American, Bear, and Cosumnes Watersheds Resilience Plan Quantitative Vulnerability Assessment

Final

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Acronyms and Abbreviations

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
ABC	American, Bear, and Cosumnes
AEP	Annual Exceedance Probability
ANN	Artificial Neural Network
BAU	Business As Usual
cfs	cubic foot/feet per second
cm	centimeter(s)
CT	Central Tendency
CVFPP	Central Valley Flood Protection Plan
CVP	Central Valley Project
CWD	climatic water deficit
CWP	cold-water pool
DCD	Delta Channel Depletion (model)
DLL	Dynamic Link Library
DSM2	Delta Simulation Model
DWR	California Department of Water Resources
EID	El Dorado Irrigation District
EIS	Environmental Impact Statement
EOS	??
EOS	End of September
GCM	Global Climate Model
HD	Hot-Dry
ITP	Incidental Take Permit
N/A	not applicable
NDOI	??
NID	Nevada Irrigation District

NOD	??
PCWA	Placer County Water Agency
PUD	Public Utility District
RCP	Representative Climate Pathway
SLR	sea level rise
SMUD	Sacramento Municipal Utility District
SSID	South Sutter Irrigation District
SSP	Shared Socioeconomic Pathway
SWE	snow water equivalent
SWP	State Water Project
TAF	thousand acre-feet
TUCP	Temporary Urgency Change Petition
UWMP	Urban Water Management Plan
VIC	Variable Infiltration Capacity
WW	Warm-Wet

1. Introduction

The American, Bear, and Cosumnes (ABC) Watersheds Resilience Pilot Study evaluates climate-related risks and vulnerabilities across water-dependent sectors and land uses throughout the watershed. This Vulnerability Assessment is designed as a two-phased framework that integrates qualitative evaluation with quantitative analysis to support informed, risk-based decision-making.

Together, this approach identifies where climate stressors intersect with high sensitivity, limited adaptive capacity, and far-reaching consequences. This highlights systems where early action, targeted investment, and deeper quantitative analysis can most effectively strengthen watershed resilience.

1.1 Quantitative Vulnerability Assessment

The second phase of the Vulnerability Assessment builds directly on the qualitative findings through quantitative, scenario-based modeling designed to evaluate how identified vulnerabilities manifest under future climate conditions. This phase translates qualitative risk drivers into measurable changes in system performance, allowing the magnitude, frequency, and persistence of impacts to be assessed across the watershed.

The quantitative analysis leverages a suite of integrated modeling tools to simulate system response under a range of plausible future conditions. Rather than relying on a single projection, the assessment employs multiple climate scenarios that represent different combinations of temperature change, precipitation patterns, hydrologic variability, and sea level rise. This scenario-based approach captures uncertainty in future climate trajectories and supports robust, risk-informed evaluation.

Water sectors and land uses evaluated include the following:

- Surface water supply
- Groundwater supply
- Flood management
- Water quality
- Ecosystems
- Recreation
- Hydropower
- Agricultural and urban water supply

For each sector, tailored performance metrics and indicators are used to evaluate system behavior under future scenarios. Examples of these metrics include changes in reservoir storage reliability, groundwater storage trends, flood frequency and exposure, river temperature and water quality thresholds, ecological flow conditions, recreation access, and hydropower generation.

Results from quantitative modeling provide a deeper characterization of vulnerability pathways, revealing where climate stressors produce threshold exceedances, compound impacts, or cascading effects across sectors and planning areas. By grounding vulnerability in quantitative evidence, this second phase complements the qualitative assessment and provides a defensible foundation for prioritizing adaptation strategies, informing investment decisions, and guiding subsequent phases of resilience planning.

1.2 Study Area

The study area for the ABC Watersheds Resilience Pilot Study is presented on Figure 1-1. This area covers the entirety of the American River, Cosumnes River, and Bear River watersheds, as well as the North American, South American, and majority of the Cosumnes River Bulletin 118 groundwater basins. Land uses across the watershed are highly varied, with much of the urban and agricultural development consolidated in the lower elevation portions of the watershed to the west. As such, management of flood and water quality conditions as well as surface water and groundwater supplies are vital for preserving both the human and ecological communities in this area. While smaller, rural communities are present in the upper watershed areas to the east, much of this area provides hydropower generation and recreational opportunities, supplies the remaining watershed with surface water, and serves as protected forest.

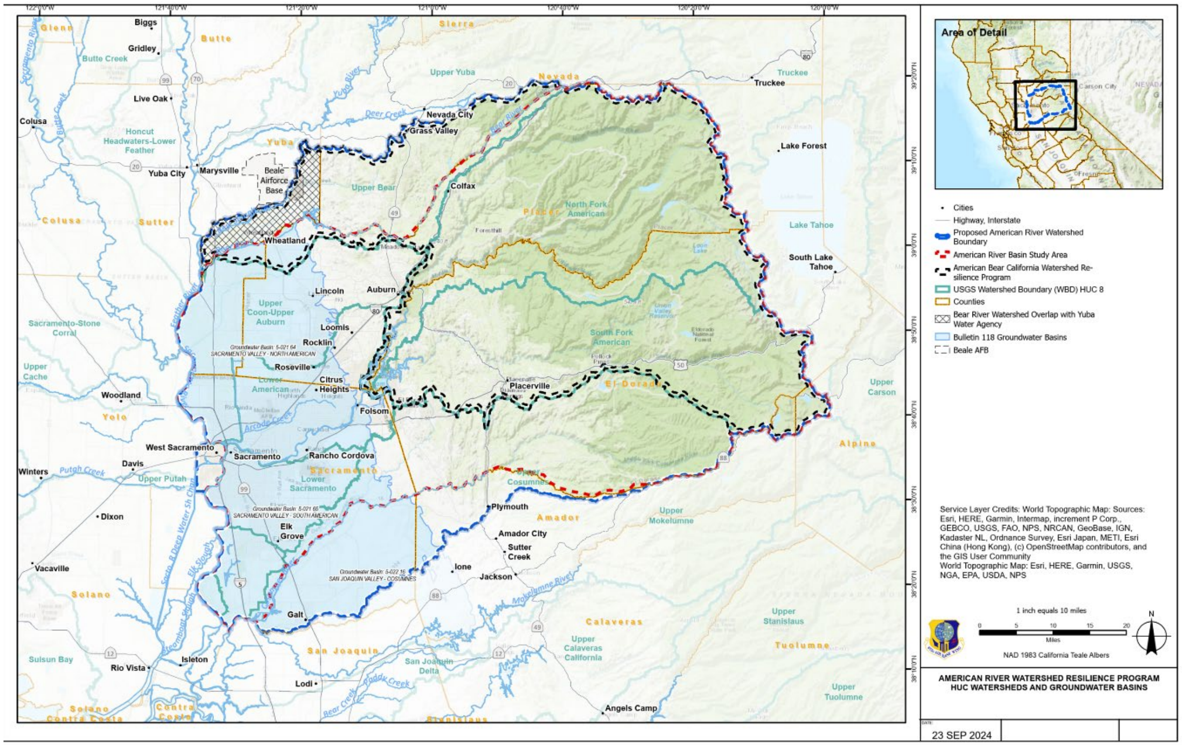


Figure 1-1. American, Bear, and Cosumnes Watersheds Resilience Pilot Study Area

2. Quantitative Vulnerability Analysis

To characterize the varied land uses and water sections across the study area, a diverse set of modeling tools have been employed to evaluate vulnerabilities under a range of future climate scenarios. These modeling tools are presented in Table 2-1 and are described in further detail later in this section. Additional details on the development of climate change and sea level rise scenarios are discussed in Section 1.2.

Table 2-1. Overview of Vulnerability Assessment Modeling Tools

Tool	Description	Sector(s)
CalSim 3	Simulates system operations of the State Water Project and Central Valley Project and interactions with groundwater supplies at a monthly time-step	S, E, R
CalSimHydro	Characterizes surface hydrologic modeling for individual water budget areas, rim watersheds, and Sacramento-San Joaquin Delta subregions and is used as an input for CalSim 3	E, R
CalSimHydroEE	Characterizes surface hydrologic modeling for elements not covered by the CalSimHydro domain and is used as an input for CalSim 3	Input only
SmallWatersheds Model	Characterizes surface runoff and inflow to groundwater basins from small watershed areas that overlap water budget areas and rim watersheds; this is also used as an input for CalSim 3	Input only
DCD Model	Characterizes surface water hydrology for Delta Islands and is used as an input for CalSim 3	Input only
Variable Infiltration Capacity Model	Utilizes meteorological data to simulate hydrologic processes and is used as an input for CalSimHydro and other CalSim-related inputs	E, R
HEC-5Q	Leverages outputs from CalSim 3 to simulate water temperatures and other water quality conditions	W, E
Long-term Generation (LTGen) Model	Leverages outputs from CalSim 3 to estimate hydropower generation at selected reservoirs	H

Notes:

DCD = Delta Channel Depletion (model)
E = Ecosystem
F = Flood Management
G = Groundwater Supply
H = Hydropower
R = Recreation
S = Surface Water Supply
W = Water Quality

The modeling tools outlined herein have been leveraged to evaluate a series of vulnerability indicators and metrics relevant to selected water sectors and land uses. These are outlined in Section 2.1.2. In some cases, indicators and metrics may be used as proxies for assessing the vulnerability of certain considerations within each sector that are not directly represented through these tools. Models have inherent limitations, and some facets of watershed may need to be explored or revisited in further detail during subsequent efforts.

2.1 Quantitative Vulnerability Assessment Approach

The quantitative vulnerability assessment evaluates how key water-resource systems respond to future climate stressors using a scenario-based framework. The approach translates a large ensemble of climate projections into a small, representative set of planning scenarios that capture both central tendencies and plausible extremes. These scenarios provide a consistent basis for assessing system sensitivity to climate hazards under mid- and late-century climate conditions. They support the qualitative assessment and provide comparative assessment of the magnitude of likely changes across the watershed.

2.1.1 Climate and Sea Level Change Scenarios

This section provides details about the methodology used in developing hydroclimate boundary conditions for the CalSim 3 models to represent Mid-Century (Central Tendency [CT]), Late-Century (Hot-Dry [HD]), and Late-Century (Warm-Wet [WW]) climate conditions and sea level change scenarios. Figure 2-1 shows the workflow for the development of three future climate change scenarios. Table 2-1 shows the various datasets used for development of climate change scenarios to represent future climate conditions.

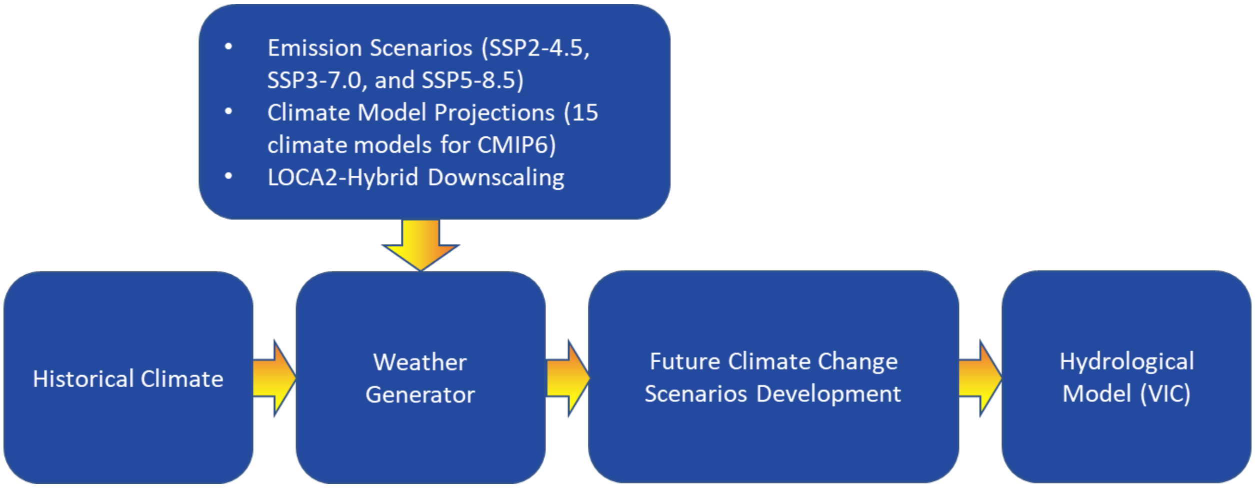


Figure 2-1. Workflow for climate change scenarios development

Observed Historical Meteorology Data and Processing

Livneh et al. (2013) provided daily historical meteorology data at 1/16° (approximately 6 km or approximately 3.75 miles) spatial resolution over the period 1915 through 2015. This period was extended using the PRISM (Daly et al. 1994) daily historical meteorology data from 2016 to 2021 (OSU 2025). This extended daily historical precipitation, and minimum and maximum temperatures data were adjusted based on PRISM monthly data to correct biases found in the period of interest.

Temperature Detrending

The bias-corrected minimum (T_{min}) and maximum (T_{max}) temperature were detrended using the Linear Trend Removing Technique to represent the current climate condition (Zhang et al. 2011). The anchor period used for the temperature detrending was over the period 1991-2020, consistent with the National Oceanic and Atmospheric Administration (NOAA) climatological normal period (NCEI 2025).

Global Climate Models

The Coupled Model Intercomparison Project Phase 6 (CMIP6) datasets used as input for the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR6) (Intergovernmental Panel on Climate Change [IPCC] 2021). CMIP6 Global Climate Models (GCMs) feature higher spatial resolution with enhanced physical parameterizations, and improved representations of synoptic processes. The temporal extent of CMIP6 GCMs typically covers a wide range of periods to capture both historical (1850 to 2014) and future (2015 to 2100) climate scenarios. Shared Socioeconomic Pathways (SSPs) are scenarios used in climate research to explore how global societal trends might influence future greenhouse gas emissions and climate change. The five main SSPs Representative Climate Pathways (RCPs) combination used in CMIP6 are SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP4-6.0, and SSP5-8.5 (Hausfather 2018).

The Scripps Institution of Oceanography employs a hybrid-statistical downscaling method known as Localized Constructed Analogs version 2 Hybrid (LOCA2-Hybrid). LOCA2-Hybrid uses a hybrid downscaling scheme with a pattern library obtained from dynamically downscaled GCM-Weather Research Forecasting (WRF) Model runs that that were bias-corrected to the ERA5-WRF-BC training data (Pierce et al., 2023). The LOCA2-Hybrid dataset for California offers a 3-km resolution, providing detailed climate data for the region over 1950 to 2100.

Global Climate Model Selection

The selection of the GCM for downscaling is achieved by ranking the GCMs that best capture the relevant characteristics of the climate in California. The recommendations of a set of GCMs for downscaling to support climate change analysis and applications in California is outlined in Krantz et al. (2021).

California's academic institutions are advancing climate research by implementing hybrid-statistical downscaling methods to support the California Energy Commission initiatives. At UCLA, the WRF Model is used for dynamic downscaling, producing several physically based projections available for public and analytical use. These projections are then utilized to train the Localized Construct Analogs (LOCA2-Hybrid) at Scripps Institution of Oceanography. The LOCA2-Hybrid datasets, which are hybrid-statistical in nature, involve bias-corrected GCM outputs adjusted to align with station observations. The hybrid-statistical downscaling method has generated data for 15 General Circulation Models with a total of 199 ensemble runs (Table 2-2).

Table 2-2. Details of the CMIP6 LOCA2-Hybrid General Circulation Models

Downscaling Method	Hybrid-Statistically Downscaled / LOCA2-Hybrid
Institution	UCSD - Scripps Institute of Oceanography
Models	15 models *ACCESS-CM2, CESM2-LENS, CNRM-ESM2-1, EC-Earth3, EC-Earth3-Veg, FGOALS-g3, GFDL-ESM4, HadGEM-GC31-LL, INM-CM5-0, IPSL-CM6A-LR, KACE-1-0-G, MIROC6, MPI-ESM1-2-HR, MRI-ESM2-0, and TaiESM1*
Bias Correction	15 models
Extent	1950-2100
Spatial Resolution	3-km (California)
Temporal Resolution	Daily (native resolution) and monthly
Shared Scenario Pathways	SSP2-4.5, SSP3-7.0, and SSP5-8.5
Ensemble Runs	This downscaling method created data for 15 GCMs with a total of 199 ensemble runs

In addition to climate change scenario development, GCM datasets and other data sources (Cal-Adapt, previous climate assessments, etc.) were used to evaluate changes under future conditions for a range of climatic and hydrologic metrics. These include changes in temperature, extreme heat days, precipitation, extreme precipitation, runoff, flooding, snow water equivalent, drought, and wildfire. Understanding the changes in these metrics is key to characterizing drivers for many of the vulnerabilities evaluated for individual water sectors highlighted in this appendix, as well as how historical hazards are projected to evolve over time. Additional details are documented in Attachment A.

Climate Change Scenario Workflow

Future climate change scenarios were developed using 129 projections derived from 15 selected GCMs within the CMIP6 dataset. These projections include variant members from each GCM to capture model uncertainty. The scenarios encompass a wide range of potential climate conditions, from median projections to extreme cases, and were defined for two future periods, Mid-Century (2041 to 2070) and Late-Century (2071 to 2100). To represent the distribution of projected conditions, percentile thresholds were applied to represent the CT during the Mid-Century, and WW and HD conditions during the Late-Century (Table 2-3).

The percentile thresholds were selected to represent a range of plausible climate futures while maintaining statistical robustness. The 50th percentile was chosen for the Mid-Century scenario to reflect CT conditions, providing a baseline for planning under median projections. For Late-Century scenarios, the 75th and 25th percentiles were used to capture extremes in precipitation and temperature. The WW scenario represents a wetter but moderately warm future, while the HD scenario depicts a hotter and drier climate. This approach ensures that the scenarios encompass both median trends and potential extremes, supporting risk-informed decision-making.

Table 2-3. Statistics for Development of Climate Change Scenarios

Scenario	Scenario Name	Period	Mean Precipitation Change (%)	Mean Temperature Change (°F)
1	Mid-Century (CT)	2041 to 2070	50th percentile	50th percentile
2	Late-Century (WW)	2071 to 2100	75th percentile	25th percentile
3	Late-Century (HD)	2071 to 2100	25th percentile	75th percentile

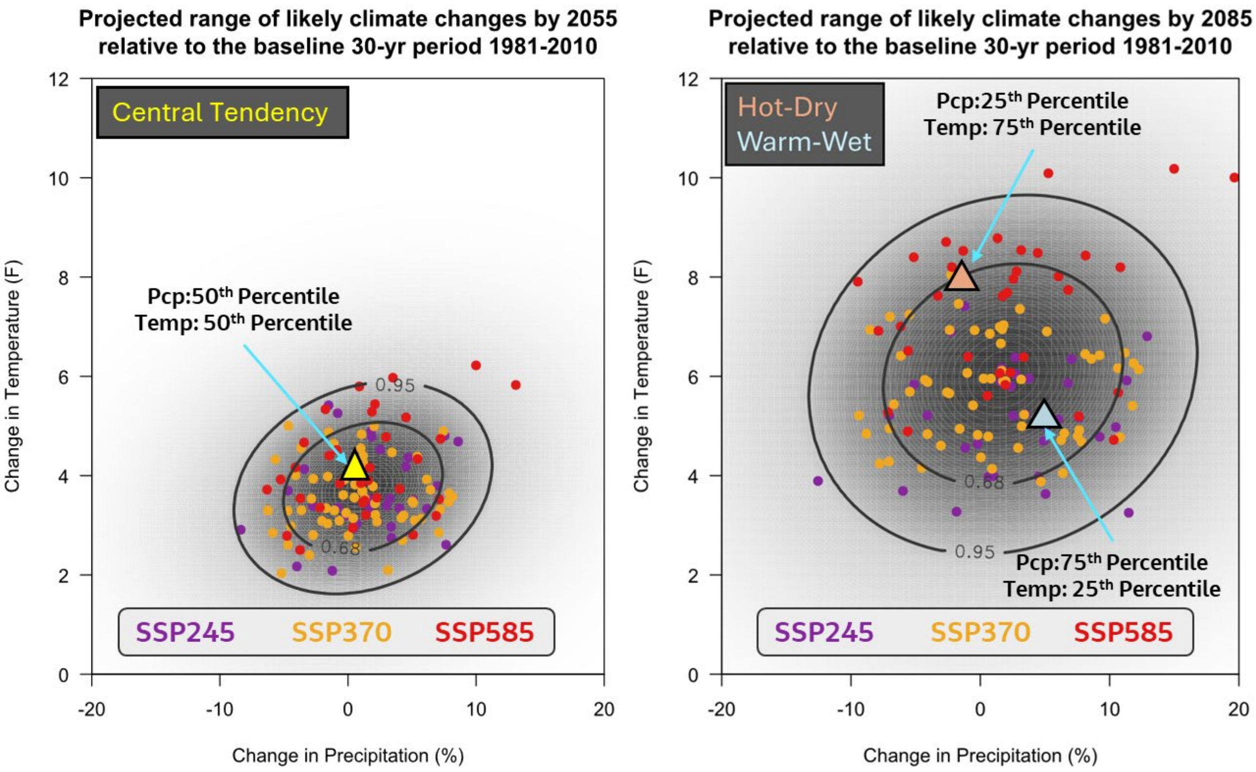
The approach involves the following steps for the development of the climate change scenarios:

1. The spatially averaged climate variables for the American River watershed were computed from the gridded 3-km CMIP6 dataset using 129 climate projections spanning 1950–2100.
2. For each projection, a 30-year slice of daily precipitation and maximum and minimum temperature was extracted for the Existing Baseline period (1981 to 2010) and two future periods: Mid-Century (2041 to 2070) and Late-Century (2071 to 2100).
3. Daily climate data were aggregated to the water-year scale for the Existing Baseline and future periods. Then the changes were computed as the ratio (future period divided by Existing Baseline period) for precipitation and 'deltas' (future period minus Existing Baseline period) for temperature for Mid-Century and Late-Century for 129 projections (Figure 2-2).

4. Change values were averaged across all ensemble members for each GCM, resulting in 41 variant-averaged estimates for precipitation, and maximum and minimum temperature for Mid-Century and Late-Century

5. The percentile threshold from the 41 change values were calculated for the specific climate change scenario (Table 2-3). For example, the 25th percentile of precipitation change and 75th percentile of temperature change during Late-Century was calculated to represent Late-Century (HD) scenario.

Figure 2-2 illustrates the uncertainty associated with CMIP6 climate projections for two future periods: Mid-Century (2041 to 2070) and Late-Century (2071 to 2100). Each panel displays the distribution of 129 model projections for changes in temperature and precipitation relative to the 1981 to 2010 Existing Baseline, under three emissions pathways (SSP2-4.5, SSP3-7.0, SSP5-8.5). Probability contours highlight the concentration of projections and the range of plausible outcomes. This figure demonstrates the spread of projections and the approach used to select representative scenarios for planning and risk assessment.


Mid Future (2041-2070)

Late Future (2071-2010)

Figure 2-2. Probability Plot Representing the Uncertainty from CMIP6 Projections

Table 2-4 and Figure 2-3 summarizes projected climate changes for the three climate change scenarios. Mid-Century (CT) shows negligible precipitation change (0.2%) and moderate warming of 2.4°C (maximum) and 2.1°C (minimum), with a 15.6% increase in extreme precipitation. Late-Century (WW) projects higher precipitation (+7.4%), moderate warming (3.1°C maximum, 2.9°C minimum), and a 21.5% rise in extreme precipitation. Late-Century (HD) indicates reduced precipitation (-1.4%), substantial warming (4.5°C maximum, 4.3°C minimum), and the largest increase in extreme precipitation (30.5%).

Table 2-4. Precipitation and Temperature changes for the development of climate change scenarios

Scenario Number	Scenario Name	Mean Precipitation Change (%)	Maximum Temperature Change (°C)	Minimum Temperature Change (°C)	Extreme Precipitation Change (%)
1	Existing Baseline	N/A	N/A	N/A	N/A
2	Mid-Century (CT)	0.2	2.4	2.1	15.6
3	Late-Century (WW)	7.4	3.1	2.9	21.5
4	Late-Century (HD)	-1.4	4.5	4.3	30.5

N/A = not applicable

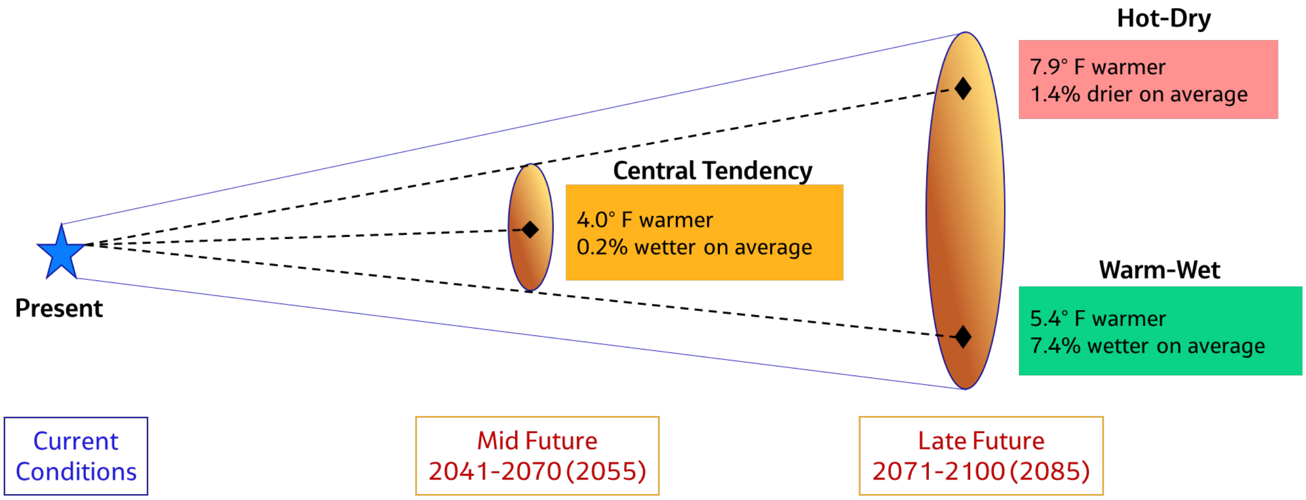


Figure 2-3. Projected Changes under the Climate Change Scenarios

Weather Generator

The estimated changes in the precipitation and temperature from the climate model projections and historical precipitation and temperature were used to develop the climate change scenarios using the Weather Generator. The Weather Generator was developed by the California Department of Water Resources (Najibi and Steinschneider, 2023). The Weather Generator is designed to separately model dynamic and thermodynamic atmospheric mechanisms of climate variability and change through statistical abstractions of these processes.

Sea Level Rise Assumptions

Each period includes different sea level rise (SLR) assumptions. The Existing Baseline assumes 0 centimeters (cm) SLR, while the Mid-Century (CT) assumes 30 cm SLR and the Late-Century (HD) and Late-Century (WW) assumes 55 cm SLR. The elevated SLR in the future periods corresponds to greater challenges in meeting water quality standards in the Sacramento-San Joaquin Delta (Delta).

Salinity is not directly calculated in CalSim 3. Instead, compliance with water quality objectives is determined based on flow-salinity relationships in the Delta calculated with an Artificial Neural Network (ANN) developed by the California Department of Water Resources (DWR). The ANN is a statistical model that translates water quality standards into flow equivalents using information from CalSim, the DCD model, and the Delta Simulation Model (DSM2). For each SLR scenario, a unique ANN is integrated within CalSim 3 as a Dynamic Link Library (DLL).

More information on the development of the three SLR ANN DLLs (0 cm, 30 cm, and 55 cm) is provided in the State Water Project (SWP) Adaptation Strategy Appendix A (DWR 2025).

The SLR for each period was selected based on the availability of DWR's ANN DLLs and the documentation provided in the SWP Adaptation Strategy and SWP Delivery Capability Report Technical Addendum (California Department of Water Resources, 2023a).

The data developed using the forementioned approach is used for the assessment of the vulnerability of the various water sector in the American River watershed (Table 2-5).

Table 2-5. Climate Change Analysis Principal Data Sources

Data	Use in Climate Change Analysis	Spatial and Temporal Resolution	Source
Daily Gridded Historical Climate Data (Livneh et al. 2013)	Running Variable Infiltration Capacity (VIC) model simulations and developing climate change scenarios	Daily data at 1/16° (~6 km) spatial resolution over the period 1915 to 2015	UW n.d.
Daily Historical Gridded Climate Data (PRISM)	Extending Livneh et al. daily gridded historical climate data	Daily data at ~800 m spatial resolution over the period 2016 to 2020 and ~4 km spatial resolution for 2021	OSU 2025
Monthly Historical Gridded Climate Data (PRISM)	Adjusting the extended Livneh et al. daily gridded historical climate data	Monthly data at ~800 m spatial resolution over the period 1895 to 2020 and ~4 km spatial resolution for 2021	OSU 2025
CMIP6 Downscaled Climate Projections (LOCA2-Hybrid method)	Developing climate change scenarios	Daily data at 1/32° (~3 km) spatial resolution over the period 1950 to 2100	Pierce et al. 2023
CMIP5 Wildfire Dataset	Analyzing wildfire decadal probabilities	1/16° (~6 km) resolution from 1952 to 2099	UCB 2018
2022 Central Valley Flood Protection Plan Update Datasets	Characterizes changes in flow and stage frequency under various climate and project implementation scenarios, as well as subsequent estimates of community impacts	Inundation maps for impact areas within the State Plan of Flood Control	DWR 2022

~ = approximately
km = kilometer(s)
LOCA = localized constructed analog
m = meter(s)
OSU = Oregon State University
UW = University of Washington
UCB = University of California, Berkeley
VIC = Variable Infiltration Capacity

2.1.2 Vulnerability Indicators and Metrics

Indicators and metrics are the foundation for the Quantitative Vulnerability Assessment conducted for relevant water resource sectors in the subsequent sections. Definitions for each of these terms are as follows:

- **Indicator**: Observable aspects of a given water resource sector that provide insight into existing conditions, projected conditions, and responses to adaptation. Indicators are intended to inform decision-making processes.
- **Metric**: Quantitative measurement of a given indicator. Metrics must be relevant, spatially specific, time sensitive, sensitive to climate, actionable, and comparable across scenarios.

Prior to conducting individual vulnerability assessments, a series of potential metrics were identified for a list of indicators relevant to each water resources sector. From here, a subset of the full list of potential metrics were selected and carried forward for the vulnerability analysis. This subset was chosen based on the modeling tools, data sources, and resources available for conducting quantitative vulnerability analysis. Table 2-6 provides an overview of the indicators, potential metrics, and selected metrics for each water resources sector. In some cases, identified indicators could only be assessed qualitatively using; in these cases, no metrics were assigned.

Table 2-6. Overview of Identified and Selected Indicators and Metrics by Water Resources Sector

Water Resources Sector	Indicator	Potential Metric(s)	Selected Metric(s)
Surface Water Supply	Monthly and Annual Flow	▪ Change in monthly and annual flow distribution ▪ Annual and seasonal diversions from the American River ▪ Change in lowest quartile annual flow ▪ Change in runoff and water deficit conditions based on locally derived water sources	▪ Change in unimpaired inflow to Folsom between November and March
Surface Water Supply	Water Supply Reliability	▪ Unmet demand ▪ Change in population and total water use ▪ Change in per-person water use	▪ Frequency of time Folsom storage is below 90 and 200 TAF
Surface Water Supply	Folsom Reservoir Condition	▪ Change in end-of-September storage of Folsom Reservoir ▪ Change in end-of-December storage of Folsom Reservoir	▪ End-of-December storage ▪ End-of-September storage ▪ End-of-May storage
Surface Water Supply	Upper Reservoir Condition	▪ Total upper watershed end-of-September storage ▪ Total Upper American River Project, Total 184 El Dorado Irrigation District, and Total Middle Fork Project end-of-September storage	▪ End-of-September storage for upper watershed hydropower reservoirs
Groundwater Supply	Groundwater Level Trends	▪ Change in groundwater level ▪ Land subsidence ▪ Estimated water use ▪ Estimated groundwater use ▪ Estimated groundwater storage change ▪ Initial progress on plan implementation regarding projects and management actions	▪ Net change in average depth to groundwater
Groundwater Supply	Total Volume of Storage	▪ Net change in annual groundwater storage ▪ Changes in reliance on American River over Cosumnes River due to groundwater overdraft	▪ Net change in annual groundwater storage
Groundwater Supply	Groundwater Quality Trends	▪ Change in groundwater quality	▪ N/A (qualitative)
Flood Management	Flood Stage	▪ Change in snowpack levels with more rain causing higher flood probability ▪ Change in 1% annual exceedance probability precipitation intensity	▪ Change in 1% annual exceedance probability precipitation intensity

Water Resources Sector	Indicator	Potential Metric(s)	Selected Metric(s)
Flood Management	Population Exposure to Flood Events	▪ Change in urban flood risk due to greater flows in the Lower American River during storms ▪ Population exposure (including change in exposure) to 100-year flood risk	▪ Change in urban flood risk ▪ Change in population exposure to selected flood events
Flood Management	Asset Exposure to Flood Events	▪ Change in flood inundation area for 100-year events	▪ Change in flood inundation for selected flood events
Flood Management	Folsom Reservoir	▪ Change in uncontrolled spill frequency for Folsom Reservoir	▪ N/A (qualitative)
Water Quality	Drinking Water Quality Impairments	▪ Change in natural receiving water temperature ▪ Change in dissolved oxygen ▪ Change in conditions leading to harmful algal blooms	▪ Frequency of consecutive dry days with Lower American River temperatures above 19 degrees Celsius
Water Quality	Environmental Water Quality Impairments	▪ Changes in flow needed to maintain water quality metrics ▪ Increases in salinity in the Delta due to project SLR ▪ Increased long-term water quality risks from wildfires due to intensified weather conditions, tree mortality resulting from stressed conditions and infestations ▪ Change in natural receiving water temperature ▪ Change in dissolved oxygen ▪ Change in conditions leading to harmful algal blooms ▪ Change in conditions leading to nutrient loading events and turbidity events	▪ Deviation from suitable temperature targets at Watt Avenue Bridge
Ecosystem	Natural & Ecological Flows	▪ Change in flow needed to protect endangered fishery species ▪ Change in distribution of hydrological conditions for minimum flows ▪ Changes in environmental flows during periods of drought ▪ Deviation from Lower American River Modified Flow Management Standard ▪ Change in spring lowest quartile flow	▪ Frequency of flows exceeding environmentally beneficial flow thresholds ▪ Change in unimpaired streamflow in upper watersheds
Ecosystem	Aquatic Ecosystem Suitability	▪ March through May and June through November Folsom storage ▪ Percent of months with Lower American River flows below 500 cfs and 800 cfs ▪ Deviation from Lower American River Modified Flow Management Standard ▪ Change in river temperature	▪ Deviation from suitable temperature targets at Watt Avenue Bridge

Water Resources Sector	Indicator	Potential Metric(s)	Selected Metric(s)
Ecosystem	Forest Health & Ecosystem Services	▪ Change in combined actual evapotranspiration and climatic water deficit ▪ Change in growing degree days	▪ Change in annual and seasonal climatic water deficit
Ecosystem	Landscape Condition	▪ Change in wildfire burn probability ▪ Change in wildfire burn area	▪ Change in annual wildfire burn probability ▪ Change in annual wildfire burn area
Ecosystem	Ecological Water Quality Impairments	▪ Changes in water temperature of Folsom Reservoir and the Lower American River ▪ Change in summer and fall stream temperature and dissolved oxygen between November and February relative to upper tolerable thresholds for species ▪ March through October river temperatures below upper tolerable thresholds for species ▪ Maximum weekly average temperature and temperature on November 1	▪ Deviation from suitable temperature targets at Watt Avenue Bridge
Ecosystem	Fish Habitat Conditions	▪ November through February exceedance flows that provide access to percentage of available spawning habitat ▪ March through October flows that provide access to percentage of available rearing habitat ▪ Number of salmonid habitat projects implemented and documentation of total acreage and effectiveness ▪ Number of non-salmonid natural resource projects implemented and documentation of utility and effectiveness	▪ Change in 2-year annual exceedance probability flows
Recreation	Recreational Uses	▪ Folsom Lake surface area between May and September ▪ Upper watershed reservoir surface area between May and September ▪ Boating use per day ▪ Change in recreational opportunities in rivers, lakes, and snow ▪ Change in average annual days between November and June with snow water equivalent above a given threshold ▪ Changes in seasonal flows impacting recreational uses	▪ Changes in frequency of recreational days for lakes ▪ Changes in frequency of recreational days for rivers ▪ Changes in the frequency of inundation for the American River Parkway ▪ Changes in April 1 snow water equivalent
Recreation	Tourism	▪ Change in recreational opportunities in rivers, lakes, and snow ▪ Change in average annual days between November and June with Snow water equivalent above a given threshold	▪ Changes in frequency of recreational days for lakes

Water Resources Sector	Indicator	Potential Metric(s)	Selected Metric(s)
		▪ Change in heat wave frequency ▪ Change in heat wave duration ▪ Change in average annual calm days	▪ Changes in frequency of recreational days for rivers ▪ Changes in the frequency of inundation for the American River Parkway ▪ Changes in April 1 snow water equivalent
Hydropower	Hydropower Generation	▪ End-of-September reservoir storage for Folsom and upper watershed reservoirs ▪ Change in hydropower production ▪ Monthly inflow-generation alignment index ▪ Changes in runoff timing affecting reservoir storage and reducing hydropower generation opportunities ▪ Change in power bypass	▪ End-of-September reservoir storage for Folsom and upper watershed reservoirs ▪ Change in hydropower generation

cfs = cubic foot/feet per second
TAF = thousand acre-feet

2.2 Surface Water Supply Vulnerability Assessment

2.2.1 Purpose

The purpose of the Surface Water Supply Vulnerability Assessment is to evaluate the effects of climate change on surface water supply throughout the ABC Watersheds Resilience Pilot Study that covers the American River, Cosumnes River, and Bear River watersheds. These watersheds contain a complex system of reservoirs used for water supply, flood control, and hydropower generation. Changes to climate, population growth, and land use are projected to cause greater imbalances to water supply and demand. These changes will likely increase the complexity in operating reservoirs to meet downstream demands and regulatory requirements. Furthermore, the potential effects of climate change introduce uncertainty in water supply reliability. The following sections evaluate the potential outcomes of surface water supply when water management practices and regulation are left unchanged.

Three key water supply metrics were evaluated:

1. Folsom Reservoir storage at the end of December, September, and May
2. American River Inflow to Folsom Reservoir from March through November
3. Storage in hydropower reservoirs in the Upper American River Project, Middle Fork Project, El Dorado Irrigation District Project 184, and the Bear River

2.2.2 Methodology

The surface water supply of four climate periods was estimated using CalSim 3, a planning model of California water resources that simulates reservoir storage levels, river flows, and surface water diversions and deliveries on a monthly time-step based on hydrology from water years 1921 through 2021. CalSim 3 was developed jointly by the Bureau of Reclamation (Reclamation) and the DWR and is considered the best available planning-level analytical tool for evaluating Central Valley Project (CVP) and SWP system operations. It includes detailed representation of the reservoirs, rivers, points of diversions, and demands in the American River watershed and includes current facility specifications and operational regulations. More detail on CalSim 3 is included in Attachment B.

Four climate scenarios were developed and simulated in CalSim 3: Existing Baseline, Mid-Century (CT), Late-Century (HD), and Late-Century (WW). Table 2-7 summarizes the scenarios that were evaluated. Each model includes different hydrologic inputs (i.e., rim inflows) and demand assumptions reflective of the climate, level of development, and land use for each period. All other model assumptions were kept the same between each scenario so that water resource management practices remain consistent throughout the Mid-Century and Late-Century. A detailed description of the modeling assumptions is included in Attachment B. Most of the modeling assumptions are constant between each scenario to focus the analysis on changes in hydrology, SLR, land use, and level of development. Moreover, this analysis presents the effects of climate change when project operations, regulations, and existing water resource facilities are unadjusted.

Table 2-7. Climate Scenarios Modeled

Scenario	Climate Condition	Sea Level Rise
Existing Baseline	Existing Conditions	0 cm
Mid-Century (CT)	2055 CT	30 cm

Scenario	Climate Condition	Sea Level Rise
Late-Century (HD)	2085 HD	55 cm
Late-Century (WW)	2085 WW	55 cm

Folsom Reservoir Storage

Folsom Reservoir is part of the CVP and is operated by Reclamation for water supply, environmental purposes, and flood risk management. With 975 TAF storage capacity, the reservoir relies heavily on snowpack from the upper regions of the watershed. Changing climate conditions are projected to reduce the size of the snowpack and alter the timing of runoff entering the reservoir. Reclamation's operation of Folsom Reservoir is constrained by regulatory requirements, such as minimum instream flow standards and Delta Outflow objectives.

For Folsom Reservoir, end-of-month storage was evaluated in May, September, and December. Storage conditions at the end of May indicate water supply availability at the end of the wet season and the beginning of the delivery season for many water users. End-of-September storage represents the volume of water that is carried from the previous water year to the following water year. End-of-December storage represents conditions at the end of the calendar year. Additionally, Folsom Reservoir is operated to a minimum end-of-December storage objective of 230 TAF in dry conditions. This standard was set by the Bureau of Reclamation and the Sacramento Water Forum in the Water Forum Agreement (Sacramento Water Forum, 2025). Compliance with this minimum storage objective was evaluated for each climate condition.

American River Inflow to Folsom Reservoir

The American River watershed primarily receives precipitation as snowpack. Inflow to Folsom Reservoir was calculated from CalSim 3 on a volumetric basis between March and November to represent inflow during the primary water supply release period outside of flood control season. It was calculated by combining the inflows from the North and South Forks of the American River, which are the two primary sources of inflow to the reservoir. The volumetric inflow in March through November is used as a guide to determine water-year type classifications by the Sacramento Water Forum (Sacramento Water Forum, 2017). Each year type classification and the corresponding flow volumes are included in Table 2-8.
The frequency of years above and below these year type classification thresholds were evaluated among the four climate periods simulated by CalSim 3.

Table 2-8. Water-year Types as Defined by Water Forum Agreement

Threshold (Mar-Nov)	Year Type Above	Year Type Below
1,600 TAF	Wet	Average
950 TAF	Average	Drier
400 TAF	Drier	Driest

Upper Reservoir Storage

While Folsom Reservoir is the largest reservoir in the study area, there is a complex system of reservoirs, tunnels, and power plants in the Upper American River watershed. The Upper American River includes the following three hydroelectric projects:

- Project 184 (El Dorado Irrigation District)
    - Silver Lake, Caples Lake, Lake Aloha, Echo Lake

- Middle Fork Project (Placer County Water Agency)
    - French Meadows Reservoir, Hell Hole Reservoir
- Upper American River Project (Sacramento Municipal Utilities District [SMUD])
    - Loon Lake, Gerle Creek Reservoir, Union Valley Reservoir, Ice House Reservoir

The El Dorado Hydroelectric Project 184 includes hydroelectric facilities on the South Fork American River and its tributaries, Echo Creek, and in the Counties of El Dorado, Alpine, and Amador. The Middle Fork Project is located along the Middle Fork American River, the Rubicon River, and several associated tributary streams within Placer County. The Upper American River Project includes dams and powerhouses operated by SMUD along the South Fork American River and its tributaries.

Each of the above projects are operated under the Federal Energy Regulatory Commission (FERC), which includes minimum water supply objectives for hydroelectric projects in the American River watershed (FERC 2014). Table 2-9 includes end-of-September storage objectives for three of the hydroelectric projects evaluated in the Vulnerability Assessment. CalSim 3 was used to evaluate compliance with these storage objectives under each climate condition described in Table 2-9.

Table 2-9. Storage thresholds for hydroelectric projects.

Project	Volume (TAF)	Source
EID Project 184	17 TAF	FERC Minimum
Middle Fork Project	76 TAF	FERC Minimum
Upper American River Project	198 TAF	Minimum in Existing Baseline

Additionally, the following reservoirs along the Bear River were included in the Vulnerability Assessment to evaluate the effects of climate change on water supply for the Nevada Irrigation District (NID) and South Sutter Irrigation District (SSID):

- Rollins Lake (NID)
- Combie Reservoir (NID)
- Camp Far West Reservoir (SSID)

CalSim 3 outputs of end-of-September storage volumes of the three reservoirs listed herein were used to evaluate the effects of climate change on Bear River water supply. The NID and SSID deliver water for hydropower production, recreation, and environmental objectives.

2.2.3 Results

Figure 2-4 shows monthly average inflow to Folsom Reservoir in December through August. Future conditions are projected to correspond with reduced levels of annual unimpaired inflows entering the American River due to reduced size in snowpack. Additionally, warmer temperatures and changing precipitation levels are projected to cause a shift in the timing of upstream runoff, where a higher proportion of annual unimpaired inflow occurs in December through March and less occurs in May through August. Reduced levels of unimpaired inflow, especially later in the year, pose challenges in managing water supply to meet downstream demands and regulatory requirements.

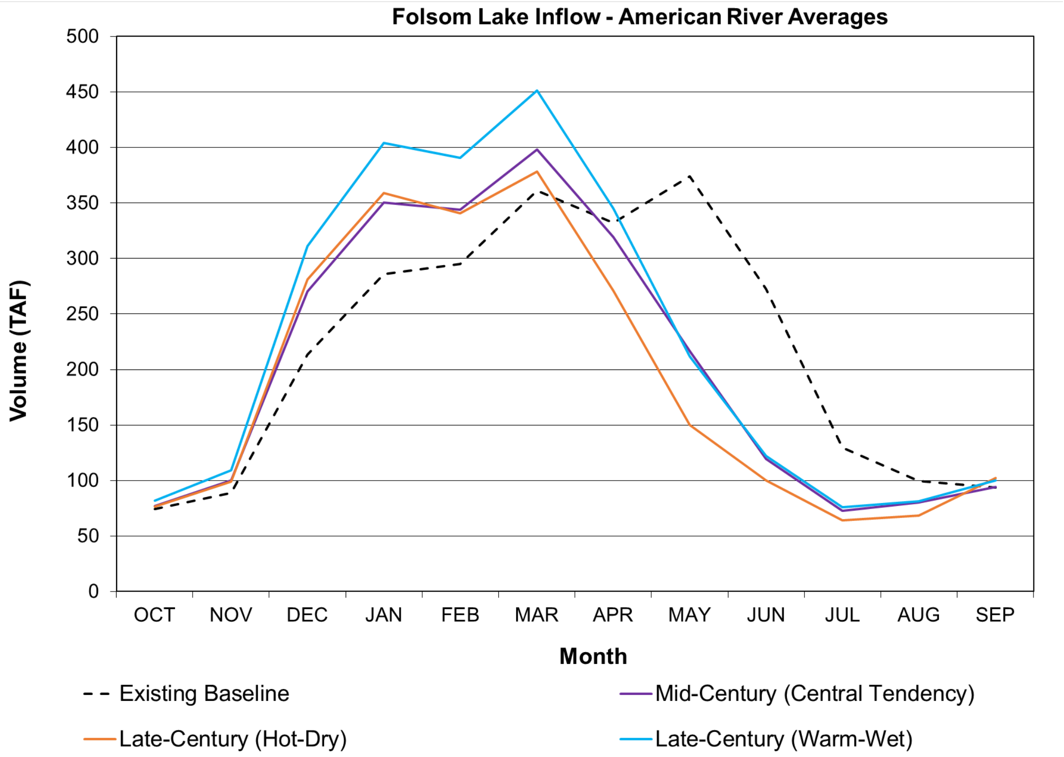


Figure 2-4. Monthly Average Folsom Reservoir Inflow.

Figure 2-5 presents an exceedance of probability charge of annual March through November volumes of inflow to Folsom Reservoir. This figure also includes thresholds used by the 2017 Water Forum Agreement to indicate water-year type classifications (Table 2-9). About 50% of the years in the Existing Baseline would be classified as Wet per the Water Forum guidelines. Only 28% of the Existing Baseline simulation includes inflow levels consistent with Drier and Driest water supply conditions.

Each future climate period includes less American River inflow than the Existing Baseline on an annual basis, resulting in higher frequencies of drier year type classifications. The Mid-Century (CT) period includes 30% of years in the Wet classification, 29% of years in the Average classification, 30% of years in the Drier classification, and 10% in the Driest classification.

The Late-Century (HD) scenario includes the least annual volume of inflow and corresponds with the highest frequency of drier water-year classification. In Late-Century (HD) conditions, March through November inflow volume is less than 400 TAF in 18% of the simulation period (100 years), reflecting "Drier/Driest" conditions per the Water Forum Agreement. This is a substantial increase from the Existing Baseline, which only includes 2% of years in Drier/Driest conditions. Overall, the Late-Century (HD) period includes 26% of years in the Wet classification, 28% of years in the Average classification, 27% of years in the Drier classification, and 18% in the Driest classification.

The Late-Century (WW) period includes the most runoff in December and January relative to any other period. If the late century trends warm and wet, more annual runoff is expected than if it trends hot and dry. The Late-Century (WW) period includes similar levels of annual inflows to the American River relative to the Mid-Century (CT) period. The Late-Century (WW) period includes 34% of years in the Wet classification, 30% of years in the Average classification, 28% of years in the Drier classification, and 7% in the Driest classification.

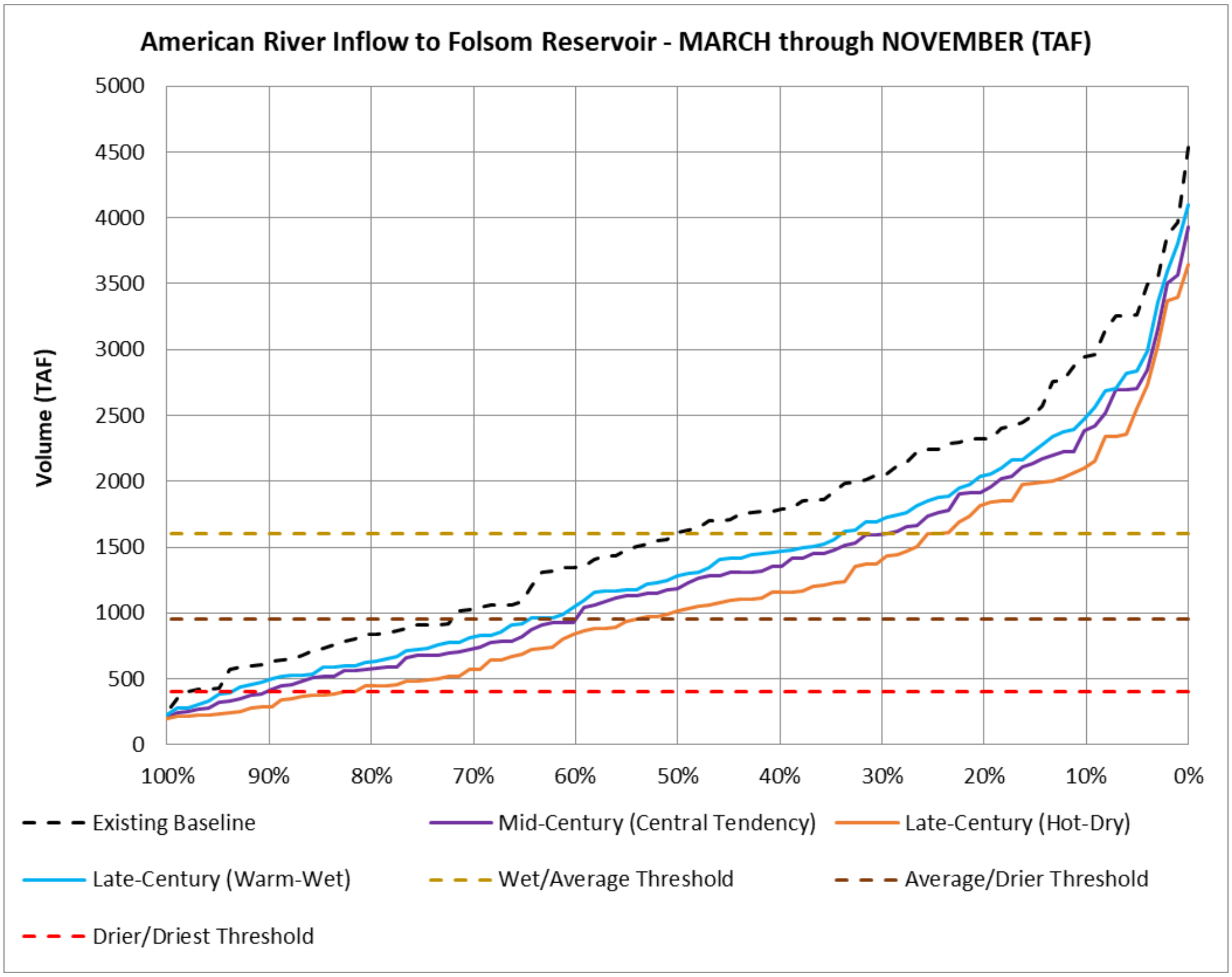


Figure 2-5. American River Inflow Volume (TAF) in March through November - Exceedance of Probability.

Figure 2-6 presents an exceedance of probability chart for end-of-September storage in Folsom Reservoir, which represents the carryover storage from the previous water year to the following water year. Carryover storage reflects how much water remains in the reservoir for use in the forthcoming year. As shown, Folsom carryover storage is significantly impacted in the Mid-Century period and in both Late-Century periods. Operations of Folsom storage below dead pool conditions, or 90 TAF, are not permitted in the model. Such low storage levels completely restrict flexibility in meeting water supply objectives. The Existing Baseline includes zero instances of deadpool conditions. However, each future period includes several instances of deadpool conditions at the end of September. The Late-Century (HD) model includes 11 years in which Folsom storage levels reached modeled dead pool conditions. These conditions occur in drought years, such as 1931 through 1934, 1976 through 1977, 1991 through 1992, and 2013 through 2015. The lower storage levels in the future scenarios result from reduced unimpaired inflows, less precipitation, and higher temperatures resulting in earlier snowmelt.

In the Existing Baseline, end-of-September storage in Folsom Reservoir is at the modeled flood control limit of 752 TAF in 29% of the simulation. The Mid-Century (CT) period reaches this limit less often, in only 8% of the years. The Late-Century (HD) period reaches this limit in the least at 2% of the years.

The Late-Century (WW) period includes similar levels of carryover storage to the Mid-Century (CT) period and reaches the flood control limit in 5% of the years.

In the Late-Century (WW) period, rim inflows and snowmelt into the American Rivers are generally higher in December through March than the other scenarios. Much of this water is spilled from upstream reservoirs due to limited storage capacity and is lost to Delta Outflow. However, the higher level of runoff in the Late-Century (WW) period allows for greater upstream storage in droughts compared to the Mid-Century (CT) period and especially the Late-Century (HD) period.

