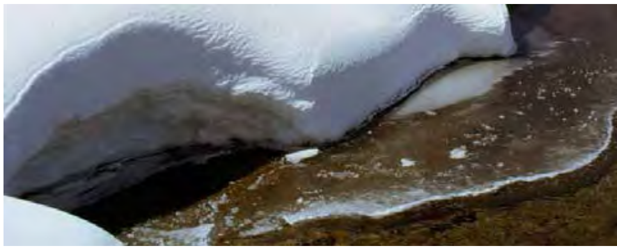
CALIFORNIA DEPARTMENT OF WATER RESOURCES



California Climate Science and Data

FOR WATER RESOURCES MANAGEMENT

June 2015

The California Department of Water Resources

is engaged in the science and data critical for climate change adaptation and mitigation. This booklet summarizes the latest indicators, implications and strategies for water managers in California with regard to a changing climate and the water-energy nexus. The steady march toward warmer global temperatures, greater weather extremes, reduced snowpack, higher sea level, and compromised water supply reliability warrant consideration by water managers in their decision making.

Unless otherwise indicated, scientific literature references are from the California Water Plan Update 2013 http://www.waterplan.water.ca.gov/cwpu2013/final/index.cfm.

For more on DWR's Climate Change Program and contact information, please go to: http://www.water.ca.gov/climatechange/.

Elissa Lynn, Editor

Climate Change Program, June 2015.

Introduction

Climate change creates critical challenges for California water resources management. The vulnerability of the water sector to climate change stems from a modified hydrology that affects the frequency, magnitude, and duration of extreme events, which, in turn, affect water quantity, quality, and infrastructure. Warmer temperatures drive the snow line higher and reduce snowpack, resulting in less water storage. Intense rainfall events will continue to affect the state, possibly leading to more frequent and/or more extensive flooding. The acceleration of sea level rise will produce higher storm surges during coastal storms. Droughts are likely to become more frequent and persistent during this century.

Because California contains multiple climate zones, each region of the state will experience a combination of impacts from climate change unique to that area. While significant uncertainties still remain for local precipitation and temperature changes, projections at the regional and statewide levels are already available. Water supply managers in California have multiple tools and institutional capabilities to limit vulnerability to changing conditions, which can also serve as response mechanisms to a wide range of climate changes.

This brochure summarizes the observations, projections, and challenges that climate change poses for water resources management in California, and highlights climate change content developed for the California Water Plan Update 2013 (http://www.waterplan.water.ca.gov/cwpu2013/final/index.cfm),

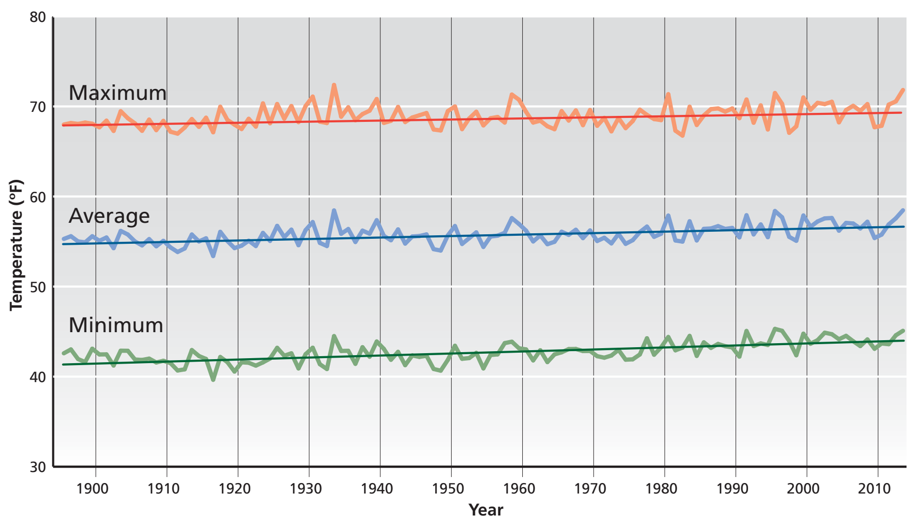
The impacts of climate change in California have been detected in temperature, precipitation and runoff records. Snowpack has historically served California as a critical reservoir, melting during the peak demand period in late spring and summer. As the climate continues to warm, flood protection, water supply infrastructure and water management practices may need to be adapted to address the impacts of California's changing hydrologic regime.

What Changes Have Been Observed in California?

TEMPERATURES

California temperatures have shown a warming trend in the past century. According to the Western Region Climate Center, the state has experienced an increase of 1.1 to 2 degrees Fahrenheit (°F) in mean temperature in the past century. Both minimum and maximum annual temperatures have increased, but the minimum temperatures (+1.6 to 2.5 °F) have increased more than maximums (+0.4 to 1.6 °F).

California's Observed Average Temperatures



Temperatures in California have undergone a slow but steady warming over the past century. These trends indicate higher wildfire potential, habitat risk, and changing hydrology. Observational air temperatures for California can be found on the California Climate Tracker at the Western Region Climate Center: http://www.wrcc.dri.edu/monitor/cal-mon/.

CoCoRaHS

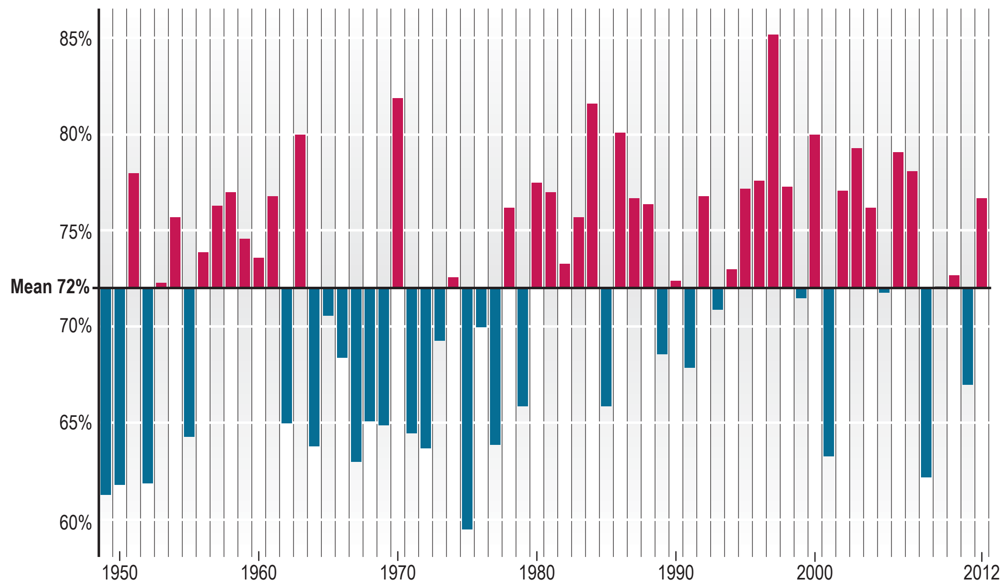
The Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) is a non-profit, community based network of volunteers that take daily local measurements of rain, hail and snow. By providing high quality, accurate measurements, the observers supplement existing automated networks and provide useful data to scientists, resource managers, and decision makers. The DWR Climate Change Program staff support CoCoRaHS through regional coordination, data management, and volunteer recruitment. Staff also promote CoCoRaHS through science and water workshops for teachers. To enroll in the program, go to: http://www.cocorahs.org

Photo courtesy of CoCoRaHS

Rain/Snow Historical Trends

Location of main analysis area in California

Rain as Percentage of Total Precipitation



Percentage of precipitation falling as rain over the 33 main water supply watersheds of the State is shown for water years ending 1949 through 2012 (Oct 1948-Sept 2012), using Western Region Climate Center historic precipitation and freezing level re-analysis (http://www.wrcc.dri.edu/).

These watersheds experience a mean of 72 percent of precipitation as rain; years with red bars have a higher percentage of rain than the mean, and years with blue bars have a lower percentage of rain than the mean. Years with a higher percentage of rain are more common in the later period of record, in agreement with expectations under a warming climate and previous studies. There is substantial annual variability due to climate signals that occur on annual and decadal scales.

http://www.water.ca.gov/climatechange/docs/Estimating%20Historical%20California%20Precipitation%20DWR%20CWP%207-7-2014%20FINAL.pdf

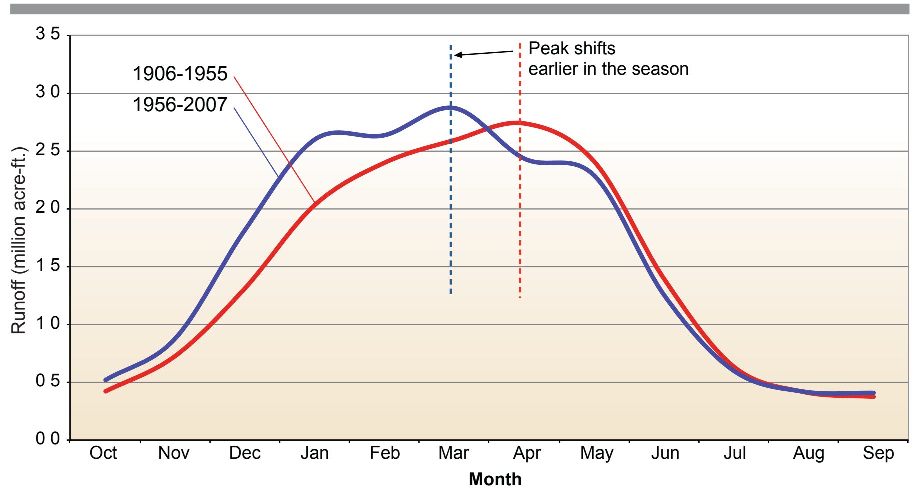
RAIN/SNOW TRENDS

In recent decades, there has been a trend toward more rain than snow in the total precipitation volume. This factor plays a role in reducing total snowpack, which represents up to one-third of the state's water supply.

