BUREAU OF RECLAMATION

Sacramento and San Joaquin River Basins

SECURE Water Act Section 9503(c) Report to Congress

U.S. Department of the Interior

March 2021

Mission Statements

The Department of the Interior conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acronyms and Abbreviations

°F	degrees Fahrenheit
3C	California Crop Coefficient
Basins Study	Sacramento-San Joaquin Rivers Basin Study
BDO	Reclamation's Bay Delta Office
CalFish Track	Central Valley Acoustic Tagging Project
CCWD	Contra Costa Water District
COMPASS	Comprehensive Passage Model
CVOO	Central Valley Operations Office
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
Delta	Sacramento-San Joaquin Rivers Delta
DPWD	Del Puerto Water District
DWR	State of California Department of Water Resources
ESA	Endangered Species Act
ET	evapotranspiration
HGSSJVM	HydroGeoSphere San Joaquin Valley Model
LVE2	Project Los Vaqueros Expansion Feasibility Study for Phase 2
MAF	million acre-feet
NCAR	National Center for Atmospheric Research
Reclamation	Bureau of Reclamation
SacPAS	Sacramento River Prediction and Assessment of Salmon
SCVWD	Santa Clara Valley Water District
SDM	Structured Decision Making
SECURE Water Act	Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act
SJRECWA	San Joaquin River Exchange Contractors Water Authority
SLLPIP	San Luis Low Point Improvement Project
SWP	California's State Water Project
WARMF	Watershed Analysis Risk Management Framework
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WEAP	Water Evaluation and Planning Plant Growth Model
WIIN	Water Infrastructure Improvements for the Nation Act


Oregon
California
Nevada
Trinity River Watershed
Trinity River
Shasta Dam
Redding
Red Bluff
Sacramento River Basin
Tehama-Colusa Canal
Sacramento River
Oroville
Yuba City
Folsom Dam
Sacramento
San Joaquin River Basin
Stockton
Oakland
San Joaquin River
Pacific Ocean
San Jose
Delta Mendota Canal
Fresno
Tulare Lake Basin
Friant Kern Canal
California Aqueduct
Kern River
Bakersfield
Sacramento and San Joaquin Basins
Legend
Major Reclamation Dam
C.W. Bill Jones Pumping Plant
Major City
Major River or Tributary
Tehama-Colusa Canal
Delta Mendota Canal
California Aqueduct
Friant-Kern Canal
Basin and Watershed Boundary
Lake or Reservoir
CVP San Felipe Division
Sacramento and San Joaquin Delta
State Boundary
N
W
E
S
0
50
100
200
Miles

Sacramento and San Joaquin River Basins

States:

- California
- Oregon

Major U.S. Cities:

- Redding
- Sacramento
- Stockton
- San Jose
- Fresno
- Bakersfield

Major Water Uses:

- Agriculture (5.4 million acre-feet)
- Municipal (310,000 acre-feet)
- Hydropower (2.1 gigawatts)
- Flood Control
- Recreation
- Navigation
- Fish and Wildife Habitat

River Basin Area: 60,000 square miles

River Length: Sacramento 445 miles; San Joaquin 366 miles

Major Rivers/ Tributaries:

- Feather
- American
- Stanislaus
- Merced
- Kern

Notable Reclamation Facilities:

- **20** dams
- **11** powerplants
- **500+** miles of canals

Contents

ABOUT

This basin report is part of the 2021 Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act Report to Congress, prepared by the Bureau of Reclamation in accordance with Section 9503(c) of the SECURE Water Act of 2009, Public Law 111-11. The 2021 SECURE Water Act Report follows and builds upon the first two SECURE Water Act Reports, submitted to Congress in 2011 and 2016. The report characterizes the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

The 17 Western States form one of the fastest growing regions in the Nation, with much of the growth occurring in the driest areas. The report provides information to help water managers address risks associated with changes to water supply, quality, and operations; hydropower; groundwater resources; flood control; recreation; and fish, wildlife, and other ecological resources in the West.

To see all documents included in the 2021 SECURE Water Act Report to Congress, go to: https://www.usbr.gov/climate/secure/

Friant Dam is located on the upper San Joaquin River in the Sierra Nevada foothills of Fresno County, California near the town of Friant. The dam, completed in 1942, forms Millerton Lake and was built by the Bureau of Reclamation. The dam and reservoir provide water for irrigation of the San Joaquin Valley, which is distributed by the Madera and Friant-Kern Canals.

SECTION 1

Water Management Challenges

The Central Valley regions that depend on the Sierra Nevada and Coast Range mountains for water have been facing rising demands for water from rapidly increasing populations; changes in land use; and growing urban, agricultural, and environmental demands. These demands already exceed the capacity of the existing water management system to supply adequate water, especially during the record drought periods in California in recent years. Rising sea levels, along with declining water quality, are also increasing threats to endangered species and constraining export of agricultural and municipal water supplies to Central Valley Project (CVP) and California State Water Project (SWP) water users in the San Joaquin and Tulare Lake Basins. Additionally, agricultural demands have been decreasing in recent years as urban demands have been increasing. This imbalance between water supplies and demands has resulted in groundwater overdraft and land subsidence (a sinking of the earth from groundwater extraction) in some parts of the Central Valley.

The challenges posed by uncertainty in socioeconomic and climatic conditions highlight the need for Federal, State, and local agency partnerships to effectively address the complex and interrelated effects of changing conditions on future Central Valley water management. The Bureau of Reclamation (Reclamation), in partnership with five cost-share partners—the State of California Department of Water Resources (DWR), California Partnership for the San Joaquin Valley, El Dorado County Water Agency, Madera County Resources Agency, and the Stockton East Water District—initiated the Sacramento-San Joaquin Rivers Basin Study (Basins Study) (Reclamation, 2016) to evaluate these challenges and explore potential strategies to address them. This section describes the water management challenges present in the Sacramento, San Joaquin, and Tulare Lake Basins.

Basin Overview

The Sacramento, San Joaquin, and Tulare Lake Basins are located in the Central Valley of California. The Central Valley is carpeted by vast agricultural regions and dotted with numerous population centers. There are currently more than 6.5 million acres of irrigated lands supporting a diverse range of permanent and annual agricultural crops. About 6.5 million people live in the Central Valley today, and it is the fastest growing region in California.

The Central Valley is divided into three basins—the Sacramento Valley, San Joaquin Valley, and the Tulare Lake Basins. The major rivers in these basins include:

The Sacramento River – The largest river in California with a mean annual flow of approximately 18 million acre-feet (MAF). From its headwaters near Mount Shasta, its drainage area is approximately 27,000 square miles in the northern Sacramento Valley portion of the Central Valley.

The San Joaquin River – The second largest river in California with a mean annual flow of 6 MAF. From its headwaters in the south-central Sierra Nevada mountains, its drainage area consists of the San Joaquin Valley in central and southern portions of the Central Valley.

The Kings, Kaweah, Tule, and Kern Rivers – The major rivers in the Tulare Lake Basin. They have a combined mean annual runoff of approximately 2 MAF. The headwaters of these rivers are located in the southern Sierra Nevada mountains and their drainage area consists of the southern San Joaquin and Tulare Lake Basins.

The Sacramento and San Joaquin Rivers both flow into the Sacramento-San Joaquin Rivers Delta, which is the largest estuary on the West Coast of the United States **(Figure 1)**. In the Delta, tidal influence mixes these rivers with seawater in a complex maze of channels and man-made islands surrounded by levees with internal drains. The Delta drains about 40 percent of California's land area and has a total area of about 1,150 square miles.

The map on page iv shows areas that are of importance to Reclamation's water management in California, including the Sacramento, San Joaquin, and Tulare Lake Basins. These areas of importance also include a part of the Trinity River watershed, from which water is exported to the Sacramento River, and the San Felipe Division of Reclamation's Central Valley Project. The designation of these areas as the Basin Study Area was used in the Sacramento-San Joaquin Rivers Basin Study (Reclamation, 2016).

The CVP and SWP are the two major water management projects in the Central Valley. Reclamation began construction of the CVP in 1933. Today it consists of 20 dams, 11 hydropower plants, and more than 500 miles of canals that serve multiple purposes. The agricultural water deliveries irrigate about 3 million acres of land in the Sacramento, San Joaquin, and Tulare Lake Basins. The 1992 Central Valley Project Improvement Act (CVPIA) dedicated about 1.2 MAF of annual supplies for environmental purposes. The State of California built and operates the SWP, which provides up to about 3 MAF/year, on average, of water supplies from Lake Oroville on the Feather River to irrigate 750,000 acres in the Central Valley, as well as to provide supplemental water to about 25 million Californians in the central and southern coastal areas. The combined CVP/SWP developed water supply is about 8.7 MAF/year on average.

Figure 1. The Sacramento-San Joaquin Rivers Delta.
(Photograph courtesy of U.S. Fish and Wildlife Service)

	Agricultural	Urban	Total
Sacramento River System	4,541	610	5,151
Delta and Eastside Streams	1,545	107	1,652
San Joaquin River System	4,695	342	5,037
Tulare Lake Basin	14,152	970	15,122
Total Central Valley	**24,933**	**2,029**	**26,962**

Table 1. Estimated period (1923 to 2010) average annual agricultural and urban historical water demands in thousands of acre-feet per year.

Water Use in the Basin

California's population continues to grow rapidly and is projected to exceed 40 million people by 2020. About 6.5 million people are currently living in the Central Valley. The California Department of Finance projects the Central Valley population to grow to 12 million people by 2040. This population growth is reflected in an increasing need for water supplies. It is estimated that total Central Valley urban water demands could increase from about 2 MAF/year to more than 3.8 MAF/year by the end of the 21st century (Reclamation, 2016). However, this urban demand could significantly increase to as much as 7 MAF/year if the population increases more rapidly.

