoirs from June to September per decade through 2040
- a reduction in yield of 24 million gallons per day by 2040

The model results also indicate that the predicted deviation in precipitation does not range significantly outside the range of natural variability.

SPU is widening the scope of its climate change analyses by co-sponsoring regional studies with King County (in which Seattle is located), the Cascade Water Alliance, and the Washington Department of Ecology as part of a larger regional water supply planning process, which also incorporates climate change. A wide cross-section of organizations are participating in the planning process—including state agencies, county and city governments, water districts, and the Muckleshoot Indian Tribe—with the University of Washington's Climate Impacts Group as the technical lead on climate change. The process is designed to develop information regarding

current and emerging water resource management issues in and around King County, including climate change. This partnership is a multi-year effort to analyze water resource conditions and management in order to better meet the region's water demand. The process will examine all available water sources, including reclaimed water and conservation. Climate change is one of five resource management issues under study, with a technical committee in place on each issue to produce reports and recommendations that could be included in water planning processes in the region.[17]

Building on past research and other endeavors, SPU plans to expand its knowledge of the evolving science behind climate change by continuing to partner with leading scientists. This research will help to further refine SPU's understanding of the local impacts of climate change and provide an increased understanding of how its system can adapt over time. SPU is particularly interested in learning more about the impacts of climate change on frequency of flood events, water demand, and fall rains, because the timing and intensity of these events are key vulnerabilities for the Seattle water supply system. Additionally, SPU seeks to develop hydroclimatic reconstructions, a practice that involves using tree-ring samples to reconstruct past hydroclimatic conditions in order to assess its system's vulnerability to climate change. The utility also aims to utilize more scenario planning, employ physical downscaling methods, and quantify the effectiveness of its changes in operations.[18] SPU anticipates revisiting its climate change analysis at least every six years in conjunction with its Water Supply Plan update, or sooner, if new significant information becomes available.

East Bay Municipal Utility District

The East Bay Municipal Utility District supplies water and provides wastewater treatment for customers in parts of Alameda and Contra Costa counties in the Eastern portion of the San Francisco Bay Area, including Oakland and Berkeley. Its water system serves approximately 1.3 million people in a 325-square mile region.

East Bay Municipal Utility District (EBMUD) is another agency that has emerged as a leader in assessing the impacts of climate change on water resources. In 2003, EBMUD conducted a dual-faceted vulnerability analysis to quantify impacts on its system: a planning model operated on a monthly timestep, and an operations model based on a daily hydrograph. Its monthly planning model used a database of historical river flows and tested its sensitivity to climate change by shifting 28 percent of historical April to July runoff volume into the November to March period, to estimate the reliability of system operations with less late-season snowmelt. The 28 percent figure was based on a study conducted by Maurice Roos, Chief Hydrologist of the California Department of Water Resources, which assessed how a shift in climate would impact the Mokelumne watershed, EBMUD's primary water source. Roos estimated that a 5 degree Fahrenheit temperature increase in the Mokelumne watershed might result in a 28 percent shift in runoff. EBMUD's analysis did not reveal significant impacts from this shift, as the historical record shows that in most years there has been more snowmelt in the watershed than can be stored. However, the extent of future precipitation changes in this watershed due to climate change is unknown. In dry years, annual runoff volume is less than the total reservoir capacity, and the timing of snowmelt would have little effect on system reliability. An overall reduction in precipitation, however, would have direct effects on this runoff and the amount of water available for storage. Model simulation of the historical record adjusted for an earlier snowmelt confirmed that the district's water supply and carryover storage would not be reduced significantly in most years. The only exception is water year 1997, which was exceptionally wet and warm in early winter but dry beginning in February. If the spring runoff from snowmelt in that year reduced by 28 percent, EBMUD found that the carryover storage would have been reduced, which would affect system reliability if a drought period were to follow. Such a sequence of events is of concern to

CITY LEVEL

East Bay Municipal Utility District (EBMUD) at a Glance

- conducted a dual-faceted vulnerability analysis to quantify climate change impacts on its system: a planning model operated on a monthly time step and an operations model based on a daily hydrograph.
- concluded that changes in precipitation patterns and flooding due to climate change could compromise system reliability.
- became the first water district to join the California Climate Action Registry by pledging to annually track, report, and certify its greenhouse gas emissions.

EBMUD. The operations model analyzed the impacts of a 5 degree Fahrenheit temperature increase on water year 1997's daily hydrograph based on historical sequence of snowfall and rainfall inputs. The results of this analysis were intuitive: with a climate change-induced runoff shift, flood control consistently was revealed as an issue that the district must be prepared to address.[19,20]

EBMUD has made it a priority to invest in the production, use, and refinement of new supply-forecasting tools. By developing and using these tools, the district further reduces the uncertainties of climate change impacts on its water supply. By better understanding its water system's particular vulnerabilities, EBMUD can effectively managing the stresses on its supply. In order to diversify its water supply sources, the district is also constructing the Freeport Regional Water Project, in partnership with the Sacramento County Water Agency. This project, which will allow EBMUD to divert water from the Sacramento River, was carefully negotiated with Sacramento County, environmentalists and other interests.