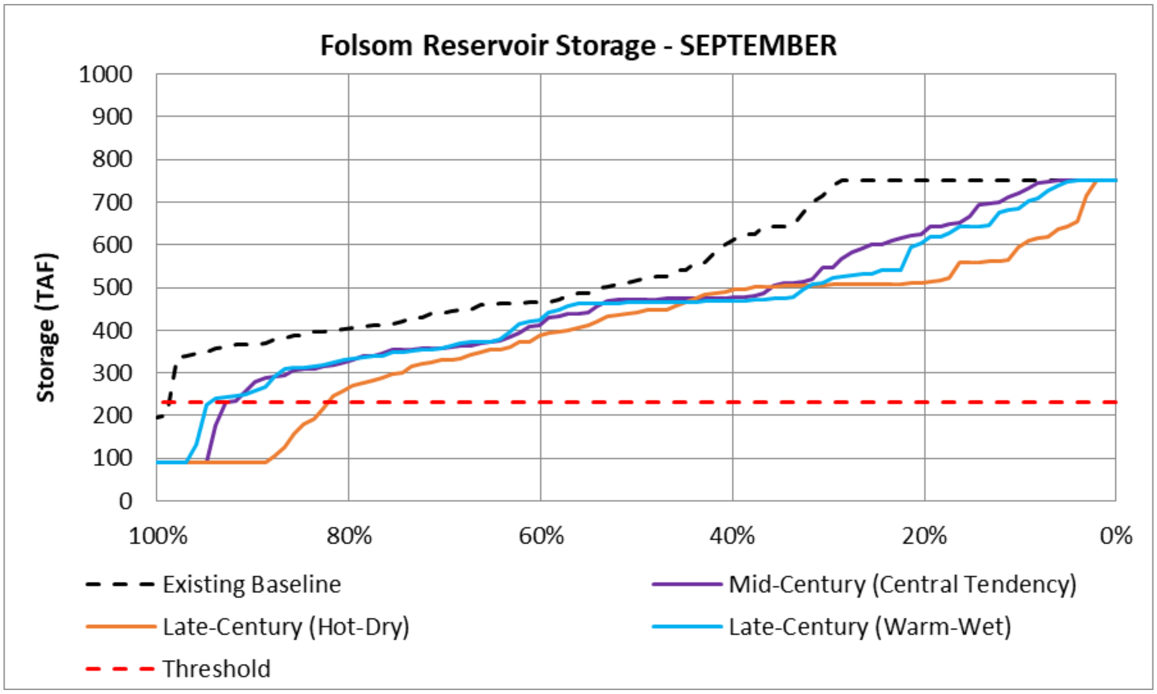


Figure 2-6. End-of-September Folsom Storage

Figure 2-7 presents an exceedance of probability chart for end-of-December Folsom storage. The Water Forum's Memorandum of Understanding identifies a minimum storage level of 300 TAF by the end of December each year. However, in years with dry conditions, the minimum is relaxed to 230 TAF (Water Forum, 2025). The Existing Baseline complies with this standard in 99% of the CalSim 3 simulation period. The Mid-Century (CT) scenario exceeds 230 TAF at the end of December in 96% of the years. The Late-Century (WW) scenario often includes end-of-December storage levels similar to the Mid-Century (CT) scenario; however, it is compliant with the 230 TAF objective in 99% of years, similar to the Existing Baseline. End-of-December storage levels are often elevated in the Late-Century (WW) scenario due to high levels of precipitation in December. End-of-December Folsom storage exceeds 230 TAF in only 86% of the simulation in the Late-Century (HD) scenario.

Each future climate condition shows a reduction in water supply available in Folsom Reservoir prior to the beginning of the new calendar year. About 55% of the time, end-of-December storage is less in the Mid-Century (CT) period than it is in the Existing Baseline. Most of these reductions occur in average and drier years. The Late-Century (HD) period includes less end-of-December storage than all other periods in 65% of the years. The Late-Century (WW) period includes similar end-of-December storage levels to the Mid-Century (CT) period.

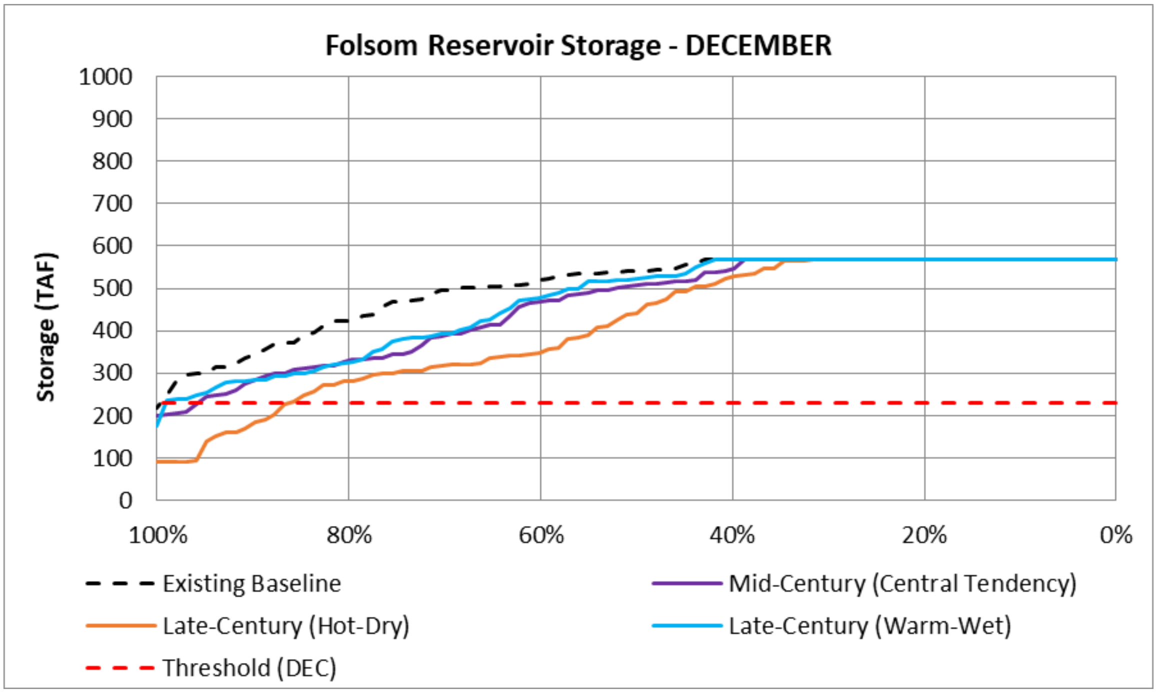


Figure 2-7. End-of-December Folsom Storage

Figure 2-8 presents an exceedance of probability chart for end-of-May Folsom storage which represents the storage going into the summer season. The Existing Baseline never goes below the 230 TAF standard in the CalSim 3 simulation period. The Mid-Century (CT) scenario exceeds 230 TAF at the end of May in 98% of the years. The Late-Century (WW) scenario often includes end-of-May storage levels similar to the Mid-Century (CT) scenario and also exceeds the standard in 98% of years. End-of-May Folsom storage exceeds 230 TAF in only 89% of the simulation in the Late-Century (HD) scenario.

Overall, each future climate condition shows a reduction in water supply available in Folsom Reservoir prior to the summer, which comprises the bulk of the delivery season for water users in the Lower American River. About 70% of the time, end-of-May storage is less in the Mid-Century (CT) period than it is in the Existing Baseline. The Late-Century (HD) period includes less end-of-May storage than all other periods in 90% of the years. The Late-Century (WW) period includes similar end-of-May storage levels to the Mid-Century (CT) period.

In the Existing Baseline, end-of-May storage in Folsom Reservoir reaches the modeled flood control limit of 967 TAF in 58% of the simulation. The Mid-Century (CT) period reaches this limit less often, in only 31% of the years. The Late-Century (HD) period reaches this limit in the least (10% of the years). The Late-Century (WW) period includes similar levels of carryover storage to the Mid-Century (CT) period and reaches the flood control limit in 30% of the years.

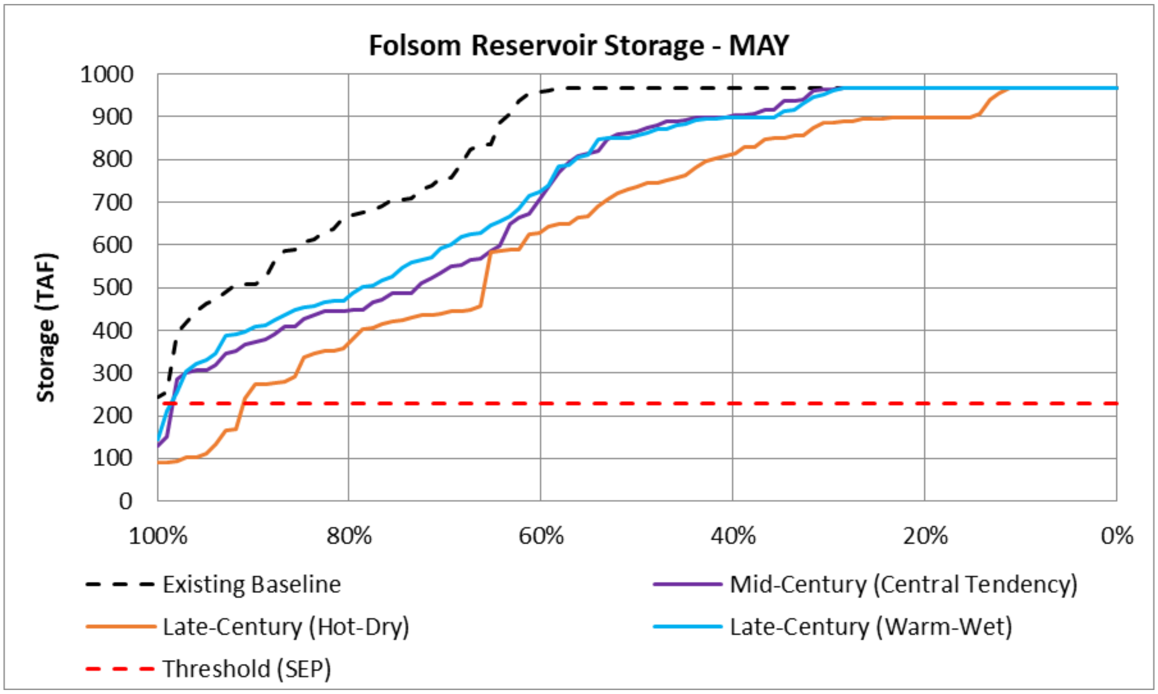


Figure 2-8. End-of-May Folsom Storage

CalSim 3 results indicate that climate change will significantly reduce upper watershed storage for hydropower production. Figure 2-9 presents EID Project 184 storage. Under Existing Conditions, end-of-September storage exceeds the FERC minimum in 92% of the 100 years in the simulation. The Mid-Century (CT) scenario exceeds the FERC minimum in 39% of the simulation. The Late-Century (WW) scenario exceeds the standard in 21% of years. Storage exceeds the FERC minimum in only 2% of years in the Late-Century (HD) scenario.

Each future climate condition shows a reduction in water supply available for EID Project 184 for 100% of the years simulated in CalSim 3 (100 years). The average end-of-September EID Project 184 water supply in the Mid-Century (CT) period is than it is in the Existing Baseline. The Late-Century (HD) period includes less end-of-May storage than all other periods in 90% of the years. The Late-Century (WW) period includes similar end-of-May storage levels to the Mid-Century (CT) period.

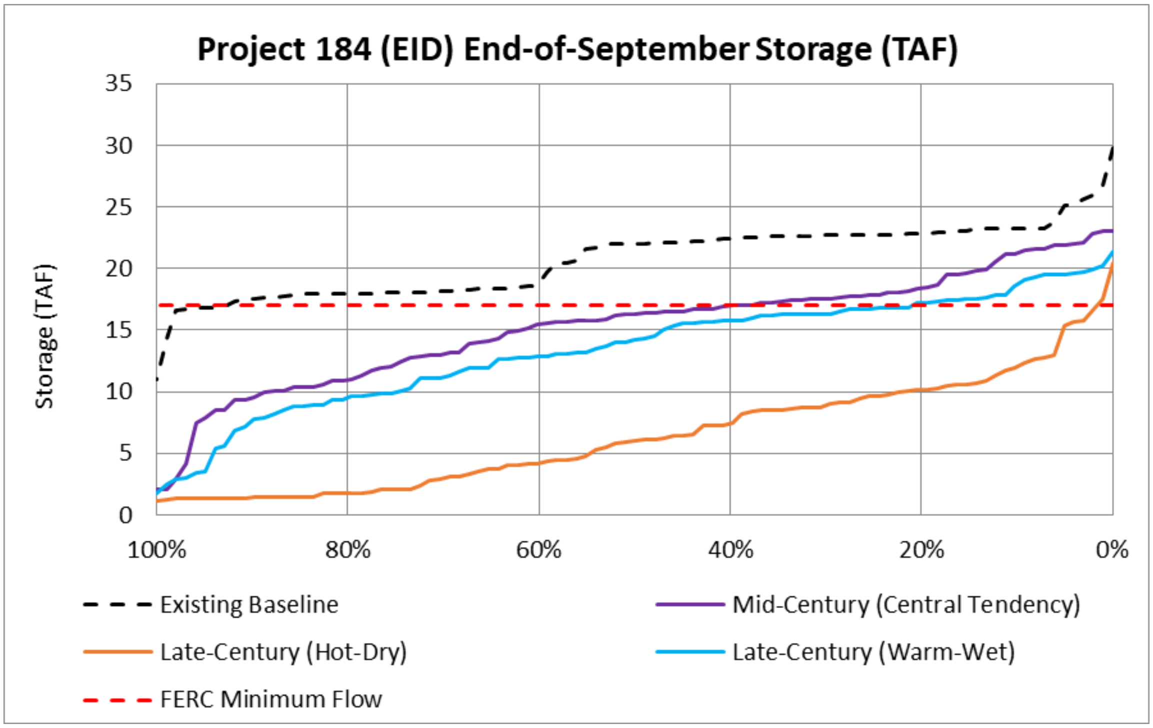


Figure 2-9. End-of-September EID Project 184 Storage

Figure 2-10 presents Middle Fork Project storage at the end of September. Under Existing Conditions, end-of-September storage always exceeds the FERC minimum in the100-year simulation. The Mid-Century (CT) scenario exceeds the FERC minimum in 92% of years in the simulation. The Late-Century (WW) scenario exceeds the standard in 92% of years as well. Storage exceeds the FERC minimum in only 82% of years in the Late-Century (HD) scenario.

Unless water supply is very high (exceeding 230 TAF), each future climate condition includes reduced levels of Middle Fork Project storage at the end of September relative to the Existing Baseline. In over 80% of the CalSim 3 simulation period, the Mid-Century (CT) and Late-Century (WW) scenarios include less water supply for the Middle Fork Project than the Existing Baseline. Water supply in the Late-Century (HD) scenario is most impacted, often presenting end-of-September storage reductions of greater than 100 TAF compared to the Existing Baseline.

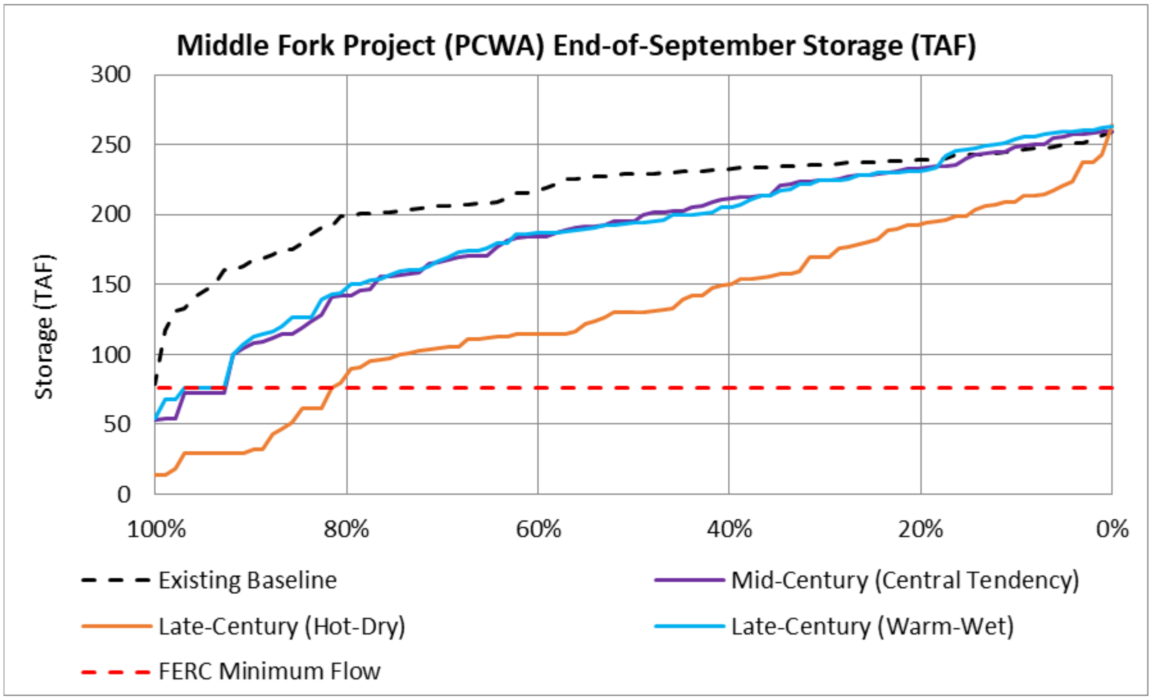


Figure 2-10. End-of-September Middle Fork Project Storage

Figure 2-11 presents Upper American River Project storage. Under Existing Conditions, end-of-September storage always exceeds the FERC minimum in the 100-year simulation. The Mid-Century (CT) scenario exceeds the FERC minimum in 96% of years in the simulation. The Late-Century (WW) scenario exceeds the standard in 97% of years. Storage exceeds the FERC minimum in only 87% of years in the Late-Century (HD) scenario.

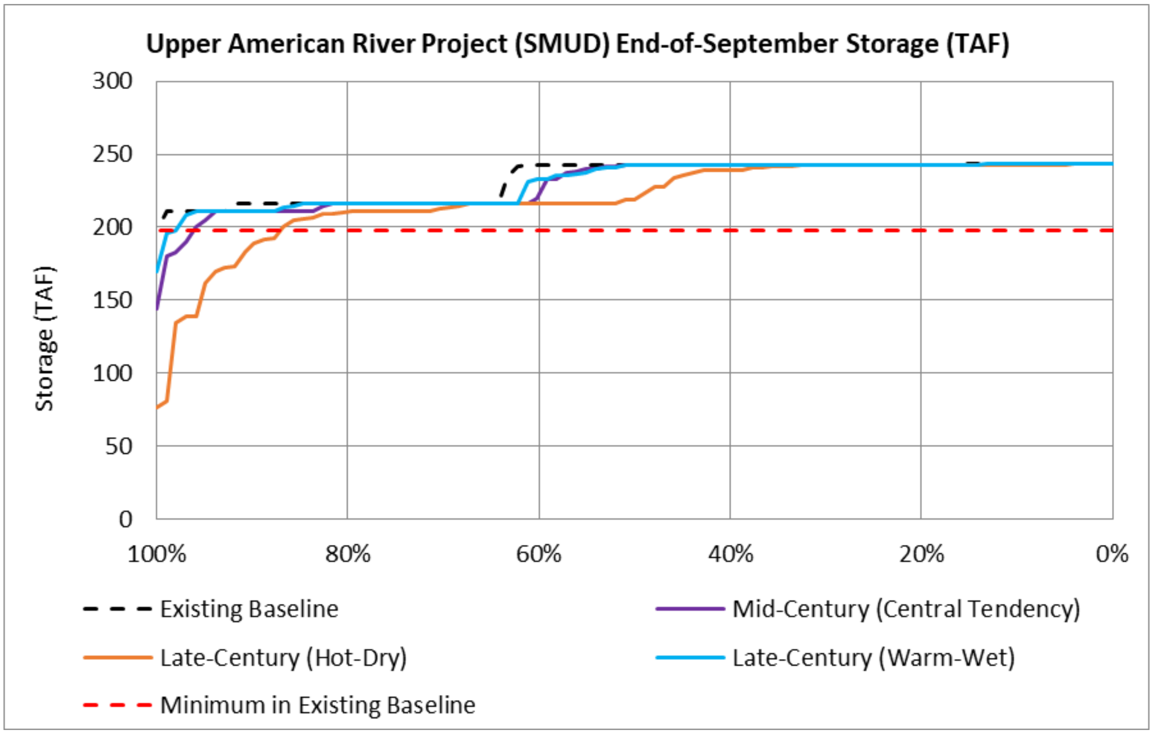


Figure 2-11. End-of-September Upper American River Project Storage

Figure 2-12 presents Bear River storage for the NID and SSID in Rollins Lake, Combie Reservoir, and Camp Far West Reservoir. This water supply is not operated to any specified FERC objectives. As shown, Bear River water supply in the future periods is reduced relative to the Existing Baseline by 19% to 26%.

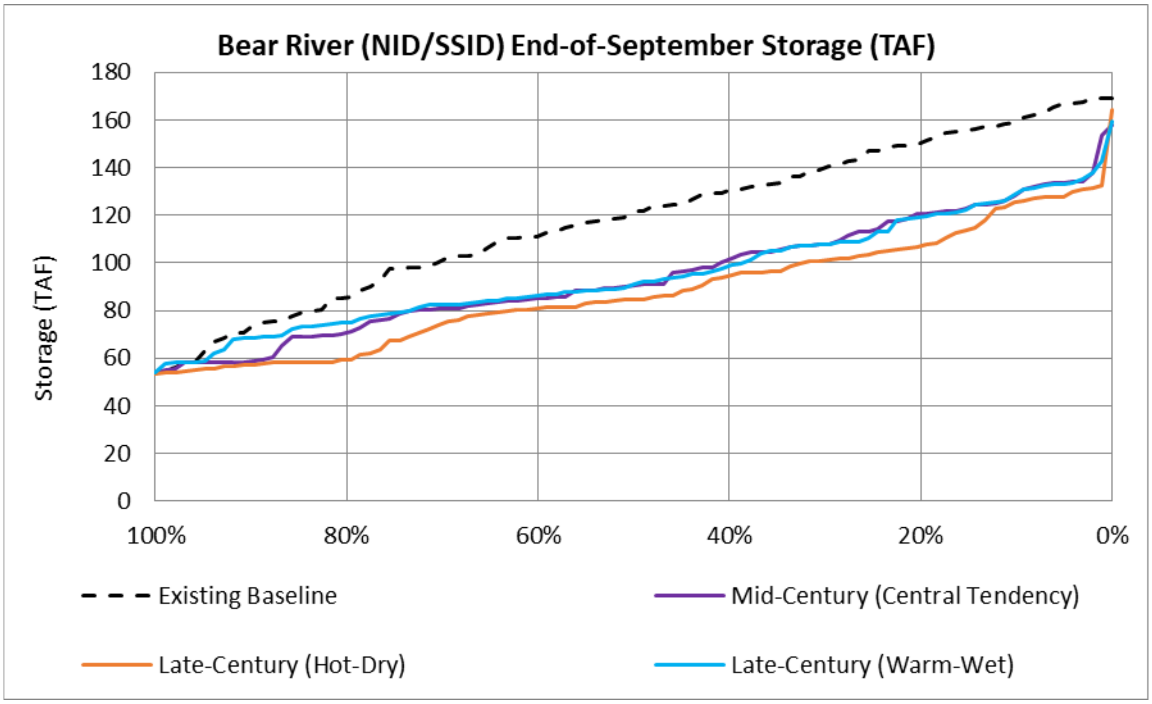


Figure 2-12. End-of-September Bear River Storage for the Nevada Irrigation District and South Sutter Irrigation District

Overall, CalSim 3 modeling suggests that future conditions will correspond with reduced levels of surface water supply due to reductions in annual unimpaired inflows entering the American River watershed. Warmer temperatures and changing precipitation levels will cause a shift in the timing of upstream runoff, where a higher proportion of annual water supply will be available in December through March and less will be available in May through August. Reduced levels of unimpaired inflow, especially later in the year, may pose complexities in managing water supply to meet downstream demands and regulatory requirements. The modeling suggests that, without adjustment to management strategies, reservoirs will be impacted with substantially reduced storage levels. If management of surface water supply is left unchanged, there will be higher frequency of reservoirs reaching inoperable levels of storage, causing shortages in water supply to satisfy downstream demands and regulatory objectives.

2.3 Groundwater Supply Vulnerability Assessment

2.3.1 Purpose

The purpose of the Groundwater Supply Vulnerability Assessment is to evaluate potential vulnerabilities in groundwater supply resulting from projected changes in climate throughout the ABC Watersheds Resilience Planning area. Within the Study Area, three groundwater subbasins, the North American, South American, and Cosumnes Subbasins, serve as the focus areas for the assessment of groundwater supply vulnerability. To evaluate potential vulnerabilities in groundwater supply, changes in groundwater storage as analyzed and presented by in the North American, South American, and Cosumnes Groundwater Sustainability Plans (GSPs) were summarized to characterize conditions under historical, current, and future conditions and highlight potential vulnerabilities in groundwater supply under climate conditions.

The following sections discuss the methodology used to evaluate groundwater supply vulnerability and the results of the groundwater supply vulnerability analysis.

2.3.2 Methodology

To evaluate groundwater supply vulnerability, changes in groundwater storage under historical, current, and future conditions were summarized from the GSPs for the North American, South American, and Cosumnes Subbasins. The following sections provide further details on the methodology applied to evaluate projected groundwater conditions.

Groundwater Sustainability Plan Summaries

During development of GSPs for the North American, South American, and Cosumnes Subbasins, a groundwater flow model covering these three subbasins was developed, calibrated, and applied to support development of groundwater budgets, and for evaluation of Sustainable Management Criteria. As part of GSP requirements, 50-year projections of future conditions were required to evaluate sustainability over the 50-year Sustainable Groundwater Management Act planning horizon.

Development of the groundwater flow model, herein referred to as "CoSANA", is documented as part of Appendix M of the Cosumnes Subbasin GSP.

- Current Conditions Baseline Scenario
- Current Conditions DWR 2030 CT Climate Change Scenario
- Projected Conditions Baseline Scenario
- Projected Conditions American River Basin Study (ARBS) CT 2070 Climate Change Scenario
- Projected Conditions DWR Extreme I (drier with extreme warming) 2070 Climate Change Scenario
- Projected Conditions DWR Extreme II (wetter with moderate warming) 2070 Climate Change Scenario

2.3.3 Results

The following sections describe the summaries of groundwater conditions as published in the GSPs for the North American, South American, and Cosumnes Subbasins.

Groundwater Sustainability Plan Summaries

To support evaluation of groundwater supply vulnerability across the North American, South American, and Cosumnes Subbasins, summaries of groundwater conditions from each Subbasin's GSP are provided in the subsequent sections.

North American Subbasin

As part of the North American Subbasin GSP, groundwater budgets representing Historical, Current, Projected, and projected conditions with climate change were developed using the CoSANA Model. Full discussion of the assumptions and results of the North American Subbasin groundwater budgets are provided in Section 6 of the North American Subbasin GSP.

Table 2-10 shows a summary of annual average groundwater inflows, outflows, and the change in groundwater storage under historical, current, and projected conditions. On average, historical, current, and projected conditions, the change in groundwater storage is positive, suggesting inflows are generally greater than outflows during these years. Variability from year to year can occur with increases in recharge occurring in wet years contributing to increases in groundwater storage, whereas, in dry years less recharge from precipitation and streamflow occurs and more groundwater is pumped to meet agricultural demands. Under projected conditions with climate change, groundwater outflows exceed groundwater inflows resulting in a decline in groundwater storage, on average. The reductions in groundwater storage are largely a result of increased agricultural pumping resulting from climate-related increases in evapotranspiration and the associated agricultural water use demand.

Table 2-10. Summary of Annual Average Groundwater Inflows, Groundwater Outflows, and Change in Groundwater Storage for the North American Subbasin

Scenario	Analysis Period	Annual Average Groundwater Inflows (AF)	Annual Average Groundwater Outflows (AF)	Annual Average Change in Groundwater Storage
Historical Conditions	WYs 2009 to 2018	383,000	351,100	31,900
Current Conditions	WYs 1970 to 2019	384,700	369,900	14,900
Projected Conditions	WYs 1970 to 2019	393,800	388,400	5,400
Projected Conditions with Climate Change	WYs 1970 to 2019	399,500	403,000	-3,500

South American Subbasin

As part of the South American Subbasin GSP, groundwater budgets representing Historical, Current, Projected, and projected conditions with climate change were developed using the CoSANA Model. Full discussion of the assumptions and results of the South American Subbasin groundwater budgets are provided in Section 2.4 of the South American Subbasin GSP.

Table 2-11 shows a summary of annual average groundwater inflows, outflows, and the change in groundwater storage under historical, current, and projected conditions. Under historical and current conditions, groundwater inflows are greater than groundwater outflows resulting in a positive change in groundwater storage. Variability in the change in groundwater storage is tied to climate and hydrologic conditions where wet years lead to greater availability in surface water, reducing the need for groundwater pumping. Conversely, drier years result in more groundwater pumping to meet agricultural demands not met by surface water or precipitation. In general, surface water supply remained relatively consistent in drier years, however, the lack of precipitation increased agricultural water use demands.

Under projected conditions and projected conditions with climate change, groundwater outflows tended to be greater than groundwater inflows, resulting in a decline in groundwater storage. One factor contributing to the reduction in groundwater storage under projected conditions is changes in land use which result in increased impervious areas in the subbasin which causes reductions in deep percolation. When climate change is accounted for under projected conditions, the increased reduction in groundwater storage is largely attributed to increased agricultural pumping.

Table 2-11. Summary of Annual Average Groundwater Inflows, Groundwater Outflows, and Change in Groundwater Storage for the South American Subbasin

Scenario	Analysis Period	Annual Average Groundwater Inflows (AF)	Annual Average Groundwater Outflows (AF)	Annual Average Change in Groundwater Storage
Historical Conditions	WYs 2009 to 2018	275,400	267,700	7,700
Current Conditions	WYs 1970 to 2019	274,800	272,600	2,200
Projected Conditions	WYs 1970 to 2019	292,100	293,200	-1,100

Projected Conditions with Climate Change	WYs 2022 through 2071	298,900	305,100	-6,200

Cosumnes Subbasin

As part of the South American Subbasin GSP, groundwater budgets representing Historical, Current, Projected, and projected conditions with climate change were developed using the CoSANA Model. Full discussion of the assumptions and results of the Cosumnes Subbasin groundwater budgets are provided in Section 10.2.4 of the Cosumnes Subbasin GSP.

Table 2-12 presents a summary of annual average groundwater inflows, groundwater outflows, change in groundwater storage, and the sustainable yield for the Cosumnes Subbasin for the 20-year historical period and four projected future conditions. Based on the GSPs evaluation of historical conditions, a relationship between the change in groundwater storage and the specific WY type (i.e., whether it was a wet year or dry year) was determined where increases in groundwater storage occur during wet years and decreases in groundwater storage occur during dry years. Declines in groundwater storage were especially evident in multi-year drought conditions, suggesting groundwater conditions are sensitive to climate conditions.

Table 2-12. Summary of Annual Average Groundwater Inflows, Groundwater Outflows, and Change in Groundwater Storage for the Cosumnes Subbasin

Scenario	Analysis Period	Annual Average Groundwater Inflows (AF)	Annual Average Groundwater Outflows (AF)	Annual Average Change in Groundwater Storage
20-year Model Evaluation Period	WYs 1999 through 2018	144,200	154,900	-10,700
Current Conditions Baseline	WYs 2022 through 2071	149,800	150,200	-400
Projected Conditions Baseline	WYs 2022 through 2071	149,800	150,200	-400
Projected Conditions ARBC CT 2070 Climate Change	WYs 2022 through 2071	144,500	154,500	-10,000
Projected Conditions DWR Extreme I 2070 Climate Change	WYs 2022 through 2071	137,900	156,500	-18,600
Projected Conditions DWR Extreme II 2070 Climate Change	WYs 2022 through 2071	163,800	160,000	3,800

2.4 Flood Management Vulnerability Assessment

2.4.1 Purpose

The purpose of the Flood Management Vulnerability assessment is to quantify impacts on structures and populations in the pilot area under future climate scenarios. Future climate scenarios include increased precipitation and associated river flows that can lead to expanded areas of inundation for the same annual exceedance probability (AEP) event. In the American River, for example, the 100-year flow (0.01 AEP event) increases from approximately 115,000 cfs under current climate to about 140,000 under 2072 climate with a high emissions scenario (see Figure 2-19). Regulation of flow by Folsom Reservoir explains the horizontal portion of the flow frequency curve.

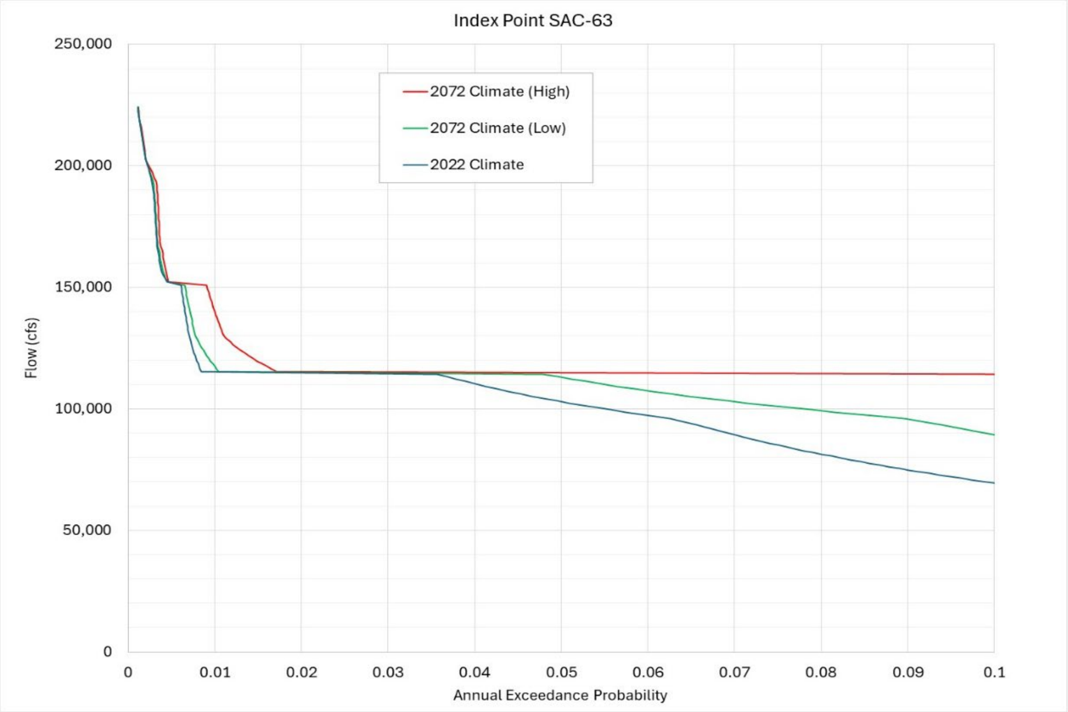


Figure 2-13. Flow Frequency Distribution at SAC-63 Index Point for Events larger than 10-year Storm (0.10 AEP).

2.4.2 Methodology

Jacobs used existing hydraulic model simulation results of potential flooding in areas adjoining the American, Sacramento, and tributary rivers to quantify impacts to buildings and structures. The California Department of Water Resources provided Jacobs with raster files of potential inundation of urban areas developed as part of the Central Valley Flood Protection Plan 2022 Update. The inundation maps were provided for a series of assumed breach events that were developed to support a Flood Damage Assessment (FDA) analysis included in the CVFPP update.

The inundation information provided by DWR included fifteen impact areas that overlap with the watersheds included in the project study area. These 15 impact areas range in size as summarized in Table 2-13. The analysis presented herein focuses on 5 index areas representing 67% of the total area (areas 30, 36, 40, 44, and 63) and 87% of the total structures at risk in the 15 impact areas. The impact areas and watershed boundaries are presented in Figure 2-20, with the 5 focus areas highlighted for clarity.

DWR conducted hydraulic model simulations of between 6 and 8 breach scenarios at each of their index points. These simulations used river flows based on the 1986 flood event and applies various scale factors between 10 and 260 percent to model a large range of events. The river flows and stages modeled range in AEP from 0.76 (a 1.3-year return interval event) to 0.00145 (a 689-year event). The limited number of runs covering a large range of flow magnitudes reduces the ability to directly quantify climate impacts, as will be discussed below.

Table 2-13. DWR Impact Areas in Pilot Study Area

Index Area	Size (sq mile)
SAC28	22.0
SAC 29	79.8
SAC 30	75.2
SAC 36	86.7
SAC 37	38.7
SAC 38	10.4
SAC 39	12.1
SAC 40	66.0
SAC 43	0.5
SAC 44	55.0
SAC 45	0.2
SAC 47	15.5
SAC 48	0.3
SAC 52	0.9
SAC 63	85.3
Total	548.6

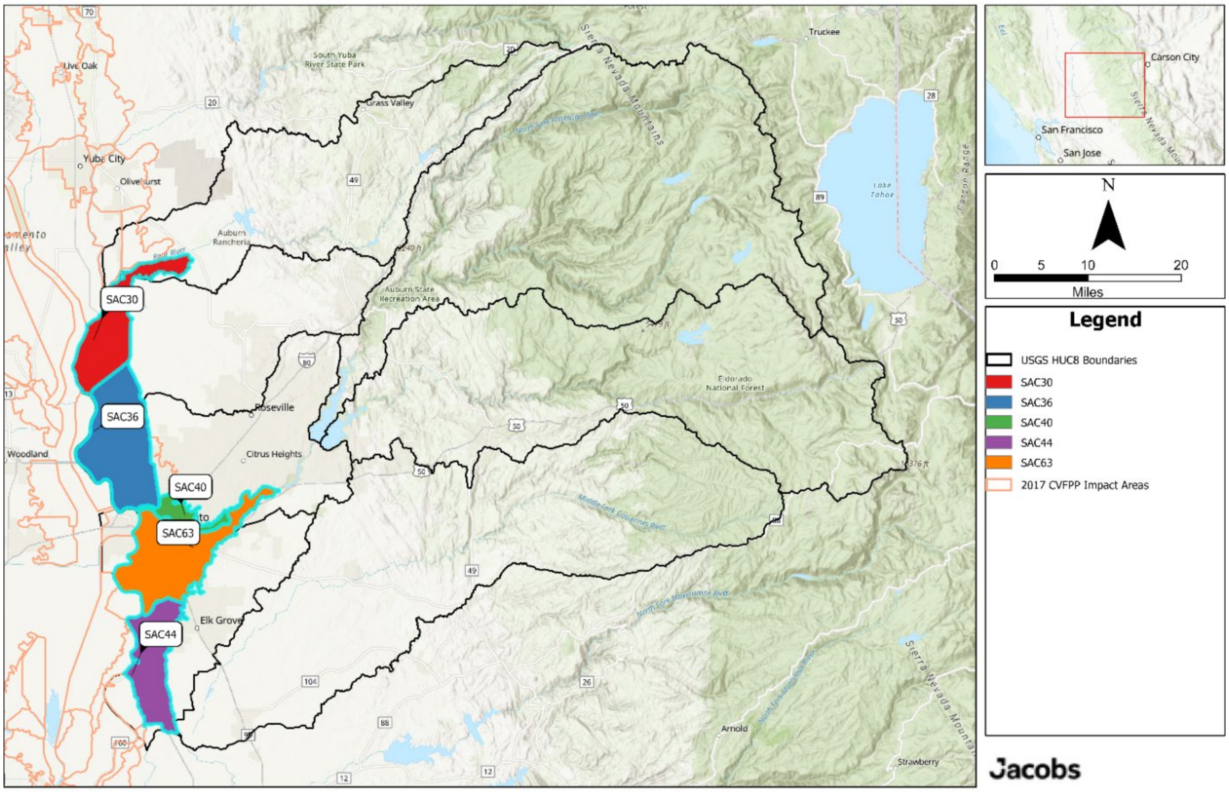


Figure 2-14. Index Areas in Pilot Study Area

2.4.3 Results

The analysis conducted to identify impacts of future climate on flood inundation extents was primarily a GIS exercise in which the inundation raster files provided by DWR were used to quantify the number of structures impacted by a given flood event. Quantification of structures inundated in each of the 5 focus impact areas was performed for a subset of the 6 to 8 available breach scenarios modeled in each impact area. The return interval range of simulations analyzed was 19 years to 304 years. Other breach events were disregarded either because they were of very low probability (a levee breach for example during a 5-year flow event) or low frequency (500+year events). DWR's use of 6 to 8 scaling factors did not allow for analysis of events of standard return intervals, such as the 50 and 100-year storm events. Future studies could modify the selection of events based on standard return intervals to allow for direct comparison of climate impacts at a given storm return interval.

Table 2-14 provides a summary of residences inundated by 13 storm events across 5 impact areas. The five impact areas used in the analysis include over 200,000 structures, which is 87% of the total structures in all 15 impact areas. For each impact area, either 2 or 3 events were used. Table 1.5-2a also includes the return interval in years of each event. There were no depth filters used to classify a structure as impacted; future refinements could include water depth. Population impacts for the same storm events are summarized in Table 2-15.

Table 2-14. Summary of Impacted Residences with Associated Return Intervals under Current Climate

	Event 1		Event 2		Event 3	
Impact Area	Residences	Return Interval (years)	Residences	Return Interval (years)	Residences	Return Interval (years)
SAC-36	29,573	28	29,793	139	30,187	304
SAC-63	67,519	24	77,615	124	93,500	258
SAC-30	461	19	481	92		
SAC-40	9,515	24	9,547	124	9,781	258
SAC-44	2,529	15	4,470	63		

Table 2-15. Summary of Impacted Population with Associated Return Intervals under Current Climate

	Event 1		Event 2		Event 3	
Impact Area	People	Return Interval (years)	People	Return Interval (years)	People	Return Interval (years)
SAC-36	116,706	28	117,190	139	117,645	304
SAC-63	273,124	24	309,488	124	358,305	258
SAC-30	1,037	19	1,286	92		
SAC-40	46,755	24	46,915	124	48,137	258
SAC-44	15,002	15	21,352	63		

Details of the analysis for each impact area are best provided by walking through an example, using area SAC63, which includes downtown Sacramento (Figure 2-21) and over 134,000 structures, which is 58 percent of all structures in the 15 impact areas. Impact Area SAC63 covers 85.3 square miles. Table 2-16 summarizes 7 available estimates of inundation in the SAC63 impact area, with scaling percentages of the 1986 event between 40 and 240 percent. Figure 2-22 shows the water surface elevation relative to the channel cross section and levee crest elevation for the seven breach events modeled at this location.

Table 2-17 shows the shift in event frequency with future climate, as a given flow would be expected to occur more frequently in the future with a warming climate yielding larger precipitation events and more snowmelt. At the SAC63 index point, a flow of 159,723 cfs has a return interval of 124 years under current climate conditions, but is expected to occur more frequently in 2072, with return intervals of between 65 and 103 years depending on the climate scenario. A breach event at this flow, which would inundate 83,763 structures, could occur with approximately twice the probability under future climate as under present climate conditions.

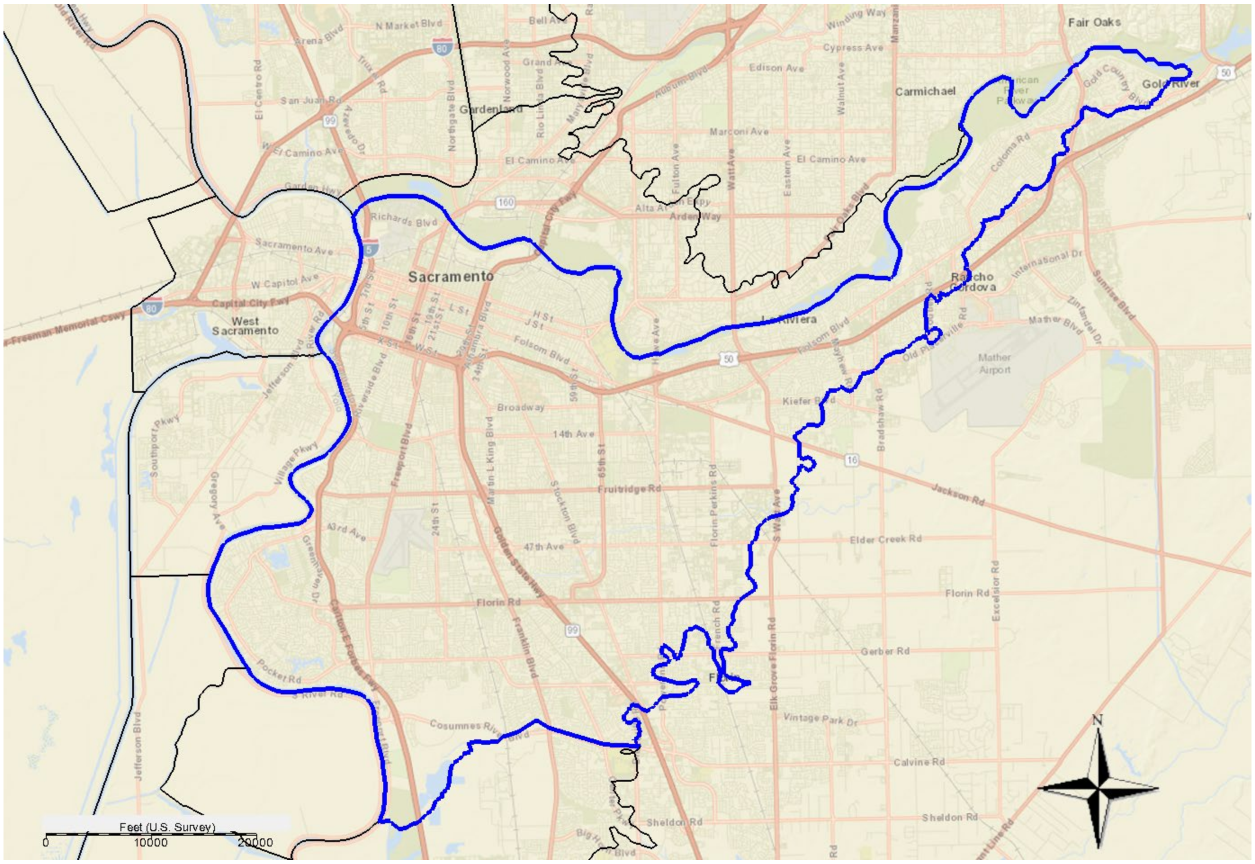


Figure 2-15. SAC63 Impact Area, Sacramento City and County, CA

Table 2-16. Details of SAC63 Impact Area Scale Simulations

Scale	Return Interval for Current Climate (years)	Inundation (square miles)	Percent Inundation (of 85.3 square mile area)
1986_40%	5	3.4	4.0
1986_60%	12	13.3	15.6
1986_80%	15	22.4	26.2
1986_105%	24	41.4	48.5

Scale	Return Interval for Current Climate (years)	Inundation (square miles)	Percent Inundation (of 85.3 square mile area)
1986_125%	124	48.9	57.3
1986_145%	258	58.4	68.5
1986_240%	310	66.2	77.7

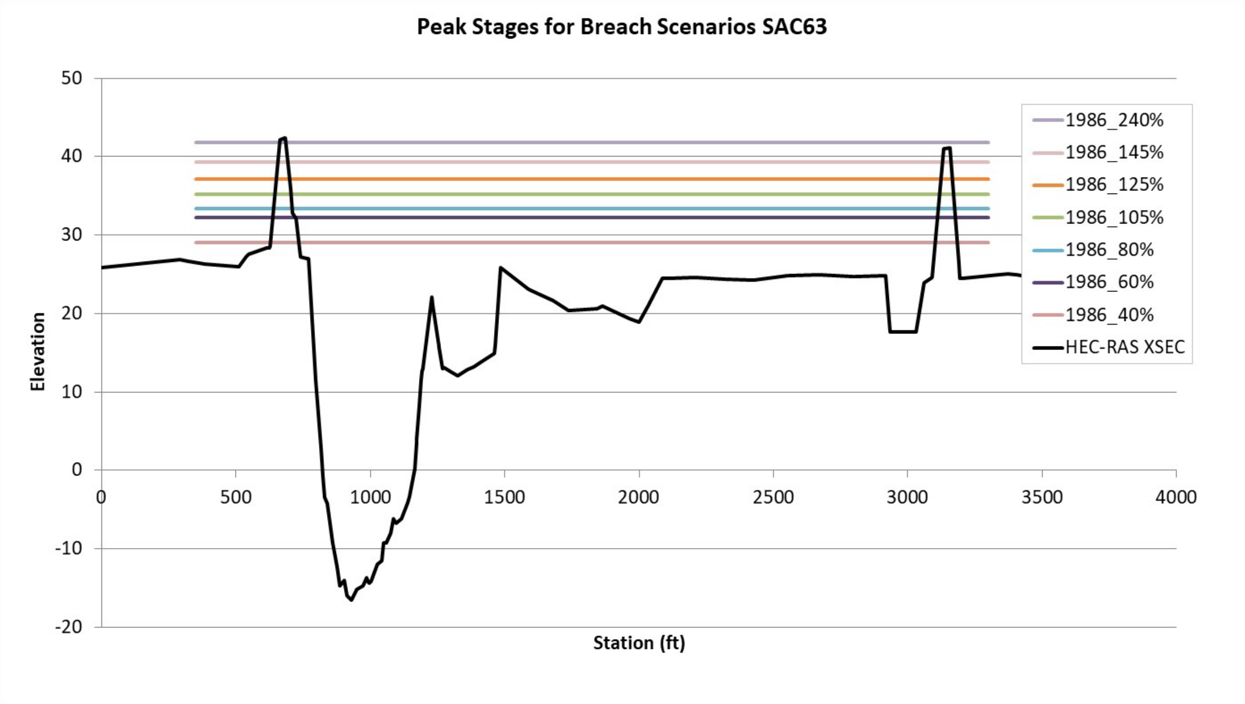


Figure 2-16. Stages during Modeled Breach Events for SAC63 Impact Area

Table 2-17. Return Interval in Years for Four Climate Scenarios

Scale Event	Flow (cfs)	2022	2072 Low Climate	2072 Mid Climate	2072 High Climate
1986_60%	114,323	12	8	7	4
1986_80%	114,986	15	11	9	5
1986_105%	129,904	24	18	15	8
1986_125%	159,723	124	103	89	65
1986_145%	193,270	258	249	229	229

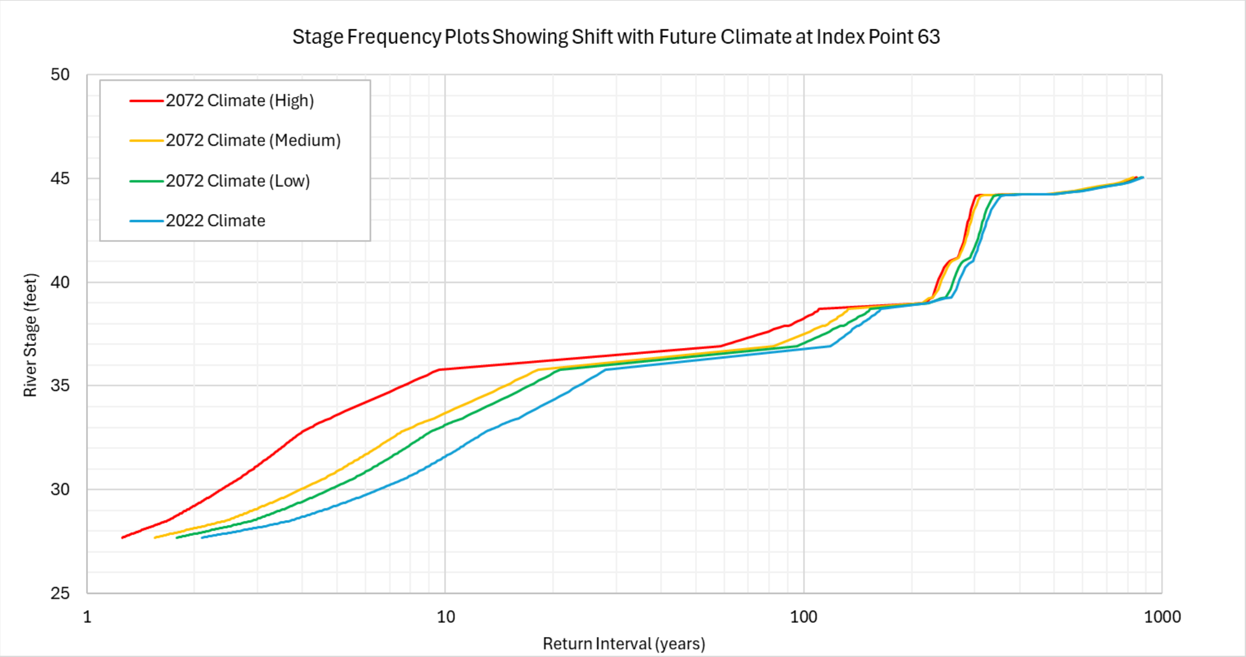


Figure 2-17. Stages Frequency Plots Showing Shift with Future Climate at Index Area 63

Figure 2-23 shows four plots of the frequency distribution of river stage at index point Sac 63 for current climate (2022) and three versions of 2072 climate (low, medium, and high emissions scenarios). The curves shift upward with future climate, more so for those with higher emissions assumptions. The figure can be used to extract stages at a given return interval, such as a 10-year or 100-year storm event. Table 2-18 presents the river stage for five return interval storm events from the 10-year to the 500-year event, summarizing key datapoints from Figure 2-23.

The shape of the curves are influenced by reservoir operations. The flatter portion of the curves between about the 10- and 100-year return interval indicate an ability of reservoir operations to limit the impact of floods on downstream water levels by holding water back in system reservoirs. Above the 100-year event, reservoirs are less able to reduce downstream stages because of limited storage capacity. At the highest stages on the curve, there is a second flatter portion of the curves that indicate overtopping of system levees. and an increase in overbank flooding, but minimal increases in river stage.

For the 10-year event (0.10 AEP), river stages are projected to rise between 2.1 and 4.2 feet by 2072 depending on the climate scenario. Increased river stages will put additional pressure on existing levees and increase the likelihood of failure. The predicted increase in stage is smaller for larger flow events, with stage increases of 0.6 to 0.8 feet for the 25-year event, and 0.4 to 1.6 feet to the 100-year event, based on available model results. Note that these predicted stages include assumed certain levee breaches as discussed above. Increased stages are minimal for the 200 and 500-year events generally because of the extensive overtopping of system levees at these flow events. Once the river stage exceeds the local levee crest, additional flows yield more external flooding and show little difference in stage inside the river channel itself.

Table 2-18. Stages at Sac63 at Key Events for Four Climate Scenarios

Return Interval Event (years)	2022	2072 Low Climate	2072 Mid Climate	2072 High Climate
10	31.6	33.1	33.7	35.8
25	35.3	35.8	35.9	36.1
50	36.1	36.2	36.3	36.7
100	36.7	37.1	37.5	38.3
200	38.9	38.9	38.9	38.9
500	38.9	44.3	44.3	44.3

2.4.4 Limitations

There are several limitations to quantifying increased flood risk under future climate scenarios in the American River watershed. The existing levee system provides substantial flood protection in the region, with portions of the system rated as 200-year protection with plans to provide Urban Level of Protection ULOP to the City and County of Sacramento by 2030. Analysis of potential flooding has historically involved modeling potential levee breaches and calculating areas of inundation behind the assumed breach. This is the approach used by DWR in the analysis conducted to support the 2017 and 2022 Central Valley Flood Protection Plan Updates. Results of this analysis are the best available estimates of urban flooding and formed the basis for the flood management analysis presented herein.

The limited number of breach simulations yielding estimates for inundation in the 15 impact areas limits the ability to provide a direct comparison of climate risk at a given return interval event. There is not enough resolution in the selected events to show, for example, the change in inundation at the 100-year flood under current and future climate conditions. Future work would require significantly more modeled events to allow for direct comparison of flood impacts at a given return interval event. For example, flows corresponding to the current 100-year return interval event as well as the 100-year events under future climate scenarios would have to be simulated with the hydraulic model to be able to quantify the increase in flood impacts at the 100-year event under future climate scenarios. The currently available set of model simulations does not include enough granularity to make this comparison.

DWR provided information on levee fragility and performance used in the FDA analysis to support the 2017 CVFPP Update. Probabilities were assigned to the breach events used in the study, based on local river stages. Table 2-19 provides details of the probability of failure for a range of water surface elevations that cover the range of scale events used in the inundation and impact analysis. It is important to note that probability of the breach events associated with the inundation maps used to quantify flood impacts have probabilities ranging from 0.7 percent for the 24-year flood to 8.3 percent for the 258-year flood. So, the 105% scale event analyzed above, that leads to inundation of 67,519 residences and impacts 273,124 people (Table 2-17 and Table 2-18), has a probability of about 1 percent because it assumes a hypothetical levee failure.