The Central Valley is one of the most productive agricultural regions in the world **(Figure 2)**. With more than 6.5 million acres under irrigation, it produces more than 230 types of crops, including more than half of the fruits, vegetables, and nuts grown in the United States. During the period from 1998 to 2010, the DWR (DWR, 2014) estimated that Central Valley agricultural water demands ranged from 18 MAF to 26.8 MAF, while urban water demands ranged from 1.7 MAF to 2.4 MAF. Based on historical climate data during the period from 1923 to 2010, and assuming a 2006 level of agricultural land use and urban population, the Basins Study (Reclamation, 2016) estimated period average water demands by sector for each of the Central Valley basins are shown in **Table 1**.

In 2013, Central Valley agricultural production was valued in excess of $43 billion dollars. However, in agricultural regions of the Central Valley, one in five residents lives below the poverty level. Urban growth has been occurring at the expense of agricultural land use. Based on data developed for the California Water Plan (DWR, 2014), the Basins Study estimated that, under current trends on the conversion of agricultural land to urban uses, irrigated lands could decline from 6.5 to 5.4 million acres by 2040 and to 5.3 million acres by 2099. This reduction in irrigated acreage, along with potential changes in climate, could result in a reduction of total Central Valley agricultural demands from 21.7 MAF/year to as little as 19.7 MAF/year.

On average, the CVP/SWP managed water supply of about 8.7 MAF is considerably less than the estimated combined annual agricultural plus urban water demands in the Central Valley of 26.9 MAF/year. In addition, 1.2 MAF/year is dedicated to environmental uses as required by the CVPIA. Notably, there is a significant imbalance between supplies and demands. Consequently, there are many years when CVP/SWP water users receive significantly less water than they could put to beneficial use.

Figure 2. Central Valley Project water delivery to agriculture.

Groundwater Overdraft

This imbalance in water supply and demand also contributes to a variety of other management challenges. In particular, in order to obtain additional supplies, water users frequently turn to groundwater pumping. On average, nearly 40 percent of the water used by California's farms and cities is pumped from groundwater aquifers. In some basins, groundwater withdrawal exceeds the long-term rate of recharge. It is estimated that agricultural regions use an average of approximately 2 MAF/year of water from groundwater pumping and significantly more in dry years. This "overdraft" creates many associated problems that include declining water levels that lead to higher energy costs to pump water; land subsidence which causes damage to canals, levees, roads, and other infrastructure; reduced flow in nearby rivers; and reduced water quality, especially in coastal and estuarian regions, such as the Delta where saline water occurs.

During the drought period between 2012 and 2016, groundwater pumping reduced water levels enough that more than 3,500 relatively shallow domestic wells went dry. In 2014, the State of California passed the Sustainable Groundwater Management Act. It requires local agencies to develop and implement plans that will bring their basins into balance. Many of the critically over drafted basins occur in the San Joaquin and Tulare Lake Basins in the southern Central Valley. By 2020, the basins are required to develop and implement plans that will achieve groundwater sustainability over a 20-year period.

Droughts

Droughts have been a regular occurrence in the Central Valley during the 20th and 21st centuries. However, the increased warming that has led to recent droughts has contributed to progressively severe impacts in agricultural, natural, and urban environments. The period from 2012 to 2015 was the driest period in the recorded history of the Central Valley and was estimated to be the driest in the last 1,200 years. These drought conditions led to the death of an estimated 100 million trees in the watersheds surrounding the Central Valley, and contributed to the occurrence of intense wildfires, soil erosion, reduced upper watershed water retention capacity, and increased reservoir sedimentation **(Figure 3)**.

Figure 3. Severe signs of drought in the San Joaquin River.

Figure 4. Water releases into the San Joaquin River.

Atmospheric Rivers

California experiences highly variable climate conditions which often produce extreme dry periods followed by extreme wet periods. These high precipitation events are frequently associated with the occurrence of Atmospheric Rivers. Atmospheric Rivers are long, relatively narrow atmospheric regions that can transport large amounts of water vapor from the tropics to the West Coast of North America. While droughts are slower to develop than Atmospheric Rivers, this climate variability makes balancing of flood protection and water supply storage in the CVP/ SWP and other major reservoirs challenging.

Floods

The 2012 to 2015 drought was followed by the wettest winter ever recorded in 2016 to 2017 **(Figure 4)**. In February, the combined inflow to Shasta, Oroville, and Folsom Dams was more than 750,000 acre-feet in a single day. The emergency spillway of Oroville Dam was employed for the first time in 48 years. Also, damage to the main spillway caused by the high flows resulted in the evacuation of nearly 200,000 people downstream along the Feather River. To maintain enough flood storage capacity while providing flood protection, about 370,000 acre-feet had to be released from these reservoirs 2 days later.

While the United States Army Corps of Engineers has invested considerable resources in levees protecting major population centers, such as the Sacramento metropolitan area, there is still considerable flood vulnerability in older and less engineered levees, such as those in the Delta.

Environmental Demands – Threatened and Endangered Species and Other Aquatic Species

Another significant challenge is management of the Delta's key role as the hub of the CVP/SWP conveyance infrastructure for exportation of Sacramento Valley water supplies to south-of-the-Delta urban and agricultural water users, while also providing habitat to several threatened or endangered species including Delta smelt (*Hypomesus transpacificus)* **(Figure 5)**, Sacramento River winter-run Chinook salmon *(Oncorhynchus tshawytscha)*, and Central Valley spring-run and California Central Valley steelhead trout *(Oncorhynchus mykiss)*.

The factors contributing to the decline of these aquatic species are numerous and complex. Delta smelt are found only in the Delta estuary. They are threatened with extinction due to a variety of conditions including entrainment losses related to export pumping, unfavorable salinity and temperature habitat conditions in the Delta, and reduced Delta outflow. Increasing sea levels will contribute to increasing salinity which will negatively impact the extent and quality of Delta smelt habitat. The Chinook salmon and Steelhead trout are also affected by a lack of quality rearing habitat in the Delta, as well as limited availability of suitable spawning habitat conditions (water temperature) in the upper reaches of the Sacramento and San Joaquin Rivers.

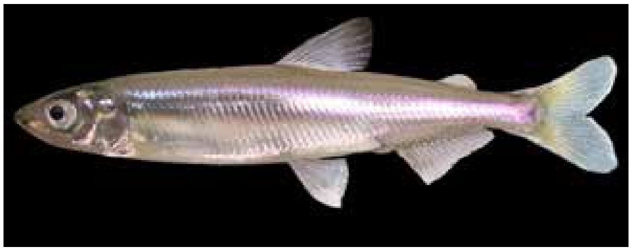
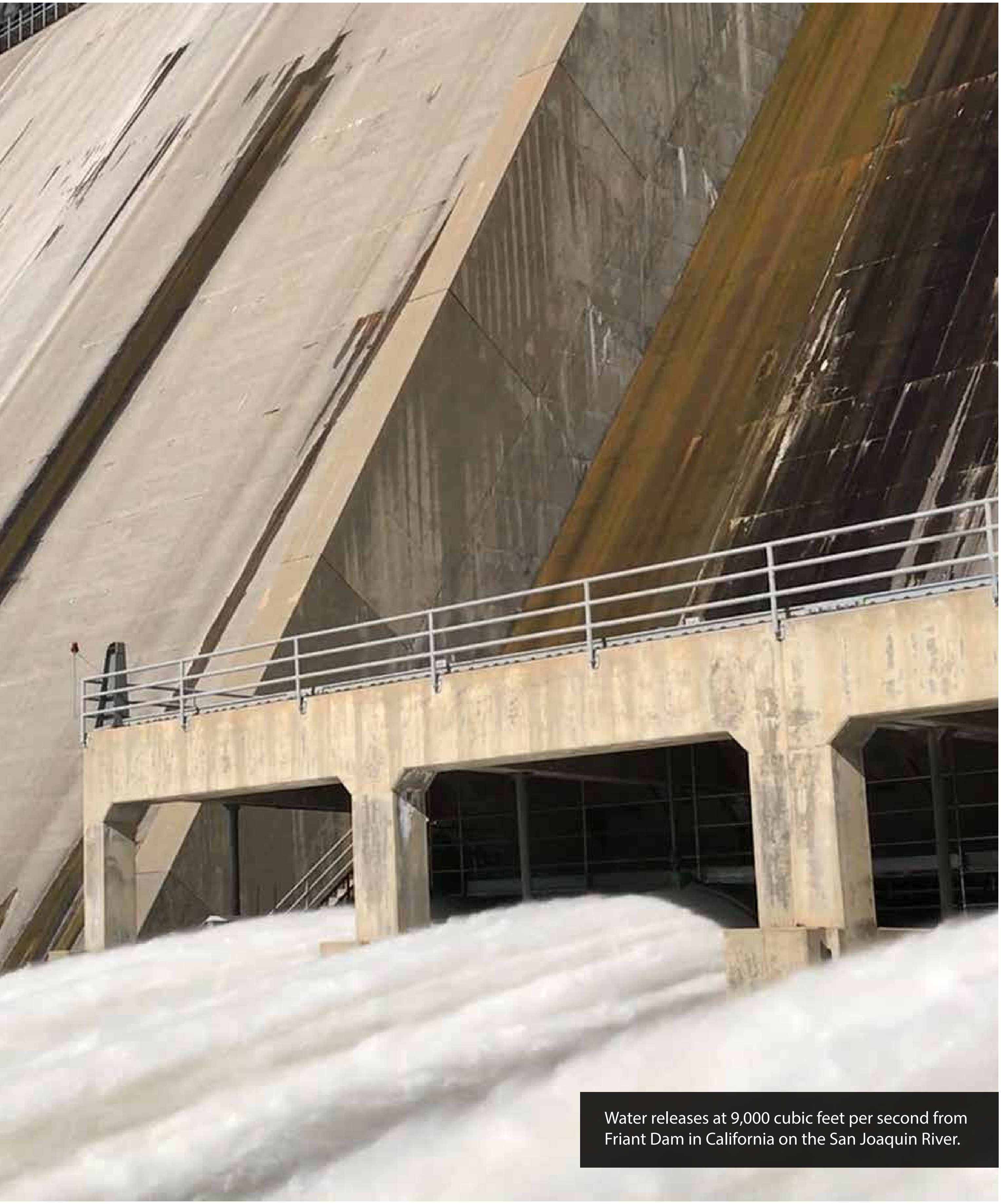


Figure 5. Image of Delta smelt.