RUNOFF TIMING

The timing of runoff has changed in California's largest water-supply watershed, the Sacramento River System, shifting to earlier in the season. Snowmelt provides an annual average of 15 million acre feet of water, slowly released by melting from about April to 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. The water management community has invested in, and depends on, a system based on historical hydrology, but managing to historical trends will no longer work.

Monthly Average Runoff of Sacramento River System



Average monthly runoff in the Sacramento River System is a critical component of California's water supply. Flood protection and water supply infrastructure have been designed and optimized for historical conditions. However, the timing of peak monthly runoff between 1906-1955 (red line) and 1956-2007 (blue line) has shifted nearly a month earlier indicating that this key hydrology metric is no longer stationary. Timing is projected to continue to move earlier in the year, further constraining water management by reducing the ability to refill reservoirs after the flood season has passed.

PALEOCLIMATE (TREE RING) RECORDS

The value of paleoclimatic records is to document natural climate variability, including extreme events, prior to the period of instrumental records. The information is also helpful in assessing the skill of climate models in representing past conditions, such as extended periods of drought. Tree-ring data from species such as western juniper and Jeffrey pine give climate scientists a record of natural hydrologic variability extending centuries into the past. University of Arizona scientists from the Laboratory of Tree-Ring Research have developed hydrologic reconstructions for the Sacramento, San Joaquin and Klamath Rivers for the California Department of Water Resources.

The decadal scale droughts of the 1920s-30s and 1980s-90s, particularly in the Sacramento and San Joaquin River basins, remain notably severe in the centuries-to-millennium context. For the Sacramento and San Joaquin River Basins the record-low flow occurred in the year 1580, with only about half the total flow of the driest reconstructed year (1924) of the modern measured time frame.

The 12th century contains the driest 50-year period in the Sacramento basin, while late 1400s contains multi-decadal periods with flows lower than 20th and 21st century droughts of this length in the San Joaquin. In the Klamath River basin, single and multi-year periods of drought in the latter half of the 1600's were the most severe periods in this reconstruction.

California's multi-year drought that began in 2012 will certainly rank as one of the driest periods on record, but its duration and the coincident temperatures will determine final comparison with the paleoclimatic extremes.

Western juniper from Sardine Point, Sierra Nevada, California (inner ring date: 830; outer ring date: 1342). Such samples from snags and remnant wood on the landscape in the Sierra Nevada and Rocky Mountains reveal past episodes of widespread multi-decadal drought unmatched in duration and severity by droughts of recent centuries. Drought in the mid-1100s was unusual for encompassing both the Sacramento and Colorado River Basins. Collected July 2013 by the University of Arizona, Laboratory of Tree-Ring Research, Tucson, AZ. The Paleoclimate Study can be accessed at http://www.water.ca.gov/climatechange/articles.cfm

What Does the Future Hold?

TEMPERATURE PROJECTIONS

Future projections of temperatures across California by Scripps Institution of Oceanography indicate that by 2060-2069 mean temperatures will be 3.4 to 4.9 °F higher across the state than they were in the period 1985-94. Seasonal trends indicate a greater increase in the summer months (4.1 to 6.5 °F) than in winter months (2.7 to 3.6 °F) by 2060-2069.

PRECIPITATION PROJECTIONS

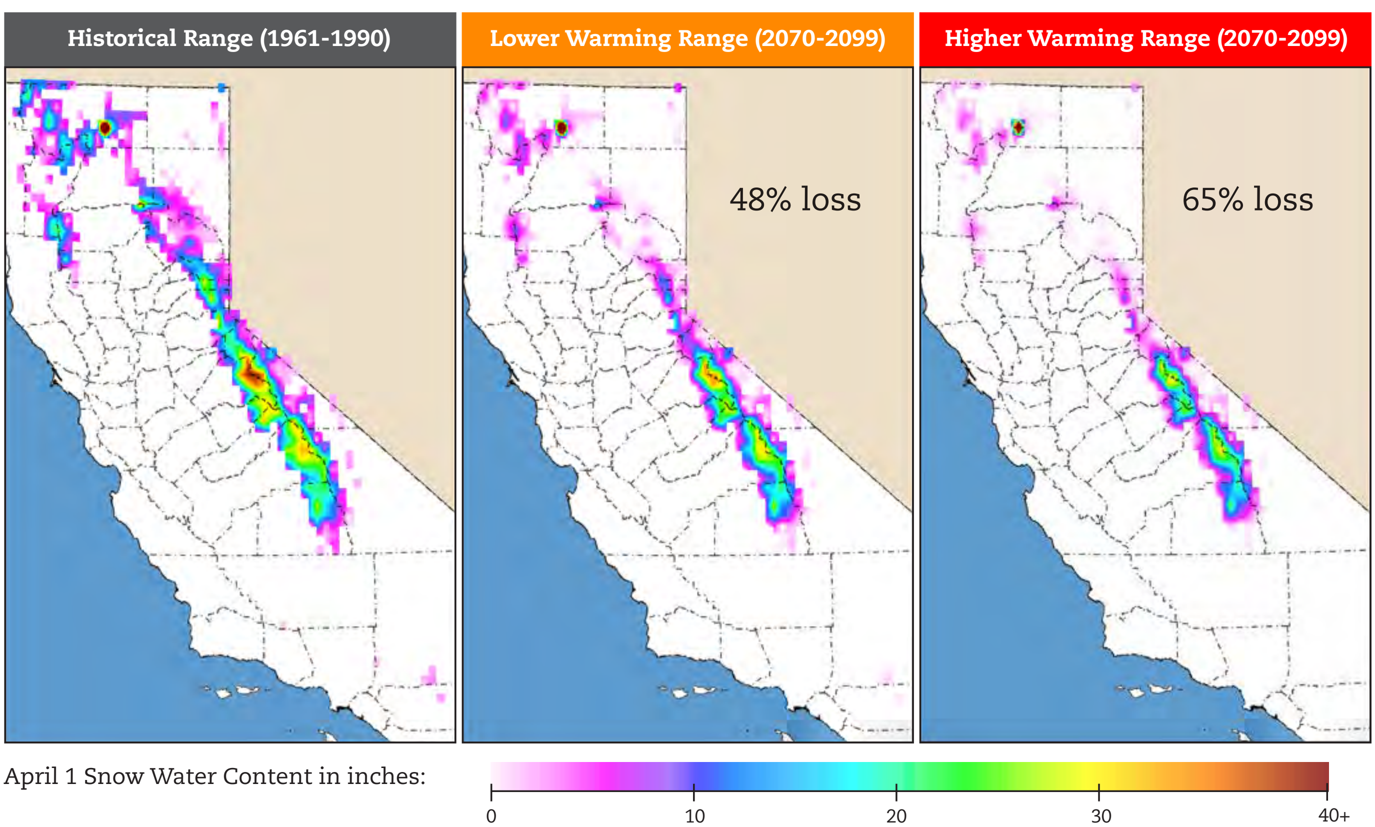
Climate change will lead to a number of hydrologic impacts for California. More intense dry periods are anticipated under warmer conditions, leading to extended, more frequent drought. Extremes on the wet end of the spectrum are also expected to increase, due to more frequent warm, wet atmospheric river events and a higher proportion of precipitation falling as rain instead of snow. These wetter extremes impact the system's ability to provide effective flood protection.

Most climate model precipitation projections for the state anticipate drier conditions in Southern California, with heavier and warmer winter precipitation in Northern California. Because there is less scientific detail on localized precipitation changes, there is a need to adapt to this uncertainty at the regional level (see pages 14-17).

SNOWPACK PROJECTIONS

While observed trends indicate California's climate is already changing, future climate change is anticipated to bring even greater water resource impacts. Based on modeling research at Scripps Institution of Oceanography, by the end of the century, the Sierra snowpack may experience a 48-65 percent loss from the 1961-1990 average. As the northern Sierra's peaks are relatively lower than the southern Sierra, a warmer climate is projected to cause greater snowpack reduction in the state's northern mountains.

Historical and Projected California Snowpack



Historical and projected April 1 Snow Water content for the Sierra for lower and higher warming scenarios depicting the effect of human generated greenhouse gases and aerosols on climate. By the end of this century, the Sierra snowpack is projected to experience a 48 to 65 percent loss from its average at the end of the previous century.

HOW DO SCIENTISTS USE CLIMATE MODELS IN CALIFORNIA?

Climate models are computer programs that use mathematical equations to represent relevant processes in the atmosphere, ocean, land and ice that make up the earth's climate system. Different global climate models (GCMs) are run on large computer systems at several international centers to explore past, present and possible future climate conditions. GCMs are "driven" by known or assumed climate forcings, including fluctuations in solar energy, volcanic activity, changing greenhouse house gas concentrations, aerosols, and land use changes. Based on these forcings, GCMs project global climate conditions and how they might change over time. A "simulation" refers to a single run of a GCM for one set of climate conditions.

Climate change simulations are not perfect forecasts; they are affected by uncertainty in assumed future emissions of aerosols and greenhouse gases, the model's representation of the real climate system, and natural variability. Because of these uncertainties, climate scientists consider ensembles (groups) of climate simulations from several GCMs to investigate different scenarios and a range of possible future variations and changes. Additionally, the climate science community is exploring a set of possible "Representative Concentration Pathways" which provide scenarios of future greenhouse gas emissions and other anthropogenic influences. The various GCMs are run to represent each of these future scenarios, resulting in hundreds of available climate simulations.