Table 2-19. Sac63 Probability of Failure

Scale Event	Return Interval (years)	Peak Water Level (feet)	Levee Performance	
1986_40%	5	29.03	WSE (feet)	Probability of Failure
1986_60%	12	32.27	29.7	0.0%
1986_80%	15	33.39	31.9	0.3%

Scale Event	Return Interval (years)	Peak Water Level (feet)	Levee Performance	
1986_105%	24	35.15	35.0	0.7%
1986_125%	124	37.18	38.0	1.3%
1986_145%	258	39.31	41.0	8.3%
1986_240%	310	41.86	44.8	35.0%

2.5 Water Quality Vulnerability Assessment

2.5.1 Purpose

The purpose of the Water Quality Vulnerability Assessment is to evaluate the effects of climate change on water quality throughout the ABC Watersheds Resilience Pilot Study that covers the American River, Cosumnes River, and Bear River watersheds.

Three key water quality parameters were evaluated under Existing Baseline, Mid-Century (CT), Late-Century (HD), and Late-Century (WW) scenarios:

1. River temperature: quantitative analysis
2. Dissolved Oxygen: qualitative analysis
3. Cyanobacterial Blooms: qualitative analysis

2.5.2 Methodology

The HEC-5Q model, a FORTRAN-based system, simulates reservoir and river water temperatures using storage, flow, and meteorological input data. It consists of two main components: HEC-5 and HEC-5Q. HEC-5, developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (1998), simulates flows on a daily basis, calculating storage and flows at designated system nodes. HEC-5Q, developed by Resource Management Associates (1998), calculates temperatures throughout the model domain. It processes 6-hour meteorological inputs, including equilibrium temperatures, heat exchange rates, shortwave radiation, and wind speed, applying these to HEC-5-simulated storage and flows to generate water temperature simulations at specified locations.

For this project, the American River HEC-5Q model was used to quantify river temperature increases under a range of future climate scenarios. It utilizes inputs derived from CalSim 3 outputs, downscaled to daily time series, and incorporates 6-hour meteorological data from both calculated and observed sources. The model has played a crucial role in several environmental and water management initiatives, including the Bureau of Reclamation's Final Environmental Impact Statement for the Biological Assessment for the 2019 Reinitiation of Consultation on the Coordinated Long-Term Operation of the CVP and SWP (Bureau of Reclamation 2019), as well as the 2024 Record of Decision, also referred to as the 2024 ROD (Bureau of Reclamation, 2024).

The current version of the model has been updated to integrate CalSim 3 outputs, as detailed in the 2024 ROD, Appendix F, Attachment F.1-3. Additionally, meteorological inputs were updated to account for future climate scenarios proposed for this project. The American River HEC-5Q model simulates reservoir and river temperatures from Folsom Dam to the confluence with the Sacramento River, including temperature simulations for Folsom Lake and Lake Natoma. Figure 2-24 illustrates the model coverage area.

Figure 2-18. American River HEC-5Q Model Coverage

American River HEC-5Q Assumptions

The HEC-5Q model utilizes meteorological inputs, including equilibrium temperatures, surface heat exchange rates, shortwave radiation, and wind speed at the Gerber, Nicolaus, and Modesto California Irrigation Management Information System stations. Exchange rates and equilibrium temperatures are derived from hourly observed data at each of these stations. To account for future climate impacts, the model assumes that equilibrium temperature inputs will be modified based on the projected change in daily average air temperature under various future climate scenarios. Research consistently shows that rising air temperatures lead to increased water temperatures, regardless of the climate scenario (Webb and Walsh 2004, Cushing 1997, Isaak et al. 2012). Given the projected increase in air temperatures under future climate scenarios, a corresponding increase in water temperature is anticipated.

HEC-5Q specifies inflow temperatures for each inflow boundary condition using seasonal curve fit values with superimposed diurnal variations. These variations are calculated based on heat exchange parameters. The model adjusts equilibrium temperatures to reflect inflow location environments and applies scaling factors to emphasize seasonal values. This approach ensures that climate change effects incorporated in the equilibrium temperature translate to changes in inflow temperatures (Bureau of Reclamation 2015). For the American River model, similar to what was done for previous studies (Bureau of Reclamation 2019, 2024), only equilibrium temperatures at Nicolaus station were adjusted for three future climate scenarios to reflect projected temperature changes, which in turn influence inflow temperatures. More details on the equilibrium temperature adjustment methodology are described in the 2024 ROD, (Bureau of Reclamation 2024), Appendix F, Attachment F.1-3 Model Updates.

Folsom Lake and Lake Natoma are operated by CalSim 3 output. Temperature logics, which are independent of operations logic, can be applied to any CalSim scenario. The temperature target logic determines the allocation of the limited cold-water pool (CWP) throughout the temperature management season. When the reservoir is colder, operations are adjusted to utilize CWP more aggressively.

To comply with the 2009 NMFS Biological Opinion temperature requirement, Reclamation manages Folsom Dam release temperatures according to schedules outlined in Appendix 2-D of the NMFS BO.

These schedules establish monthly temperature targets at Watt Avenue for Folsom Dam operations from May to October (temperature management season), based on forecasted Folsom storage and inflow. The initial temperature schedule for each year is determined through an operations plan developed by Reclamation and approved by the American River Operations Group. The assumptions used in the American River HEC-5Q model are summarized in Table 2-20.

Table 2-20. American River HEC-5Q Model Assumptions

	Existing Baseline	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
Period of simulation	100 years (1922-2021)	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Climate	Existing Conditions, 0 SLR	2055 CT, 30 SLR	2085 HD, 55SLR	2085 WW, 55 SLR
Boundary flows and storages	Monthly time series (from CALSIM 3 output)	Monthly time series (from CALSIM 3 output)	Monthly time series (from CALSIM 3 output)	Monthly time series (from CALSIM 3 output)
Folsom Lake	Monthly time series (from CALSIM 3 output). Limited to physical specifications of reservoir	Monthly time series (from CALSIM 3 output). Limited to physical specifications of reservoir	Monthly time series (from CALSIM 3 output) Limited to physical specifications of reservoir	Monthly time series (from CALSIM 3 output) Limited to physical specifications of reservoir
Lake Natoma	Monthly time series (from CALSIM 3 output). Limited to physical specifications of reservoir	Monthly time series (from CALSIM 3 output). Limited to physical specifications of reservoir	Monthly time series (from CALSIM 3 output) Limited to physical specifications of reservoir	Monthly time series (from CALSIM 3 output) Limited to physical specifications of reservoir
Folsom Temperature Management	Similar to 2009 NMFS BiOp Appendix B (See 2015 LTO for details)	Similar to 2009 NMFS BiOp Appendix B (See 2015 LTO for details)	Similar to 2009 NMFS BiOp Appendix B (See 2015 LTO for details)	Similar to 2009 NMFS BiOp Appendix B (See 2015 LTO for details)

2.5.3 Results

Water Temperature:

Figure 2-25 through Figure 2-28 present the results of HEC-5Q model simulations, illustrating monthly average river temperatures under various climate scenarios. These figures showcase a series of monthly pattern plots that compare temperature trends across following locations along the river: American River below Folsom Dam, American River below Nimbus Dam, American River at Watt Avenue, and above the American River confluence with the Sacramento River.

The HEC-5Q model results show a few key findings. The model predicts increasing river temperatures in future climate scenarios compared to the baseline, indicating potential long-term warming of the river. Among the simulated scenarios, the Late-Century HD scenario shows the most significant temperature increase, representing the most extreme warming condition. Additionally, the model predicts higher temperatures during summer months across all scenarios, likely due to reduced river flow and increased air temperature during this period. Model results indicate that as the river progresses downstream, temperatures generally increase. This warming effect is more pronounced in the HD scenario. The HD scenario consistently exhibits the largest temperature increases, both temporally (across months) and spatially (moving downstream, from below Folsom Dam to above the American River confluence), suggesting this scenario represents the most severe potential impact on river temperatures.

Table 2-21, which summarizes the monthly long-term average change in river temperatures at Watt Avenue (compliance location), corroborates these findings. For HD scenario, average monthly increases in temperature at Watt Ave range from a low of 3.5 degrees Fahrenheit (°F) in January to a high of 6.3°F in June. The CT scenario shows more moderate temperature changes, with average monthly increases ranging from 1.4°F in December to 3.7°F in June. The WW scenario demonstrates similar impacts to the CT scenario, with temperature increases ranging from 1.7°F in April to 3.7°F in June. These results also highlight a higher impact on river temperature under the HD scenario and comparable impacts in the WW and CT scenarios. A more detailed look at water temperature compliance is provided in Section 2.6.3.

The increase in temperature under future climate conditions is shown on Figure 2-25 through Figure 2-28 to increase with distance downstream of Folsom Dam, highlighting the relative influence of meteorological forcings compared to reservoir operations. Given the model results, it is unlikely that reservoir operations can be adjusted to remove the impacts of future climate on river temperatures downstream at Watt Ave. Warming from surface heat exchange would likely overcome any benefits from alterations in the management of the CWP, especially during months of relatively low flows.

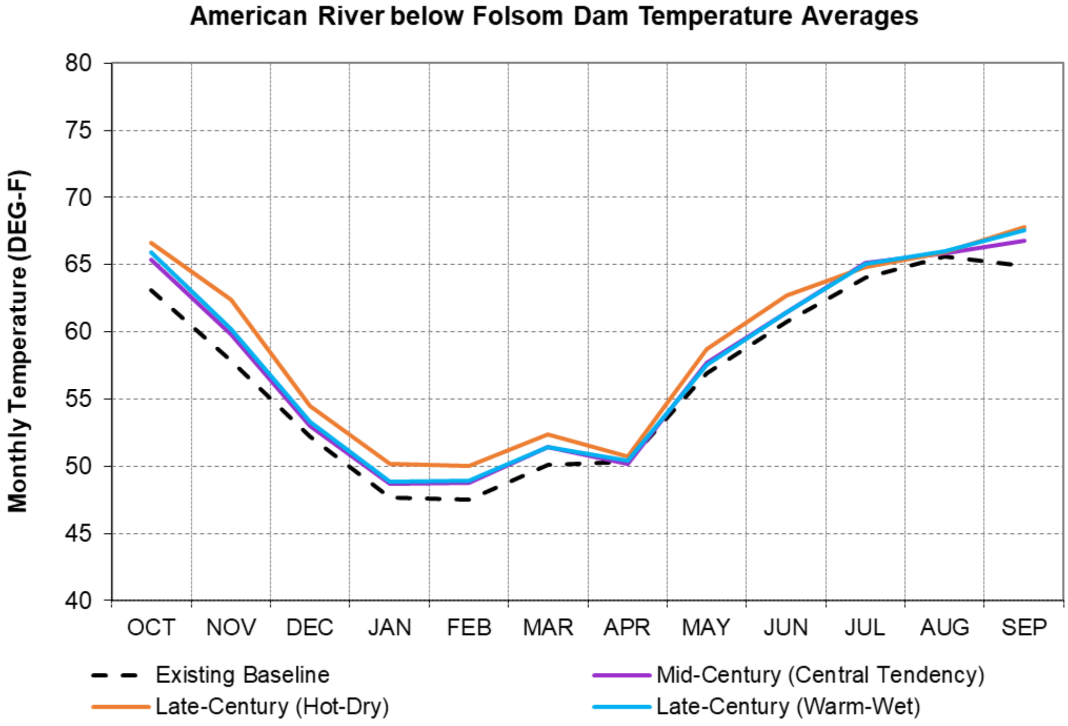


Figure 2-19. Long-Term Monthly Average Temperature in the American River below Folsom Dam

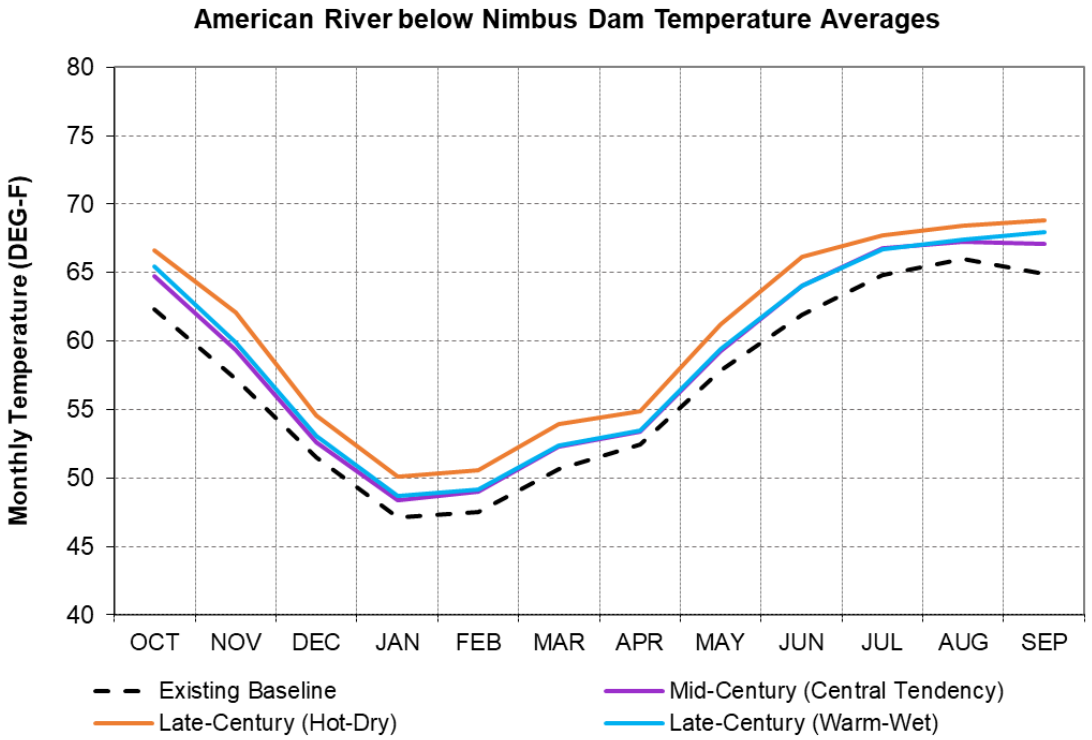


Figure 2-20. Long-Term Monthly Average Temperature in the American River below Nimbus Dam

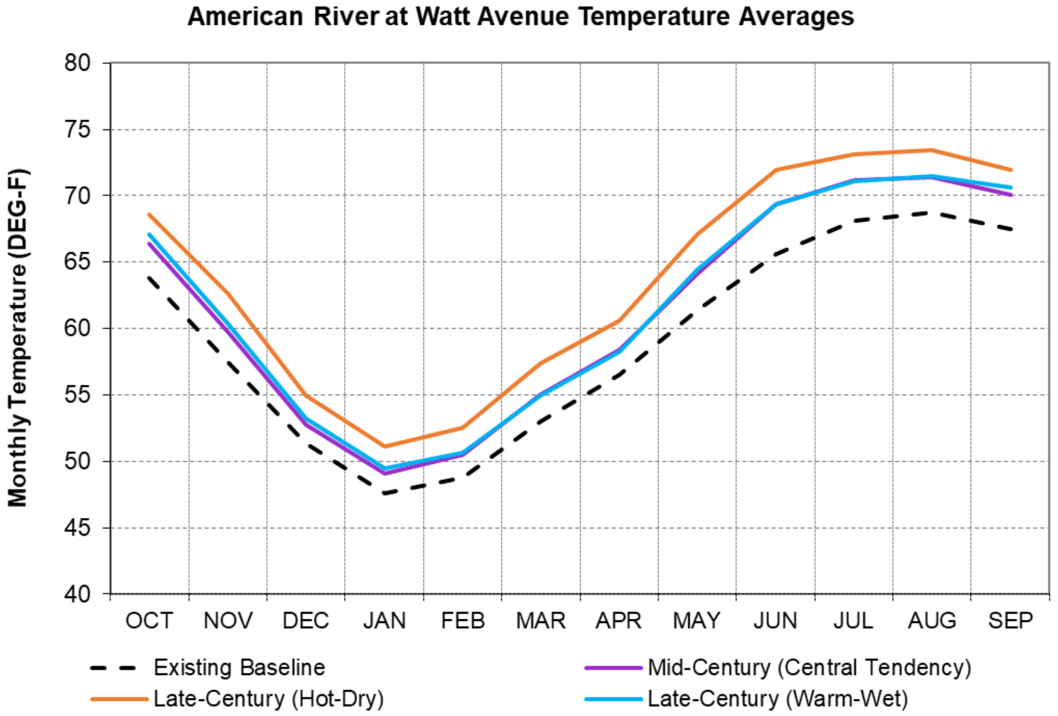


Figure 2-21. Long-Term Monthly Average Temperature in the American River at Watt Avenue

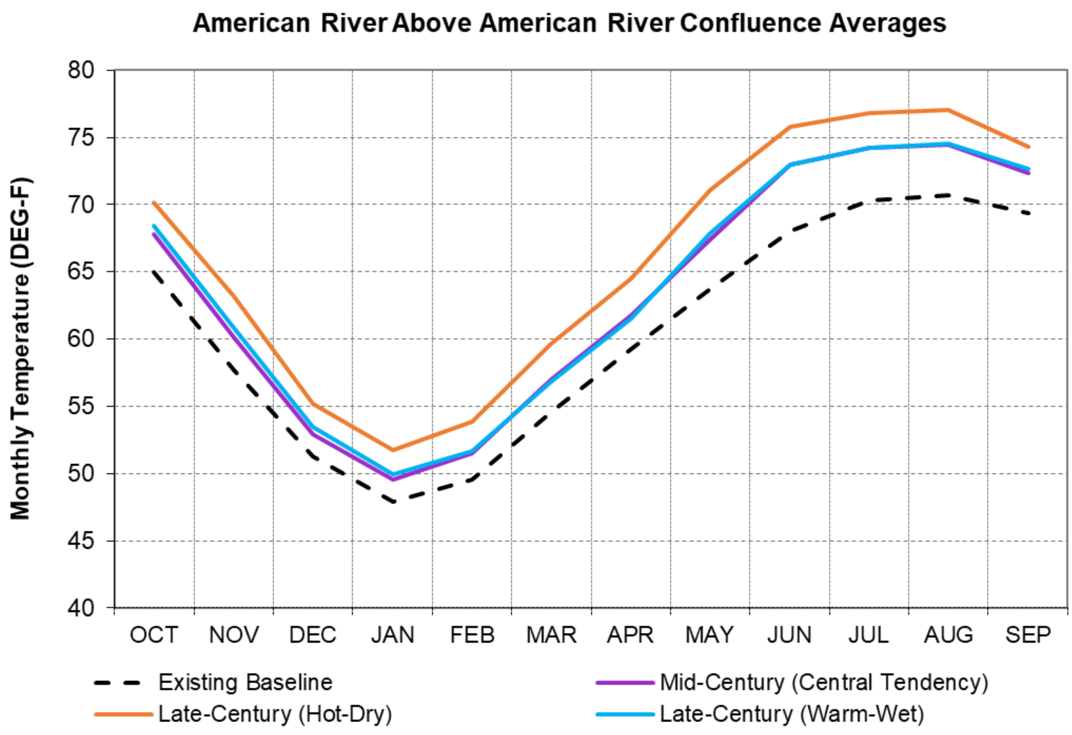


Figure 2-22. Long-Term Monthly Average Temperature in the American River above Confluence

Table 2-21. Long-Term Monthly Average River Temperature Change at Watt Avenue (deg F): Future Scenario – Existing Baseline

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mid-Century (CT)	2.6	2.3	1.4	1.5	1.8	2.1	1.9	2.7	3.7	3.1	2.7	2.6
Late-Century (WW)	3.4	2.9	1.9	1.8	1.9	2.0	1.7	3.0	3.7	3.0	2.8	3.2
Late-Century (HD)	4.8	5.2	3.6	3.5	3.8	4.4	4.1	5.7	6.3	5.1	4.7	4.5

The HEC-5Q model results for the Lower American River, as shown in Figure 2-25 through Figure 2-28 and summarized in Table 2-21, provide quantitative insights into potential future river temperature changes. While similar modeling was not conducted for the Cosumnes and Bear rivers, we can draw qualitative conclusions for these rivers based on the spatial distribution of air temperatures in the region (Figure 2-29) and the simulated flow patterns across the three river systems (Figure 2-30 through Figure 2-32).

The special map of the region (Figure 2-29) shows similar air temperature change patterns across the upper portions of the American, Cosumnes, and Bear rivers. The lower portions of these rivers also exhibit comparable air temperature trends. In late future scenarios, air temperatures are projected to increase across all three river basins, with the HD scenario showing the most significant warming. Given the established correlation between air and river temperatures, we can infer that changes in river temperatures for the Cosumnes and Bear rivers may follow patterns similar to those modeled for the American River.

Examination of simulated flow distribution and variation (Figure 2-30 through Figure 2-32) indicates notable differences between the rivers. The American River shows higher flow rates compared to the Cosumnes and Bear rivers, with monthly patterns showing higher flow peaks across all seasons. In contrast, the Cosumnes and Bear rivers shows similar flow ranges and climate impacts, generally lower than those observed in the American River.

The temporal effects of climate scenarios on river flows indicate interesting distinctions. For the American River, future climate scenarios project higher flows in winter but notably lower flows in spring and summer. This seasonal shift in flow patterns is less pronounced or not observed to the same extent in the Cosumnes and Bear rivers. This is likely a function of the size an elevation in the upper portion of the respective watersheds, with more mountainous influence in the American River watershed and more potential for snowmelt influences on the seasonal hydrograph. This difference in flow dynamics can have important implications for river temperatures. In the American River, the projected lower spring and summer flows are likely to contribute to higher river temperatures during these seasons, particularly in future climate scenarios. The reduced water volume would be more susceptible to warming from increased air temperatures. However, for the Cosumnes and Bear rivers, the absence of significant flow reductions in spring and summer may result in less pronounced temperature increases compared to the American River.

These observations lead to some qualitative projections for the Cosumnes and Bear rivers. While these rivers may experience temperature increases in future scenarios due to rising air temperatures, the impact might be less severe than in the American River, especially during spring and summer. The more stable flow patterns in the Cosumnes and Bear rivers could potentially moderate the impact on water temperatures during these critical periods.

While quantitative data is not available, it's reasonable to expect that the Cosumnes and Bear rivers may experience temperature increases in future scenarios, particularly in the HD scenario. However, the American River's more pronounced seasonal flow variations, particularly the reduction in spring and summer flows under future climate scenarios, suggest it may be more susceptible to temperature changes than the Cosumnes and Bear rivers. The less dramatic seasonal flow changes in these latter two rivers could potentially buffer against extreme temperature increases, especially during the warmer months.

To confirm these inferences and provide more detailed insights into water resource management, quantitative modeling of the Cosumnes and Bear rivers would be beneficial. Such modeling could account for the unique flow and reservoir characteristics of each river system and provide a more comprehensive understanding of potential future climate impacts across the region. This would enable more accurate predictions of river temperature changes and inform targeted strategies for managing these vital water resources in the face of changing climate conditions.

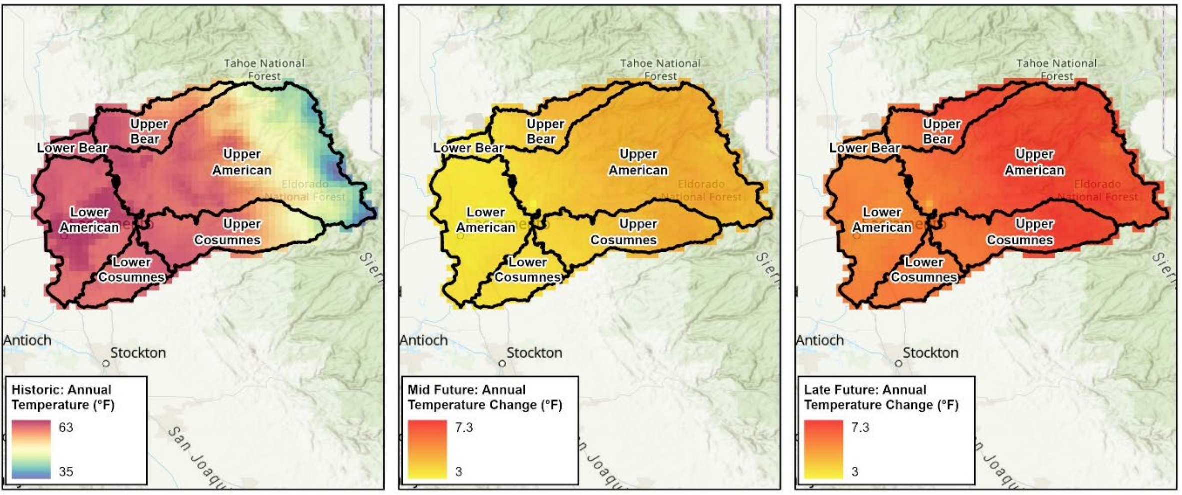


Figure 2-23. Spatial Distribution of Air Temperature Changes (deg F)

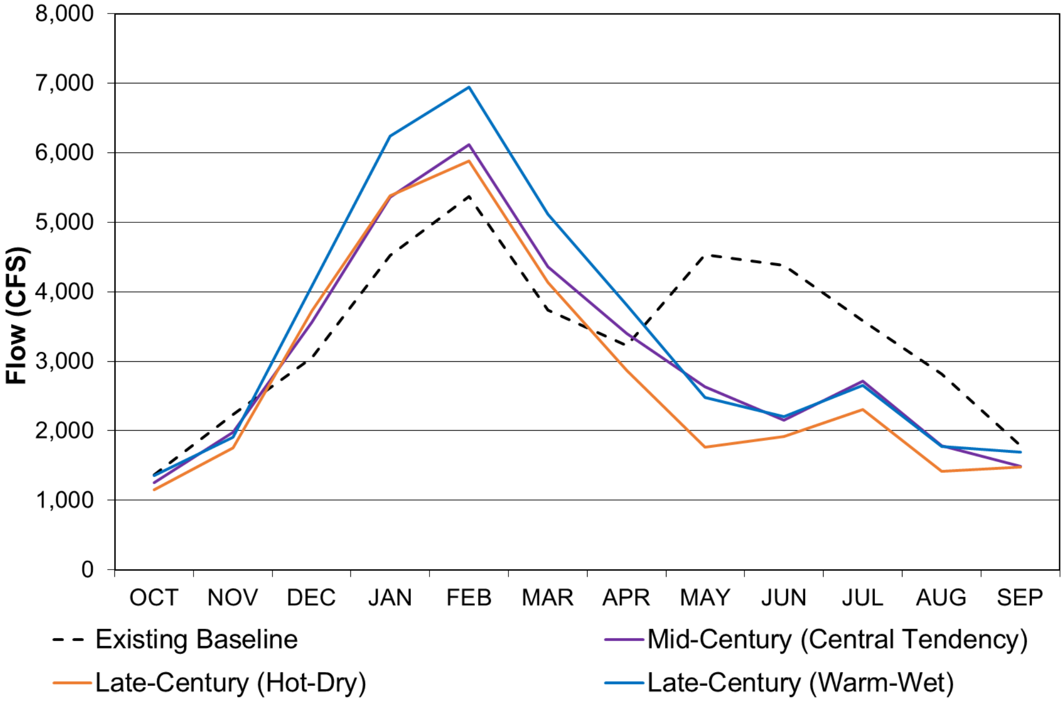


Figure 2-24. American River Long-Term Monthly Average Flow above Confluence with Sacramento River

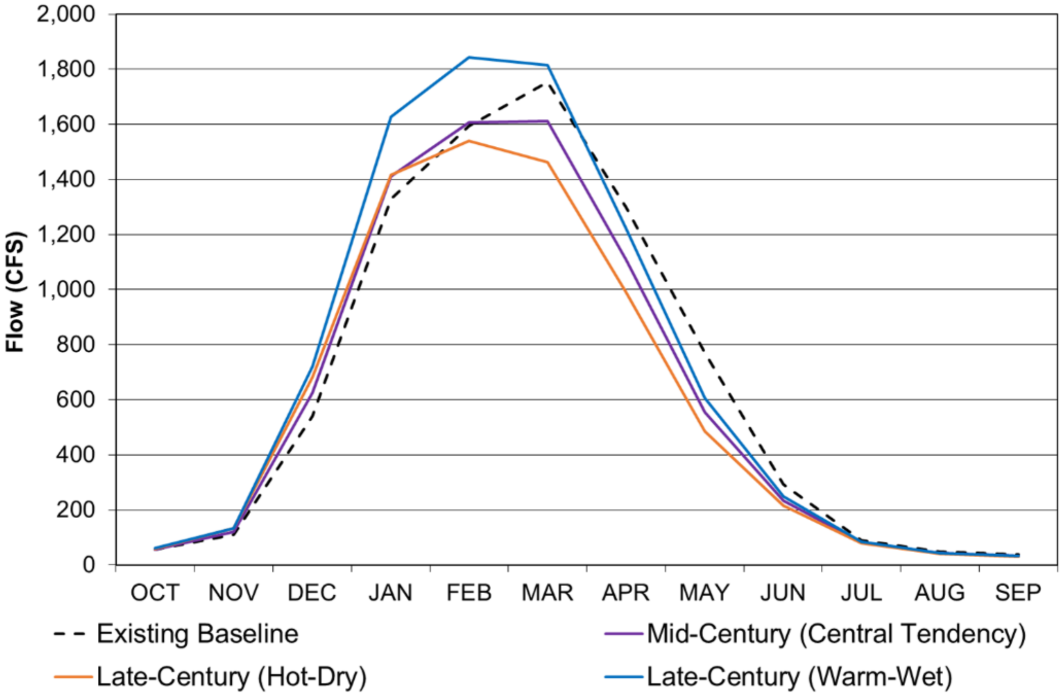


Figure 2-25. Cosumnes River Long-Term Monthly Average Flow at Confluence with Mokelumne River

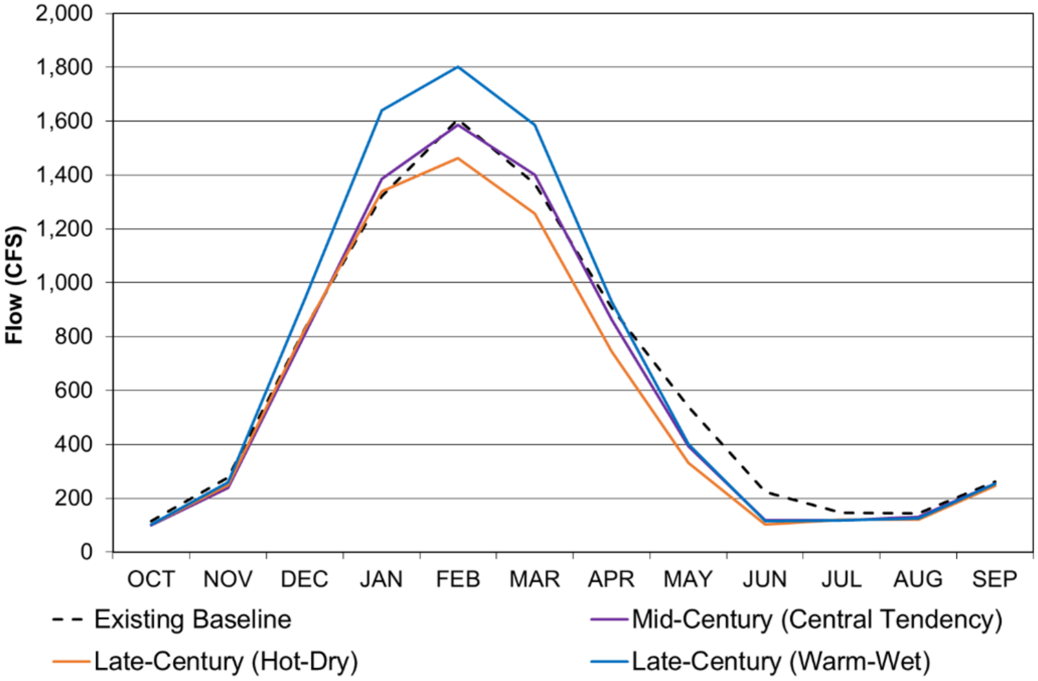


Figure 2-26. Bear River Long-Term Monthly Average Flow at the Confluence with the Feather River

Dissolved Oxygen

The concentration of dissolved oxygen (DO) in water is affected by several environmental factors including water temperature, salinity, and atmospheric pressure. There is an inverse relationship between water temperature and DO. Colder water has a higher capacity to retain dissolved oxygen compared to warmer water. As river temperature increases, the dissolved oxygen concentration typically decreases (NOAA 2021). At 20°C (68°F), water can hold about 9.2 mg/L of oxygen at sea level, however it decreases to approximately 7.6 mg/L when water temperature increases to 30°C (86°F). Therefore, given that water temperatures are projected to increase under future climate scenarios in the Lower American River, and potentially in the Cosumnes and Bear rivers as well, it’s expected to see lower dissolved oxygen (DO) levels in these river systems. In the American River at Watt Avenue for instance, average monthly temperature is predicted to increase from 66°F to 72°F in June under HD scenario, which can lead to about 6% reduction in DO from 9.3 mg/L to 8.71 mg/L. This is because warmer water holds less dissolved oxygen. Therefore, as river temperatures rise, the amount of oxygen available in the water for aquatic life will likely decrease.

Cyanobacterial Blooms

Water temperature is one of the driving factors influencing cyanobacteria blooms production (SCCWRP 2015). Cyanobacteria often bloom at temperatures above 25°C (77°F), with optimal growth between 25°C and 35°C (77°F and 95°F). Simulated water temperatures in the American River suggest that average monthly temperatures do not exceed 25°C (77°F), even under the HD future climate scenario. Consequently, the predicted increases in river temperature are unlikely to substantially elevate the risk of cyanobacterial blooms in the American River system under the projected future climate scenarios. However, it's important to note that while temperature is a significant factor, other variables such as nutrient levels, flow rates, and localized conditions can also influence bloom formation and should be considered in comprehensive risk assessments.

The changes in flow patterns, particularly in the American River where lower flows are expected during spring and summer, may exacerbate the risk of cyanobacterial blooms. Reduced water flow can lead to increased water residence time and decreased turbulence, both of which can promote cyanobacterial growth. The combination of warmer temperatures and altered flow regimes could potentially create ideal conditions for bloom formation, especially during the warmer months. While the extent of these impacts may vary among the three rivers due to differences in their flow patterns and temperature changes, the overall trend would not suggest a significant increased likelihood of cyanobacterial blooms in future climate scenarios. Despite the limited temperature-driven risk, the potential for increased bloom occurrences could still present challenges for water quality management, aquatic ecosystem health, and recreational use of the American River. Consequently, monitoring and managing cyanobacterial blooms is likely to become an increasingly critical component of river management strategies in the face of changing climate conditions.

2.6 Ecosystem Vulnerability Assessment

2.6.1 Purpose

The American River watershed is home to a diverse range of habitats and species, each with their own set of vulnerabilities to climate change and subsequent responses from the watershed. Predicting ecosystem responses to these changes can be challenging because responses themselves may be both directly and indirectly affected by shifts in future conditions and can be highly location and community specific. Fundamentally, native habitats and species require functioning natural processes to provide resiliency to climate change. Shifts in the timing, magnitude, and duration of flows; changes in water and air temperatures; and increases in drought severity under future climate conditions can influence the natural processes and environmental cues that ecosystems rely on. The purpose of this assessment is to evaluate the selection of ecosystem-related indicators and metrics to further determine the vulnerability of ecosystems to change climate. This Vulnerability Assessment is not intended to comprehensively analyze all facets of conditions that may impact ecosystems; it is focused on metrics and indicators that can be sufficiently represented using the modeling tools available for this effort.

2.6.2 Methodology

The Ecosystem Vulnerability Assessment utilized a variety of data sources, noted in Table 2-22, to analyze selected metrics. Additional details and application of each data source are described in the following subsections.

Table 2-22. Ecosystem Vulnerability Assessment Data Sources

Data Source	Assessed Metrics
CalSim 3	▪ Frequency of Flows Exceeding Environmentally Beneficial Flow Thresholds ▪
CalSimHydro	▪ Change in Unimpaired Streamflow in Upper Watersheds
HEC-5Q	▪ Deviation from Suitable Temperature Targets at Watt Avenue Bridge
VIC	▪ Change in Annual and Seasonal Climatic Water Deficit
CMIP5	▪ Change in Annual Wildfire Burn Probability ▪ Change in Annual Wildfire Burn Area
2022 CVFPP Update	▪ Change in 2-year AEP Flows

CalSim 3

CalSim 3 data outputs were used to assess vulnerabilities related to natural and ecological flows and riparian and groundwater-dependent ecosystems. For natural and ecological flows, the frequency of flows exceeding environmentally beneficial flow thresholds during certain months (Sacramento Water Forum 2015, California Fish Passage Forum 2017, State Water Resources Control Board 2022) were determined using monthly reservoir release or flow outputs from locations in CalSim 3 noted in Table 2-23. Outputs from relevant months across the entire 100-year simulation period were used to identify flows corresponding to individual exceedance probabilities. From there, the exceedance probabilities of identified flow thresholds were determined under each CalSim 3 scenario to determine the frequency of changes to the occurrence of these thresholds under future conditions.

Table 2-23. CalSim 3 Outputs Used for Assessing Changes in Environmentally Beneficial Flows

Location	CalSim 3 Output	Months	Threshold(s)
Camp Far West Reservoir Releases	C_CMPFW	April-June	25 cfs
Camp Far West Reservoir Releases	C_CMPFW	July-March	10 cfs
Lake Natoma Releases	C_NTOMA	All Months	500 cfs; 800 cfs
Cosumnes River Flow below Granlees Dam	C_CSM033	October-December	150 cfs

CalSimHydro

CalSimHydro outputs provided monthly time-series data that were utilized for determining vulnerabilities related to natural and ecological flows in upper watersheds. More specifically, these outputs were used to qualitatively assess shifts in unimpaired streamflow. While significant portions of the American River watershed are regulated systems (i.e., flows are managed by upstream reservoirs), there are portions that have little to no influence from reservoir operations. Many of the upstream reservoirs in the watershed are also used primarily for hydropower generation rather than water supply. To assess these changes, total monthly rim inflows above the following approximate locations were used:

- Bear River: Rollins Lake
- North Fork American River: Lake Clementine
- Middle Fork American River: Confluence with North Fork American
- South Fork American River: Chili Bar
- Cosumnes River: Michigan Bar

Long-term average trends were then compared across the four CalSim scenarios used to evaluate shifts in conditions under climate change. Implications of these changes are discussed in Section 2.6.3. While VIC-generated outputs could be used for similar findings at a greater temporal resolution, its unimpaired streamflow data has inherent biases that are not present in the CalSimHydro-generated outputs.

HEC-5Q

While HEC-5Q results are discussed in further detail in Section 2.5, the Ecosystem Vulnerability Assessment considers deviations from the Modified Flow Management Standard Proposed Water Right Terms and Conditions (American River Water Agencies 2017) for the American River at Watt Avenue Bridge as a means for determining vulnerabilities for aquatic ecosystems and ecological water quality impairments. HEC-5Q runs were not conducted for the Bear River or Cosumnes River. Daily HEC-5Q outputs across the entire simulation period for each scenario were used to generate exceedance probabilities between three selected time periods. The probability of exceeding a threshold temperature identified in the Modified Flow Management Standard Proposed Water Right Terms and Conditions was then determined. These are noted below:

- May 15-September 30: 65 degrees Fahrenheit
- October 1-15: 60 degrees Fahrenheit
- October 16-31: 56 degrees Fahrenheit

VIC

The Ecosystem Vulnerability Assessment leverages gridded VIC model outputs for determining vulnerabilities related to forest health and ecosystem services. Annual and seasonal climatic water deficit (i.e., measure of demand in vegetation that cannot be met from available soil moisture) were used to evaluate changes that may signal shifts in stress of the landscape across the entire study domain. Increases in climatic water deficit may imply a reduction in forest health and ecosystem services and greater prevalence of drought conditions.

CMIP5

Cal-Adapt (2025) provides gridded CMIP5-based outputs related to wildfire-related metrics. These outputs have been post-processed by UC Merced and the Geospatial Innovation Facility at UC Berkely to estimate changes in wildfire burned area and decadal wildfire probability under future climate conditions

(Westerling 2018, Dale et al. 2018). Similar to the VIC model outputs noted above, these gridded outputs have been utilized to determine vulnerabilities related to landscape conditions. Higher projected wildfire burned areas and increased decadal wildfire probabilities can indicate more severe and frequent wildfires, resulting in worsened landscape conditions.

2022 CVFPP Update

Flow and stage frequency outputs for selected index points from the 2022 CVFPP Update technical analysis (DWR 2022a) were used as a proxy for assessing vulnerabilities to fish habitat by evaluating changes in 2-year flood flows and stages. The 2022 CVFPP Update includes three future climate scenarios (low, median, and high) centered in 2072 for comparison with 2022 conditions. Additional details on these climate scenarios are noted in the 2022 CVFPP Update Technical Analysis Summary Report (insert citation). Flow and stage frequency outputs at index points representative of the following locations were used to identify 2-year flood flows and stages under existing and future conditions:

- SAC36_SAC38: Sacramento River Upstream of Confluence with American River
- SAC40_SAC63: American River Upstream of Confluence with Sacramento River
- SAC38b: SAC63a: Sacramento River Downstream of Confluence with American River

Additionally, the equivalent return interval for existing 2-year flows under future climate change conditions was also determined at these locations. It is important to note that these flow and stage frequency outputs do not provide an indication of the change in duration for these flow events. The duration of such events is an important consideration for fish habitat; this is described in further detail in Section 2.6.3.

2.6.3 Results

Results for the Ecosystem Vulnerability Assessment are organized in the following subsections according to individual ecosystem-related conditions that have been evaluated.

Natural and Ecological Flows

Figure 2-33 through Figure 2-36 display the frequency (i.e., percent occurrence of a given month over the entire simulation period) of monthly reservoir releases or flows above selected thresholds for Camp Far West Reservoir, Lake Natoma, and the Cosumnes River below Granlees Dam. For Camp Far West Reservoir, both the 25 cfs and 10 cfs thresholds for April through June and July through March, respectively, show little (less than 1%) to no change across the entire simulation period under future climate conditions. These thresholds are representative of minimum flows for Fall-run Chinook Salmon on the Bear River (State Water Resources Control Board 2022). It is important to note that because CalSim 3 has a monthly time-step, there may be additional variability in daily reservoir releases at selected locations. Nevertheless, these results indicate that minimum flows along the Bear River appear to be sufficiently resilient under future climate conditions.

Lake Natoma uses two flow thresholds, 500 cfs and 800 cfs, to characterize the percent of available spawning and rearing habitat for the American River. At 800 cfs and 500 cfs, flows provide 80% and 40% of the maximum available spawning habitat (Sacramento Water Forum 2015). Flows below these thresholds can substantially reduce opportunities for salmonid spawning and rearing. Under the Existing Baseline scenario, flows below 500 cfs have less than a 1% chance of occurrence over the full simulation period. However, Mid-Century and Late-Century (WW) conditions increase the frequency of such occurrences to 2%. For Late-Century (HD) conditions, flow occurrences below 500 cfs increase to 5%. For the 800 cfs threshold, the Mid-Century, Late-Century (WW), and Late-Century (HD) scenarios display an increase in frequency from the Existing Baseline scenario (roughly 10%) of 6%, 2%, and 11%, respectively.

For the Cosumnes River, the percent occurrence of flows exceeding the 150 cfs threshold, representative of the recommended minimum flows for fish passage, are largely consistent across all scenarios (California Fish Passage Forum 2017). The Late-Century (WW) scenario displays a 3% increase in frequency of flows exceeding 150 cfs over the other three scenarios. The majority of occurrences with flows exceeding this threshold occur in December.

Shifts in unimpaired inflows for the Bear, North Fork American, Middle Fork American, South Fork American, and Cosumnes rivers are shown in Figure 2-37 through Figure 2-41. While the Bear and American rivers are largely regulated systems, the Cosumnes River is fully unregulated. Evaluating shifts in unimpaired streamflow can provide an indication of changes in the timing and magnitude of flows and subsequently, how natural processes may be impacted by climate change. In general, shifts for the Bear River and Cosumnes River are similar. The Mid-Century and Late-Century (HD) scenarios show a decrease in annual surface water supply, and the Late-Century (WW) scenario shows an increase in total annual inflows and a slight shift in peak flows to earlier in the water year relative to the Existing Baseline. The North, Middle, and South Fork American rivers show a significantly more dramatic shift in peak flows to earlier in the year, with higher flows from October to March and a reduction in flows from April to August relative to the Existing Baseline. This suggests a greater historical contribution from snowmelt for these areas; warmer conditions under climate change are driving snowmelt earlier in the season and resulting in more precipitation falling as rain rather than snow. In unable to be sufficiently managed by downstream facilities (i.e., Folsom Lake), these changes may result in lower spring and summer flows for aquatic species. This is likely driving the increase in flows below thresholds identified in Figure 2-35.

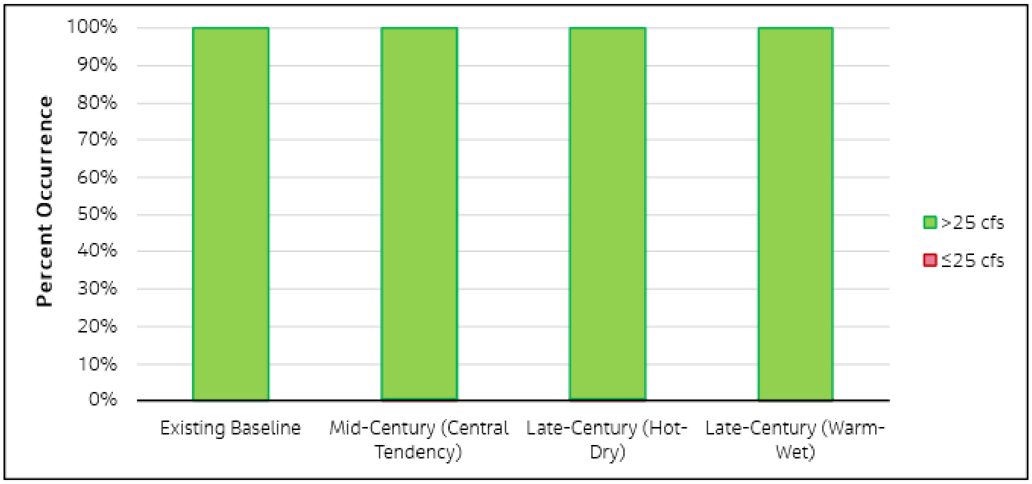


Figure 2-27. Camp Far West Reservoir Monthly Average Releases (April-June)

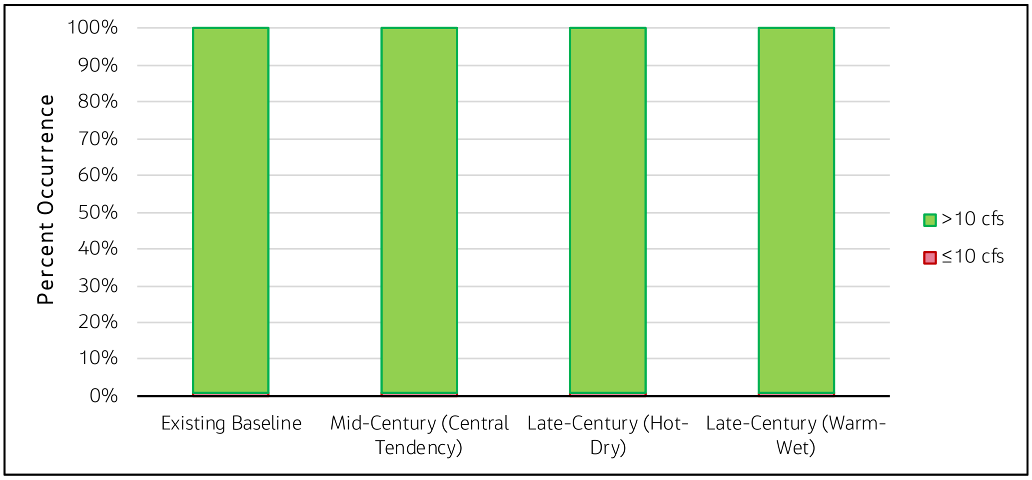


Figure 2-28. Camp Far West Reservoir Monthly Average Releases (July-March)

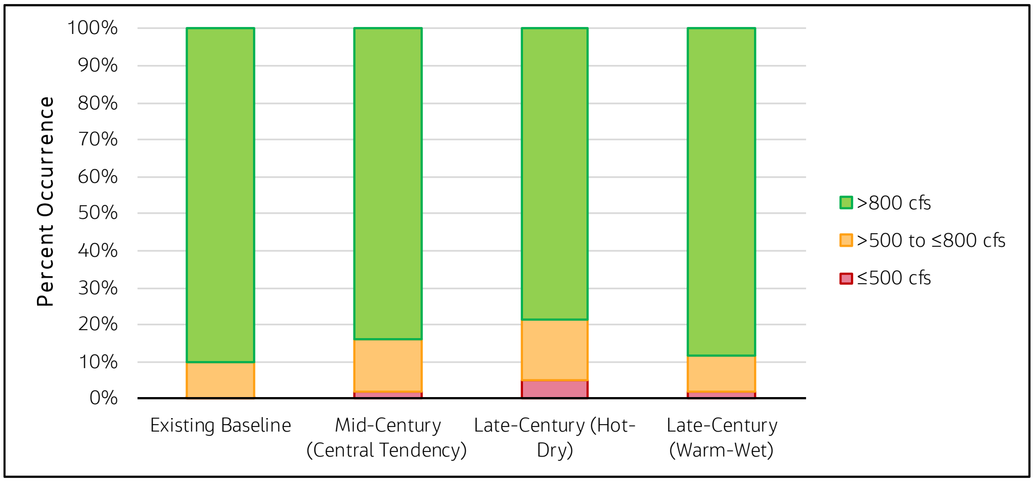


Figure 2-29. Lake Natoma Monthly Average Releases

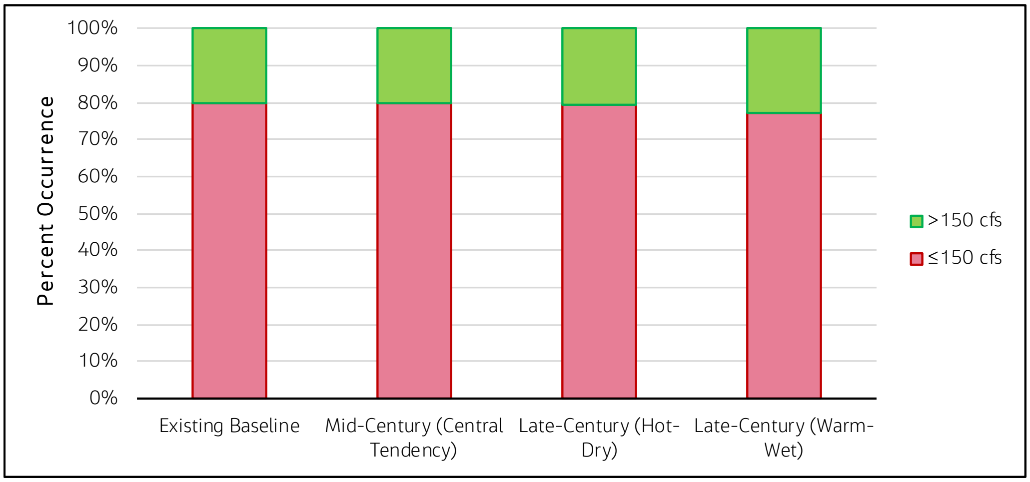


Figure 2-30. Cosumnes River Monthly Average Flow below Granlees Dam (October-December)

