California Watershed Resilience Assessment

July 2024

Contents

Appendices

Figures

Tables

Acronyms and Abbreviations

AET	actual evapotranspiration
Assessment	watershed resilience assessment
CAP	climate action plan
CDEC	California Data Exchange Center
CMIP5	Coupled Model Intercomparison Project 5
DWR	California Department of Water Resources
GCM	general circulation model
GSP	groundwater sustainability plan
HUC	hydrologic unit code
IRWMP	integrated regional water management plan
km	kilometer
LHMP	local hazard mitigation plan
LOCA	localized constructed analog
LUCAS	land use change simulation model
NOAA	National Oceanic and Atmospheric
OLU	operational landscape unit
PET	potential evapotranspiration
RCP	representative concentration pathway
SWE	snow water equivalent
State	State of California
USGS	United States Geological Survey
UWMP	urban water management plan
VIC	variable infiltration capacity
Water Plan	California Water Plan
°C	degrees Celsius
°F	degrees Fahrenheit

1. Overview

1.1 Purpose

The purpose of the California Watershed Resilience Assessment (Assessment) is to provide a high-level evaluation of the current state of watershed climate vulnerability, climate risk, and climate preparedness for watersheds throughout California. The goal of this Assessment is to provide high-level, statewide, consistent information that describes the vulnerabilities at the watershed scale. This evaluation also assesses the progress that has been made to increase climate preparedness in the water sector. This information will be used to:

- Better understand where and what type of risks exist in California's watersheds.
- Improve understanding of the status of resilience preparedness statewide.
- Inform scoping of the Watershed Resilience Program and how the State of California (State) can best coordinate, support, and partner with local and regional partners in improving their climate resilience.
- Inform the development of watershed networks.

This Assessment serves as a statewide qualitative synthesis of the current state of watershed resilience, which has not been presented elsewhere, and supports the California Water Plan's (Water Plan's) emphasis on watersheds and resilience.

The impacts of climate change can vary among communities with different social, economic, and demographic factors. Also, location and existing vulnerabilities can influence how climate change affects communities and ecosystems differently. This Assessment provides a preliminary analysis of watershed climate resilience that can support more comprehensive watershed resilience planning across the state.

1.2 Introduction

The impacts from climate change are affecting California in several ways, ranging from higher temperatures, reduced snowpack, rising sea levels, and more variable precipitation events. Although these impacts affect California as a whole, individual communities and ecosystems within the state will be affected by climate change differently depending on the projected climate risks and existing vulnerabilities of specific regions.

This technical report presents the approach and findings of a high-level statewide Assessment to support the Water Plan and the Watershed Resilience Program. Similar to the priorities of the 2021 California Climate Adaptation Strategy, the Assessment uses the best available climate science to provide insight on how different climate risks will affect the state. The Assessment is consistent with the Water Plan's goals to promote climate change adaptation and provide resilience information to support California's regions. The Assessment includes an evaluation of both climate vulnerability and resilience preparedness at the watershed scale.

In the Assessment, vulnerability is defined as the degree of climate change impacts in the state's watersheds. Climate vulnerability is evaluated quantitatively using metrics of climate change impacts to water supply, groundwater, water quality, flood management, ecosystems, recreation, and hydropower under future conditions. The climate vulnerability metrics analyzed those listed below.

- Water Supply: Projected change in runoff and water deficit conditions based on locally derived water sources.
- Flood management: Projected intensity of flood events using 1 percent annual exceedance probability flows.
- Groundwater: Projected infiltration of precipitation to deep soil layers within an aquifer.
- Water Quality: Projected change in water temperature and dissolved oxygen in water bodies.
- Ecosystem: Projected variation in the seasonality (timing) and magnitude of streamflow to support ecosystems.
- Hydropower: Projected impact to hydropower generation of the major reservoirs.
- Recreation: Projected change in recreational opportunities in rivers, lakes, snow, and coastal areas based on analyzing flows, snow depth, and sea level rise.
- Wildfire: Wildfire risks related to increases in hot, dry weather and prolonged dry periods is assessed for the future period.

Climate preparedness in each watershed is assessed through review of climate adaptation and resilience planning and actions. In the Assessment, ratings of risk are developed from the combined assessment of climate vulnerability and preparedness.

The result of this Assessment is a summary of the condition of climate vulnerability, preparedness, and climate risk across California using 48 distinct watersheds. The Assessment is consistent with both the California Climate Adaptation Strategy and with the Water Resilience Portfolio efforts to evaluate regional water resiliency. California Department of Water Resources (DWR) staff coordinated with the Governor's Office of Planning and Research in developing this assessment.

2. Watershed Boundaries

For this Assessment, 48 watersheds were delineated in California (Figure 2-1). These watersheds are hydrologically consistent with hydrologic unit code (HUC)-6 or HUC-8 hydrologic units as delineated by the U.S. Geological Survey (USGS). The use of combined HUC-6 and HUC-8 hydrologic units was necessary to attempt to create similar levels of scale in the Sacramento and San Joaquin basins as those in other parts of the state.