GCMs provide broad-brush representations of temperatures, precipitation amounts and timing, winds and other hydrologic processes. In a GCM, the complexity of California's topography and climate is simplified and is represented by merely a handful of data points. To determine watershed- or regional-level responses to climate and hydrologic changes, the data from a GCM must be developed to a finer scale through a process known as downscaling.

Climate model simulations do not provide strong consensus regarding precipitation trends in most locations around the globe, including California. It is possible that throughout the 21st century, the total amount of precipitation statewide will remain, on average, about the same. However, the distribution, timing and type of that precipitation may vary. What is quite certain is that future years will continue to be subjected to natural climate variability, such as El Niño and other large-time-scale oscillations.

Climate model simulations provide greater consensus in temperature trends - virtually all models show significant warming in future decades. Climate models project that by mid-century (2060-2069) temperatures in California will be 3.4 to 4.9 °F higher across the state than they were from 1985 to 1994.

Climate modeling will continue to produce more realistic and improved capability to explore future conditions, as observations accumulate and better fundamental understanding is gained by scientists. These advances will lead to a better understanding of possible scenarios, including the frequency of extremes such as drought and floods that California will face in the future.

CALIFORNIA STATE CLIMATOLOGIST

The California State Climatologist Office (SCO) is maintained in the Department of Water Resources.. The role of the SCO is to collaborate with National Oceanic and Atmospheric Administration programs to provide climate information and interpretation for California, and work with Department of Water Resources personnel, other State and federal agencies and the academic community on projects related to climate, climate change, and their intersection with water management.

http://www.water.ca.gov/floodmgmt/hafoo/csc/

AASC
AMERICAN ASSOCIATION OF STATE CLIMATOLOGISTS

Choosing Global Climate Models to use for California Water Resources Planning

Criteria

- Scientists recommend using information from several Global Climate Models
- Using information from all available GCMs isn't practical
- Remove GCMs that fall short in representing historical climate and hydrologic processes important for California's water resources planning

Method

Start with 31[1] GCMs

Global

Global Climatology Filter[2,3]

Evaluate how each GCM represents global historical

- Solar Radiation
- Air Temperature
- Atmospheric Pressure, Wind

Remove ~10 GCMs

Western U.S.

Western U.S. Climate & Hydrology Filter[4]

Evaluate how each GCM represents Western US historical

- Air Temperature
- Precipitation
- Atmospheric Pressure Patterns
- El Niño Southern Oscillation Patterns

Remove ~5 GCMs

California

California Hydrology & Extremes Filter

Evaluate how each GCM represents California historical

- Dry and Wet Precipitation Extremes
- Heat Waves and Cold Snaps
- El Niño Spatial and Temporal Patterns

Remove ~5 GCMs

10 GCMs to use for CA water planning

GCM Recommendations for California

The remaining 10 GCMs are recommended for water resources planning because they represent important components of historical climate at global, regional, and statewide scales

References:
[1] CA-DWR Climate Change Technical Advisory Group analysis used GCMs available at the start of the investigation that met certain data requirements (2013).
[2] Gleckler, P. J., Taylor, K. E., and Doutriaux, C.: Performance metrics for climate models, J. Geophys. Res.-Atmos. (2008).
[3] IPCC, Climate Change 2013: The Physical Science Basis, Cambridge University Press, Cambridge, UK and New York (2013).
[4] Rupp, D. E., J. T. Abatzoglou, K. C. Hegewisch, P. W. Mote: Evaluation of CMIP5 20th century climate simulations for the Pacific Northwest USA, J. Geophys. Res.-Atmos. (2013).

CLIMATE MODEL SELECTION

The Department of Water Resources has engaged an external advisory panel, the Climate Change Technical Advisory Group (CCTAG), to provide guidance and perspective on climate change analysis for water resources in California (http://www.water.ca.gov/climatechange/cctag.cfm).

A large collection of model simulations is a practical challenge to many users and decision makers because of the large amount of data and number of simulations to process, analyze and evaluate. To develop a more tractable climate change ensemble, a model sampling or "culling" procedure must be undertaken. To identify this subset, first a comparison between model output and historical observations was made. After assessing how GCMs performs globally, each model was reviewed for how well it replicates the climate structure of the western United States, and then finally, for how well it characterizes key variables for managing water resources in California, such as temperature, precipitation and relative humidity. These models comprise a more appropriate subset for water resources analysis than those used in previous climate change studies by the State of California, such as the CAT-12 scenarios (Climate Action Team, 2008), although there is no guarantee that model performance has a strong influence on the credibility of projections.

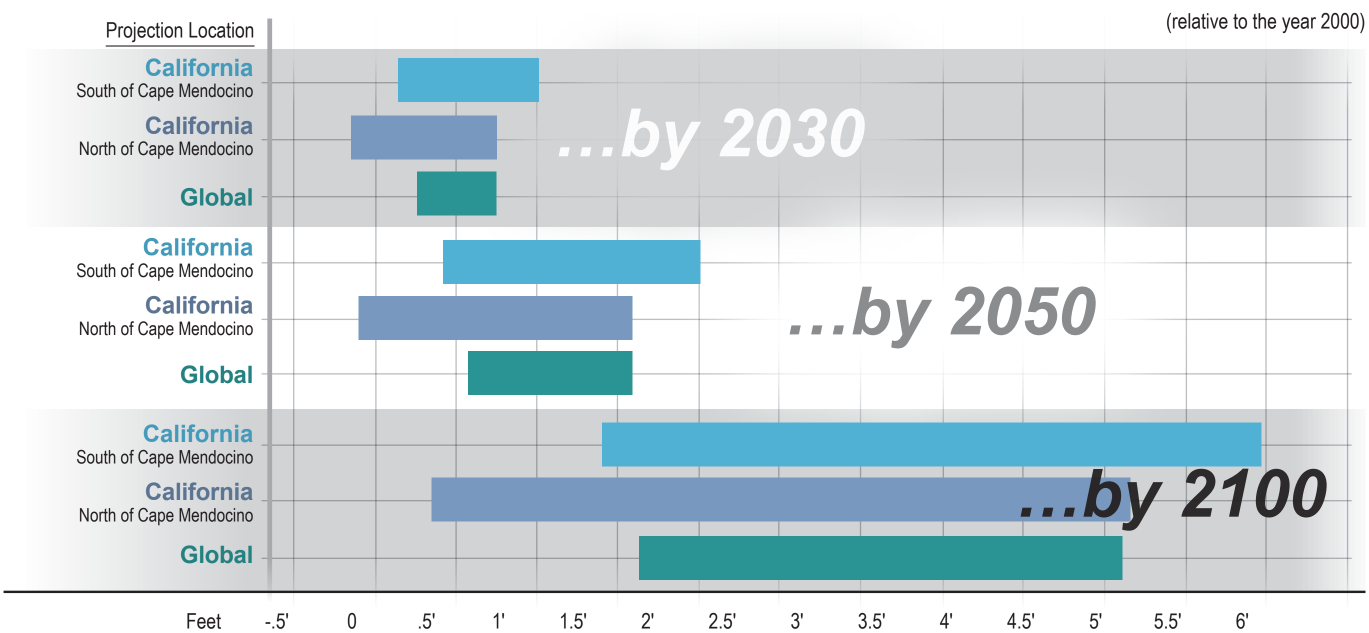
SEA LEVEL RISE

A warming climate causes sea level to rise in two ways; first, by warming the oceans which causes the water to expand, and second, by melting land ice which transfers water to the ocean. Recent satellite data shows that the rate of sea level rise is accelerating, with melting of land ice now the largest component of global sea level rise (about 65 percent), largely because ice loss rates are increasing.

During the last century, sea level at the Golden Gate in San Francisco has shown a 7-inch rise, similar to global measurements. Future sea level rise along the California coast may be uneven. Models indicate that it depends on the global mean sea level rise and regional factors, such as ocean and atmospheric circulation patterns; melting of modern and ancient ice sheets; and tectonic plate movement.

The sea-level rise implications for California include increased risk of storm surge and flooding for coastal residents and infrastructure, including many of the State's low-lying coastal wastewater and recycled water treatment plants. Most coastal damage from sea level rise is caused by the confluence of large waves, storm surges, and high astronomical tides during strong El Niño conditions. The State is vulnerable to these impacts, some of which are projected to increase under climate change. Even if storms do not become more intense and/or frequent, sea level rise itself will magnify the adverse impact of any storm surge and high waves on the California coast. Some observational studies report that the largest waves are already getting higher and winds are getting stronger, but data records do not go back far enough to confirm whether these are long term trends.

California and Global Sea Level Rise projections



Reprinted with permission from "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future," 2012, from the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.

Summary of regional projections of mean sea level rise from a National Research Council of the National Academies (http://dels.nas.edu/Report/Level-Rise-Coasts/13389) study, sponsored by California, Oregon, Washington, and three federal agencies. The highest observed values of sea level rise will occur during winter storms, especially during El Niño years when warmer ocean temperatures result in temporarily increased sea levels. Observed values can be much greater than the mean values shown here. For example, observed California sea levels during winter storms in the 1982-83 El Niño event were similar in magnitude to the mean sea levels now being projected for the end of the 21st century.

For the millions who rely on drinking water or agriculture irrigated by Delta water exports, the most critical impact of rising seas will be additional pressure on an already vulnerable levee and water delivery system, which protects numerous islands currently below sea level and sinking. Catastrophic levee-failure risk continues to increase, with the potential to inundate Delta communities and interrupt water supplies throughout the State. Even without levee failures, Delta water supplies and aquatic habitat may be affected at times, owing to more seawater intrusion caused by sea level rise. Without additional releases of freshwater from reservoirs to repel higher sea levels, sea water will penetrate further into the Delta and will degrade drinking and agricultural water quality and alter ecosystem conditions. Alternatively, releasing additional freshwater from reservoirs to repel the higher sea levels will have impacts on water supply.