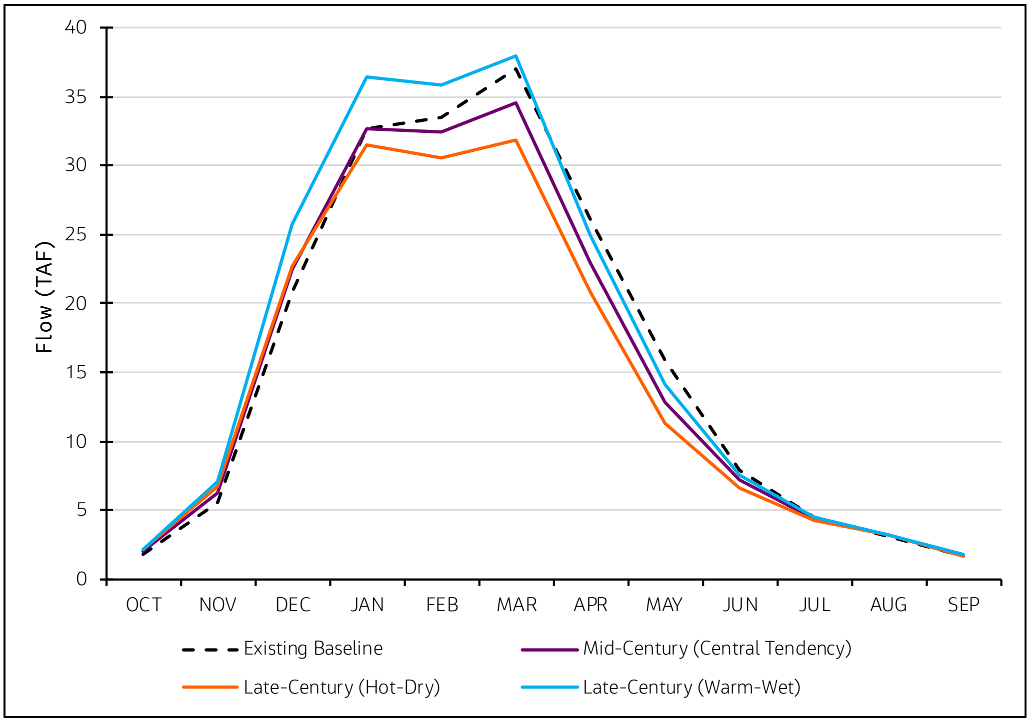


Figure 2-31. Bear River Inflow to Rollins Lake

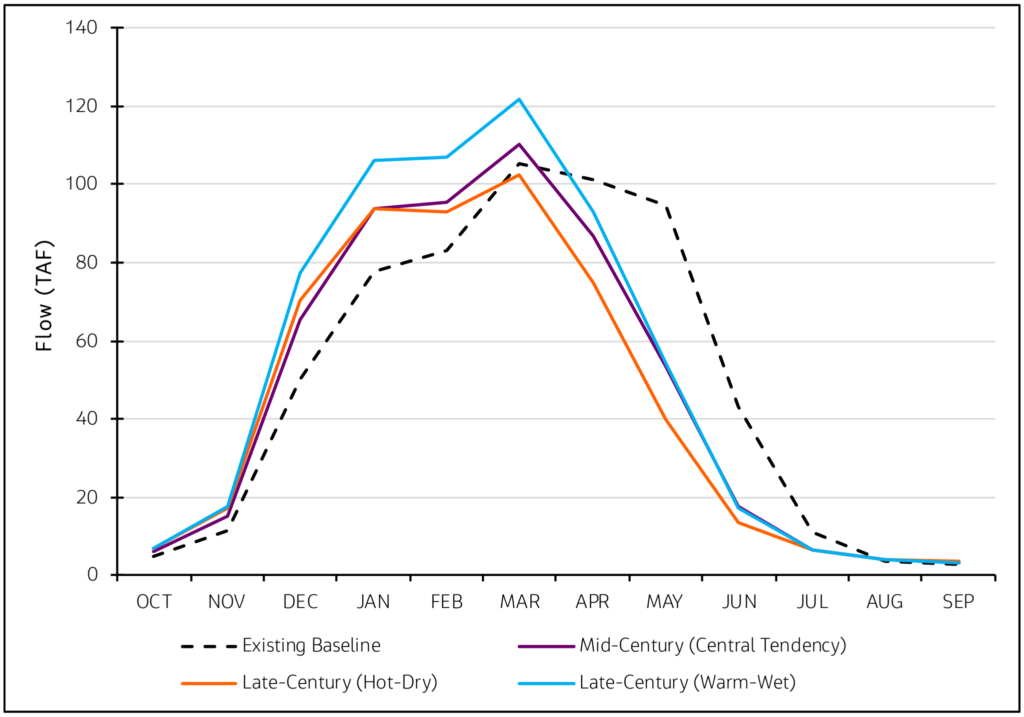


Figure 2-32. North Fork American Inflow to Lake Clementine

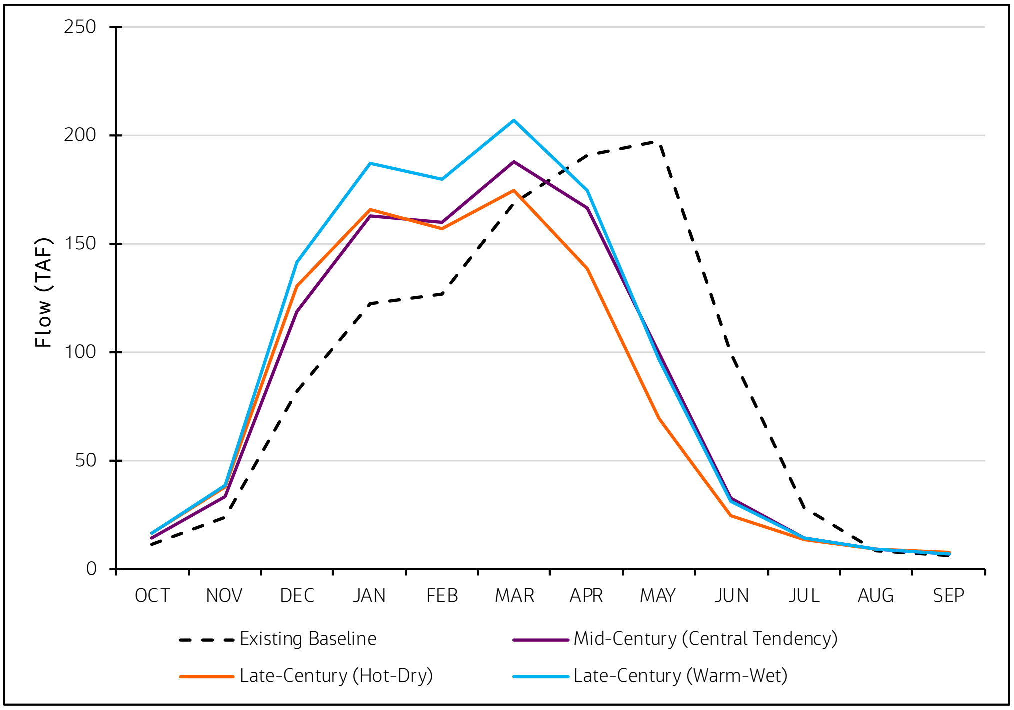


Figure 2-33. Middle Fork American Inflow to Confluence with North Fork American

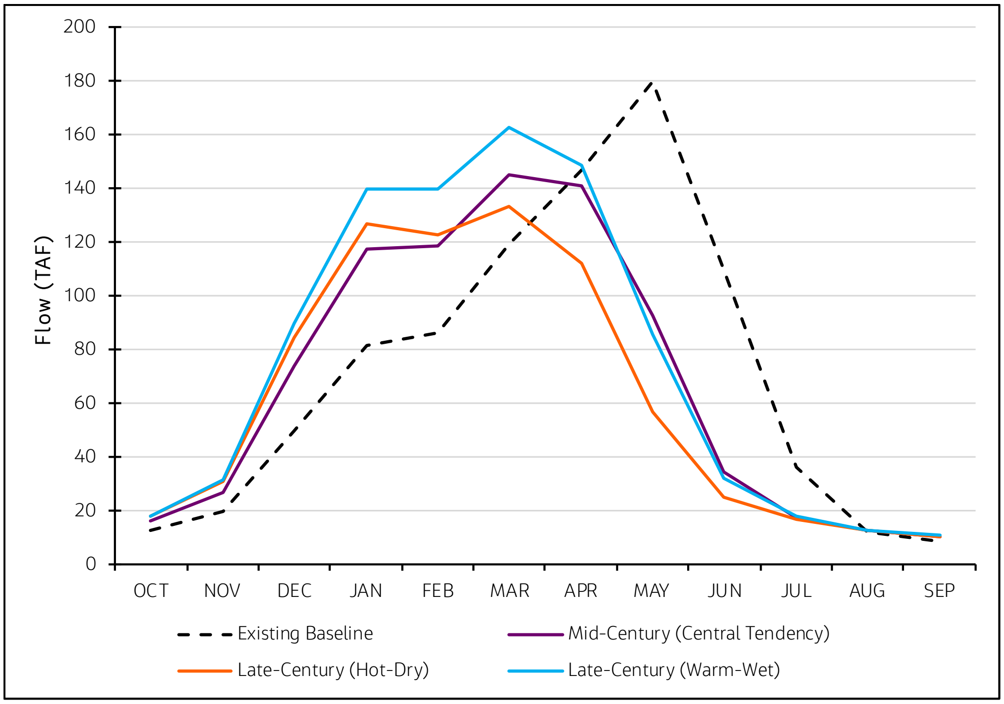


Figure 2-34. South Fork American Inflow to Chili Bar

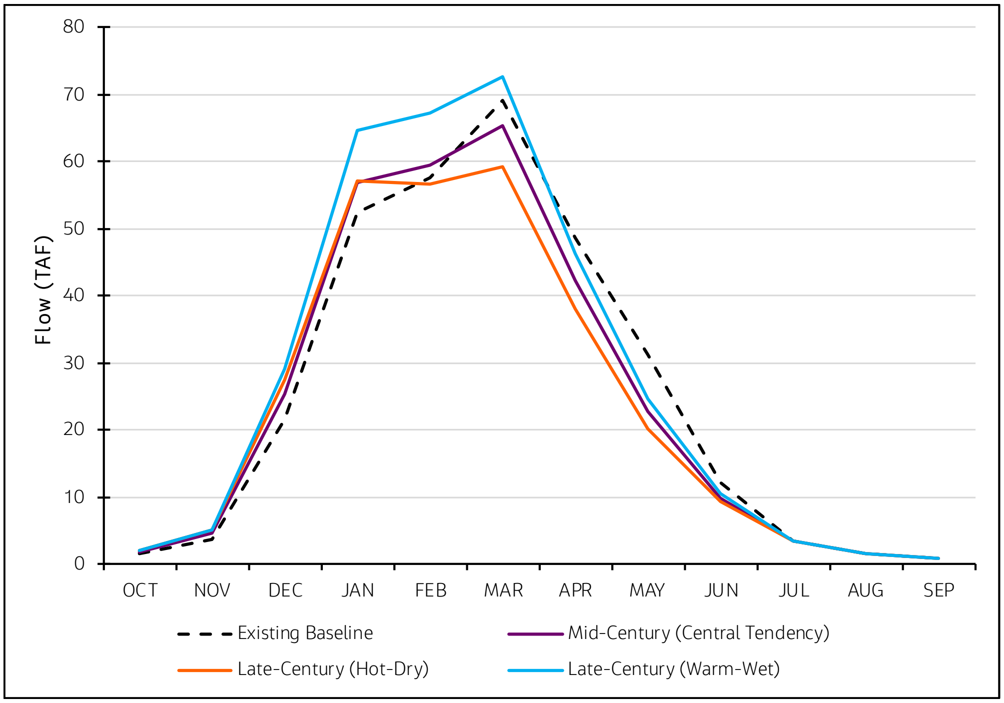


Figure 2-35. Cosumnes River Inflow to Michigan Bar

Aquatic Ecosystems and Ecological Water Quality Impairments

The availability of cold water is vital for Fall-run Chinook salmon and steelhead along the American River. Water temperatures between May and November are a key indicator of suitable spawning and rearing habitat under future climate conditions (Sacramento Water Forum 2015). If temperatures are too high, juveniles may not spawn or may not be able to survive. The Modified Flow Management Standard Proposed Water Right Terms and Conditions (American River Water Agencies 2017) identifies a series of temperature thresholds at Watt Avenue that have been used to assess vulnerabilities for aquatic ecosystems. For May 15 through September 30 (Figure 2-42), 32% of days over the entire simulation period under the Existing Baseline were below the 65 °F threshold. This is reduced to 12%, 10%, and 4% under the Mid-Century, Late-Century (WW), and Late-Century (HD) scenarios. For the 60 °F threshold from October 1 through 15 (Figure 2-43), 6% of days were sufficient. Less than 1% of days under future climate conditions achieved this threshold for the other scenarios. For the 56 °F threshold for October 16 through October 31 (Figure 2-44), less than 1% of days were below this temperature for both the Existing Baseline and Mid-Century scenarios. The Late-Century scenarios had no days where this threshold was met. Water temperatures are explored in further detail in Section 1.6.

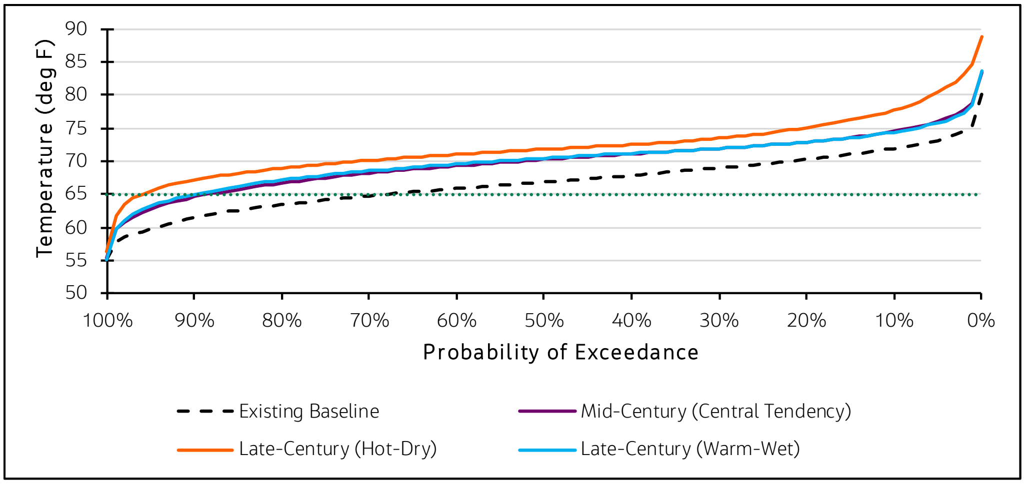


Figure 2-36. Watt Avenue Bridge Daily Temperature Exceedance (May 15-September 30)

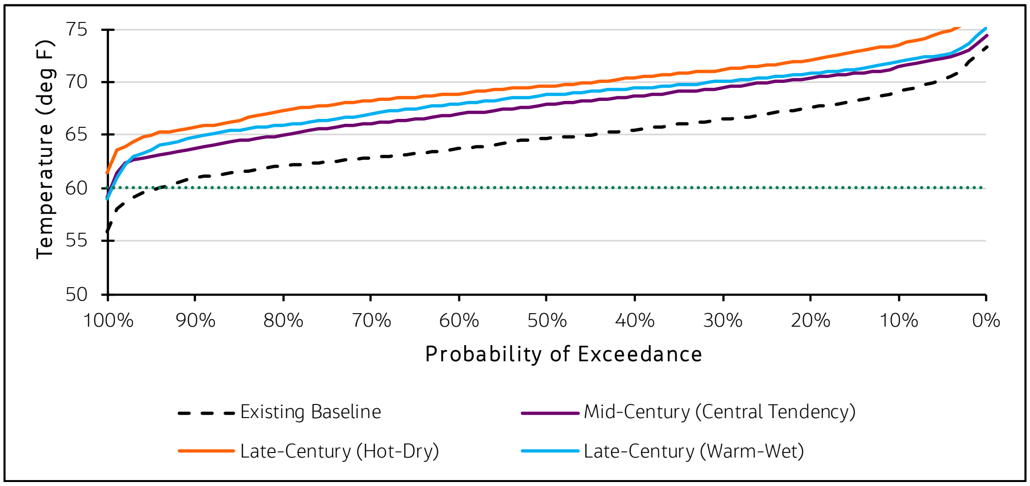


Figure 2-37. Watt Avenue Bridge Daily Temperature Exceedance (October 1-15)

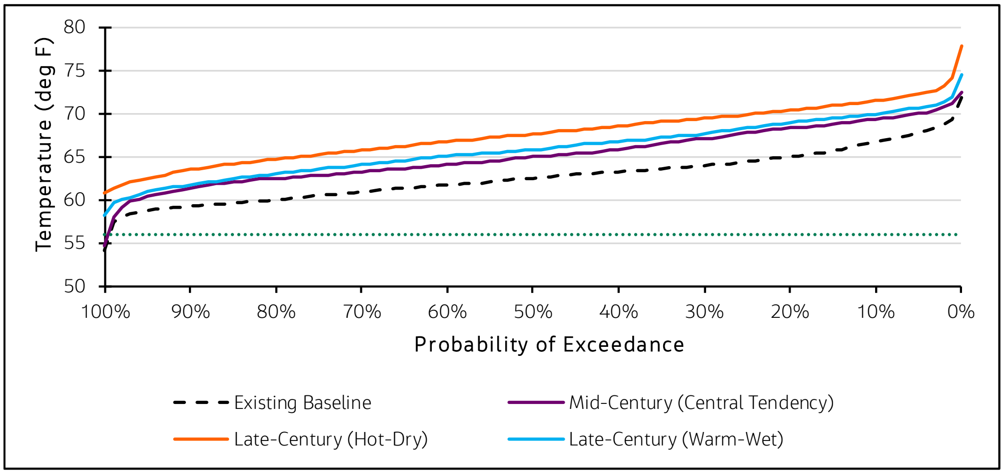


Figure 2-38. Watt Avenue Bridge Daily Temperature Exceedance (October 16-31)

Forest Health and Ecosystem Services

Annually, changes in total climatic water deficit (CWD) show the largest shift in upper watersheds relative to historical conditions, suggesting that these areas are likely to experience greater stress under both Mid-Century and Late-Century conditions (Figure 2-49). However, it is important to note that historical conditions display near-zero deficits; the same change at other locations in the watershed would result in a lower percent change under future conditions if that location experiences larger preexisting deficits. Increases in CWD suggest an increase in stress in vegetation, which may indicate degradation in forest health and a reduction in ecosystem services. Seasonal changes in CWD are discussed as follows:

- **Fall (Figure 2-50):** Changes in CWD for Mid-Century and Late-Century conditions are relatively similar, with a minor increase in deficit over most of the watershed and slightly higher changes in near-zero historical locations in the upper watershed.
- **Winter (Figure 2-51):** Large percent decrease in deficit for upper watersheds and a slight increase in deficit for lower watershed areas.
- **Spring (Figure 2-52):** Similar patterns to winter CWD, with higher percentage increases in deficit in foothill and lower elevation areas of the upper watershed, likely driven by earlier spring snowmelt.
- **Summer (Figure 2-53):** Large percent increase in CWD for upper watersheds, with minor decreases in CWD for lower watershed areas.

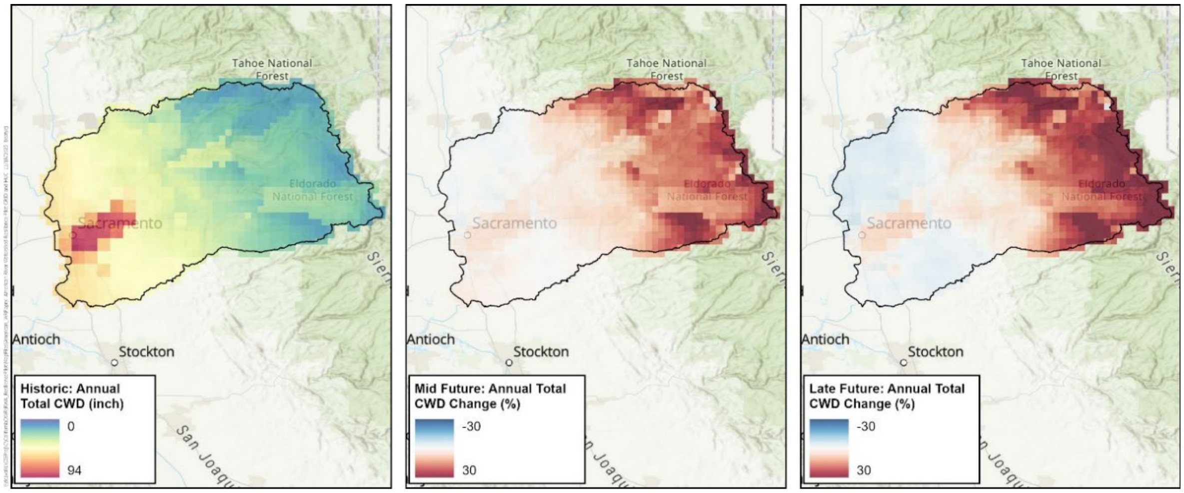


Figure 2-39. Change in Average Annual Total Climatic Water Deficit

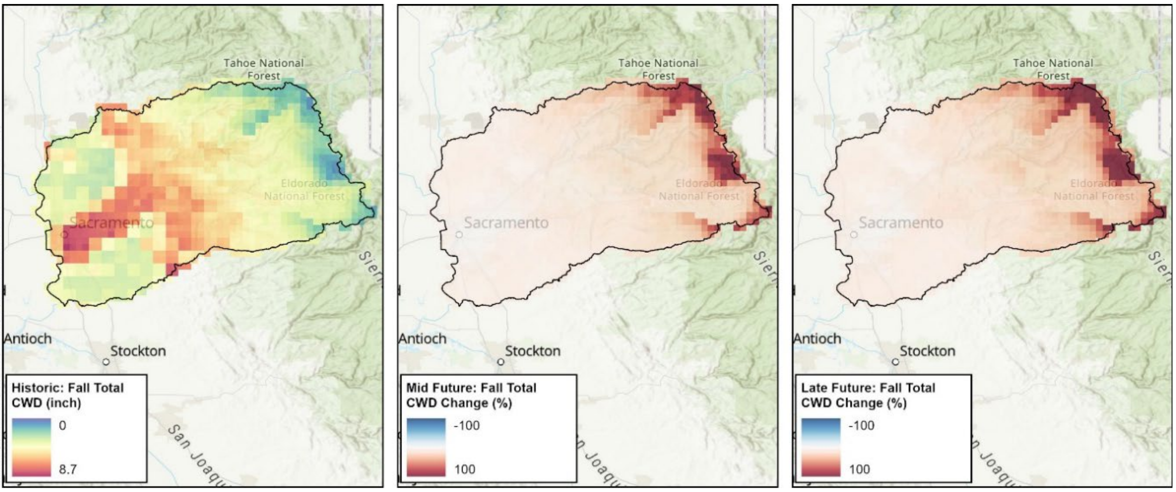


Figure 2-40. Change in Average Fall Total Climatic Water Deficit

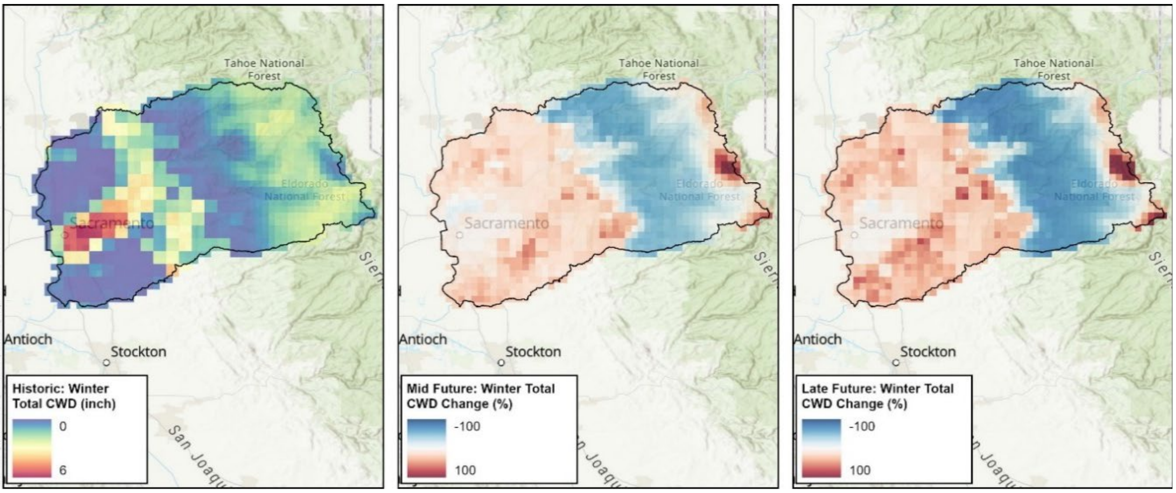


Figure 2-41. Change in Average Winter Total Climatic Water Deficit

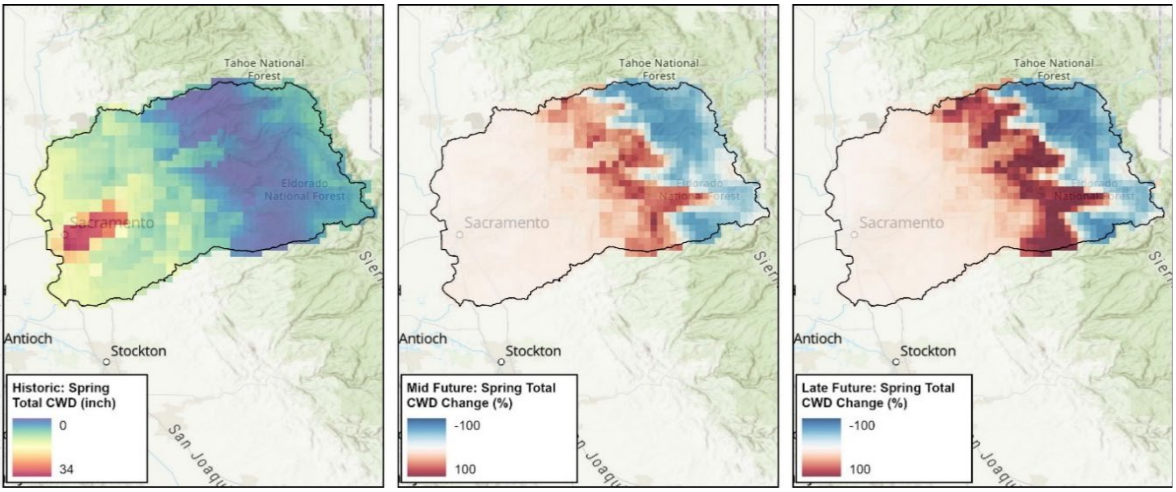


Figure 2-42. Change in Average Spring Total Climatic Water Deficit

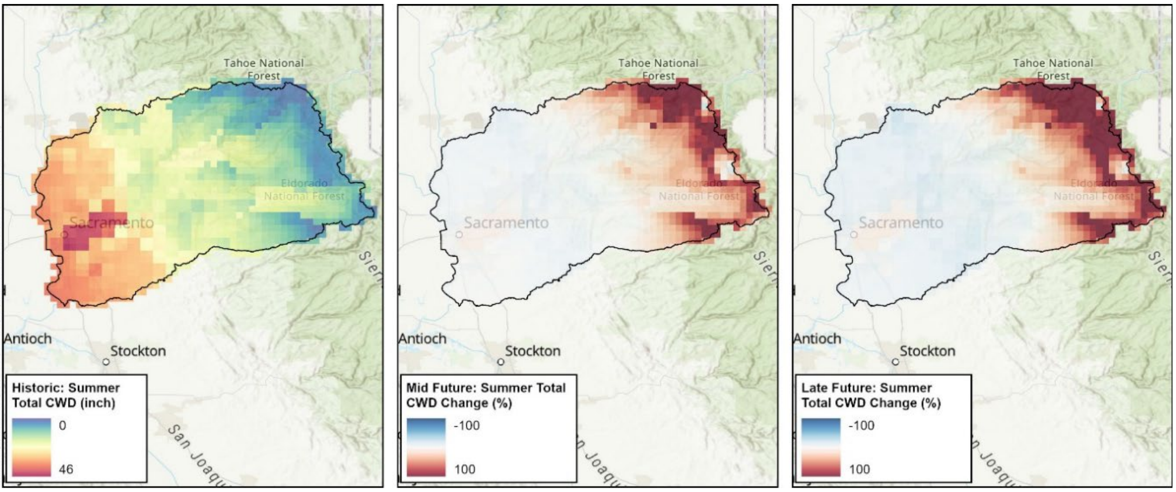


Figure 2-43. Change in Average Summer Total Climatic Water Deficit

Landscape Condition

Mid-century and late-century changes in average decadal wildfire probability (Figure 2-54) and average annual wildfire burn area (Figure 2-55) were used to evaluate the vulnerability of the landscape to climate change. For changes in average decadal wildfire probability, areas that display the largest decadal wildfire probability under historic conditions are most likely to experience the greatest increase in wildfire probability under future conditions. For average annual wildfire burn area, lower watershed areas display a decrease in burn area under both mid future and late future conditions. Conversely, upper watersheds show a nearly 100% increase over historical conditions, suggesting more severe wildfires in these areas. Patterns between the mid future and late future conditions are similar, with Late-Century conditions showing a greater magnitude of change in most grid cells. Ultimately, these results suggest that wildfires are likely to become more common under future climate conditions. More severe wildfires are likely to occur in upper watersheds due to drier conditions described previously for the changes to CWD.

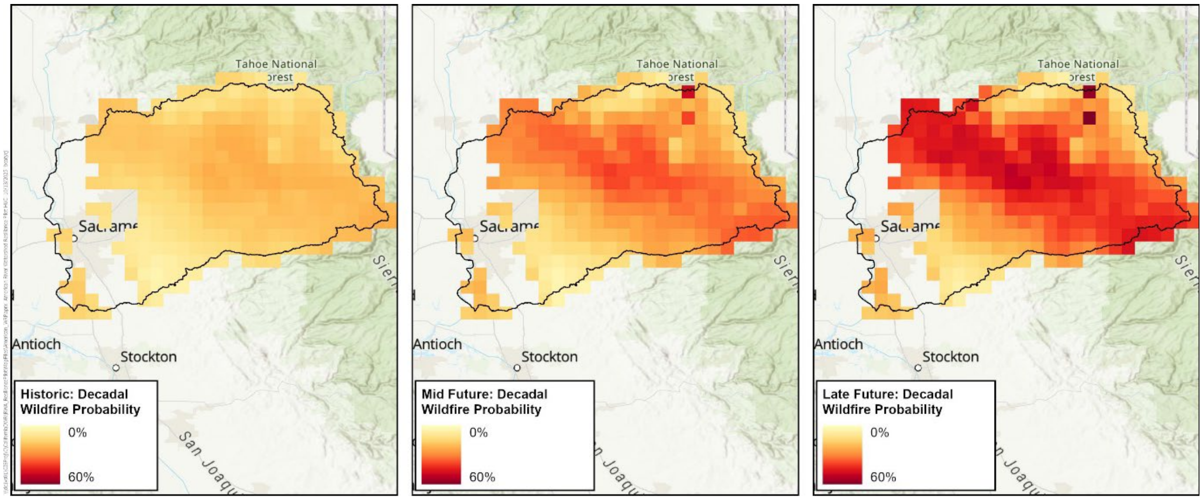


Figure 2-44. Change in Average Decadal Wildfire Probability

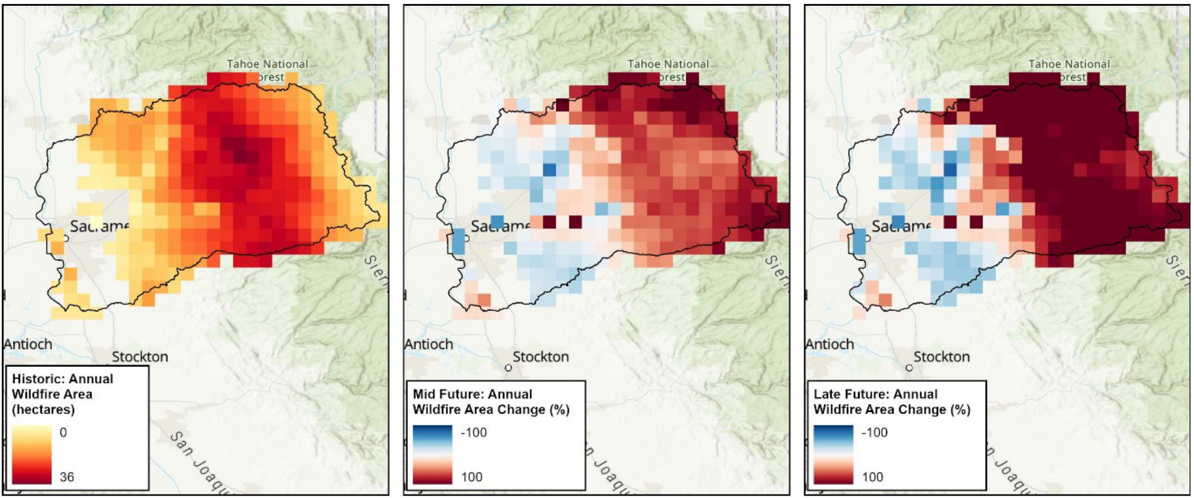


Figure 2-45. Change in Average Annual Wildfire Burn Area

Fish Habitat

In addition to the changes in water temperature described above, the frequency of 2-year flows is an important indicator for floodplain-dependent fish species (DWR 2022b). To evaluate changes in these conditions, results from the 2022 CVFPP Update were leveraged. Figure 2-56 and Figure 2-57 display the change in 2-year AEP flow and stage, respectively, for selected index points near the American River confluence with the Sacramento River. In general, both flow and stage increase under future climate conditions, with the American River showing the greatest increase in flow relative to baseline conditions, even with implementation of flood improvement projects. Additionally, the recurrence interval of 2-year flows is likely to decrease (i.e., become more frequent) under future conditions, as displayed in Figure 2-58. However, because the 2022 CVFPP Update outputs do not provide an indication of changes in event duration, it cannot be determined whether these changes would be beneficial for the suitability of fish habitat. Durations of at least 2 weeks are ideal for salmonid habitat suitability between December and May (DWR 2022b).

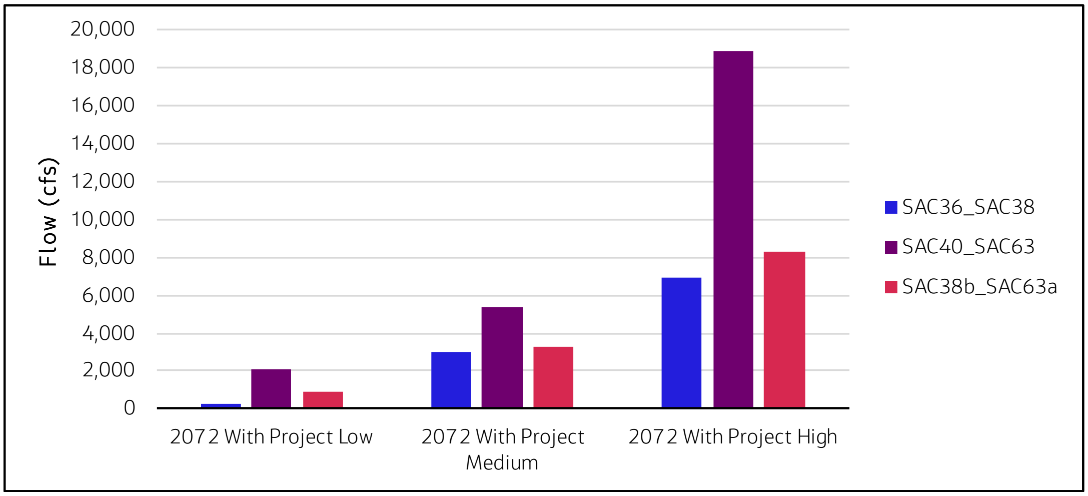


Figure 2-46. Change in 2-year Annual Exceedance Probability Flow

Note:

SAC36_SAC38 = Sacramento River above confluence with American River; SAC 40_SAC63 = American River above confluence with Sacramento River; SAC38b_SAC63a = Sacramento River below confluence with American River

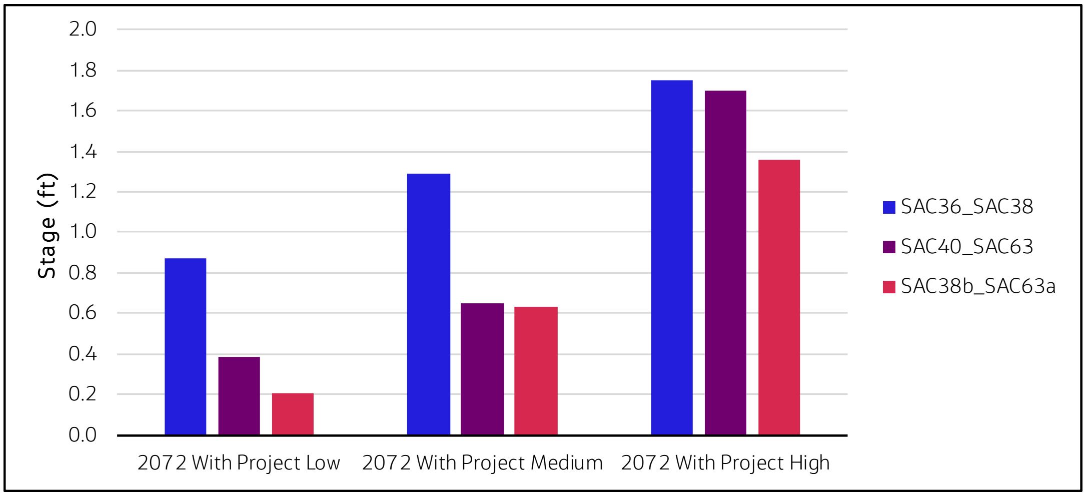


Figure 2-47. Change in 2-year Annual Exceedance Probability Stage

Note:

SAC36_SAC38 = Sacramento River above confluence with American River; SAC 40_SAC63 = American River above confluence with Sacramento River; SAC38b_SAC63a = Sacramento River below confluence with American River

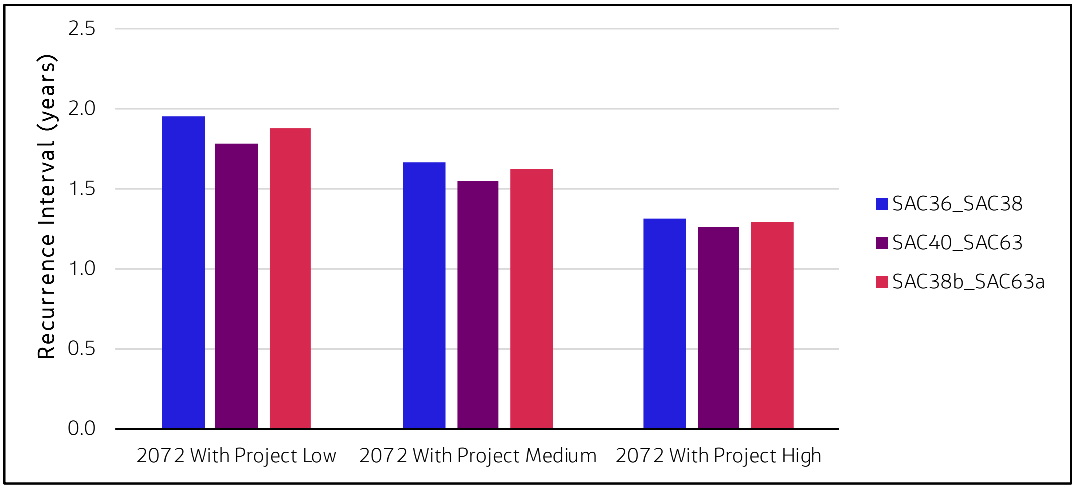


Figure 2-48. Annual Recurrence Interval for Baseline 2-year Flow under Future Conditions

Note:

SAC36_SAC38 = Sacramento River above confluence with American River; SAC 40_SAC63 = American River above confluence with Sacramento River; SAC38b_SAC63a = Sacramento River below confluence with American River

2.7 Recreation Vulnerability Assessment

2.7.1 Purpose

Recreational opportunities within the American River watershed are plentiful and have close ties to regional economies and tourism. Lakes within the watershed provide opportunities for swimming, boating, and other activities; rivers allow for kayaking, canoeing, rafting, and more; upper watershed areas offer snow-based recreation; and the American River Parkway provides over 30 miles of bike trail, park areas, beaches, and more. As the watershed responds to shift in precipitation and temperature as a result of climate change, the quality and availability of these recreational opportunities may decrease. The purpose of the Recreation Vulnerability Assessment is to evaluate a selection of recreation-related indicators and metrics to further determine the vulnerability of recreational opportunities to change climate. This Vulnerability Assessment is not intended to comprehensively analyze all facets of conditions that may impact recreation; it is focused on metrics and indicators that can be sufficiently represented using the modeling tools available for this effort.

2.7.2 Methodology

The Recreation Vulnerability Assessment utilized a variety of data sources, noted below in Table 2-24, to analyze selected metrics. Additional details and application of each data source are described in the following subsections.

Table 2-24. Ecosystem Vulnerability Assessment Data Sources

Data Source	Assessed Metrics
CalSim 3	▪ Changes in Frequency of Recreational Days for Lakes ▪ Changes in Frequency of Recreational Days for Rivers ▪ Changes in Frequency of Inundation for American River Parkway
CalSimHydro	▪ Changes in Frequency of Recreational Days for Rivers
VIC	▪ Changes in April 1 Snow Water Equivalent

CalSim 3

CalSim 3 outputs were used to evaluate changes to recreational opportunities in lakes, rivers, and along the American River Parkway. For each of these areas, monthly time series at selected locations were compared with relevant thresholds that supported characterization of changes in frequency of recreationally relevant days. For recreation on lakes, minimum and maximum boat ramp elevations were compared with monthly reservoir elevations for Folsom Lake, Rollins Lake, and Camp Far West Reservoir (Folsom Lake Marina 2025, NID 2025). Identified boat ramps and corresponding elevations are noted below in Table 2-25; recreation on lakes were only considered between May and September.

Table 2-25. Boat Ramp Elevations

Boat Ramp	Bottom Elevation (feet)	Top Elevation (feet)	Reservoir
Brown's Ravine - Main Ramp	397	466	Folsom
Brown's Ravine - Hobie Ramp	380	435	Folsom
Folsom Point	408	466	Folsom
Granite Bay - Low Water Ramp	370	410	Folsom
Granite Bay - Stage 1	401	420	Folsom
Granite Bay - Stage 2	426	435	Folsom
Granite Bay - Stage 3	437	450	Folsom
Granite Bay - Stage 4A	430	466	Folsom
Granite Bay - Stage 4B	450	466	Folsom
Granite Bay - 5%	408	466	Folsom
Peninsula - Old Ramp	426	466	Folsom

Boat Ramp	Bottom Elevation (feet)	Top Elevation (feet)	Reservoir
Peninsula - New Ramp	438	466	Folsom
Rattlesnake	430	466	Folsom
Greenhorn[a]	2130	2170	Rollins
Peninsula[a]	2143	2183	Rollins
Orchard Spring[a]	2130	2170	Rollins
Long Ravine[a]	2133	2173	Rollins
North Shore[b]	276	300	Camp Far West
South Shore[b]	286	315	Camp Far West

Notes:

[a] Top elevation of boat ramp is assumed to be 40 feet above reported elevation.

[b] Elevations were approximated using Google Earth.

For recreation on rivers, monthly CalSim 3 flow outputs for the Cosumnes River at Michigan Bar were utilized to characterize the availability of recreational activities on the upper run, Middle Fork, and lower run of the Cosumnes River between January and May. Because the Cosumnes River is unregulated, recreational opportunities are more prevalent during the wet season when flows are sufficiently high. Thresholds utilized for these activities are noted below in Table 2-26 (California Creeks 2025a, 2025b, 2025c).

Table 2-26. Flow Thresholds for Recreation along the Cosumnes River

Location	Recreation Type	Minimum Flow (cfs)	Maximum Flow (cfs)
Upper Run	Inflatable Kayak	400	2500
Upper Run	Raft	600	2000
Upper Run	Kayak	500	2500
Middle Fork	Inflatable Kayak	300	1200
Middle Fork	Kayak and Small Raft	600	1200
Lower Run	Inflatable Kayak	400	2500
Lower Run	Raft	600	2000
Lower Run	Kayak	500	2500

For impacts to recreation along the American River Parkway, flow thresholds corresponding to closure or evacuation procedures at Parkway facilities were considered. Monthly flow outputs between October and April for two locations within CalSim (Lake Natoma releases and flow for the American River at H Street) were compared to individual flow thresholds to characterize the frequency of impacts to recreation at Parkway facilities. These two locations were selected to be mindful of potential backwater effects from the Sacramento River at lower flows. While certain flows may result in partial closure at some facilities, it was assumed that any partial closure resulted in some level of impairment to recreation at a given location. Additionally, while closure or evacuation procedures were noted up to 100,000 cfs, CalSim 3 results rarely exceeded 50,000 and never exceeded 75,000 cfs. The monthly time-step of CalSim also does not fully capture peak flood flows that may occur within short durations each month. Thresholds for each facility are noted in Table 2-27 (Sacramento County 2016, 2019).

Table 2-27. American River Parkway Facility Inundation Thresholds

Facility	Closure Threshold (cfs)	CalSim 3 Output
Discovery	10,000	C_AMR004
Del Paso	10,000	C_AMR004
Bushy Lake	10,000	C_AMR004
Paradise Beach	10,000	C_NTOMA
Campus Commons	10,000	C_NTOMA
Howe Avenue	10,000	C_NTOMA
Watt Avenue	10,000	C_NTOMA
Sarah Park	100,000	C_NTOMA
Harrington	50,000	C_NTOMA
Gristmill	10,000	C_NTOMA
William B. Pond	10,000	C_NTOMA
Goethe	100,000	C_NTOMA
Ancil Hoffman	75,000	C_NTOMA
Sarah Court	75,000	C_NTOMA
Rossmoor Bar	50,000	C_NTOMA
Upper Sunrise	20,000	C_NTOMA
Lower Sunrise	75,000	C_NTOMA
Sacramento Bar	75,000	C_NTOMA
Sailor Bar (Illinois)	30,000	C_NTOMA
Woodlake	20,000	C_AMR004
Cal Expo	20,000	C_AMR004
Camp Pollock	20,000	C_AMR004
Northgate	30,000	C_AMR004
PCA Bridge	20,000	C_AMR004
El Manto	75,000	C_NTOMA
Ambassador	100,000	C_NTOMA
River Bend	30,000	C_NTOMA

CalSimHydro

CalSimHydro outputs were utilized to assess changes in riverine recreation along the South Fork American River below Chili Bar between May and September. This run of the South Fork American River is a popular location for river rafting, kayaking, and other activities. Flows are managed depending on the unimpaired inflow to Folsom Lake. The volume of unimpaired inflows dictates the timing and duration of recreational flows along this stretch of the South Fork American River, as noted in *Chili Bar Hydropower Project Summary* (Hydropower Reform Coalition and River Management Society 2015). The classification of water-year type using unimpaired inflow to Folsom Lake is shown in Table 2-28 (Sacramento Municipal Utility District 2015). Monthly total rim inflows above Folsom Lake were utilized from CalSimHydro to calculate the change in distribution of individual water-year types across each CalSim scenario as a proxy for evaluating the change in quality of recreational opportunities along this run.

Table 2-28. American River Water-year Classification Thresholds

Water-year Type	Description
Wet	Greater than 3.5 MAF unimpaired inflow
Above Normal	Between 3.5 and 2.6 MAF unimpaired inflow
Below Normal	Between 2.6 and 1.7 MAF unimpaired inflow
Dry	Between 1.7 and 0.9 MAF unimpaired inflow
Critically Dry	Less than 0.9 MAF unimpaired inflow
Super Dry	Any critically dry year immediately preceded by a dry or critically dry year or any dry year that is immediately preceded by any combination of 2 dry or critically dry years

VIC

The Recreation Vulnerability Assessment leverages gridded VIC model outputs for determining vulnerabilities for snow-based recreational opportunities. April 1 snow water equivalent was used to evaluate changes in the duration of winter recreation season across the entire study domain. Decreases on April 1 snow water equivalent may imply a reduction in snowpack and a shorter winter recreation season.

2.7.3 Results

Recreational Opportunities in Lakes

Vulnerabilities to recreational opportunities at lakes were assessed by evaluating May through September changes in key thresholds related to boat ramp access for Rollins Lake, Camp Far West Reservoir, and Folsom Lake. Changes under the Mid-Century and Late-Century scenarios were analyzed by determining the change in the percent occurrence of reservoir elevations at each of the identified thresholds. For Rollins Lake, the optimal reservoir elevation is from 2143 feet to 2170 feet, representative of the window where all boat ramps are open. While future climate conditions indicate lower reservoir storage between May and September, the Existing Baseline includes a sharp increase in reservoir volume at an exceedance probability of roughly 50% (Figure 2-59). This sharp increase reduces the frequency of optimal reservoir conditions as the 2170 feet threshold is more regularly exceeded. As such, the Mid-Century, Late-Century (WW), and Late-Century (HD) scenarios result in a 23%, 23%, and 31%, respectively, increase in frequency of optimal reservoir elevations for boat launch access (Table 2-29).

Camp Far West Reservoir includes two boat ramps; the optimal reservoir elevation (i.e., where both boat ramps are open) to support boat access is 286 feet to 300 feet. Exceedance probabilities for reservoir elevations between May and September are shown in Figure 2-60. Under future climate conditions, the optimal window remains fairly consistent relative to the Existing Baseline scenario. For the Mid-Century and Late-Century (WW) scenario, the frequency of the optimal reservoir elevations decreases and increases by 0.2%, respectively. The Late-Century (HD) scenario displays a decrease of approximately 4% (Table 2-30). It is important to note that the frequency of both minimum reservoir elevations that provide boat access are projected to increase under future climate conditions. While the Mid-Century and Late-Century scenarios display a decrease in overall reservoir volume during the months (i.e., elevations above maximum boat ramp elevations become less frequent), the overall window where any boat ramp can provide access to Camp Far West Reservoir decreases by roughly 2% to 9%, depending on scenario.

Boat ramps at Folsom Lake are considerably more complex, offering 13 different options for lake access. Figure 2-61 shows the exceedance probabilities of monthly Folsom Lake reservoir elevations between May and September; changes in key thresholds for identified boat ramps are displayed in Table 2-31. Due to the number of boat ramps and variety in access to the lake, there is no single window where all boat ramps are open. As such, discussion is focused on changes to the upper and lower thresholds identified for this location. For reservoir elevations below 370 feet (i.e., where all boat ramps are closed), the frequency of occurrences increases by approximately 4%, 3%, and 14% under the Mid-Century, Late-Century (WW), and Late-Century (HD) scenarios, respectively. Conversely, for reservoir elevations above 466 feet between May and September, the frequency of occurrences decreases by 12%, 13%, and 17%, respectively. It is important to note that modeled results for monthly elevations exceeding 466 feet are extremely minor and are still likely to provide boat access between May and September. With this in mind, future projections indicate that overall boat access to Folsom Lake will be reduced by between 3% to 14%, depending on scenario.

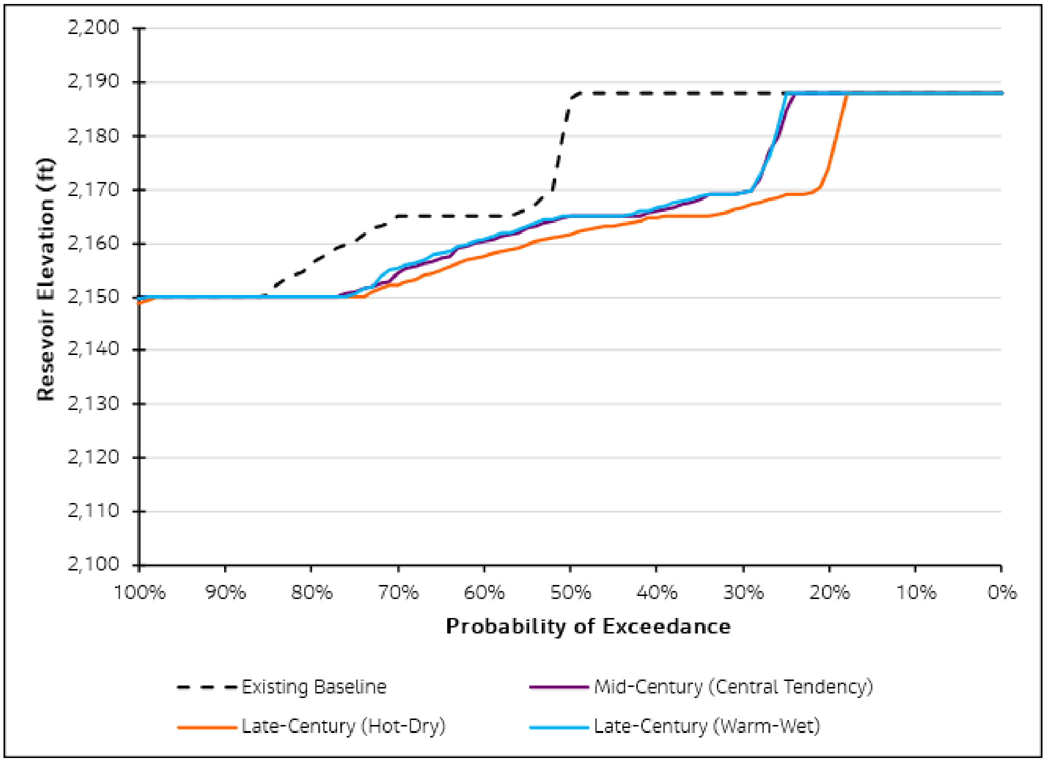


Figure 2-49. Rollins Lake Monthly Water Surface Elevation (May-September)

Table 2-29. Change in Rollins Lake Frequency of Threshold Exceedance (May-September)

Threshold (feet)	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
>2183	-25.2%	-31.8%	-24.8%
>2173 to ≤2183	1.4%	0.4%	1.0%
>2170 to ≤2173	0.8%	0.7%	0.8%
>2143 to ≤2170	23.1%	30.7%	23.1%
>2133 to ≤2143	0.0%	0.0%	0.0%
>2130 to ≤2133	0.0%	0.0%	0.0%
≤2130	0.0%	0.0%	0.0%

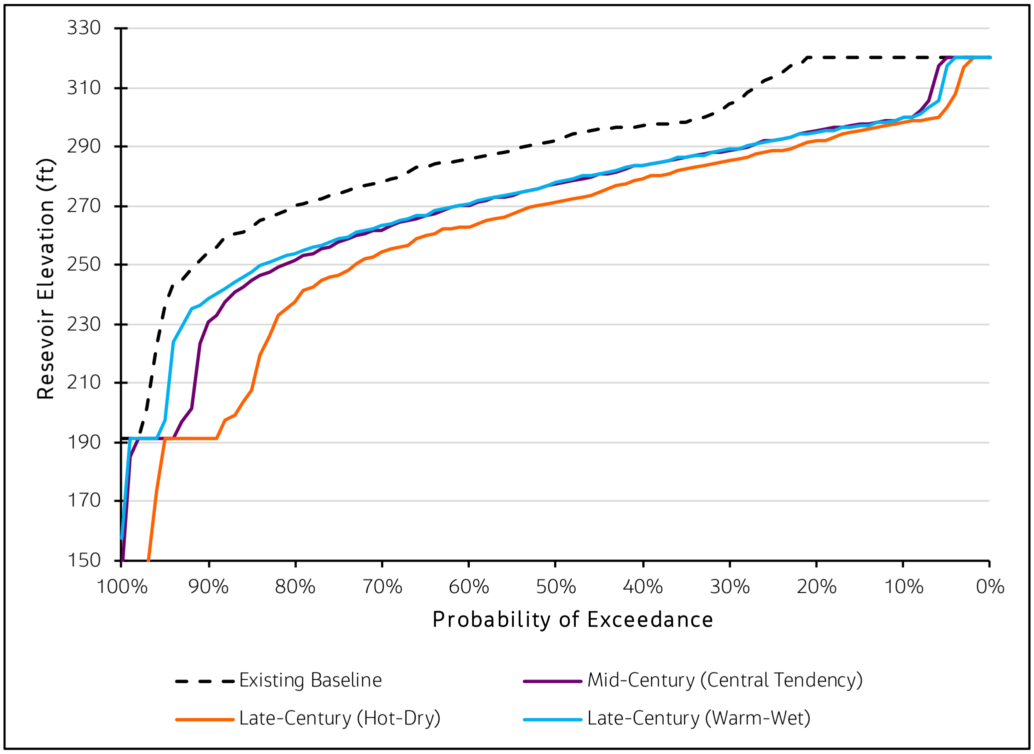


Figure 2-50. Camp Far West Reservoir Monthly Water Surface Elevation (May-September)

Table 2-30. Change in Camp Far West Reservoir Frequency of Threshold Exceedance (May-September)

Threshold (feet)	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
>315	-18.0%	-20.9%	-19.0%
>300 to ≤315	-5.8%	-5.8%	-4.9%
>286 to ≤300	-0.2%	-3.9%	0.2%
>276 to ≤286	2.8%	1.4%	2.5%
≤276	21.2%	29.3%	21.2%

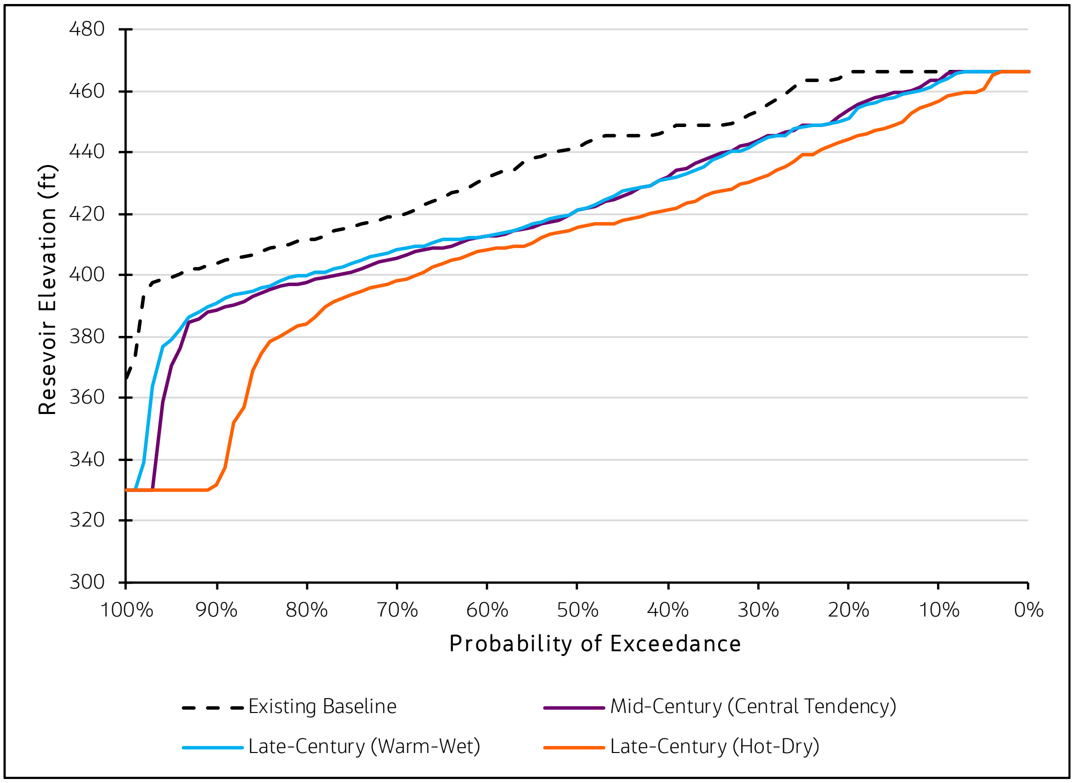


Figure 2-51. Folsom Lake Monthly Water Surface Elevation (May-September)

Table 2-31. Change in Folsom Lake Frequency of Threshold Exceedance (May-September)

Threshold (feet)	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
>466	-11.7%	-16.7%	-12.7%
>450 to ≤466	1.0%	-1.8%	1.2%
>438 to ≤450	-8.7%	-10.8%	-8.9%
>437 to ≤438	-0.2%	-0.6%	-0.3%
>435 to ≤437	0.6%	0.6%	0.3%
>430 to ≤435	-0.6%	-0.1%	0.8%
>426 to ≤430	0.0%	0.7%	1.1%
>420 to ≤426	1.5%	1.8%	0.4%
>410 to ≤420	-0.5%	0.5%	2.7%
>408 to ≤410	1.5%	1.8%	0.6%
>401 to ≤408	-1.7%	-2.1%	-0.8%
>397 to ≤401	3.3%	0.5%	2.3%
>380 to ≤397	10.4%	10.5%	9.3%
>370 to ≤380	0.7%	1.8%	1.1%
≤370	4.5%	13.7%	3.0%

Recreational Opportunities in Rivers

Recreational opportunities in rivers were assessed for both the South Fork American River and Cosumnes River. For the South Fork American River below Chili Bar, the quality of recreational opportunities each year is contingent on the American River water-year type classification. Figure 2-62 shows the distribution of wet, above normal, below normal, dry, critically dry, and super dry years across each of the modeled CalSim scenarios. In general, wetter conditions provide higher quality recreational opportunities along the South Fork American River. For wet years, Mid-Century and Late-Century (HD) scenarios show a 2-year decrease relative to the Existing Baseline scenario. The Late-Century (WW) scenario, conversely, displays a 2-year increase in wet water years. For above normal, similar trends are displayed, with the Late-Century (HD) scenario showing a substantially larger decrease (4 additional years) than the Mid-Century scenario. Below normal water years are more frequent under Mid-Century conditions, and between 2 to 4 years less frequent depending on Late-Century scenario. All future scenarios display a reduction in the frequency of dry water years relative to the Existing Baseline. Critically dry days increase substantially under the Mid-Century and Late-Century scenarios, ranging from 4 to 10 years depending on scenario. Finally, super dry years for the Existing Baseline and Late-Century (WW) scenario are similar, the Mid-Century scenario shows a 2-year increase, and the Late-Century (HD) scenario displays a 7-year increase over the simulation period. These trends suggest that the quality of recreation along the South Fork American River is likely to decrease under both the Mid-Century and Late-Century (HD) scenarios. For the Late-Century (WW) scenario, wetter conditions suggest a greater frequency of wet and above normal years and a lower frequency of below normal and dry years. Increased frequency of wetter years is somewhat offset by the increased prevalence of critically dry years. Assuming the increase in annual surface water volumes can be adequately captured and managed, these conditions may suggest a higher quality for recreation (e.g., kayaking and rafting) along this run.

