STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
OCTOBER 2008

MANAGING AN UNCERTAIN FUTURE

Climate Change Adaptation Strategies for California's Water

INTRODUCTION 1

SUMMARY 2

THE CHALLENGES AHEAD 4

IMPERATIVE TO ACT 8

Adaptation Strategies 10

Investment 10

Provide Sustainable Funding for Statewide and Integrated Regional Water Management 10

Regional 11

Fully Develop the Potential of Integrated Regional Water Management 11

Aggressively Increase Water Use Efficiency 13

Statewide 16

Practice and Promote Integrated Flood Management 16

Enhance and Sustain Ecosystems 21

Expand Water Storage and Conjunctive Management of Surface and Groundwater Resources 23

Fix Delta Water Supply, Quality and Ecosystem Conditions 25

Improving Management and Decision-Making Capacity 27

Preserve, Upgrade, and Increase Monitoring, Data Analysis and Management 27

Plan for and Adapt to Sea Level Rise 28

Identify and Fund Focused Climate Change Impacts and Adaptation Research and Analysis 29

NEXT STEPS 30

INTRODUCTION

For California water managers, the future is now. Climate change is already having a profound impact on water resources as evidenced by changes in snowpack, river flows and sea levels.

The Department of Water Resources (DWR) will continue to play a leadership role in adapting to these changes. DWR is already engaged in a number of efforts designed to improve California's ability to cope with a changing climate. However, more must be done. This report recommends a series of adaptation strategies for state and local water managers to improve their capacity to handle change. Many of the strategies will also help adapt our water resources to accommodate non-climate demands including a growing population, ecosystem restoration and greater flood protection.

Several of the recommendations in this report are ready for immediate adoption, while others need additional public deliberation and development. Some can be implemented using existing resources and authority, while the majority will require new resources, sustained financial investment and significant collaborative effort.

Many of California's most important water resource investments remain dependent on bond funding approved by voters. As a result, they are well-funded in some years, but underfunded in most. This history of uneven and irregular investment has delayed progress in areas that have the potential to yield substantial gains over short periods of time.

DWR presents this report as part of the process of updating the California Water Plan, and as part of the California Resources Agency's draft statewide Climate Adaptation Plan. Overall, this report urges a new approach to managing California's water and other natural resources in the face of a changing climate.

Lester A. Snow
Director

Adapt or perish,
now as ever, is nature's
inexorable imperative.
- H. G. Wells

SUMMARY

Climate change is already affecting California's water resources. Bold steps must be taken to reduce greenhouse gas emissions. However, even if emissions ended today, the accumulation of existing greenhouse gases will continue to impact climate for years to come. Warmer temperatures, altered patterns of precipitation and runoff, and rising sea levels are increasingly compromising the ability to effectively manage water supplies, floods and other natural resources. Adapting California's water management systems in response to climate change presents one of the most significant challenges of this century.

Chinook salmon

What we know:

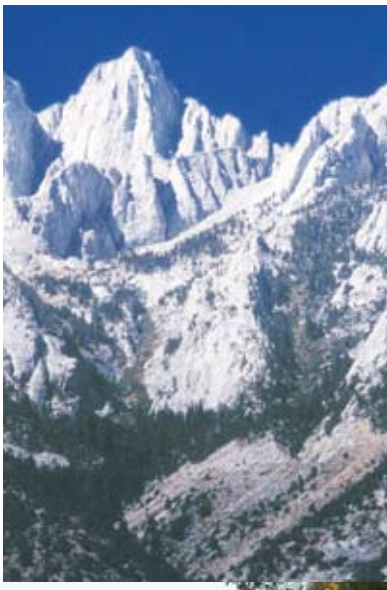
- Historic hydrologic patterns can no longer be solely relied upon to forecast the water future;
- Precipitation and runoff patterns are changing, increasing the uncertainty for water supply and quality, flood management, and ecosystem functions;
- Significant and ongoing investments must be made in monitoring, researching, and understanding the connection between a changing climate, water resources and the environment;
- Extreme climatic events will become more frequent, necessitating improvements in flood protection, drought preparedness and emergency response;
- Water and wastewater managers and customers – businesses, institutions, farms, and individuals – can play a key role in water and energy efficiency, the reduction of greenhouse gas emissions, and the stewardship of water and other natural resources;
- Impacts and vulnerability will vary by region, as will the resources available to respond to climate change, necessitating regional solutions to adaptation rather than the proverbial one-size-fits-all approach; and
- An array of adaptive water management strategies, such as those outlined in this White Paper, must be implemented to better address the risk and uncertainty of changing climate patterns.

California's water crisis

The history of water in California is one of conflict and perseverance. Concerns over the availability, quality and distribution of water are not new, but those concerns are growing. Solutions are becoming more complex as water managers navigate competing interests to reliably provide quality water to farms, businesses, and homes, while managing floods, protecting the environment, and complying with legal and regulatory requirements.

California water management includes an array of complicated issues. For example, the Sacramento-San Joaquin Delta, the hub of the state's water supply and delivery system and a crossroads of other critical infrastructure, faces serious ecosystem problems and substantial seismic risk that threaten water supply reliability and quality. Many groundwater basins suffer from overdraft and pollution. The Colorado River, an important source of water for Southern California, has suffered an historic drought that has helped to highlight the changing hydrology and its impact on water supplies. Throughout California, flood risk grows as levees age and more people live and work in floodplains, and changing climate yields higher flood flows.

Bottom: *Sacramento River*
Below: *Snowpack on Mt. Whitney*



What's happened already?

While the exact conditions of future climate change remain uncertain, there is no doubt about the changes that have already happened. Analysis of paleoclimatic data (such as tree-ring reconstructions of streamflow and precipitation) indicates a history of naturally and widely varying hydrologic conditions in California and the west, including a pattern of recurring and extended droughts. The average early spring snowpack in the Sierra Nevada decreased by about 10 percent during the last century, a loss of 1.5 million acre-feet of snowpack storage (one acre-foot of water is enough for one to two familes for one year). During the same period, sea level rose seven inches along California's coast. California's temperature has risen 1°F, mostly at night and during the winter, with higher elevations experiencing the highest increase. A disturbing pattern has also emerged in flood patterns; peak natural flows have increased on many of the state's rivers during the last 50 years. At the other extreme, many Southern California cities have experienced their lowest recorded annual precipitation twice within the past decade. In a span of only two years, Los Angeles experienced both its driest and wettest years on record.

THE CHALLENGES AHEAD

The trends of the last century – especially the increases in hydrological variability – will likely intensify this century, and abrupt changes in climate could also occur. The Intergovernmental Panel on Climate Change (IPCC) notes that the western United States may be especially vulnerable to water shortages. While the existing system has some capacity to cope with climate variability, extreme weather events resulting in increased droughts and floods will strain that capacity to meet future needs. California has invested in, and now depends upon, a system that relied on historical hydrology as a guide to the future for water supply and flood protection. However, due to climate change, the hydrology of the past is no longer a reliable guide to the future.

Rising temperatures affect California's snowpack levels

Loss of natural snowpack storage

One of the most critical impacts for California water management may be the projected reduction in the Sierra Nevada snowpack – California's largest surface "reservoir." Snowmelt currently provides an annual average of 15 million acre-feet of water, slowly released between April and July each year. Much of the state's water infrastructure was designed to capture the slow spring runoff and deliver it during the drier summer and fall months. Based upon historical data and modeling, DWR projects that the Sierra snowpack will experience a 25 to 40 percent reduction from its historic average by 2050. Climate change is also anticipated to bring warmer storms that result in less snowfall at lower elevations, reducing the total snowpack.

Historical and Future Hydrology

Use of historical hydrologic data has long been the standard of practice for designing and operating water supply and flood protection projects. For example, historical data are used for flood forecasting models such as the National Weather Service's River Forecast System Model and to forecast snowmelt runoff for water supply. This method of forecasting assumes climate "stationarity" – that the climate of the future will be similar to that of the relatively brief period of historical hydrologic record.