Water releases at 9,000 cubic feet per second from Friant Dam in California on the San Joaquin River.

Summary of Studies in the Central Valley

- Summary Report Central Valley Project Integrated Resource Plan (Reclamation, 2013)
- California Water Plan Update 2013 (DWR, 2014)
- West Wide Climate Risk Assessment, Sacramento and San Joaquin Basins, Climate Impact Assessment (Reclamation, 2014)
- Sacramento-San Joaquin Rivers Basin Study (Reclamation, 2016)
- California Water Plan Update 2018 (DWR, 2019)

Nimbus Dam on the American River, California.

SECTION 2

Analysis of Impacts to Water Resources

Fundamental to the analysis of impacts to water and related resources is the balance between water supply and demand. Climate and its variability are basic factors affecting water supply. These primary factors include precipitation, temperature, humidity, wind, solar radiation, and atmospheric green-house gas concentrations. How much green-house gas is emitted into the atmosphere is a major factor affecting climate and contributing to future water supply uncertainty.

Although societal choices have climatic effects, water demands are more strongly influenced by socioeconomic activities. These water demands include needs for a variety of agricultural, urban, and environmental water uses. How societies will make choices between these potentially competing needs is a major factor contributing to future water demand uncertainties.

Understanding risks to water and related resources, as well as developing effective strategies to mitigate impacts, requires determining the extent of imbalances between both current and future water supplies and demands. However, uncertainties in both supply and demand must be addressed in order to make these analyses meaningful.

One approach to address these uncertainties is to establish reasonable ranges of potential changes in climate and socioeconomic conditions. By combining different projected levels of socioeconomic activities with a wide range of potential changes in climate in the 21st century, a variety of scenarios representing future uncertainties can be developed. These scenarios are not intended to be predictions of future conditions, but rather a characterization of future uncertainties. For a detailed explanation of climate projections relied on by Reclamation, please refer to Reclamation's 2021 West-Wide Climate and Hydrology Assessment, Section 2.1, and for a discussion of associated uncertainties, please refer to Section 9.1. Applying models of hydrology and water management, these scenarios are used to better understand the potential range of supply/demand imbalances and their impacts on agriculture, urban, and environmental water needs. These impacts become the basis for the development of potential mitigation strategies. Finally, the performance of these strategies are evaluated and tradeoffs between them determined for a variety of water and related resource categories.

This multi-step process is illustrated in this and the following section. The first step in this process is to characterize historic and projected changes in temperature; precipitation; snowpack, runoff and streamflow; evapotranspiration (ET); and sea level rise. A summary of these changes is presented below:

Temperature

In the Central Valley, average annual temperature varies considerably with cooler temperatures at higher elevations and a warming trend from north to south. Since the beginning of the 20th century, there has been an overall increase in average annual temperature in California of about 1°F (degrees Fahrenheit). Relative to the historic climate (1981 to 2010), temperatures are projected to increase steadily during the 21st century, with generally greater changes occurring farther away from the coast reflecting a continued ocean cooling influence. In the Central Valley, warming increases of approximately 1.8°F are projected to occur in the early 21st century with approximately 4°F of increase by mid-century. By the late 21st century, increases are projected to reach almost 6.5°F in the easternmost Sierra Nevada portions of the Basins Study Area.

Precipitation

In the Central Valley, precipitation increases with elevation with greater amounts occurring in the coastal and Sierra Nevada mountain regions. There is also a decreasing trend from the Sacramento Valley in the north to the Tulare Lake Basin in the south. Precipitation occurs primarily in the late fall and winter months and varies considerably between years. Although temporal trends in annual precipitation are not as apparent as temperature trends, there has been a general trend toward increased precipitation variability since the mid-1970s. In the Sacramento Valley **(Figure 7)**, San Joaquin Valley and Tulare Lake Basin, very little change in future precipitation is projected to occur throughout the 21st century. In the Sierra Nevada mountains, slight increases in precipitation are projected to occur in the early (2 percent), mid-century (1 percent), and late 21st century (2 percent).

Snowpack, Runoff, and Streamflow

In the Sierra Nevada and Coast Range mountains, winter precipitation may accumulate temporarily as snowpack and then become runoff or infiltrate into the ground when it melts. In the 20th century, widespread decreases in springtime snowpack were observed consistently across the lower elevations of the Western United States. Snowpack losses tend to be larger at low elevations because rising temperatures cause more precipitation to occur as rainfall at relatively warmer lower elevations. Rising temperatures have also caused snowpack to melt earlier in the spring, which causes a shift in the timing of runoff and streamflow. Snowpack, as measured by April 1st Snow Water Equivalent, is projected to decrease continuously throughout the 21st century.

In the Sierra Nevada mountains, snow water equivalent is projected to decrease by about 5 percent in the higher elevations of the watershed by as early as 2025. By mid-century, a decrease in the snow water equivalent of about 10 percent is projected and by the end of the century, a decrease of up to 15 percent is projected to occur.

Evapotranspiration

Watershed ET reduces soil moisture which contributes to reduced runoff, streamflow, and groundwater recharge. Actual ET is projected to increase continuously during the 21st century, primarily in higher elevations of the mountains surrounding the Central Valley. By the end of the century, a 15 percent increase in

Figure 7. Millerton Reservoir in California.

actual ET may occur in the forested regions of the northern and central Sierra Nevada Mountains. These higher elevation watershed regions experience more pronounced impacts because increased warming will increase the length of the growth period, which in turn will result in additional ET by vegetation. While warmer winter temperatures, especially at lower elevation, will lead to increased winter runoff, the increase in ET during the growing season will decrease stream baseflows during the summer and early fall seasons.

Sea Level Rise

Global and regional sea levels have been rising steadily over the past century and are expected to continue to increase throughout this century. Over the past several decades, sea level measured at tide gauges along the California coast has risen at a rate of about 6.7 to 7.9 inches per century (Cayan et al., 2009). Sea level rise is an important factor that impacts California's water resources, especially water quality in the Delta. Higher sea level is associated with increasing salinity in the Delta, which influences the suitability of its water for agricultural, urban, and environmental uses.

Rising sea levels also increase the risk of levee failure in the Delta, which can significantly disrupt the exportation of water supplies to urban and agricultural water users in the south-of-the-Delta regions. The National Research Council completed a comprehensive assessment of sea level change projections for the Pacific Coast of North America (NRC, 2012). In the San Francisco Bay and Delta region, mean sea level rise is projected to accelerate during the century, reaching about 1 foot of sea level rise by mid-century and about 3 feet by the end of the century.

Next, the impacts analyses presented in this section were selected to correspond generally with resource categories identified in Section 9503(c) of the Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act (P.L. 11-111), including water delivery reliability, water quality, hydropower, flood control, recreational use, and ecological resources.

The impacts on the SECURE Water Act resource categories, along with corresponding performance metrics, are shown on **Figure 8** for these scenarios. Note that this discussion presents a range of potential impacts that might occur without any of the adaptations described in the following section occurring.

As illustrated in **Figure 8**, the first column on the left side shows each of the SECURE Water Act resource categories. In the "Impacts (Period 2015 to 2099)" column, performance metrics associated with each resource category are shown. The next three columns display the period average impacts for each scenario. Improvements in conditions relative to historic conditions of more than 10 percent are represented by green bars on the right side of the vertical line. Declining conditions of more than 10 percent are represented by red bars on the left side on the vertical line. Improvements or declines of less than 10 percent are represented by yellow bars on the right and left sides of the vertical line, respectively. The bar size indicates the relative magnitude of the impact.

As shown, climate uncertainty is a major factor determining the magnitude of impacts. For the Warm-Wet climate scenario, there are only three negative impacts including water quality (Delta salinity), flood control (reservoir flood control), and Fish and Wildlife Habitats (food web productivity), and all of these impacts are less than 10 percent relative to historical conditions.