Many of the Sacramento-San Joaquin Delta islands lie below sea level, as this view of one of the Delta channels shows. Sea level rise poses an additional threat to already-stressed Delta levees which protect Delta communities and farms, as well as water supplies for millions of Californians.

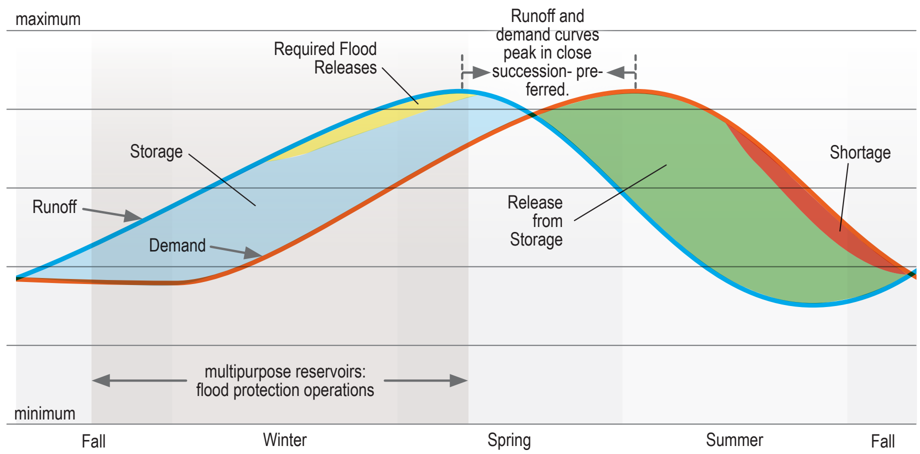
IMPACT TO WATER SUPPLY SYSTEMS

This figure shows conceptually how the hydrologic changes anticipated under a warming climate place additional stress on water supply systems. These changes increase the volume of runoff that arrives at reservoirs during the flood protection season and reduce the stored water available to meet summer peaks in water demand. At the same time, higher temperatures, resulting from climate change, increase peak summer demands beyond historical levels. Existing infrastructure will need to be adapted to the new timing of runoff, as well as accommodate higher flows from more powerful individual storm events in a warmer atmosphere. Overall flexibility needs to be incorporated into water infrastructure and operations.

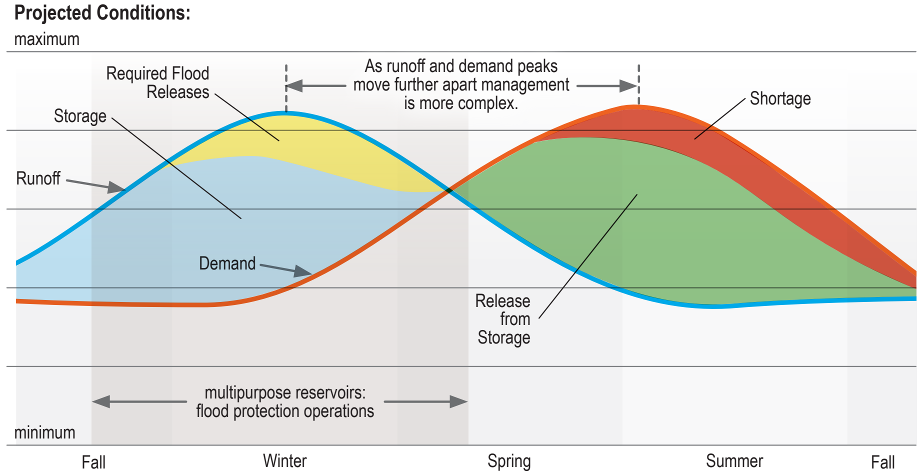
How Earlier Runoff Affects Water Availability

The impacts of earlier runoff and increased summertime water demand are shown conceptually in the two curves. The curves show the general shape and timing of runoff and demand in California (individual watersheds will each have unique characteristics). Under "Current Conditions" (top box) runoff peaks in early spring only a few months before demand peaks in early summer. Much of the difference between high runoff and low demand in fall and winter can be captured and stored in the state's existing surface and groundwater storage facilities. That storage meets most of the demands later in spring and summer and shortages are minimal. Under "Projected Conditions" (lower box) runoff peaks in mid-winter, months before demand peaks in spring and summer. Summer-time demand is higher due to higher temperatures and high demand lasts longer into early fall due to longer growing seasons. Earlier runoff is captured in storage facilities, but because the runoff arrives while reservoirs are being managed for flood protection, much of the runoff must be released to maintain flood protection storage space in reservoirs. In spring and summer demand far exceeds runoff and releases from storage, making shortages much more common.

Current Conditions:



Projected Conditions:

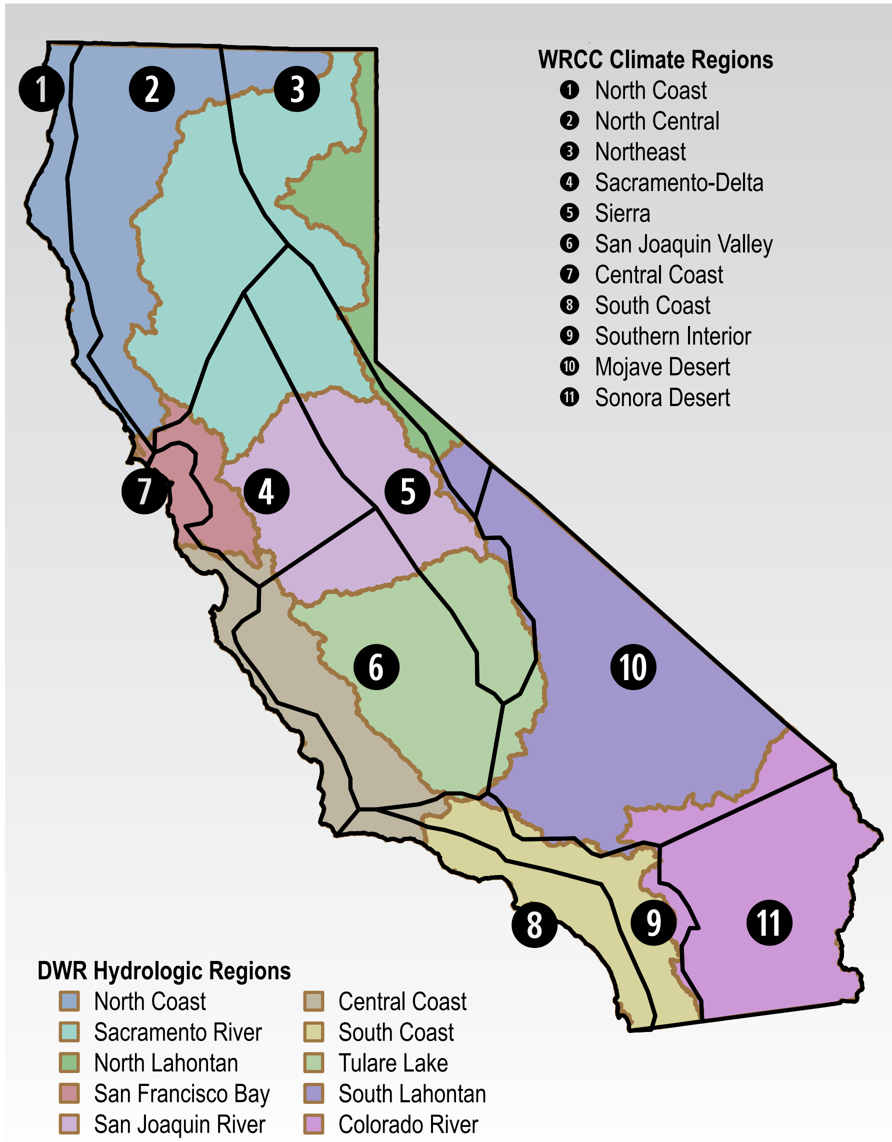


Regional Impacts and Strategies

Due to the geographical, topographic and climatic variations of California, both the impacts from and strategies for climate change are regionally dependent. This sec i n highl ghts regionally specific temperature change observations, projected temperature increases, climate change vulnerabilities and Resource Management Strategies (RMSs) best suited to respond to climate change at the regional level.

The figures on pages 12 and 3 show observed temperature changes and future temperatures projections for various parts of the state. There is a great deal of variability among and within regions for both the historical and future trends. The mapping convention for the temperature figures comes from the Western Region Climate Center, explained below.