Paleoclimatology (which relies upon records from ice sheets, tree rings, sediment, and rocks to determine the past state of Earth's climate system), as well as other research revealing expected impacts of climate change, indicate that our traditional hydrologic approach can no longer be solely relied upon. That is, the hydrologic record cannot be used to predict expected increases in frequency and severity of extreme events such as floods and droughts. Going forward, model calibration or statistical relation development must happen more frequently, new forecast-based tools must be developed, and a standard of practice that explicitly considers climate change must be adopted.

Drought

Warming temperatures, combined with changes in rainfall and runoff patterns will exacerbate the frequency and intensity of droughts. Regions that rely heavily upon surface water (rivers, streams, and lakes) could be particularly affected as runoff becomes more variable, and more demand is placed on groundwater. Combined with urbanization expanding into wildlands, climate change will further stress the state's forests, making them more vulnerable to pests, disease and changes in species composition. Along with drier soils, forests will experience more frequent and intense fires, resulting in subsequent changes in vegetation, and eventually a reduction in the water supply and storage capacity benefits of a healthy forest.

Climate change will also affect water demand. Warmer temperatures will likely increase evapotranspiration rates and extend growing seasons, thereby increasing the amount of water that is needed for the irrigation of many crops, urban landscaping and environmental water needs. Reduced soil moisture and surface flows will disproportionately affect the environment and other water users that rely only on annual rainfall such as non-irrigated agriculture, livestock grazing on non-irrigated rangeland and recreation.

Floods

The amount of snow is critical for water supply and environmental needs, but so is the timing of snowmelt runoff into rivers and streams. Rising snowlines caused by climate change will allow more of the Sierra Nevada watersheds to contribute to peak storm runoff. High frequency flood events (e.g. 10-year floods) in particular will likely increase with a changing climate. Along with reductions in the amount of the snowpack and accelerated snowmelt, scientists project greater storm intensity, resulting in more direct runoff and flooding. Changes in watershed vegetation and soil moisture conditions will likewise change runoff and recharge patterns. As streamflows and velocities change, erosion patterns will also change, altering channel shapes and depths, possibly increasing sedimentation behind dams, and affecting habitat and water quality.
With potential increases in the frequency and intensity of wildland fires due to climate change, there is a potential for more floods following fire, which increase sediment loads and water quality impacts.

The Colorado River

Climate research in the Colorado River basin has shown that natural climate variability alone has resulted in droughts far more severe than those in the basin's measured historical record. Understanding additional impacts of climate change on the Southwest's most important river basin has been a subject of ongoing interest in the academic community. In addition to impacts on runoff, anticipated warming in the arid Southwest is also expected to increase water demands.

For the purposes of federal flood insurance, the Federal Emergency Management Agency (FEMA) has traditionally used the 100-year flood event, which refers to the level of flood flows that has a one-percent chance of being exceeded in any single year. As California's hydrology changes, what is currently considered a 100-year flood may strike more often, leaving many communities at greater risk. Moreover, as peak flows and precipitation change over time, climate change calls into question assumptions of "stationarity" that is used in flood-related statistical analyses like the 100-year flood (see sidebar on page 4). Planners will need to factor a new level of safety into the design, operation, and regulation of flood protection facilities such as dams, floodways, bypasses and levees, as well as the design of local sewers and storm drains.

Water quality

Changes in the timing of river flows and warming atmospheric temperatures may affect water quality and water uses in many different ways. At one extreme, flood peaks may cause more erosion, resulting in turbidity and concentrated pulses of pollutants. This will challenge water treatment plant operations to produce safe drinking water. Flooding can also threaten the integrity of water works infrastructure. At the other extreme, lower summer and fall flows may result in greater concentration of contaminants. These changes in streamflow timing may require new approaches to discharge permitting and non-point source pollution. Warmer water will distress many fish species and could require additional cold water reservoir releases. Higher water temperatures can also accelerate some biological and chemical processes, increasing growth of algae and microorganisms, the depletion of dissolved oxygen, and various impacts to water treatment processes. An increase in the frequency and intensity of wildfires will also affect watersheds, vegetation, runoff and water quality.

Sea level rise

Sea levels are rising, and it is generally accepted that this trend will continue. However, the exact rate of rise is unknown, due to ongoing scientific uncertainty about the melting of ice sheets on western Antarctica and Greenland and the potential for abrupt changes in ocean conditions. Recent peer-reviewed studies estimate a rise of between seven to 55 inches by 2100 along California's coast.

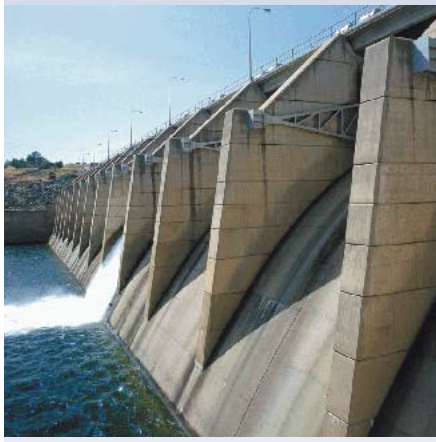
Winter storm in southern Sierra Nevada mountain range

The implications of a seven-inch rise are dramatically different than a rate of rise towards the upper end of the range. However, even a rise at the lower end of this range poses an increased risk of storm surge and flooding for California's coastal residents and infrastructure, including many of the state's wastewater treatment plants. Moreover, sea level rise can contribute to catastrophic levee failures in the Delta, which have great potential to inundate communities, damage infrastructure, and interrupt water supplies throughout the state.

Even without levee failures, Delta water supplies and aquatic habitat will be affected due to saltwater intrusion. An increase in the penetration of seawater into the Delta will further degrade drinking and agricultural water quality and alter ecosystem conditions. More freshwater releases from upstream reservoirs will be required to repel the sea to maintain salinity levels for municipal, industrial and agricultural uses. Alternatively, changes in upstream and in-Delta diversions, exports from the Delta, and improved conveyance through or around the Delta may be needed. Sea level rise may also affect drinking water supplies for coastal communities due to the intrusion of seawater into overdrafted coastal aquifers.

Hydroelectric generation

Climate change will reduce the reliability of California's hydroelectricity operations, which, according to the California Climate Action Registry and the California Air Resources Board, is the state's largest source of greenhouse gas emissions-free energy. Changes in the timing of inflows to reservoirs may exceed generation capacity, forcing water releases over spillways and resulting in lost opportunities to generate hydropower. Higher snow elevations, decreased snowpack, and earlier melting may result in less water available for clean power generation during hot summer months, when energy demand is highest. The impact is compounded overall by anticipated increased energy consumption due to higher temperatures and greater water demands in summer when less water is available. The potential for lengthier droughts may also lower reservoir levels below that which is necessary for power generation.



Thermalito Diversion Dam Powerplant

Dam Safety

Implemented by DWR's Division of Safety of Dams (DSOD), California has one of the most comprehensive dam safety programs in the world.

Preliminary assessments by DSOD of how climate change may potentially impact dam safety reveal that increased safety precautions may be needed to adapt systems to higher winter runoff, frequent fluctuation of water levels, and the potential for additional sediment and debris from drought-related fires. Additionally, climate change will impact the ability of dam operators to estimate extreme flood events.

THE IMPERATIVE TO ACT

As understanding of climate change improves, the challenge for California's water community is to develop and implement strategies that improve resiliency, reduce risk, and increase sustainability for water and flood management systems and the ecosystems upon which they depend.

California water management systems have provided the foundation for the state's economic vitality for more than 100 years, providing water supply, sanitation, electricity, recreation and flood protection.