For this Assessment, these watershed units were developed to reflect the scale for which watershed resilience planning might occur and to ensure that hydrological boundaries were fully consistent with HUC-6 and HUC-8 boundaries.

Figure 2-1 Watersheds used for California Watershed Resilience Assessment

3. Assessment Approach

The Assessment includes an evaluation of two main elements for each watershed: climate vulnerability and climate preparedness.

Climate vulnerability is evaluated quantitatively for each watershed using a set of metrics related to climate change impacts to water supply, groundwater, water quality, flood management, ecosystems, recreation, and hydropower resource areas. The climate vulnerability ratings should not be interpreted as "definitive" impacts to each watershed, but rather should be used as "indicative" of potential impacts that help focus future study. The change in percentages for vulnerability ratings across the state are not fully consistent because percentage is computed based on historical value for each watershed, which differs among the watersheds.

Climate preparedness in each watershed is assessed through review of climate adaptation and resilience planning and actions. For both climate vulnerability and preparedness, a qualitative rating using a five-point scale was developed for each watershed.

Climate risk ratings are then developed from the combined assessment of climate vulnerability and preparedness. For example, an area with high climate vulnerability and low preparedness would result in a highest risk rating. But an area with high climate vulnerability, and high level of preparedness, may result in a moderate climate risk. Understanding where the risks are greatest and what the preparedness gaps are will help inform State efforts. In addition, for each watershed, the most significant types of climate vulnerabilities (e.g., extreme precipitation, flooding, drought, wildfire or impacts to groundwater, water quality, ecosystem, recreation, and hydropower) are identified.

3.1 Vulnerability Assessment Approach

The evaluation of climate vulnerability relies on existing climatological, hydrological, and other models and data sets. Downscaled climatological data and climate model projections were obtained from Cal-Adapt (University of California, Berkeley, and the California Energy Commission (CEC) 2023). Hydrological responses to these climatic changes were derived from modeling conducted using the variable infiltration capacity (VIC) model. Future wildfire risk projections were derived from modeling and analysis from the University of California, Merced, and obtained from Cal-Adapt. Coastal flooding projections were obtained from the National Oceanic and

Atmospheric Administration (NOAA) coast sea level rise and coastal flood modeling dataset under various sea level rise projections. The sea rise projections are consistent with California Ocean Protection Council 2018 guidance (California Ocean Protection Council 2018). Other data sources, such as DWR climate change studies and California climate change assessments, were also reviewed including *California Climate Adaptation Strategy* (California Natural Resources Agency 2021), *California's Fourth Climate Change Assessment* (California Natural Resources Agency, California Governor's Office of Planning and Research, State of California Energy Commission 2018), *Delta Adapts* (Delta Stewardship Council 2021), DWR's *Climate Action Plan* (California Department of Water Resources 2020), and DWR's Flood Reports (California Department of Water Resources 2013; California Department of Water Resources 2022).

The 20 individual downscaled general circulation model (GCM) projections were selected from 10 different Coupled Model Intercomparison Project Phase 5 (CMIP5) GCMs and two different representative concentration pathways, RCP 4.5 and RCP 8.5. These GCMs were chosen by the DWR Climate Change Technical Advisory Group based on a regional evaluation of climate model ability to reproduce a range of historical climate conditions (California Department of Water Resources Climate Change Technical Advisory Group 2015). These 20 climate projections were downscaled using a statistical downscaling method called "locally organized constructed analogs (LOCAs)" at 1/16th degree (~6 kilometers [km]) (~3.75 miles) spatial resolution by Scripps Institution of Oceanography (Pierce et al. 2014). LOCA downscaled climate model projections data were collected from Scripps Institution of Oceanography.

These climatological, and hydrological, resource changes were mapped to each watershed and used to assess climate vulnerabilities. A five-point rating of climate vulnerability was assigned to each watershed for each type of climate vulnerability. The vulnerability types consist of the changes in the following areas: temperature, precipitation, water supply, flooding, groundwater recharge, stream water quality, ecosystem, recreation, hydropower, drought, and wildfire. A summary of the climatological and hydrological data and projections used in the assessment are included in Table 3-1.

For this assessment, the "historical period" is defined as 1981–2010, the "near period" is defined as 2026–2055, and the "late future period" is defined as 2056-2085. For the analysis of the extreme events (flood and drought), 50-year periods are used, and the "historical period" is defined as 1951–2000, the "near future period" is defined as

2001–2050, and the "late future" is defined as 2050–2099. The 30-year standard reference period is recommended by the World Meteorological Organization and NOAA as the most appropriate length to represent "normal." The 50-year longer period is used for extreme events (flood and drought) analysis as large amounts of sufficiently long period of data are desirable. In terms of seasons for this assessment, "fall" is defined as October to December, "winter" is defined as January to March, "spring" is defined as April to June, and "summer" is defined as July to September (U.S. Bureau of Reclamation 2012).