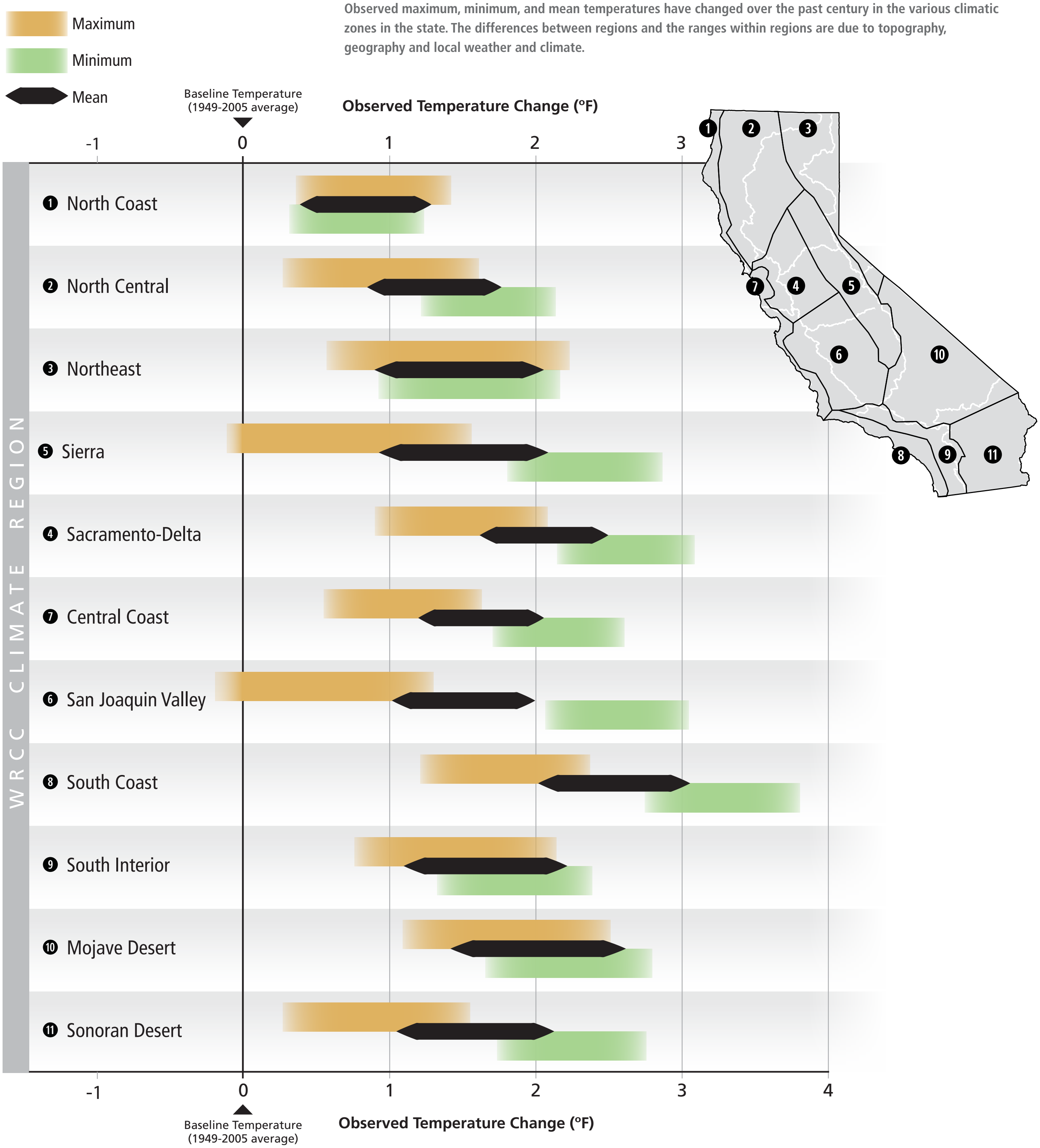
DWR Hydrologic and Western Region Climate Center Climate Regions



The Western Region Climate Center (WRCC) divides California into 11 separate climate regions, and generates historic temperature time-series and trends for these regions (http://www.wrcc.dri.edu/monitor/cal-mon/frames_version.html). DWR uses 10 Hydrologic Regions, with the Delta and Mountain Counties being overlays of other DWR Hydrologic Regions. Each DWR Hydrologic region spans one or more of the WRCC climate regions.

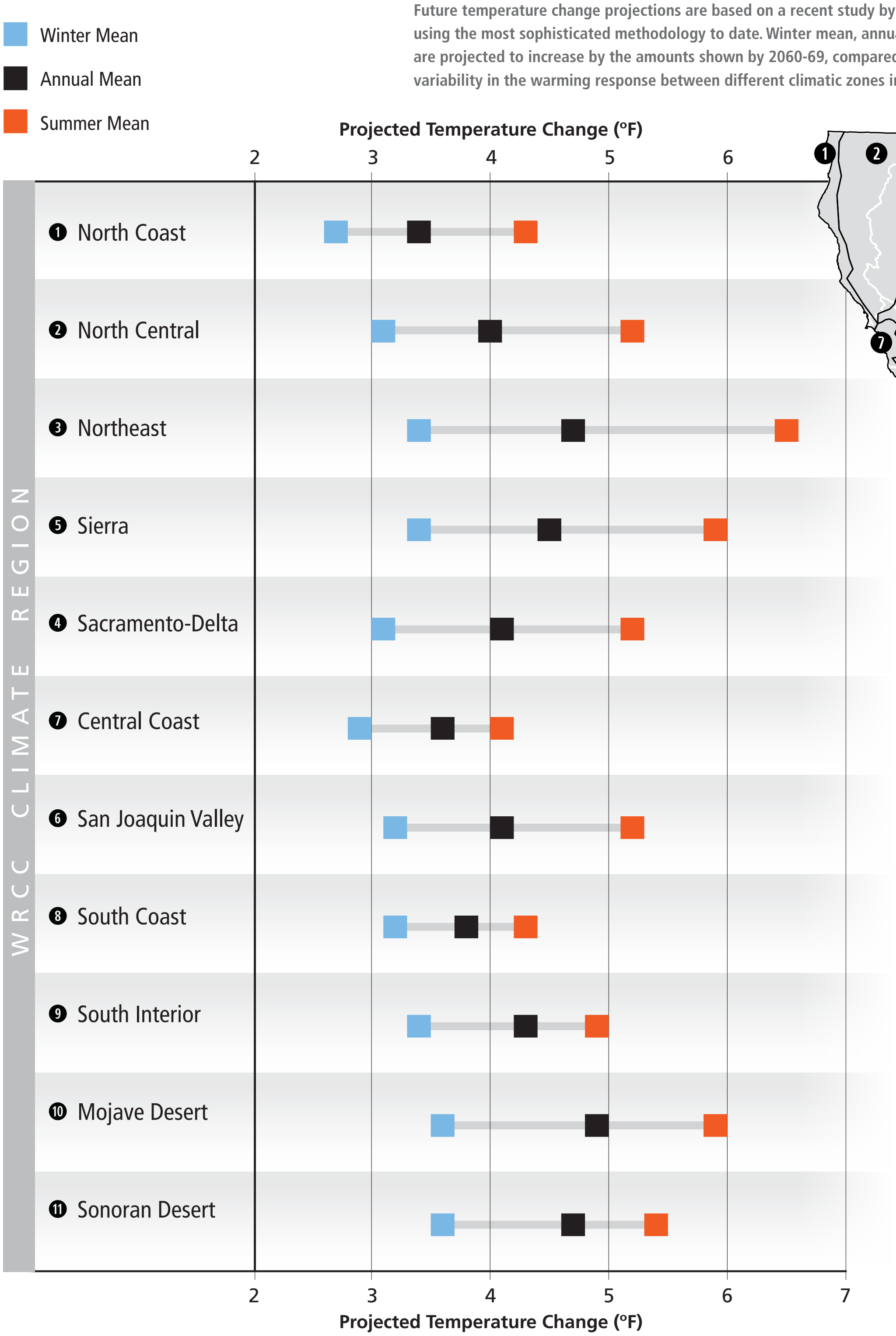
Observed Temperature Change 1895-Present

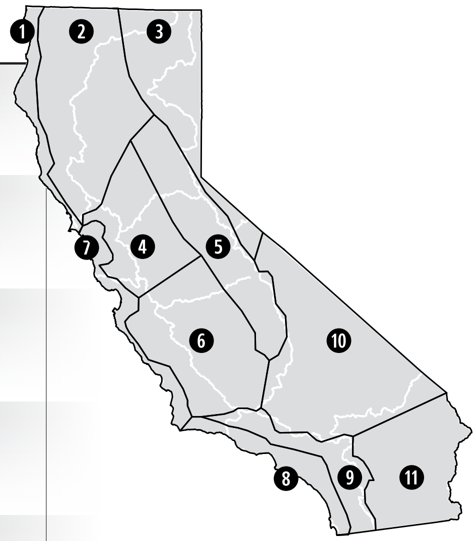
Observed maximum, minimum, and mean temperatures have changed over the past century in the various climatic zones in the state. The differences between regions and the ranges within regions are due to topography, geography and local weather and climate.



Projected Temperature Increase by Mid-21st Century

Future temperature change projections are based on a recent study by Scripps Institution of Oceanography using the most sophisticated methodology to date. Winter mean, annual mean, and summer mean temperatures are projected to increase by the amounts shown by 2060-69, compared to the period from 1985-1994. There is variability in the warming response between different climatic zones in California.





VULNERABILITIES

Because of the economic, geographical, and biological diversity of California, vulnerabilities and risks due to current and anticipated future changes are best assessed on a regional basis. A few of the key climate vulnerabilities for each hydrologic region are provided below to highlight how climate change vulnerabilities vary throughout California (see California Water Plan Update 2013 Hydrologic Regions map on page 15, which are slightly different than the WRCC regions used on pages 12 and 13).

South Coast

- Coastal infrastructure and near-shore ecosystems are vulnerable to increasing sea level and storm surges, while coastal aquifers could be affected by increasing salinity intrusion.
- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk, debris flows, and degradation of habitat for special-status species.
- Higher temperatures and longer dry seasons would increase wildfire risk and impair water quality in local streams and lakes.
- Loss of snowpack storage may reduce reliability of imported water supplies

South Lahontan

- Higher temperatures and longer dry seasons would increase wildfire risk and impair water quality in local streams and lakes.
- Loss of snowpack storage may reduce reliability of surface imported water supplies and replenishment of local supplies, and result in greater demand on groundwater resources.
- Reduced snowpack and changes in runoff timing would impact the winter-dependent economy supporting disadvantaged communities.

Colorado River

- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk and debris flows.
- More frequent and longer droughts would reduce imported water supply reliability and decrease local water quality and habitat.

Central Coast

- Coastal infrastructure and near-shore ecosystems are vulnerable to increasing sea level and storm surges, while coastal aquifers could be affected by increasing salinity intrusion.
- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk, debris flows, and degradation of habitat for special-status species.
- Higher temperatures and longer dry seasons would increase wildfire risk and impair water quality in local streams and lakes.