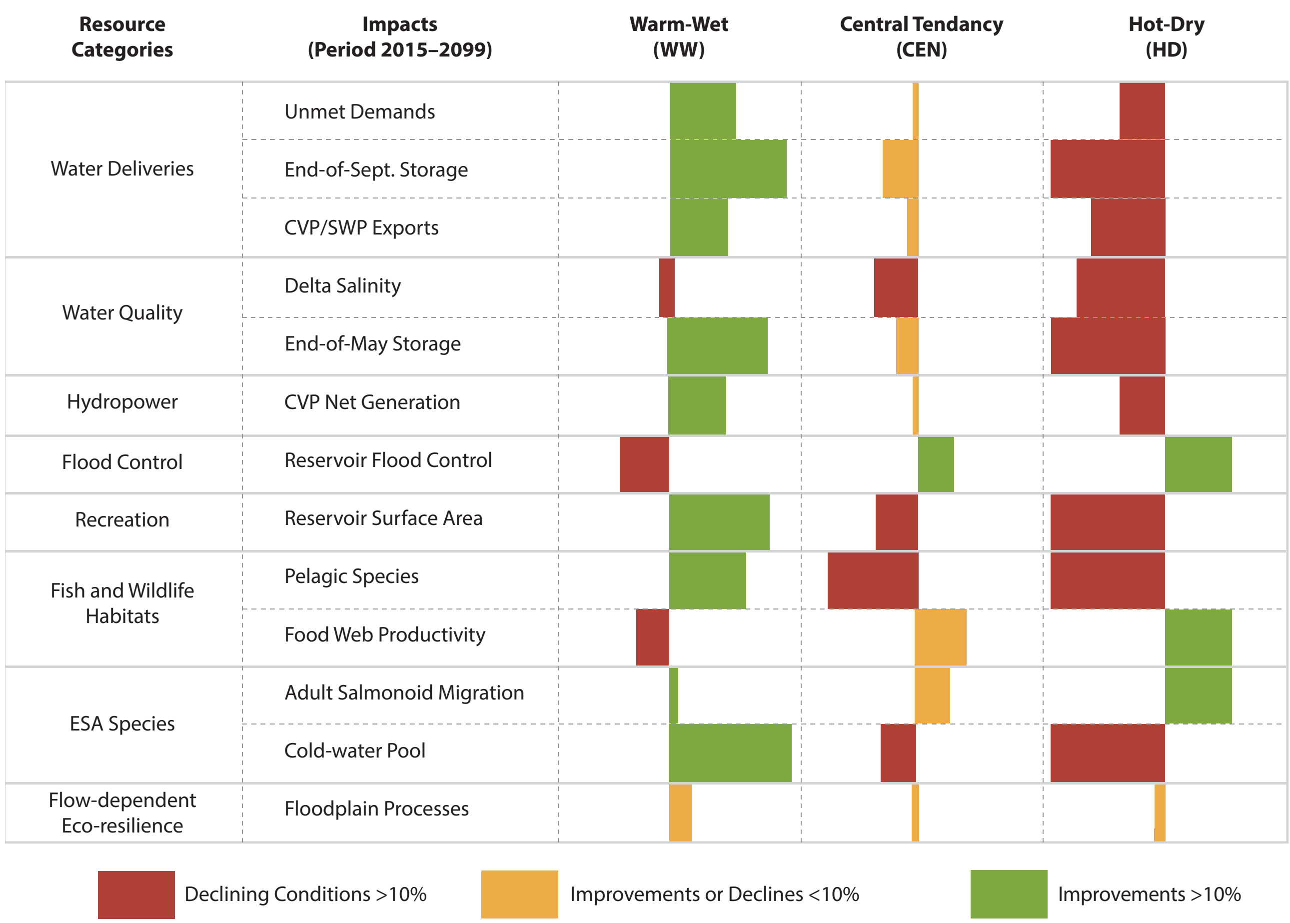


Figure 8. Analysis of impacts by resource category.

Note: Pelagic fish live and spawn in the water column (not near the bottom or the shore) of coasts, open oceans, and lakes. There are several pelagic species native to the Delta, including Delta and longfin smelt.
ESA = Endangered Species Act; CVP = Central Valley Project; SWP = California's State Water Project

In the Central Tendancy scenario, there is very little change in impacts either positive or negative except for Delta salinity, which is greater than a 10 percent decline. However, in the Hot-Dry scenario, most of the impacts are negative and greater than 10 percent.

For each of the resource categories, a discussion of how climate uncertainty affects the performance metrics is provided below:

Water Deliveries

The primary factor influencing water deliveries **(Figure 9)** is the effect of precipitation on streamflow and water supplies in reservoirs. As these factors decrease, unmet demands (the difference between water supply and demand) increase. End-of-September is a metric of carryover storage that indicates the water supply available for delivery in the next water year in the event of poor winter precipitation. This metric declines as the climate becomes drier. Similarly, export pumping also declines as climate conditions become drier.

Water Quality

There are two primary factors affecting water quality, in particular in regards to salinity. Delta salinity is affected by both sea level rise as ocean temperature increases and by reduced Delta outflow with a drier climate, which allows more sea water intrusion into the Delta. In addition, the ability of the CVP/SWP reservoirs to maintain adequate water temperatures in upstream spawning habitat declines as cold-water pool created from spring snowmelt filling reservoirs represented by End-of-May Storage declines.

Hydropower

Water levels in CVP reservoirs are the primary factors affecting hydropower. As the climate becomes drier, declining reservoir levels result in a reduction in net (production minus use) CVP hydropower generation.

Figure 9. Central Valley Project water from the San Joaquin River is used to grow many crops, including almonds in the San Joaquin Valley.

Flood Control

The primary factor affecting flood control is reservoir flood storage capacity. In a drier climate, the reduction in reservoir inflows results in more flood storage capacity than in a wetter climate. This leads to improved flood control conditions.

Recreation

The surrogate performance measure used for recreation is reservoir surface area. Higher amounts were assumed to be more favorable to recreational activities **(Figure 10)**. Consequently, as climate becomes wetter, the reservoir surface area becomes larger leading to improved recreation conditions.

Fish and Wildlife Habitat

The primary factor affecting the pelagic species is the occurrence of saline water in the eastern Delta. To the extent that saline ocean water moves eastward into the interior Delta, habitat conditions for Delta smelt deteriorate. Therefore, as sea level rises and Delta outflow declines in a hotter-drier climate, pelagic species habitat declines. On the other hand, declining food web productivity is related to the occurrence of increasing upstream (reverse) flows in channels of the San Joaquin River. These reverse flows increase in magnitude and frequency as CVP/SWP export pumping increases. However, export pumping typically declines as climate conditions become drier, which ultimately leads to improved food web productivity.

Endangered Species Act (ESA) Species

Chinook salmon and steelhead fish species were selected for the impact analysis **(Figure 11)**. The Delta rearing areas for these species are subject to a variety of stressors affecting their migration, including entrainment due to CVP/SWP export pumping. Consequently, for adult salmon migration negative impacts are greatest, although not especially severe relative to historic conditions, in a wetter climate because CVP/SWP export pumping is greater than in the drier climate. In the upstream spawning areas, the adults and smolts are sensitive to water temperature. In the summer and early fall months, maintaining sufficiently cool

Figure 10. Kayaking on the San Joaquin River.

water temperatures is accomplished by releasing water from the cold water pool stored in CVP/SWP reservoirs. Therefore, negative impacts to Chinook salmon and steelhead trout are greater in a hotter, drier climate than in a wetter one.

Flow-dependent Eco-resiliency

For this category, floodplain processes contributing to creation and maintenance of riparian habitats were analyzed. In the Sacramento Valley, high flows during the spring snowmelt runoff season create new point bar surfaces that support the establishment of riparian vegetation. To analyze impacts, the magnitude of Sacramento River flows during the spring months were compared to historical period flows. There were only minor changes in flows regardless of climate. This is primarily due to the fact that existing flood control and water supply operations at Shasta Dam are designed to prevent the occurrence of large flows during the late winter and early spring months.

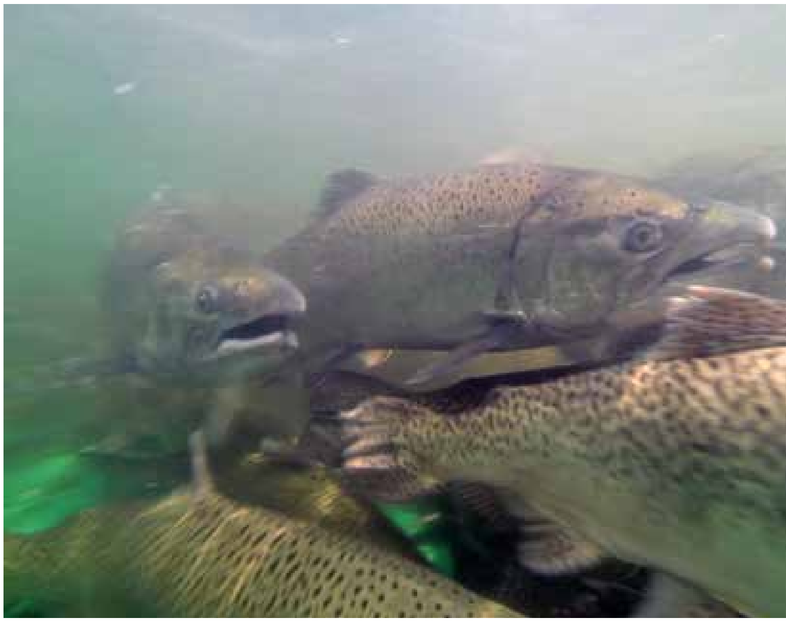


Figure 11. San Joaquin River threatened adult spring-run Chinook salmon.

Flood irrigation using Central Valley Project water from the San Joaquin River at an almond orchard in the Central Valley of California (GettyImages).

SECTION 3

Potential Adaptation Strategies to Address Vulnerabilities

Based on the analysis of impacts to SECURE Water Act resource categories, a variety of potential adaptation strategies were considered by Reclamation, in consultation with the Basins Study partners. To examine a broad range of potential water management actions, the partners, water management agencies, interested stakeholders, and the general public were asked to submit actions. Several workshops and a public meeting were held to solicit ideas and proposals for actions. During this process, Reclamation, consultants, and partners also compiled an initial list of actions based on those included in the California Water Plan Update 2013 (DWR 2014), Least-Cost Central Valley Project Yield Increase Plan (Reclamation 1995), Central Valley Project Integrated Resource Plan (Reclamation 2013), and other basin studies. These water management actions were evaluated by the Basins Study team and 20 representative actions were identified. **Figure 12** shows the 20 representative water management actions, ordered from highest to lowest cost, along with their corresponding "quantity of yield" and "timing" evaluations.