For all future climate scenarios, temperatures are projected to increase, but temperature projections vary in terms of magnitude. Of the climate model projections, the median annual average temperatures across the watersheds suggest an increase of 1.3 degrees Celsius (°C) to 1.9 °C (2.3 [degrees Fahrenheit] °F to 3.4 °F) for the near future period and 2.2 °C to 3.3 °C (4 °F to 5.9 °F) for the late future period. In the summer, temperatures are projected to increase more than temperatures in winter.

For most of California, precipitation projections are more uncertain, both annually and seasonally. Southern California watersheds are likely to experience a decrease in magnitude of precipitation, while Northern California watersheds are projected to experience an increase in magnitude of precipitation. Compared to the near future period, changes in precipitation are projected to intensify in the late future period. Less frequent, more severe extreme precipitation events from landfalling atmospheric rivers may further increase in the future. But increased warming from climate change likely will result in less frequent, more severe atmospheric river events, leading to an increased prevalence of atmospheric river conditions (Espinoza et al. 2018; Huang et al. 2020). In addition, atmospheric river storms are projected to contribute to a greater amount of total annual precipitation under future conditions (Gershunov et al. 2019). Summer precipitation is projected to increase, and the spring precipitation is projected to decrease during the near and late future periods.

Some common terminologies used in this document are defined below.

Runoff: Runoff is the flow across the land surface of water that accumulates on the surface when the rainfall rate exceeds the infiltration capacity of the soil.

Baseflow: Baseflow is the portion of the streamflow that is sustained between precipitation events, fed to streams by delayed pathways. Baseflow is the sustained flow of a stream in the absence of direct runoff.

Potential Evapotranspiration (PET): Potential evapotranspiration represents the combined loss of water through the plant's process of transpiration via its vascular system, and evaporation of water from the earth's surface.

Actual Evapotranspiration (AET): Actual evapotranspiration is the quantity of water that is actually removed from a surface as a result of the processes of evaporation and transpiration.

Snow Water Equivalent (SWE): Snow water equivalent is the depth of water that would cover the ground if the snow cover were in a liquid state.

Table 3-1 Summary of Hydrometeorological Data Sources to Support Climate Vulnerability Assessment

Data	Use in Analysis	Spatial and Temporal Resolution	Source
Precipitation and temperature projections from Coupled Model Intercomparison Project Phase 5 (CMIP5) downscaled climate model simulations	Use for analyzing drought, groundwater recharge, and water quality	Daily data from 1950 to 2099	Cal-Adapt
Runoff, baseflow, potential evapotranspiration (PET), actual evapotranspiration (AET) and snow water equivalent (SWE) projections from CMIP5 downscaled climate model simulations	Use for analyzing water supply, drought, flood, groundwater recharge, ecosystem flow, hydropower, and recreation	Daily data from 1950 to 2099	Cal-Adapt
Historical streamflow, storage, outflow, and evaporation from reservoirs	Use for analyzing hydropower and lake recreation opportunities	Monthly data	Variable Infiltration Capacity (VIC) California Data Exchange Center
Wildfire scenario from CMIP5 downscaled climate model simulations	Use for analyzing wildfire burned area and decadal probabilities	1/16-degree (approximately 6 kilometers) resolution from 1952 to 2099	Cal-Adapt
Sea level rise projections and coastal flooding	Use for analyzing coastal recreational opportunities	Projected future inundation area data	State of California Sea-Level Rise Guidance (Ocean Protection Council) National Oceanic and Atmospheric Administration (NOAA)

Data	Use in Analysis	Spatial and Temporal Resolution	Source
Precipitation and temperature projections from CMIP5 downscaled climate model simulations	Use for analyzing drought, groundwater recharge, and water quality	Daily data from 1950 to 2099	Cal-Adapt
Runoff, baseflow, PET, AET, and SWE projections from CMIP5 downscaled climate model simulations	Use for analyzing water supply, drought, flood, groundwater recharge, ecosystem flow, hydropower, and recreation	Daily data from 1950 to 2099	Cal-Adapt
Historical streamflow, storage, outflow, and evaporation from reservoirs	Use for analyzing hydropower and lake recreation opportunities	Monthly data	VIC

The following sections provide a summary of the primary climate vulnerability metrics and analysis methodologies.