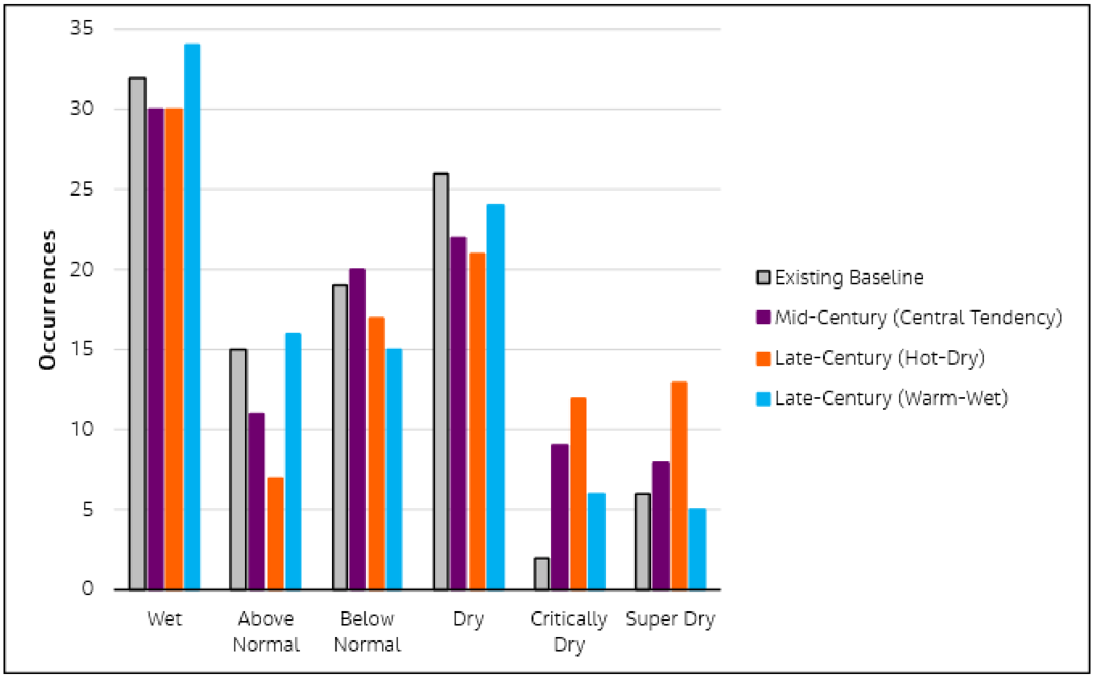


Figure 2-52. American River Water-year Type Distribution

For the Cosumnes River, a threshold-based assessment of monthly flows at Michigan Bar were used to determine the availability of various riverine recreational activities between January and May. This time period was selected because of the unregulated nature of the Cosumnes River necessitating the presence of higher flows to accommodate recreation. Thresholds were assigned to the upper (Highway 49 to Latrobe Road) and lower (Latrobe Road to Highway 16 at Rancho Murieta) runs as well as the Middle Fork (below Outingdale to Highway 49) Cosumnes River (California Creeks 2025a, 2025b, 2025c). Thresholds for the upper and lower runs are identical for the recreation activities considered (Table 2-31). The availability of months applicable for recreation across the full simulation period are presented for each climate scenario in Figure 2-63. Results indicate a decrease in recreational opportunities under all future conditions. While the Late-Century (WW) scenario may result in an increase in total annual flows between January and May, these exceed the allowable threshold for any of the recreation activities considered for all areas along the Cosumnes River. Similar trends are displayed in Figure 2-64 and Figure 2-65, which present a breakdown in the availability of individual types of recreation for each area considered. In general, without a mechanism to manage shifts in the timing and peaks of flow events, riverine recreation along the Cosumnes River is anticipated to decrease under all future climate conditions.

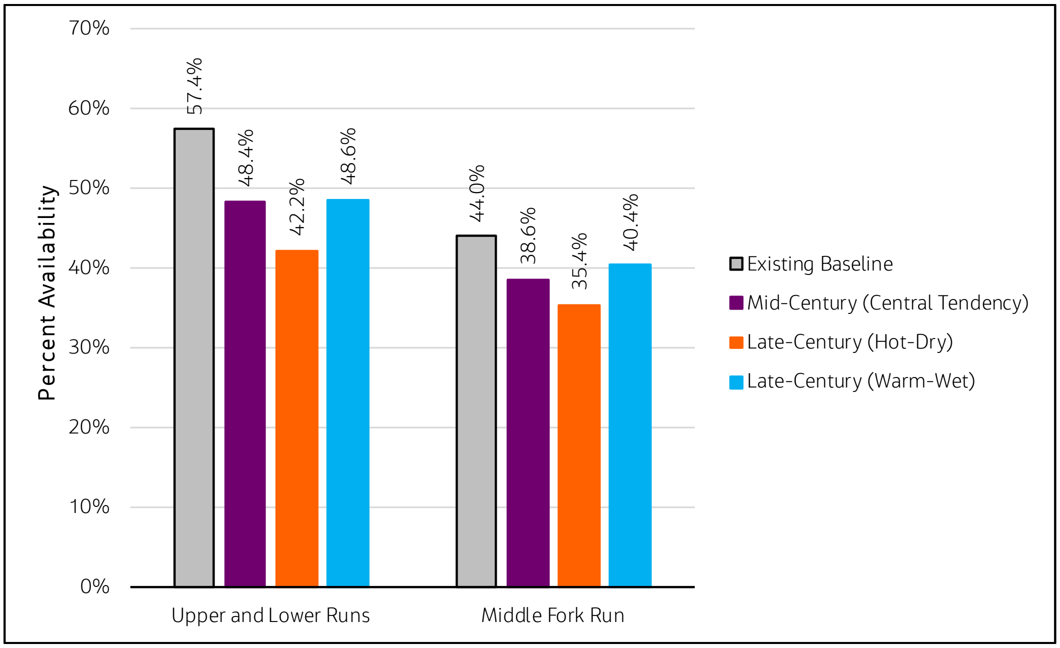


Figure 2-53. Cosumnes River January-May Recreation Availability

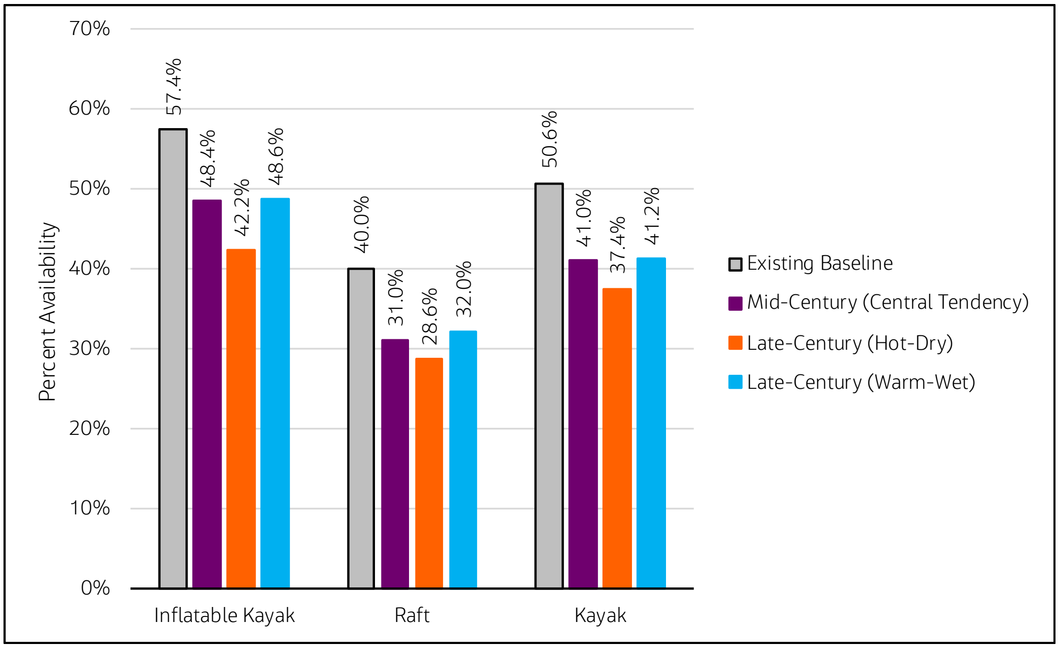


Figure 2-54. Cosumnes River Upper & Lower Runs January-May Recreation by Activity

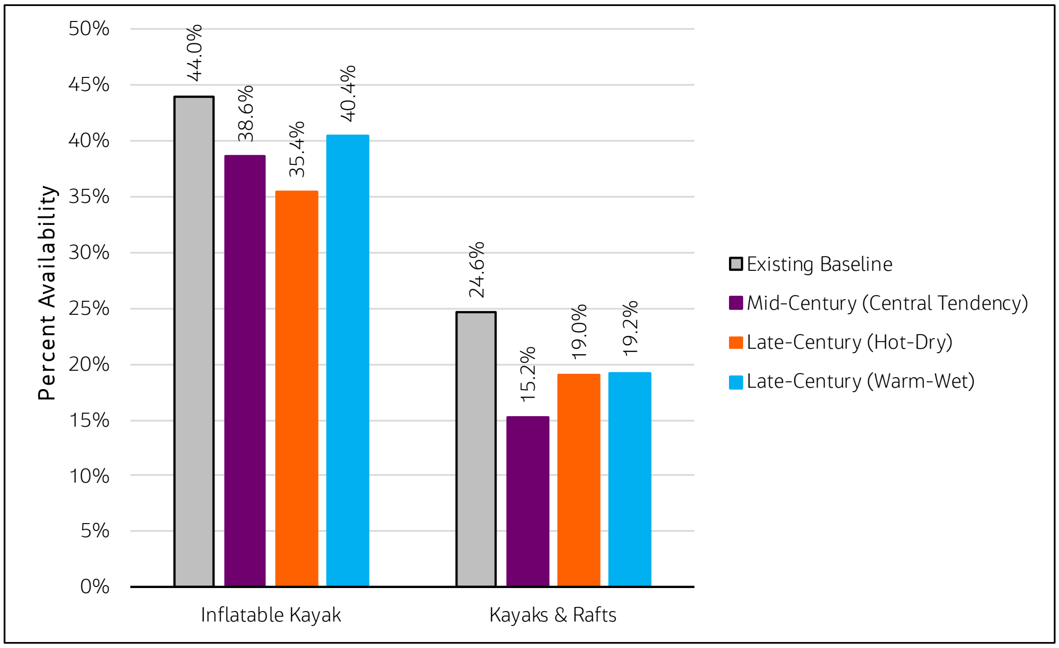


Figure 2-55. Cosumnes River Middle Fork Run January-May Recreation by Activity

Recreational Opportunities in Snow

The vulnerability of snow-based recreational opportunities was evaluated by examining shifts on April 1 snow water equivalent (SWE). SWE is representative of the total amount of water contained within snowpack on April 1 of each year. Under historical conditions, SWE is highest in the higher elevation locations of the upper watershed. By Mid-Century, an up to 80% reduction on April 1 SWE, particularly for lower portions of the upper watershed. This suggests that snowmelt is likely to occur earlier in the year for all locations as a result of warmer temperatures. These trends are magnified by the late century, with an even greater portion of the upper watershed displaying similar reductions. These results suggest that the window for snow-based recreation is anticipated to decrease under future climate conditions. While some snowpack is likely to be present, earlier snowmelt is likely to drive unsatisfactory conditions for snow recreation earlier in the winter season. This can result in economic impacts for ski resorts and other entities that are reliant on these types of recreation for business.

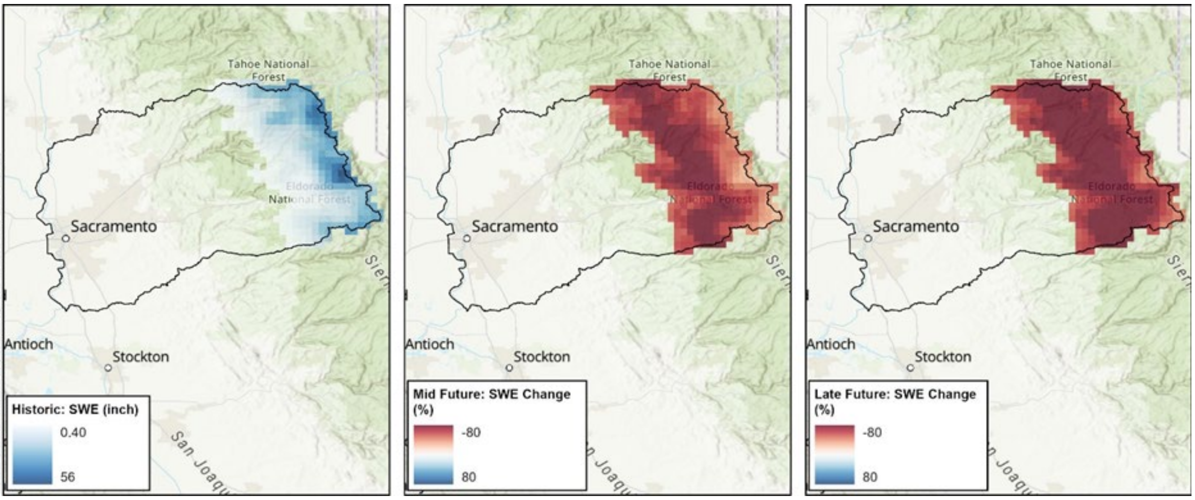


Figure 2-56. Changes on April 1 Snow Water Equivalent under Future Climate Conditions

Recreational Opportunities along American River Parkway

As noted above, the American River Parkway provides a plethora of recreational opportunities along the over 30-mile bike trail and over 20 different parks and other facilities. During high flow events, access to these facilities is impact, either through partial closures or full evacuation of these facilities. As a result, recreation is not always viable at these locations, particularly during months when flows are highest (i.e., October through April). Monthly releases from Lake Natoma (Figure 2-67) and flow along the American River at H Street (Figure 2-68) were used to evaluate differences in the percent occurrence of key flow thresholds corresponding to closure and evacuation procedures. In general, both locations show similar trends, with only minor differences in monthly flow volumes as a result of local inflows and backwater effects. At 10,000 cfs for each location, 10 of the 27 facilities listed in Table 2-31 are impacted by high flows (i.e., through inundation). At 20,000 cfs, this increases to 15 facilities, and by 30,000 cfs and 50,000 cfs, flows impact 18 and 20 facilities, respectively. Under future climate conditions, the frequency of flows between 10,000 cfs decreases between October and April. However, this is offset by increases in flows above each of the other identified thresholds. Changes vary from increases of 0.6% to 1.8%, depending on the scenario. This suggests that the availability of recreational activities along the American River Parkway is anticipated to decrease slightly under all future climate scenarios. While not immediately significant, the monthly time-step for CalSim does not provide full insight into peak flows that may only last between 1 to 3 days. As such, it is likely that impacts to Parkway facilities may occur more frequently than what is demonstrated in Figure 2-67 and Figure 2-68. Section 1.5 provides additional details on flood-related vulnerabilities for portions of the Lower American River and other portions of the study area.

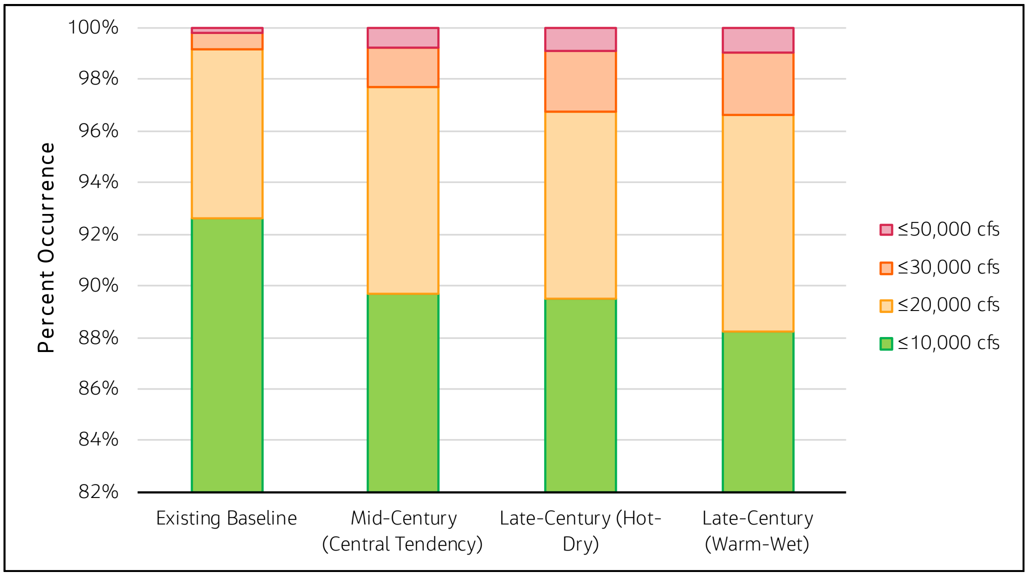


Figure 2-57. Lake Natoma Monthly Average Releases (October-April)

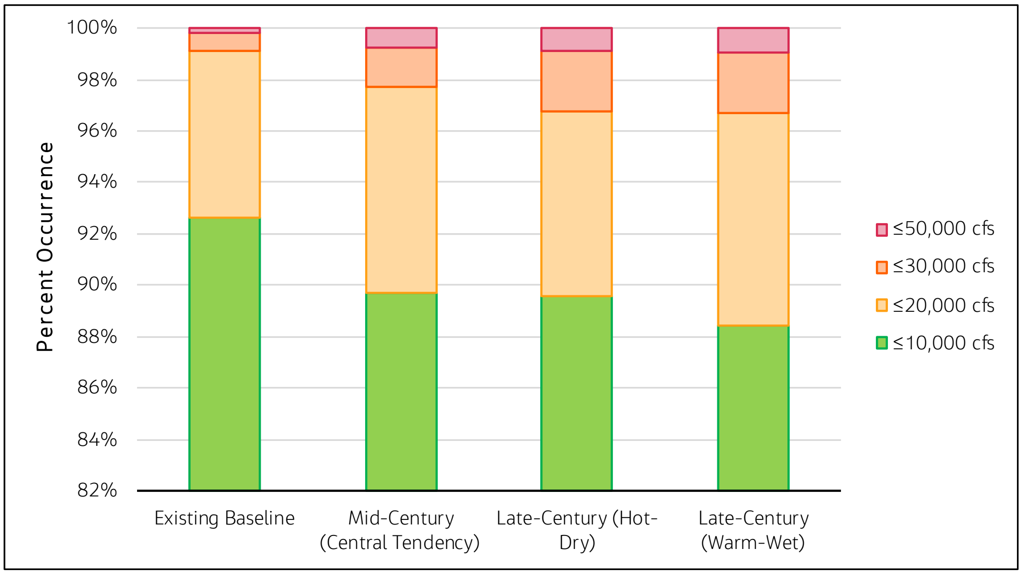


Figure 2-58. American River Flow Below H Street (October-April)

2.8 Hydropower Vulnerability Assessment

2.8.1 Purpose

The American River watershed, spanning high-elevation snow-dominated headwaters to its confluence with the Sacramento River, is a hydroclimatically sensitive system that underpins a major portion of Northern California's renewable energy portfolio. Its steep orographic gradients, substantial snowpack storage, and rapid runoff response support a cascade of hydropower facilities—including the Upper American River Project and the Folsom-Nimbus system—that convert variable inflows into both firm and peaking generation. Hydropower operations in the basin are tightly coupled to seasonal flow regimes, reservoir rule curves, and interannual climate variability, requiring continuous optimization to balance energy production with flood-risk reduction, downstream temperature and flow objectives, and multi-sector water-supply demands. Generally, power production is higher during summer months when reservoir levels are higher and water is released to satisfy delivery requirements. As warming temperatures shift snowmelt timing and alter runoff magnitude, the watershed has become a focal point for integrated hydrologic-energy modeling and adaptive operations research aimed at maintaining system reliability under evolving climate conditions.

Changes in the timing of snowmelt and precipitation can also alter streamflow into major reservoirs, impacting hydropower production. The hydroelectric generation facilities are selected and the projected changes for inflows, storage-elevation, and generation are used to characterize the relative impact to hydropower generation under three future climate change scenarios.

2.8.2 Methodology

The dams in the American River watershed were used to calculate hydropower generation, and end-of-September storage. The dams commissioned for hydropower generation within the CalSim 3 framework were included in the analysis. Dams with storage components not modeled by CalSim 3 were excluded from the study. The list of the reservoirs for hydropower analysis is shown in Table 2-32 and Figure 2-69.

Hydropower generation for the Folsom Powerhouse and Nimbus Powerplant were estimated using the Long-Term Generation (LTGen) model developed by Reclamation and DWR. LTGen uses reservoir storage and release data from CalSim 3 to calculate monthly average energy generation at all CVP and SWP reservoirs with power facilities. The model estimates energy capacity in megawatt housr (MW) energy generation in gigawatt hours (GWh) for the full CalSim 3 simulation period – October 1921 to September 2021. Documentation of LTGen is included in Attachment U.1 of Appendix U in the 2021 CVP and SWP Long-Term Operations Final Environmental Impact Statement (EIS) (Bureau of Reclamation. 2024b).

The hydrological conditions of the other 13 dams are modeled using the CalSim 3 model. Dam characteristics—such as storage and power capacity—and relationships among storage, elevation, power, and energy are assumed constant for future periods. The dam information was obtained from the National Inventory of Dams (U.S. Army Corps of Engineers & Federal Emergency Management Agency). The CalSim 3 model simulated outflow and storage of the dams were used for the estimation of monthly hydropower generation and annual energy generation. The monthly storage accounts for inflows, outflows, losses, and evaporation from the reservoir surface. The reservoirs include a minimum storage level that may not be operated (i.e., deadpool or "inactive storage"). If storage reaches deadpool, then releases are not allowed. However, evaporation may reduce storage below deadpool conditions. Also, the reservoirs include storage thresholds that may not be exceeded for flood protection or dam safety. Storage zones vary from reservoir to reservoir. Flood protection thresholds may also vary month to month. A linear storage-elevation equation based on the reservoir storage capacity and dam height is used for the estimation of water level. The hydropower and energy generation were calculated using standard formulas. More details are available in California Watershed Resilience Assessment Report (DWR 2024).

The changes in the end-of-September storage, hydropower generation, and annual energy generation are calculated for the Mid-Century (CT), Late-Century (HD), and Late-Century (WW) periods with reference as Existing Baseline period.

Table 2-32. List of the reservoirs in the American River Study Area

S. No.	Reservoir	River	Storage Capacity (AF)	Dam Height (ft)
1	Folsom	American	977000	340
2	Natoma	American	8760	87
3	Rollins	Bear	65988	228
4	Combie	Bear	5555	100
5	Camp Far West	Bear	137280	203
6	French Meadows	Middle Fork American	134000	231
7	Hell Hole	Rubicon	207000	410
8	Loon Lake	Rubicon	69309	108
9	Gerle	Rubicon	1260	74
10	Union Valley	Silver Creek	266369	455
11	Ice House	Silver Creek	43496	152
12	Aloha	South Fork American	5063	33
13	Echo	South Fork American	1860	14
14	Caples	South Fork American	22338	86
15	Silver	South Fork American	13130	32

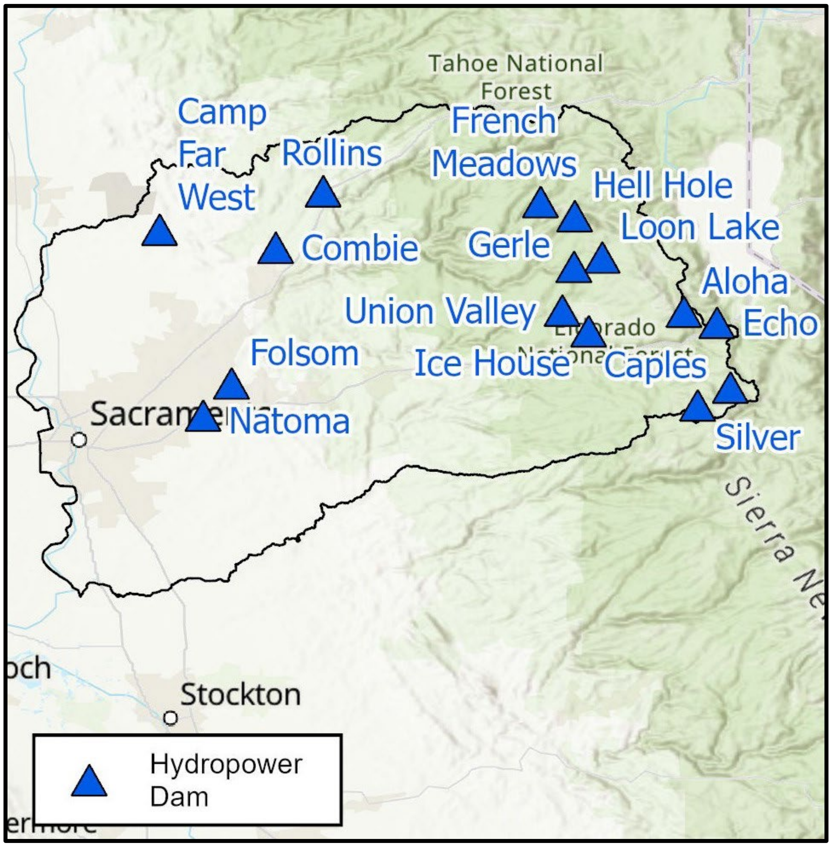


Figure 2-59. Reservoirs in the American River Study Area

2.8.3 Results

The Folsom–Nimbus system is the primary hydropower facility in the American River watershed. Under climate change, Folsom's end-of-September storage is projected to decline by 16.5% in Mid-Century (CT), 27.7% in Late-Century (HD), and 17.8% in Late-Century (WW) scenarios. Lower storage levels correspond with lower power capacity at the reservoir, which is an upper limit of energy generation based on head and flow. Results show that power capacity at the Folsom Power Facility decreases by 5.7%, 12.6%, and 4.6% during the Mid-Century (CT), Late-Century (HD), and Late-Century (WW) scenarios, respectively. Moreover, the annual energy generation at Folsom is projected to decrease by 17.5% in Mid-Century (CT), 28.6% in Late-Century (HD), and 12.6% in Late-Century (WW) scenarios. For Natoma, storage reductions are smaller, resulting in less than 1.2% decrease in hydropower capacity and less than 3% decrease in annual energy output under future climate change scenarios.

An exceedance of probability chart of annual power capacity at Folsom is shown in Figure 2-70. Each future period includes less power capacity because of reductions in reservoir levels (head) and reservoir releases. Monthly average energy generation at Folsom is shown in Figure 2-71. Energy generation at the Folsom Power Facility is significantly less in May through August in the future scenarios relative to the Existing Baseline. This reduction in energy generation is correlated with reduced Folsom storage levels and storage releases in the Mid-Century (CT), Late-Century (HD), and Late-Century (WW) scenarios. The Mid-Century (CT) scenario includes sufficient storage and releases in December through April to sustain similar energy generation to the Existing Baseline during the winter, but less in May through September. The Late-Century (WW) scenario includes the most Folsom releases in December through March, allowing for the greatest production of hydropower in the winter among all scenarios. The Late-Century (WW) scenario includes similar levels of energy generation to the Mid-Century (CT) scenario for the rest of the year. The Late-Century (HD) scenario includes the lowest storage levels and least releases year-round, resulting in less hydropower use than any other scenario for each month of the year.

Figure 2-72 presents monthly average energy generation at the Nimbus Power Facility. Figure 2-73 presents an exceedance of probability chart of the total annual energy generation at the Nimbus Power Facility. This facility generates hydropower from releases from Lake Natoma, which serves as a regulating reservoir for releases from Folsom Lake. Consequently, the release pattern of Lake Natoma is similar to that of Folsom Lake. Likewise, the pattern of energy generation at Nimbus Power Facility closely resembles the pattern at the Folsom Power Facility, albeit at a smaller scale. Relative to the Existing Baseline, the three future scenarios all include less hydropower production in May through August. The Late-Century (WW) scenario maintains similar levels of energy generation to the Existing Baseline in December through April. The Late-Century (HD) scenario includes the least energy generation year-round because of the least reservoir releases.

Figure 2-74 illustrates projected changes in end-of-September storage across multiple hydropower dams under three climate scenarios: Mid-Century (CT), Late-Century (HD), and Late-Century (WW), relative to the Existing Baseline. Most reservoirs show significant storage reductions, particularly under the Late-Century (HD) scenario, where declines exceed 40% for facilities such as Camp Far West, Aloha, Echo, Caples and Hell Hole, with Silver approaching an 80% reduction. WW conditions generally result in smaller decreases, though some reservoirs like Silver and Camp Far West still exhibit reductions greater than 30%. Folsom experiences moderate declines (16–28%), while Natoma remains largely unaffected. Conversely, a few reservoirs, including Echo and Union Valley under WW conditions, show slight increases in storage. The reduction in the storage of the hydropower dams is least under the Mid-Century (CT) scenario. The monthly storage variation in the hydropower dams under climate change scenarios is shown in

Figure 2-75. These variations highlight the sensitivity of reservoir storage to climate extremes and the potential implications for hydropower reliability.

Figure 2-76 and Figure 2-77 show projected changes in hydropower generation and annual energy generation for the dams in the American River watershed for Mid-Century (CT), Late-Century (HD), and Late-Century (WW), relative to the Existing Baseline. Most reservoirs experience reductions in generation, with the largest declines observed at Aloha and Echo, exceeding 80% under all scenarios. Silver also shows substantial decreases, ranging from 20% to 40%. In contrast, Union Valley exhibits notable increases in generation, particularly under Late-Century (WW) conditions, where gains approach 80%. Other reservoirs such as Camp Far West and Combie experience reductions ranging from 20 to 40%.

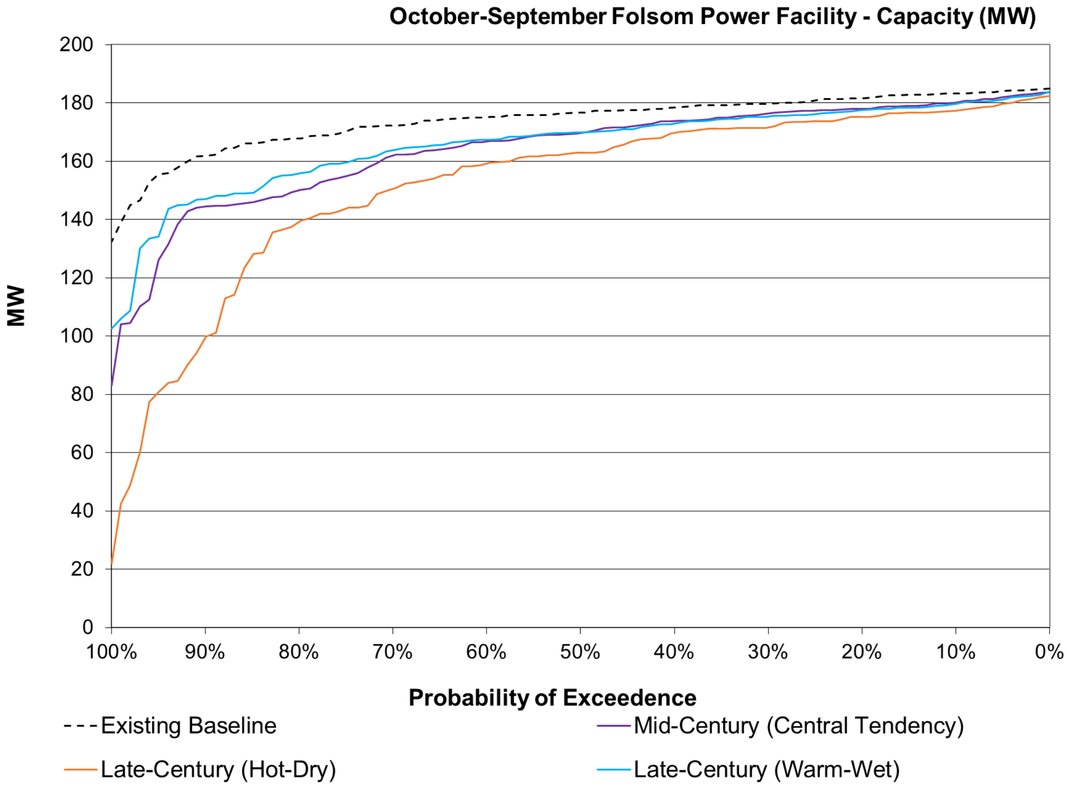


Figure 2-60. Annual Power Capacity at Folsom Exceedance of Probability (megawatt)

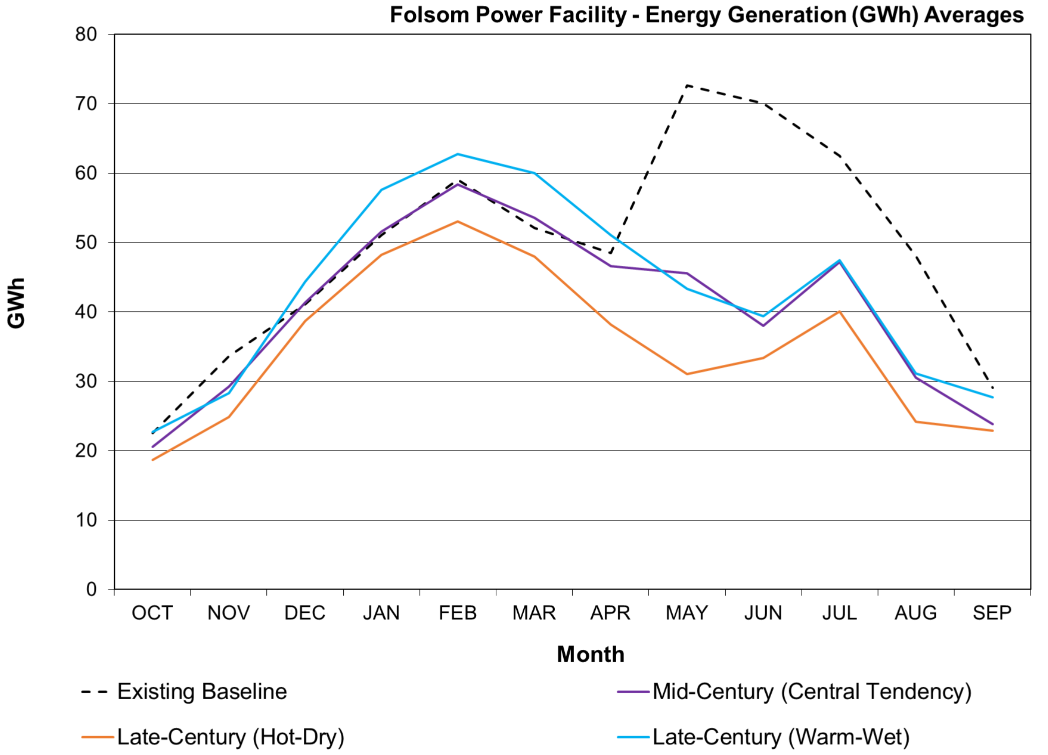


Figure 2-61. Monthly Average Energy Generation at Folsom

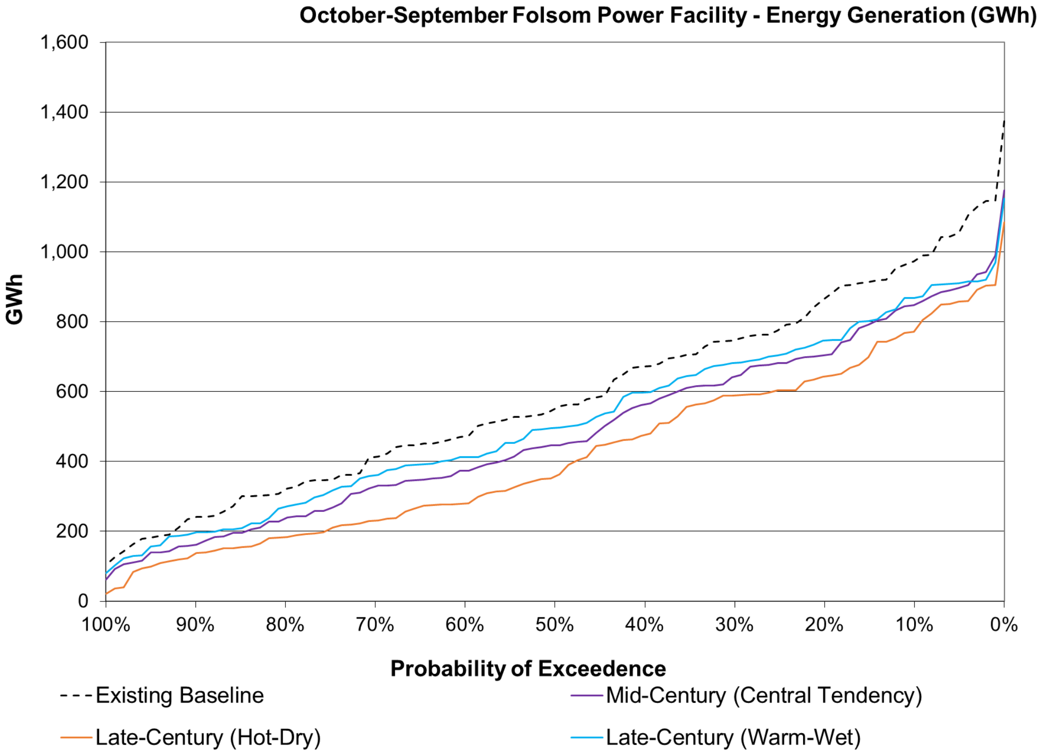


Figure 2-62. Total Annual Energy Generation at Folsom Exceedance of Probability

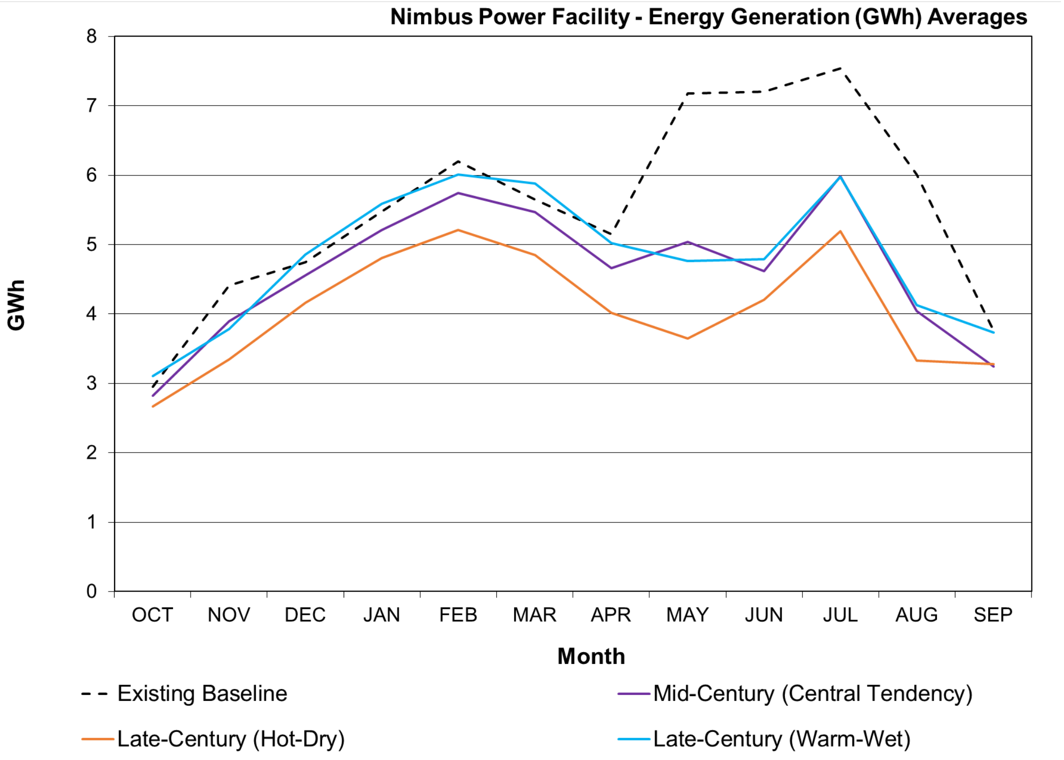


Figure 2-63. Monthly Average Energy Generation at Nimbus

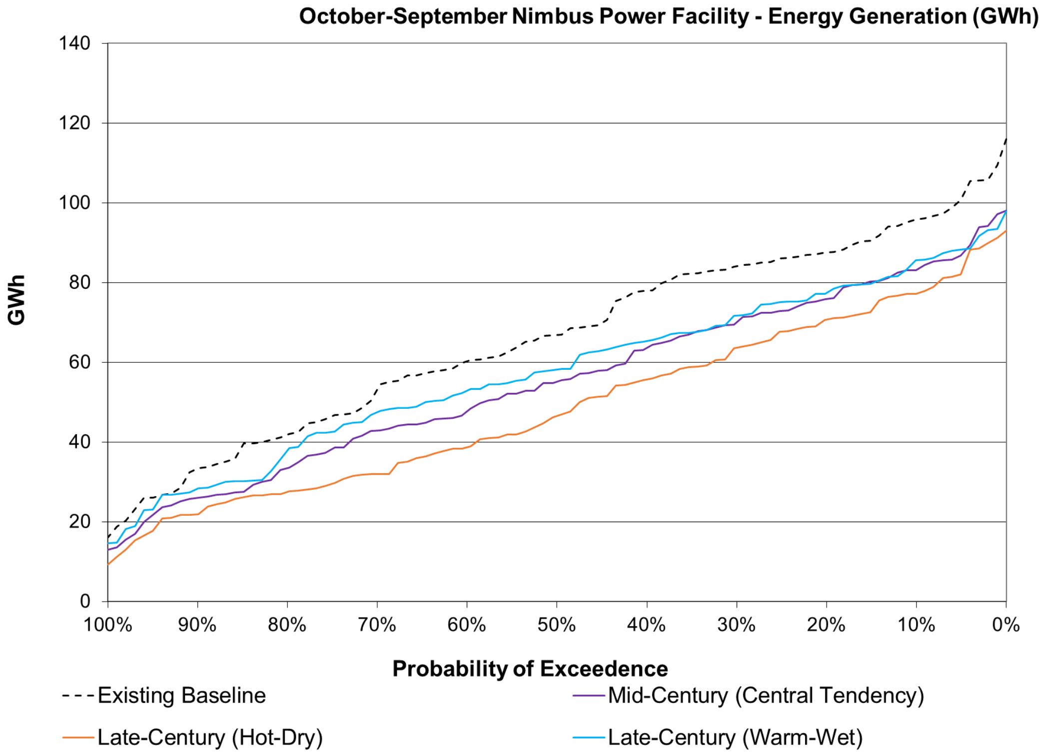


Figure 2-64. Total Annual Energy Generation at Folsom Exceedance of Probability

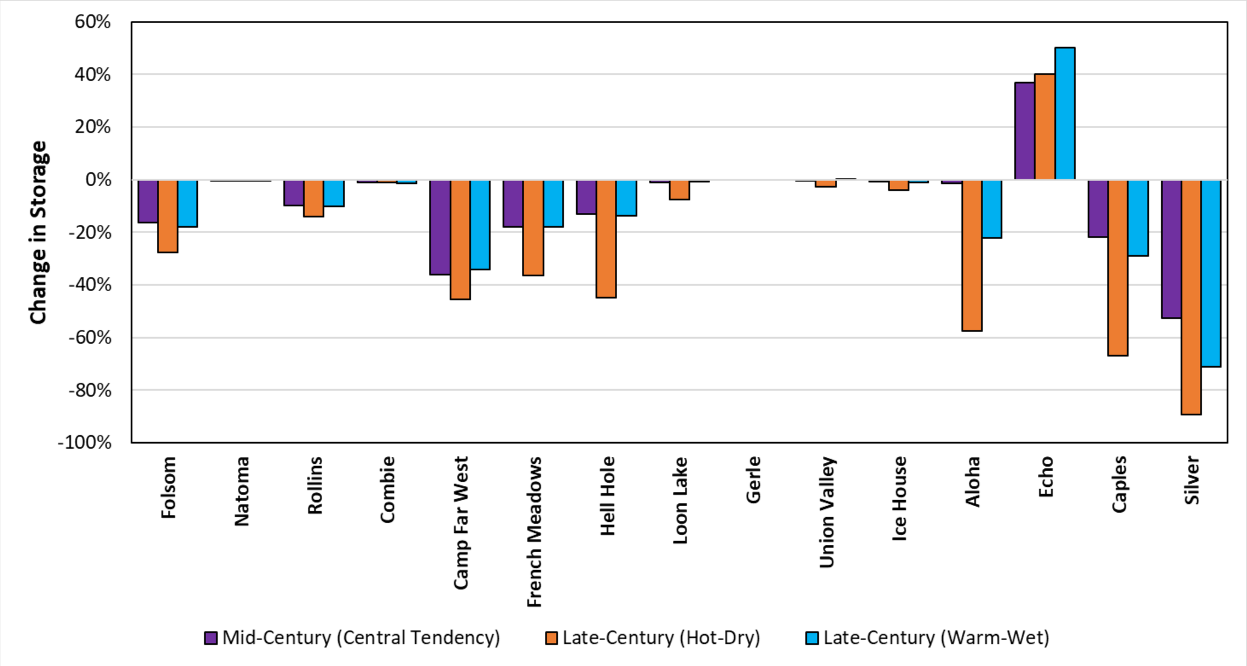


Figure 2-65. Change in the end-of-September storage in the hydropower dams during the Mid-Century (CT), Late-Century (HD), and Late-Century (WW) periods relative to Existing Baseline period

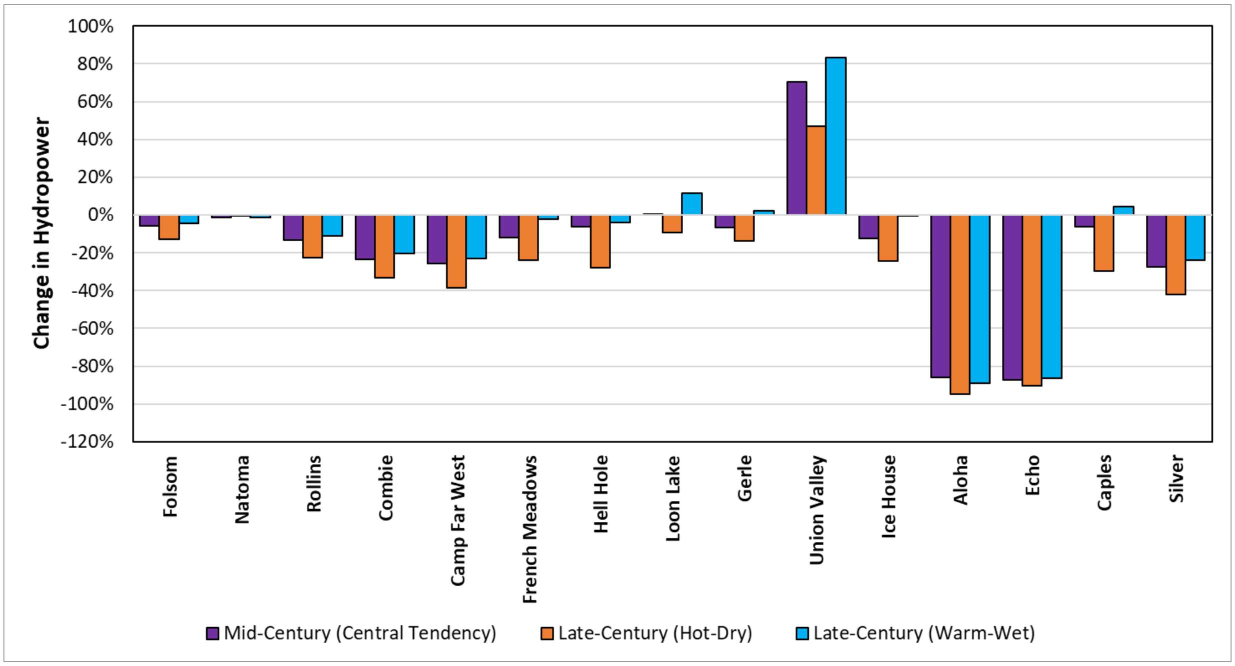


Figure 2-66. Changes in the hydropower generation for the hydropower dams during the Mid-Century (CT), Late-Century (HD), and Late-Century (WW) periods relative to Existing Baseline period

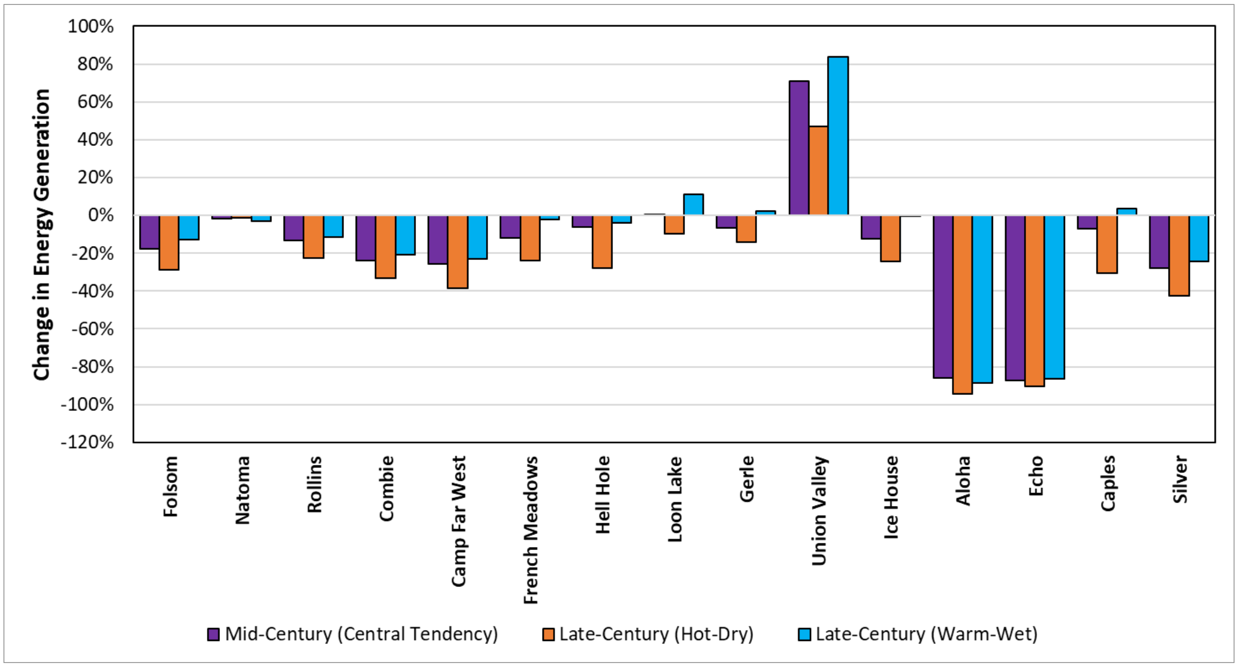
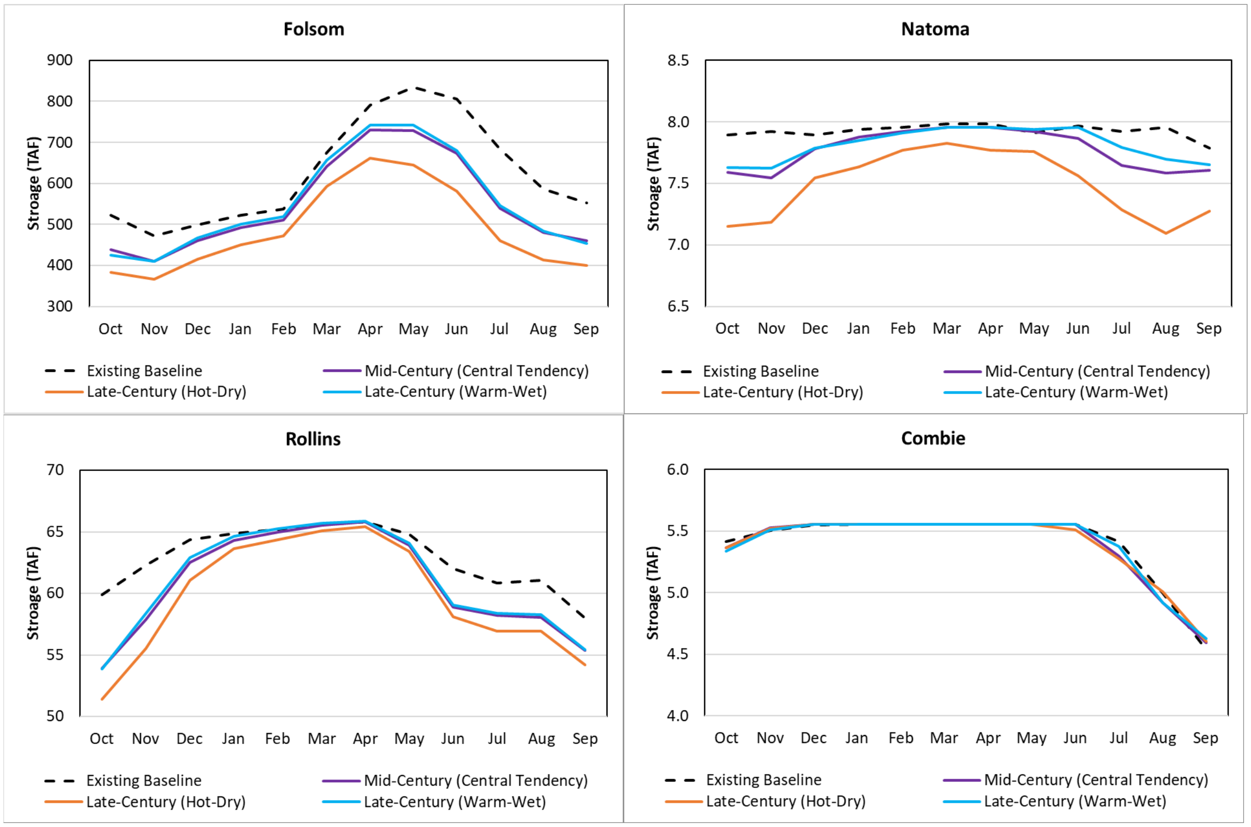
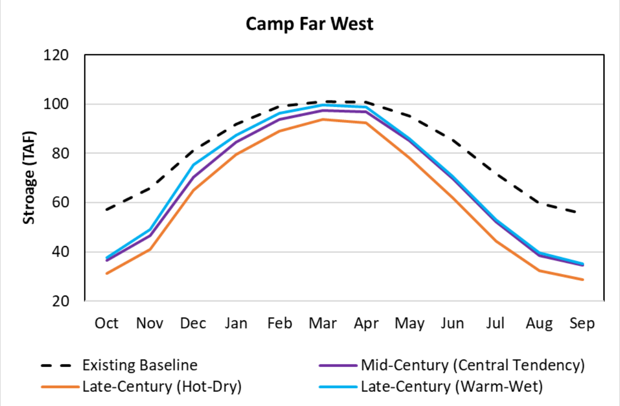