San Joaquin River

- Loss of snowpack storage may reduce reliability of surface water supplies and result in greater demand on groundwater resources.
- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk, debris flows, and degradation of habitat for special-status species.
- Increased air and water temperatures would place additional stress on sensitive ecosystems and species.
- Increasing temperatures and variable precipitation patterns would affect agricultural crops by reducing winter chill-hours, increasing extreme heat days and increasing evapotranspiration.

Tulare Lake

- Loss of snowpack storage may reduce reliability of surface imported water supplies and replenishment of local supplies, and result in greater demand on groundwater resources.
- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk, debris flows, and degradation of habitat for special-status species.
- Increased air and water temperatures would place additional stress on sensitive ecosystems and species.
- Increasing temperatures and variable precipitation patterns would affect agricultural crops by reducing winter chill-hours, increasing extreme heat days and increasing evapotranspiration.

San Francisco Bay

- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk.
- Sea level rise may increase the susceptibility of tidal wetlands to more frequent, longer and deeper flooding.
- Increases in temperature and changes in precipitation patterns may alter ecosystems and impact native species.
- Loss of snowpack storage may reduce reliability of surface water supplies and result in greater demand on other sources of supply.

Sacramento-San Joaquin Delta (overlay area)

- Increases in temperature and changes in precipitation patterns may alter ecosystems and impact native species.
- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk.
- Water quality may be impacted by lower summer low flows, and increased water temperatures.
- Sea level rise may increase stress on Delta levees and change water quality.

Mountain Counties (overlay area)

- Increases in temperature and changes in precipitation patterns may alter ecosystems and impact native species.
- Loss of snowpack storage may reduce reliability of surface water supplies
- Snowpack reduction may have significant impacts on the water-related tourism industry.
- Higher temperatures and longer dry seasons may increase wildfire risk.

Sacramento River

- Increased air and water temperatures would place additional stress on sensitive ecosystems and species.
- Loss of snowpack storage may reduce reliability of surface water supplies and result in greater demand on groundwater resources.
- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk.
- Water quality could be impacted by more intense storm events, decreased summer low flows, and increased water temperatures.

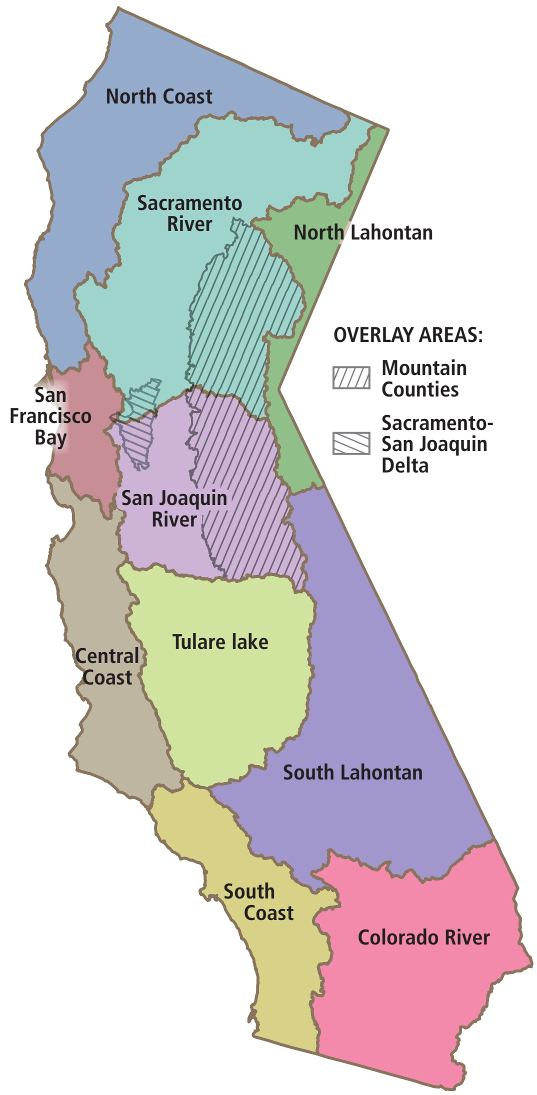
North Coast

- Loss of snowpack storage may reduce summer low flows for local rivers leading to increased stress on fish and other aquatic species.
- Impacts to fisheries are possible due to shifts in ocean chemistry which lower pH, reducing oyster and clam productivity.
- Sea level rise may make tidal marshland susceptible to more frequent, longer and deeper flooding.
- Higher temperatures and longer dry seasons would increase wildfire risk and impair water quality in local streams and lakes.

North Lahontan

- Increased air and water temperatures would place additional stress on sensitive ecosystems and species.
- Loss of snowpack storage may reduce reliability of surface water supplies and result in greater demand on groundwater resources.
- Magnitude and frequency of extreme precipitation events may increase, resulting in greater flood risk.
- Higher temperatures and longer dry seasons would increase wildfire risk.

DWR Hydrologic Regions



CLIMATE CHANGE ADAPTATION THROUGH RESOURCE MANAGEMENT

Climate Change Vulnerability

- Drought
- Flood
- Changing Hydrology
- Sea Level Rise
- Wildfire
- Rising Temperatures
- Ecosystem Services

California Water Plan Update 2013 presented a comprehensive and diverse set of Resource Management Strategies (RMSs) that can help meet the water-related resource management needs of each region and the State. An RMS is a technique, program, or policy that helps local agencies and governments manage their water and related resources. RMSs can be considered as tools in a toolkit. Just as the mix of tools in any given kit depends on the job to be accomplished, the combination of strategies will vary from region to region, depending on climate, projected growth, existing water system, environmental and social conditions, and regional goals.

Each RMS is summarized below along with its potential adaptation benefits for certain climate change vulnerabilities (see key to the left.) For a complete description of each RMS, please visit the California Water Plan Update 2013 at http://www.waterplan.water.ca.gov/cwpu2013/.

Resource Management Strategies

Reduce Water Demand

Agricultural Water Use Efficiency: Water delivery and use practices to achieve net water savings or increased production.

Urban Water Use Efficiency: Practices that maximize use of available water supplies by reducing waste and increasing efficiency.

Improve Flood Management

Flood Management: Considers land and water resources on a watershed scale, employing structural and nonstructural flood management measures to maximize the benefits of floodplains, minimize loss of life and damage to property from flooding, and recognize benefits to ecosystems from periodic flooding.

Improve Operational Efficiency and Transfers

Conveyance – Delta: New facility would help meet the coequal goals of the Delta Plan by providing for a more reliable supply of water while simultaneously maintaining sufficient bypass flows for State and federally listed species of concern.

Conveyance – Regional/Local: Improvement and maintenance of water conveyance systems to improve system reliability, protect water quality, increase available water supplies, and provide operational flexibility.

System Reoperation: Changing existing operation and management procedures for a water resources system consisting of supply and conveyance facilities and end user demands with the goal of increasing desired benefits from the system.

Water Transfers: Temporary or long-term change in the point of diversion, place of use, or purpose of use due to a transfer, sale, lease, or exchange of water or water rights.

Conjunctive Management and Groundwater Storage: Coordinated and planned use and management of surface water and groundwater resources to maximize the availability and reliability of water supplies.

Desalination (Brackish and Sea Water): Removal of salts from saline waters; desalinate sea water for coastal communities and brackish groundwater for inland water users.

Precipitation Enhancement: Commonly called "cloud seeding," artificially stimulates clouds to produce more rainfall or snowfall than they would produce naturally.

Municipal Recycled Water: Recycling of municipal wastewater treated to a specified quality to enable it to be used again.

Surface Storage – CALFED/State: Refers to five potential surface storage reservoirs that are being investigated by the California Department of Water Resources (DWR), U.S. Bureau of Reclamation (USBR), and local water interests. See Surface Storage Regional/Local for surface storage definition.

Surface Storage – Regional/Local: Human-made, above-ground reservoirs to collect water for later release when needed. Surface storage has played a key role in California where the quantity, timing, and location of water demand frequently does not match the natural water supply availability.

Improve Water Quality

Drinking Water Treatment and Distribution: Development and maintenance of public water treatment and distribution facilities. Reliability, quality, and safety of the raw water supplies are critical to achieving this goal.

Groundwater/Aquifer Remediation: Removal of contaminants which affect beneficial use of groundwater.

Matching water quality to use: Management strategy that recognizes that not all water uses require the same water quality.

Pollution Prevention: Reducing or eliminating waste at the source by modifying production processes, promoting the use of non-toxic or less toxic substances, implementation of practices or conservation techniques that reduce generation or discharge of pollutants, and application of alternative technologies to prevent pollutants from entering the environment.

Salt and Salinity Management: Reduces salt loads that impact a region; also a key component of securing, maintaining, and recovering usable water supplies. A few of the ways salts enter surface and ground water supplies are through the natural geology, sea water intrusion and fertilizer application.

Urban Stormwater Runoff Management: Activities to manage both stormwater and dry-weather runoff. Dry-weather runoff occurs when, for example, excess landscape irrigation water flows to the storm drain.

Practice Resource Stewardship

Agricultural Land Stewardship: Agricultural lands used to produce public environmental benefits in conjunction with the food and fiber they have historically provided while keeping lands in private ownership.

Ecosystem Restoration: Improve condition of modified natural landscapes and biological communities to provide for their sustainability and for their use and enjoyment by current and future generations.

Forest Management: Management activities on public and privately-owned forest lands to improve availability and quality of water for downstream users.

Land Use Planning and Management: Collaboration between land use planners and water managers to promote more efficient and effective land-use patterns and integrated regional water management (IRWM) practices to produce safer and more resilient communities.

Sediment Management: Strategies to address excessive sediment in watersheds. Sediment is material such as sand, silt, or clay, suspended in or settled on the bottom of a water body.

Watershed Management: Process of creating and implementing plans, programs, projects, and activities to restore, sustain, and enhance watershed functions.