Each water management action was also categorized according to the type of management strategy as follows. Each strategy is assigned a color to help highlight the management response strategy type for each water management action in **Table 2**.

- **Reduce water demand:** Increase agricultural, municipal, and industrial water use efficiency.
- **Increase water supply:** Increase regional wastewater reuse; increase ocean desalination; and develop local supplies (e.g., rainwater harvesting).
- **Improve operational efficiency:** Implement conjunctive (coordinated use of surface water and groundwater) groundwater management; enhance groundwater recharge; improve salinity and nutrient management; improve river temperature management; and increase surface storage.
- **Improve resource stewardship:** Improve forest health, particularly in the higher-elevation forested watersheds.
- **Improve institutional flexibility:** Improve regulatory flexibility and adaptability to enhance water system efficiency.
- **Improve data and management:** Improve data management and the use of data to support near- and long-term decision making.

Given the complex nature of the multiple challenges identified in the impact analysis, no single water management action can improve conditions for all SECURE Water Act resource categories. Therefore, the water management actions were combined into seven portfolios representing a variety of approaches to address the identified impacts. These portfolios included:

- **Least Cost:** This portfolio focuses on water management actions that increase yield at minimal cost per acre-foot of yield.
- **Regional Self-Reliance:** This portfolio focuses on regional and local actions that can be accomplished without large-scale infrastructure investments.
- **Healthy Headwaters and Tributaries:** This portfolio focuses on actions to increase spring flows in upstream reaches of the Sacramento River and fall flows in the Delta.
- **Delta Conveyance and Restoration:** This portfolio focuses on actions that increase Delta exports using new Delta conveyance infrastructure, along with environmental actions to improve Delta habitat conditions.
- **Expanded Water Storage and Groundwater:** This portfolio focuses on new surface water storage, Delta conveyance, and groundwater management actions to increase conjunctive use and groundwater recharge.

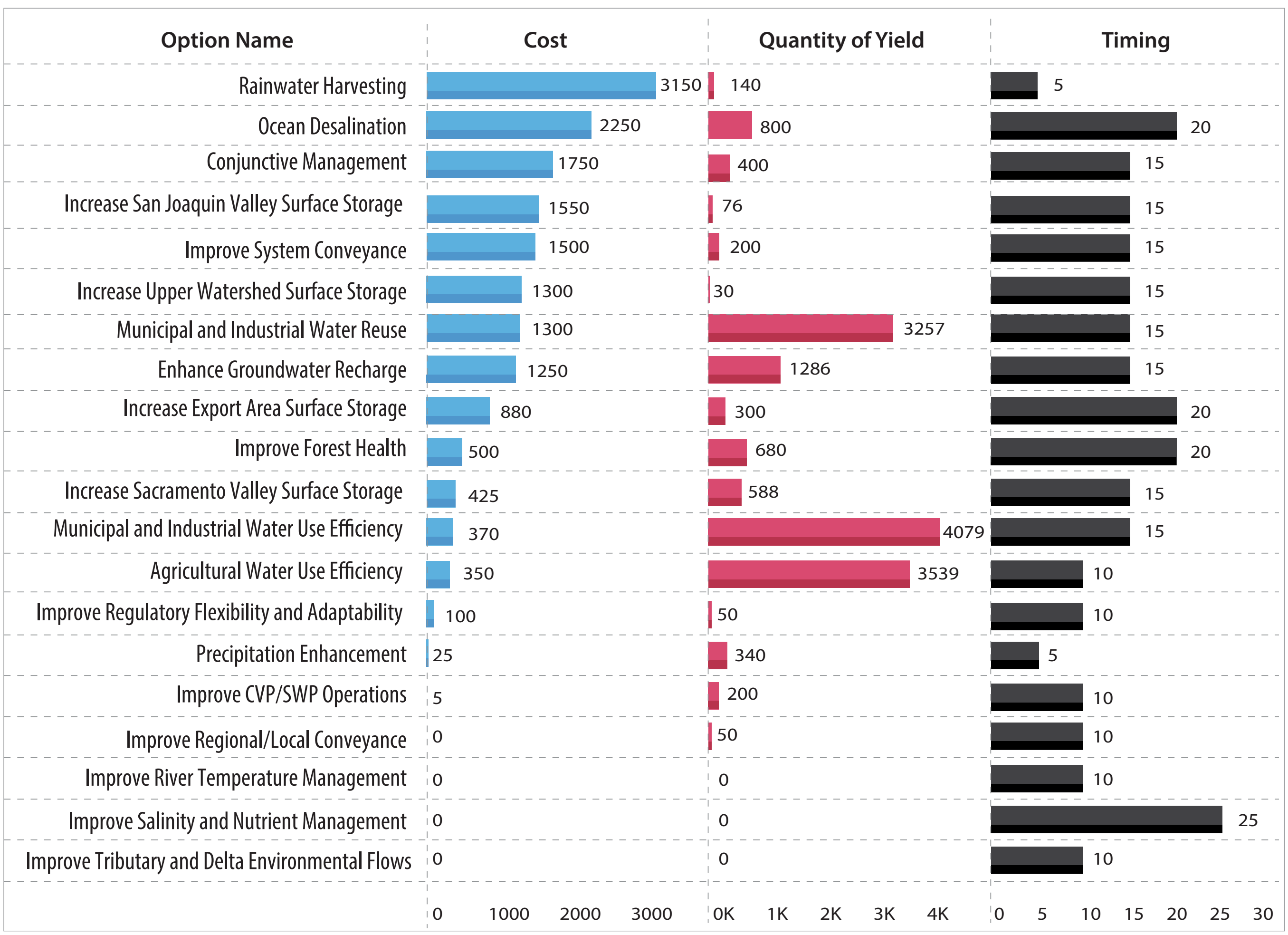


Figure 12. Evaluations of cost (dollars/acre-feet/year), quantity of yield (thousands of acre-feet), and timing (years to operation) for each of the 20 representative water management actions (Reclamation, 2016).

Note: CVP = Central Valley Project; SWP = California's State Water Project

- **Flexible System Operations and Management:** This portfolio includes actions to increase conjunctive use management and groundwater recharge.
- **Water Action Plan:** This portfolio contains all the actions included in California's 2013 Water Action Plan.

The water management actions included in each portfolio are shown in **Table 2**. The colors highlight the management response strategy type for each water management action, including **reduce demand (green)**, **increase supply (blue)**, **improve operational flexibility (black)**, **improve resource stewardship (orange)**, and **improve institutional flexibility (grey)**. The improve data and management is an overarching action for all portfolios and is not shown in this table.

It is important to recognize that these portfolios represent only a limited number of potential adaptation strategies. They are intended primarily to explore a variety of approaches to address impacts, as well as to gain insight into how climate uncertainty affects portfolio performance and tradeoffs **(Figure 14)**. The performance and climate sensitivity of each portfolio are analyzed in this section.

- **Least Cost:** The projections for this portfolio perform especially well in the Water Delivery, Fish and Wildlife Habitat, and ESA Species resource categories. These improvements could occur primarily due to the Demand Reduction and Operations strategies. This would involve combining improved agricultural/urban water use efficiency, new Delta conveyance, and increased surface water storage in the Sacramento and San Joaquin Valleys. These improvements are relatively insensitive to climate with the largest improvements relative to No Action occurring in the Hot-Dry climate.
- **Regional Self-Reliance:** The projections for this portfolio perform well in the Water Delivery and Recreation resource categories. These improvements could occur primarily due to Demand Reduction, Increase Supply, and Operations strategies. This would involve combining improved agricultural/urban water use efficiency, regional water reuse and treatment, and increased groundwater recharge and storage. These improvements are moderately sensitive to climate with increasingly negative impacts to Fish and Wildlife Habitats in the Delta occurring as climate becomes warmer and drier. Like the Least Cost portfolio, Water Deliveries have a large improvement relative to No Action in the Hot-Dry climate.
- **Healthy Headwaters and Tributaries:** This portfolio provides limited improvements found only in the upper reaches of the Sacramento River and its tributaries. Negative impacts could occur in the Recreation and ESA Species categories primarily due to spring releases reducing reservoir levels and cold-water pool. These declines relative to No Action are relatively insensitive to climate. In the wetter climate with additional water supply available for spring release, the Floodplain Processes metric shows some potential improvement relative to No Action.
- **Delta Conveyance and Restoration:** This portfolio by itself has limited impacts on most resource categories with the exceptions of Fish and Wildlife Habitats and ESA Species in the Delta. These improvements could primarily benefit salmonids, but have little effect on pelagic species. Relative to No Action, these improvements are insensitive to climate.

Water Management Action	Least Cost	Regional Self-Reliance	Healthy Headwaters and Tributaries	Delta Conveyance and Restoration	Expanded Water Storage	Flexible System Operations	Water Action Plan
Increase Agricultural Water Use Efficiency	Reduce Demand	Reduce Demand					Reduce Demand
Increase Municipal and Industrial Water Use Efficiency	Reduce Demand	Reduce Demand					Reduce Demand
Increase Regional Reuse		Increase Supply					Increase Supply
Increase Ocean Desalination		Increase Supply					Increase Supply
Precipitation Enhancement	Increase Supply	Increase Supply					Increase Supply
Rainwater Harvesting		Increase Supply					Increase Supply
Conjunctive Groundwater Management		Operations			Operations	Operations	Operations
Enhance Groundwater Recharge		Operations			Operations	Operations	Operations
Improve Tributary Environmental Flows			Operations				Operations
Improve System Conveyance	Operations			Operations	Operations		Operations
Increase Sacramento Valley Surface Storage	Operations				Operations		Operations
Increase San Joaquin Valley Surface Storage					Operations		Operations
Increase Export Area Surface Storage	Operations				Operations		Operations
Increase Upper Watershed Surface Storage					Operations		Operations
Improve Forest Health	Resource		Resource				Resource
Improve Regulatory Flexibility/Adaptability	Institutions					Institutions	Institutions

Table 2. Summary of water management actions included in each portfolio.

- **Expanded Water Storage and Groundwater:** The projections for this portfolio perform especially well in the Water Delivery and ESA Species resource categories. It has mixed results in the Fish and Wildlife Habitats category with positive impacts on the Food Web Productivity metric and negative impacts on pelagic species. It has consistently negative significant impacts on Recreation in all climate scenarios and increasing negative impacts on pelagic species as climate becomes warmer and drier. These results demonstrate that without either Demand Reduction and/or Supply Increase, existing reservoir capacity is insufficient to maintain both favorable reservoir water levels and enough Delta outflow to support these resources. These improvements/deteriorations are mostly insensitive to climate.
- **Flexible System Operations and Management:** This portfolio has no significant impacts on any of the resource categories except in hotter and drier climates. In this case, it does support some improvements in the Water Delivery and Water Quality resource categories by increased conjunctive use of groundwater. However, without the construction of new Delta conveyance infrastructure, deterioration in the Delta Food Web Productivity metric occurs.
- **Water Action Plan:** The projections for this portfolio perform well in the Water Delivery, Fish and Wildlife Habitat, and ESA Species resource categories in all climate types. In the wetter climates with more water supply available for spring release, there is a deterioration in the Recreation category along with a significant improvement in the Floodplain Processes performance metric relative to No Action.

The analysis of portfolio performance reveals several important general characteristics that occur across the range of portfolios considered in this study. These characteristics are as follows:

- Portfolios generally perform consistently across the wide range of climate uncertainties studied.
    - For example, the Least Cost portfolio projects positive Water Delivery benefits in all climate scenarios studied.
    - The effectiveness of a particular portfolio may increase or decrease in magnitude; however, it does not reverse from improvement to deterioration or vice versa under different climate scenarios.
- Portfolio performance varies across the range of resource categories.
    - For example, the Regional Self-Reliance portfolio improves Water Deliveries, but consistently results in deterioration of the Food Web Productivity metric.
    - The extent of these tradeoffs depends on specific climate conditions.
    - Implementing a particular portfolio results in varying degrees of improvement or deterioration in other resource categories.
- Water management projects consistent effects on portfolio performance.
    - For example, including new Delta conveyance consistently improved Unmet Demands, CVP/SWP Exports, and Food Web Productivity in the Least Cost, Delta Conveyance and Restoration, Expanded Water Storage and Groundwater, and Water Action Plan portfolios.

Water Storage Projects

Reclamation and its partners are exploring options for increased water storage in the Sacramento Valley, San Joaquin Valley, and Export Areas (CVP/SWP Delta exports) **(Figure 13)**. Additionally, Reclamation and its partners are studying groundwater conjunctive use management, enhanced recharge, and improved operational flexibility. These water management actions were included in several of the adaptation strategy portfolios that were discussed above and demonstrated in the Basins Study to benefit multiple resource categories. Many of these actions are currently being studied and moving towards implementation as described in this section.

In the Sacramento Valley, the Sites Joint Powers Authority and Reclamation are conducting a feasibility investigation to evaluate the potential for up to 1.8 MAF of new off-stream water storage at the proposed Sites Reservoir. This State-led project includes diverse participants representing a variety of local, State, and Federal interests. The proposed project would be operated collaboratively with other Federal and State projects. The project aims to enhance water management flexibility; increase the reliability of supplies; reduce diversions on the Sacramento River during critical fish migration periods; and provide storage and operational benefits to the CVP, including Delta ecosystem enhancement and water supply resiliency in drier years.

In the Delta, Reclamation and the Contra Costa Water District (CCWD) completed the Los Vaqueros Expansion Feasibility Study for Phase 2 (LVE2 Project) in January 2020. The LVE2 Project would expand CCWD's Los Vaqueros Reservoir from 160,000 to 275,000 acre-feet. The project would improve Bay Area water supply reliability and water quality, increase water deliveries for south-of-the-Delta wildlife refuges, protect Delta fisheries, and provide additional Delta ecosystem benefits. One of the features of the project, the Transfer-Bethany Pipeline, would provide water supply capabilities for south-of-the-Delta water needs without using the Tracy Pumping Facility, which would reduce the potential for loss of juvenile salmonids and endangered Delta smelt.

In the San Joaquin Valley, the San Luis Low Point Improvement Project (SLLPIP) is a joint study by Reclamation in cooperation with the Santa Clara Valley Water District (SCVWD). The purpose of the project is to address water supply reliability and schedule certainty issues for SCVWD associated with low water levels in San Luis Reservoir. The SLLPIP would help to maintain high quality, reliable, and cost-effective water supply for SCVWD to ensure that SCVWD receives its annual CVP contract allocations at the time needed to meet its existing water supply commitments.

Figure 13. Aerial view of New Melones Dam, a rockfill dam 40 miles east of Stockton, California on the Stanislaus River.

To date, the analysis indicates that an expansion of Pacheco Reservoir located on Pacheco Creek in the Coast Range Mountains west of San Luis Reservoir is technically, financially, and economically feasible.

In the Export Area, the Del Puerto Canyon Reservoir Project is a State-led project under the Water Infrastructure Improvements for the Nation (WIIN) Act located on Del Puerto Creek in the foothills of the Coast Range Mountains, west of Patterson, California. Del Puerto Water District (DPWD) and the San Joaquin River Exchange Contractors Water Authority (SJRECWA) are studying the benefits of creating a locally-owned and managed reservoir to provide approximately 82,000 acre-feet of off-stream storage. The purpose of the project is to develop water storage south-of-the-Delta near the SJRECWA and DPWD service areas without increasing demands on pumping through the Delta. To increase water supply reliability, water would be pumped from the Delta-Mendota Canal (CVP facility) during wet years when water is available and later used when supplies are limited. The reservoir would be filled with the sponsors' current CVP allocations and inflow from Del Puerto Creek. The water supply would serve agricultural users and environmental purposes, such as wildlife refuge water supply.