Figure 2-67. Changes in the annual energy generation for the hydropower dams during the Mid-Century (CT), Late-Century (HD), and Late-Century (WW) periods relative to Existing Baseline period

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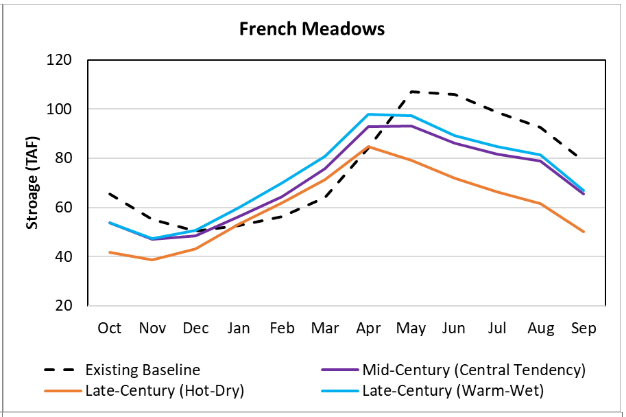
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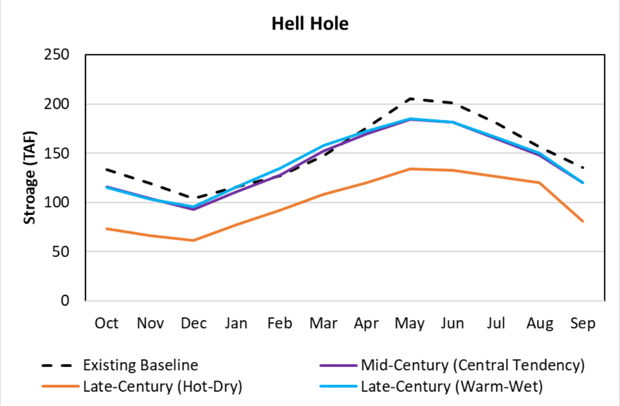
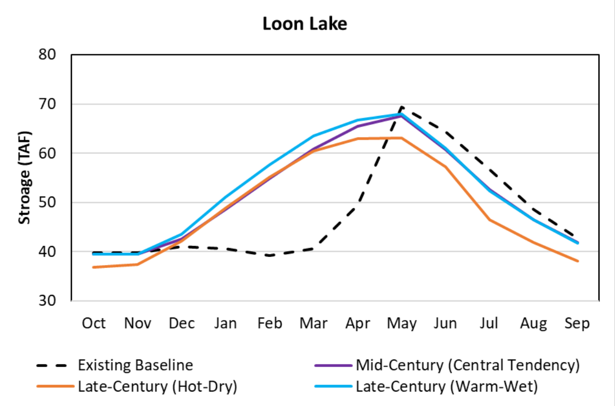
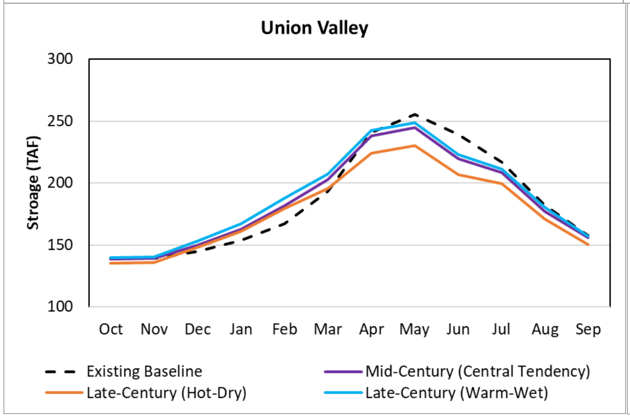

Hell Hole


Loon Lake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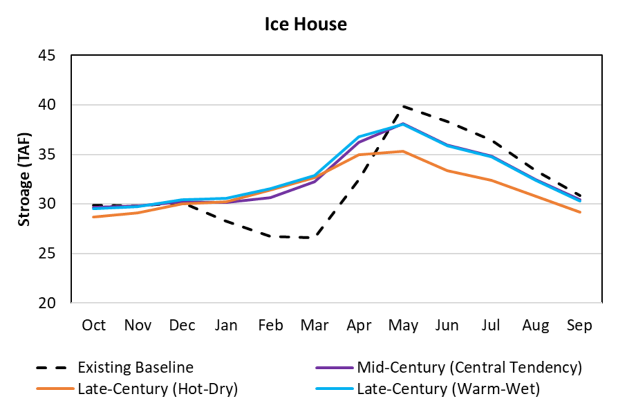
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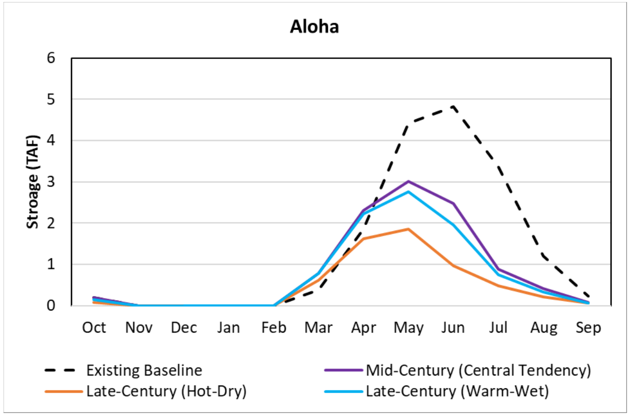
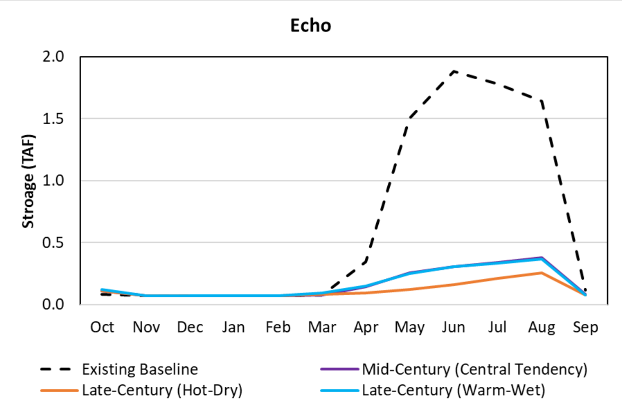

Aloha


Echo

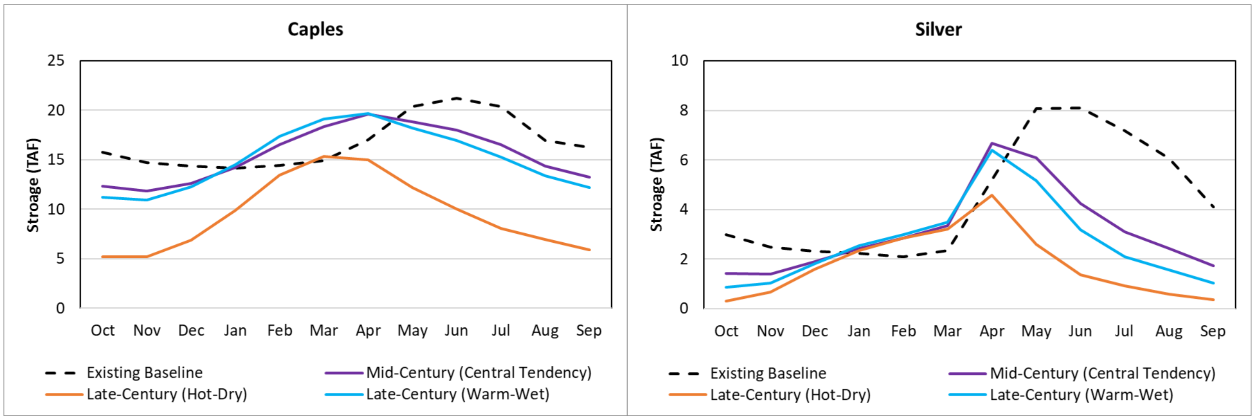


Figure 2-68. Long-term monthly storage variation in the hydropower dams during the Existing Baseline period, Mid-Century (CT), Late-Century (HD), and Late-Century (WW) periods

2.9 Agricultural and Urban Water Supply

2.9.1 Purpose

This section provides an assessment of agricultural and urban water supply for the Existing Baseline, Mid-Future (Central-Tendency), Late-Future (Hot-Dry), and Late-Future (Warm-Wet) climate periods included in the ABC Watersheds Resilience Pilot Study Vulnerability Assessment. The demands, surface water deliveries, groundwater deliveries, and supply-demand imbalances discussed in this report are based on CalSim 3 model results. Details on CalSim 3 and the modeling assumptions for each ABC Watersheds Resilience Pilot climate period are included in Attachment B.

Agricultural water use and demands vary based on land use conditions, projected potential evapotranspiration, and soil moisture conditions. Each of these factors is expected to change in the future, resulting in greater imbalances between supply and demand. Development of projected climate conditions are discussed in Attachment A, which describes the resulting projected changes in annual average temperature for Historic, Mid-Future, and Late-Future conditions. The annual average temperature is projected to increase by 4 °F during the Mid-Future and 6.3 °F by Late-Future (Figure 2-78) with respect to the historical period (1981-2010). In general, rising temperatures are expected to increase agricultural applied water requirements by increasing potential evapotranspiration and reducing soil moisture conditions, requiring more supply to meet agricultural demands. Further details on the modeling of evapotranspiration are discussed in Attachment B which describes the assumptions associated with CalSim 3 modeling.

2.9.2 Methodology

Agricultural & Urban Water Demands

In CalSim 3, agricultural water demands are based on land use assumptions and projected changes to applied water demands based on assumed climate conditions for each scenario. The land use assumptions for the Existing Baseline are based on the average of 2004 through 2013 land use data from the California Land & Water Use database, and supplemented with the County Land Use Surveys from the 1990's and early 2000's. Urban demands are based on the 2020 Urban Water Management Plan (UWMP). These assumptions are consistent with historic and adjusted historic CalSim 3 models developed for DWR's SWP Delivery Capability Report (DCR 2023) (California Department of Water Resources, 2023).

For the Mid-Century (Central-Tendency) period, land use assumptions are consistent with the Existing Baseline. However, urban demands on the American River were extrapolated from 2020 UWMP levels to year 2055 based on project annual demands for year 2085 as described in Appendix D of the 2019 American River Basin Study (2019 ARBS). Furthermore, a growth rate was developed based on annual demand levels in 2020 (from the 2020 UWMP) to projected annual demand levels in 2085 (from the 2019 ARBS report) and used to estimate annual demand levels in 2055. This method was only applied to urban demands from the American River service area. All other urban demands were kept consistent with DWR's SWP Climate Adaptation Strategy CalSim 3 models representing year 2043 (DWR 2025).

The Late-Century (Hot-Dry) and Late-Century (Warm-Wet) periods include land use assumptions consistent with the Existing Baseline and Mid-Century (Central-Tendency) periods. The Late-Century urban demands in the American River service area are consistent with the 2085 annual demands and monthly patterns from the 2019 ARBS study. All other urban demands are consistent with the Mid-Century (Central-Tendency) scenario. Annual urban demands for each demand unit in the study area are presented in Table B-2 and Table B-3 of Attachment B.

Table 2-33 includes the CalSim 3 demand units for the agricultural sector in the Valley Floor region of the American River watershed. In CalSim 3, total long-term average annual demand in this region ranges from 799 TAF to 843 TAF, depending on the climate period. Agricultural demands in this region are projected to increase in the future. This demand is met by surface water deliveries, water reuse, and by groundwater pumping. In general, surface water is the preferred source of delivery and groundwater is relied upon only when surface water supply is insufficient to meet demands.

Table 2-33. Agricultural Demand Units in the American River Valley Floor Region

Demand Unit (CalSim 3)	Demand Unit Description
22_NA	Non-District
22_SA1	Natomas Central Mutual Water Company (MWC), Pleasant Grove-Verona MWC, miscellaneous Settlement Contractors
22_SA2	Feather River Diverters (non-district)
23_NA	Camp Far West Irrigation District, South Sutter Water District, non-district
24_NA2	Placer County Water Agency (PCWA) Zone 5, non-district
24_NA3	PCWA Zone 1
26N_NA	Non-District
26S_NA	Non-District
60N_NA2	Omochumne-Hartnell Water District, Clay Water District, Galt Irrigation District
60N_NA5	Non-District, Riparian Diverters

Table 2-34 includes the CalSim 3 demand units for agricultural purposes in the foothills of the American River watershed. The total long-term average annual demand in this region is expected to increase from 36 TAF to 46 TAF. All of this demand is met by surface water because of a lack of access to groundwater supply.

Table 2-34. Agricultural Demand Units in the American River Foothill Region

Demand Unit (CalSim3)	Demand Unit Description
24_NA1	Nevada Irrigation District (ID)
ELDID_NA1	El Dorado ID Eastern water supply region
ELDID_NA2	El Dorado ID Western water supply region
ELDID_NA3	El Dorado ID El Dorado Hills supply region
GDPUD_NA	Georgetown Divide PUD
EDCOCA_NA1	Potential Ag demands in OCA, north of the South Fork American River.
EDCOCA_NA2	Potential Ag demands in OCA, south of the South Fork American River (west of Hwy 49)
EDCOCA_NA3	Potential Ag demands in OCA, south of the South Fork American River (east of Hwy 49)

Table 2-35 includes the urban demand units included in CalSim 3 for the Valley Floor region. The total long-term average annual demand in this region ranges from 421 TAF to 853 TAF, depending on the climate period. Similar to agricultural demands, urban demands are projected to increase in the future due to population growth. Most of the urban demand in this region is met by surface water deliveries and is supplemented by groundwater pumping when needed.

Table 2-35. Urban Demand Units in the American River Valley Floor Region

Demand Unit (CalSim 3)	Demand Unit Description
22_NU	Northgate 880
23_NU	Self-Supplied
24_NU2	PCWA: Lower Zone 6, Foothill-Sunset WTP; PCWA: City of Lincoln (FO-SU)
24_NU4	Self-supplied
26N_NU1	Self-supplied SSWD – NSA (Arcade NH) SSWD – NSA (Northridge) McClellan Cal-Am WC – Antelope Lincoln Oaks Cal-Am-WC - West Placer Rio Linda Elverta CWD
26N_NU2	Carmichael Water District
26N_NU3	City of Sac (North)
26N_NU4	SSWD - SSA
26N_NU5	Golden State WC – Arden Del Paso Manor WD SCWA Zone 41 – Arden Park Vista Cal-Am WC – Arden
26N_PU1	City of Roseville
26N_PU2	San Juan WD
26N_PU3	Orange Vale WC Citrus Heights WD Fair Oaks WD City of Folsom (Ashland)
26S_NU1	City of Sacramento (S)
26S_NU2	Cal-Am WC – Parkway Cal-Am WC – Suburban Cal-Am WC – Rosemont
26S_NU3	Florin Tokay Park Fruitridge Vista
26S_NU4	Aerojet
26S_PU1	Folsom

Demand Unit (CalSim 3)	Demand Unit Description
26S_PU2	Golden State WC
26S_PU3	California Parks and Recreation
26S_PU4	SCWA – SSA (Zone 40)
26S_PU5	EGWD
26S_PU6	SCWA – CSA, Vineyard SCWA – NSA, Mather-Sunrise Security Park
60N_NU1	Galt, Lodi
60N_NU2	Rancho Murieta CSD
60N_PU	SMUD – Rancho Seco Power Plant

Table 2-36 includes the urban demand units for in the American River Foothill Region of the study area. The total urban demand is forecasted to double by the late century. The long-term average annual demand is 61 TAF in the Existing Baseline and 126 TAF in the Late-Century. Most of this demand is met by surface water, with limited groundwater supply available for the Placer County Water Agency (PCWA) and the Nevada Irrigation District.

Table 2-36. Urban Demand Units in the American River Foothill Region

Demand Unit (CalSim 3)	Demand Unit Description
PCWA3	Alta, Dutch Flat, Colfax, Applegate, Meadow Vista
24_NU1	PCWA: Upper Zone 1 (AU-BO)
24_NU3	Nevada ID – North Auburn
ELDID_NU1	EID Eastern water supply region
ELDID_NU2	EID Western water supply region
ELDID_NU3	EID EDH water supply region
EDCOCA_NU1	EDC OCA (N. SFA)
EDCOCA_NU2	EDC OCA (S. SFA, west of Hwy 49)
EDCOCA_NU3	EDC OCA (S. SFA, east of Hwy 49)
GDPUD_NU	Georgetown Divide PUD
GDPUD_PU	Georgetown Divide PUD

2.9.3 Results

This section presents average annual urban and agricultural demands, surface water deliveries, and groundwater deliveries for each climate period modeled in the ABC Watersheds Resilience Pilot Study. The results shown in this section also present the imbalance between supply and demand, where negative values indicate that the combination of surface water delivery and groundwater delivery is less than the demand.

Table 2-37 demonstrates the proportion of demand met by surface water (including water reuse) and by groundwater in the Valley Floor of the American River watershed. The table also includes the supply-demand imbalance (shortage) of this region. Results indicate that both surface water and groundwater use are projected to increase to meet increased future demands. When demands cannot be met by surface water, the model relies on groundwater pumping. Consequently, greater reliance on groundwater is observed in climate periods with limited surface water supply. In the Mid-Century (CT), Late Century (HD), and Late-Century (WW) scenarios, supply-demand imbalances for the agricultural sector remain similar to the Existing Baseline at the expense of increased levels of groundwater pumping. The Late-Century (HD) scenario, which includes the least surface water supply availability, includes the greatest groundwater use, elevating the risk of overdraft conditions in the valley floor.

Water shortages in the urban sector are greater in the mid-century and late-century despite increased reliance on groundwater pumping. The Late-Century (HD) scenario includes the greatest imbalances due to limited surface water supply and high demand levels. Although the Late-Century (WW) scenario includes similarly high demand levels, it includes more surface water runoff than the HD scenario, which allows for more surface water deliveries and less shortages.

Table 2-37. Long-Term Average Water Budget for Valley Floor Region (TAF/yr)

Scenario	Type	Total Demand	Demand Met by Surface Water	Demand Met by Groundwater	Imbalance
Existing Baseline	Urban	421	306	104	-11
	Agriculture	799	313	480	-6
	Total	**1,220**	**619**	**584**	**-17**
Mid-Century (Central Tendency)	Urban	622	465	124	-33
	Agriculture	853	324	522	-7
	Total	**1,475**	**789**	**646**	**-40**
Late-Century (Hot-Dry)	Urban	766	505	201	-60
	Agriculture	843	308	527	-8
	Total	**1,610**	**813**	**728**	**-69**
Late-Century (Warm-Wet)	Urban	767	553	165	-48
	Agriculture	835	315	514	-6
	Total	**1,602**	**868**	**679**	**-54**

Table 2-38 presents the long-term average annual water budgets for the Foothill region of the American River watershed. This region includes limited access to groundwater pumping and receives most of its supply from surface water. Results indicate that surface water and groundwater use are projected to increase at a smaller rate than the urban demand of this region. Consequently, supply-demand imbalances for urban users become more negative in future climate conditions.

Supply-demand imbalance for the agricultural sector is also impacted in future conditions. The mid-to-late-century results suggest that growing agricultural demand cannot be met by surface water supply. Additionally, groundwater is not available to agricultural users in the Foothill region. The Late-Century HD scenario includes the greater water shortage due to the least surface water availability. The Late-Century WW scenario includes similar annual surface water deliveries and supply-demand imbalances. However, note that this imbalances reported in these tables represent long-term averages and that some years may have higher or lower water shortages.

Table 2-38. Long-Term Average Water Budget for Foothill Region (TAF/yr)

Scenario	Type	Total Demand	Demand Met by Surface Water	Demand Met by Groundwater	Imbalance
Existing Baseline	Urban	61	59	1	-2
	Agriculture	38	28	0	-10

Scenario	Type	Total Demand	Demand Met by Surface Water	Demand Met by Groundwater	Imbalance
	Total	99	86	1	-12
Mid-Century (Central Tendency)	Urban	96	76	3	-17
	Agriculture	46	28	0	-18
	Total	142	104	3	-35
Late-Century (Hot-Dry)	Urban	126	79	5	-42
	Agriculture	46	25	0	-21
	Total	172	104	5	-63
Late-Century (Warm-Wet)	Urban	126	86	3	-37
	Agriculture	46	28	0	-18
	Total	172	113	3	-55

Table 2-39 presents the long-term average annual water budgets for the entire American River watershed for each climate period. The Existing Baseline includes a supply-demand imbalance of -13 TAF/yr for urban users and -16 TAF/yr for agricultural users. The Mid-Century (CT) period includes reduced water supply reliability that mostly impacts the urban sector and agricultural users in the foothills. In the late century, both urban and agricultural users will experience worsening supply-demand imbalances as water supply availability is insufficient to satisfy growing demands. Water shortages and reliance on groundwater pumping will be greatest if the late century is hot and dry.

Table 2-39. Long-Term Average Water Budget for Valley Floor & Foothill Regions (TAF/yr)

Scenario	Type	Total Demand	Demand Met by Surface Water	Demand Met by Groundwater	Imbalance
Existing Baseline	Urban	482	365	105	-13
	Agriculture	837	340	480	-16
	Total	1,319	705	585	-29
Mid-Century (Central Tendency)	Urban	718	540	127	-50
	Agriculture	899	352	522	-25
	Total	1,617	893	649	-75
Late-Century (Hot-Dry)	Urban	892	584	205	-103
	Agriculture	889	333	527	-29
	Total	1,781	917	733	-132
Late-Century (Warm-Wet)	Urban	892	639	168	-85
	Agriculture	881	342	514	-24
	Total	1,773	981	683	-110

Table 2-40 shows the total demand, surface water delivery, and groundwater delivery in critically dry year types based on the Sacramento 40-30-30 Water Supply Index. In the future, upstream snowmelt and unimpaired runoff is expected to decrease, leading to reduced water supply, especially in drier conditions. In the late century, reservoirs are expected to hold less storage year after year. For example, CalSim 3 modeling for the Late-Century (HD) scenario shows that Folsom Reservoir will reach inoperably low storage conditions in 11% of the simulation period (11 out of 100 years). By contrast, the Existing Baseline includes zero instances of inoperably low storage conditions. When storage supply is unavailable, demands are met from groundwater pumping. As shown in Table 2-40, the Late-Century (HD) period includes the greatest proportion of groundwater pumping in critically dry years. Such high levels of groundwater pumping can lead to overdraft, which risks land subsidence, groundwater contamination, and higher pumping costs. In critically dry years, the supply-demand imbalance for the agricultural sector almost doubles from the Existing Baseline to the Late-Century (Hot-Dry) period.

Table 2-40. Critical Year Average Water Budget for Valley Floor & Foothill Regions (TAF/yr)

Scenario	Type	Total Demand	Demand Met by Surface Water	Demand Met by Groundwater	Imbalance
Existing Baseline	Urban	482	343	122	-17
	Agriculture	868	333	507	-28
	Total	1,350	676	629	-46
Mid-Century (Central Tendency)	Urban	718	479	169	-70
	Agriculture	929	329	560	-40
	Total	1,646	808	729	-109
Late-Century (Hot-Dry)	Urban	892	487	279	-127
	Agriculture	911	310	557	-44
	Total	1,803	796	836	-171
Late-Century (Warm-Wet)	Urban	892	553	227	-112
	Agriculture	912	324	548	-40
	Total	1,805	877	776	-152

In conclusion, agricultural and urban demands are expected to increase in the future as surface water supply availability is expected to decrease, causing greater reliance on groundwater and greater imbalances in supply and demand. Increased use of groundwater pumping, especially during droughts, will elevate the risk of overdraft conditions in the valley floor of the American River watershed. Water users in the foothills have less access to groundwater pumping and will experience greater imbalances between supply and demand than users in the valley floor. Average annual shortage for the urban sector grows from 13 TAF/yr (Existing Baseline) to 132 TAF/yr (Late-Century (Hot-Dry)). Average annual shortage for the agricultural sector grows from 16 TAF/yr (Existing Baseline) to 29 TAF/yr (Late-Century (Hot-Dry)). Drier years result in greater shortages despite increased reliance on groundwater.

2.9.4 Limitations

In CalSim 3, groundwater is used to meet demands when they cannot be met by surface water. Furthermore, the model assumes that unlimited groundwater is available to meet most of the demand units in the Valley Floor region, apart from 26N, certain users of 26S, and 60N_NU2 (Rancho Murieta CSD). In the future, groundwater regulations and overdraft conditions may reduce groundwater supply availability. Consequently, groundwater reliability in the mid to late century may be lower than what is forecasted by the CalSim 3 modeling. Reduced groundwater availability would lead to greater supply-demand imbalances in the future, especially for the agricultural sector.

2.10 Quantitative Vulnerability Assessment Summary

In summary, the Quantitative Vulnerability Assessment yielded the following findings for each water sector:

- **Surface Water Supply**: Future conditions are projected to correspond with reduced levels of annual unimpaired inflows entering the American River. Additionally, warmer temperatures and changing precipitation levels will cause a shift in the timing of upstream runoff, where a higher proportion of annual unimpaired inflow occurs in December through March and less occurs in May through August. Reduced levels of unimpaired inflow, especially later in the year, pose challenges in managing water supply to meet downstream demands and regulatory requirements.
    - By the Mid-Century, inflows to the American River may decrease by 22% relative to the Existing Baseline in December through August. Compliance with storage objectives at Folsom and the upper watersheds will be impacted. Lower American River flows will reduce by 9% on an average annual basis, corresponding with water supply available to meet demands of service contractors and to comply with minimum instream flow requirements. Much of the reduced flow volume occurs in May through August. Water supply for hydroelectric projects in the Upper American River is impacted and compliance with regulatory objectives decreases.
    - In the Late-Century, the state of surface water supply was highly dependent on whether the climate trends warm and wet or hot and dry. If warm and wet, rim inflows and snowmelt will generally be higher in December through April than has been observed historically. Much of this water would be spilled from upstream reservoirs due to limited storage capacity and lost to Delta Outflow. Additionally, rim inflows would be less than historical levels in April through August. Overall, a warm and wet Late-Century climate would include 16% less December-August inflows to the American River. Similarly to the Mid-Century outlook, American River flows are significantly reduced relative to the Existing Baseline in May through September.
    - If conditions in the Late-Century are hot and dry, inflow to the American River may reduce by 32% in December through August. A hot and dry Late-Century climate would yield significantly reduced storage levels. Compliance with the Folsom end-of-December storage standard of 230 TAF (Water Forum, 2025) would be significantly impacted. Lower American River flows will reduce by 17% on an average annual basis, causing great challenges in meeting demands of service contractors while also complying with hydroelectric objectives and downstream minimum flow requirements.
- **Groundwater**: Changes in groundwater storage are sensitive to climate and hydrologic conditions where increases in groundwater storage occur during the wet periods when recharge from precipitation and streamflow tends to be higher. Decreases in groundwater storage tend to occur during drier periods when recharge from precipitation and streamflow tends to be lower and when groundwater pumping to meet agricultural demands is higher due to increased temperatures. In summary, groundwater inflows are generally larger during wet years and smaller during drier years which has a larger influence on the change in groundwater storage over time. Key findings from the groundwater analysis include:
    - Seasonal variability in the change in groundwater storage is observed across all climate scenarios, where increases in storage are driven by recharge from precipitation and streams during wet periods and larger decreases in groundwater storage are driven by evapotranspiration and groundwater pumping during drier periods.
        - This dynamic indicates potential vulnerabilities in groundwater supply during the drier periods where groundwater storage declines can result in lower water levels which may result in some wells running dry.
    - Increased temperature and decreased precipitation cause an increase in agricultural demand which can lead to increased groundwater pumping causing larger declines in groundwater storage during the drier periods.

  - The North American, South American, and Cosumnes Subbasin GSPs have indicated other factors that can have an influence on groundwater storage conditions, such conditions are as follows:
    - Increased urbanization can lead to more impervious areas which reduces the amount of groundwater recharge that can occur, reducing the total inflow to the groundwater system which can lead to larger declines in groundwater storage.
    - In wet years, when surface water supplies are abundant, opportunities for managed aquifer recharge can positively impact groundwater conditions by increasing groundwater storage for later use in the drier months and years when surface water supplies are less abundant.
- **Flood Management**: Increased river flows under future climate scenarios are expected to shift the flow frequency curve such that the current AEP event (say the 100-year Flood) would happen more frequently in the future.
  - As levee breaches are generally a function of river flow and stage, and since high flows will occur more frequently in the future, breaches and subsequent inundation of urban areas currently protected by levees will likely occur more frequently in the future.
  - Flood modeling of inundation in urban areas protected by levees requires assumptions on the location, timing, size, and shape of the potential breach. Modeled flood inundation extents, such as those used by DRW in work supporting the Central Valley Flood Protection Plan, and in this analysis to quantify flood impacts, must be interpreted with an understanding of the risk or probability of levee failure.
  - Modeling flood inundation in areas not protected by levees is much more straightforward and does not require assumptions on levee breaches. In such areas, increased climate will extend inundation extents for a given return interval event, as flows and river stages at a given event will increase in the future. Flood maps will expand laterally, potentially inundating more structures, as warmer climates increase river flows.
- **Water Quality:** The water quality assessment for the American River watershed focuses on evaluating key parameters in the American River, Cosumnes, and Bear River basins. These parameters include river temperature, dissolved oxygen levels, and the presence of algal blooms. The study examines these factors under current conditions and three potential future climate scenarios to understand how water quality might change over time. Key findings from the water quality analysis can be summarized as follows:
  - American River temperature changes:
    - All future climate scenarios show increased river temperatures compared to the baseline.
    - The Late-Century HD scenario demonstrates the most significant temperature increases.
    - Summer months exhibit higher temperatures across all scenarios.
    - Temperatures generally increase as the river progresses downstream.
  - Cosumnes and Bear rivers temperature changes:
    - While not directly modeled, these rivers are expected to experience similar temperature increase patterns based on air temperature projections.
    - The impact might be less severe than in the American River due to more stable flow patterns.
  - Dissolved Oxygen:
    - Dissolved oxygen levels are expected to decrease as water temperatures rise.
    - In the American River at Watt Avenue, the HD scenario predicts a potential 6% reduction in dissolved oxygen in June.

  - Cyanobacterial Blooms:
    - The predicted temperature increases in the American River are unlikely to substantially elevate the risk of cyanobacterial blooms, as temperatures remain below the optimal range for bloom formation.
- **Ecosystem**: Increases in temperature are driving conditions where snowmelt occurs earlier in the year and more precipitation to fall as rain rather than snow. In upper watersheds, this results in a reduction in late spring and summer baseflow, warmer water temperatures, higher winter peak flows, and in some cases, a reduction in total annual water supply. These changes, as they propagate downstream, are projected to result in additional exceedances for key minimum flow and water temperature thresholds, promoting conditions that are threatening for aquatic, riparian, and groundwater-dependent ecosystems. Warmer temperatures also result in seasonal shifts in total climatic water deficit (CWD), resulting in an overall decrease in forest health and ecosystem services in upper watershed areas. This is exacerbated by a heightened risk of more severe wildfires, resulting in a degradation of the condition of the landscape in these areas. Ultimately, outcomes of the Vulnerability Assessment indicate a heightened risk to ecosystems under future climate conditions. Existing infrastructure and operations are unable to fully mitigate many of the warmer and drier conditions that threaten ecological communities. Key results include the following:
  - Relative to the Existing Baseline, the frequency of monthly average flows exceeding 800 cfs decreases by between 2 to 10% below Lake Natoma. Conversely, shifts in minimum flow exceedances below Camp Far West Reservoir and Granlees Dam are largely unchanged under future conditions.
  - Changes to upper watershed hydrographs along the North Fork, Middle Fork, and South Fork American rivers are far more pronounced than those along the Bear and Cosumnes rivers, demonstrating increased peak flows during the wet season and a reduction in flows during late spring and summer months.
  - The frequency of daily water temperatures exceeding 65 degrees Fahrenheit between May 15 and September 30 increases by 20% to 28%, depending on scenario.
  - CWD decreases during the winter and spring in the upper watershed, suggesting earlier snowmelt and drier conditions during the fall and summer. Annually, this results in an increase in total CWD by up to 30% in some locations in these areas.
  - By the late century, decadal wildfire probability has increased by up to 60% in some locations. Similarly, projected changes in burn areas indicate up to a 100% increase in upper watershed areas.
  - The frequency of 2-year peak flows is likely to increase but given the sharper peaks in hydrographs noted in upstream areas of the American River watershed, the duration of beneficial flows that promote floodplain inundation and spawning habitat may decrease.
- **Recreation**: Recreational opportunities within the American River are largely dependent on total annual water supplies, reservoir operation, and shifts in temperatures. During drier water years, the prevalence and quality of recreation in lakes, rivers, and upper watersheds may decrease, and in wet years, conditions may preclude certain activities due to high flows and storage. Changes under climate change are highly location specific due to differences in existing infrastructure, water management regimes, and other factors. Key findings from the recreation assessment include the following:
  - The frequency of conditions sufficient for boat access at Folsom Lake decrease by between 3 to 14%, depending on climate scenario. Similar trends at Camp Far West Reservoir are also present (2% to 9%). However, the frequency of recreational days at Rollins Lake increases by up to 31% due to rarer occurrences of reservoir elevations that preclude boat access.

  - The quality of recreation along the South Fork American River below Chili Bar is projected to decrease under the Mid-Century and Late-Century (HD scenarios). However, assuming existing infrastructure can adequately manage increases in peak flows, the Late-Century (WW) scenario may result in a greater frequency of higher quality recreation in some years.
  - Because the Cosumnes River is unregulated, changes under future conditions suggest an overall decrease in the number of days suitable for recreation along all runs of the Cosumnes River. Decreases range from roughly 10 to 15% for the upper and lower runs and between 4 to 9% for the Middle Fork run.
  - Up to 80% reductions on April 1 SWE are noted for some locations in the upper watershed, suggesting a decrease in the total number of recreation days for snow-based recreation activities.
  - The frequency of flows above 10,000 cfs between October and April along the American River Parkway increase by roughly 2 to 4%. This is likely to result in more frequent closures of Parkway facilities during these months, reducing the availability of recreational activities between late fall and early spring.
- **Hydropower**: Changes in the magnitude and timing of American River inflows can have a significant effect on hydroelectric production. Generally, power production is higher during summer months when reservoir levels are higher and water is released to satisfy delivery requirements. Reductions to storage levels in the late spring and summer, as projected by future climate modeling, will result in reduced energy capacity and generation. Over time, adjustments to hydropower operations will be needed to maintain balance in energy production with flood protection, downstream flow standards, and water supply demands. Under current operations, projected changes to climate will cause overall reductions to reservoirs in the American River watershed; thereby reducing the potential for hydropower production. Energy generation will be especially impacted in May through August. Key results include the following:
  - Reduction in storage at Folsom Reservoir, the largest hydropower facility in the American River watershed, is projected to decrease average annual energy generation by about 13% to 29%.
  - Most reservoirs in the American River watershed that are compatible with hydropower production are projected to include lower storage levels in the future, particularly in May through August. This results in less total energy generated through hydropower in the entire watershed.
  - Storage conditions are sensitive to extreme changes in climate. Hydropower production is most impacted when the climate becomes hot and dry. If the late century is warm and wet, hydropower production will be relatively high in December through April, but relatively low in May through August, and low overall on an average annual basis relative to Existing Conditions.
- **Agriculture and Urban Water Supply:** Agricultural and urban demands are expected to increase in the future and surface water supply availability is expected to decrease, causing greater reliance on groundwater and greater imbalances in supply and demand. Average annual temperature and potential evapotranspiration are projected to increase, while soil moisture conditions are projected to decrease. Consequently, agricultural applied water requirements will increase, requiring more water supply to meet demands. However, projected average annual surface water supply is projected to decrease, causing greater reliance on groundwater pumping and greater water shortages for agricultural and urban users.
  - Average annual shortage for the urban sector grows from 13 TAF/yr (Existing Baseline) to 132 TAF/yr (Late-Century (HD)).
  - Average annual shortage for the agricultural sector grows from 16 TAF/yr (Existing Baseline) to 29 TAF/yr (Late-Century (HD)).

- With limited access to groundwater, water users in the foothills will experience greater shortages than users in the valley floor.
- Drier years result in greater shortages and greater risk of overdraft conditions caused by elevated reliance on groundwater.
- Increased use of groundwater pumping, especially during droughts, will elevate the risk of overdraft conditions in the valley floor of the American River watershed.

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Attachment A. Climatic and Hydrologic Metrics

The evaluation of climate vulnerability relies on existing data sets of the main drivers of climate change effects, primarily projected changes in temperature and changes in precipitation under future climate change conditions. In addition, anticipated hydrological responses to these climatic changes such as flooding, drought, and wildfire risks are derived from existing sources including Cal-Adapt, California Department of Water Resources (DWR) climate change studies, and California climate change assessments. The vulnerability types consist of changes in the following areas: temperature, precipitation, runoff, drought, flooding, and wildfire (Table A-1).

Table A-1. Details of the Climatic and Hydrologic Vulnerability Metrics

S. No.	Climatic/ Hydrologic Metrics	Definition	Period	Analysis period
C1	Temperature	Projected change in annual average temperature (degrees F [°F])	Annual	Historical: 1981 to 2010 Mid Future: 2041 to 2070 Late Future: 2071 to 2100
C2	Extreme Heat Days	Projected change in number of extreme heat days per year when daily maximum temperature is above 95°F (days/yr)	Annual	Historical: 1981 to 2010 Mid Future: 2041 to 2070 Late Future: 2071 to 2100
C3	Precipitation	Projected change in annual precipitation (%)	Annual	Historical: 1981 to 2010 Mid Future: 2041 to 2070 Late Future: 2071 to 2100
C4	Extreme Precipitation	Projected change in 1% annual exceedance probability precipitation (%)	Annual	Historical: 1981 to 2010 Mid Future: 2041 to 2070 Late Future: 2071 to 2100
H1	Runoff	Projected change in annual total flow (baseflow + surface runoff) (%)	Annual	Historical: 1981 to 2010 Mid Future: 2041 to 2070 Late Future: 2071 to 2100
H2	Floods	Projected changes in 1% annual exceedance probability flows based on 1-day and 3-day unimpaired flow (%)	Annual	Historical: 1961 to 2010 Mid Future: 2016 to 2065 Late Future: 2051 to 2100
H3	Snow Water Equivalent	Projected change in April 1 SWE (%)	Annual	Historical: 1981 to 2010 Mid Future: 2041 to 2070 Late Future: 2071 to 2100
H4	Drought	Projected change in maximum cumulative annual deficit value based on total flow (%)	Annual	Historical: 1961 to 2010 Mid Future: 2016 to 2065 Late Future: 2051 to 2100
H5	Wildfire	Projected changes for estimated decadal wildfire probabilities (%)	Decadal	Historical: 1981 to 2010 Mid Future: 2041 to 2070 Late Future: 2071 to 2100

AEP = Annual Exceedance Probability

C1. Temperature

Climate change is expected to cause an increase in temperature in the future. Projected changes in temperature are calculated by analyzing the following index:

- *Projected changes in average annual temperature*

Methodology: Temperature metric is estimated using the projected temperature from 15 climate models under SSP2-4.5 (Shared Socioeconomic Pathway), SSP3-7.0, and SSP5-8.5. Projected temperature from 41 climate projections is used to estimate the change in annual temperature. The median changes are calculated for mid future (2041-2070) and late future (2071-2100) periods with respect to historical period (1981-2010).

Approach

a. Daily temperature for the 1/32nd LOCA2-Hybrid grids in American River watershed domain was used from the 41 climate projections.
b. The daily temperature was accumulated at annual scale (October to September) for estimating the index values during Historical (1981 to 2010), Mid (2041 to 2070) and Late (2071 to 2100) future periods.
c. The absolute values of the annual index during the Historical, Mid and late future periods were utilized to calculate the relative change for the future periods for 41 climate projections.
d. The projected change in the temperature was reported as the median change of the annual index from the 41 climate projections during the Mid and late future.

Key Results: The annual average temperature is projected to increase by 4 ºF during the mid future and 6.3 ºF during the late future (Figure A-1). The Valley Floor region currently experiences warmer conditions than the Sierra region; however, climate projections indicate that the Sierra is expected to undergo a more substantial increase in temperatures over time. These rising temperatures are anticipated to accelerate snowmelt, shift the timing of runoff, and increase evapotranspiration, collectively influencing regional water availability and ecosystem dynamics.

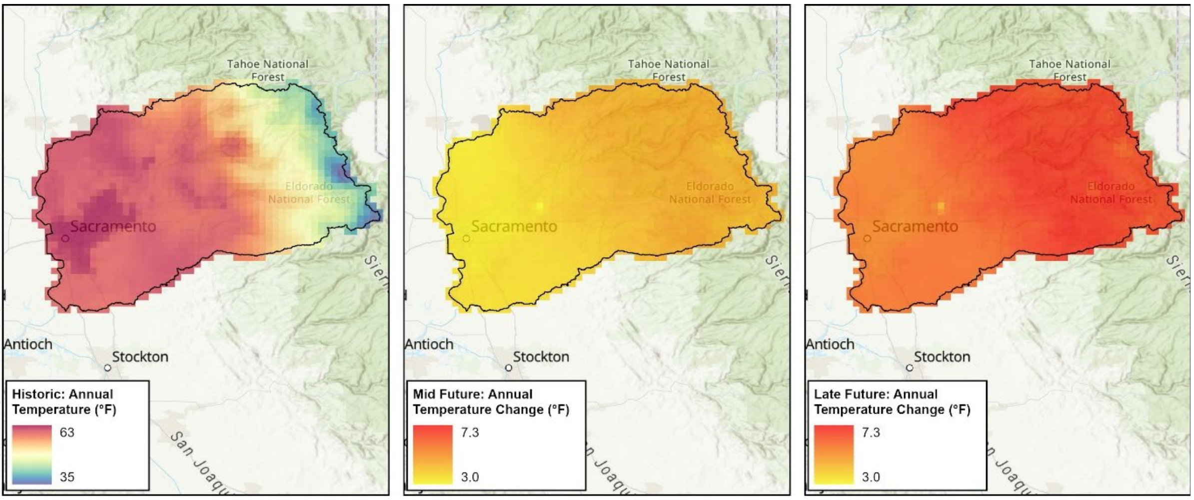

Figure A-1. Change in the annual temperature during Mid future (2041 to 2070, center, °F) and late future (2071 to 2100, right, °F) with respect to historical period (1981 to 2010, left, °F) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

C2. Extreme Heat Days

Climate change is expected to cause an increase in heat days due to rise in temperature in the future. Projected changes in heat days are calculated by analyzing the following index:

- *Projected changes in extreme heat days*

Methodology: Extreme Heat Days metric is estimated using the projected temperature from 15 climate models under SSP2-4.5 (Shared Socioeconomic Pathway), SSP3-7.0, and SSP5-8.5. Projected maximum temperature from 41 climate projections is used to estimate the change in extreme heat days. Extreme heat days are defined as the days of the year when daily maximum temperature is above 95 °F.
The median changes are calculated for mid future (2041-2070) and late future (2071-2100) periods with respect to historical period (1981-2010).

Approach

a. Daily maximum temperature for the 1/32nd LOCA2-Hybrid grids in American River watershed domain was used from the 41 climate projections. Daily extreme heat day was identified as days with maximum temperature higher than 95 °F.

b. The daily extreme heat days was accumulated at annual scale (October to September) for estimating the index values during Historical (1981 to 2010), Mid (2041 to 2070) and Late (2071 to 2100) future periods.

c. The absolute values of the annual index during the Historical, Mid and Late future periods were utilized to calculate the relative change for the future periods for 41 climate projections.

d. The projected change in the extreme heat days was reported as the median change of the annual index from the 41 climate projections during the Mid and late future.

Key Results: The extreme heat days are projected to increase by 23 days/year during the mid future and 39 days/year during the late future (Figure A-2). Warmer areas of the Valley Floor are more susceptible to experiencing extreme heat days, and projections indicate that the number of such days will rise by approximately 20 to 40 across the region. Warmer stream and river temperatures will reduce suitable habitat for cold-water species. Most commercial agriculture is located in the valley floor and foothills. This increase in extreme heat is expected to elevate irrigation demands, raise water temperatures, and affect recreational activities, with broad implications for both resource management and community well-being.

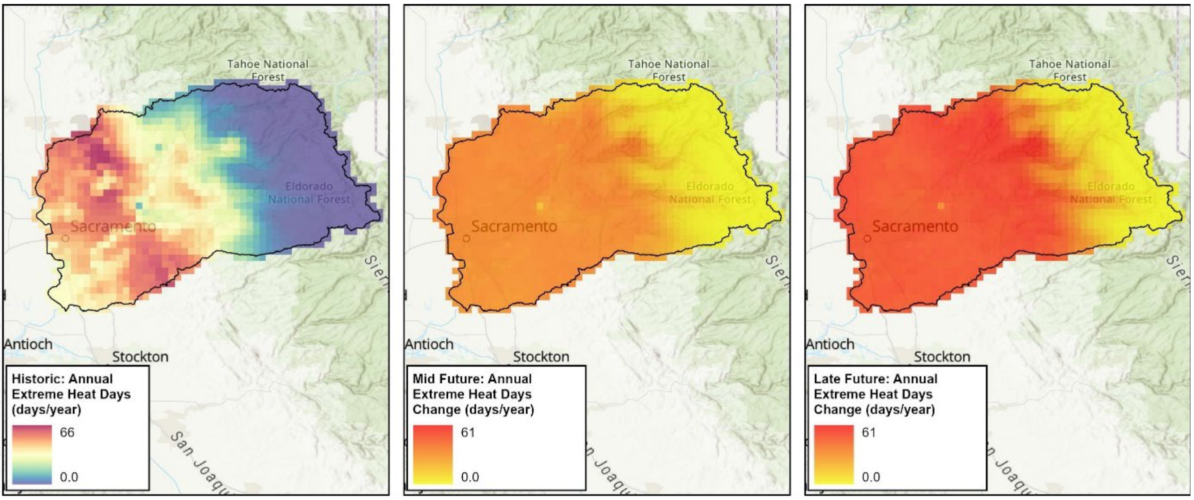

Figure A-2. Change in the extreme heat days during Mid future (2041 to 2070, center, days/year) and late future (2071 to 2100, right, days/year) with respect to historical period (1981 to 2010, left, days/year) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

C3. Precipitation

Climate change is expected to change the average precipitation in the future. Projected changes in precipitation are calculated by analyzing the following index:

- *Projected changes in average annual precipitation*

Methodology: Precipitation metric is estimated using the projected temperature from 15 climate models under SSP2-4.5 (Shared Socioeconomic Pathway), SSP3-7.0, and SSP5-8.5. Projected precipitation from 41 climate projections is used to estimate the change in annual precipitation. The median changes are calculated for mid future (2041-2070) and late future (2071-2100) periods with respect to historical period (1981-2010).

Approach

a. Daily precipitation for the 1/32nd LOCA2-Hybrid grids in American River watershed domain was used from the 41 climate projections.

b. The daily precipitation was accumulated at annual scale (October to September) for estimating the index values during Historical (1981 to 2010), Mid (2041 to 2070) and Late (2071 to 2100) future periods.

c. The absolute values of the annual index during the Historical, Mid and late future periods were utilized to calculate the relative change for the future periods for 41 climate projections.

d. The projected change in the precipitation was reported as the median change of the annual index from the 41 climate projections during the Mid and late future.

Key Results: The annual precipitation is projected to increase by 0.2% during the mid future and 2.8% during the late future (Figure A-3). The Sierra region receives substantially more precipitation than the Valley Floor, and projected increases in annual precipitation are relatively modest for both the mid-future and late-future periods. These changes are expected to be most pronounced during the winter and summer months. Even with modest shifts, variations in precipitation patterns will affect a wide range of sectors, particularly surface water and groundwater supplies.

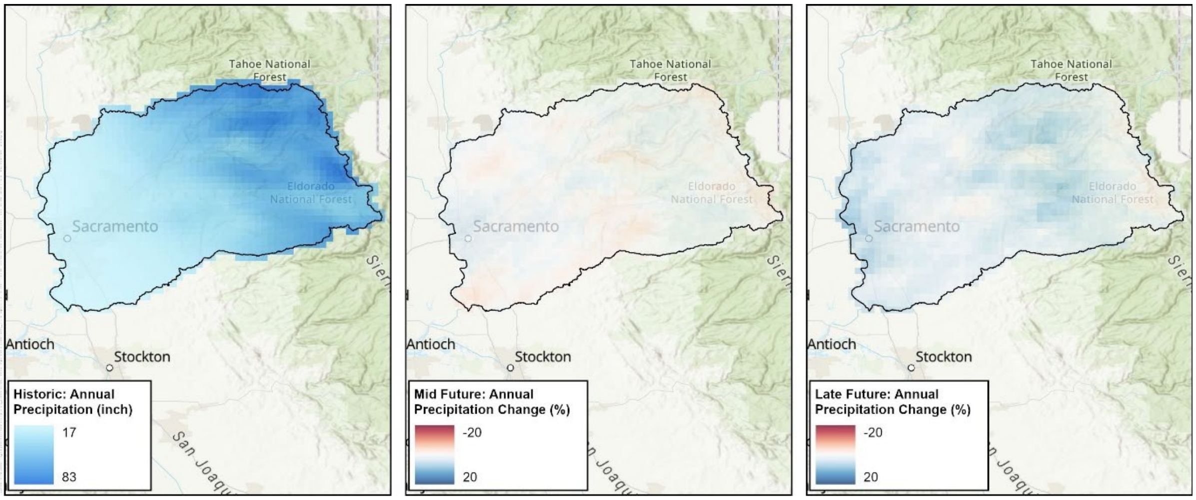

Figure A-3. Change in the annual precipitation during Mid future (2041 to 2070, center, %) and late future (2071 to 2100, right, %) with respect to historical period (1981 to 2010, left, inch) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

C4. Extreme Precipitation

Climate change is expected to change the extreme precipitation in the future. The projected changes in 1% AEP value are calculated based on daily precipitation in the future periods compared to historical period. Projected changes in extreme precipitation are calculated by analyzing the following index:

- *Projected changes in extreme precipitation*

Methodology: Extreme precipitation metric is estimated using the projected precipitation from 15 climate models under SSP2-4.5 (Shared Socioeconomic Pathway), SSP3-7.0, and SSP5-8.5. Projected precipitation from 41 climate projections is used to estimate the change in extreme precipitation. Extreme precipitation is defined as the 1% AEP precipitation value. The maximum value is estimated for each water year from daily precipitation time series. The change in the 99th percentile values of the daily maxima precipitation is computed for mid future (2041-2070) and late future (2071-2100) periods with respect to historical period (1981-2010) and the median from the 41 climate projections is estimated.

Approach

a. Daily precipitation for the 1/32nd LOCA2-Hybrid grids in American River watershed domain was used from the 41 climate projections.

b. The daily precipitation was utilized for estimating 99th percentile values of daily maxima precipitation for each water year at annual scale (October to September) for estimating the index values during Historical (1981 to 2010), Mid (2041 to 2070) and Late (2071 to 2100) future periods.

c. The absolute values of the annual index during the Historical, Mid and late future periods were utilized to calculate the relative change for the future periods for 41 climate projections.

d. The projected change in the extreme precipitation was reported as the median change of the annual index from the 41 climate projections during the Mid and late future.

Key Results: The extreme precipitation is projected to increase by 15% during the mid future and 18% during the late future (Figure A-4). Upper watersheds are projected to experience a greater increase in extreme precipitation compared to other areas within the watershed. This heightened intensity of precipitation is expected to serve as the primary driver of flood risks, with significant implications for regional water management and hazard preparedness.

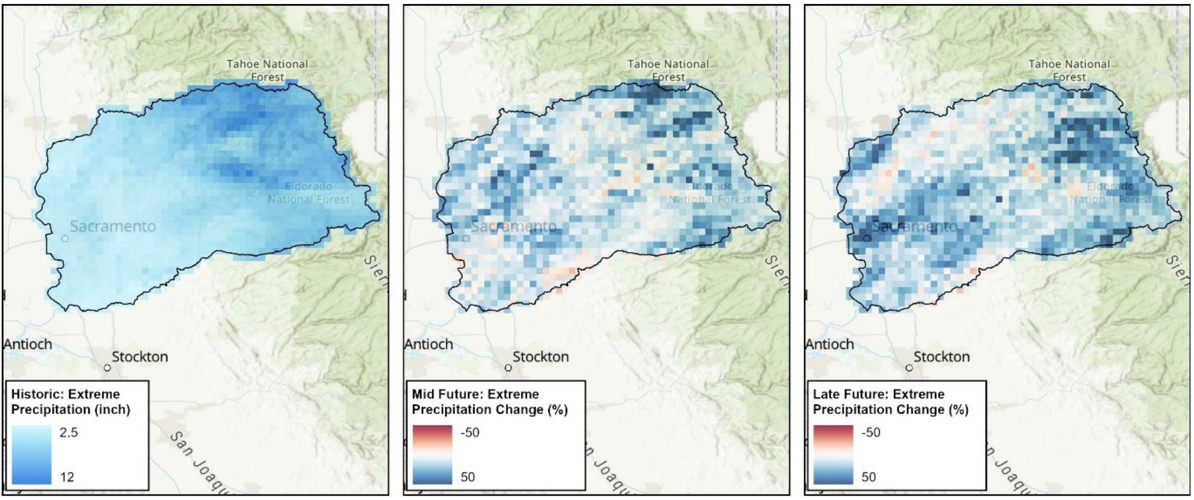

Figure A-4. Change in the extreme precipitation during Mid future (2041 to 2070, center, %) and late future (2071 to 2100, right, %) with respect to historical period (1981 to 2010, left, inch) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

H1. Runoff

Climate change is expected to change the total runoff in the future. Projected changes in runoff are calculated by analyzing the following index:

- *Projected changes in average total runoff*

Methodology: VIC model-simulated surface runoff and base flow fluxes for 15 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5 is used to estimate the change in annual total runoff. Total runoff is defined as the grid-based flow using the summation of surface runoff and baseflow aggregated at the annual scale based on each water year. The median changes are calculated for mid future (2041-2070) and late future (2071-2100) periods with respect to historical period (1981-2010).