Recharge Area Protection: Ensuring that areas suitable for recharge continue to be capable of adequate recharge rather than being covered by urban infrastructure, such as buildings and roads, and preventing pollutants from entering groundwater to avoid expensive treatment that may be necessary prior to beneficial use.

People and Water

Economic Incentives: Financial assistance, water pricing, and water market policies intended to influence water management. Economic incentives can influence the amount and time of water use, wastewater volume, and source of water supply.

Outreach and Engagement: Use of tools and practices by water agencies to facilitate contributions by public individuals and groups toward good water management outcomes.

Water and Culture: Linking cultural considerations to water management. Increasing the awareness of how cultural values, uses, and practices are affected by water management, as well as how they affect water management, will help inform policies and decisions.

Water-Dependent Recreation: Planning for water-dependent recreation activities in water projects, water managers play a critical role in ensuring that all Californians today and into the future are able to enjoy such activities.

Other

Other Resource Management Strategies: A variety of water management strategies could potentially generate benefits that meet one or more water management objectives, however these management strategies have limited capacity to strategically address long-term regional water planning needs. Strategies include crop idling for water transfers, dewvaporation or atmospheric pressure desalination, fog collection, irrigated land retirement, rain-fed agriculture, snow fences, and waterbag transport/storage technology.

Water-Energy Nexus

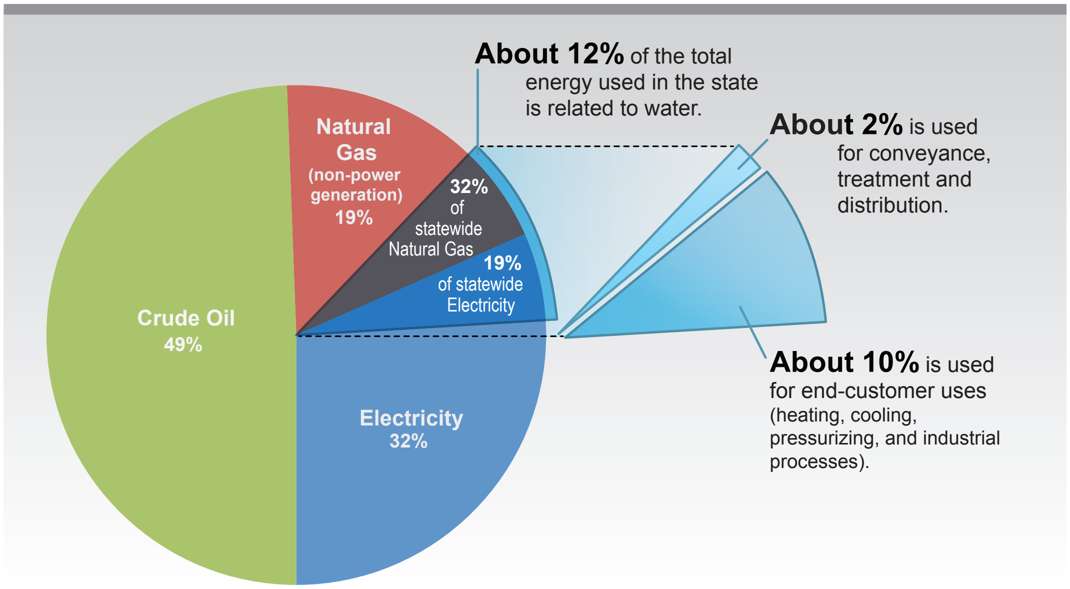
Water and energy have a complex relationship with multiple interdependencies, often called the water-energy nexus. Energy is used throughout the water sector to extract, convey, treat, distribute, and heat water. "Energy intensity" is the total amount of energy calculated on a whole system basis, required for the use of a given amount of water in a specific location.

Water-related energy use in California is depicted in the figure below, including electricity, natural gas, and crude oil consumption. The California Energy Commission's (CEC's) 2005 study estimated that water systems and users in California accounted for about 19 percent of statewide electricity consumption and 32 percent of statewide natural gas (non-power generation) consumption. The majority of water sector energy consumption is by water end-users, including water heating and cooling; advanced treatment by industrial users; and on-site pumping and pressurization for irrigation and other purposes. The remaining water-sector energy consumption occurs in water and wastewater system operations, including water extraction, conveyance, treatment, distribution, and wastewater collection and treatment.

Most electricity generation and energy uses result in greenhouse gas (GHG) emissions related to climate change. Reducing energy intensity and energy uses can reduce GHG emissions in the water sector and contribute to climate change mitigation.

The other side of the water-energy nexus relates to the amount of water used in producing energy, including water used in the energy sector for extraction of natural gas and other fuels, used as the working fluid for hydropower or the working fluid and cooling in thermal generation systems, and used for irrigating biofuels.

Energy Use Related to Water



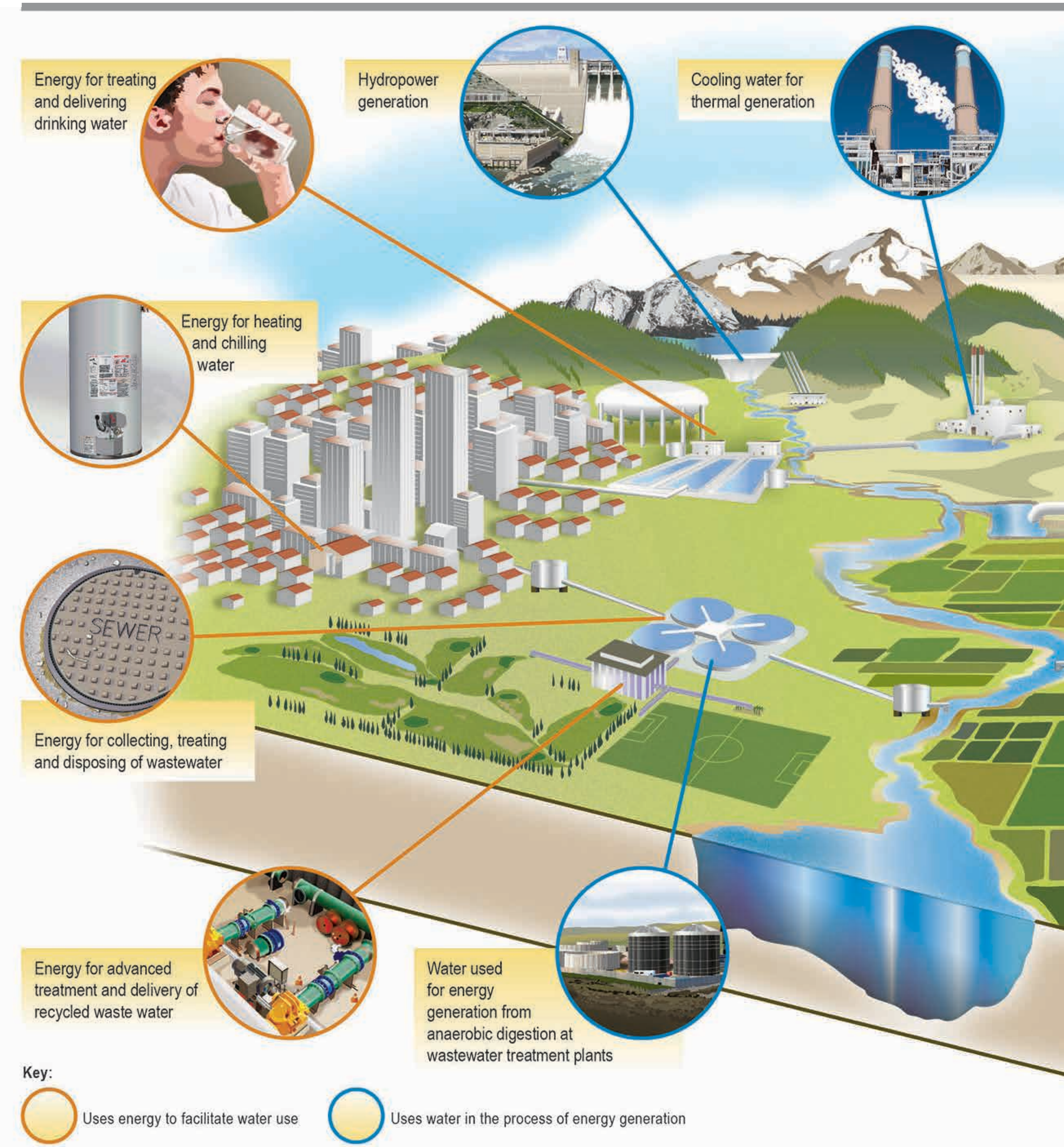
The Lodi Energy Center (shown above), a new natural gas energy plant that opened in August 2012 has enabled California's State Water Project to substantially cut greenhouse gas emissions. The Department of Water Resources (DWR) shares the 296-megawatt capacity facility with Lodi Electric Utility, City of Azusa, Bay Area Rapid Transit (BART), City of Biggs, City of Gridley, City of Healdsburg, City of Lompoc, Modesto Irrigation District, Plumas-Sierra Rural Electric Cooperative, Power and Water Resources Pooling Agency (PWRPA), Silicon Valley Power, and City of Ukiah. This new facility provides DWR cleaner energy to replace a portion of its power formerly served by coal-fired generation. The Lodi Energy Center's advanced emission control technology and fast-start capability allow it to deliver about 200 megawatts of power capacity within just 30 minutes. This feature helps grid operators integrate intermittent weather dependent sources of renewable electricity generated by the sun and wind into California's electrical system. Fast-start capability also reduces greenhouse gas emissions by 30 percent when compared to conventional units.