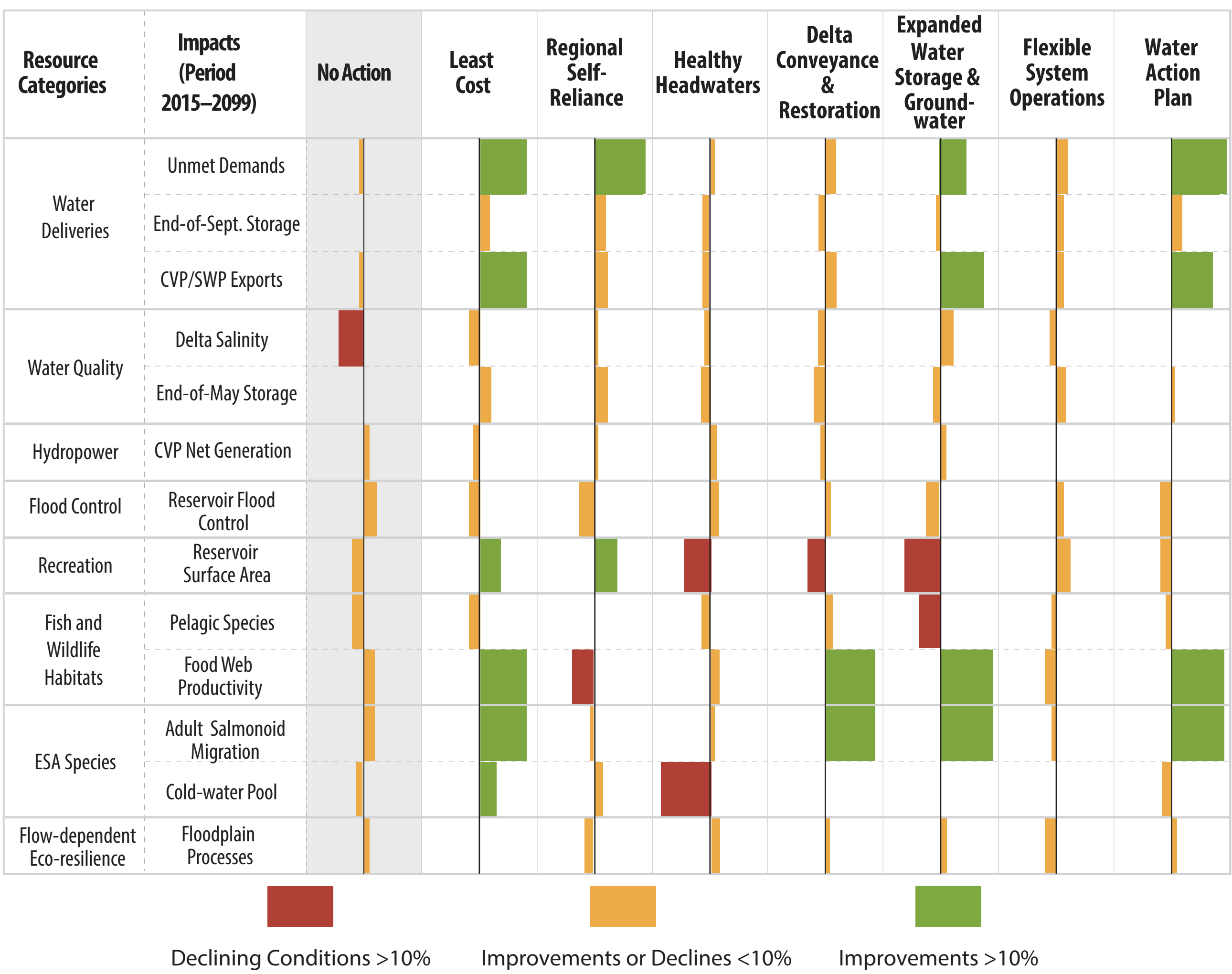


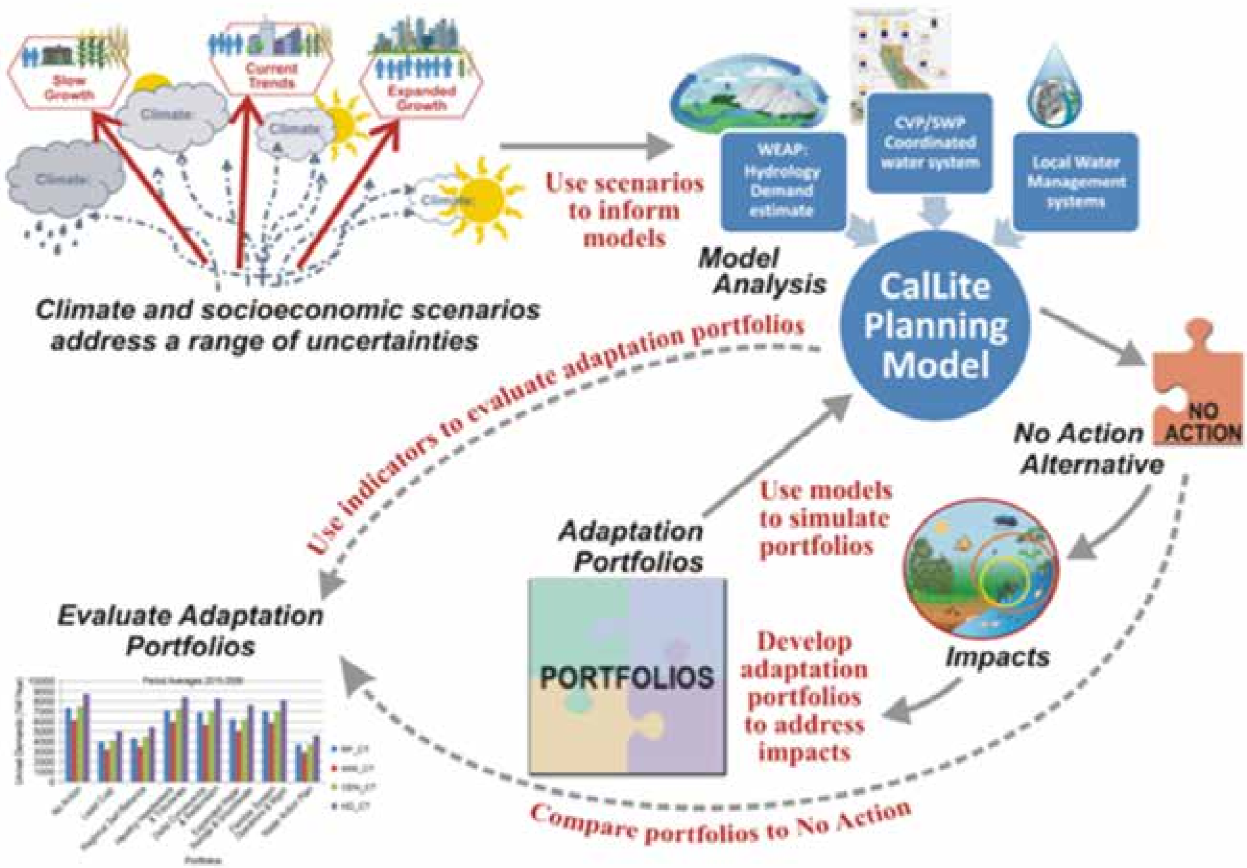
Figure 14. Portfolio Performance in the Central Tendency Climate Scenario.

Water temperature modeling is performed on the Sacramento, American, and Stanislaus Rivers, including modeling of temperature control shutter operations on Shasta (pictured here) and Folsom Dams. Also, Reclamation has developed models of tributary water temperatures to support the Central Valley Project Improvement Act program goal of increasing endangered salmon species in the Sacramento Valley watershed (GettyImages).

SECTION 4

Innovations

The Basins Study completed in 2016 implemented a variety of innovative data preparation analytical modeling methods. To characterize 21st century uncertainty, the Basins Study employed a scenario-based approach for both climate and socioeconomic conditions. **Figure 15** illustrates the overall study approach by starting in the upper left corner and following the arrows.



Note: WEAP = Water Evaluation and Planning Plant Growth Model; CVP = Central Valley Project; SWP = California's State Water Project

Figure 15. Scenario-based approach and analytical framework to evaluate impacts, develop adaptation strategies, and assess portfolio tradeoffs.

One unique aspect of the climate projections used in the Basins Study was that they were constructed to be continuously changing in time as opposed to the step changes representing 30-year future time periods that have been used in most other studies. This feature allows the simulation to better represent when adaptation strategies would most likely be implemented. Additionally, an innovation used was that the climate-socioeconomic scenarios were formed in such a way as to capture more extreme aspects of the future projections and thereby characterize a greater range of the future uncertainties. Another innovative aspect of the climate projections was that, in addition to temperature and precipitation, the scenarios included concentrations of carbon dioxide representative of the climate scenario. Also, the projections included estimates of solar radiation, humidity, and wind speed based on atmospheric conditions observed at agricultural meteorological stations located in the Central Valley. Including these meteorological factors provided the opportunity to simulate both crop evapotranspiration and yield using physiologically-based modeling methods included in the Water Evaluation and Planning (WEAP) Plant Growth Model.

Figure 16. At 336 miles long, the San Joaquin River is the second longest river in California, after the Sacramento River.

Improving Modeling Methods

The Basins Study used the first Central Valley-wide integrated suite of modeling tools. The innovative tools were capable of dynamically simulating hydroclimate, recharge, runoff and snowmelt, surface water flow, groundwater and interactions, land use and population changes, and irrigation management. In addition, the tools simulated physiologically-based crop growth, evapotranspiration, and yield. The CalLite-CV operations model was developed to efficiently represent the complex operations of the CVP and SWP (as well as other water managers) and the effects of sea level rise on the Delta. The operational modeling of the CVP and SWP has also been updated with the introduction of the CalSim 3 model. The new model incorporates major improvements and enhancements from its predecessor, including finer model spatial resolution, better water supply and demand estimation, dynamic groundwater representation and simulation, and extended model spatial and temporal domains. Another innovation in this basin is the development of CalSim Hydro, the surface hydrology modeling system of CalSim 3, which greatly facilitates data input for CalSim 3. CalSim Hydro consists of four models, including a rainfall runoff model, a water demand calculator, a rice water use model, and a wetland model. CalSim Hydro determines the amount of applied irrigation water, crop ET, surface water runoff, and deep percolation to groundwater. Reclamation is also updating CalSim 3 with the latest DWR county agricultural land surveys and analysis of remote sensing imagery.

Salinity Forecasting Models

CVP operations are affected by water quality regulations both in the Delta and the upstream watersheds. In the San Joaquin River **(Figure 16)**, salinity inflows to the Delta are a major concern and Reclamation is required to make releases from New Melones Reservoir to meet salinity standards established by the State Regional Water Boards and by the Environmental Protection Agency. To address these requirements, Reclamation and local partners have developed a real-time management capability and salinity forecasting in the lower San Joaquin River. The salinity forecasting models use the National Oceanic and Atmospheric Administration's California-Nevada River Forecast Center streamflow forecasts as the basis of salinity forecasts. Two models are being used. The Environmental Protection Agency's Watershed Analysis Risk Management Framework (WARMF) model, which is a physically based watershed model, makes weekly forecasts of daily salinity with 2-week lead times. Another model developed by Reclamation uses statistical regression methods to provide daily forecasts of salinity with a 14-day lead time. Both model outputs are published on the web.

Water Temperature Modeling

Water temperature is a water quality concern for adult spawning and rearing of juvenile salmonids in the Sacramento and San Joaquin watersheds. Seasonal targets are established by regulatory guidelines. Water temperature modeling is performed on the Sacramento, American, and Stanislaus Rivers, including modeling of temperature control shutter operations on Shasta and Folsom Dams. Reclamation has also developed models of tributary water temperatures to support the CVPIA program goal of increasing endangered salmon species in the Sacramento Valley watershed.

Enhancing our Understanding of Species Listed Under the Endangered Species Act

The Delta is the hub of the CVP and SWP water operations. Due to prolonged drought and increasing concerns over endangered species, CVP exports to south-of-the-Delta water service and settlement contractors has become increasingly difficult to maintain. To meet these challenges, Reclamation has engaged with other Federal, State, and local stakeholders in the development of a suite of data collection and modeling tools to better understand, forecast, and respond to opportunities to export water while meeting regulatory requirements for both endangered species and California's agricultural and urban water users.

One example is a cooperative team including members from Reclamation's Bay Delta Office (BDO), Central Valley Operations Office (CVOO), and the Regional Division of Planning. The team is partnering with DWR to model weekly opportunities to increase Delta exports using the DWR's DSM2 model. Every week, modeling is performed with the latest operational information and forecasts to determine opportunities to increase exports without harm to ESA species. This project also supports web-based interactive visualizations to facilitate collaborative operational decisions.

Additionally, BDO and CVOO are collaborating on a variety of other science and modeling-based activities:

- **Directed Outflow Project –** A partnership with DWR that seeks to evaluate the hypothesis that endangered Delta smelt habitat quality and survival is improved when low salinity occurs in Suisun Bay.