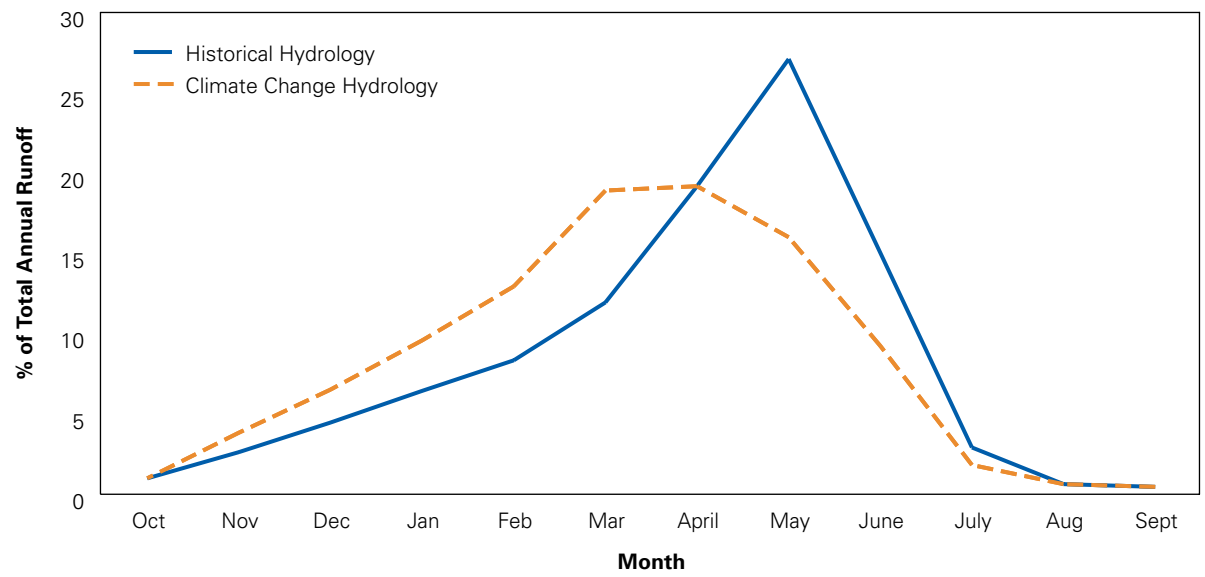
EBMUD is also working to prevent global warming by minimizing its climate change footprint. As discussed, it was the first water district to join the California Climate Action Registry—a non-profit public/private partnership established by California statute, which provides a voluntary greenhouse gas (GHG) registry to promote early actions to reduce GHG emissions. As a member of the Registry, EBMUD pledges to annually track, report, and certify its greenhouse gas emissions. EBMUD's efforts to mitigate its own impact on global warming were recognized by the Environmental Protection Agency, who presented the district with a Green Power Leadership Award. [21]

Furthermore, EBMUD has taken its concerns about global warming beyond district boundaries to California Governor Arnold Schwarzenegger and the state legislature. In a December 2005 letter, General Manager Dennis Diemer urged the Governor and the Climate Action Team to proactively assess how global warming may affect water supply and the economy in California's 10-Year Strategic Growth Plan. Then in March 2006, the District actively supported California's Assembly Bill 32.

Cosumnes, American, Bear and Yuba (CABY) Watersheds

The Cosumnes, American, Bear and Yuba rivers are four adjacent watersheds located in California's central-Sierra region. The CABY alliance involves a diverse membership

Figure A-2: EBMUD's Projected Streamflow Shift Due to Climate Change



EBMUD's comparison of long-term average unimpaired runoff under historical conditions and with its climate change model's 28% shift from April-July runoff volume to the November-March time period.

body including representatives from agriculture, recreation, Native American tribes, the business community and local, state, and federal governments.

Various stakeholders of four watersheds: Cosumnes, American, Bear, and Yuba (CABY) have cited climate change as a guiding principle in their first-ever collective Integrated Regional Water Management Plan (IRWMP). The purpose of the IRWMP is to provide an integrative approach to water management that is oriented toward the collective goals of the region's water users.[22] The plan was adopted by ten participating organizations as of December 2006, including the El Dorado Irrigation District, Gold County Fly Fishers, the U.S. Tahoe National Forest, the Yuba Watershed Council, the Bear River Watershed Group, American Rivers, Natural Heritage Institute, and the Nevada Irrigation District. Implementation by a regional entity is expected to begin in 2007, which will oversee the execution, monitoring, and success of projects in the IRWMP.

As it lays the framework for its IRWMP, CABY is assessing how it can prepare for climate change by maximizing its tools, policies, and current system infrastructure. CABY is using the Water Evaluation And Planning (WEAP) system to help measure potential climate change impacts on hydrology . The WEAP system, developed by the Stockholm Environmental Institute's Boston Center and the Tellus Institute, is a microcomputer tool developed for integrated water resources planning. It analyzes a system's water supply generated through watershed hydrological processes using a water management model driven by water demand and environmental requirements, governed by the natural watershed and the region's network of reservoirs, canals, and diversions. WEAP generates scenarios that examine a full range of water planning issues, including climate change. [23]

Liz Mansfield, CABY Project Director and El Dorado Irrigation District Watershed Coordinator, explains that WEAP can assist the region in developing a plan to manage climate change effects on its regional system. The CABY planning team has highlighted specific vulnerabilities to investigate, such as reservoir operations. A shift in runoff timing could have significant effects on the region's water supply, due to the delicate balance involved in reservoir management. The CABY region is at a high altitude with limited-capacity reservoirs that often remain full year-round for recreational and hydropower purposes. Analyzing how climate change will shift runoff in this region is critical to planning efforts for effective reservoir management.[24]

CABY also recognizes its elevated susceptibility to fire in the face of climate change. The region is densely vegetated, with a high volume of forested areas. CABY's planning community is seeking to understand the extent to which the expected increase in fires brought on by climate change will affect regional water supply and water quality. By gaining a clearer sense of climate change's effects on their system, the CABY planners can develop proactive strategies to meet effectively the needs of the region's water users.