3.1.1 Water Supply

For the purpose of this Assessment, water supply vulnerability is assessed by comparing the projected runoff with water deficit conditions for future scenarios for all watersheds. Water supply metrics are based on locally derived water sources and do not include water imports, transfers, or any additional external sources. The metric is calculated by analyzing the following indices:

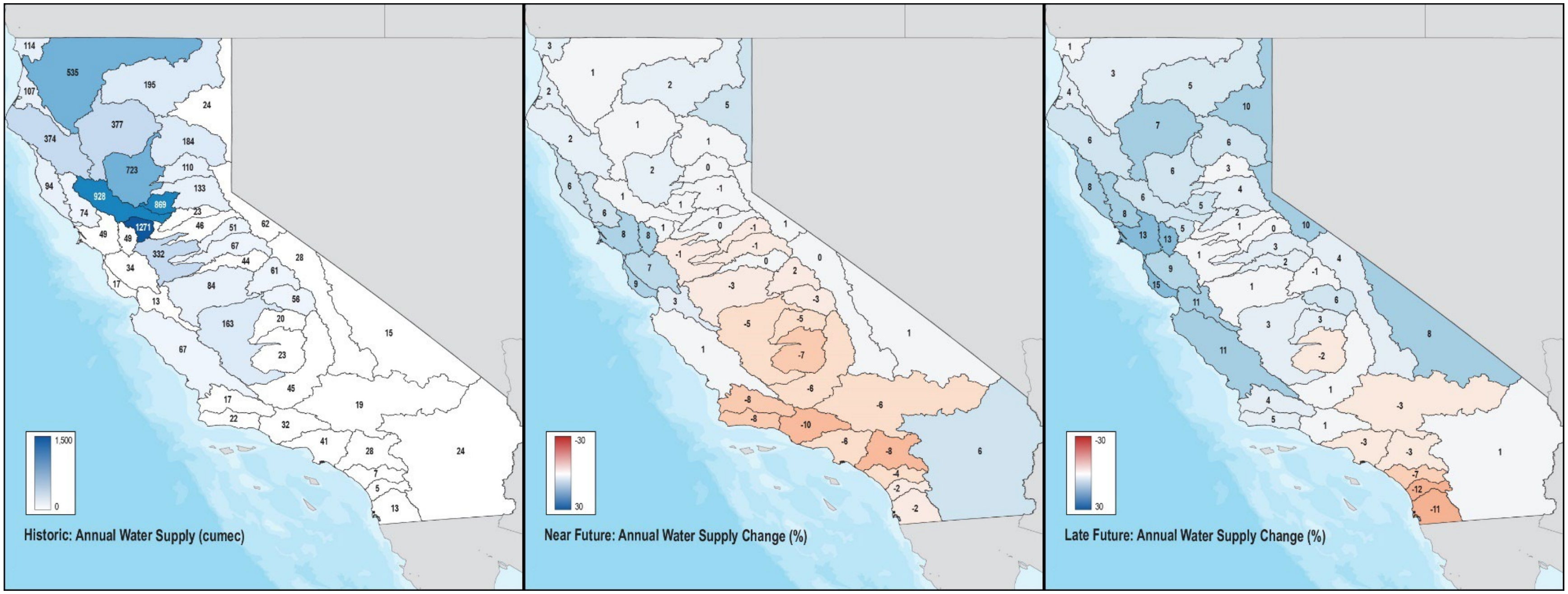
- Projected changes in average and lower quartile (25th percentile) annual and seasonal available water supply.
- Projected changes in drought severity and duration.

Methodology: VIC-simulated surface runoff and base flow fluxes models for 20 climate projections are used to estimate the change in annual, seasonal, and low-quartile (25th percentile) total runoff. Total runoff is defined as the watershed flow which incorporates the routed flow from the upstream watersheds using the summation of surface runoff and baseflow aggregated at the annual and seasonal scale based on each water year. The change from the 20 climate projections is estimated for the near future and late future periods with respect to the historical period.

Drought severity and duration are estimated using the routed runoff deficit simulated by the VIC model for 20 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 longest consecutive periods of annual flow below average conditions. This method is chosen for its simplicity and consistency across all watersheds. Drought duration is calculated as the longest consecutive duration of low flows and drought severity is defined as the maximum cumulative flow deficit during the drought periods. Change in these indices is estimated from 20 climate projections for near future and the late future periods with respect to the historical period. Appendix A provides more details on methodology.