- **Sacramento River Prediction and Assessment of Salmon (SacPAS) –** Monitoring, evaluation, and web-based data products funded by Reclamation for ESA. SacPAS includes a salmon smolt passage model based on the National Oceanic and Atmospheric Administration's Comprehensive Passage Model (COMPASS) to characterize movement and survival of juvenile fish through the Sacramento River system.
- **Central Valley Acoustic Tagging Project (CalFish Track) –** This project provides improved monitoring of acoustically tagged juvenile salmon entering the Delta, including a juvenile salmon model (STARS) of travel times and routes, along with probabilities of survival.
- **Structured Decision Making (SDM) –** A collaborative process with participation by State, Federal, and local stakeholders which includes the use of numerical tools to facilitate analysis of data related to fisheries performance, mitigation actions, and habitat restoration. The result is a comprehensive, science-based approach that explicitly links activities with CVPIA objectives. An output of SDM is intended to assist in prioritization of actions to achieve the anadromous fish doubling goal of the CVPIA, and to document the best understanding of science affecting the CVPIA Fish Resource Area.

Subsidence Modeling and Infrastructure Improvements

Groundwater is an important source of water supply in the Central Valley. During years of drought, water users have relied on its use extensively and, over time, groundwater levels have declined significantly resulting in land subsidence. The San Joaquin and Tulare Lake Basins have historically experienced some of the highest subsidence rates in the world, which has caused damage to Reclamation's Delta-Mendota and Friant-Kern canals.

Reclamation's HydroGeoSphere San Joaquin Valley Model (HGSSJVM) now is being used to estimate potential subsidence rates. These estimations will help engineers planning canal repairs. In 2015, the Sustainable Groundwater Management Act was enacted requiring the development of groundwater management plans. In turn, the HGSSJVM also will be used to assist Reclamation water users in developing and implementing their groundwater sustainability plans.

CVP Hydropower Operations Program

The CVP has a notable hydropower operations program with eleven hydroelectric powerplants that have a combined nameplate rating of 2,100 megawatts and generate an annual average of more than 4 billion kilowatt-hours of carbon-free energy **(Figure 17)**. Operations of CVP hydropower are optimized using regulating reservoirs such that hydropower flexibility does not influence river flows. Reclamation uses a comprehensive and robust Power Operations program to maintain and further optimize the efficiency, reliability, and availability of its valued CVP hydropower resource. From an operations perspective, CVP hydropower is flexible and adaptable to new markets which increases the value to Reclamation's public (not-for-profit) power customers. These customers receive the CVP's hydropower surplus beyond the generation needed to pump project water and, through that arrangement, public power customers also contribute to habitat restoration.

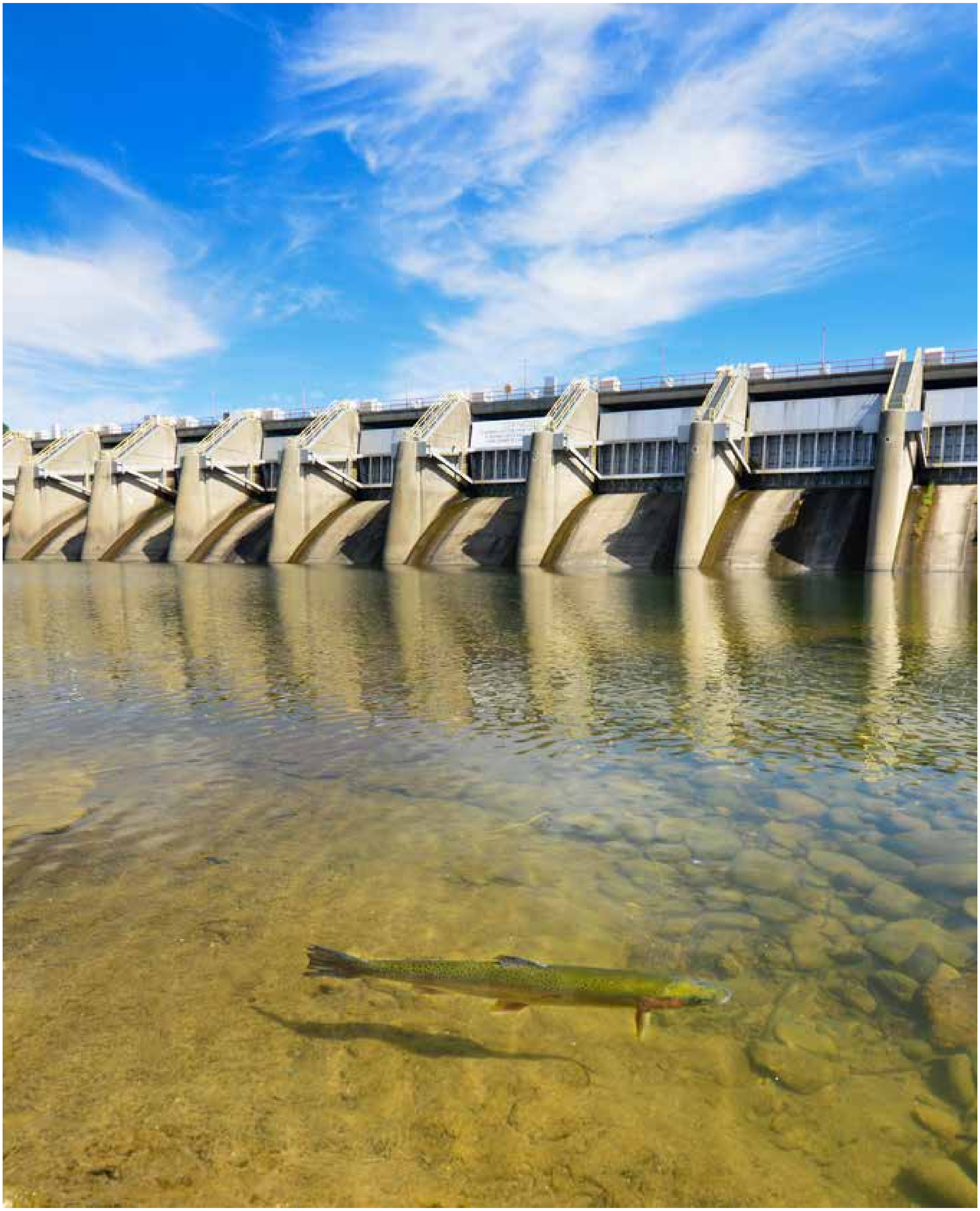


Figure 17. A lone steelhead drifts languidly through the shallow water of Nimbus Dam, a hydroelectric dam on the American River above Sacramento, California (GettyImages).

The American River flowing through Sacramento, California (GettyImages).

SECTION 5

Next Steps

The completion of the Basins Study has provided Federal, State, and stakeholder organizations with new opportunities to build on the resource impact analyses and adaptation strategies by developing more detailed and comprehensive follow-on studies. Based on several of the strategies and portfolios identified, stakeholders and Reclamation have initiated follow-on activities and studies including those outlined in this section.

Basin Studies

The American River Basin Study is currently in progress. The study involves six non-Federal partners participating with Reclamation. It aims to develop more detailed strategies and portfolios that improve water supply reliability in the American River basin by refining adaptation strategies initially explored in the Basins Study, including groundwater conjunctive use management, enhanced recharge, increased water storage, and operational flexibility.

Water Management Options Pilot Studies

Reclamation has also initiated a new funding opportunity announcement through its Basin Study Program for Water Management Options Pilot studies. These studies will allow entities in basins with a completed basin study to build on the analyses and strategies developed in the basin study with the objective of potential implementation. In the Sacramento Valley, the following Pilot studies have been selected for funding:

- **Sacramento Regional Water Bank:** This study further refines how a stakeholder-proposed groundwater bank could operate conjunctively with Reclamation's Folsom Reservoir. The proposed water bank would improve water supply reliability in the Sacramento region and environmental flows for fish and wildlife in the lower American River.
- **River Arc Project:** This study proposes to evaluate the potential to convey water diverted from the Sacramento River to the Placer County Water Agency service area. This project would serve as an additional water source to improve supply reliability in northern Sacramento and southern Placer Counties.

California Crop Coefficient (3C) Science Collaborative

In the water-limited Western United States, the accuracy of crop water demand estimation is of significant importance for climate-adaptive long-range water resource planning, seasonal forecasting of water allocations and deliveries, and short-term irrigation management and scheduling. In California, the University of California Agriculture and Natural Resources and the DWR have formed the California Crop Coefficient (3C) Science Collaborative to update crop coefficients of major crops throughout California that require a high water demand. In response to Reclamation's External WaterSMART (Sustain and Manage America's Resources for Tomorrow) Applied Science Tools Funding Opportunity Announcement, the 3C Collaborative partners, with extensive support from the agricultural community, submitted a successful proposal.

In addition to updating crop coefficients through literature and field investigation activities, the 3C project will make the updated crop coefficient information available through a web-based repository. The repository will be usable for a suite of existing water management tools to enhance the capability for modeling/forecasting of water demand and irrigation scheduling.

Aerial view of Sacramento River flowing through farmland near Sacramento, California (GettyImages).

Also, the 3C project will organize training sessions and workshops and develop educational materials to encourage the broad adoption of updated crop coefficient information.

Estimation of Historical and Future Climate Trends

Reclamation is also collaborating with the Earth System Research Laboratories of the National Oceanic and Atmospheric Administration and the National Center for Atmospheric Research (NCAR) to produce historical and future climate trend estimates using state-of-the-art techniques for representing orographic (mountain) precipitation and occurrence of rain versus snow in the Sierra Nevada mountains and other Western regions. Next steps include modeling of runoff produced in Central Valley watersheds and application of these results to the CalSim 3 model. The goal of these activities will be to generate improved estimates of reservoir inflows and their effects on CVP and SWP operations.

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Cover photo: Scenic view of Shasta Lake. Mt. Shasta covered with snow appears in the background. Visitors enjoy recreation and beautiful views of the lake.