What we are seeing in the CABY regional planning effort is part of a new trend—water managers using climate change vulnerability analyses to shape integrated planning efforts. In the past, climate change analyses have generally been produced as stand-alone documents, CABY uses the findings from its vulnerability analyses as a pillar in its planning framework.

AGENCY LEVEL

CABY at a Glance

- the managers of four watersheds—Cosumnes, American, Bear, and Yuba (CABY)—joined forces to examine how global warming will impact its watershed on a regional level.
- used a microcomputer tool that analyzed climate change vulnerability.
- used the findings of the vulnerability analysis as a foundation of CABY's integrated planning efforts.
- determined that reservoir operations and vulnerability to forest fires were two particular threats to the region, and are planning response strategies to mitigate these risks.

California Department of Water Resources

The California Department of Water Resources manages the State Water Project, including the California Aqueduct. The department's numerous roles include providing flood control services, aiding local water districts in water management and conservation activities, and planning for future statewide water demands.

In July 2006, The California Department of Water Resources (DWR) released the first statewide analysis of

likely climate change effects on water supply. The agency commissioned the study in response to Governor Arnold Schwarzenegger's June 2005 Executive Order, which established greenhouse gas emissions targets for California and required biennial reports regarding potential climate change effects in numerous areas.

Progress on Incorporating Climate Change into Management of California's Water Resources, is the product of the Climate Change Work Team, a group formed by DWR in conjunction with the U.S. Bureau of Reclamation to incorporate climate change science into California's water resources planning and management. DWR is communicating to local water agencies the results of the report and the various analysis tools used therein, which could be used by others to address climate change-related issues. The goal of these efforts is to assist water managers in future climate change analysis and to help them identify information gaps for future research.

DWR's report concludes that climate change has the potential to reduce the yield of the state's two major water projects by as much as 10 percent—a highly noteworthy figure considering that over 20 million California residents receive a portion of their water supply from those two projects (the State Water Project, or SWP, and the federal Central Valley Project, or CVP). The report notes that climate change creates a more active hydrological cycle, thereby altering the timing, intensity, location, amount and variability of precipitation. The study anticipates that these variations in precipitation events may lead to increases in extreme weather events, such as storms, flood events, and droughts. DWR expects more floodwaters to manage in winter, followed by less snowmelt to store in reservoirs for use during the warmer, summer months. By the year 2050, an average loss of 5 million acre-feet or more of annual water storage in the state's snowpack is expected—more than the capacity of the state's largest reservoir, Lake Shasta. In addition, the combination of more frequent extreme events coupled with lower winter reservoir storage levels, which may be required in response to higher peak streamflows, presents a key challenge for operators of the state's reservoirs.

In addition, the study points out that sea level rise due to climate change could have multiple implications for California, including erosion of coastal land area and possible sea water intrusion in coastal aquifers. Sea water flooding may pose a serious threat to land, at the mouths of rivers and streams, and in estuaries.

The San Francisco Bay-Delta, an important source of water for Southern California, the San Joaquin Valley and the Bay Area, is particularly susceptible to several effects of climate change. From a water resources perspective, the most significant effects of climate change on the Delta are increased salinity intrusion, as well as increased vulnerability of Delta levees to sea level rise. An increase in sea water intrusion in the Delta could lead to a degradation of water quality for the State Water Project and the Central Valley Project. Climate change also has significant, if uncertain, implications for the Delta's fragile ecosystem, which is home to various threatened and endangered species. (See The Other New Orleans: California's Delta Water Supply and Sea Level Rise.)

DWR researchers expect that higher air temperatures due to climate change will likely elevate water temperatures in the ocean as well as in the state's lakes and waterways. These increased water temperatures may harm aquatic species sensitive to temperature, particularly threatened and endangered aquatic species. In addition, some foreign invasive species may thrive in these new warmer conditions, further threatening the health of aquatic ecosystems. Water quality could be compromised as well, including a reduction in dissolved oxygen levels. Warmer water will raise the need for temperature control releases from reservoirs. Simultaneously, however, cold-water storage in reservoirs will be constrained due to the expected effects of climate change, such as diminished snowpack and lower storage levels.

According to DWR, future water demand is expected to grow, as a result of global warming. The report finds that warming-caused impacts to evapotranspiration, commercial and industrial use, environmental water demand, and domestic water use may be some of the most significant climate change-related challenges facing California. Increases in evaporative cooling demand and a higher consumption of water by concentrated animal feeding

STATE LEVEL

California Department of Water Resources (DWR) at a Glance

- commissioned a study to determine how global warming will affect California's water resources on a state-wide level.
- helped local and regional water managers understand how its climate change response strategies fit into the larger statewide plan for action, enabling decision makers to plan a more coordinated response to rising temperatures.

facilities are also expected. Moreover, climate change could require more water in order to control rising temperatures for sensitive aquatic species. This need to mitigate rising water temperatures could be an important issue in fragile areas such as the San Francisco Bay-Delta, a delicate ecosystem that provides habitat for many threatened and endangered species. In addition, DWR predicts that basic domestic water demand will rise with higher temperatures, mainly from drinking water for humans and pets, and increased bathing and evaporative cooling. Future population growth in the state promises to bring additional water demand, tightening the squeeze on this limited resource.

DWR emphasizes the need for water agencies and researchers to incorporate climate change impacts and potential associated risks into the planning and management of California's water supply. DWR emphasizes the need to understand the probability of various climate change scenarios and to evaluate how they could affect different regions. By better understanding these potential impacts, decision makers are better equipped to plan appropriate response strategies.[25]

New Mexico Office of the State Engineer/ Interstate Stream Commission

The Office of the State Engineer is responsible for administering the state's water resources by supervising, measuring, appropriating, and distributing all surface and groundwater in New Mexico. The Interstate Stream Commission duties include protecting New Mexico's water rights under eight interstate stream basins, ensuring the state's compliances with each basin, and planning for future water needs.