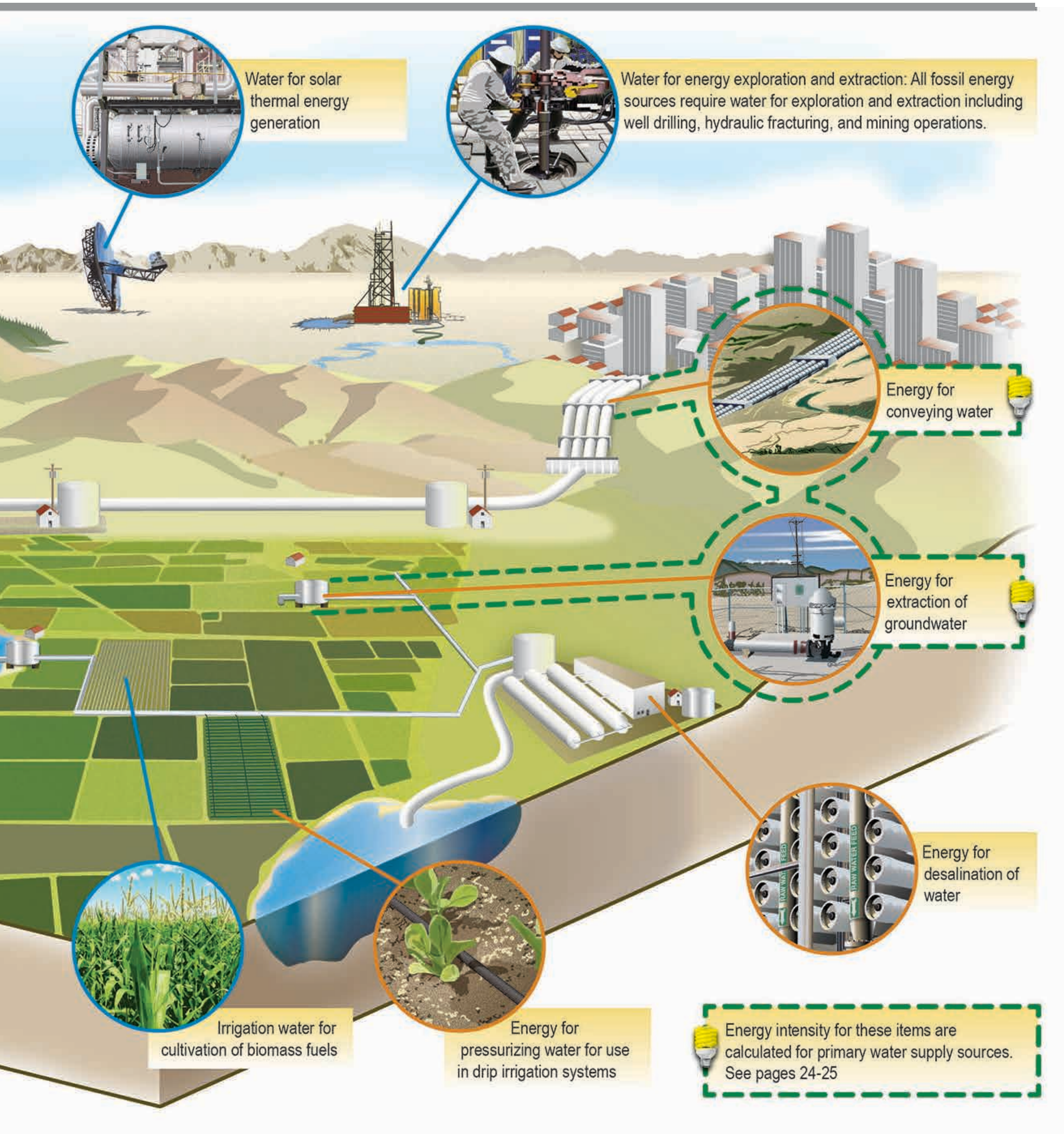
Water requirements for energy systems are highly variable and depend on many factors.

The Water Energy Connection diagram on page 20 illustrates the multiple ways that water and energy sectors are interwoven in California. Connections where water is used in the generation of energy are highlighted in blue, while connections where energy is expended in the use of water are highlighted in orange. The energy required for extraction and conveyance of water are indicated with green hatches and yellow light bulbs, which is further detailed on pages 23-25.

Understanding the relationship of water and energy is important for decision-making, with regard to using limited water and energy supplies efficiently to meet increasing future demands. The connections between these sectors should be kept in mind when making resource and planning decisions.

The Water and Energy Connection




Water for solar thermal energy generation
Water for energy exploration and extraction: All fossil energy sources require water for exploration and extraction including well drilling, hydraulic fracturing, and mining operations.
Energy for conveying water
Energy for extraction of groundwater
Energy for desalination of water
Irrigation water for cultivation of biomass fuels
Energy for pressurizing water for use in drip irrigation systems
Energy intensity for these items are calculated for primary water supply sources. See pages 24-25

California Hydrologic Regions and Major Water Projects

ENERGY INTENSITY OF REGIONAL WATER USAGE

Energy is used in the water sector to extract, convey, treat, distribute, use, condition, and dispose of water and wastewater. The California Water Plan Update 2013 provides detailed information on the water-energy connection, including energy intensity (EI) information at the regional level. EI information is designed to help inform the public and water utility managers about the relative energy requirements of the major water supplies used to meet demand. Because energy usage is closely related to GHG emissions, this information can support measures to reduce GHG emissions, as mandated by the State.

The energy intensity regional figures on pages 24-25 show the amount of energy associated with the extraction and conveyance of one acre-foot of water for each of the major water sources within ten hydrologic regions. The Delta and Mountain Counties are covered in the regional reports they overlay.

The relative quantity of each water source used within a region is also included, as a percentage. Energy required for water treatment, distribution, and end uses of the water are not included. Not all water types are available in each region. Some water types flow mostly by gravity to the delivery location and may require little or no energy to extract and convey. As a default assumption, minimum EI of at least 250 kilowatt hours per acre-foot (kWh/af) was assumed for all water types. The map on page 22 shows California's diverse set of local, State, and federal water projects superimposed over the state's hydrologic regions to provide context for the energy intensity regional figures. For additional detail on EI figures, see http://www.water.ca.gov/climatechange/water-energy.cfm.

Teerink Pumping Plant north of Los Angeles lifts water 232.5 feet. The pumping plant is one of 20 operated as part of the State Water Project (SWP). DWR implements a comprehensive program to continuously monitor, maintain, and increase the energy efficiency of pumps and turbines throughout the SWP system. By continuously evaluating and improving pumping and hydroelectric generating efficiencies, DWR minimizes energy needs and maximizes energy generated. http://www.water.ca.gov/about/swp.cfm.

Energy Intensity per Acre-Foot of Water

Energy intensity (EI) in these figures is the estimated energy required for the extraction and conveyance of one acre-foot of water. An acre-foot is the volume of water that would cover one acre to a depth of one foot; equal to 43,560 cubic feet or 325,851 gallons; it approximates the water needs of a family of four for one year. These figures reflect only the amount of energy needed to move from a supply source to a centralized delivery location (not all the way to the point of use). Small light bulbs are for EI greater than zero, and less than 250 kilowatt hours per acre foot (kWh/AF). Large light bulbs represent 251-500 kWh/AF of water (e.g., four light bulbs indicate that the water source has EI between 1,501-2,000 kWh/AF). The percent of regional water supply may not add up to 100% because not all water types are shown in this figure. EI values of desalinated and recycled water are covered in Resource Management Strategies, Volume 3 of the California Water Plan. For detailed energy intensity information see http://www.waterplan.water.ca.gov/technical/cwpu2013/index.cfm#climate

North Coast

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	21%
State (Project)	*This type of water not available*	0%
Local (Project)	<250 kWh/AF	27%
Local Imports	<250 kWh/AF	1%
Groundwater	<250 kWh/AF	28%

San Francisco

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	*This type of water not available*	0%
Federal (Project)		12%
State (Project)		12%
Local (Project)	<250 kWh/AF	15%
Local Imports	*<250 kWh/AF	38%
Groundwater		19%

* Hetch Hetchy is a net energy provider

Central Coast

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	*This type of water not available*	0%
Federal (Project)		7%
State (Project)		3%
Local (Project)	<250 kWh/AF	3%
Local Imports	*This type of water not available*	0%
Groundwater		79%

South Coast

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)		21%
Federal (Project)	<250 kWh/AF	<1%
State (Project)		27%
Local (Project)	<250 kWh/AF	4%
Local Imports	0*	5%
Groundwater		33%

* Los Angeles Aqueduct is a net energy provider

Sacramento River

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	28%
State (Project)	<250 kWh/AF	<1%
Local (Project)	<250 kWh/AF	30%
Local Imports	*This type of water not available*	0%
Groundwater	<250 kWh/AF	19%

San Joaquin

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	16%
State (Project)		<1%
Local (Project)	<250 kWh/AF	29%
Local Imports	*This type of water not available*	0%
Groundwater	<250 kWh/AF	31%

Tulare Lake

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	15%
State (Project)		8%
Local (Project)	<250 kWh/AF	16%
Local Imports	*This type of water not available*	0%
Groundwater		50%

North Lahontan

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	*This type of water not available*	0%
State (Project)	*This type of water not available*	0%
Local (Project)	<250 kWh/AF	44%
Local Imports	*This type of water not available*	0%
Groundwater	<250 kWh/AF	22%

South Lahontan

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	*This type of water not available*	0%
State (Project)		14%
Local (Project)	<250 kWh/AF	7%
Local Imports	*This type of water not available*	0%
Groundwater		64%

Colorado River

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply
Colorado (Project)	<250 kWh/AF	79%
Federal (Project)	*This type of water not available*	0%
State (Project)		1%
Local (Project)	<250 kWh/AF	<1%
Local Imports	*This type of water not available*	0%
Groundwater		9%

DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA