Chapter 5. The Evolving Nature of California's Water Economy

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Abstract

The California water sector faces many challenges and demonstrates the ability to adapt. With a water-dependent economy, the state of California's water sector is very vulnerable to external climatic shocks as well as changes in demands by an ever-growing population and dynamic agricultural sector. In response to these challenges, the California water sector continues to reform itself by introducing various types of waters, and developing regulatory tools to protect sustainable water use, water quality, and water-dependent ecosystems. In addition to the evolution of the technological, institutional, and agronomic capacities of the water-using framework, the state has seen changes in the perceptions and behaviors of its water consumers and decision-makers.

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The California Aqueduct bifurcates to the East Branch (left) and West Branch (right) as it travels into Southern California at the border of Kern and Los Angeles Counties.

Photo Credit: California Department of Water Resources

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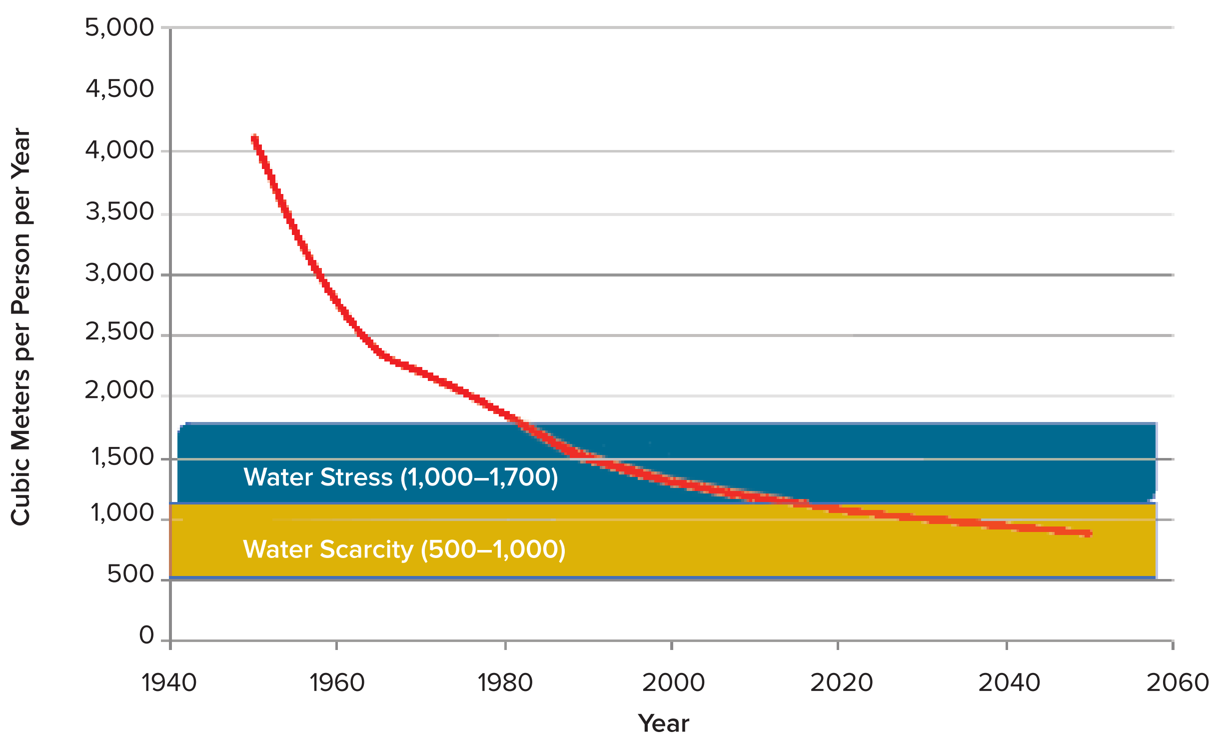
Introduction

California has an advanced water economy. A comprehensive water distribution network connects its significant surface water and groundwater resources. California has complex institutional arrangements to regulate the amount of water used in each sector, with unique quantity and quality requirements that make it hard to maximize the benefits of water resources. Challenges such as population growth, rural to urban migration, and climate change are manifested in frequent, severe and prolonged droughts and the reciprocal relationship between precipitation (north) and population concentration and demand for water (south).

Figure 5.1 presents available renewable water per capita in California, using data on water availability and population from 1950 through 2050 (population projections for 2015–2050). This is a crude measure of water scarcity that assumes the amount of available renewed water in the state is more or less fixed (between 74,000 and 123,500 million cubic meters—60 million and 100 million-acre feet—per year, depending on the year (PPIC, 2016). A fixed quantity of available water for a growing population suggests declining available renewable water per capita. Using the simple mean of 98,400 million cubic meters suggests that California enters the zone of water scarcity around 2020.

Declining water availability makes water a subject for public policy debate (Hanak et al., 2011). This chapter explains the external forces shaping water availability and usage, including historical trends in water availability and consumption by sectors and regions, the effects of climate change, and changes in the socioeconomic conditions of the demand side. Policy reforms and external shocks have led to changes in perceptions regarding various types of water that were undesirable in the past—such as recycled wastewater. The chapter will conclude with a futuristic set of possible scenarios with implications for California.

Figure 5.1. Water Availability in California, 1950–2050 (Cubic Meter per Person per Year)



Source: Authors' elaboration, based on Dinar, 2016: Figure 1a

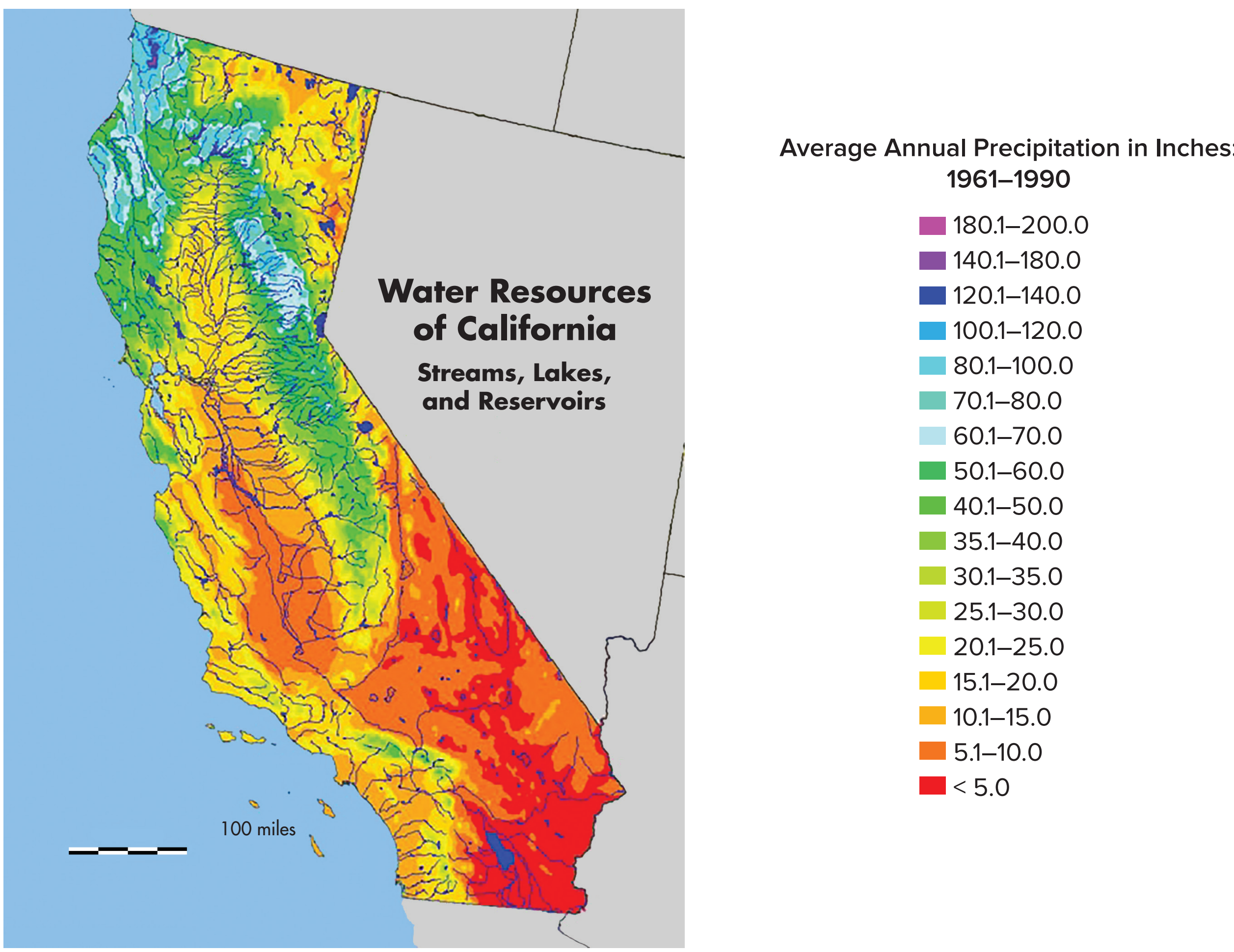
Note: 1 acre-foot = 1,235 cubic meters

Water Supply/Sources and Consumption by Main Sectors

California receives almost two-thirds of its water supply in the northern one-third of the state, primarily in the coastal areas and in the Sierra Nevada (Figure 5.2). However, most water is consumed in the southern two-thirds of the state. The major regions of water use include the fertile Central Valley, which has large agricultural lands, the urban areas of San Francisco, Los Angeles and other coastal regions, as well as the southern deserts. The water balance of the state consists of 246.7 cubic kilometers (km^3) of precipitation and 154.2 km^3 of evapotranspiration, which leaves about 92.5 km^3 of available runoff for use. California also has 18.5 km^3 of snow storage, 53 km^3 of reservoir storage and more than 185 km^3 of groundwater storage (California Department of Water Resources, 2016).

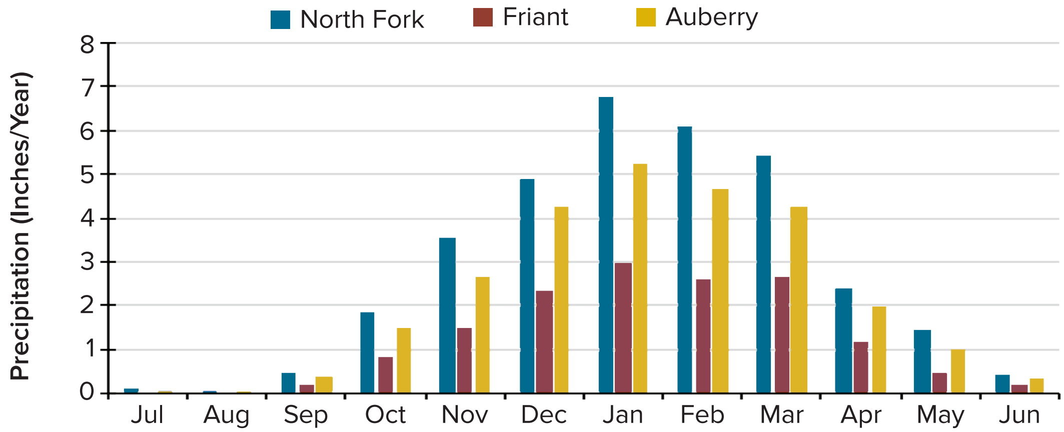
California's precipitation varies geographically and within and across seasons. Most precipitation occurs between November and April, concentrated from December through February, as demonstrated, using main water supply watersheds. The months of May through September see very little, if any, precipitation (Figure 5.3). In addition to seasonal variations in precipitation, there are significant variations across years (Figure 5.4), ranging from critically dry years to wet years.

Figure 5.2. Precipitation in California



Source: Geology Café, 2014

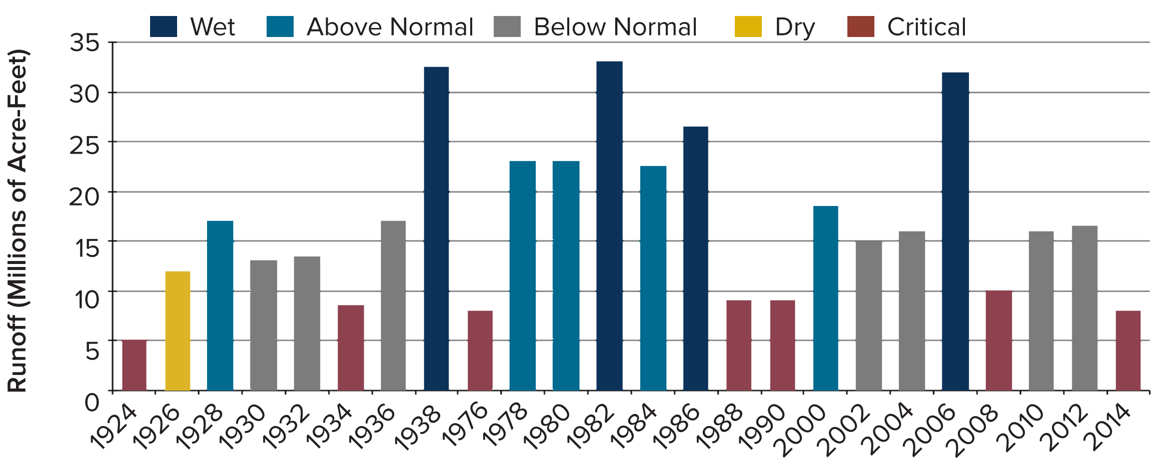
Figure 5.3. California Monthly Precipitation



Source: Authors' elaboration based on data used by Sierra Foothill Conservancy, 2014

Note: North Fork, Friant, and Auberry are locations of meteorological stations on a water reservoir/dam. North Fork is in Madera County, Friant and Auberry are in Fresno County.

Figure 5.4. Sacramento Four Rivers Unimpaired Runoff, 1924–2014



Source: Authors' elaboration based on data from California State Water Resource Control Board, 2016

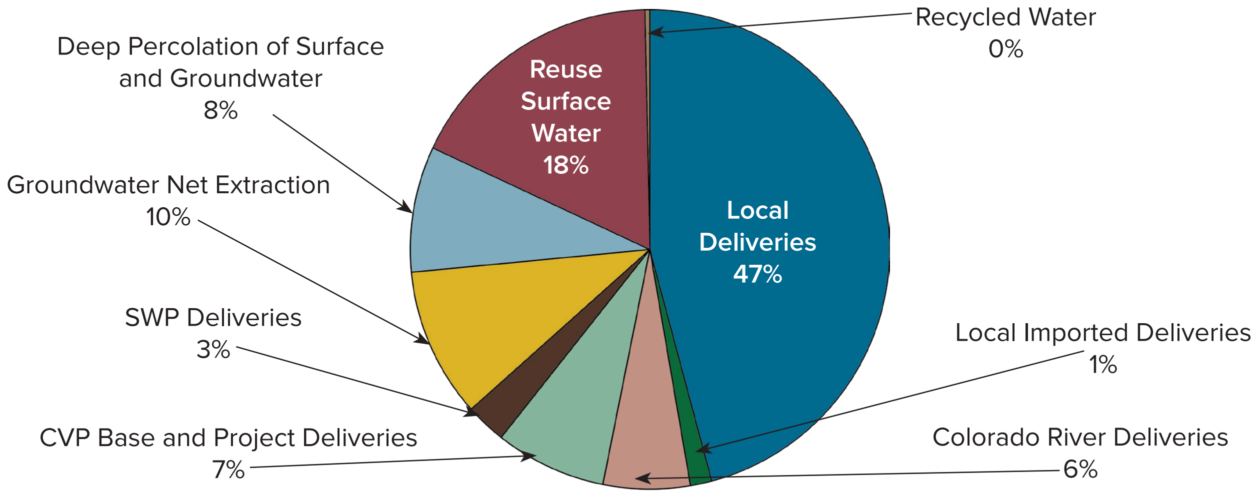
Note: Runoff is the amount of local precipitation that flows into streams and recharges groundwater (runoff and precipitation are highly correlated).

Dettinger et al. (2011) provide another illustrative measure of variability of water supply. They calculate the coefficient of variation (CV) of annual precipitation (Standard deviation /mean) for all measuring stations in the U.S. for the period 1951–2008. The eastern and central regions experience a low range of precipitation variability (CV ranging between 10–30 percent) while California experiences a wide range with levels of variability ranging from 10–30 percent in the northwest regions of the state to 30–70 percent in the southern regions of the state.

Water Resources

Due to the large spatial and inter-annual variations in precipitation (Figures 5.2, 5.3, and 5.4), California has developed a diverse portfolio of water sources. During a normal year, the state gets 47 percent of its water from local projects, 6 percent from Colorado River deliveries, 8 percent from federal projects, 3 percent from the state water project (SWP), 18 percent from groundwater sources, and 18 percent from surface water reuse (Figure 5.5). This diverse portfolio of water resources helps California to be resilient in dry years, particularly in areas of the state that have multiple water sources supplied by federal, state, and local projects.

Figure 5.5. California Water Sources



Source: Authors' elaboration based on data from California Department of Water Resources, California Water Plan Update, 2013

Water supply projects have created significant water storage capacity. The state currently has about 53 km^3 of surface water storage, primarily in reservoirs along the Sierra Nevada and northern coastal regions of California (Figure 5.6). In addition, California has over 185 km^3 of groundwater storage in the Central Valley, the Salinas Valley, the Santa Maria Valley, the Ventura Coastal Plain and aquifers in the desert regions. California also receives annual snowpack storage in the Sierra Nevada of about 18.5 km^3 (California Natural Resources Agency, Department of Water Resources, 2014), which provides additional in-place storage in winter months. Many California dams are used for flood control purposes in the winter and early to mid-spring seasons, so reservoirs are often kept low to allow room for flood control, sometimes forcing operators to release water they would otherwise store. In the late spring and summer, reservoirs capture and utilize the melting snowpack in the months between May and August. One issue of significant concern to California is that increases in temperatures from global climate change are expected to lead to a shift in precipitation from snow to rain, and to early melt of the snowpack. Current models estimate that the snowpack will decrease by 30 percent, from 18.5 km^3 per year to around 12 km^3 per year (California Natural Resources Agency, Department of Water Resources, 2007).

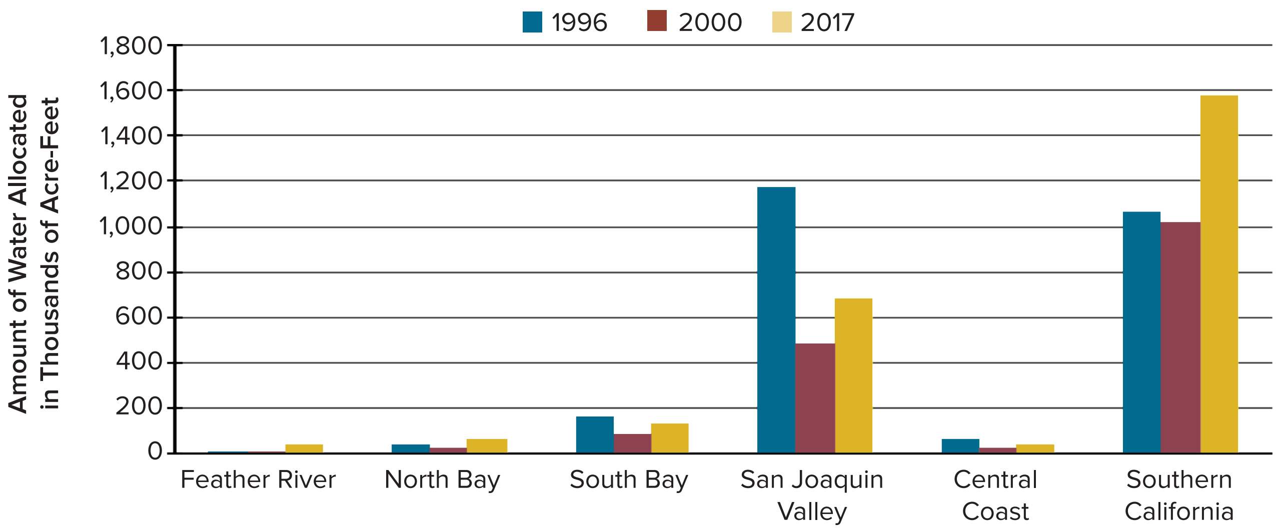
Surface Water from State and Federal Projects

Due to the spatial and temporal variability in water supply, California has created one of the most complex water supply systems in the world. Local, state, and federal water projects are spread throughout the state, collecting, storing, and conveying water to demand centers.

The major local projects belong to the larger cities of the state and to some of the older agricultural regions. The urban projects include: the Hetch Hetchy water project that supplies water to San Francisco and parts of the Bay Area; the Mokelumne River project that supplies water to the East Bay cities in the San Francisco Bay Area; the Los Angeles Aqueduct that takes water from the east side of the Sierra Nevada to the city of Los Angeles; the Colorado River Aqueduct that moves water from the Colorado River to Southern California cities and coastal communities.

The State Water Project (SWP) delivers water from Northern California to farms in the Central Valley, cities in the Bay Area, and cities and farms in Southern California. The Oroville Dam on the Feather River, the tallest U.S. dam, anchors the SWP. Water flows from this reservoir into the Sacramento River and travels south to the Sacramento-San Joaquin Delta. Pumps move the water into the California Aqueduct, which carries the water over 710 kilometers south along the west-side of the San Joaquin Valley. It supplies water to several coastal communities through branch aqueducts and delivers water to farmers in the

Figure 5.6. Water Allocation in the State Water Project, 1996, 2000, 2017



Source: Authors' elaboration, based on data in California Department of Water Resources, Management of the California State Water Project, 2017a

southern portion of the San Joaquin Valley; the remaining water is then pumped up 610 meters over the Tehachapi Mountains to Southern California agricultural and urban water users. The SWP distributes water to 29 locations. The project provides water for 25 million California residents and 750,000 acres of irrigated farmland; 70 percent of the allocated water goes to urban areas and 30 percent goes to agricultural areas in various regions of the state.

The Central Valley Project (CVP) is a federal project that collects water in Northern California's Trinity and Shasta reservoirs, as well as a series of reservoirs along the west side of the Sierra Nevada. The CVP also uses the Sacramento River and the Sacramento-San Joaquin Delta to deliver water to the pumps of the Delta-Mendota Canal, which also runs down the western side of the San Joaquin Valley parallel to the California Water Aqueduct. The Delta-Mendota Canal is much shorter than the California Water Aqueduct and ends at the Mendota Pool on the San Joaquin River, where the water enters the San Joaquin River and flows north back towards the Sacramento-San Joaquin Delta, essentially creating a loop. This allows the federal CVP to distribute water to many different places, mostly to farmers, towns along its route, and for wildlife preserves in the central part of the state. The CVP includes the Friant-Kern Canal, which moves water from the southern Sierra Nevada southward to Bakersfield, supplying communities and agricultural lands on the eastern side of the San Joaquin Valley.

Both the CVP and the SWP rely on the Sacramento-San Joaquin Delta to move water from north to south. This delta has become the linchpin of California's water system: the water projects move water from north to south in an ecosystem where water would normally be moving from east to west. Parts of the Delta are influenced by tidal forces, forcing the projects to release extra water in order to maintain low salinity levels in the water. Due to reduced flows, pumping, and changes in flow direction, there are several endangered species in the Sacramento-San Joaquin Delta ecosystem. In an effort to alleviate this problem, the state of California proposed a controversial plan to move water from the Sacramento River under the Delta to the pumping stations through a series of massive tunnels. If implemented, this plan would reduce the amount of water flowing in the Delta, but allow for more natural flows of Delta water in the east to west direction. It would also allow more tidal influences in the Delta, which might help to restore and improve the Delta ecosystem.

The Colorado River collects water from seven states as it flows from Wyoming to the Sea of Cortez. Allocation of the Colorado River took place through an interstate pact in 1922 and an international treaty with Mexico in 1944. The international Colorado River Treaty allocates the 20 km^3 of water estimated to be available annually in the basin as follows: 1.85 km^3 to Mexico and 18.5 km^3 allocated among the five states in the U.S. side of the basin. California's allocation is 5.4 km^3 of water (U.S. Bureau of Reclamation, 2016).

When first allocated, historic data showed higher flows in the river basin than current flows, meaning that the river is over-allocated and rarely flows through its natural course to the Sea of Cortez in Mexico.

The federal government operates several dams on the Colorado River, the Coachella Canal, and the All-American Canal to supply water to farmers in the Imperial and Coachella valleys. Through the Colorado River Aqueduct, Colorado River water is distributed by the Metropolitan Water District of Southern California to Southern California cities from Los Angeles to San Diego (Glenn Canyon Dam Adaptive Management Program, 2012).

California's water systems are intertwined. The California Aqueduct, the Delta-Mendota Canal, the Los Angeles Aqueduct, and the Colorado River Aqueduct share certain facilities where water is exchanged, adding to the resiliency of the system.

Local Projects

In addition to the massive federal and state projects, many cities developed local water projects for all or a portion of their supplies. These local projects supply water to coastal and Central Valley agricultural regions. We briefly describe a couple of these projects below.

The Los Angeles Aqueduct (Owens Valley Aqueducts)

The city of Los Angeles developed a water supply plan to utilize both the SWP water and amend it with its own water projects, such as local groundwater supplies and the Los Angeles Owens Valley Aqueducts (Los Angeles Department of Water and Power, 2015).

There is a wide variation in total water supply and water sources to Los Angeles. Starting in 1992, recycled water has been increasingly used as a source for water supply to the city, although still a minute quantity.

The Hetch Hetchy Aqueduct

Snowmelt from the high Sierra Nevada and water from the Tuolumne River at the Hetch Hetchy Valley in the Yosemite National Park serve as the primary water source for the City of San Francisco and several municipalities in the greater San Francisco Bay Area via the Hetch Hetchy Project, operated by the San Francisco Public Utilities Commission (SFPUC). The project provides annually 330 million cubic meters of water, which is nearly 80 percent of the water supply for nearly 3 million people in the region (San Francisco Public Utilities Commission, 2005). A map of the Hetch Hetchy Aqueduct and Water Supply System can be found in *Maven's Notebook*, Hetch Hetchy Water and Power System, (n.d.).

The Mokelumne Aqueduct

The Mokelumne Aqueduct is a 95-mile water conveyance system that collects 450 million cubic meters of water a year from the Mokelumne River watershed for 1.5 million people in 35 municipalities in the East Bay of the San Francisco Bay Area. The entire infrastructure of dams, canals, pipes, and reservoirs is owned and operated by the East Bay Municipal Utility District (EBMUD) and provides over 90 percent of the water delivered by the agency (East Bay Municipal Utility District, 2015). A map of the Mokelumne Water Supply Project can be found in *Maven's Notebook*, Mokelumne Aqueduct, (n.d.).

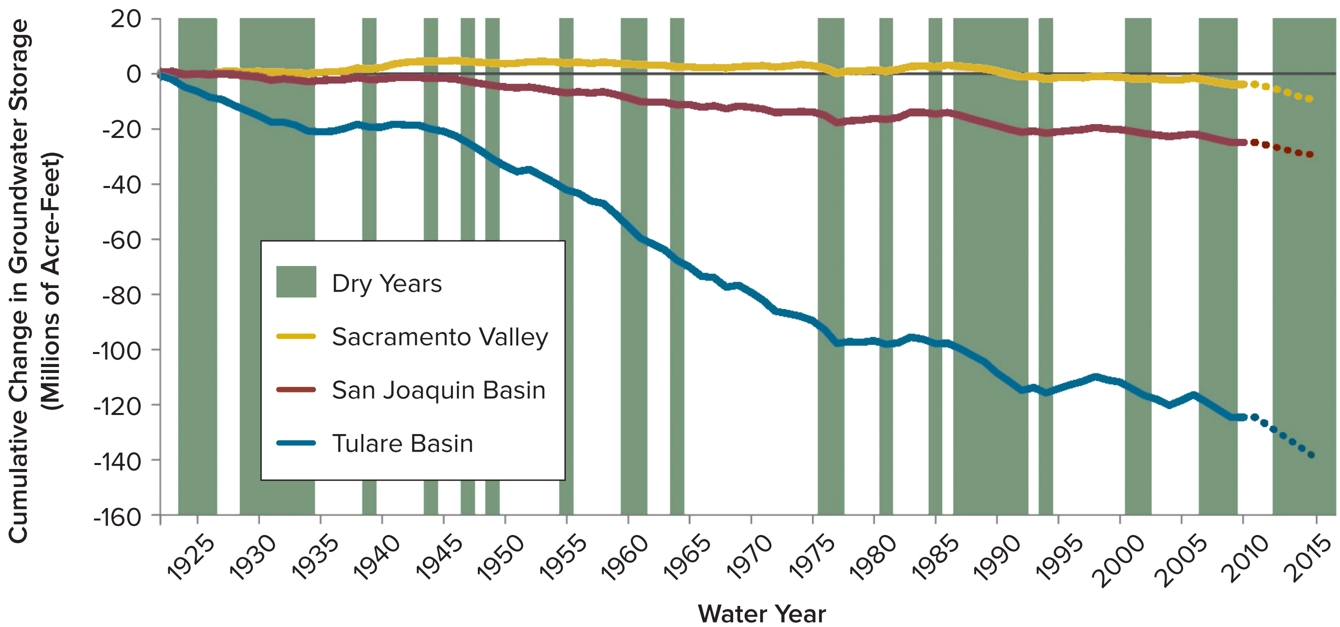
Groundwater Supplies

California has 515 groundwater basins. Groundwater is an important source of water: nearly one-third of water originates from groundwater sources under normal conditions, and up to 60 percent during drought and severe drought years (California Natural Resources Agency, Department of Water Resources, 2015).

Groundwater levels in many regions of the state have been declining for many years (Figure 5.7). At the end of 2017, 21 groundwater basins were critically depleted, reflecting intensified pumping during the recent drought. Major groundwater declines occurred in the Central Valley—especially the San Joaquin Valley—and in the Salinas Valley and areas of the South Coast. (www.water.ca.gov/Programs/Groundwater-Management/Groundwater-Elevation-Monitoring--CASGEM).

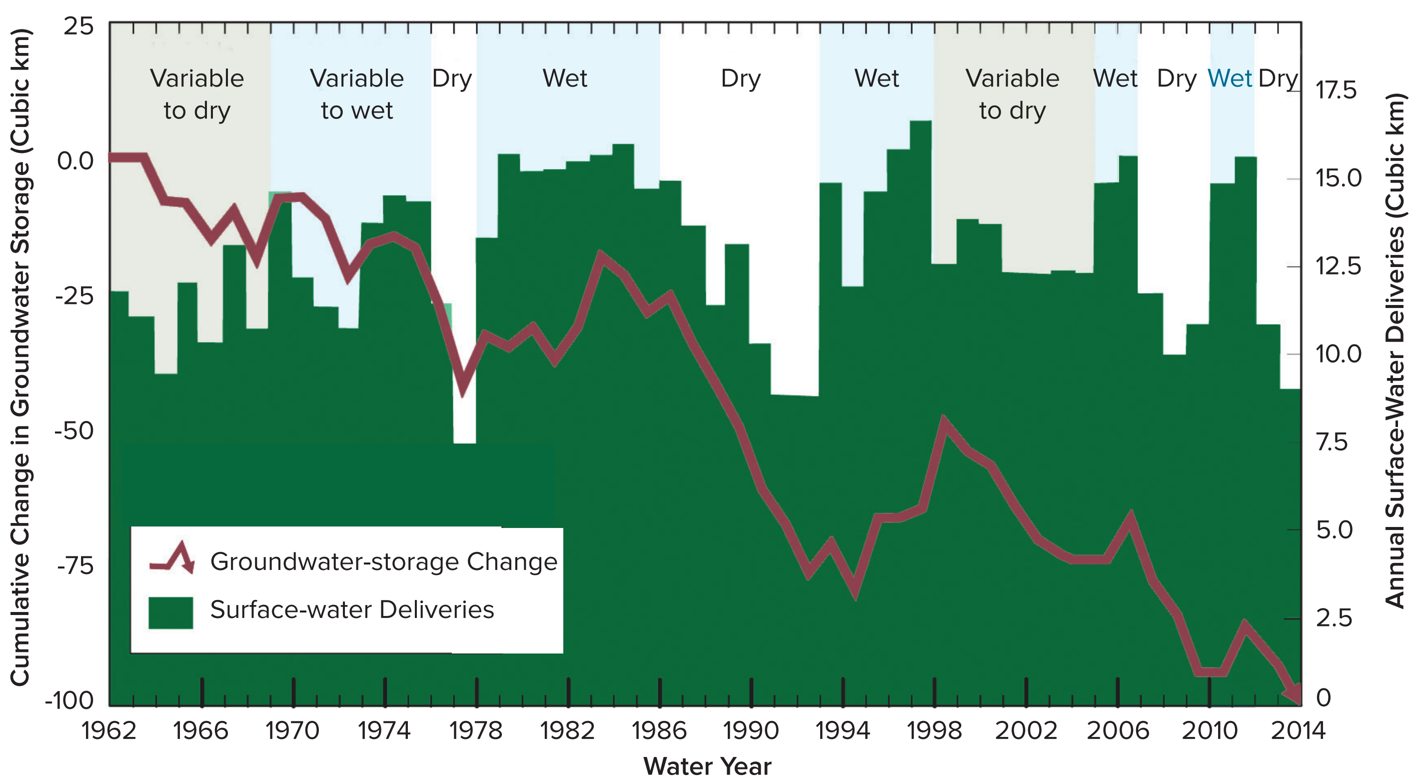
The Central Valley's aquifers are the source of irrigation water to many farmers. As can be seen in Figure 5.8, groundwater stocks decrease during dry years (white and gray areas) and increase during wet years (blue areas). Figure 5.8 presents a reciprocal correlation between surface water deliveries and groundwater-storage change in that aquifer system.

Figure 5.7. Groundwater Pumping Depletes Reserves in Central Valley Basins, 1924–2016



Source: Public Policy Institute of California, 2017: Ground Water (Permission granted)

Figure 5.8. Change in Groundwater Storage in the Central Valley Aquifer, 1962–2014



Source: U.S. Geological Survey, 2016 (Permission Granted)

Table 5.1. Recycled Wastewater Reuse for Various Purposes in California, 2001, 2009, 2015

Year	2001		2009		2015	
Beneficial Reuse	Acre-Feet/Year (Thousands)	Percent Total	Acre-Feet/Year (Thousands)	Percent Total	Acre-Feet/Year (Thousands)	Percent Total
Golf Course Irrigation	115	22	44	7	56	8
Landscape Irrigation			112	17	126	18
Agriculture Irrigation	239	45	245	37	219	31
Commercial	22	4	6	1	5	1
Industrial			50	7	67	9
Geothermal Energy Production	1	<1	15	2	18	3
Seawater Intrusion Barrier	22	4	49	7	54	8
Groundwater Recharge	49	9	80	12	115	16
Recreational Impoundment	35	7	26	4	28	4
Natural Systems: Restoration, Wetlands, Wildlife Habitat	22	4	30	4	24	3
Other (Sewer flushing, misc. wash-down etc.)	20	4	12	2	2	<1
Grand Total	525		669		714	

Source: California State Water Resources Control Board (n.d.)
Notes: Acre-feet (in thousands) are rounded values.
In 2001, Golf Course and Landscape Irrigation were grouped in a single category; Commercial and Industrial were also grouped as one category.

The declining water levels in the Central Valley's aquifers are severe but not unique. For example, as measured in nearly 3000 wells, changes in groundwater levels between spring 2010 and spring 2014 (California Department of Water Resource, 2015) suggest that water levels in most California aquifers declined during the drought years of 2010–2014. Sixty percent of the wells experienced a decline of more than 2.5 feet during this period, while nearly 15 percent of the wells, mostly in Southern California, experienced an increase in water levels (many wells in this category are in adjudicated aquifers).

Alternative Water Sources

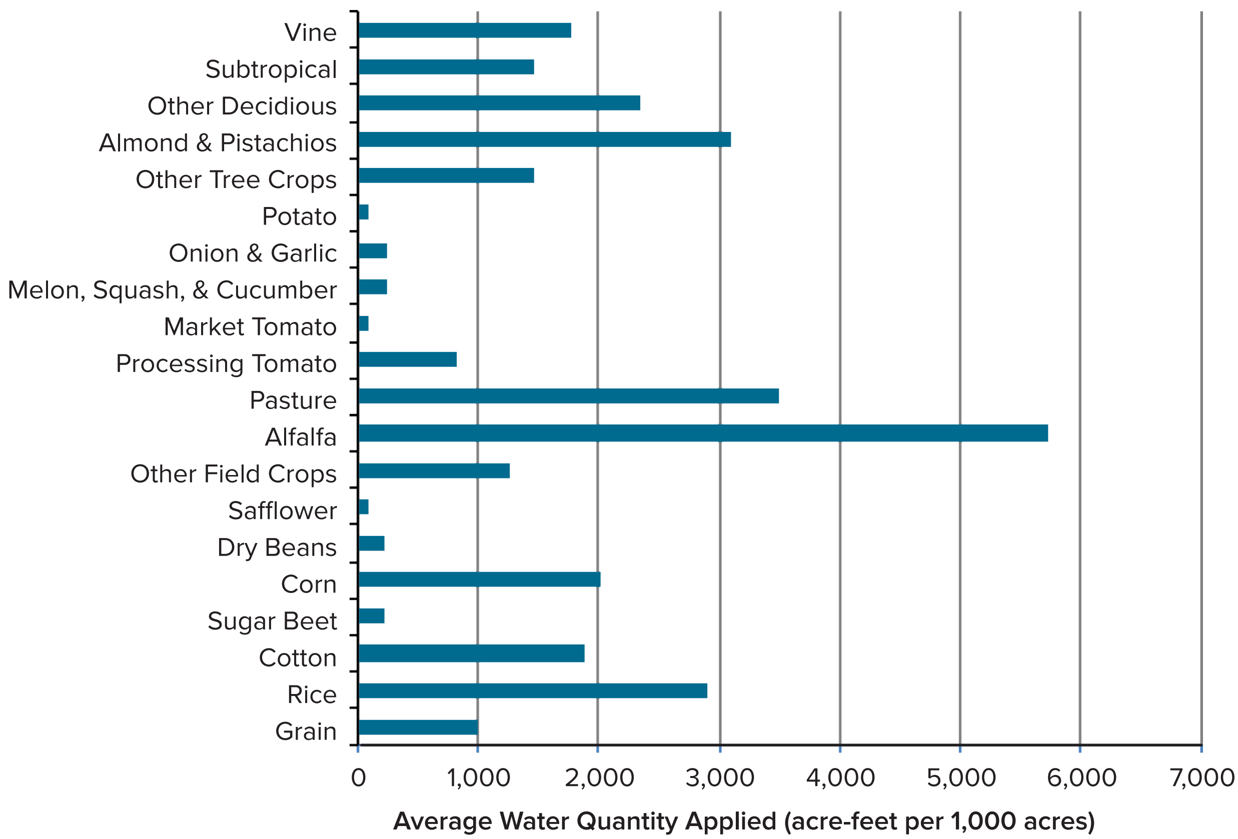
In addition to the 'traditional' fresh water resources from surface water and groundwater, California also utilizes alternative water sources that are growing in importance.

California regulations require sewage treatment prior to disposal. The majority of the treated wastewater is disposed of into the ocean and other inland waterways with only a small fraction reused, 714,000 acre-feet in 2015 (Table 5.1). This volume of wastewater reuse represents a steady increase from previous years, but it is only 13 percent of all treated wastewater in the state.

Analyzing the use of recycled wastewater over time sheds light on the changing role this resource plays in California's water economy. Table 5.1 shows that between 2001 and 2015, agriculture's percent total use of recycled water is declining as other uses such as recharge of groundwater and irrigation of urban landscapes are rising.

California has developed limited desalinated ocean water capacity as an alternative source for residential consumption. Costs and environmental regulations challenge plans for expanding the desalination capacity in California. At present, there are a handful of desalination plants, most with a small overall capacity. The exception to this is the recently built desalination facility in Carlsbad, California. This plant has a capacity of 50 million gallons per day (mgd)—the largest desalination facility in the Western Hemisphere—enough to meet 7 percent of San Diego County's current needs. Many new plants are proposed

Figure 5.9. Total Quantity of Water Applied on Specific Crops in California During 1998–2010



Source: Authors' elaboration based on data in California Department of Water Resources, Agricultural Land & Water Use Estimates, 1998–2010

and likely will be operational in the future. This information can be found in a map of existing and proposed seawater desalination plants in California (Seawater Desalination, Huntington Beach Facility, n.d.).

Desalination technologies are also being used to treat brackish groundwater for use in agriculture. Experimentation with solar desalination technologies demonstrated promising results for brackish water. There are significant brackish groundwater supplies in several areas of the state.

Water Consumption

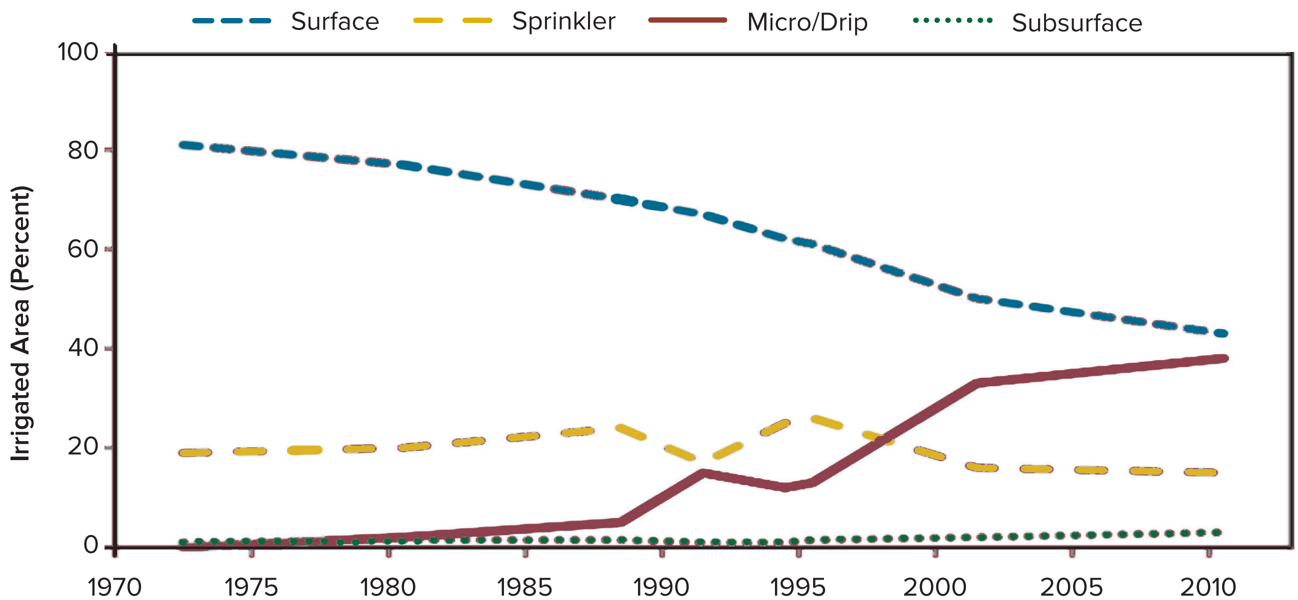
The allocation of California's water supplies are as follows: environmental flows take 49 percent (31 percent for wild and scenic rivers, 9 percent for to instream flows, 7 percent for Sacramento-San Joaquin Delta outflows, and 2 percent for managed wetlands), irrigated agriculture takes 41 percent and urban water use takes 10 percent.

Agriculture

Agriculture is the largest user of water. California has over 80,000 farms with agricultural sales of nearly $50 billion per year ($53.5 billion in 2014). There are over 25.5 million acres of agricultural lands in California, including half in pasture and rangeland, and 9 million acres of irrigated cropland. About two-thirds of that cropland is in annual crops and about one-third of it is in permanent crops such as orchards and vineyards (California Department of Food and Agriculture, 2015).

Figure 5.9 presents the quantity of water applied on major crops between 1998 and 2010. Alfalfa, to highlight the most water-intensive crop, used 5,727 acre-foot of water per 1,000 acres of land during that period. Water scarcity has encouraged farmers to (1) adopt more efficient irrigation technologies, and (2) alter the mix of crops grown in response to changes in markets, climate, and water availability.

Figure 5.10. Changes in Irrigation Technology Shares in California, 1972–2010



Source: Taylor and Zilberman, 2017

In addition to changes in crop mix, between 1972 and 2010, micro and drip irrigation technologies usage increased from 0 to nearly 40 percent of the irrigated area. By contrast, surface irrigation fell from 80 to 40 percent of the irrigated area (Figure 5.10).

Urban

Urban water consumption in California accounts for about 10 percent of water usage in the state (Figure 5.11). In recent years, agricultural and urban water consumption are declining, likely due to increased water prices, conservation efforts, public media impacts, and drought-related policies.

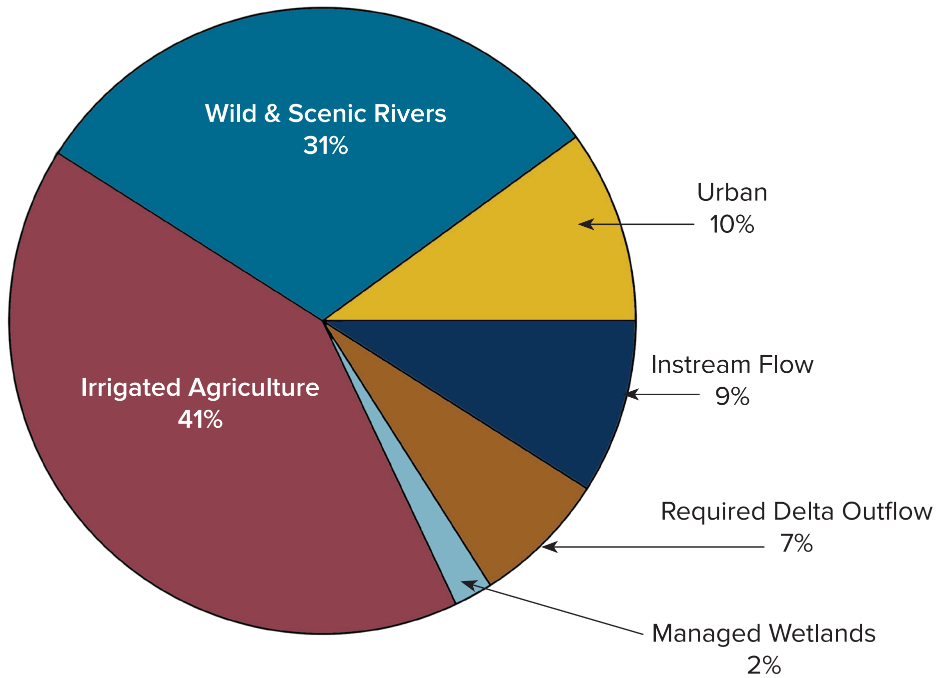
Environment

Environmental water usage includes four categories: water in rivers that are protected as "Wild and Scenic" under federal and state law, water required to maintain habitat within streams, water that supports wetlands within wildlife preserves, and water that is needed to maintain water quality for agricultural and urban use. Water use for the environment varies across California's regions, with variation between dry and wet years. Between wet years (2006) and dry years (2001), the share of water for the environment is reduced from 62 percent to 36 percent, while the shares of urban use and agricultural use increase from 8 percent to 13 percent and 29 percent to 50 percent, respectively (Public Policy Institute of California, Water Use in California, 2016).

Hydropower

California has 287 hydroelectric generation plants (California Energy Commission 2008), mostly located in the eastern mountain ranges with a total capacity of about 21,000 megawatts (MW) (California Energy Commission, 2017). Hydroelectric generation is subject to variation depending on the year (wet versus dry) (California Energy Commission, 2017). It is hard to estimate the volume of water that runs annually through these power plants because their production relies on water in rivers and reservoirs that are subject to variation, depending on the water situation in that year. With warming climate and frequent droughts, the loss of snowpack and increased winter runoff diminish the high-elevation hydropower generation during summer months (PPIC, 2016).

Figure 5.11. California Dedicated Water Uses



Source: Authors' elaboration based on data in California Natural Resources Agency, Department of Water Resources, 2014; California Water Plan Update 2013

Climate Change

Climate change will have a profound effect on California's water resources by changing precipitation patterns (California Department of Water Resources, Climate Change, n.d.) due to increased variability in 'atmospheric river flows' that affect snowpack and river flows (Scripps Institute of Oceanography, 2015). Such changes are expected to intensify in the future, leading to shifts in patterns of precipitation (more rain than snow), which are expected to increase risk of flooding, and pose challenges for a reliable water supply.

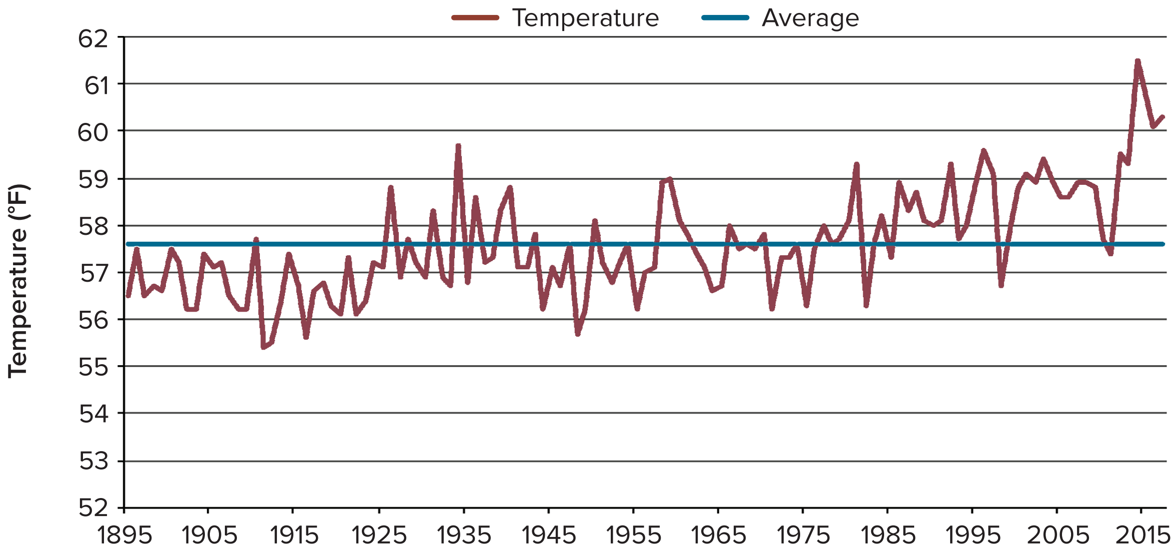
Climate change has already resulted in more variable weather patterns throughout California. Higher variability can lead to longer and more extreme droughts. The sea level is expected to continue rising, adversely affecting the Sacramento-San Joaquin Delta, the hub of the California water supply system and the source of water for 25 million Southern Californians and millions of acres of prime irrigated farmland. California is also expected to face warmer temperatures in the future. The increase in temperatures will cause snowpack to melt faster and earlier and increase evaporation from reservoirs and from open water conveyance systems (California Department of Water Resources, Climate Change, n.d.).

Climate Change Impacts

California faces several climate-warming scenarios (California Energy Commission, 2006) that will affect precipitation, snowpack, and temperature. An increase in temperatures will: reduce the amount of precipitation that falls as snow; increase the amount that falls as rain; melt the snowpack earlier in the year; and, increase evapotranspiration in natural and agricultural lands, thus increasing statewide water usage by plants.

Precipitation is expected to change over this century. Climate models vary in precipitation estimates but the four most used models show a slight decrease in average precipitation between 1950 and 2090 (Cal-Adapt Data, Precipitation, n.d.). While the decadal changes in precipitation between 1950 and 2090 may be small, changes to

Figure 5.12. California Mean (Annual) Temperature, 1895–2015



Source: Authors' elaboration, based on data in National Climate Data Center

snowpack are expected to be significant (Cal-Adapt Data, Snowpack, n.d.). Change in snowpack above the state's key reservoirs will necessitate changes in reservoir operations and changes in surface and groundwater storage strategies.

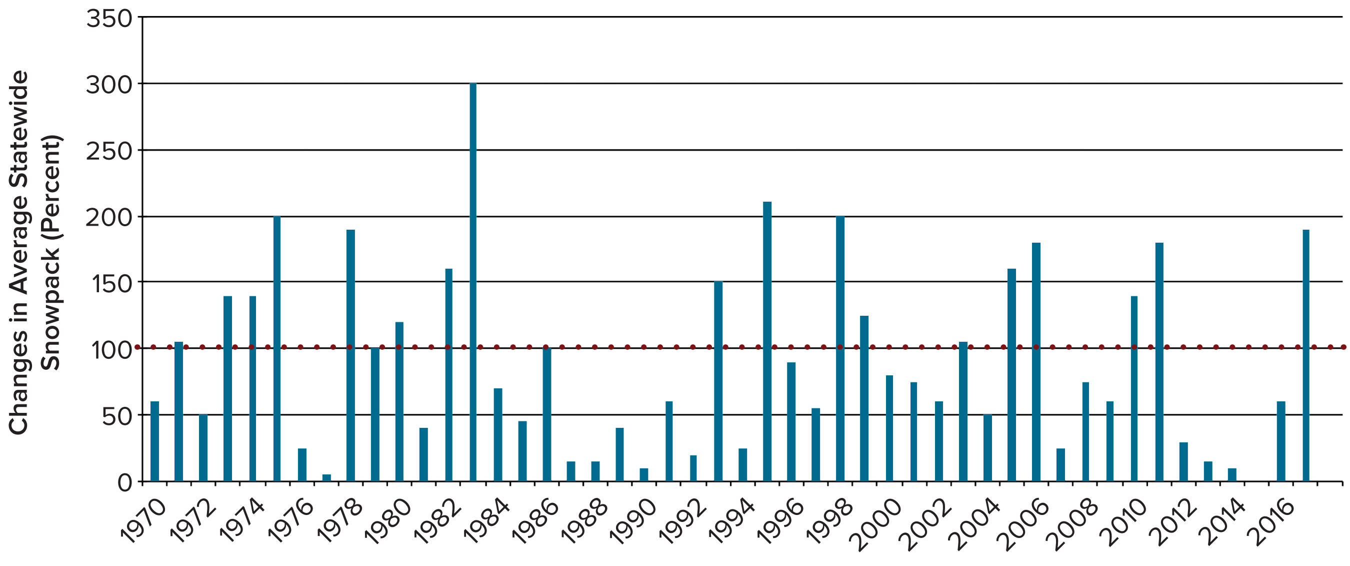
The temperature in California has been steadily increasing since the 1970s (Figure 5.12). In addition to the increasing trend in temperatures, the spatial distribution of the temperature increases is also important. The greatest increases in temperatures are expected at higher elevations, where it exacerbates the reduction in snowpack and increases snowmelt earlier in the season (Cal-Adapt, Annual Temperature, n.d.). Increased temperatures in these elevations will increase water demand from mountain ecosystems (predominantly forests), which will further reduce stream flow and recharge to surface and groundwater storage systems.

The Sierra Nevada snowpack contributes a third of California's water. Drought reduces the snowpack, while wet and cold winters increase it (Figure 5.13).

Increases in temperatures can increase the frequency and severity of droughts. Figure 5.14 shows how the most recent drought in California intensified over time in terms of duration and geographic extent.

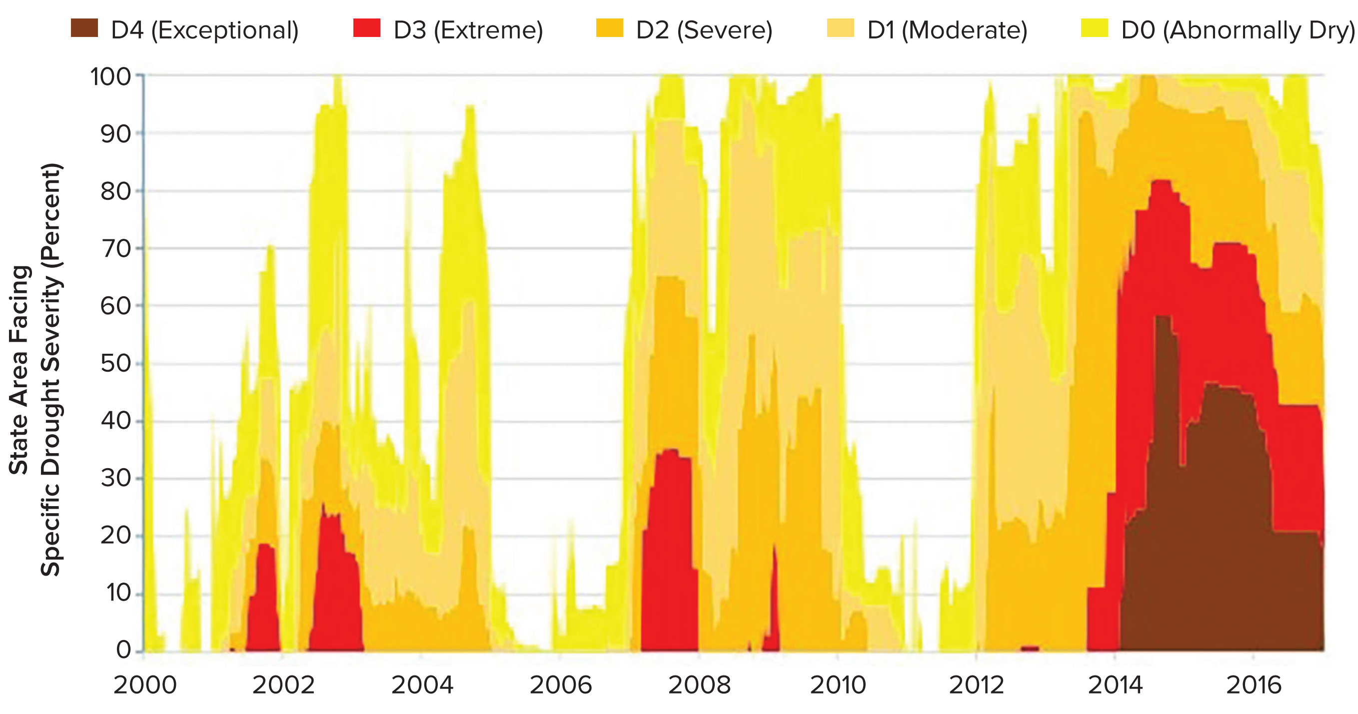
Impacts of the 2011–2016 drought in California were mirrored in depletion of both groundwater aquifers (see section on groundwater on page 113) and major surface water reservoirs across the state. During this drought, precipitation was at a record low. Annual precipitation data from the 8-station index in the northern Sierra Nevada (California Department of Water Resources, California Data Exchange Center, 2017) shows the accumulated decrease in precipitation in California during the 2011–2016 drought. This prolonged catastrophic drought situation led California water policy makers to implement several regulatory interventions aiming to conserve water. These will be discussed in the next sections.

Figure 5.13. Sierra Nevada Snowpack on May 1: Percent of May 1 Average Statewide Snowpack, 1970–2017



Source: Authors elaboration based on data in California Department of Water Resource, Bay Area News Group. Snowpack, 2017

Figure 5.14. Drought Severity and Longevity in California, 2000–2017



Source: Climate Signals, California Drought Monitor. Based on data in Drought Monitor, University of Nebraska, Lincoln, (n.d.)

Changes in Demands for Water

Several factors and processes are associated with changes in the water sector in California. First, California had a surge in population growth due to its relatively pleasant climate and increased job opportunities. Second, a rural to urban migration intensified over time, affecting demand for drinking water, need for treating sewage, and opportunities for use of recycled water. Third, there is a change to the crop mix, especially in regions facing higher levels of water scarcity. Lastly, attitudes are changing regarding (1) the importance of environmental amenities, (2) the sources and impact of climate change, and (3) the use of recycled water for irrigation of crops, of open spaces, and for recharge to groundwater.

Population Growth

California's population doubled from 20 million to 40 million between 1965 and 2020. Due to population growth, water demand increases and availability per capita decreases. It also means that more sewage treatment is necessary, which implies a new water source in the form of recycled wastewater.

Urban Expansion

The urban share of population has been increasing. Competition between rural/agricultural water users and urban users increases the need to invest in infrastructure to convey additional water and distribute it to new urban developments. Cities will also need to spend more on constructing and operating wastewater treatment plants.

Urbanization affects the environment and the hydrologic cycle. Urban areas affect the water cycle because paved surface areas (streets, driveways, parking lots) pick up pollutants and prevent rainwater from percolating naturally to the aquifer. Urbanization also has positive consequences, such as a concentration of sewage and economies of scale for using treated wastewater in the agricultural sector surrounding the city. Agricultural water users may give up freshwater to the city for treated wastewater from the city, a possible win-win arrangement. In the case of California, urban populations increased from 50 percent of total population in 1900 to nearly 95 percent in 2010 (U.S. Census Bureau, Decennial Censuses Urban and Rural Definitions and Data United States, Regions, Divisions, and States, Table 5.1, 2010). This increase in urban population has significant impacts on the state's water systems. With appropriate policy interventions, the production of recycled water can reduce the demands on freshwater in the state.

Changing Cropping Patterns

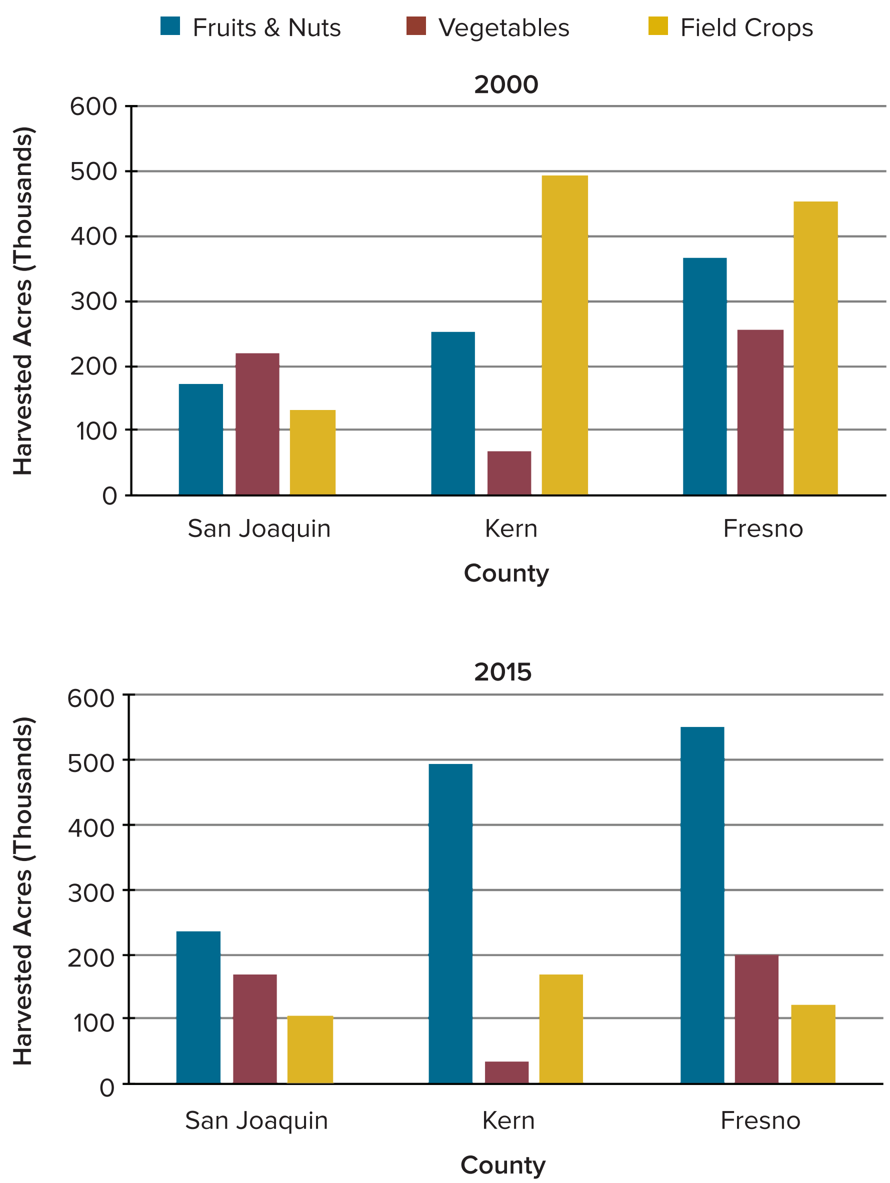
Market forces and water availability are major factors affecting planting decisions of agriculture growers. Droughts in California affect cropping-pattern decisions. Growers' perception and fear about future water availability makes them change their cropping patterns. Figure 5.15 presents changes in cropping patterns over time in three major agricultural counties of California. While all three counties saw an increase in fruit and nut acreage, Kern County witnessed the largest decline in field crops, while San Joaquin and Fresno counties experienced a decline in both vegetables and field crops.

Perceptions

California citizens have been involved in setting water policy priorities. A major component of the public support for, or objection to, certain policies is public attitudes, which change with exposure to scientific-based dialogue (education), and from environmental shocks (e.g., droughts).

One change in perception is the attitude towards reuse of treated recycled wastewater. A 2014 poll found that 62 percent of Californians are confident that it is possible to treat recycled water to drinking water quality standards. While this does not suggest an implicit agreement to use recycled treated wastewater for drinking purposes, such confidence indicates an easier path to household reuse in the future. Change in climate, having direct impacts on agriculture and water resources, is a concern to

Figure 5.15. Changes in Cropping Patterns in Several Leading Agricultural Counties in California



Source: Authors' elaboration based on *World Population Review*, 2017

agricultural growers. A study (Niles et al., 2013) focusing on Yolo County growers suggests a range of responses regarding climate change interactions with agricultural production. The main findings suggest that 60 percent of farmers believe that the climate is changing and that it poses risks to agricultural production. These perceptions are expected to lead to behavioral changes regarding water consumption and technology adoption as part of the adaptation efforts of the farming community.

Regulations to Reduce Water Use

When facing severe water scarcity, California has had to consider changes to the way water is managed and allocated. During the 1986–1991 drought, an institution defined as the Water Bank was established to act as a water broker, buying and selling water-use rights from willing sellers to interested buyers (California Department of Water Resources, 1991). The Water Bank gave rise to water trading among buyers and sellers. The 2011–2016 drought led to institutional changes such as water pricing reforms, mandatory water-use restrictions (that are expected to be renewed independently of removal of the drought emergency), and the Sustainable Groundwater Management Act (SGMA) of 2014. These reforms are discussed in this section.

Governor's Decree to Cut Water Use (Urban and Agricultural)

> "In January 2014, Governor Jerry Brown urged Californians to voluntarily cut their water usage by 20 percent to help preserve the state's already limited supply during this severe drought. But sometimes, asking nicely doesn't work. Between January and May, water use was reduced by a measly percent. Clearly, the voluntary approach isn't enough—water use is even up in some communities—and the state needs to take a harder line."
> (*Los Angeles Times*, July 14, 2014)

Data on how Californians responded in the short-run (May 2014) suggest (*LA Times,* July 14, 2014) that water users in Northern California were more effective than water users in Southern California in meeting the Governor's decree. Analysis of the water districts' performance in May 2014 (compared to previous water years' use) suggests a range of performances contingent on the set of measures water districts had in place in addition to the mandatory water reduction, as follows:

- Districts with only mandatory water restrictions: –5 percent;
- Mix of mandatory and voluntary water restrictions: +2 percent;
- Voluntary water restrictions: +4 percent;
- Lawn watering limited to fewer than three days per week: –9 percent;
- Lawn watering allowed for three or more days a week: +3 percent.

Results for the longer run (November 2014) suggest (California State Water Resources Control Board, Bay Area News Group, 2014b) a statewide reduction of 9.8 percent in water consumption, with northern coastal regions reaching nearly 20 percent reduction, Central Valley regions reaching 15–25 percent reduction, and Southern California and desert regions reaching 1–7 percent reduction.

The 2014 Sustainable Groundwater Management Act

During the record-breaking drought of 2011–2016, agriculture increased groundwater pumping by over 100 percent. In response to the increase in pumping, along with the recognition that for many areas of the state groundwater aquifers had been over-pumped for years, the state passed the Sustainable Groundwater Management Act (SGMA) of 2014.

SGMA requires local agencies to assess and manage groundwater use in a sustainable manner or the state will step in and improve groundwater management in the basin until local agencies can demonstrate an ability to do so themselves. SGMA requires local governments (including water districts) to work together to form Groundwater Sustainability Agencies (GSAs). These agencies were supposed to have been formed by June 30, 2017 (Table 5.2). Failure to form single or multiple GSAs that cover each groundwater basin forces the state to place basins on probation and require extraction reporting within the basin.

Once formed, the GSAs have differential deadlines to create Groundwater Sustainability Plans (GSPs). Critically overdrafted basins have until January 31, 2020, while high and medium over-drafted basins have until January 31, 2022, to create GSPs. Each GSP has 20 years from their submission deadline to achieve sustainability. Sustainability in the SGMA legislation is defined by the avoidance of six undesirable states:

Table 5.2. Sustainable Groundwater Management Act Timeline

Date	Deadlines
September 16, 2014	Groundwater management legislation become law
January 1, 2015	Legislation goes into effect
January 31, 2015	California Department of Water Resources (DWR) establishes initial groundwater basin priority
December 31, 2016	DWR estimate of water available for groundwater replenishment due
June 30, 2017	Deadline to form Groundwater Sustainability Agencies (GSAs)
July 1, 2017	Pumpers in probationary basins must report extractions
January 31, 2020	Groundwater Sustainability Plans (GSPs) required for all high and medium priority groundwater basins in designated critically over-drafted basins
January 31, 2022	GSPs required for all remaining high and medium-priority groundwater basins
January 31, 2040–42	Basins must achieve sustainability

Source: Buena Vista Water Storage District, 2014

(1) Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

(2) Significant and unreasonable reduction of groundwater storage.

(3) Significant and unreasonable seawater intrusion.

(4) Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.

(5) Significant and unreasonable land subsidence that substantially interferes with surface land uses.

(6) Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

Bringing basins into balance will require GSAs to raise fees, create reporting requirements, assess potential groundwater enhancement opportunities, and manage withdrawals. The GSPs that incorporate all of the above components must have measurable milestones and are subject to review and approval by the California State Water Resources Control Board.

Water Quality

The Porter-Cologne Act of 1969 empowers the State Water Resources Control Board as well as the nine Regional Water Quality Control Boards to protect the state's water from degradation. Each board enforces water quality controls through Waste Discharge Requirements (WDR).

For the Central Valley, agricultural impacts on water quality are regulated under the Irrigated Lands Regulatory Program (ILRP), which was created in 1999 and expanded in 2012. Growers in the Central Valley are required to file individual permits for their operation or may join coalitions that pool permits and reduce filing requirements. There are 13 geographic coalitions across the Central

Valley, and one coalition entirely for rice production, that monitor surface water and groundwater quality and work with their members to avoid contamination.

The regional and state water boards are in the process of requiring growers to report nutrient applications to their respective coalitions. These coalitions will be responsible for collecting and summarizing this information. Ultimately, many believe that this reporting will improve nutrient use efficiency and reduce nutrient pollution. It is unclear whether additional nutrient-based regulatory restrictions will be imposed on agriculture.