New Mexico is the next state after California to analyze the potential impacts of climate change on its state's water resources. Governor Bill Richardson's 2005 Executive Order directed the New Mexico Office of the State Engineer to prepare an analysis of the likely effects of global warming on the state's ability to manage water resources in collaboration with other state agencies, research institutions, and water planners. The report, *The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources,* summarizes its findings.

Based on 18 climate simulations prepared by scientists throughout the world, the report highlights potential impacts to New Mexico that generally reflect those expected throughout the West, including changes in snowpack, variability in available water, increased unpredictability in precipitation patterns, and a rise in extreme events such as droughts and flooding. These changes will bring additional challenges to the management of the state's water resources. One such challenge is the fact that the water resources in the Colorado River Basin—one of New Mexico's primary sources of water supply—are expected to decline by as much as 40 percent over the next century. In addition, mountain snowpack in the state's southern half could vanish by the late 21st century, completely eliminating natural storage that is critical for meeting demands during peak summer months.

Climate change is likely to bring significant implications for the state's rangelands, farmland, and aquatic ecosystems. Warmer temperatures combined with changing precipitation patterns suggest the possibility of increased fire activity in the state's rangelands, which make up more than two-thirds of the state's land area. In turn, the more fires are likely to intensify stress on future water resources. New Mexico's farming community is also predicted to feel serious effects from climate change. Farmland in the state could decrease as much as 25 percent as a result of increased evaporation and earlier spring runoff. Additionally, shifts in water temperature and changes in runoff timing could critically alter aquatic habitats, resulting in species loss or migration and causing new combinations of species.

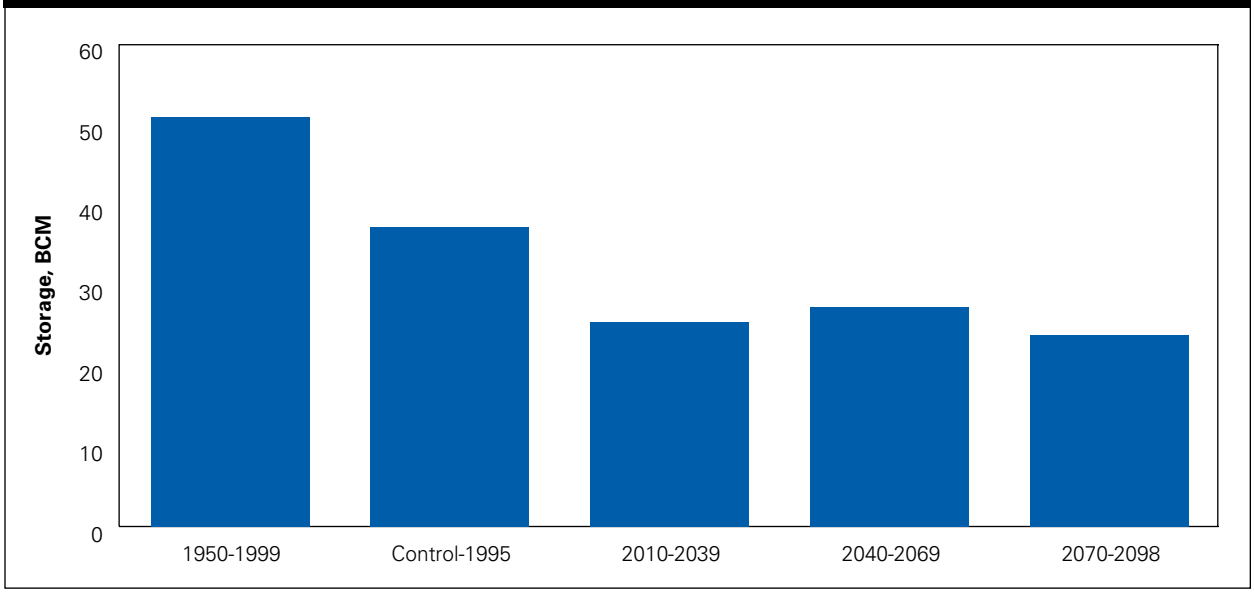
The state's report emphasizes the need for water managers to begin preparing for these potential impacts. The first step for water managers is to identify and quantify the range of climate change vulnerabilities specific to their area. Water managers are advised to conduct a vulnerability analysis of current reservoir infrastructure in order to ensure that they are capable of withstanding the additional

STATE LEVEL

New Mexico Office of the State Engineer and Interstate Stream Commission at A Glance

- commissioned a report to determine what specific global warming effects are likely to be of particular importance in New Mexico.
- recommended proactive, immediate action to mitigate the impacts of climate change, such as exploring options such as desalination of brackish water supplies and water reuse.
- recommended an integrated approach that brings together water management and policy expertise as well as state government, environmental, and agricultural representatives.

Figure A-3: Projected Changes in Average Total Colorado River Basin Reservoir Storage



For downscaled climate simulations of the U.S. Department of Energy/National Center for Atmospheric Research Parallel Climate Model (PCM) based on projected 'business-as-usual' (BAU) greenhouse gas emissions and a control climate simulation based on static 1995 greenhouse gas concentrations, and an ensemble of three 105-year future climate. Simulations for three periods, and a comparison with observed historical (1950-1999) climate. From p. 21 of report.

Source: http://www.nmdrought.state.nm.us/ClimateChangeImpact/completeREPORTfinal.pdf

pressures likely to be caused by climate change. The report also suggests that as science and technology advance, water managers should consider expanding water supplies through reuse, desalination of brackish water supplies, weather modification, expanded use of low-quality water, and reduced reservoir evaporation.

The report determines that the key to successful adaptation is a "robust scenario-based planning structure."[26] The report, compiled with input from numerous published reports and assistance from a broad group of professionals, emphasized that while a degree of uncertainty regarding possible effects of global warming will inevitably remain, we can control the degree to which climate change will affect water sources by planning for action today. The report encourages government collaboration with the various stakeholders in water planning—i.e., cities, agriculture, and the environment—as well as within the education and science community, in order to develop comprehensive planning strategies. It advises water resource planners and managers to employ an adaptive, proactive planning approach in conjunction with a "no regrets" decision-making process that focuses on desirable outcomes regardless of uncertainties.

Appendix B

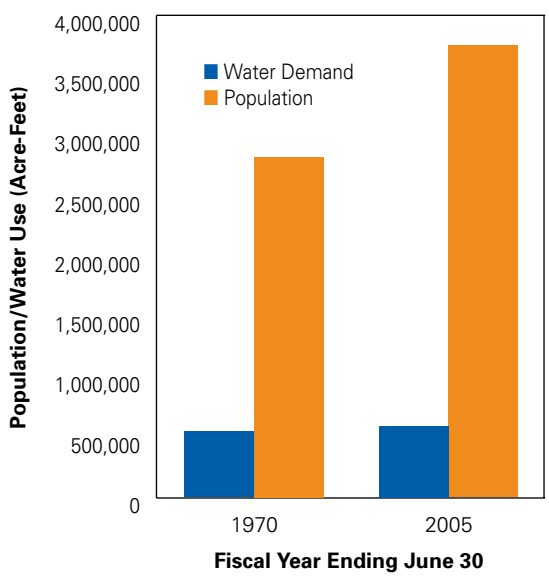
Decoupling Population Growth and Water Use

During the past several decades, many urban communities across the West have grown dramatically. Traditionally, many water planners have assumed that urban water use would grow in proportion to population. Yet in Western states, urban water use remains approximately 10 percent of the total developed water supply.[1]

In fact, as the figures below indicate, some communities have succeeded in keeping water use relatively flat, despite dramatic population growth. Los Angeles, Seattle, the San Francisco Bay area, and Denver have all experienced significant population growth in the past quarter century, yet for each, total water use has remained relatively constant. This remarkable accomplishment has been made possible by significant investments in water conservation

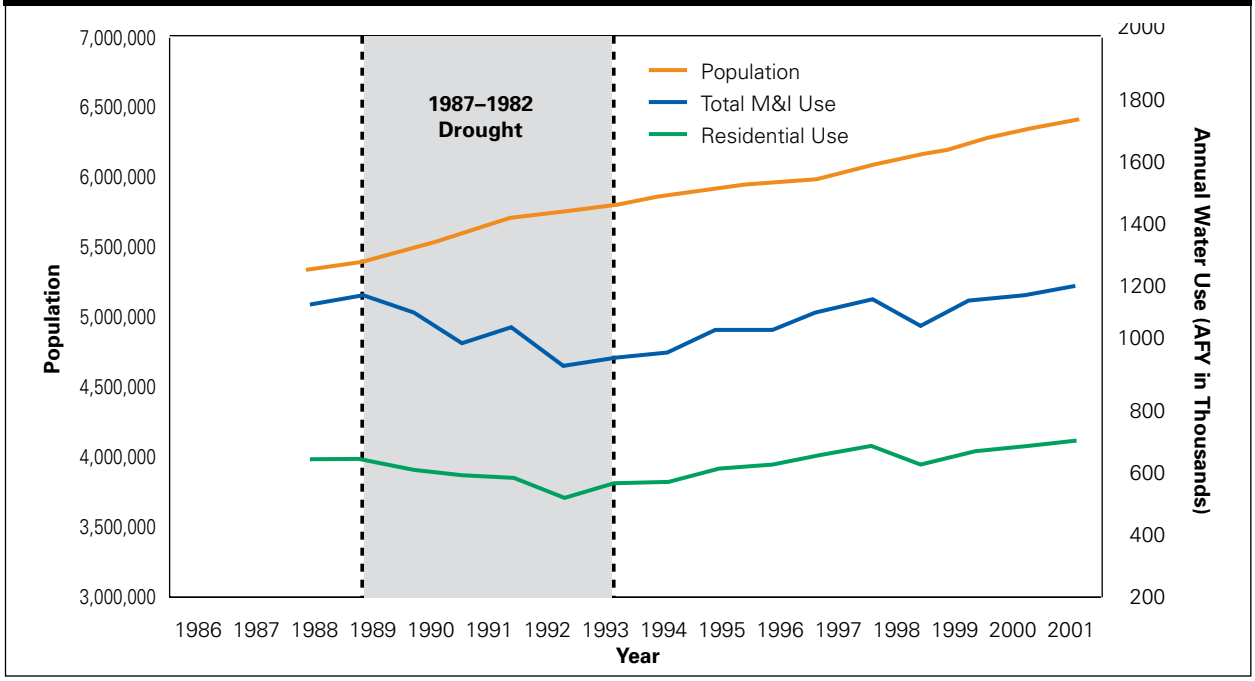
In addition to water conservation investments, some areas have also made major investments in wastewater recycling and groundwater cleanup. Several of these efforts have been prompted by droughts. In Southern California, conservation and recycling investments have also been motivated by pressure to reduce deliveries from the Colorado River and the Mono Lake basin (see Figure B-1). The progress made by these communities demonstrates the effectiveness of efficiency as a water supply tool. As discussed earlier in the report, California's new State Water Plan indicates that these tools are likely to remain the largest sources of supply for future growth. Figures B-2, B-3, and B-4 show similar progress in the San Francisco Bay area, Denver, and Seattle.