Approach

a. VIC model-simulated daily total runoff for the 1/32nd LOCA2-Hybrid grids in American River watershed domain was estimated by grid-wise summation of the surface runoff and baseflow from the 41 climate projections. VIC simulated surface runoff and baseflow values are all the grids that were extracted separately for the different climate projections.

b. The daily total runoff was accumulated at annual scale (October to September) for estimating the index values during Historical (1981 to 2010), Mid (2041 to 2070) and Late (2071 to 2100) future periods.

c. The absolute values of the annual index during the Historical, Mid and late future periods were utilized to calculate the relative change for the future periods for 41 climate projections.

d. The projected change in the total runoff was reported as the median change of the annual index from the 41 climate projections during the Mid and late future.

Key Results: The annual total runoff is projected to decrease by 2% during the mid future and increase 0.4% during the late future (Figure A-5). The Sierra region currently generates more runoff than the Valley Floor due to its higher precipitation levels. Although precipitation is generally projected to increase across the study domain, rising temperatures—particularly in the Sierra—are expected to elevate evapotranspiration rates, which will in turn reduce future runoff. While increases in runoff can enhance water supply reliability, reductions in runoff may heighten the region's vulnerability to drought conditions.

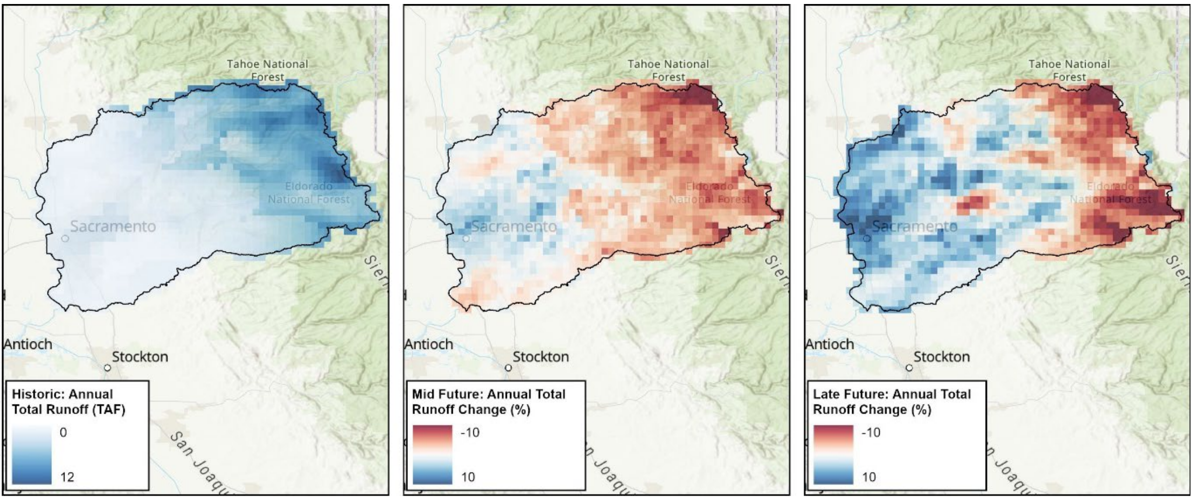

Figure A-5. Change in the total runoff during Mid future (2041 to 2070, center, %) and late future (2071 to 2100, right, %) with respect to historical period (1981 to 2010, left, TAF) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

H2. Floods

Flood impacts are estimated by forecasting the impacts of flood events for the future period. The projected changes in 1% AEP flows are calculated based on 1-day and 3-day unimpaired flow in future period compared to historical period. Projected changes in floods are calculated by analyzing the following indices:

- *Projected changes in 1% AEP flows based on 1-day unimpaired flow*
- *Projected changes in 1% AEP flows based on 3-day unimpaired flow*

Methodology: Flood analysis is conducted using the VIC model-simulated total runoff (summation of surface runoff and baseflow) for 15 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5. Total runoff is defined as the grid-based flow using the summation of surface runoff and baseflow. A –day and 3-day moving average for total runoff is generated from daily fluxes and the maximum value is estimated for the water years. The change in the 99th percentile values of the 1-day and 3-day maxima total runoff is computed for mid future (2016 to 2065) and late future (2051 to 2100) periods with respect to historical period (1961 to 2010) and the median from the 41 climate projections is estimated.

Approach

a. VIC model-simulated daily total runoff for the 1/32nd LOCA2-Hybrid grids in American River watershed domain was estimated by grid-wise summation of the surface runoff and baseflow from the 41 climate projections. VIC simulated surface runoff and baseflow values are all the grids that were extracted separately for the different climate projections.

b. For 1-day exceedance probability, the daily total runoff was utilized for estimating the annual maxima of daily total runoff for estimating the 99th percentile values during Historical (1981 to 2010), Mid (2041 to 2070) and Late (2071 to 2100) future periods. For 3-day exceedance probability, the 3-day moving average total runoff was estimated from the daily total runoff and the 99th percentile values were estimated based on annual maxima 3-day total runoff for Historical, Mid, and late future periods.

c. The absolute values of the 99th percentile values of the daily maxima and 3-day maxima total runoff during the Historical, Mid and late future periods were utilized to calculate the relative change for the future periods for 41 climate projections.

d. The projected change in the flood was reported as the median change of the index from the 41 climate projections during the Mid and late future.

Key Results: The 1-day flood magnitude is projected to increase by 19% in the mid-future period and by 31% in the late-future period (Figure A-6). In comparison, the projected increase in the 3-day flood is slightly lower, with estimated changes of 11% for the mid-future and 20% for the late-future period (Figure A-7). The Sierra region is highly susceptible to flooding, driven largely by extreme precipitation events, reduced snowpack, and earlier snowmelt. Consistent with projected increases in extreme precipitation, flood magnitudes are expected to rise moderately in the mid-future period and more substantially by the late-future period.

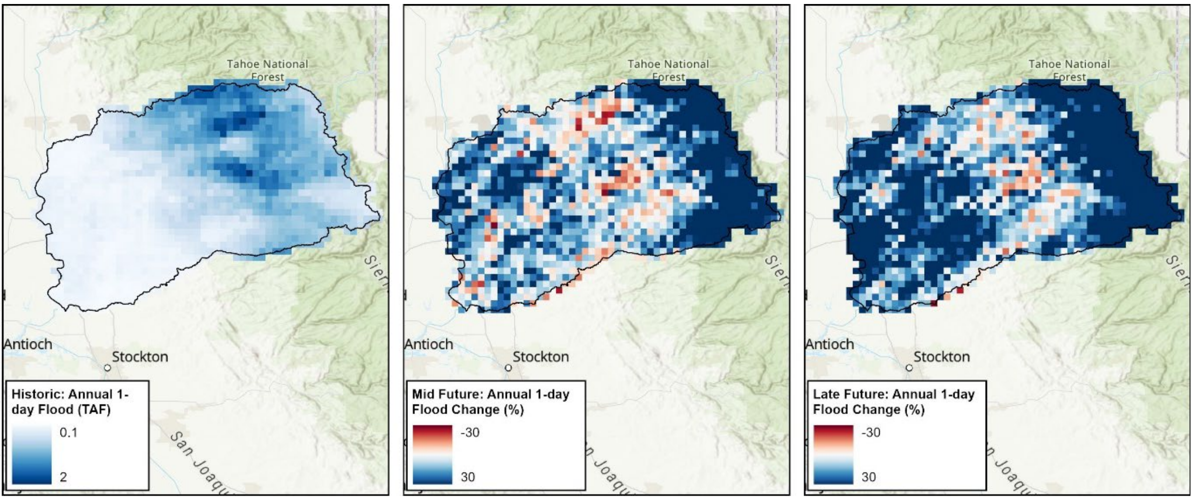

Figure A-6. Change in the 1-day flood during Mid future (2016 to 2065, center, %) and late future (2051 to 2100, right, %) with respect to historical period (1961 to 2010, left, TAF) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

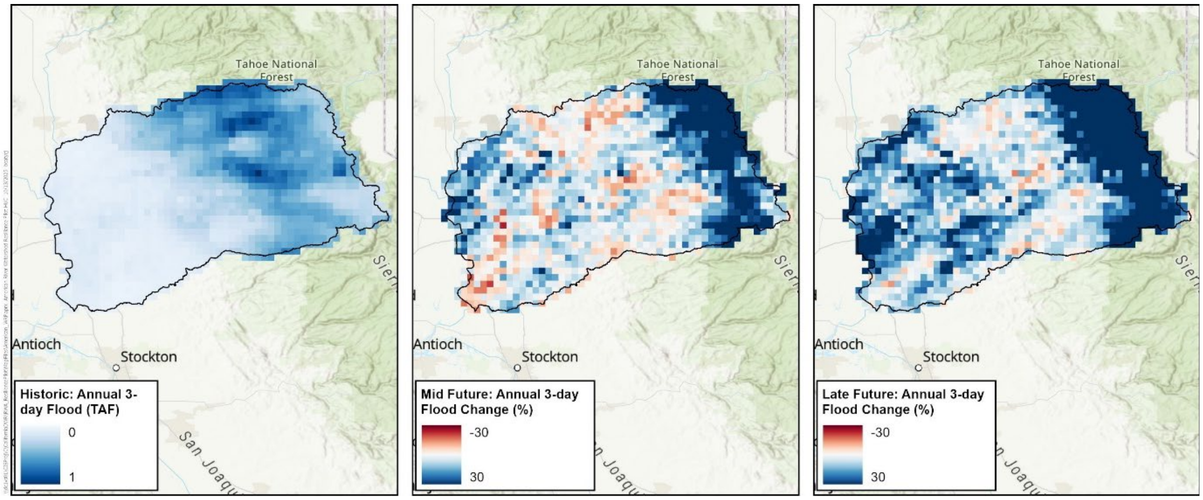

Figure A-7. Change in the 3-day flood during Mid future (2016 to 2065, center, %) and late future (2051 to 2100, right, %) with respect to historical period (1961 to 2010, left, TAF) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

H3. Snow Water Equivalent

Climate change is expected to significantly reduce snow coverage in the future due to rising temperature. As warmer conditions persist, a greater proportion of winter precipitation will fall as rain rather than snow, leading to diminished seasonal snowpack. Projected changes in snow are calculated by analyzing the following index:

- *Projected changes in April 1 Snow Water Equivalent (SWE)*

Methodology: VIC model-simulated SWE fluxes for 15 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5 is used to estimate the change in April 1 snow. The threshold used for the April 1 SWE calculation was 10 mm (0.4 inch). The median changes are calculated for mid future (2041 to 2070) and late future (2071 to 2100) periods with respect to historical period (1981 to 2010) from 41 climate projections.

Approach

a. VIC model-simulated daily SWE for the 1/32nd LOCA2-Hybrid grids in American River watershed domain was used from the 41 climate projections.

b. The April 1 SWE with value greater than 10 mm (0.4 inch) was extracted for each year during Historical (1981 to 2010), Mid (2041 to 2070) and Late (2071 to 2100) future periods.

c. The absolute values during the Historical, Mid and late future periods were utilized to calculate the relative change for the future periods for 41 climate projections.

d. The projected change in the April 1 SWE was reported as the median change from the 41 climate projections during the Mid and late future.

Key Results: The April 1 snow is projected to decrease by 66% (7.2 inches) during the mid future and 79% (4.6 inches) during the late future relative to the historical value of 16.8 inches (Figure A-8). A significant reduction in snowpack is projected for both future periods, driven by earlier snowmelt and a shift toward more winter precipitation falling as rain rather than snow. Accelerated snowmelt is expected to trigger earlier runoff, reduce spring streamflow, elevate flood risks, and create additional challenges for reservoir operations.

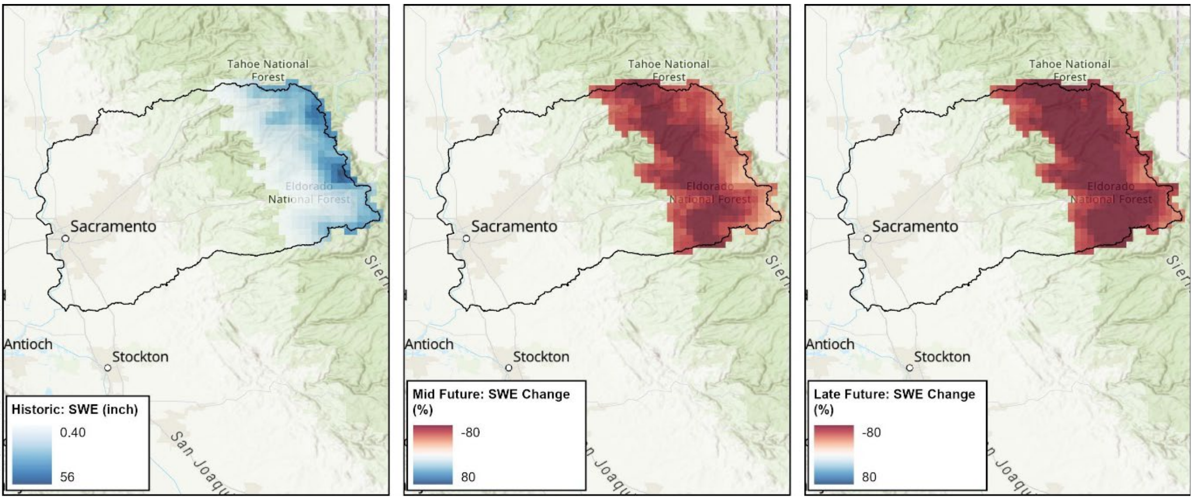

Figure A-8. Change in the April 1 snow water equivalent (SWE) during Mid future (2041 to 2070, center, %) and late future (2071 to 2100, right, %) with respect to historical period (1981 to 2010, left, inch) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5. The threshold for the SWE estimate was 0.4 inches (10 mm)

H4. Drought

Drought is assessed by comparing the projected water deficit conditions for future climate conditions. Projected changes in drought are calculated by analyzing the following index:

- *Projected changes in drought severity*

Methodology: VIC model-simulated surface runoff and base flow fluxes models for 15 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5 is used to estimate the change in drought severity. Total runoff is defined as the grid-based flow using the summation of surface runoff and baseflow aggregated at the annual scale based on each water year.

Drought severity is estimated using the grid-based runoff deficit simulated by the VIC model for 41 climate projections. Although there are many different categories of drought (meteorological, hydrological, agricultural, and socioeconomic), and approaches to measuring drought (Standardized precipitation index, Palmer drought severity index, surface water supply index), for the purpose of this assessment, drought is calculated as the annual change in the dryness (runoff). This method is chosen for its simplicity and consistency across all watersheds. Drought severity is defined as the maximum summation of the consecutive negative values. The change in the index is estimated as the median change from 41 climate projections for mid future (2016 to 2065) and late future (2051 to 2100) periods with respect to historical period (1961 to 2010).

Approach

a. VIC model-simulated daily total runoff for the 1/32nd LOCA2-Hybrid grids in American River watershed domain was estimated by grid-wise summation of the surface runoff and baseflow from the 41 climate projections. VIC simulated surface runoff and baseflow values are all the grids that were extracted separately for the different climate projections.

b. The daily values were accumulated at annual water-year scale for the estimation of the historical annual mean for Historical (1961 to 2010), Mid (2016 to 2065) and Late (2051 to 2100) future periods. Runoff deficit (when annual value minus long-term historical value is negative) was calculated for each year for Mid and late future periods using the Historical annual value as threshold.

c. The years with the positive deficit value were assigned to be zero. The cumulative deficit values were estimated for the consecutive negative values. The drought severity was estimated as the minimum value of the cumulative annual deficit value for the Historical, Mid, and late future periods.

d. The relative percentage change in the drought severity was calculated for the Historical, Near, and late future periods from 41 climate projections.

e. The projected change in drought severity was reported as the median change of the annual index from the 41 climate projections during the Mid and late future.

Key Results: The drought severity is projected to increase by 4% during the mid future and 5% during the late future (Figure A-9). The Sierra region is projected to experience more severe drought conditions in future periods as rising temperatures and reduced runoff diminish available water resources. In contrast, anticipated increases in precipitation across the Valley Floor may help moderate drought impacts in that area. Severe drought intensifies landscape dryness, contributing to crop failures, declining forest health, and heightened wildfire risk, with broad implications for ecological resilience and resource management.

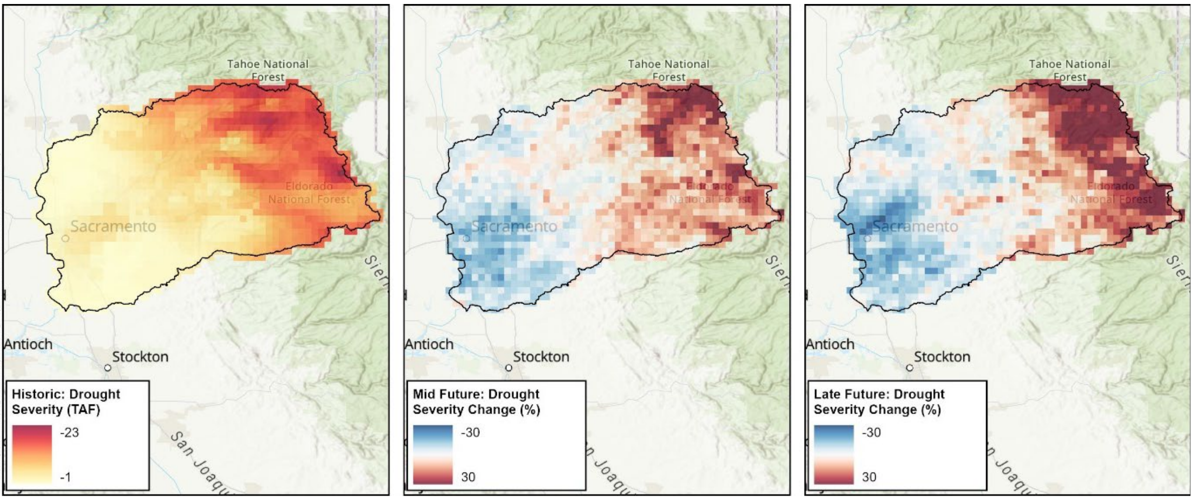

Figure A-9. Change in the drought severity during Mid future (2016 to 2065, center, %) and late future (2051 to 2100, right, %) with respect to historical period (1961 to 2010, left, TAF) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

H5 Wildfire

Increases in hot, dry weather can increase wildfire risk. Climate change can increase drought risks while higher temperatures create ideal conditions for fires to start and spread. Projected changes in wildfires are calculated by analyzing the following index:

- *Projected changes in decadal wildfire probabilities*

Methodology: Wildfire index is estimated using the decadal wildfire probability data for Business as Usual (BAU) population scenario and four climate models under RCP 4.5 and RCP 8.5 for CMIP5 from the Cal-Adapt database. The decadal wildfire probabilities median values are calculated for historical (1981 to 2010), mid future (2041 to 2070) and late future (2071 to 2100) periods.

Approach

a. Decadal wildfire probabilities data for BAU population scenario from four climate models under RCP 4.5 and RCP 8.5 for the 1/16th LOCA grids in American River watershed domain was accessed from the Cal-Adapt database.

b. The absolute values of the decadal wildfire probabilities were estimated for historical (1981 to 2010), mid future (2041 to 2070) and late future (2071 to 2100) periods for eight climate projections.

c. The projected values of the decadal wildfire probabilities were reported as the median change from the eight climate projections during the Mid and late future under BAU population scenario.

Key Results: The average decadal wildfire probability for the region is 17% for historical period and projected to be 25% for the mid future, and 32% for the late future (Figure A-10). Upper watersheds are particularly susceptible to wildfires, and increasing drought conditions are expected to heighten this vulnerability in the future. Wildfires can lead to significant environmental impacts, including degraded water quality, loss of vegetation, and reduced biodiversity.

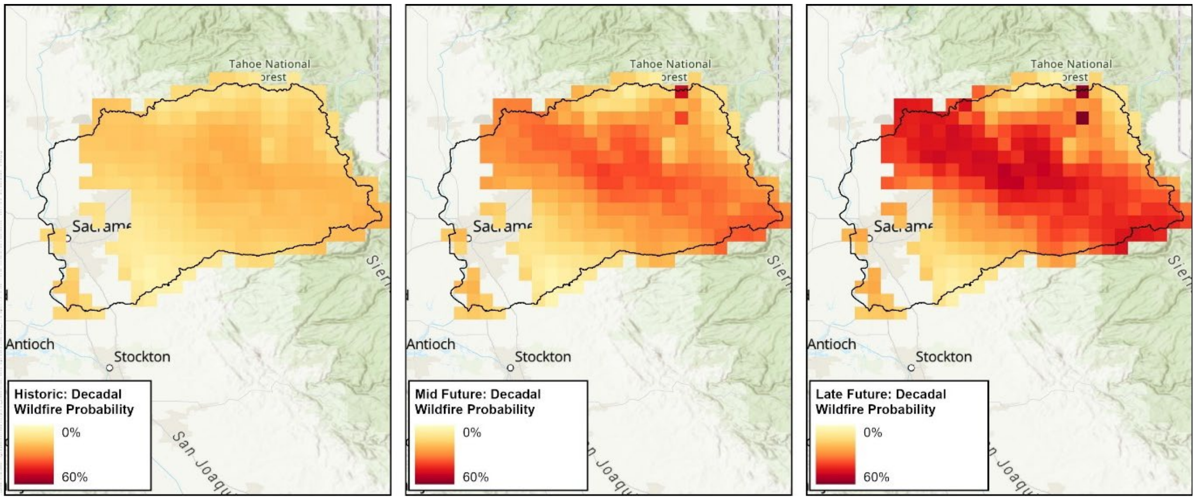

Figure A-10. Wildfire decadal probability for BAU population scenario during historical period (1981 to 2010, left, %), Mid future (2041 to 2070, center, %), and late future (2071 to 2100, right, %) using 15 CMIP6 climate models under SSP2-4.5, SSP3-7.0, and SSP5-8.5

Seasonal Changes in the Inflow to Folsom

The American River watershed primarily receives precipitation as snowpack and Folsom Reservoir is the largest reservoir in the study area. Inflow to Folsom Reservoir was calculated by combining the inflows from the North and South Forks of the American River, the two primary inflows to the reservoir.

Figure A-11 and Figure A-12 show the long-term monthly inflow to Folsom during the Existing Baseline period, Mid-Century (CT), Late-Century (HD), and Late-Century (WW) periods. The timing of peak inflow to Folsom shows a clear shift toward earlier months under future climate scenarios compared to the Existing

Baseline. Historically, peak runoff occurs around May, but under Mid-Century (CT) conditions, the peak shifts to March–April. This change is driven by warmer temperatures causing earlier snowmelt and increased winter precipitation falling as rain rather than snow. The total runoff volume for Mid-Century decreases slightly to about 2.51 MAF compared to the baseline of 2.64 MAF, indicating a modest reduction in overall inflow despite the timing shift.

For Late-Century scenarios, the changes are even more pronounced. Under the HD condition, peak inflow occurs earlier with a significant reduction in spring and summer flows. This scenario also shows the lowest total runoff volume at 2.36 MAF, reflecting drier conditions and reduced snowpack. Conversely, the WW scenario produces the highest total runoff volume at 2.77 MAF, with peak inflow occurring earlier in March and a more pronounced increase in winter flows. Both Late-Century scenarios demonstrate a strong seasonal redistribution of inflows, with higher flows in fall and winter and sharp declines in late spring and summer, posing challenges for reservoir operations and water supply reliability. Reduced levels of unimpaired inflow, especially later in the year, pose challenges in managing water supply to meet downstream demands and regulatory requirements.

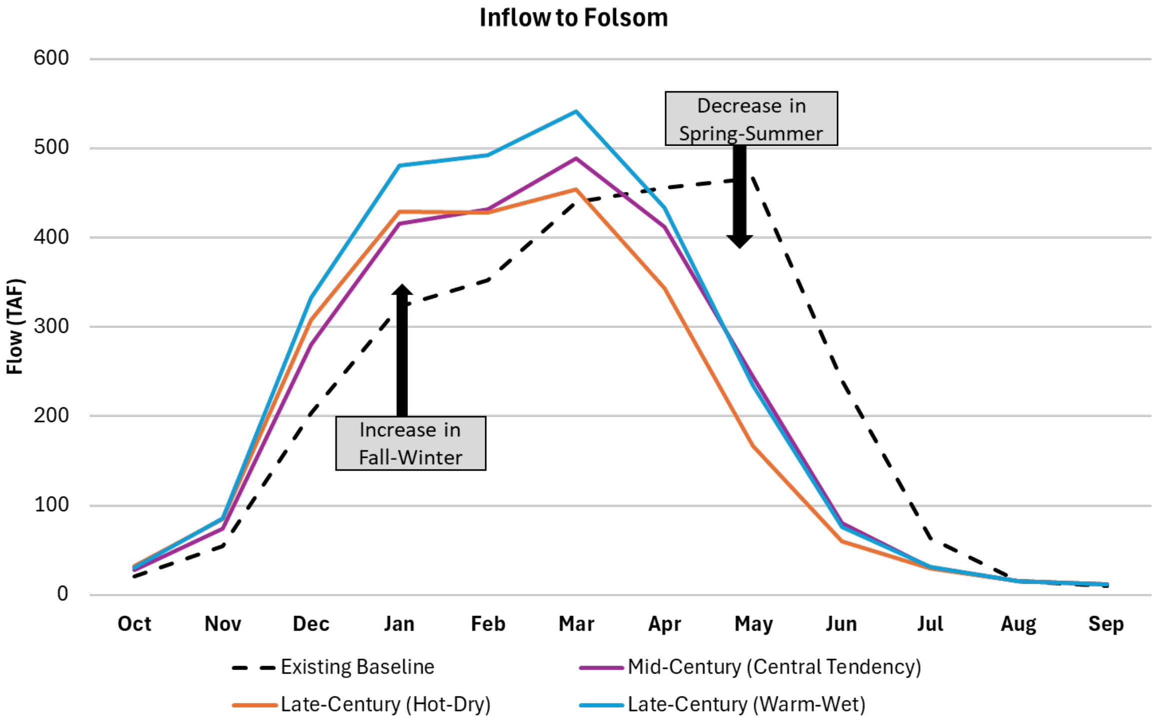

Figure A-11. Long-term monthly inflow to Folsom during the Existing Baseline period, Mid-Century (CT), Late-Century (HD), and Late-Century (WW) periods

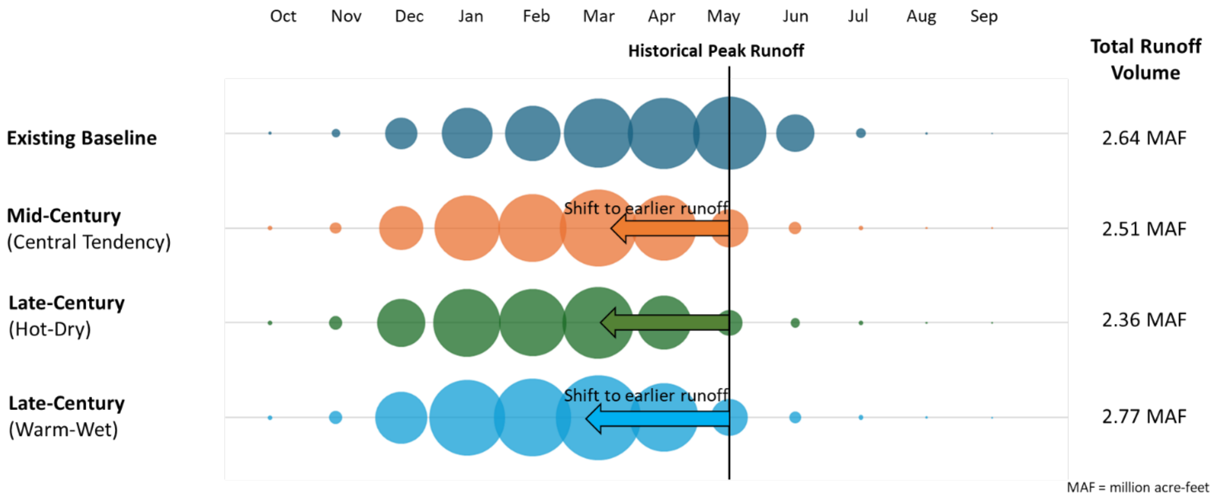

Figure A-12. Changes in the timing of peak inflow to Folsom for Mid-Century (CT), Late-Century (HD), and Late-Century (WW) periods relative to the Existing Baseline period

Drought Severity and Duration Changes for Folsom

Drought severity and duration are estimated using the unimpaired inflow to Folsom for observed streamflow and 41 climate projections (Figure A-13). Streamflow deficit (when annual value minus long-term historical value is negative) was calculated for each year using the Historical annual value as threshold. The years with the positive deficit value were assigned to be zero. The cumulative deficit values and number of years were estimated for the consecutive negative values. The drought severity was estimated as the minimum value of the cumulative annual deficit value and the drought duration was estimated as the maximum values of the cumulative years with streamflow deficit.

Observed records indicate that multi-year droughts, such as those in 1928–1935 and 1987–1992, resulted in cumulative deficits exceeding 8,000 TAF and spanning over 8 years. More recent droughts, including 2012–2016 and 2020–2021, also exhibit substantial deficits, though shorter in duration, underscoring the increasing frequency of severe but compressed drought periods. Some climate model projections (e.g., GFDL-ESM4 SSP3-7.0 and FGOALS-g3 SSP5-8.5) suggest potential future droughts could rival or surpass historical extremes, with cumulative deficits exceeding 10,000 TAF within 6-10 years. These findings emphasize the critical need for adaptive water management strategies to mitigate risks associated with prolonged and severe hydrologic deficits under both observed and projected conditions.

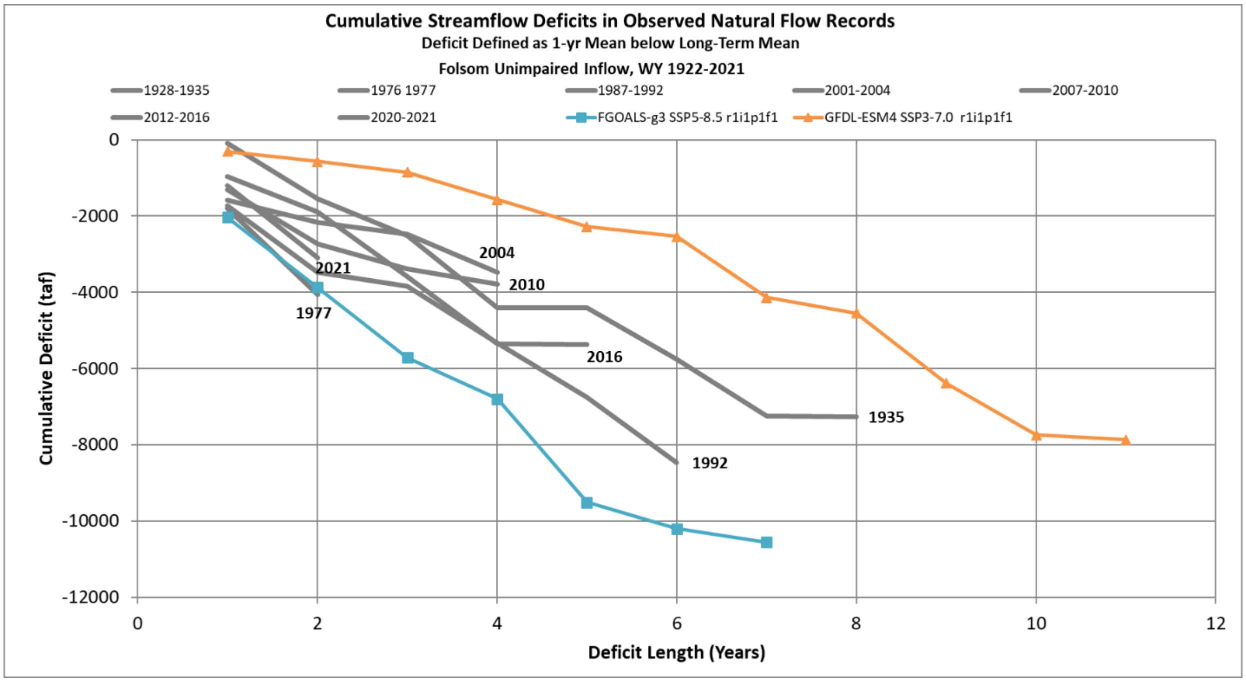

Figure A-13. Drought severity and duration in observed and projected natural flows to Folsom

Attachment B. CalSim 3 Modeling

This report provides and overview of the CalSim 3 operations planning model and how it was modified to evaluate the Existing Baseline, Mid-Century (Central Tendency [CT]), Late-Century (Warm-Wet [WW]), and Late-Century (Hot-Dry [HD]) scenarios included in the American, Bear, and Cosumnes Watersheds Resilience Pilot Vulnerability Analysis. CalSim 3 is used to simulate reservoir operations and surface water supplies in California. The model outputs consist of reservoir storage levels, river flows, and surface water diversions and deliveries. CalSim 3 outputs are also used as inputs to secondary models to simulate metrics not directly calculated in CalSim, such as river temperature, water quality, and fish mortality. For the ABC Watersheds Resilience Pilot Vulnerability Assessment, CalSim 3 was primarily used to assess the effects of climate change on the American River study area. This attachment also includes a brief overview of the effects of future climate change on the rest of the water resources system included in the spatial domain of CalSim.

This report begins with an overview of CalSim 3 and is followed by discussion on how the model assumptions and boundary conditions were developed for each ABC Watersheds Resilience Pilot climate condition. The final section presents results highlighting the effects of future climate change on California surface water supply based on CalSim 3 results from the ABC Watersheds Resilience Pilot studies.

CalSim 3 Overview

CalSim 3 is a mathematical model developed jointly by the United States Department of the Interior, Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) to simulate operations of the Central Valley Project (CVP) and State Water Project (SWP) over a range of hydrologic conditions. The model represents the best available planning-level analytical tool for CVP and SWP system operations.

CalSim 3 uses historical hydrologic information on a monthly time-step from October 1921 to September 2021 to simulate California water resource management operations, including reservoir storage, water flows in the Delta, water exports, and water deliveries. Inputs to CalSim 3 include water diversion requirements (demands), stream accretions and depletions, rim-basin inflows, irrigation efficiencies, return flows, nonrecoverable losses, and groundwater operations. Central Valley and tributary rim-basin hydrologic inputs are developed using a process designed to adjust the historical sequence of monthly stream flows over the 100-year period to represent a sequence of flows at a future level of development. Adjustments to historical water supplies are determined by imposing future level land use on historical meteorological and hydrologic conditions. The resulting hydrology represents the water supply available from Central Valley streams to the SWP and CVP at a future level of development.

CalSim 3 uses generalized rules to approximate regulatory requirements, like those in Water Right Decision 1641 (D-1641) and in recent Biological Opinions and Incidental Take Permits (ITPs). The rules are often specified as a function of water-year type or prior month’s simulated storage or flow condition. The pre-defined objectives were developed based on historical operational trends and extensive CVP and SWP operator input to provide a reasonable representation of system-wide water operations over the simulated hydrologic conditions. However, the model does not adjust these rules to respond to specific events that may have occurred historically, e.g., levee failures, fluctuations in barometric pressure that may have affected Delta tides and salinities, or facility outages. CalSim 3 results should not be expected to exactly match actual operations in a specific month or year within the simulation period since operational decisions evolve and are informed by numerous real-time operational considerations. Instead, results should only be used comparatively, evaluating relative changes from a common reference point.

CalSim 3 outputs are also used as inputs to several other models used to evaluate the effects of different operational scenarios. For example, CalSim 3 outputs are used by DSM2 to evaluate water quality in the Delta and by HEC5Q to evaluate water temperature in the Sacramento, Trinity, and American Rivers.

More detail on the development and verification of the model is available in DWR's CalSim 3 Report (California Department of Water Resources, 2022c).

CalSim 3 Water Quality Compliance (ANN)

In CalSim 3, CVP and SWP reservoirs and facilities are operated to ensure that flow and water quality requirements for these systems are met. Meeting regulatory requirements, including Delta water quality objectives, is the highest operational priority in the model. CalSim 3 uses an Artificial Neural Network (ANN) developed by DWR to approximate the flow-salinity relationship in the Sacramento-San Joaquin Delta (Delta). ANNs are commonly used to model complex relationships between inputs and outputs.

The ANN in CalSim 3 determines the flows in the Delta required to meet the salinity-related objectives. The ANN emulates flow-salinity relationships derived from DSM2, the Delta hydrodynamics and water quality model. The ANN simulates salinity at five of the locations that have D-1641 standards for salinity – Contra Costa Canal, Banks/Jones Pumping Plant, the San Joaquin River at Jersey Point, and the Sacramento River at Emmaton and Collinsville. CalSim 3 also adjusts the operations of the New Melones Reservoir to meet D-1641 at San Joaquin River at Vernalis for those locations.

Since CalSim 3 is a model with a monthly time-step and a number of daily D-1641 standards are active during only portions of a month, D-1641 standards are calculated as a monthly weighted average. For example, Delta exports are limited by D-1641 objectives during a period that is defined from April 15 to May 15. Therefore, in April, there are 14 days without the D-1641 export limitation and 16 days with the D-1641 export limitation. In CalSim II, the monthly average allowable export is determined by calculating the following: ((14 days) * (allowable export prior to pulse period) + (16 days) * (allowable export during pulse period)) / (30 days).

ABC Watersheds Resilience Pilot CalSim Model Assumptions

Four CalSim 3 simulations were used to evaluate water supply changes under different climate conditions: (1) historic hydrology (Existing Baseline), (2) Mid-Century (2055 CT), (3) Late-Century with hot and dry conditions (2085 HD), and (4) Late-Century with warm and wet conditions (2085 WW). CalSim 3 meteorologic and hydrologic boundary conditions were updated using the Weather Generator implementation described in Section 1.2.

The CalSim 3 assumptions for each study are described in Table B-1. In general, facility and operations assumptions remain consistent between each study. All scenarios include operational requirements from D-1641, the 2024 Biological Opinion, and the 2024 SWP ITP. Furthermore, it is assumed that Temporary Urgency Change Petitions (TUCPs) are imposed on Reclamation and DWR to meet public health and safety needs when dry conditions prevent meeting D-1641 standards. Modeled implementation of TUCPs is described in Appendix F Part 1 of the 2021 Long-Term Operation (LTO) CVP and SWP Final EIS (Bureau of Reclamation 2024a).

Most of the modeling assumptions were kept consistent between each scenario to focus the analysis on changes in hydrology, SLR, land use, and level of development. Moreover, model results reflect the effects of climate change when CVP/SWP operations and existing water resource facilities are unchanged.

Table B-1. CalSim 3 Model Assumptions Callouts

	Existing Baseline	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
General				
Planning Horizon	Year 2023	Year 2055	Year 2085	Year 2085
Period of Simulation	100 years (1922-2021)	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Baseline Hydrology	Adjusted Historical	Hydrology for 2055 Future Climate Conditions	Hydrology for 2085 HD Climate Conditions	Hydrology for 2085 WW Climate Conditions
SLR	0 cm	30 cm	55 cm	55 cm
Level of development **Land Use** **Urban Demands**	Land Use: Based on average of 2004 – 2013 land use data from the California Land & Water Use database, supplemented with the County Land Use Surveys from the 1990's and early 2000's Urban demands: based on 2020 Urban Water Management Plan (UWMP)	Land Use: Same as Existing Baseline Urban demands: American River urban demands interpolated from the 2020 UWMP to year 2055 based on projected 2085 demands in the 2019 American River Basin Study. Urban demands outside of the American River service area are consistent with the DWR Climate Adaptation Plan (CAP) studies representing year 2043	Land Use: Same as Existing Baseline Urban demands: American River urban demands reflecting 2085 from the 2019 American River Basin Study. Urban demands outside of the American River service area are consistent with the DWR CAP studies representing year 2043	Same as Late-Century (HD)
Water Rights, CVP/SWP Contracts				
CVP				
	Demands based on 2020 UWMP, deliveries limited to 2025 water rights, including Freeport Regional Water Project	Same as Existing Baseline, with American River demands scaled to reflect 2055 conditions based on American River Basin Study and other demands consistent with DWR CAP representing year 2043	Same as Existing Baseline, with American River demands scaled to reflect 2085 conditions based on American River Basin Study and other demands consistent with DWR CAP representing year 2043	Same as Existing Baseline, with American River demands scaled to reflect 2085 conditions based on American River Basin Study and other demands consistent with DWR CAP representing year 2043

	Existing Baseline	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
SWP				
North Bay Aqueduct	77 TAF/yr demand under SWP contracts. Up to 2.635 TAF/month of excess flow (i.e., when Standard Water Right Term 91 is not in effect, UWFE used as surrogate) under Fairfield, Vacaville, and Benecia Settlement Agreement. NOD Allocation Settlement Agreement terms for Napa and Solano. Up to 43.7 cfs of excess flow under Fairfield, Vacaville, and Benicia Settlement Agreement	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Non-Project				
	Demands based on 2020 Urban Water Management Plans, deliveries limited to 2025 water rights	Demands based on DWR CAP representing year 2043	Demands based on DWR CAP representing year 2043	Demands based on DWR CAP representing year 2043
Facilities				
Sacramento River Region	Shasta Lake - Existing, 4,552 TAF capacity;	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline

	Existing Baseline	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
San Joaquin River Region	Millerton Lake (Friant): Operated up to existing capacity of 524 TAF; New Melones – 2,420 TAF; SWP Banks Pumping Plant - 10,300 cfs (6,680 cfs permitted capacity in all months; >10,300 cfs during December 15– March 31, depending on Vernalis flow conditions); additional 500 cfs (up to 7,180 cfs) allowed July–September	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
San Francisco Bay Region	South Bay Aqueduct rehab to 430 cfs capacity (to Zone 7)	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
South Coast Region	California Aqueduct East Branch, existing capacity	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Regulatory Standards				
North Coast Region	Trinity EIS Preferred Alternative - 369 – 815 TAF/yr; Trinity Augmentation Fall Flows – 420 cfs August 1 through September 30 in all but wet years	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline

	Existing Baseline	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
Sacramento River				
Clear Creek	Clear Creek seasonally variable hydrograph minimum flows (200 cfs annual average; oscillating from 300 cfs in winter to 100 cfs in summer) with 10 TAF for pulse flows except in C years. 5 TAF for pulse flows in C years. Additionally: target 150 cfs in C years; not to exceed 840 cfs (safe outflow works capacity of Whiskeytown)	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Shasta Storage	1,900 TAF end-of-September in non-critically dry years, and Shasta is operated using Water Temperature and Storage Framework approach which establishes management “Bins”. The Bin is determined February through May based on estimated Shasta fill and carryover, forecasted inflow, projected delivery, and projected regulatory cost. The bins are used to adjust CVP allocations when needed to meet storage objectives.	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline

	Existing Baseline	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
MIF below Keswick Dam	SWRCB WR 90-5, and 2019 BiOps (stabilize fall flows to reduce redd dewatering and rebuild cold-water pool; and spring pulse flow up to 150 TAF if projected May 1 storage >4.1 MAF). Shasta storage thresholds for fall flows and spring pulse releases are as following: 3,250 cfs when EOA-Sep Shasta storage is less than 2.4 MAF 4,000 cfs when EOS Shasta storage exceeds 2.4 MAF 4,500 cfs when EOS Shasta storage exceeds 2.8 MAF 5,000 cfs when EOS Shasta storage exceeds 3.2 MAF Spring Pulse: In March of W and AN years, releases occur if end-of-February Shasta storage exceeds 3.7 MAF. In April of W and AN years, releases occur if end-of-March Shasta storage exceeds 4.1 MAF.	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Feather River	MIF below Thermalito Diversion Dam = 2006 Settlement Agreement (700 Apr 1–Sep 8;800 cfs Sep 9–Mar 31) MIF below Thermalito Afterbay outlet = 1983 DWR, DFG Agreement (750–1,700 cfs)	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline

	Existing Baseline	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
Yuba River	MIF below Englebright (Smartville) and below Daguerre Point Dam (Marysville) = SWRCB RD-1644 Operations/ WR 2008-0014 (Lower Yuba River Accord)	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
American River	American River Flow Management Standard, per 2017 Water Forum Agreement using a 90% forecast, no reduction Apr-Jun for March pulse, with a planning minimum end-of-December storage target modeled as 275 TAF	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
San Joaquin River Region	Min flow before Camanche - FERC 2916-029, 1996 (Joint Settlement Agreement) (100-325 cfs); Min flow before Woodbridge Diversion - FERC 2916-029, 1996 (Joint Settlement Agreement) (25-300 cfs)	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Sacramento River–San Joaquin Delta Region	D-1641 standards, 2020 ROD, SWP ITPs; OMR flow limits; Delta Cross Channel operations	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Delta Outflow Index (Flow, NDOI)	State Water Board D-1641 flow and salinity standards	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
Drought Condition Measures	TUCPs; spring and summer relaxations of D1641 criteria triggered by low Shasta storage and/or SacIndex value; Feb-Apr 4000 cfs NDOI requirement in lieu of X2 standards	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline

	Existing Baseline	Mid-Century (CT)	Late-Century (HD)	Late-Century (WW)
CVP water allocation				
SWP water allocation	NOD: Contract-specific; SOD: Based on supply, Ag/M&I Parity via Monterey Agreement; allocations are subject to D-1641, 2020 ROD, and 2020 SWP ITP export restrictions	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
CVP-SWP coordinated operations	In-basin use split: 80/20 (W/AN), 75/25 (BN), 65/35 (D), 60/40 (C); 60/40 export capacity (excess), 65/35 (balanced); COA 2018	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline
CVPIA 3406(b)(2)	Allocation: 800 TAF (700 TAF in Dry, 600 TAF in Critical); Accounting per 2003 DOI Policy	Same as Existing Baseline	Same as Existing Baseline	Same as Existing Baseline

Agricultural & Urban Demands

The level of development and land use assumptions for the Existing Baseline are based on the average of 2004 through 2013 land use data from the California Land & Water Use database, and supplemented with the County Land Use Surveys from the 1990's and early 2000's. Urban demands are based on the 2020 UWMP. These assumptions are consistent with historic and adjusted historic CalSim 3 models developed for DWR's SWP Delivery Capability Report (DCR 2023) (California Department of Water Resources, 2023).

For the Mid-Century (CT) period, land use assumptions are consistent with the Existing Baseline. However, urban demands on the American River were extrapolated from 2020 UWMP levels to year 2055 based on project annual demands for year 2085 as described in Appendix D of the 2019 American River Basin Study (2019 ARBS). Furthermore, a growth rate was developed based on annual demand levels in 2020 (from the 2020 UWMP) to projected annual demand levels in 2085 (from the 2019 ARBS report) and used to estimate annual demand levels in 2055. This method was only applied to urban demands from the American River service area, as shown in Table B-2 and Table B-3. All other urban demands were kept consistent with DWR's SWP Climate Adaptation Strategy CalSim 3 models representing year 2043 (DWR 2025).

The Late-Century (HD) and Late-Century (WW) periods include consistent land use assumptions with the Existing Baseline and Mid-Century (CT) periods. The Late-Century urban demands in the American River service area are consistent with the 2085 annual demands and monthly patterns from the 2019 ARBS study. All other urban demands are consistent with the Mid-Century (CT) scenario.

Table B-2. Urban Demand Units in the American River Study Area (Valley Floor Region) (1,000 acre-feet/year)

Demand Unit	Demand Unit Description	DWR DCR 2023	ARBS 2085	ABC Watersheds Resilience Pilot Existing Baseline	ABC Watersheds Resilience Pilot Mid-Century (CT)	ABC Watersheds Resilience Pilot Late-Century (HD & WW)
American River Basin Valley Floor Region						
22_NU	Northgate 880	2.0	6.4	2.7	4.4	6.4
23_NU	Self-Supplied	0.9	1.4	1.4	1.2	1.4
24_NU2	PCWA: Lower Zone 6, Foothill-Sunset WTP; PCWA: City of Lincoln (FO-SU)	23	88	33	58	88
24_NU4	Self-supplied	8.0	1.0	0.4	4.2	1.0
26N_NU1	Self-supplied SSWD – NSA (Arcade NH) SSWD – NSA (Northridge) McClellan Cal-Am WC – Antelope Lincoln Oaks Cal-Am-WC - West Placer Rio Linda Elverta CWD	31	51	40	42	51
26N_NU2	Carmichael WD	9.0	10.3	9.9	9.7	10.3
26N_NU3	City of Sac (N)	39	74	40	58	73

Demand Unit	Demand Unit Description	DWR DCR 2023	ARBS 2085	ABC Watersheds Resilience Pilot Existing Baseline	ABC Watersheds Resilience Pilot Mid-Century (CT)	ABC Watersheds Resilience Pilot Late-Century (HD & WW)
26N_NU4	SSWD - SSA	19	19	18	19	19
26N_NU5	Golden State WC – Arden Del Paso Manor WD SCWA Zone 41 – Arden Park Vista Cal-Am WC – Arden	8.0	8.1	8.1	8.1	8.1
26N_PU1	City of Roseville	32	55	32	44	55
26N_PU2	San Juan WD	12	20	14	17	20
26N_PU3	Orange Vale WC Citrus Heights WD Fair Oaks WD City of Folsom (Ashland)	29	42	32	36	42
26S_NU1	City of Sacramento (S)	72	137	74	107	137
26S_NU2	Cal-Am WC – Parkway Cal-Am WC – Suburban Cal-Am WC – Rosemont	22	37	23	30	37
26S_NU3	Florin Tokay Park Fruitridge Vista	6.0	4.1	6.2	5.0	4.1
26S_NU4	Aerojet	3.0	2.7	2.7	2.8	2.7
26S_PU1	Folsom	21	32	24	27	32
26S_PU2	Golden State WC	14	22	18	18	22
26S_PU3	California Parks and Recreation	1.0	1.0	1.0	1.0	1.0
26S_PU4	SCWA – SSA (Zone 40)	12	27	12	20	27
26S_PU5	EGWD	7.0	8.1	7.8	7.6	8.1
26S_PU6	SCWA – CSA, Vineyard SCWA – NSA, Mather-Sunrise Security Park	20	49	20	36	49
60N_NU1	Galt, Lodi	19	32	21	26	32
60N_NU2	Rancho Murieta CSD	2.0	2.9	1.7	2.5	2.9
60N_PU	SMUD – Rancho Seco Power Plant	17	17	17	17	17
Subtotal Valley Floor Region (North of American River)		251	428	270	347	428
Subtotal Valley Floor Region (South of American River)		178	319	187	254	319
Subtotal Total Valley Floor Region		429	748	457	601	748

Table B-3. Urban Demand Units in the American River Study Area (Foothills Region) (1,000 acre-feet/year).

Demand Unit	Demand Unit Description	DWR DCR 2023	ARBS 2085	ABC Watersheds Resilience Pilot **Existing Baseline**	ABC Watersheds Resilience Pilot **Mid-Century (CT)**	ABC Watersheds Resilience Pilot **Late-Century (HD & WW)**
American River Basin Foothills Region						
PCWA3	Alta, Dutch Flat, Colfax, Applegate, Meadow Vista	11	10	11	11	10
24_NU1	PCWA: Upper Zone 1 (AU-BO)	7	12	7	10	12
24_NU3	Nevada ID – North Auburn	2.0	2.7	1.5	2.4	2.7
ELDID_NU1	EID Eastern water supply region	9	31	14	21	31
ELDID_NU2	EID Western water supply region	8	30	14	20	30
ELDID_NU3	EID EDH water supply region	15	18	8	17	18
EDCOCA_NU1	EDC OCA (N. SFA)	0.0	2.1	0.0	1.1	2.1
EDCOCA_NU2	EDC OCA (S. SFA, west of Hwy 49)	0.0	5.2	0.0	2.8	5.2
EDCOCA_NU3	EDC OCA (S. SFA, east of Hwy 49)	0.0	5.2	0.0	2.8	5.2
GDPUD_NU	Georgetown Divide PUD	1.8	1.6	0.6	1.7	1.6
GDPUD_PU	Georgetown Divide PUD	7.5	6.4	2.4	6.9	6.4
Subtotal Foothills Region		61	125	59	95	125
Total		**490**	**872**	**516**	**696**	**872**

ARBS 2085 = Projected year 2085 demands from the 2019 American River Basin Study (2019 ARBS)

DWR DCR 2023 = Historic Adjusted scenario from DWR's 2023 Delivery Capability Report (DCR 2023)

PCWA = Placer County Water Agency
PUD = Public Utility District

Climate Change

CalSim 3 input parameters and secondary models were developed to represent the climate conditions for the three climate change scenarios. The adjustment of CalSim 3 and secondary model input parameters was achieved by estimating monthly and annual change factors based on historical data and future climate change scenarios.

Fractional changes (simulated future data divided by historical simulated data) were applied to the following CalSim 3 input boundary conditions:

- Inflow or Streamflow
- Precipitation
- Surface water evaporation
- Evapotranspiration (ET)

Absolute changes (difference in simulated future data and historical simulated data) were applied to CalSim 3 temperature boundary conditions. The CalSim 3 projected hydroclimate input data under different climate change scenarios, including boundary conditions, climate variables, and perturbation methods used, were developed as follows:

1. For all watersheds, simulated changes in streamflows were applied to the CalSim 3 inflows. These fractional changes (simulated future streamflows divided by historical simulated streamflows) were first applied for every month of the 106-water-year (WY) period (1915 to 2021) consistent with the VIC model-simulated patterns. A second order correction was then applied to confirm that the annual shifts in runoff at each location were consistent with the shifts observed in the VIC model.

2. Total flows of major watersheds were perturbed with the two-step process described in the first bullet. Then, the perturbed runoff of each contributing watershed was adjusted to match the perturbed total flow in the watershed moving from upstream to downstream.

3. For watersheds where streamflows are heavily impaired, a process was implemented for the re-impairments of the flows. To determine the historical inflow impairment upstream of Millerton Lake, the historical unimpaired inflow was subtracted from the historical actual inflow. This impairment was then added to the climate-change unimpaired inflow. If the resulting inflow was negative, a correction was applied so that it remained positive, without exceeding 25 thousand acre-feet (TAF).

4. A positive adjustment to historical impairment was required in 34 months of the 100-year simulation period (1,200 months in total), typically in May and June of dry years. Negative flow adjustments were applied to historical impairments in the months following positive flow adjustments so that the adjusted annual impairment remained consistent with the historical annual impairment. Negative flow adjustments were prohibited from reducing the calculated monthly impaired flow volume to less than 50 TAF. The 25 and 50 TAF limits used to adjust historical impairments kept inflows positive and balanced over time.
   - An analysis was conducted to evaluate the effects of using lower limits, such as 10 TAF (for positive adjustments) and 20 TAF (for negative adjustments). It was found that lower limits did not have a significant effect on model outcomes. These adjustments were only needed in very dry years when Millerton storage reaches dead pool regardless of the strategies that were evaluated to correct historical inflow impairments.

Similarly, fractional changes approach (described in the first bullet) were also used to simulate changes in the following climate and hydrological parameters:

- Precipitation
- Total streamflow
- Minimum and maximum temperature
- Surface water evaporation
- Potential ET from short reference crop

These changes were needed for calculation of the following input parameters to CalSim3:

- Rim inflows
- Basin average precipitation
- Point precipitation
- California Data Exchange Center unimpaired flow
- Reservoir evaporation
- Data used as inputs to the following models:
  - DCD
  - CalSimHydro
  - CalSimHydroEE
  - SmallWatersheds, a secondary model used in CalSim 3

SLR

Apart from changes in hydrology and land use, the only other difference in assumptions between each CalSim 3 model is sea level rise (SLR). The Existing Baseline assumes 0 cm SLR, while the Mid-Century (CT) model assumes 30 cm SLR and both Late-Century models assume 55 cm SLR. The increased levels of SLR in the Mid-Century and Late-Century scenarios require increased north-of-Delta reservoir releases and reduced south-of-Delta exports to maintain water quality and infrastructure integrity in the Delta.

Salinity is not directly calculated in CalSim 3. Instead, compliance with water quality objectives is determined based on flow-salinity relationships in the Delta calculated with an Artificial Neural Network (ANN) developed by the Department of Water Resources (DWR). The ANN is a statistical model that translates water quality standards into flow equivalents using information from CalSim, the DCD model, and the DSM2. For each SLR scenario, a unique ANN is integrated within CalSim 3 as a Dynamic Link Library (DLL).

More information on the development of the three SLR ANN DLLs (0 cm, 30 cm, and 55 cm) is provided in the State Water Project (SWP) Adaptation Strategy Appendix A (California Department of Water Resources, 2025).

Healthy Rivers & Landscapes

Each ABC Watersheds Resilience Pilot CalSim 3 model assumes early adoption of the Healthy River and Landscapes Program (HRL), which requires reductions to south-of-Delta exports and/or reductions to upstream storage releases from Shasta, Folsom, and Oroville to increase Delta Outflow. The implementation of the "Delta" HRL (formerly known as the Delta Voluntary Agreement (VA) action), is described for Alternative 2 with Delta VAs in Appendix F Part 1 of the 2021 LTO (Reclamation, 2024a). Other proposed HRL measures included in the 2022 Memorandum of Understanding (2022 MOU) are not considered in these models because of uncertainty in the actions being adjusted or excluded from the future regulatory framework of California water resource operations (California State Water Resources Control Board, 2022).

CalSim 3 Results

CalSim 3 results that demonstrate the effects of future climate conditions on CVP and SWP operations are included below. Figure B-1 presents end-of-September storage in Shasta, which represents the carryover storage from the previous water year to the following water year. Carryover storage reflects how much water remains in the reservoir for use in the forthcoming year. As shown, Shasta carryover storage is significantly impacted in the Mid-Century and Late-Century periods. The Late-Century HD model includes 11 years in which Shasta storage levels reached deadpool conditions (550 TAF).

Similar effects are observed in other CVP and SWP reservoirs, such as Folsom Lake (Figure B-2) and Lake Oroville (Figure B-3). The lower storage levels in the future scenarios result from reduced unimpaired inflows, less precipitation, and higher temperatures resulting in earlier snowmelt. Additionally, increased levels of storage releases for Delta Outflow contributions are needed earlier in the water year to maintain water quality standards in the Delta, which are more challenging to meet with higher SLR. As shown in Figure B-4, X2 position is typically greater (more eastward) in the scenarios with greater SLR, indicating higher salinity levels in the Delta.

The Mid-Century (CT) period includes lower annual inflows to the Sacramento, Feather, and American Rivers relative to the Existing Baseline. Additionally, there is generally a shift in runoff from later in the water year to earlier in the water year. Consequently, the Mid-Century storage levels in Shasta, Folsom, and Oroville are reduced relative to the Existing Baseline. Deadpool conditions are reached in a handful of drought years, even with the implementation of TUCPs. Similarly, CVP and SWP deliveries are lower than the Existing Baseline (Figure B-5 through Figure B-9).

In the Late-Century WW scenario, rim inflows and snowmelt for the Sacramento, Feather, and American Rivers are generally higher in December through March than the other scenarios. Much of this water is spilled from upstream reservoirs due to limited storage capacity and is lost to Delta Outflow (see Figure B-10). However, the higher level of runoff in the Late-Century (WW) period typically allows for greater upstream storage in droughts compared to the Mid-Century (CT) period and especially the Late-Century (HD) period. Additionally, CVP and SWP delivery levels are similar to the Mid-Century (CT) period.

The Late-Century (HD) period includes less rim inflows than any other period, especially in the summer. This corresponds with the lowest water supply availability among all the modeled periods. The Late-Century (HD) scenario includes the lowest storage levels, lowest river flows, and least CVP and SWP deliveries. Relative to the Late-Century (WW) scenario, CVP deliveries reduce by almost 500 TAF/yr.

Overall, the future climate models are associated with reduced levels of annual unimpaired inflows entering the American River. Additionally, warmer temperatures and changing precipitation levels cause a shift in the timing of upstream runoff, where a higher proportion of annual unimpaired inflow occurs in December through March and less occurs in May through August. Relative to the Existing Baseline, each future climate model includes lower reservoir storage levels, less river flows (especially in the summer), and less deliveries. Reduced levels of unimpaired inflow, especially later in the year, pose challenges in managing water supply to meet downstream demands and regulatory requirements. In the Late-Century, the state of surface water supply is highly dependent on whether the climate trends warm and wet or hot and dry. If warm and wet, rim inflows and snowmelt will generally be higher in December through April and will allow for elevated upstream storage conditions and increased river flows and water supply availability for deliveries. If conditions in the Late-Century are hot and dry, rim inflows in California would be substantially lower year-round, leading to significantly reduced storage levels and higher frequency of deadpool storage conditions (non-operable storage levels). If the late century is hot and dry, the ability of the CVP and SWP to regularly meet demands of service contractors while also complying with downstream minimum flow requirements would be highly impacted.

For each future climate condition, adjustments to project operations are needed to maintain similar performance to the Existing Baseline in terms of reservoir storage preservation, compliance with minimum instream flow requirements, and water supply delivery.

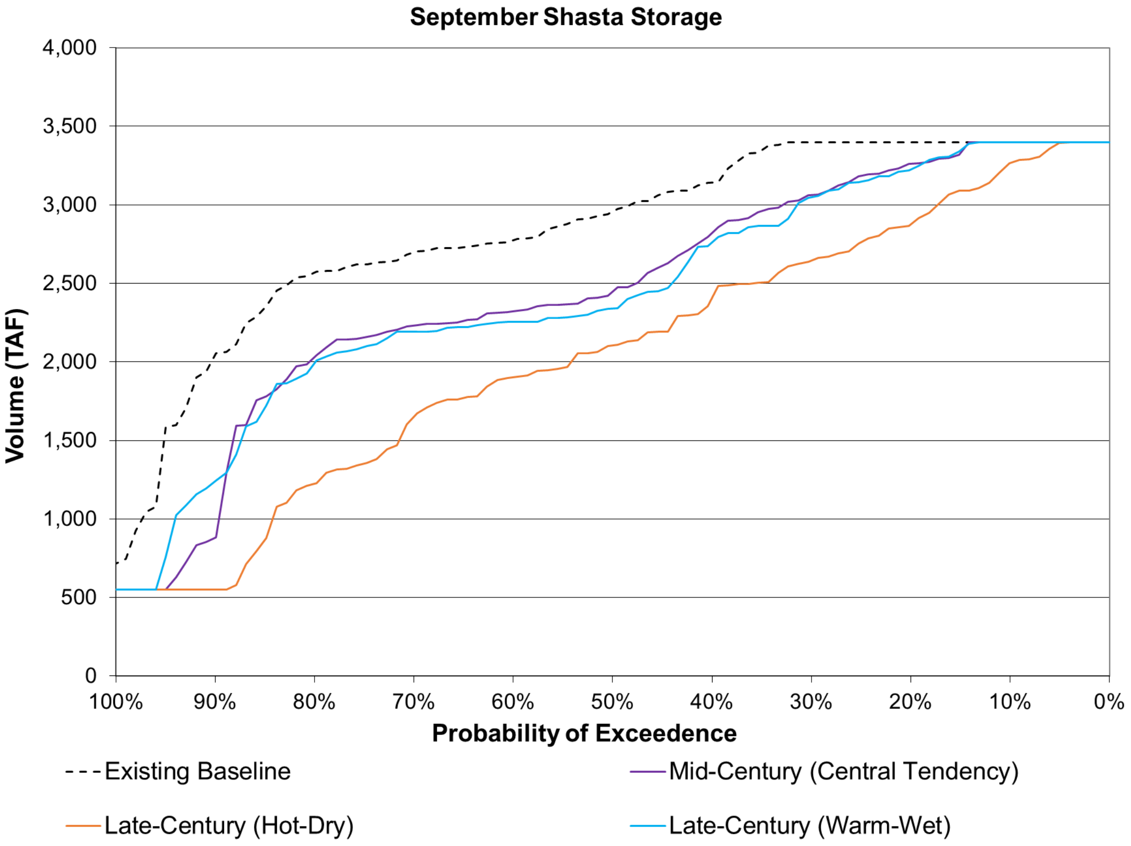

Figure B-1. End-of-September Shasta Storage

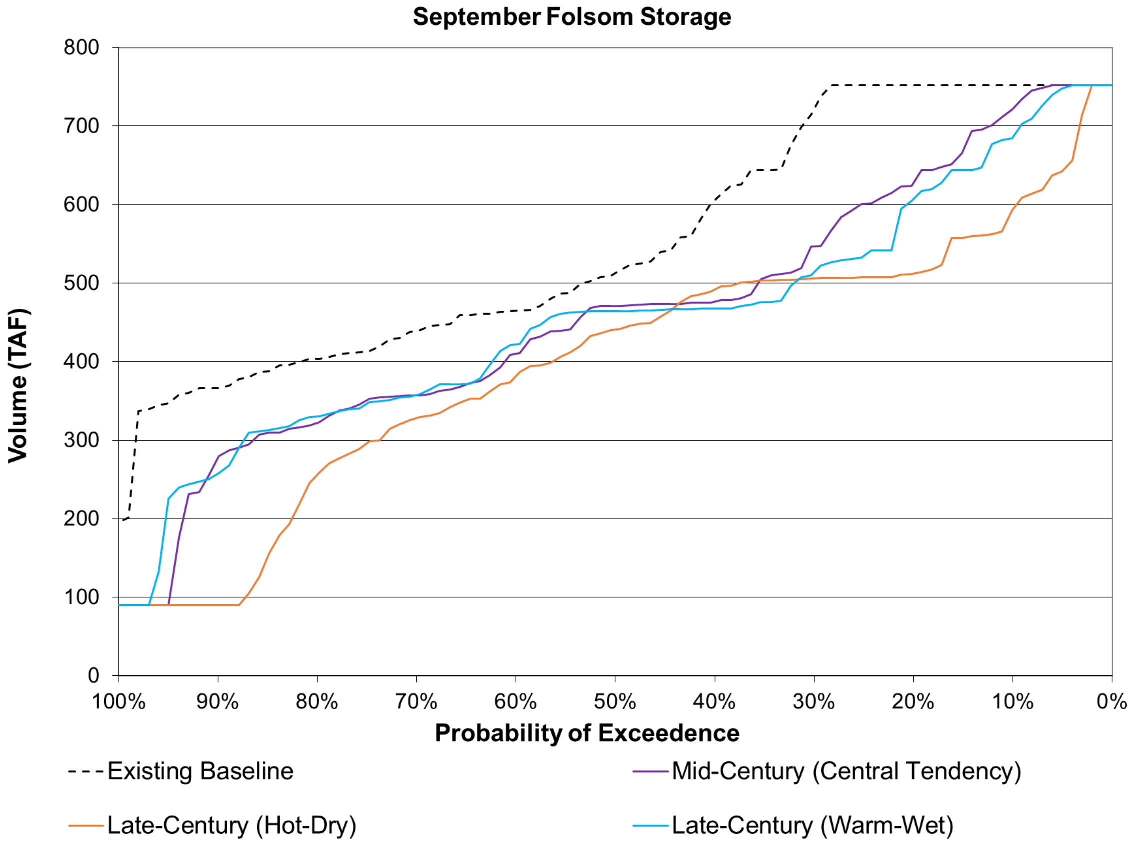

Figure B-2. End-of-September Folsom Storage

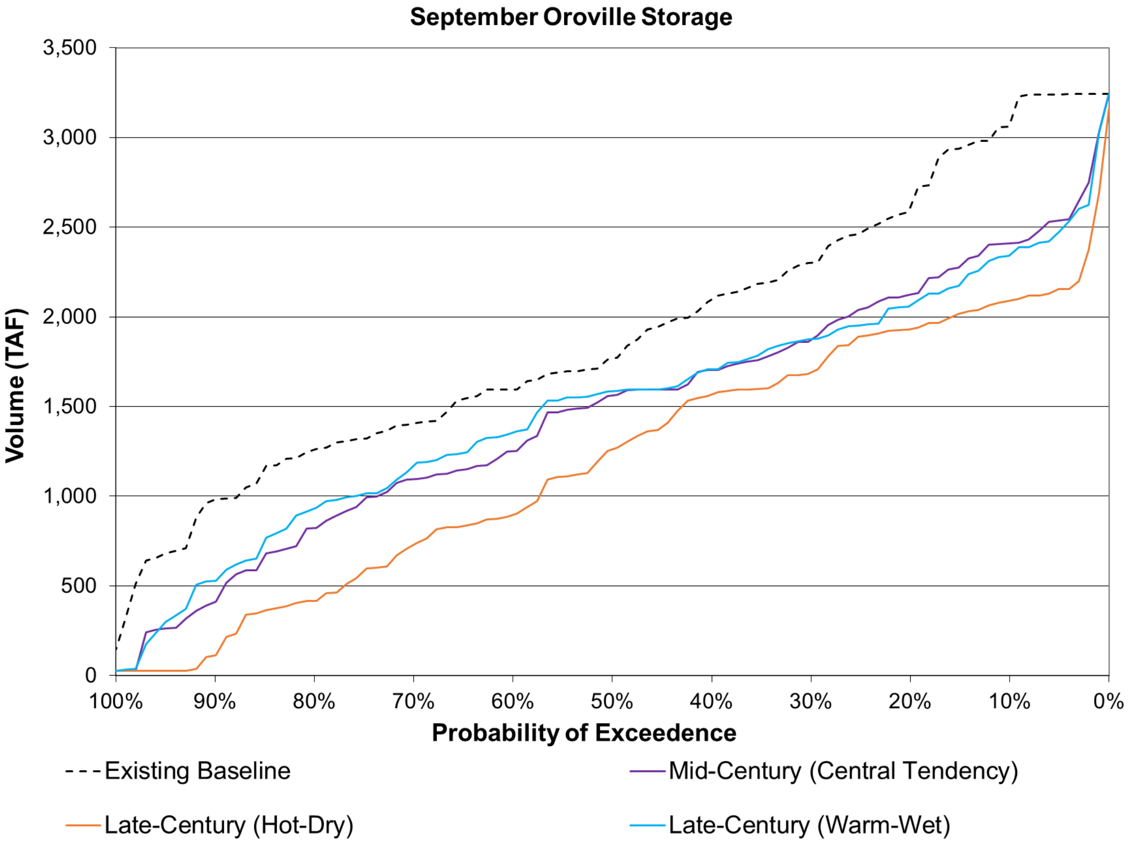

Figure B-3. End-of-September Oroville Storage

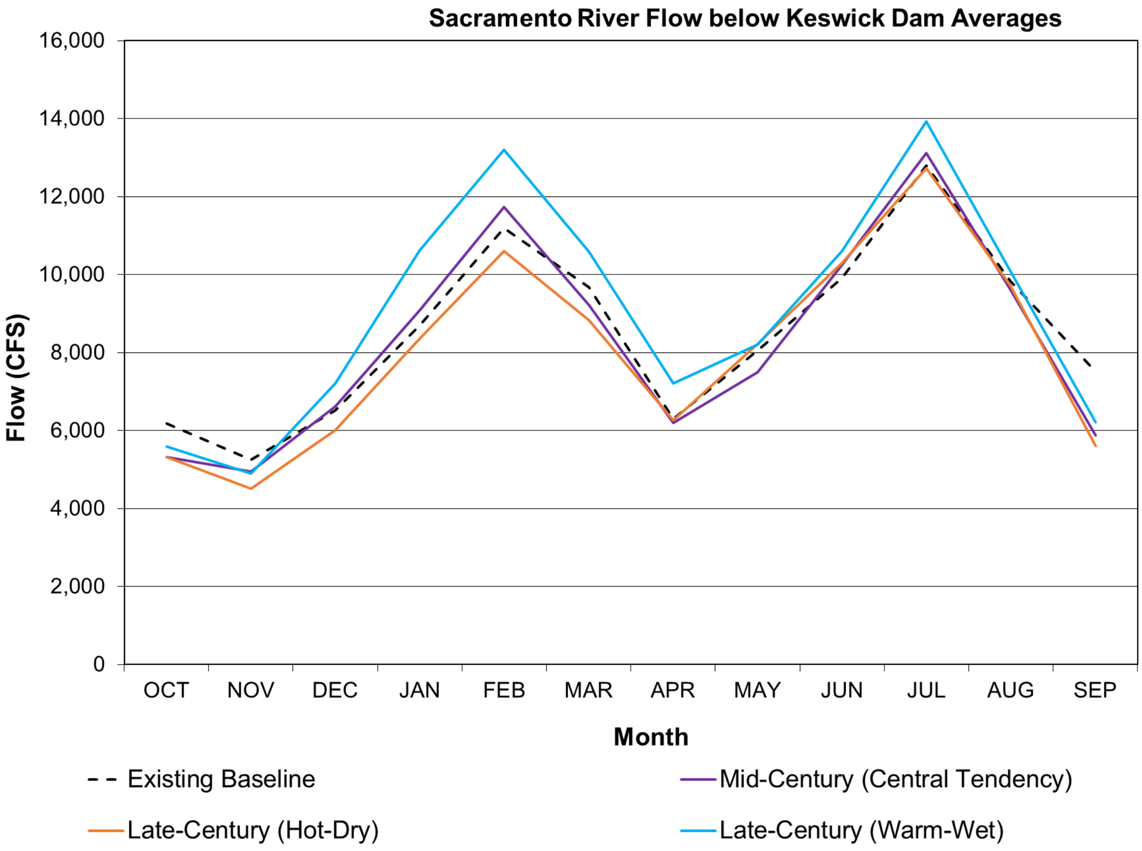

Figure B-4. Average Monthly Sacramento River Flow Downstream of Keswick Dam

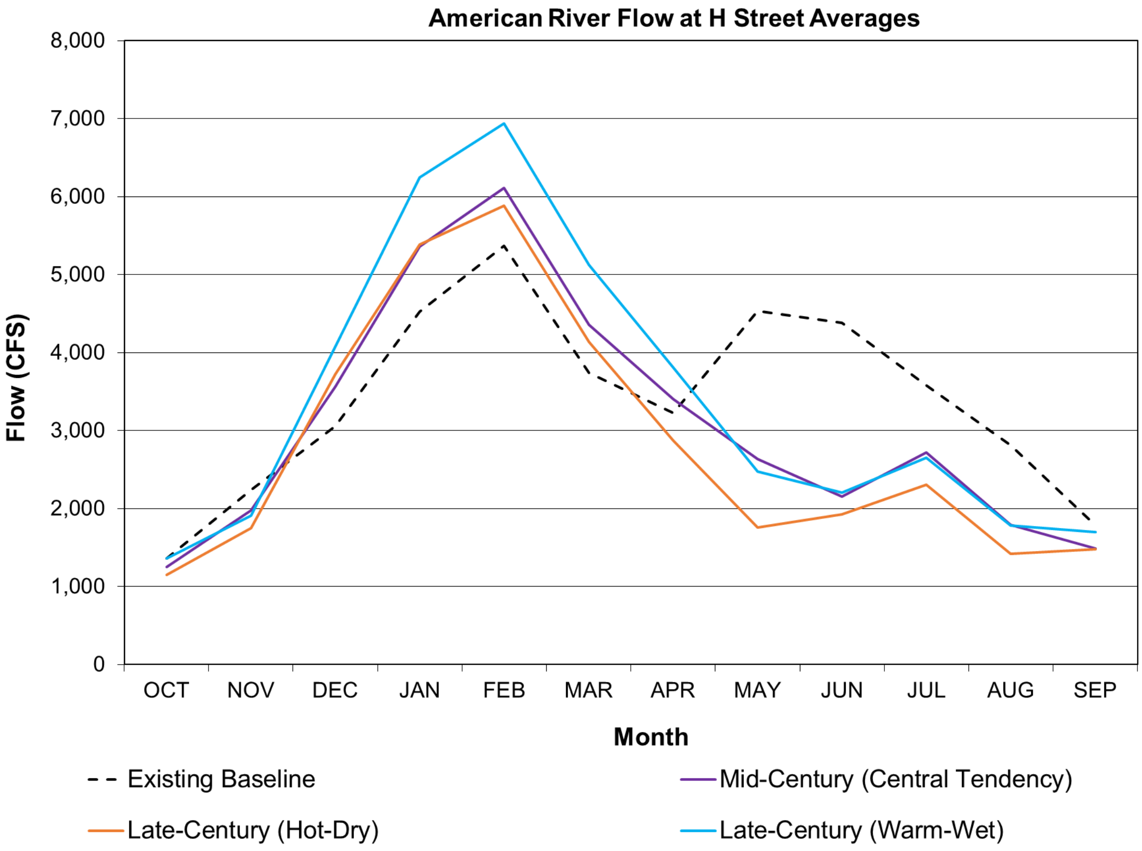

Figure B-5. Average Monthly American River Flow Downstream of H Street

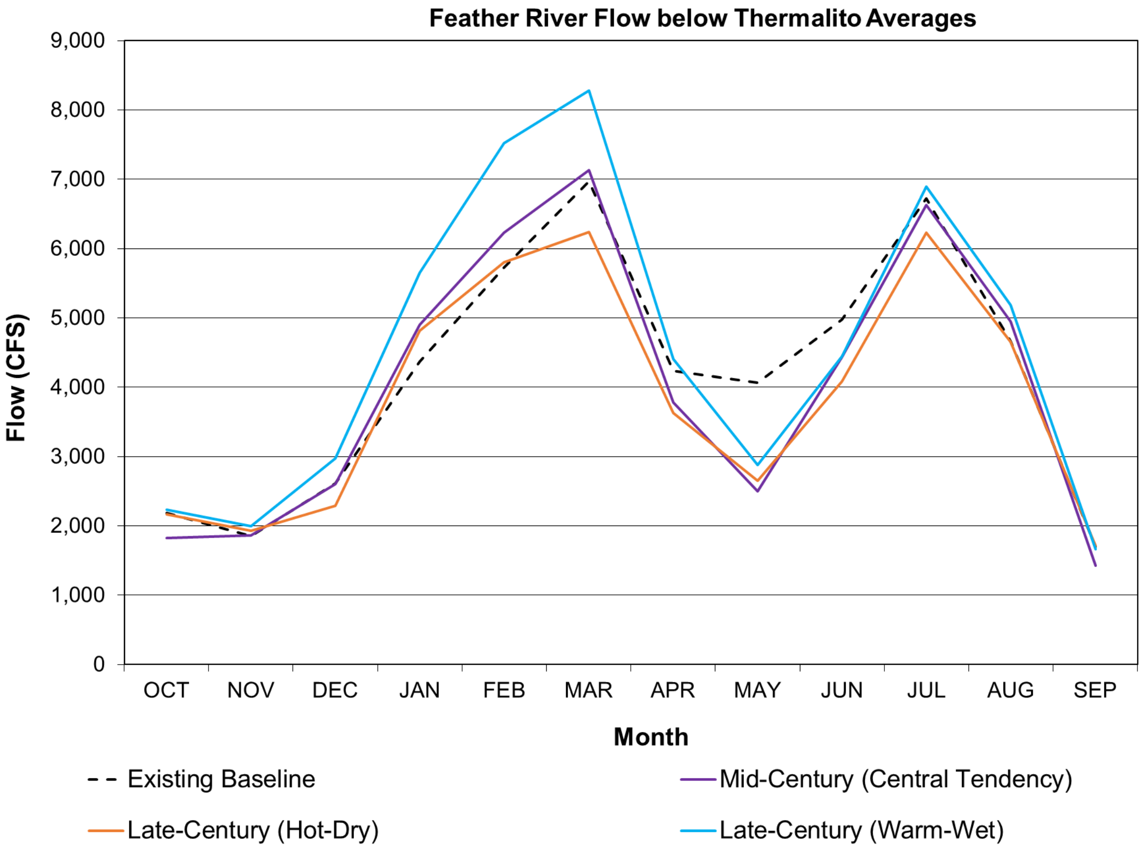

Figure B-6. Average Monthly Feather River Flow Downstream of Thermalito

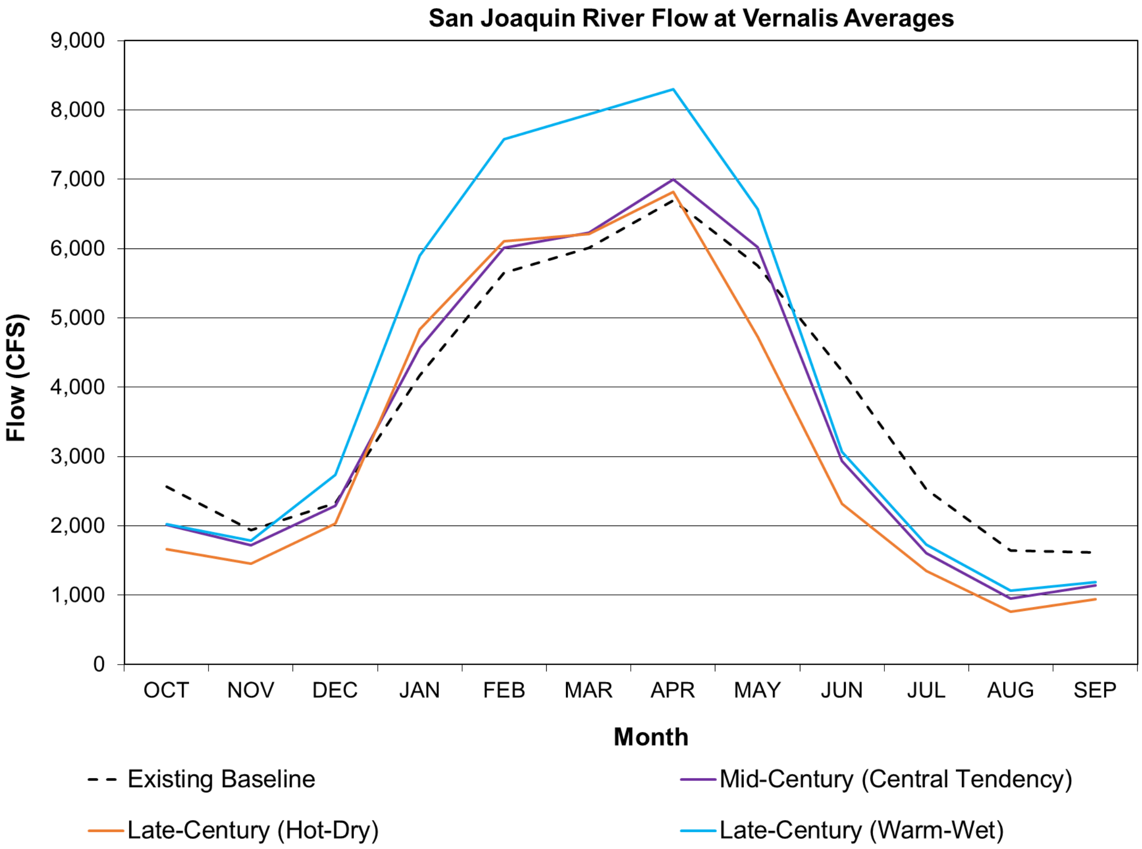

Figure B-7. Average Monthly San Joaquin River Flow at Vernalis

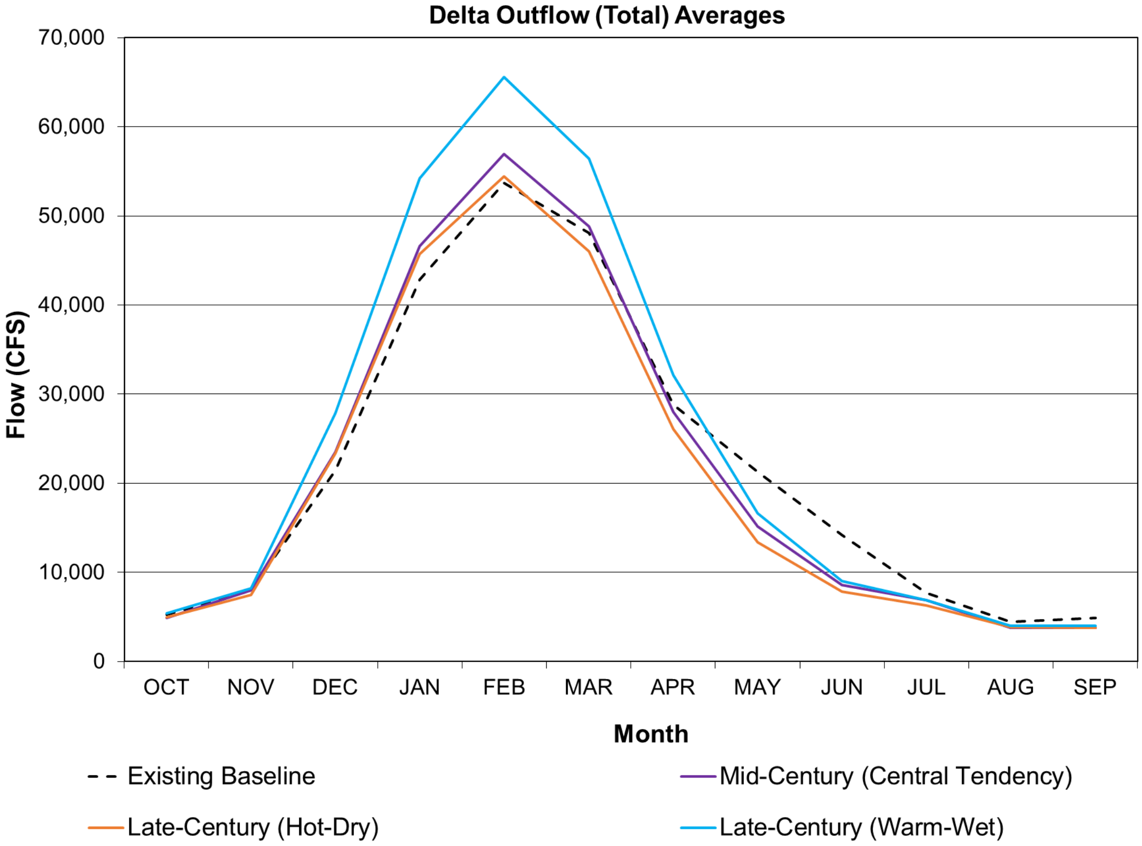

Figure B-8. Average Monthly Delta Outflow

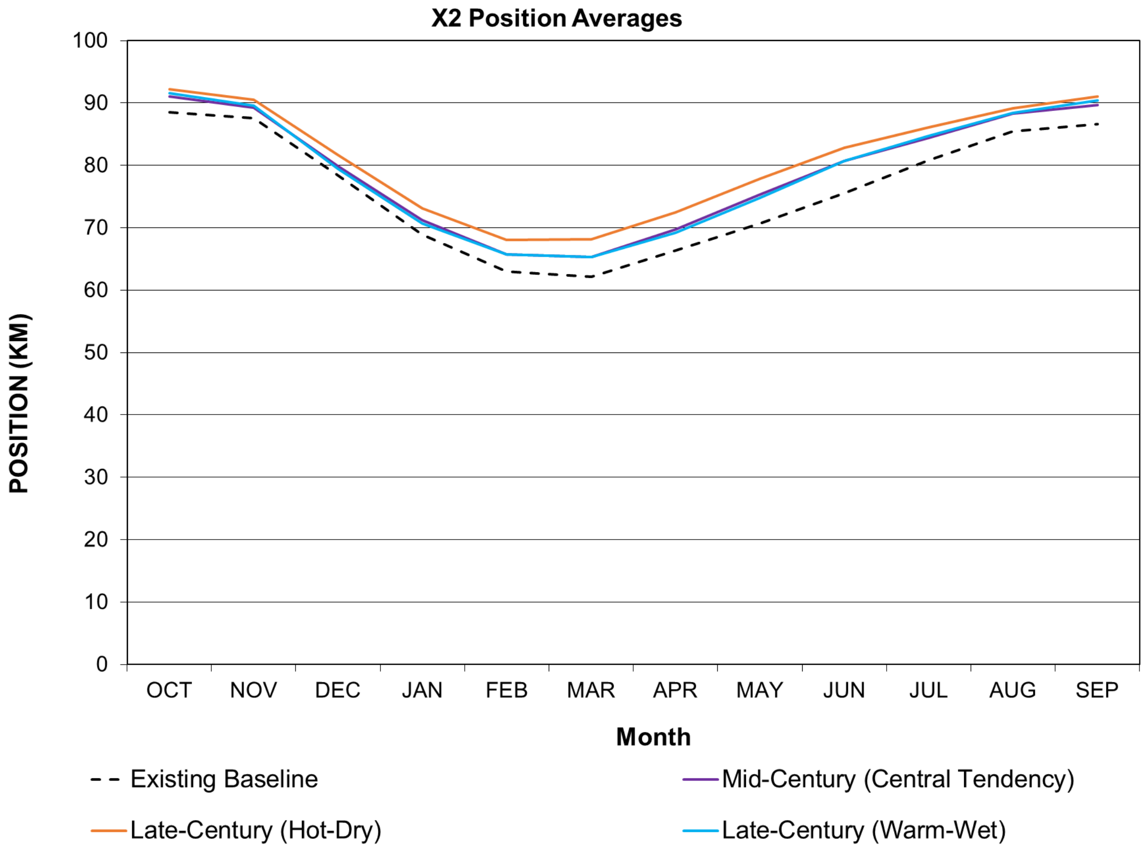

Figure B-9. Average Monthly X2 Position (eastward distance from the Golden Gate in the Delta where the tidally averaged salinity is 2 parts per thousand)

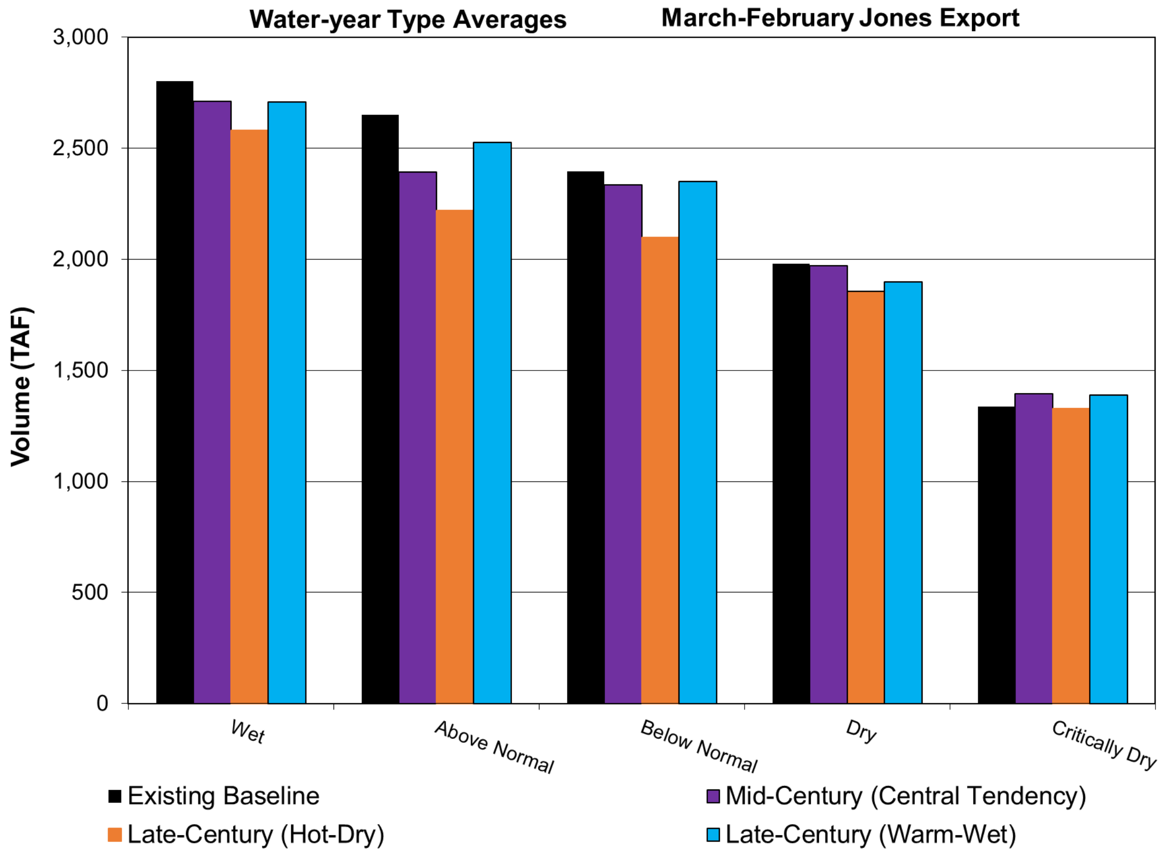

Figure B-10. South-of-Delta Exports through Jones Pumping Plant based on the Sacramento Valley Water-year Type

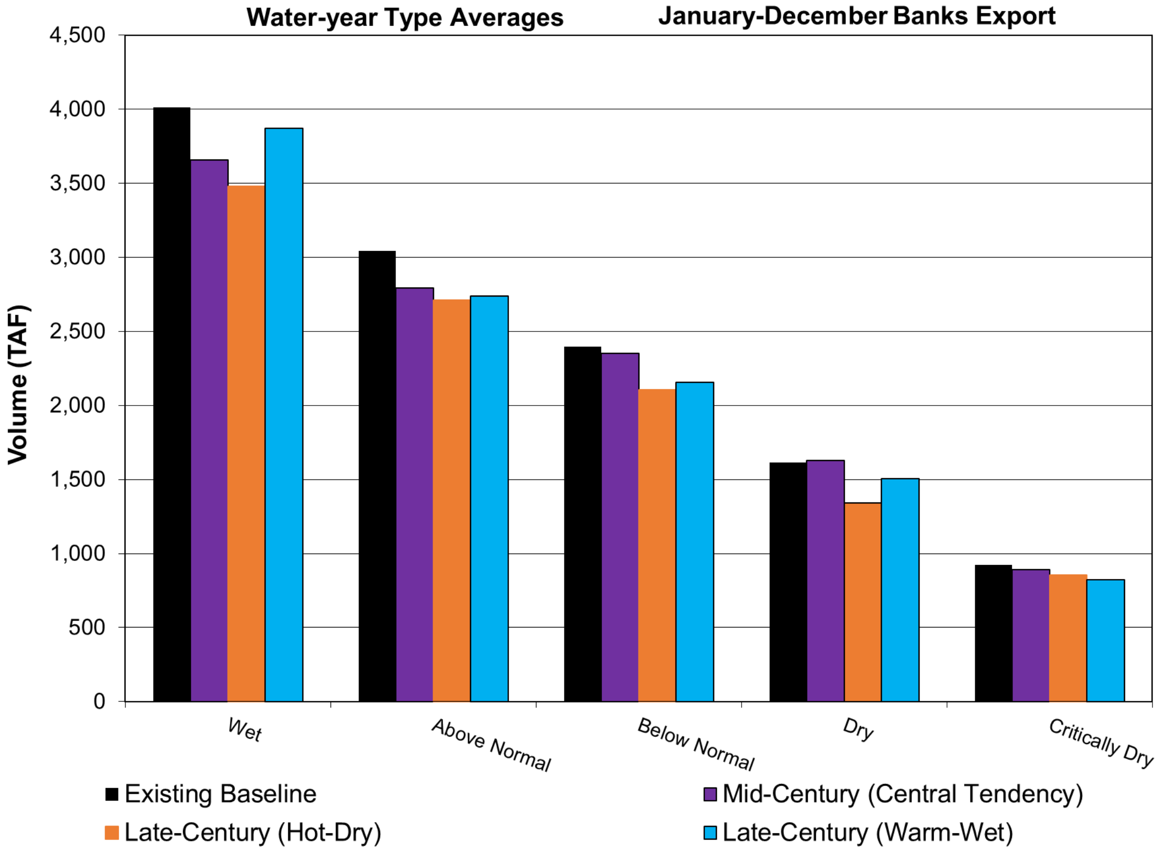

Figure B-11. South-of-Delta Exports through Banks Pumping Plant based on the Sacramento Valley Water-year Type

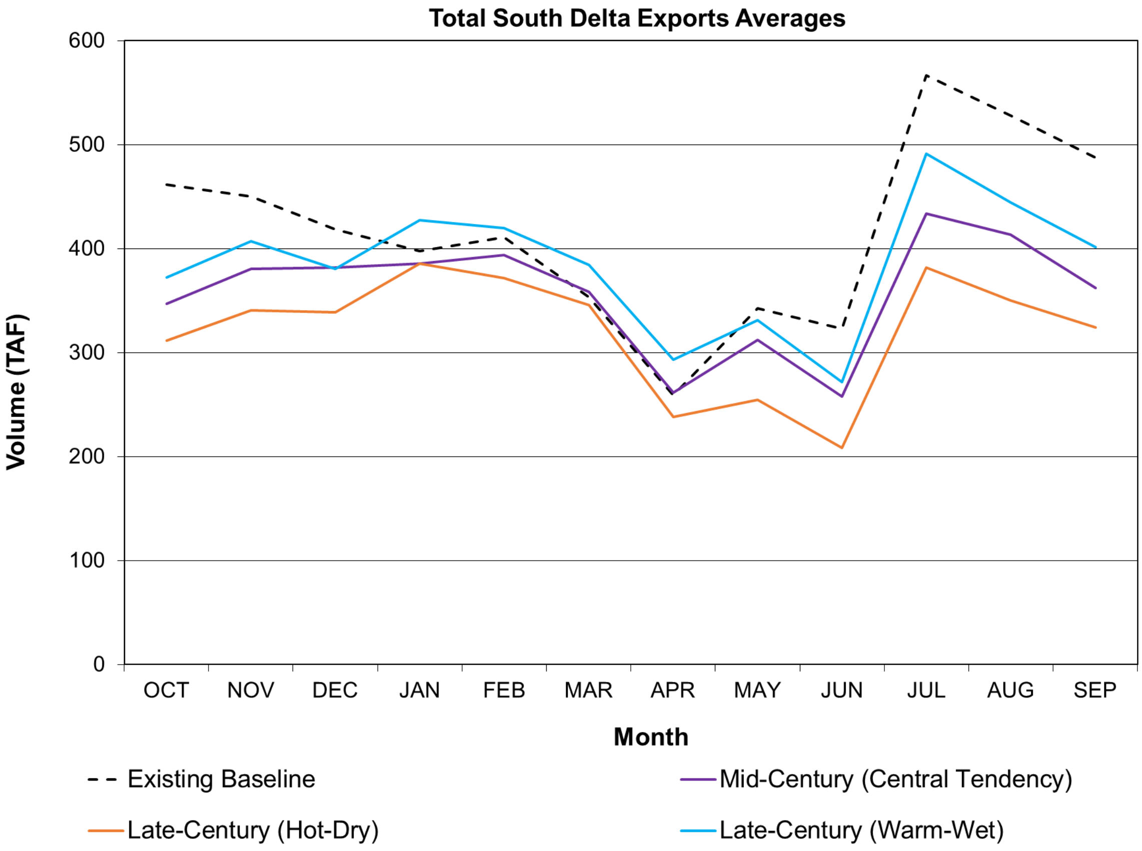

Figure B-12. Average Monthly South-of-Delta Exports

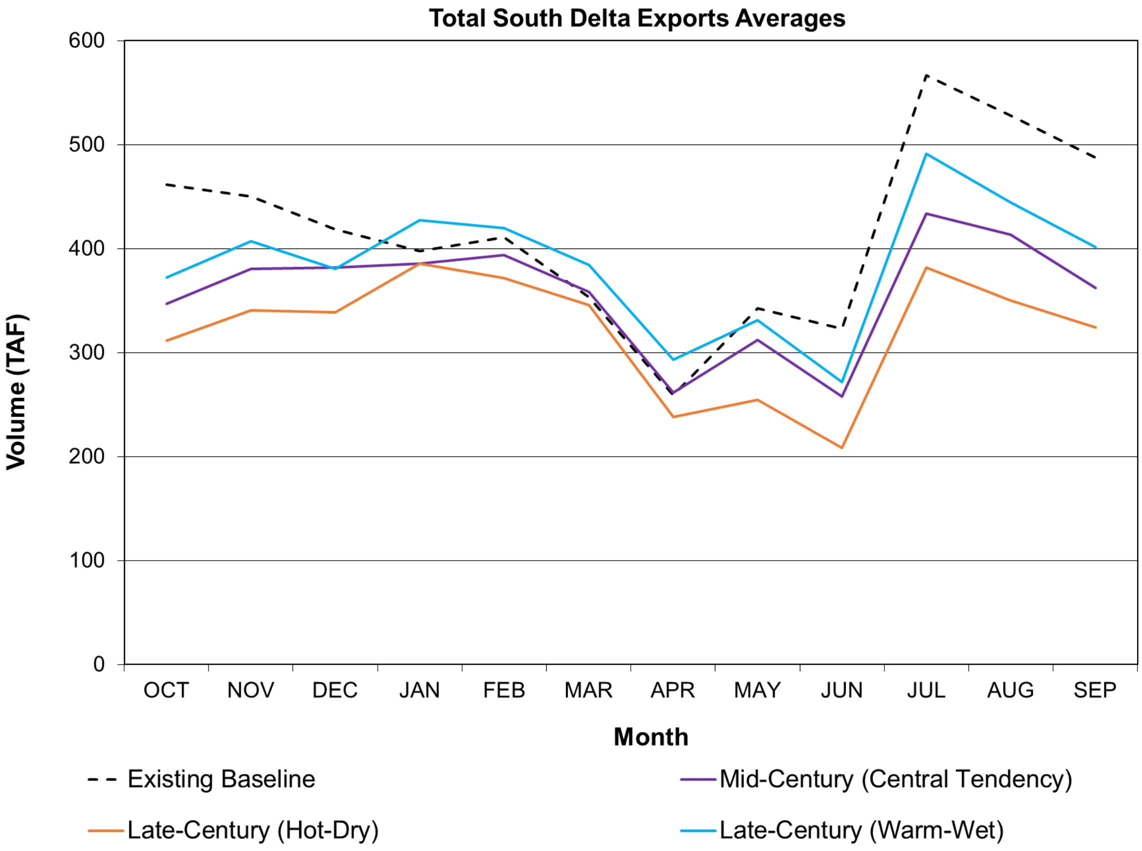

Figure B-13. Annual Volume of South-of-Delta Exports Exceedance of Probability

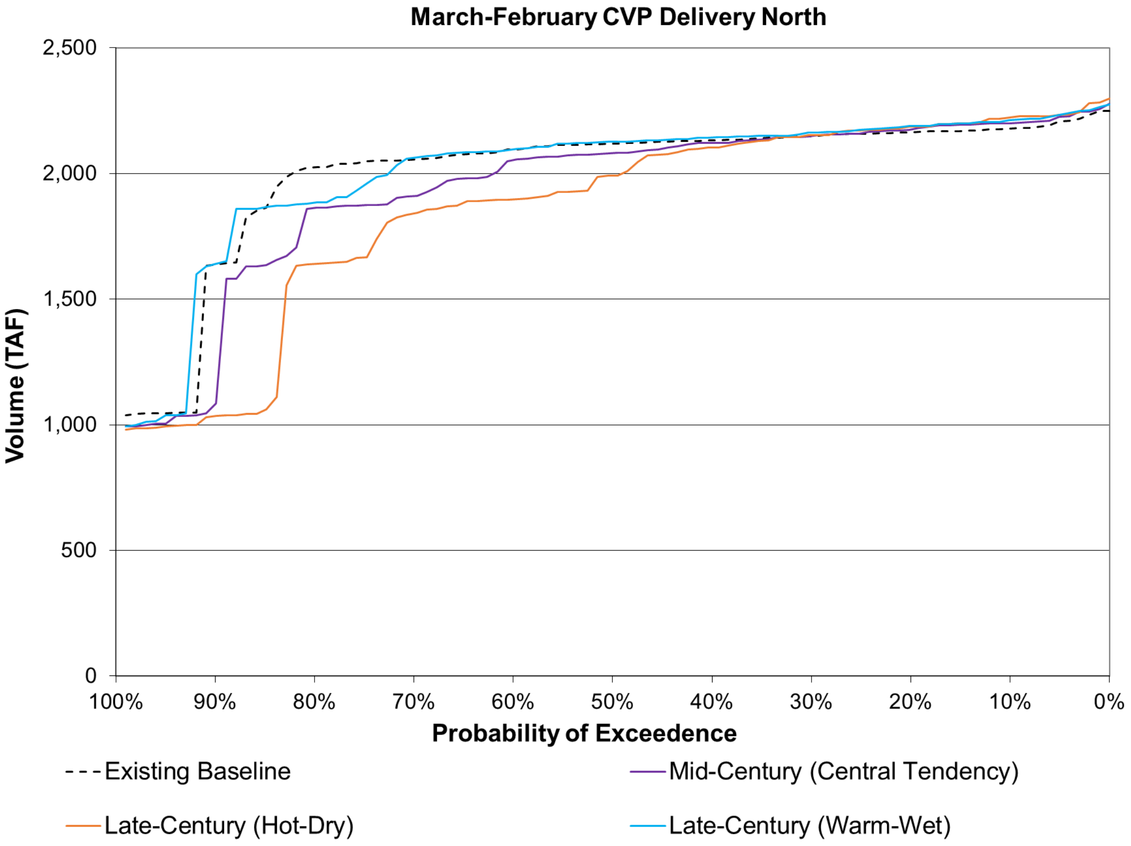

Figure B-14. Annual Volume of CVP Delivery to North-of-Delta Users

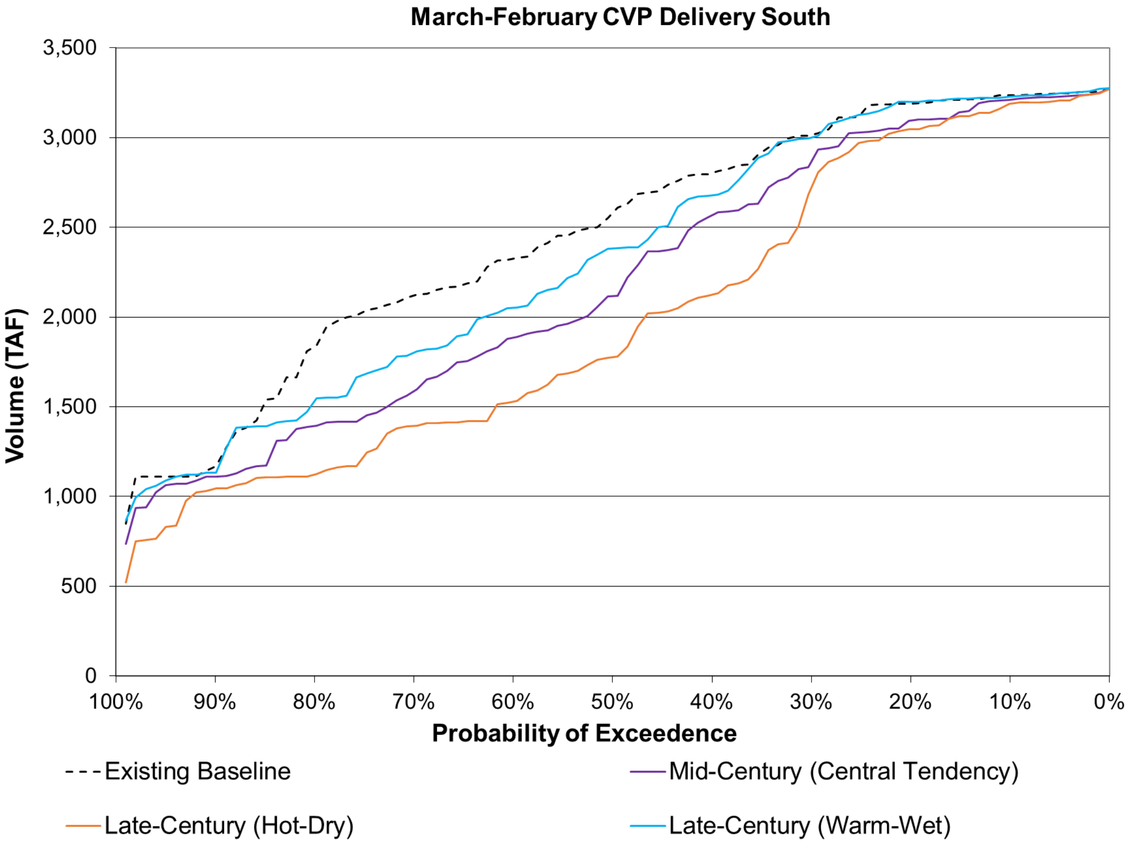

Figure B-15. Annual Volume of CVP Delivery to South-of-Delta Users

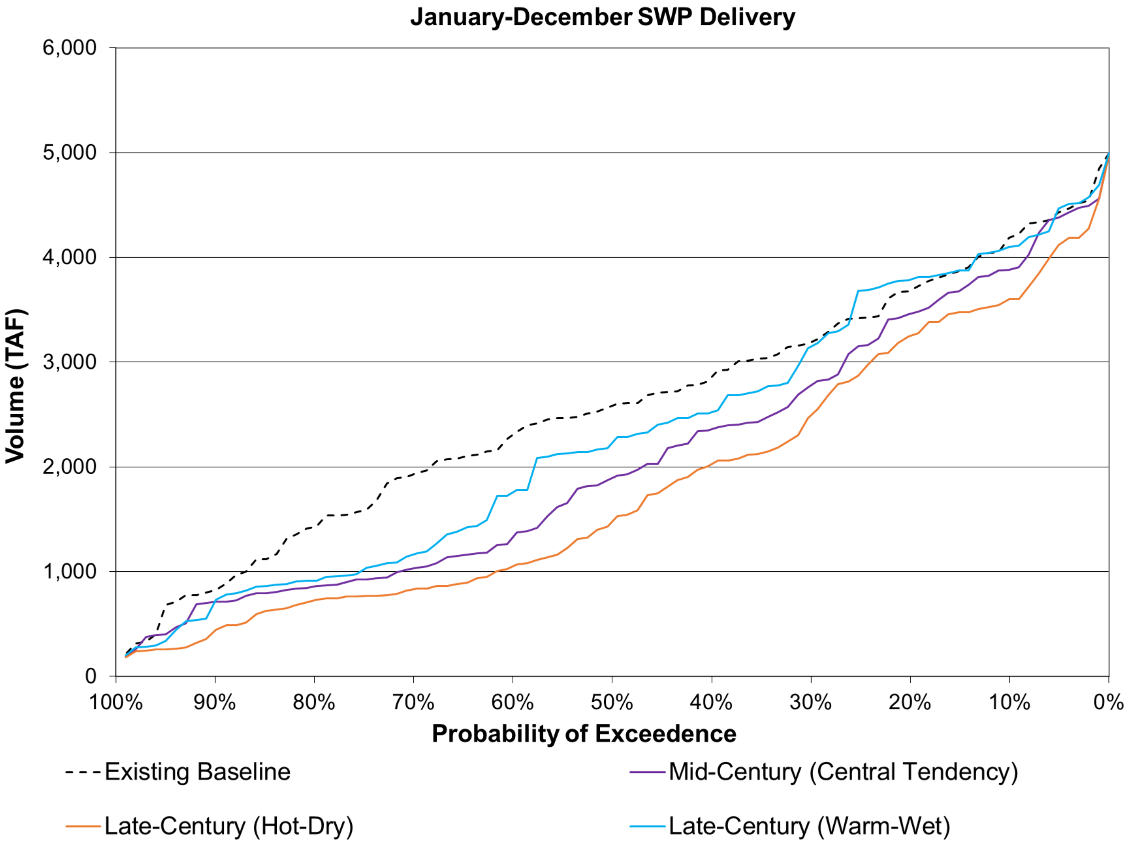

Figure B-16. Annual Volume of SWP Delivery