With the state's water resources already stressed, additional stress from climate change will only intensify the competition for clean, reliable water supplies. While doing its part to reduce greenhouse gas emissions and expand the use of clean energy sources, California's water community must concentrate on adaptation strategies to respond to the anticipated changes. The IPCC's Fourth Assessment Report (2007) states that adaptation "will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions." As understanding of climate change improves, the challenge for California's water community is to develop and implement strategies that improve resiliency, reduce risk, and increase sustainability for water and flood management systems and the ecosystems upon which they depend.

Governor Schwarzenegger signing the Global Warming Solutions Act (AB 32) in 2006

Mitigation Response

The mitigation response to climate change, or the reduction of greenhouse gas emissions that contribute to our changing climate, has received more international attention to date than adaptation. On a global scale, greenhouse gas emissions must be reduced to slow the effects of warming and climate change. California is leading the nation to enact major greenhouse gas reductions on an ambitious timeline. In 2006, Governor Arnold Schwarzenegger and the California Legislature enacted Assembly Bill (AB) 32 - The Global Warming Solutions Act. The law requires a statewide cap on greenhouse gas emissions, reductions in emissions from major sources, and the development of a mandatory reporting system for these emissions.

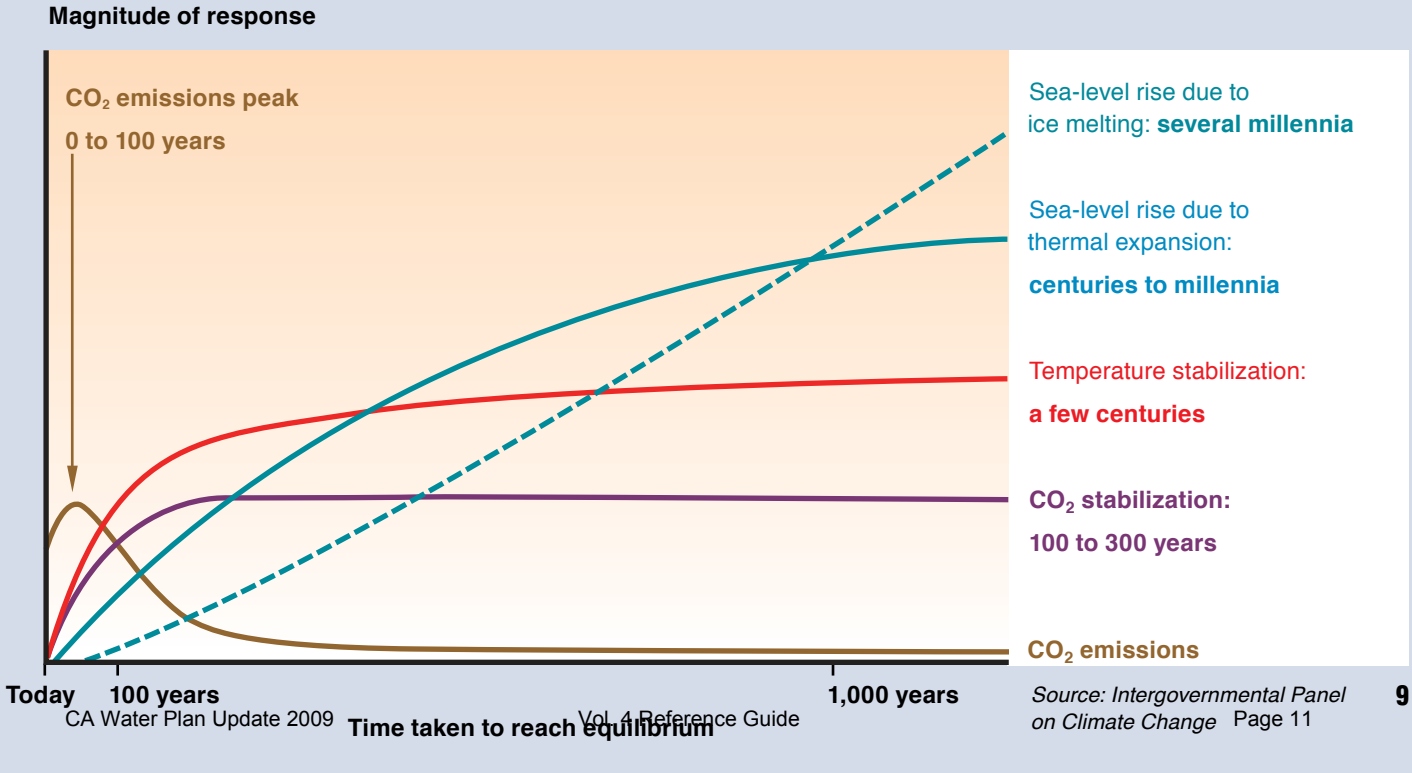
While water generates much of the state's electricity, according to the California Energy Commission (CEC), water-related energy use in California also consumes approximately 20 percent of the state's electricity, and 30 percent of the state's non-power plant natural gas (i.e. natural gas not used to produce electricity). The CEC also found that most of the energy intensity of water use in California is in the end uses by the customer (e.g. heating, processing, and pressurizing water). In fact, the CEC states that 75 percent of the electricity and nearly all of the natural gas use related to water in California is associated with the end use of water, mostly for water heating.

The Governor's Climate Action Team is overseeing the implementation of AB 32 including a multi-agency Water-Energy subgroup tasked with the development of greenhouse gas mitigation strategies for energy consumption related to water use.

Fortunately, there are multiple strategies that can help reduce the risks presented by climate change. To be successful, these adaptation strategies must be well-coordinated at the state, regional and local levels in order to maximize their effect. No single project or strategy can adequately address the challenges California faces, and tradeoffs must be explicitly acknowledged and decided upon. That said, planning and investing now in a comprehensive set of actions that informs water managers and provides system diversity and resilience will help prepare California for future climate uncertainty.

The Real McCoy ferry crossing Cache Slough, carrying traffic just upstream of Rio Vista

CO_2 concentration, temperature, and sea level continue to rise long after emissions are reduced



Source: Intergovernmental Panel on Climate Change

ADAPTATION STRATEGIES

The following pages present 10 climate change adaptation strategies for California's water. The strategies fall under four major categories: Investment, Regional, Statewide and Improving Management and Decision-Making Capacity.

...climate change presents an ongoing risk that requires a long-term commitment of funding that is properly matched to anticipated expenditures, beneficiaries and responsible parties.

Investment Strategy

Adaptive responses to climate change will not come without a cost. Climate change magnifies the problems that exist with an aging water infrastructure and growing population. While recent bond measures have provided a down payment for improving California's water and flood systems, climate change presents an ongoing risk that requires a long-term commitment of funding that is properly matched to anticipated expenditures, beneficiaries and responsible parties.

Strategy 1: Provide Sustainable Funding for Statewide and Integrated Regional Water Management

- The State Legislature should initiate a formal assessment of state and local financing mechanisms to provide a continuous and stable source of revenue to sustain the programs described herein. Activities in particular need of certainty and continuity in funding include regional water planning, inspection, maintenance, repair, and rehabilitation of flood management facilities, observational networks and water-related climate change adaptation research.

Levee repair site on Sacramento River

San Joaquin River

Regional Strategies

California spans multiple climate zones ranging from mountain to coastal. Because of this diversity, each region of the state will experience unique impacts from climate change. For some, watershed health will be the chief concern. Other areas will be affected by saltwater intrusion. Regions that depend heavily upon water imports will need strategies to cope with greater uncertainty in supply. Economic and environmental impacts depend upon location, so adaptation strategies must be regionally appropriate.

Strategy 2: Fully Develop the Potential of Integrated Regional Water Management

Integrated Regional Water Management (IRWM) planning offers a framework for water managers to address water-related challenges and provide for future needs. Over the past decade, California has improved its understanding of the value of regional planning and made significant steps to implement IRWM. Formally, IRWM is a comprehensive approach for determining the appropriate mix of water demand and supply management options and water quality actions. This approach provides reliable water supplies at lowest reasonable cost and with highest benefits for economic development, environmental quality and other societal objectives. Moreover, if appropriately developed and implemented, IRWM plans—in combination with other regional planning efforts for transportation and land use—can serve as the basis for broader community adaptation plans for climate change.