Water Pricing Reforms

As the drought intensified and following the Governor's 2014 decree, many urban water districts revised their water pricing policies to signal the scarcity of water to consumers. A survey of 217 water utilities in California (American Water Works Association, 2005–2013) in odd years, suggests that the water pricing method used, in order of increasing efficiency and effectiveness, are:

(1) Other (non-volumetric such as per-household fee);

(2) Uniform pricing (same per-unit price for any volume consumed);

(3) Declining pricing (price per-unit of water declines with consumption);

(4) Inclining pricing (price per-unit of water increases with consumption);

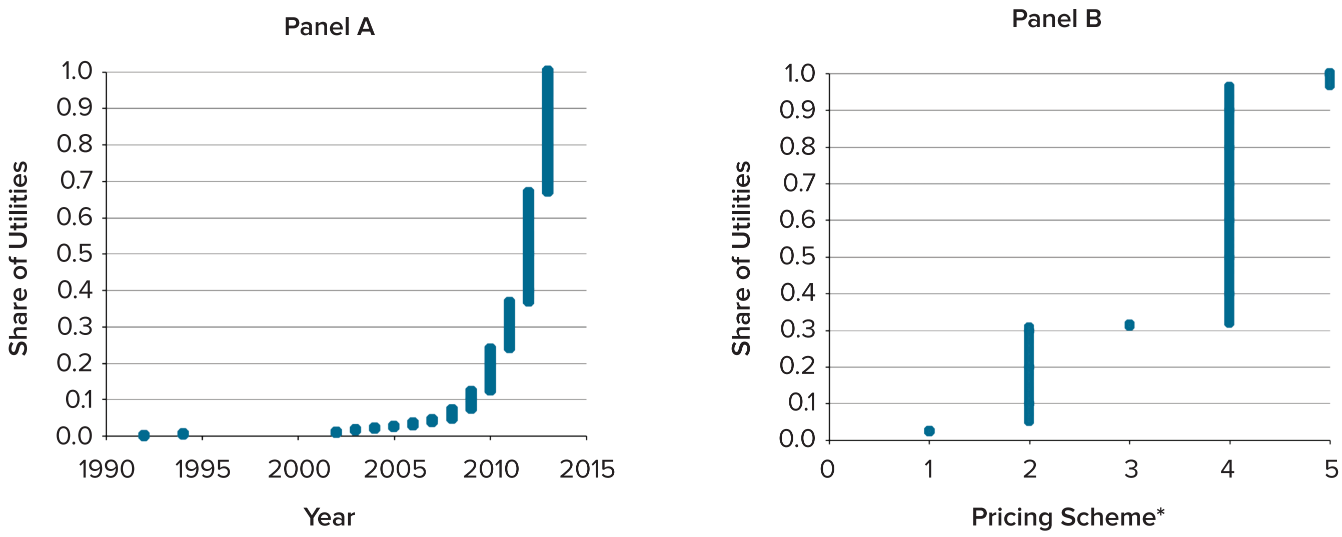
(5) Budget pricing (households face inclining tiers, but first two tiers take into account the household circumstances and varies between households).

The results presented are quite interesting. First, more than 90 percent of the urban water utilities adopted more advanced water pricing structures starting in 2010. Second, a majority of adopted pricing schemes are inclining prices (Figure 5.16).

The severe drought, combined with the financial crises that hit California in 2008, led to re-introduction of "Water Budget Rate Structures" (WBRS) that allow utilities to achieve two important objectives: (1) send the scarcity signal to consumers, and (2) secure a steady and acceptable flow of revenue to cover the fixed costs of the utility (Dinar and Ash, 2015). WBRS were initially implemented by Irvine Ranch Water District in 1991, two more water districts in 1992 and 1993, and then none until 2008. When the financial crisis combined with the drought crisis hit California, the adoption of the WBRS began to surge and in 2011 there were 12 utilities using WBRS.

Figure 5.16. Adoption of Water Pricing Schemes in California 1992–2013

Panel A: Year of Adoption of Presently Used Pricing Scheme; Panel B: Distribution of Adopted Pricing Schemes



Source: Authors' elaboration, based on data provided by AWWA, 1992-2013

Note: *Pricing schemes in the right panel are (1) Other (non-volumetric), (2) Uniform pricing, (3) Declining pricing, (4) Inclining pricing, and (5) Budget pricing; See text for more information.

Groundwater

Groundwater provides up to 100 percent of the water supply for some municipal, agricultural, and disadvantaged communities in California. Groundwater is the main source of water supply during drought years, reaching as much as 60 percent of the state's water supply (California Department of Water Resources, 2016a).

SGMA vests authority in local basin agencies to manage groundwater in a sustainable manner. However, SGMA does not modify water rights; it maintains the authority of cities and counties to manage groundwater according to their policies and ordinances.

Local groundwater ordinances are yet another regulation used for managing groundwater resources in California. Counties can develop ordinances to regulate groundwater management and groundwater transfers to destinations outside of that county (Milanes-Murcia, 2017).

With the intensification of the 2011–2016 drought, 30 of the 58 counties in California had ordinances in place to prevent water from leaving the county. The county ordinances have been identified and quantified as contributing to the impediments associated with water transfers in California, and could be one of the explanations to the question why there are so few water transactions in California (Regnacq et al., 2016).

Water Trading

Water trading is often touted as a potential solution to California's water supply challenges. Given current water allocation systems in California—a combination of riparian and appropriative rights—trading allows water to flow to its highest-valued use. Through a system of voluntary trades (markets), buyers and sellers exchange water. Market signals—prices—would ensure that water moves from lower-valued uses to a higher-valued one.

There are many complexities that must be overcome to create efficient water markets. Water itself is not an easily transported and measured commodity. There are externalities that markets can create. When water is traded, there may be local economic consequences (unemployment) as well as environmental impacts such as land subsidence and air quality impairments (from dust). This led California counties to introduce impediments that would prevent or reduce trades out of certain counties (see previous sections).

Water trade data between 1982 and 2014 (Public Policy Institute of California, California Water Market, 2016) suggest that permanent sales transactions were initiated in 1998 and remain more or less constant over time; short-term leases have decreased and long-term leases have increased over time. However, the total volume of water traded doesn't increase during dry years, suggesting that water markets in California have not emerged as a major

Table 5.3. Average Spot Market Prices During Drought and Non-Drought Years

Drought Years		Non-Drought Years	
Year	Average Price ($/Acre-Foot)*	Year	Average Price ($/Acre-Foot)*
2007	150	2006	80
2008	220	2010	180
2009	265	2011	80
2012	150		
2013	170		

Source: Based on data in WestWater Research, 2014: Figure 1
Note: *Calculations for $/acre-foot are rounded.

reallocation mechanism. While legislation was developed to boost water trading in the 1980s, it was not until the 1986–1991 drought that the drought water bank was established and 820,000 acre-feet were traded from northern to southern users. However, the quantities of water that were traded never exceeded 3–5 percent of the total water use in agricultural and urban sectors (Hanak, 2015, Regnacq et al., 2016).

Water sector institutions and local impediments are the main reasons for the inflexibility of the water market, especially during drought periods. Another factor affecting trade is the physical and institutional difficulties of moving water across different water projects. Therefore, the majority of the transactions occur between agricultural users in same project or projects in close proximity. Only in periods of severe shortage do trades occur over longer distances and between agricultural and urban users.

In an analysis of the distribution of short-term leases during 1995–2011, Regnacq et al. (2016) identify trades by proximity. The majority of contracts and volumes leased were between sellers and buyers in the same county, followed by buyers and sellers in a given region, and a relatively small number of contracts and volumes statewide.

A comparison of short-term trades (spot market water transfers) in California suggests that this trading mechanism has become one of the most important adaptation measures to address drought for users in the agricultural, urban, and environmental sectors (WestWater Research, 2014). Comparing the drought years to non-drought years (Table 5.3) suggests that market prices increased during drought periods and declined during non-drought periods.

Conclusion: Different Waters

The endemic water scarcity situation facing California has led to recognition of the importance of different types of water in the water equation of the state and of the importance of managing these waters conjunctively. This recognition is amplified during drought and water-scarce years.

Groundwater is valuable as a resource that is subject to natural recharge and a resource that can be artificially recharged and managed. The Arvin-Edison Water Storage District is probably one of the earliest groundwater management agencies in California (Arvin-Adison Water Storage District, 2003; Dinar and Xepapadeas, 1998).

Recently, with the increased duration and impact of drought in California, the state initiated several programs to promote management of aquifer recharge with various types of water. This management recognizes the value of groundwater that can be recharged during years of abundant water supply and then pumped in years with scarce supply. Wastewater is now considered a valuable resource rather than a public nuisance. Finally, desalinated water, as was discussed in earlier sections, has seen an increase in interest. All these types of water are discussed in this section.

Groundwater

Groundwater is extremely important to California because agriculture and urban cities depend on it for their water supply. In an average year, 30–40 percent of California's water supply comes from groundwater, increasing to around 60 percent in dry years. However, groundwater is hard to manage because over-pumping can lead to groundwater quality degradation by allowing intrusion of poor-quality water from adjacent aquifers and/or from ocean water intrusion in aquifers close to the Pacific Ocean. The importance of groundwater will continue to grow in California as urban and agricultural demands increase.

Between 2000–2006, 248 managed aquifer recharge projects were submitted for funding to the State of California via funding propositions. One hundred and two proposed projects were awarded funding of $879.2 million (in 2015 dollars) (Perrone and Rohde, 2016). Data in Perrone and Rohde (2016) suggest that, of the approved and presently managed aquifer recharge projects in California, a majority are from surface water, some are from storm water, and many are from wastewater and a blend of surface water, storm water, and wastewater. Two regions with major managed aquifer recharge projects are the Central Valley and Southern California.

Wastewater

As an increase in demand for water ensues, recycled water is becoming significant to the water supply of California. In some regions of California, recycled water is 7–13 percent of water used. In future years, California is planning to increase the use of recycled water. This will reduce the need for long-distance water conveyance, provide local water supplies, and be a drought-resistant resource.

Brackish Water

Brackish groundwater can be used as cooling water for power generation, for aquaculture, for mixing with freshwater, and for other uses. The use of brackish water in California rose between 2000–2010 (U.S. Geological Survey, 1950-2010. Brackish Water, National Brackish Groundwater Assessment, n.d.). Although 1950–2010 data from the U.S. Geological Survey, cited above, reports brackish water use in few sectors (not including agriculture), brackish water is used by the agricultural sector through mixing with freshwater for irrigation of traditional crops, and for direct use in irrigation of biofuel plants (Levers and Schwabe, 2017).

Desalinated Water

Desalination is seeing increased interest as a potential water supply. Due to the high cost of desalination of seawater and brackish water, this process is used infrequently. However, with population growth in California, the likely effects of climate change on severity and duration of drought, and projections of reductions in the cost of desalination (WateReuse Association, 2012), this technology could become a more attractive option for California in the not too distant future.

Future Water Resources

There is no single silver bullet to meet California's current and future water challenges. Instead, we must move forward with the existing set of institutions, infrastructure, management choices, and technologies while investing in innovative approaches to meet future needs. California's water challenges span the four major areas of water management and use: surface water supplies, groundwater supplies, surface water quality, and groundwater quality. While each challenge has unique features, they all have overlapping interactions that require managers to address water from a holistic perspective.

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