Figure B-1: Los Angeles Department of Water and Power Water Use and Population



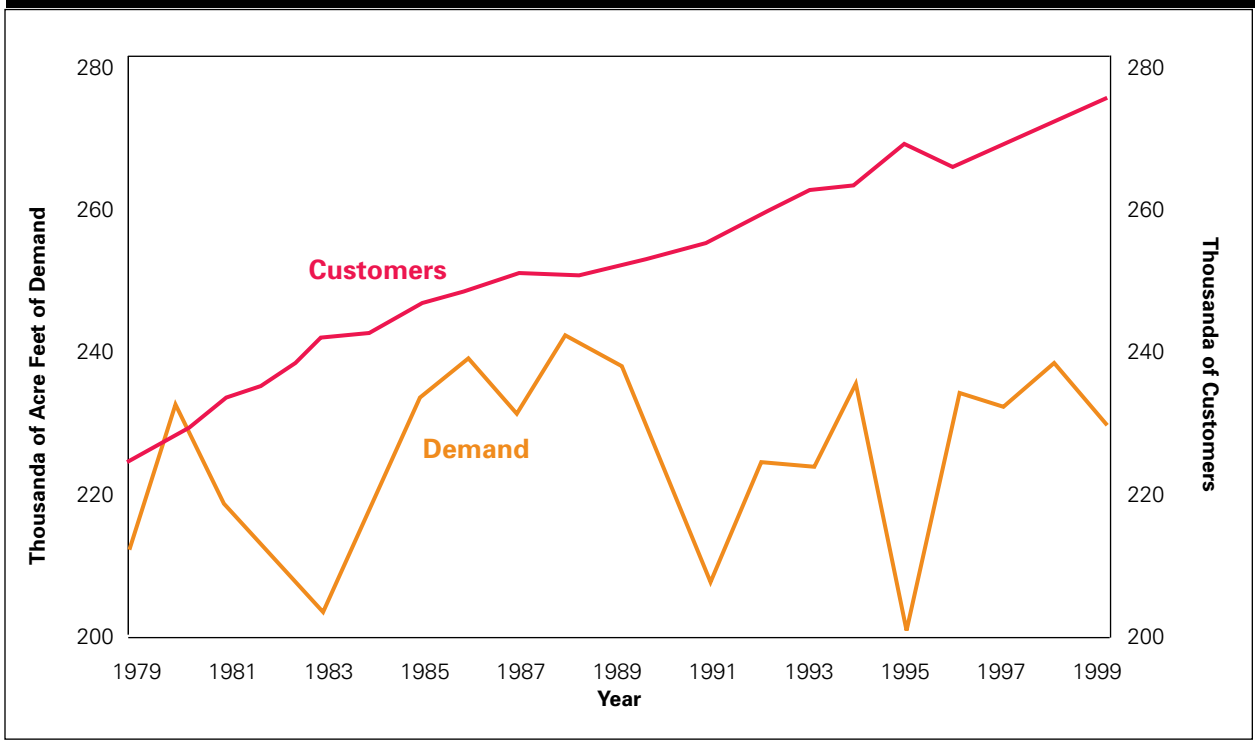
Source: Fatema Akhter, LADWP: 8/31/06 and from California Water Decisions booklet published by Environmental Water Caucus, 7/00.

Figure B-2: San Francisco Bay Area Population and Water Use



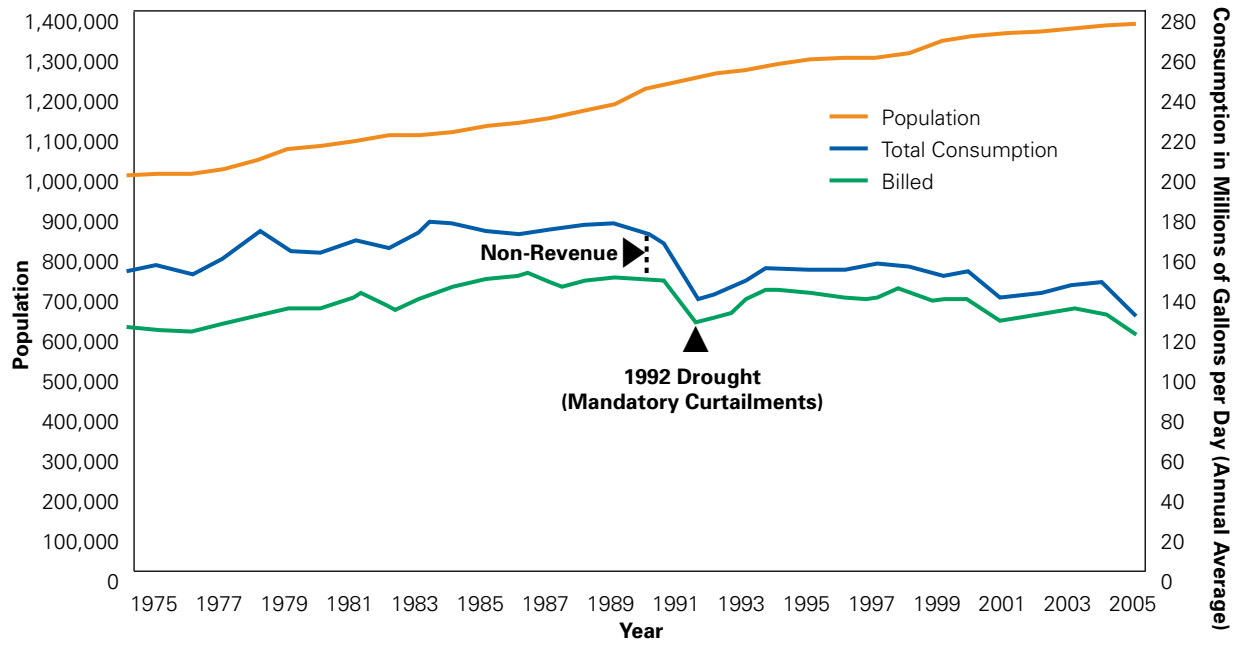
Source: Randy Kanouse, East Bay Municipal Utility District Sacramento Lobbyist. From Bay Area Integrated Regional Water Management Plan, Administrative Draft: 6/06.

Figure B-3: Denver Demand and Customer Growth of Treated Water



Source: Elizabeth Gardener, Denver Water Conservation Manager: 8/29/06.

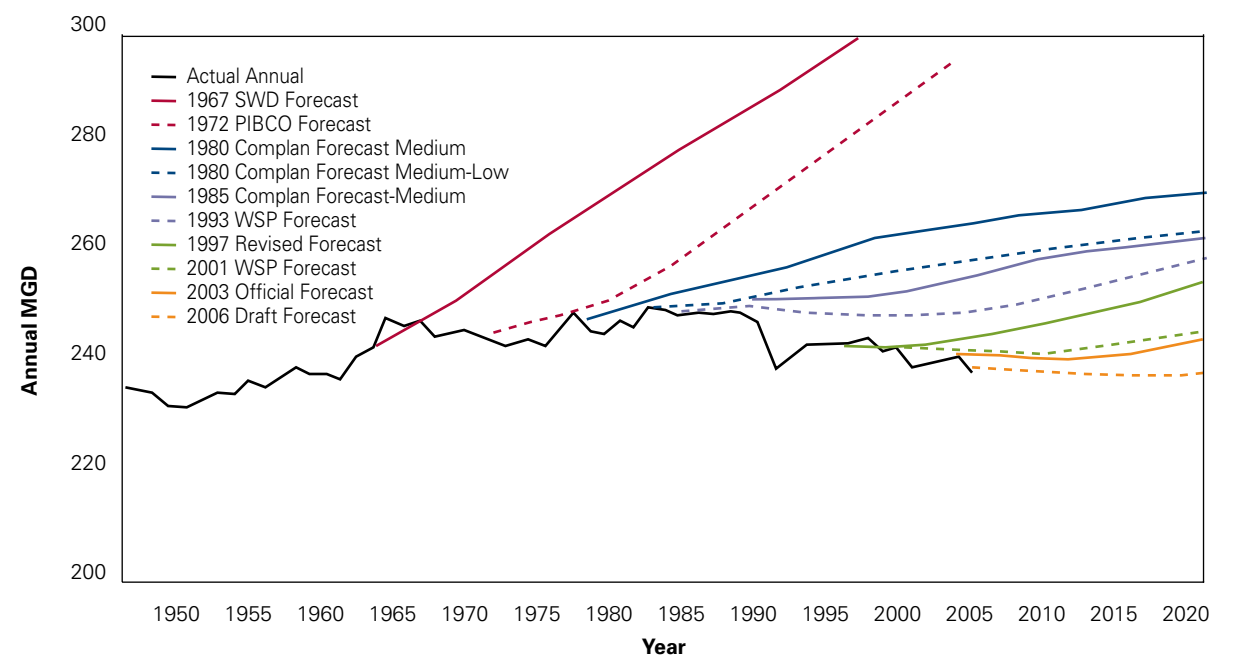
Figure B-4: Population Growth and Water Consumption from Seattle Public Utilities



Source: Pg. 2-15. Seattle Public Utilities, 2007 Water System Plan, Public Review Draft. Online access: http://www.cityofseattle.net/util/About_SPU/Water_System/Plans/2007WaterSystemPlan/index.asp.

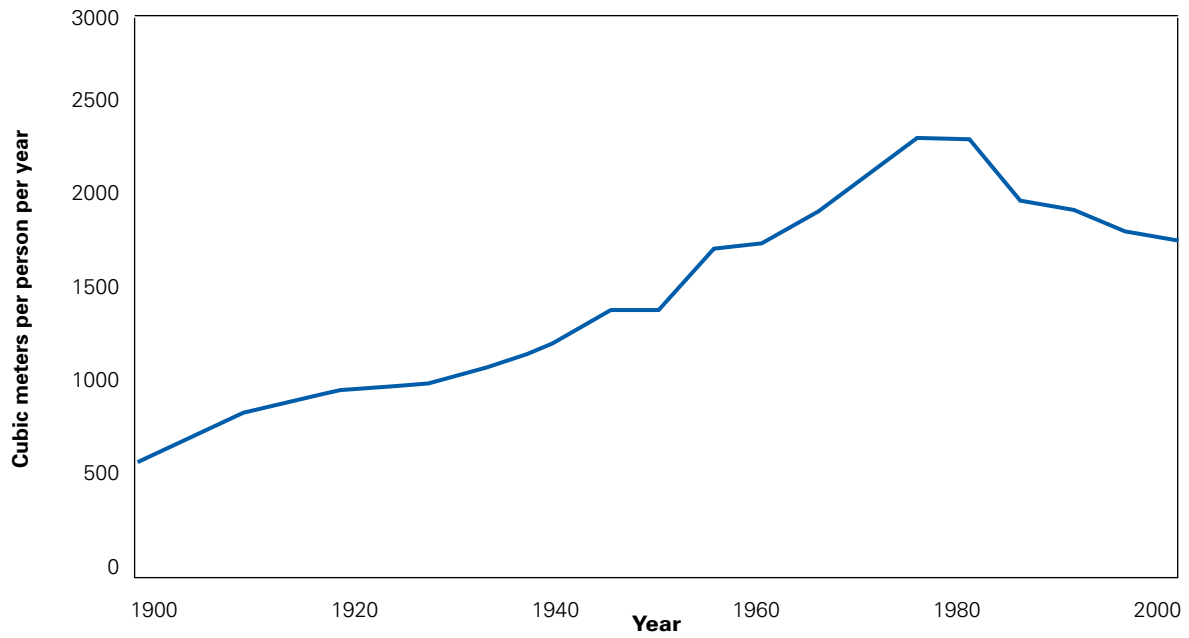
Note: Issaquah, Sammamish Plateau, and Covington area are not included in historic data because they did not become customers until 2004 when contract with CWA was signed.

Figure B-5: Seattle Public Utilities Forecasting Demand



Source: Chuck Clarke, Director, Seattle Public Utilities, personal communication with Barry Nelson.

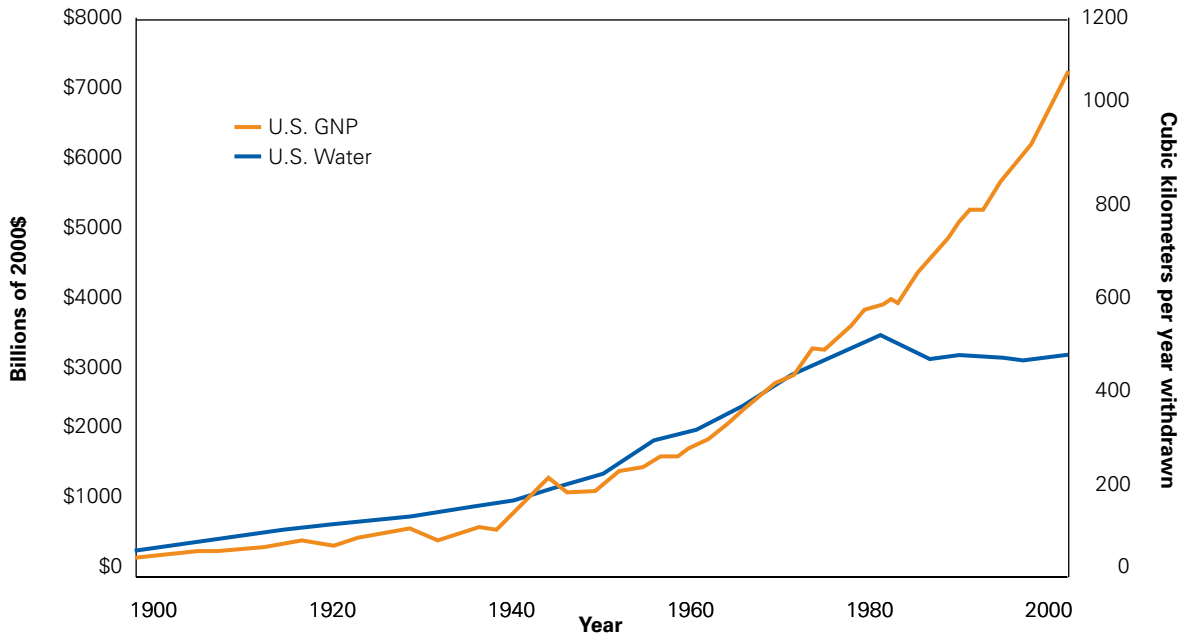
Figure B-6: United States Per Capita Water Withdrawals



Source: Source: Peter Gleick, Pacific Institute (www.pacinst.org). See also, The World's Water (Island Press, Washington DC

Note: Nationally, this figure diminishes to 6.5%.

Figure B-7: U.S. Economic Growth and Total Water Withdrawals



Source: Source: Peter Gleick, Pacific Institute (www.pacinst.org). See also, The World's Water (Island Press, Washington DC

Note: Nationally, this figure diminishes to 6.5%.

This decoupling of population and water use can be seen on the national level as well. Figure B-7 shows that, for the past quarter century, water withdrawals across the nation have remained essentially flat despite a significant increase in GNP. Figure B-6 shows that per capita water withdrawals have declined significantly over the same period. This trend is due to both increased investments in water use efficiency and a shift in the nation's economy toward industries that are less water-intensive.

INCORPORATING DEMAND MANAGEMENT IN PROJECTIONS OF FUTURE WATER USE—THE SEATTLE PUBLIC UTILITIES EXPERIENCE

Even where water agencies have made significant investments in conservation, it has taken a sustained effort for planners to incorporate fully the benefits of conservation—and the decoupling of growth and water use. Figure B-5 from Seattle Public Utilities illustrates this challenge. Total water SPU water demand has been remarkably flat for approximately three decades. For many years, however, demand forecasts projected dramatically higher future demand than has proven to be the case based largely on assumptions that previous water use trends would continue. Demand forecasting methodologies have improved significantly in a number of areas in the past thirty years. For example, since the 1980's, SPU forecasters have worked to incorporate the long-term savings as a result of conservation programs. Figure B-5 indicates, in the most recent SPU projections, demand projections track actual past water use trends.

Water demand forecasts are often designed to be conservative, because water managers are understandably hesitant to risk underestimating future demand. However, overestimations of future demand—frequently based in part on underestimations of the performance of efficiency measures—tend also to overestimate the importance of water management tools designed to increase supply. Today, conservation, water recycling and other demand management tools are now well enough established that water managers can rely on their performance over time. These tools should be carefully incorporated into future demand projections. The results of this effort can be seen in SPU's increasingly accurate demand projections—which now anticipate a continued ability to meet future water needs without a significant increase in supply.

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Chapter 3

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