Suspended irrigation system

The state will encourage—through both financial and technical assistance—IRWM planning and implementation activities that adapt water management to a changing climate.

- By 2011, all IRWM plans should identify strategies that can improve the coordination of local groundwater storage and banking with local surface storage and other water supplies such as recycled municipal water, surface runoff and floodflows, urban runoff and stormwater, imported water, water transfers, and desalinated groundwater and seawater.

IRWM is a comprehensive approach for determining the appropriate mix of water demand and supply management options and water quality actions to provide reliable water supplies at lowest reasonable cost and with highest benefits for economic development, environmental quality and other societal objectives.

- By 2011, all IRWM plans should include specific elements to adapt to a changing climate, including:
  - An assessment of the region's vulnerability to the long-term increased risk and uncertainty associated with climate change.
    - An integrated flood management component.
    - A drought component that assumes, until more accurate information is available, a 20 percent increase in the frequency and duration of future dry conditions.
  - Aggressive conservation and efficiency strategies.
  - Integration with land use policies that:
    - Help restore natural processes in watersheds to increase infiltration, slow runoff, improve water quality and augment the natural storage of water.
    - Encourage low-impact development that reduces water demand, captures and reuses stormwater and urban runoff, and increases water supply reliability.
  - A plan for entities within a region to share water supplies and infrastructure during emergencies such as droughts.

- Large water and wastewater utilities should conduct an assessment of their carbon footprint and consider implementation of strategies described in the draft AB 32 Scoping Plan to reduce greenhouse gas emissions. To take advantage of an existing framework and process for calculating their carbon footprint, these utilities should join the Climate Action Registry.

Strategy 3: Aggressively Increase Water Use Efficiency

Using water efficiently is a foundational action for water management, one that serves to mitigate and adapt to climate change. Water conservation reduces water demand, wastewater discharges, and can reduce energy demand and greenhouse gas emissions. Efficient water use can help communities cope with water shortages that may result from climate change, thus reducing economic and environmental impacts of water shortages. Water use efficiency must be a cornerstone of every water agency's water portfolio.

- As directed by Governor Schwarzenegger, DWR in collaboration with the Water Boards, the California Energy Commission (CEC), the California Public Utilities Commission, the California Department of Public Health, and other agencies, are developing and will implement strategies to achieve a statewide 20 percent reduction in per capita water use by 2020.
    - By 2010, all Urban Water Management Plans must include provisions to fund and implement all economic, feasible, and legal urban best management practices established by the California Urban Water Conservation Council (CUWCC) (see sidebar).

Drought tolerant landscaping in Southern California

Model Water Efficient Landscape Ordinance

The Water Conservation in Landscaping Act of 2006, Assembly Bill 1881, requires DWR to update the existing Model Water Efficient Landscape Ordinance (model ordinance) and adopt the model ordinance by January 1, 2009. Each local agency is required to adopt either the updated model ordinance or its own local landscape ordinance that is at least as effective by January 1, 2010. DWR is developing the updated model ordinance to reflect new technology and advances in landscape water management and to increase outdoor water conservation through improved landscape design, management and maintenance. The ordinance provides guidance to local agencies in developing and adopting landscape ordinances leading to water savings, which will reduce water demand, waste and water-related energy use.

Conservation

Urban Best Management Practices

In 1991, water suppliers and environmental organization members of the CUWCC reached agreement on a series of Best Management Practices (BMPs) that define urban water conservation measures and implementation levels. The BMPs define required actions or goals and are now widely accepted as the minimum level of conservation effort for most water suppliers in California. The BMPs are intended to reduce long-term urban demands from what they would have been without implementation of these practices.
The 14 BMPs include residential ultra-low flush toilet replacement programs, conservation pricing, large landscape conservation, and high efficiency clothes washer rebates.

The CUWCC is currently in the process of revising and updating the BMPs. More information is at **www.cuwcc.org**.

Conservation

Agricultural Efficient Water Management Practices

In 1996, the Agricultural Water Management Council prepared a list of agricultural water best management practices known as "Efficient Water Management Practices" (EWMPs). The EWMPs fall under three major categories: generally applicable, conditionally applicable and other, and include the following:

- preparation and adoption of a water management plan
- pump testing and evaluation
- canal and ditch lining
- implementation of tail-water recovery systems
- use of real-time irrigation scheduling and evapotranspiration data
- beneficial use of recycled water
- optimization of conjunctive use of ground water and surface water supplies
- incentivized pricing

Additional information and the full list of the EWMPs can be found online at **www.agwatercouncil.org**.

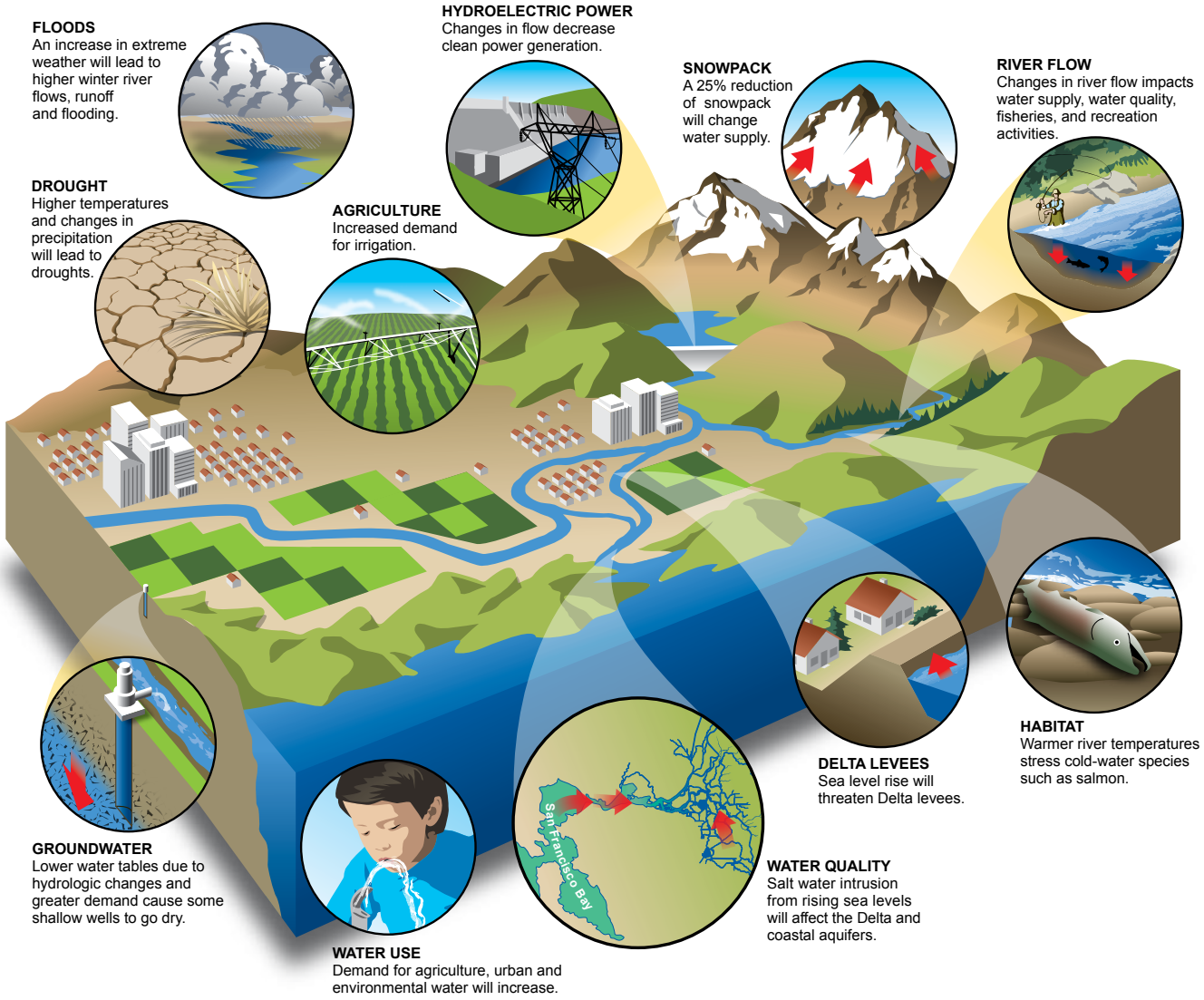
- All local governments are required by statute to adopt the State Model Water Efficient Landscape Ordinance (MWELO) or equivalent (see sidebar). Because the model ordinance only addresses new development, local governments must pursue conservation programs to reduce water use on existing landscapes.
- Notwithstanding other water management objectives, local and regional water use efficiency programs—agricultural, residential, commercial, industrial and institutional—should emphasize those measures that reduce both water and energy consumption.

These agencies, in coordination with the rest of the Water-Energy subgroup of the Governor's Climate Action Team and the CUWCC, will develop urban water use efficiency recommendations for incorporation into the California Water Plan Update 2009.

- Agricultural entities should apply all feasible Efficient Water Management Practices (EWMPs) to reduce water demand and improve the quality of drainage and return flows, and report on implementation in their water management plans.
- Recycled water is a drought-proof water management strategy that may also be an energy efficient option in some regions.
  - In those regions, wastewater and water agencies should collaboratively adopt policies and develop facility plans that promote the use of recycled water for all appropriate, cost-effective uses while protecting public health.
  - In consultation with DWR and the Department of Public Health, the Water Boards should identify opportunities to optimize water recycling consistent with existing permitting authority.

The State Water Resources Control Board (SWRCB) and the California Public Utilities Commission are authorized to impose water conservation measures in permitting and other proceedings to ensure attainment of these conservation efforts. Additionally, the Legislature should authorize and fund new incentive-based programs to promote the widespread and mainstream adoption of aggressive water conservation by urban and agricultural water systems and their users.

How climate change impacts a watershed



Oroville Dam

Statewide Strategies

California has an unparalleled water infrastructure system that stores and conveys water, manages flood flows, and interconnects many of the state's regions. However, current water resources infrastructure is already strained to meet existing, competing objectives for water supply, flood protection, environmental protection, water quality, hydropower and recreation. In a changing climate, the conflicts between competing interests are even greater as supplies become less reliable. This system of reservoirs, canals, flood bypasses and levees must be modified and managed differently to accommodate the increased variability brought by climate change. As the prediction of climate change impacts will never be perfect, flexibility must be a fundamental tactic, especially regarding water system operations.

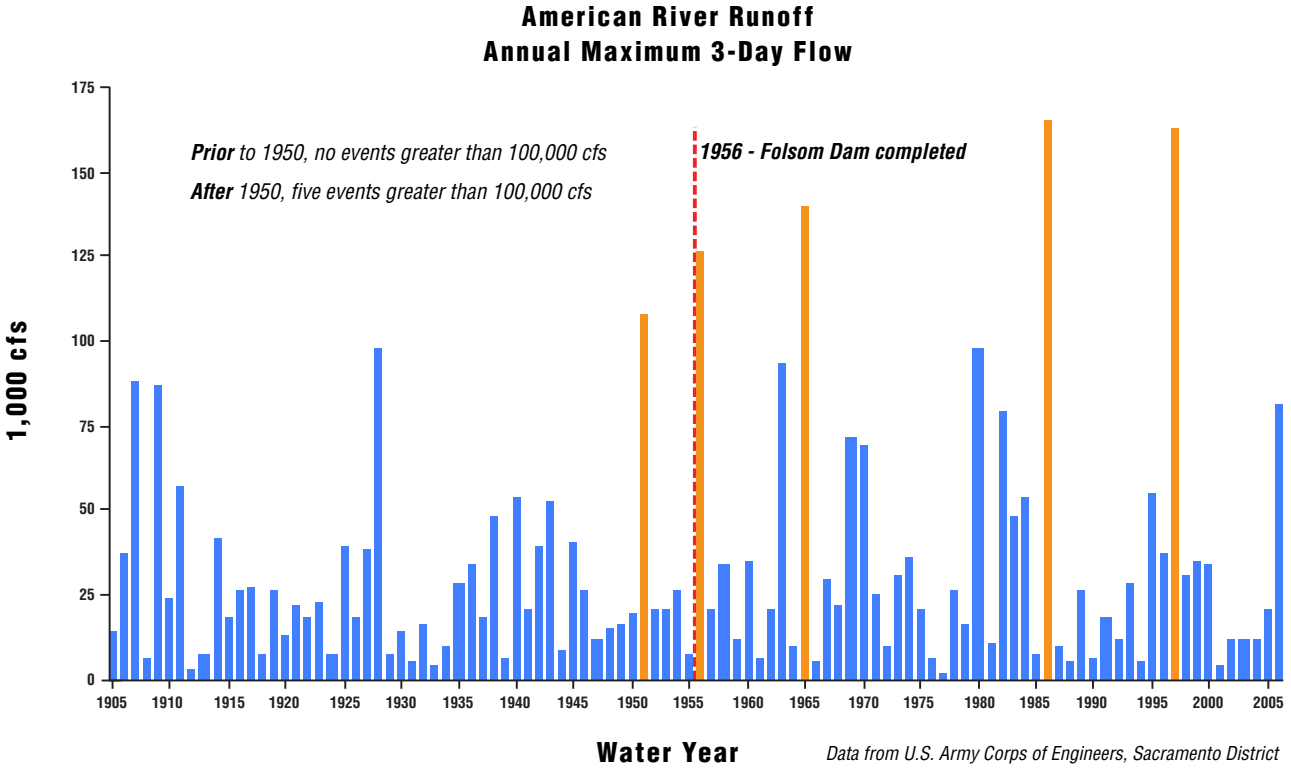
Flood systems throughout the state must be upgraded and managed to accommodate the higher variability of flood flows, to protect public safety, the economy and ecosystems.

Strategy 4: Practice and Promote Integrated Flood Management

Many Californians already face an unacceptable risk of flooding. Catastrophic flooding within the Central Valley could mirror the economic, social and environmental damages caused by Hurricane Katrina in 2005. Millions of people in California's Central Valley live behind or depend upon levees to protect them, with populations in these regions continuing to grow. Climate change will increase the state's flood risk by causing a shift toward more intense winter storms which could produce higher peak flows. Flood systems throughout the state must be upgraded and managed to accommodate the higher variability of flood flows, to protect public safety, the economy and ecosystems.

- Flood management systems must better utilize natural floodplain processes. Thus, flood management should be integrated with watershed management on open space, agricultural, wildlife areas, and other low density lands to lessen flood peaks, reduce sedimentation, temporarily store floodwaters and recharge aquifers, and restore environmental flows.

Liberty Island



The five highest floods of record on the American River have occurred since 1950.

The improved performance of existing water infrastructure cannot be achieved by any single agency, and will require the explicit cooperation of many agencies. Systemwide operational coordination and cooperation must be streamlined to respond to extreme events that may result from climate change. Successful system reoperation will require that the benefits and tradeoffs of such actions are evident to federal and local partners.

- The state will establish a System Reoperation Task Force comprised of state personnel, federal agency representatives and appropriate stakeholders that will:
  - Quantify the potential costs and benefits and impacts of system reoperation for water supply reliability, flood control, hydropower, water quality, fish passage, cold water management for fisheries and other ecosystem needs;

System Reoperation

California's water resources system includes both physical elements (such as reservoirs, aquifers, rivers, pumping plants, and canals) and non-physical elements (such as operating rules, land use practices, and environmental regulations). The addition or removal of a structural element or a change in a non-structural element often provides opportunities to optimize the operational benefits of other elements of the system.

The key to system reoperation is to integrate and connect individual system elements to illustrate how changes in use of one element can be balanced by changes in the use of other elements.

The largest challenge to system reoperation is that individual system elements are often owned and operated by independent entities.

- Support the update of U.S. Army Corps of Engineers' operations guidelines for Central Valley reservoirs;
- Support the update of flood frequency analyses on major rivers and streams;
- Evaluate the need to amend flow objectives;
- Expand the study of forecast-based operations for incorporation into reservoir operations;
- Include watershed level analyses that detail localized costs and benefits; and
- Identify key institutional obstacles that limit benefits.

- To coordinate California's water supply and flood management operations, state and federal agencies collaboratively established the Joint Operations Center (JOC). To successfully meet the challenges posed by climate change, the JOC capacity must be expanded to improve tools and observations to better support decision-making for individual events and seasonal and interannual operations, including water transfers. The JOC should be enhanced to further improve communications and coordination during emergencies, such as floods and droughts.

- By January 1, 2012, DWR will collaboratively develop a Central Valley Flood Protection Plan that includes actions to improve integrated flood management and considers the expected impacts of climate change. The plan will provide strategies for greater flood protection and environmental resilience, including:
  - Emergency preparedness, response, evacuation and recovery actions;
  - Opportunities and incentives for expanding, or increasing the use of floodway corridors to reduce stress on critical urban levees and provide for habitat, open space, recreation and agricultural land preservation;
  - Options and recommendations to provide at least 200-year level protection for all urban areas within the Sacramento-San Joaquin Valley;

- Increased use of setback levees, flood easements, zoning, and land acquisitions to provide greater public safety, floodplain storage, habitat and system flexibility;
- Flood insurance requirements to address residual risk;
- Extensive, grassroots public outreach and education; and
- The integration of flood management with all aspects of water resources management and environmental stewardship.

- All at-risk communities should develop, adopt, practice and regularly evaluate formal flood emergency preparedness, response, evacuation and recovery plans.
- Local governments should implement land use policies that decrease flood risk.
  - Local land use agencies should update their General Plans to address increased flood risks posed by climate change. General Plans should consider an appropriate risk tolerance and planning horizon for each locality.
  - Local governments should site new development outside of undeveloped floodplains unless the floodplain has at least a sustainable, 200-year level of flood protection.
  - Local governments should use low-impact development techniques to infiltrate and store runoff.
  - Local governments should include flood-resistant design requirements in local building codes.

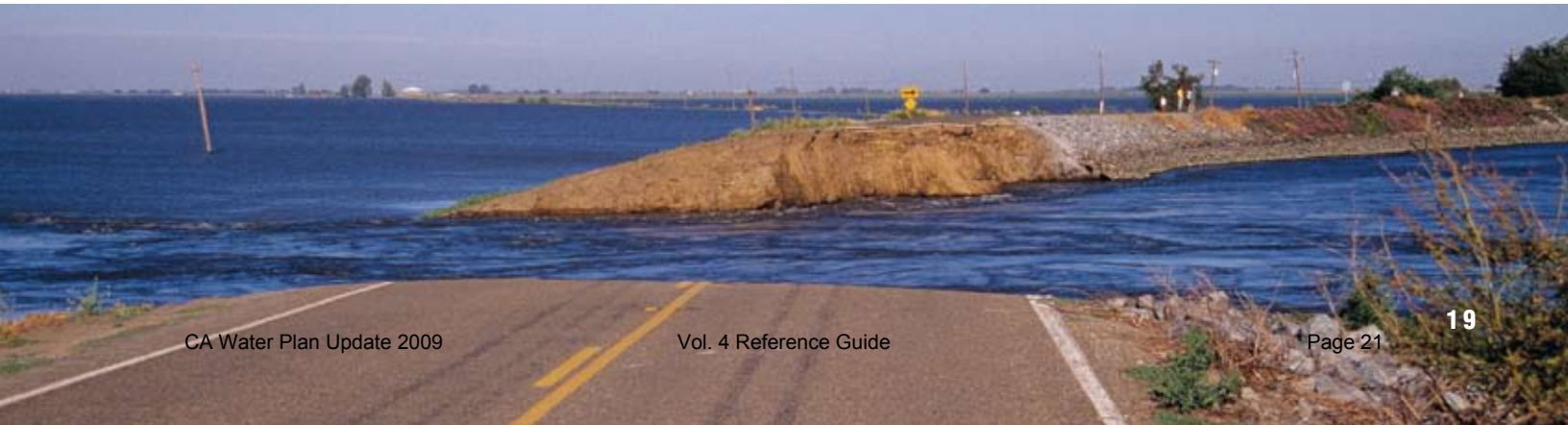
Adaptive Capacity and Resilience

Adaptive capacity is the ability of systems, organizations, and individuals to:

- adjust to actual or potential adverse changes and events,
- take advantage of existing and emerging opportunities that support essential functions or relationships, and/or
- cope with adverse consequences, mitigate damages, and recover from system failures.

Resilience is the capacity of a resource or natural system to return to prior conditions after a disturbance.

Levee break at Jones Tract



Engineer reviews flood data at DWR's Joint Operations Center

California Conservation Corps workers strengthen a levee during a high water event

FloodSAFE CALIFORNIA

FloodSAFE California is a multi-faceted, strategic initiative to improve public safety through integrated flood management. Primarily funded by Propositions 1E and 84, the FloodSAFE program is a collaborative statewide effort to accomplish the following five broad goals:

Reduce the Chance of Flooding
Reduce the frequency and size of floods that could damage California communities, homes and property, and critical public infrastructure.

Reduce the Consequences of Flooding
Take actions prior to flooding that will help reduce the adverse consequences of floods when they do occur and allow for quicker recovery after flooding.

Sustain Economic Growth
Provide continuing opportunities for prudent economic development that supports robust regional and statewide economies without creating additional flood risk.

Protect and Enhance Ecosystems
Improve flood management systems in ways that protect, restore, and where possible, enhance ecosystems and other public trust resources.

Promote Sustainability
Take actions that improve compatibility with the natural environment and reduce the expected costs to operate and maintain flood management systems into the future.

Additional information is available at **www.water.ca.gov/floodsafe**.

Setback levee being constructed near Bear River

Strategy 5: Enhance and Sustain Ecosystems

Reliable water supplies and resilient flood protection depend upon ecosystem sustainability. Building adaptive capacity for both public safety and ecosystems requires that water and flood management projects maintain and enhance biological diversity and natural ecosystem processes. Water supply and flood management systems are significantly more sustainable and economical over time when they preserve, enhance and restore ecosystem functions, thereby creating integrated systems that suffer less damage from, and recover more quickly after, severe natural disruptions. By reducing existing, non-climate stressors on the environment, ecosystems will have more capacity to adapt to new stressors and uncertainties brought by climate change.

Sheep grazing in the Yolo Bypass, west of Sacramento

- Water management systems should protect and reestablish contiguous habitat and migration and movement corridors for plant and animal species related to rivers and riparian or wetland ecosystems. IRWM and regional flood management plans should incorporate corridor connectivity and restoration of native aquatic and terrestrial habitats to support increased biodiversity and resilience for adapting to a changing climate.

- Flood management systems should seek to reestablish natural hydrologic connectivity between rivers and their historic floodplains. Setback levees and bypasses help to retain and slowly release floodwater, facilitate groundwater recharge, provide seasonal aquatic habitat, support corridors of native riparian forests and create shaded riverine and terrestrial habitats. Carbon sequestration within large, vegetated floodplain corridors may also assist the state in meeting greenhouse gas emissions reductions mandated by AB 32.

- The state should work with dam owners and operators, federal resource management agencies, and other stakeholders to evaluate opportunities to introduce or reintroduce anadromous fish to upper watersheds. Reestablishing anadromous fish, such as salmon, upstream of dams may provide flexibility in providing cold water conditions downstream, and thereby help inform system reoperation. Candidate watersheds should have sufficient habitat to support spawning and rearing of self-sustaining populations.

- The state should identify and strategically prioritize for protection lands at the boundaries of the San Francisco Bay and Sacramento-San Joaquin Delta that will provide the habitat range for tidal wetlands to adapt to sea level rise. Such lands help maintain estuarine ecosystem functions and create natural land features that act as storm buffers, protecting people and property from flood damages related to sea level rise and storm surges.
- The state should prioritize and expand Delta island subsidence reversal and land accretion projects to create equilibrium between land and estuary elevations along select Delta fringes and islands. Sediment-soil accretion is a cost-effective, natural process that can help sustain the Delta ecosystem and protect Delta communities from inundation.
- The state should consider actions to protect, enhance and restore upper watershed forests and meadow systems that act as natural water and snow storage. This measure not only improves water supply reliability and protects water quality, but also safeguards significant high elevation habitats and migratory corridors.

Left: *Sacramento-San Joaquin Delta, with Mount Diablo in background*

Below: *Los Vaqueros Reservoir*

Strategy 6: Expand Water Storage and Conjunctive Management of Surface and Groundwater Resources

Surface and groundwater resources must be managed conjunctively to meet the challenges posed by climate change. Additional water storage and conveyance improvements are necessary to provide flexibility to facilitate water transfers between regions and to provide better flood management, water quality and system reliability, in response to daily and seasonal variations and uncertainties in water supply and use.

Historically, California has depended upon its groundwater, particularly during droughts. However, many aquifers are contaminated and must be remediated before they can be used as water banks. Groundwater resources will not be immune to climate change; in fact, historic patterns of groundwater recharge may change considerably. Climate change may worsen droughts, so more efficient groundwater basin management will be necessary to avoid additional overdraft, to take advantage of opportunities to store water underground and eliminate existing overdraft.

Better management of surface storage reservoirs can also provide benefits in a changing climate. Among the benefits are capturing higher peak flows, providing cold water releases for fish, repulsing seawater intrusion to protect drinking water quality, generating clean hydroelectricity, and offsetting the loss of snowpack storage with increased water storage.

- California must expand its available water storage including both surface and groundwater storage.
- DWR will incorporate climate change considerations as it works with the U.S. Bureau of Reclamation (Reclamation) and local agencies to complete surface storage feasibility studies and environmental documentation for the Sites Reservoir and Upper San Joaquin River Basin Storage Investigations. DWR will also make climate change recommendations as it works cooperatively with Contra Costa Water District on the Los Vaqueros Reservoir Expansion Investigation, and DWR will advise Reclamation on climate change matters on the Shasta Lake Water Resources Investigation.

Conjunctive Management

Conjunctive management of surface water and groundwater refers to the joint and coordinated management of both resources. Surface water and groundwater resources typically differ significantly in their availability, quality, management needs, and development and use costs. Managing both resources together, rather than in isolation from one another, allows water managers to use the advantages of both resources for maximum benefit.

Groundwater pump

- State, federal, and local agencies should develop conjunctive use management plans that integrate floodplain management, groundwater banking and surface storage. Such plans could help facilitate system reoperation and provide a framework for the development of local projects that are beneficial across regions.

- Local agencies should develop and implement AB 3030 Groundwater Management Plans as a fundamental component of IRWM plans. Local agencies must have such groundwater management plans to:
  - Effectively use aquifers as water banks;
  - Protect and improve water quality;
  - Prevent seawater intrusion of coastal aquifers caused by sea level rise;
  - Monitor withdrawals and levels;
  - Coordinate with other regional planning efforts to identify and pursue opportunities for interregional conjunctive management;
  - Avert otherwise inevitable conflicts in water supply; and
  - Provide for sustainable groundwater use.

Irrigation in California's Central Valley

- Local land use agencies should adopt ordinances that protect the natural functioning of groundwater recharge areas.

Strategy 7: Fix Delta Water Supply, Quality and Ecosystem Conditions

The Sacramento-San Joaquin Delta is a vital water supply for 25 million Californians, a diverse and complex ecosystem, home to many communities and ultimately is a place unique to California. The Delta is not considered sustainable under current management efforts. Warmer temperatures, sea level rise and higher flood flows brought by climate change threaten to further erode the Delta's sustainability. The Delta Vision Task Force published its vision for the Delta in December 2007. In that vision, the Task Force described a future in which the Delta will continue to thrive over the coming generations, despite major challenges including climate change. The Task Force is working on a strategic plan that will outline the recommendations to realize the Task Force's vision.

In addition to the work of Delta Vision, there are three other major public processes also focusing on the Delta: the Bay-Delta Conservation Plan (BDCP), the Delta Risk Management Strategy (DRMS) and the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) (see next page).

- State agencies and stakeholders should continue to support the work of the Delta Vision Task Force, BDCP, DRMS, and DRERIP, and encourage the incorporation of adaptive responses to climate change for the Delta in all four processes.
- By June 2009, affected state agencies, led by DWR, will initiate a coordinated effort to invest in the Delta ecosystem, water conveyance improvements, flood protection and community sustainability in order to achieve a sustainable Delta.

Canadian Geese in Sacramento-San Joaquin Delta

Delta at sunset

Delta Planning Processes and Climate Change

State government is currently involved in four major planning efforts to evaluate Sacramento-San Joaquin Delta ecosystem and water supply issues and to recommend strategies and actions for their improvement — the Delta Vision, Bay-Delta Conservation Plan (BDCP), Delta Risk Management Strategy (DRMS), and Delta Regional Ecosystem Restoration Implementation Plan (DRERIP). These efforts are complementary but each process has a specific focus. All are considering the impacts of climate change on the Delta as well as a number of response strategies. Together, they should provide a set of adaptive strategies and actions that are comprehensive, consistent and build upon each other to improve the Delta ecosystem and water supply reliability.

The Governor established **Delta Vision** in 2006 to develop a durable vision for sustainable management of the Delta. Over the long term, the Delta Vision process aims to restore and maintain functions and values that are determined to be important to the environmental quality of the Delta and the economic and social well being of the people of the state. In December 2007, the Delta Vision Task Force published its Delta Vision Report comprised of 12 recommendations and in October 2008, submitted their Delta Strategic Plan to the Delta Vision Cabinet Commitee. The Cabinet Commitee will provide specific recommendations to the Governor and Legislature by the end of 2008. More information is available at **www.deltavision.ca.gov**.

The purpose of the **BDCP** is to help recover endangered and sensitive species and their habitats in the Delta in a way that also provides for sufficient and reliable water supplies. The BDCP will (1) identify and implement conservation strategies to improve the overall ecological health of the Delta, (2) identify and implement ecologically friendly ways to move fresh water through and/or around the Delta, (3) address toxic pollutants, invasive species and impairments to water quality, and (4) provide a framework to implement the plan over time. More information is available at **www.resources.ca.gov/bdcp**.

DRMS is evaluating the risks from Delta levee failures and ways to reduce those risks. Preliminary evaluations by DRMS show that the risks from earthquakes and floods are substantial and are expected to increase in the future. In Phase 1, DRMS evaluates the risk and consequences to the Delta and statewide associated with the failure of Delta levees. In Phase 2, DRMS will evaluate strategies and actions to reduce risks and consequences. Additional information is available at **www.drms.water.ca.gov**.

The **DRERIP** is identifying restoration opportunities within the Delta and Suisun Marsh ecological restoration zones. It applies the Ecosystem Restoration Program Conservation Strategy to the Delta, refines existing and develops new Delta restoration actions, and includes a conceptual model, implementation guidance, program tracking, performance evaluation, and adaptive management feedback. Additional information at **www.delta.dfg.ca.gov/erpdeltaplan**.

Improving Management and Decision-Making Capacity

Determining the impacts of climate change on the varying regions of the state requires that data about our environment be collected and analyzed in a consistent and comprehensive way. Analysis of past records, current conditions, and trends can help provide a forecast for weather, climate, supply, and flooding variables. Unfortunately, sensors and gauges that measure this information, both offshore and over land, are currently inadequate. Strategic investment is needed in measurement networks, data analysis and archiving, and forecast tools that can support operational and policy decisions by users. Additionally, funding must be sustained in all of these areas to preserve the unbroken records that are vital to understanding the impacts of climate change.

Strategy 8: Preserve, Upgrade and Increase Monitoring, Data Analysis and Management

Uncertainty in the rate and magnitude of long-term climate change must be reduced. As one example, there are currently large gaps in the hydrologic observational network (e.g. rain and snow gauges) in the areas of California most vulnerable to climate change. Improved data analysis, and interpretation supported by a robust monitoring network can help identify trends, provide for better real-time system management, and evaluate and, if necessary, correct, adaptation strategies.

- For data to be useful in climate monitoring and climate change detection, there must be better and more consistent monitoring of critical variables such as temperature, precipitation, evapotranspiration, wind, snow level, vegetative cover, soil moisture and streamflow. Expanded monitoring is especially needed at high elevations and in wilderness areas to observe and track changes occurring in the rain/snow transition zone, which is critical for projecting future water supply.
- Similarly, improved observations of atmospheric conditions are needed to help define and better understand the mechanisms of the underlying atmospheric processes that lead to California's seasonal and geographic distribution of precipitation. This will help climate modelers to better project future rain and snow patterns on a regional scale.
- Information on water use is currently limited and often unreliable. Accurate measurement of water use can facilitate better water planning and management. By 2009, DWR, the state and regional Water Boards, the Department of Public Health, and the California Bay-Delta Authority will complete a feasibility study for a water use measurement database and reporting system.

Western Governors' Association

In 2006, the Western Governors' Association (WGA) released its report on Water Needs and Strategies for a Sustainable Future, which called for member states to take specified actions to incorporate consideration of climate change into state water management. That document was followed by a 2008 WGA Next Steps report which further detailed recommendations to "change for the better the way states and the federal government carry out their respective responsibilities regarding water management in the West."

For more information about the implementation of the reports' recommendations go to **www.westgov.org**.

PIER

In 2003, the California Energy Commission created the California Climate Change Center to implement the Commission's Public Interest Energy Research (PIER) Program long-term climate change research plan. The Center is a virtual research organization with core research at the Scripps Institute and complementary research at other scientific institutions in California.

Of particular interest to the water community are studies from the 2006 and upcoming 2008 Biennial Climate Science Reports required by Executive Order S-3-05, signed by Governor Schwarzenegger on June 1, 2005.

For more information go to **www.climatechange.ca.gov/research**.

Strategy 9: Plan for and Adapt to Sea Level Rise

Of the many impacts of climate change, sea level rise presents the most difficult planning challenge because of the great uncertainty around ice sheet dynamics, and the resulting range of consequences. In addition, sea level rise depends upon regional factors such as land movement (e.g. tectonic uplift) and atmospheric conditions. Much of the Sacramento-San Joaquin Delta consists of islands that are below sea level and protected by levees of varying stability. Rising sea levels increase pressure on fragile levees and pose a threat to water quality. Local and regional investments in coastal water and flood management infrastructure, as well as coastal and bay wetlands, beaches and parks, are also vulnerable to rising seas.

- The state will establish an interim range of sea level rise projections for short-term planning purposes for local, regional and statewide projects and activities.
- The Resources Agency, in coordination with DWR and other state agencies, should convene and support a scientific panel of the National Research Council (NRC) to provide expert guidance regarding long-range sea level rise estimates and their application to specific California planning issues.
- Based upon guidance from the NRC, DWR, in collaboration with other state agencies, will develop long-range sea level rise scenarios and response strategies to be included in the California Water Plan Update 2013.

Strategy 10: Identify and Fund Focused Climate Change Impacts and Adaptation Research and Analysis

State Capitol, Sacramento

Developing more focused research can help narrow the range of uncertainty in climate change, with a concentration on the vulnerability of water and other natural resources. This research will assist in planning for new projects, management activities and policies.

- In association with research institutions such as the Regional Integrated Sciences and Assessment centers, Lawrence Livermore and Berkeley National Laboratories, and the University of California, state agencies should identify focused research needs to provide guidance on activities to reduce California's vulnerability to climate change. The state should also explore partnerships with the federal government, other western states, and research institutions on climate change adaptation.
- Since some uncertainty will always exist, the state's water supply and flood management agencies need to perform sensitivity analyses of preliminary planning studies, and risk-based analyses for more advanced planning studies. As noted earlier, until better information becomes available, local agencies should plan for droughts 20 percent more severe than historic droughts. For flooding, sensitivity and risk-based analyses should consider an appropriate risk tolerance and planning horizon for each individual situation. Selection of climate change scenarios for these analyses can be guided by recommendations of the Governor's Climate Action Team.
- The state should sponsor science-based, watershed adaptation research pilot projects to address water management and ecosystem needs. Funding for pilot projects should only be granted in those regions that have adopted IRWM plans that meet DWR's plan standards and have broad stakeholder support.
- As part of the California Water Plan Update process, every five years DWR will provide revised estimates of changes to sea level, droughts, and flooding that can be expected over the following 25 years.

NEXT STEPS

CALIFORNIA WATER PLAN UPDATE 2009

California Water Plan Update 2009 builds upon Update 2005; a strategic plan for managing California's water that promotes Integrated Regional Water Management and improved statewide water management systems. The Update 2009 collaborative process has at its center a steering committee of 20 state agencies with jurisdictions over California water issues. The improved interagency coordination provides a robust statewide perspective and the inclusion of state companion plans helps inform an added emphasis on climate change, water quality, and integrated flood management. Update 2009 is specifically advised by a Climate Change Technical Advisory Group composed of scientists and engineers with climate change expertise.

Find out more at **www.waterplan.water.ca.gov**.

CALIFORNIA CLIMATE ADAPTATION STRATEGY

Building upon the recommendations and strategies set forth in this document, the California Resources Agency is coordinating the development of a statewide, cross-sector Climate Adaptation Strategy (CAS). The CAS will synthesize the most up-to-date information on expected climate change impacts to California, provide preliminary strategies to reduce the state's vulnerability to these impacts and develop plans for short and long-term actions.

For more information please go to **www.climatechange.ca.gov/adaptation**.

ACKNOWLEDGEMENTS

The Department of Water Resources wishes to thank the members of the following groups for the feedback they provided during the development of this document.

Climate Change Technical Advisory Group of the California Water Plan Update 2009

State Steering Committee of the California Water Plan Update 2009

California Resources Agency Climate Team

DWR's Climate Change Matrix Team

There are several foundational reports and processes that guide the development of climate change responses.

Intergovernmental Panel on Climate Change, Fourth Assessment Report (2007)

California Water Plan Update 2005 and the draft Update 2009, including Regional Water Quality Control Plans (Basin Plans), DWR and SWRCB

Proceedings of the Climate Change Research Needs Workshop, Western States Water Council (2007)

Public Interest Energy Research Program, California Energy Commission

Biennial Report, Governor's Climate Action Team (2006)

Progress on Incorporating Climate Change into Management of California's Water Resources, DWR (2006)

Draft FloodSAFE Strategic Plan, DWR (2008)

Draft Delta Vision Blue Ribbon Task Force Strategic Plan (2008)

Water Needs and Strategies for a Sustainable Future, Western Governors Association (2006)

CALIFORNIA DEPARTMENT OF WATER RESOURCES

1416 Ninth Street, Sacramento, CA 95814

www.climatechange.water.ca.gov