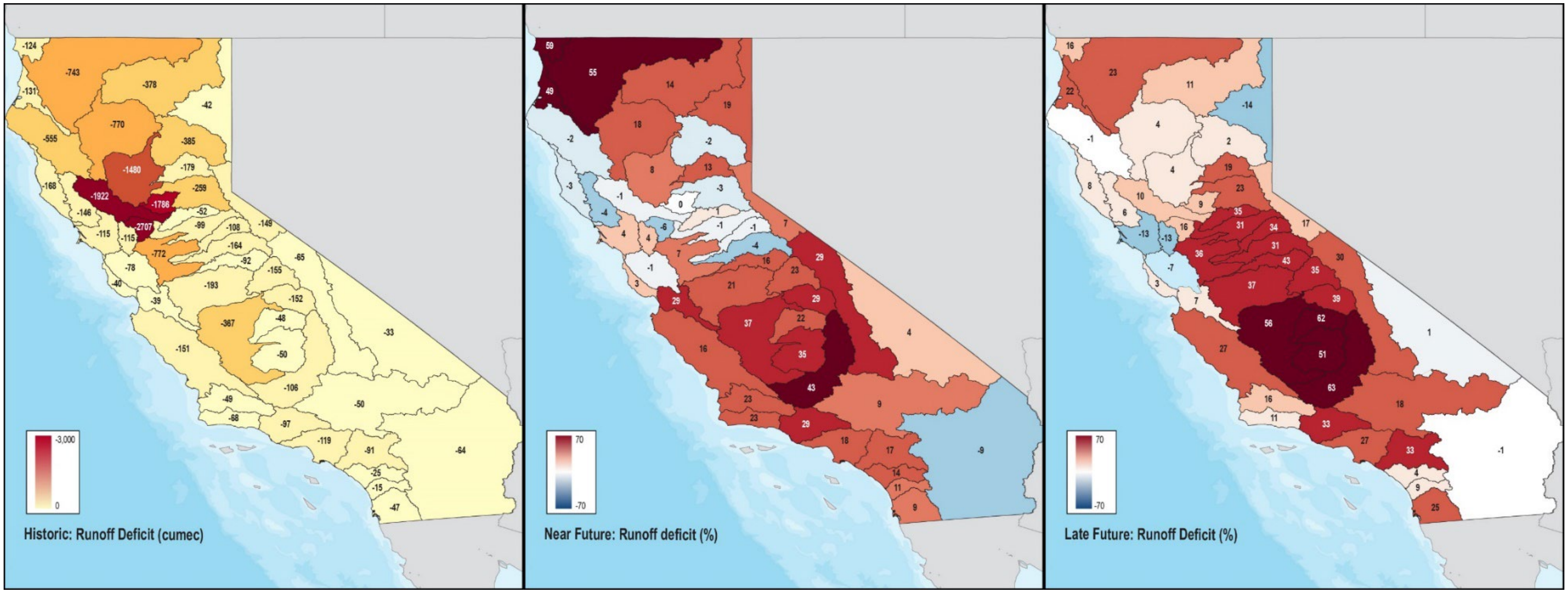
Key Results: Increases in annual water supply are expected to be greater in the late future period compared to the near future (Figure 3-1). Some watersheds in Southern California are projected to exhibit reduced water supply. Water supply is projected to increase during the fall and winter seasons but decrease for spring and summer seasons. Drought severity and duration are also expected to increase in the future (Figure 3-2).

Figure 3-1 Change in the Annual Water Supply (total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



Note: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure 3-2 Change in Drought Severity at Watershed Scale during Near Future (2001–2050, center, %) and Late Future (2050–2099, right, %) with respect to Historic Period (1951–2000, left, cumec)



Note: Change is computed using the median values from 20 climate model projections. Positive values indicate an increase in dryness.
cumec = cubic meters per second.

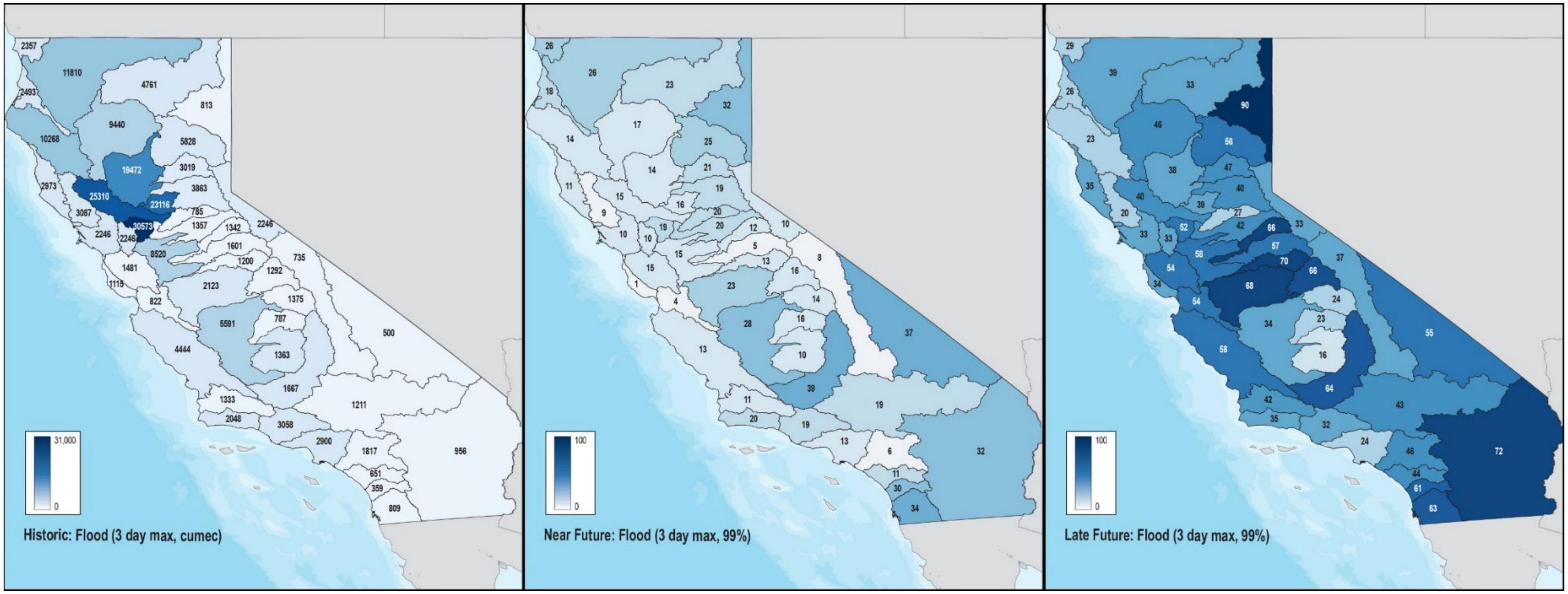
3.1.2 Flood Management

Flood impacts are estimated by forecasting the intensity of flood events for the future period. The projected changes in 1-percent annual exceedance probability flows at watershed outlets are calculated based on three-day unimpaired flow in the future period compared to the historical period.

Methodology: Flood analysis is conducted using the VIC-simulated total runoff (watershed flow includes the routed flow from the upstream watersheds using the summation of surface runoff and baseflow) for 20 climate projections. A three-day moving average for total runoff is generated from daily fluxes and the maximum value of the three-day moving average is selected for each water year from 1951 to 2099. The change in the 99th percentile values of the three-day maxima total runoff is computed for the near and future periods with respect to the historical period, and the median from the 20 climate projections is estimated. Appendix A provides more details on methodology.

Key Result: With the projected rise in extreme events, flood intensity is also expected to increase in the near future period and further exacerbate during the late future period (Figure 3-3).

Figure 3-3 Change in Flood (3-day Annual Maxima, 99th Percentile) at Watershed Scale during Near Future (2001–2050, center, %) and Late Future (2050–2099, right, %) with respect to Historic Period (1951–2000, left, cumec)



Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

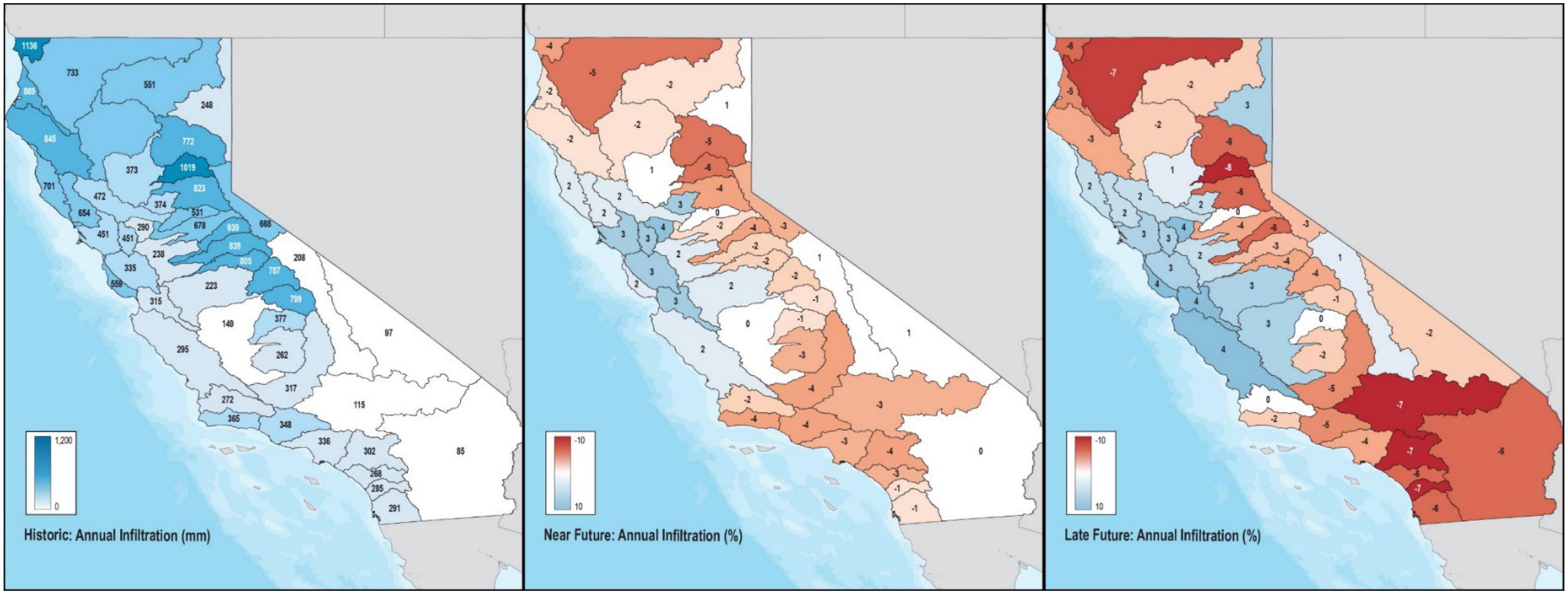
3.1.3 Groundwater

Climate change impacts on groundwater recharge are estimated as the change in infiltration of precipitation (California Department of Water Resources 2023). Infiltration is calculated as the net balance between precipitation, actual evapotranspiration, and total runoff. Projected changes in average and lower quartile groundwater recharge are estimated for the future periods compared to the historical period.

Methodology: Groundwater recharge from infiltration of precipitation is derived using precipitation, VIC-simulated actual evapotranspiration, and total runoff (summation of surface runoff and baseflow) for 20 climate projections. The annual infiltration is estimated as the net balance of precipitation minus actual evapotranspiration and runoff. The change in annual average infiltration and low-quartile annual recharge flow is calculated for the near and late future periods with respect to the historical period, and the median from the 20 climate projections is reported. Appendix A provides more details on methodology.

Key Results: Groundwater recharge changes show spatial heterogeneity with decreases in Sierra Nevada, Southern, and Northern California watersheds for the near future period (Figure 3-4). Groundwater infiltration is projected to further decrease during the late future period. The reduction in the infiltration in Southern California is driven by decrease in precipitation and runoff, while the increase in the actual evapotranspiration causes decrease in infiltration in Northern California.

Figure 3-4 Change in Annual Groundwater Infiltration at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, mm)



Notes: Change is computed using the median values from 20 climate model projections. mm = millimeters.

3.1.4 Water Quality (Temperature and Dissolved Oxygen)

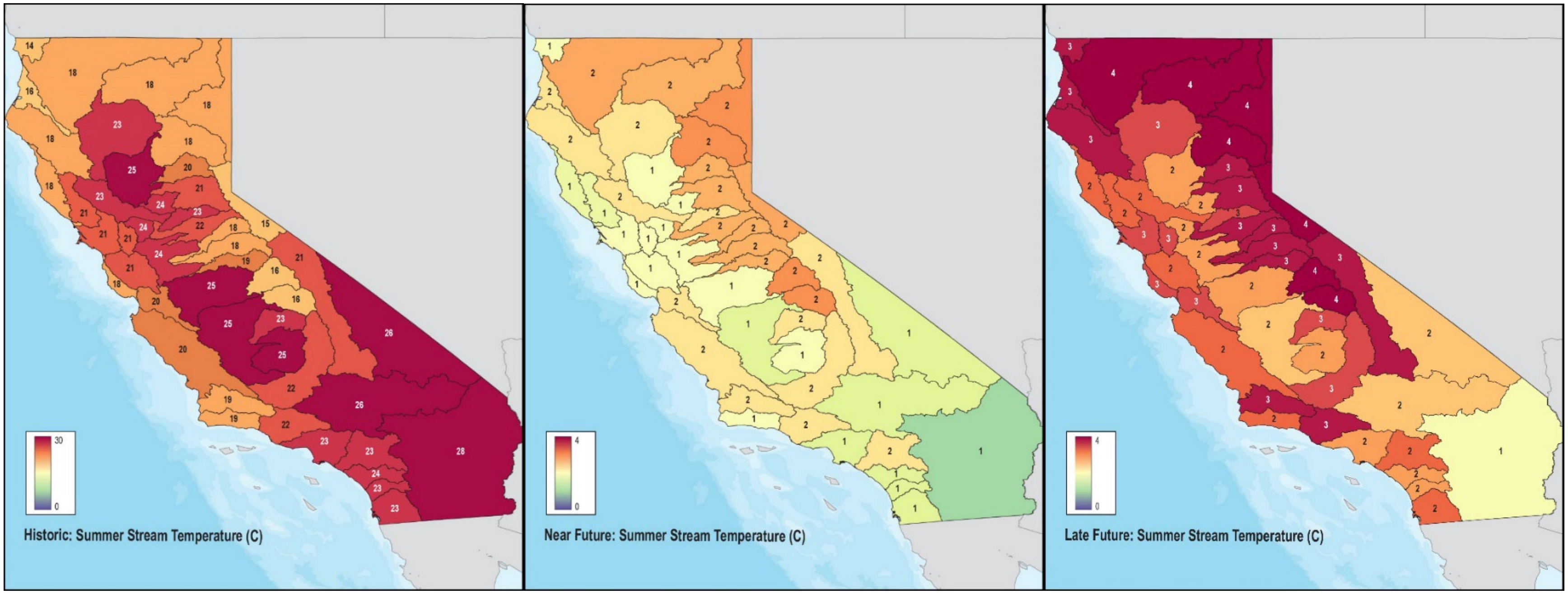
Climate change may impact water quality in various ways. The mechanisms of impact on water quality are complex and usually highly dependent on site conditions such as stream channel, riparian vegetation, elevation and slope, and subsurface flow contributions (California Water Quality Monitoring Council 2023). For the purpose of this Assessment, a high-level approach to water quality impacts evaluated potential for increased water temperature and reduced dissolved oxygen in water bodies. Based on the correlation matrices with air temperature and snowmelt, stream temperature changes are estimated for the historic and future periods. The metric is calculated by analyzing the following indices:

- Projected changes in stream temperature.
- Projected changes in dissolved oxygen.

Methodology: Computation of the stream temperature is performed by using the Köppen Climate Classification System and a nonlinear regression model equation between the stream temperature and air temperature (Kottek et al. 2006; Mohseni et al. 1998). Dissolved oxygen is estimated using the equation developed by the American Public Health Association (Greenberg et al. 1992) based on stream temperature. VIC-simulated average daily temperature for 20 climate projections are utilized for the calculation. The absolute median changes in stream temperature and dissolved oxygen are calculated for the near and future periods with respect to the historical period. Appendix A provides more details on methodology.

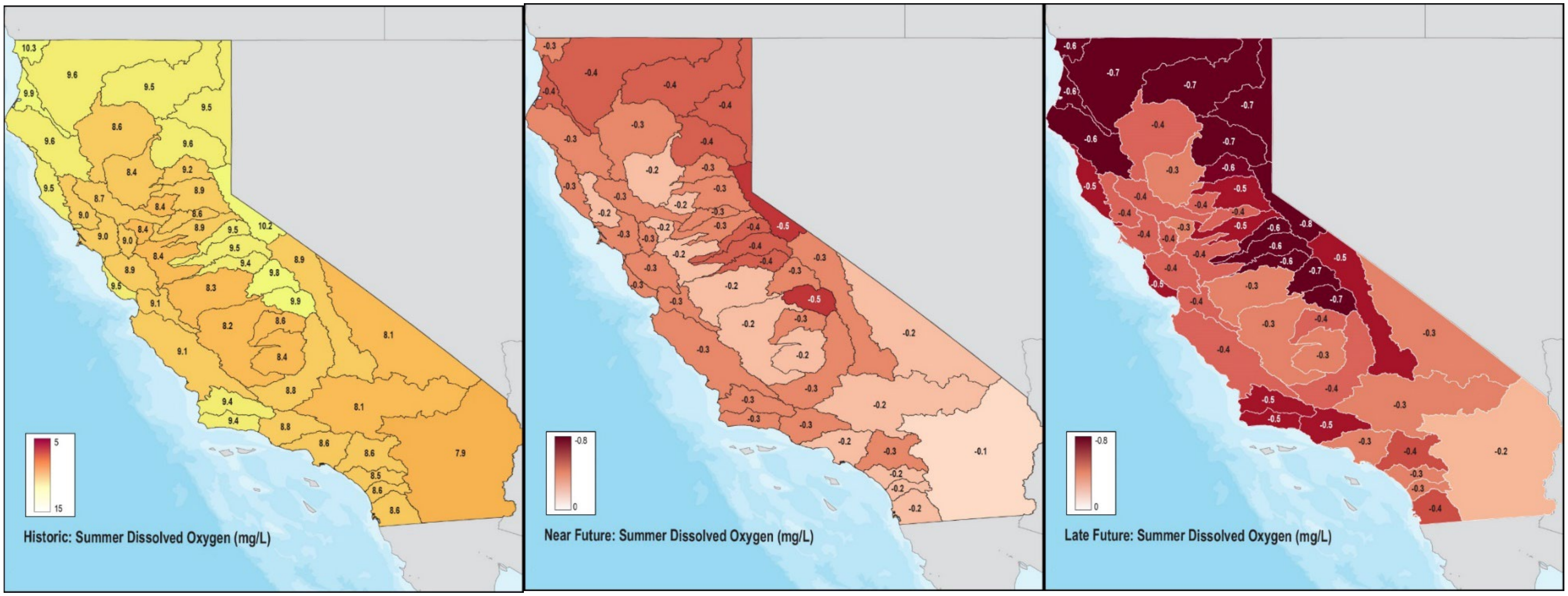
Key Results: Stream temperature and dissolved oxygen content are correlated with average air temperature. Stream water temperature is expected to increase (Figure 3-5), and dissolved oxygen content is expected to decrease for all watersheds in California (Figure 3-6).

Figure 3-5 Change in Summer Season (Jul-Sep) Stream Water Temperature at Watershed Scale during Near Future (2026–2055, center, °C) and Late Future (2056–2085, right, °C) with respect to Historic Period (1981–2010, left, °C)



Note: Change is computed using the median values from 20 climate model projections. ºC = degrees Celsius.

Figure 3-6 Change in Summer Season (Jul-Sep) Dissolved Oxygen at Watershed Scale during Near Future (2026–2055, center, mg/L) and Late Future (2056–2085, right, mg/L) with respect to Historic Period (1981–2010, left, mg/L)



Notes: Change is computed using the median values from 20 climate model projections. mg/L = milligrams per liter.

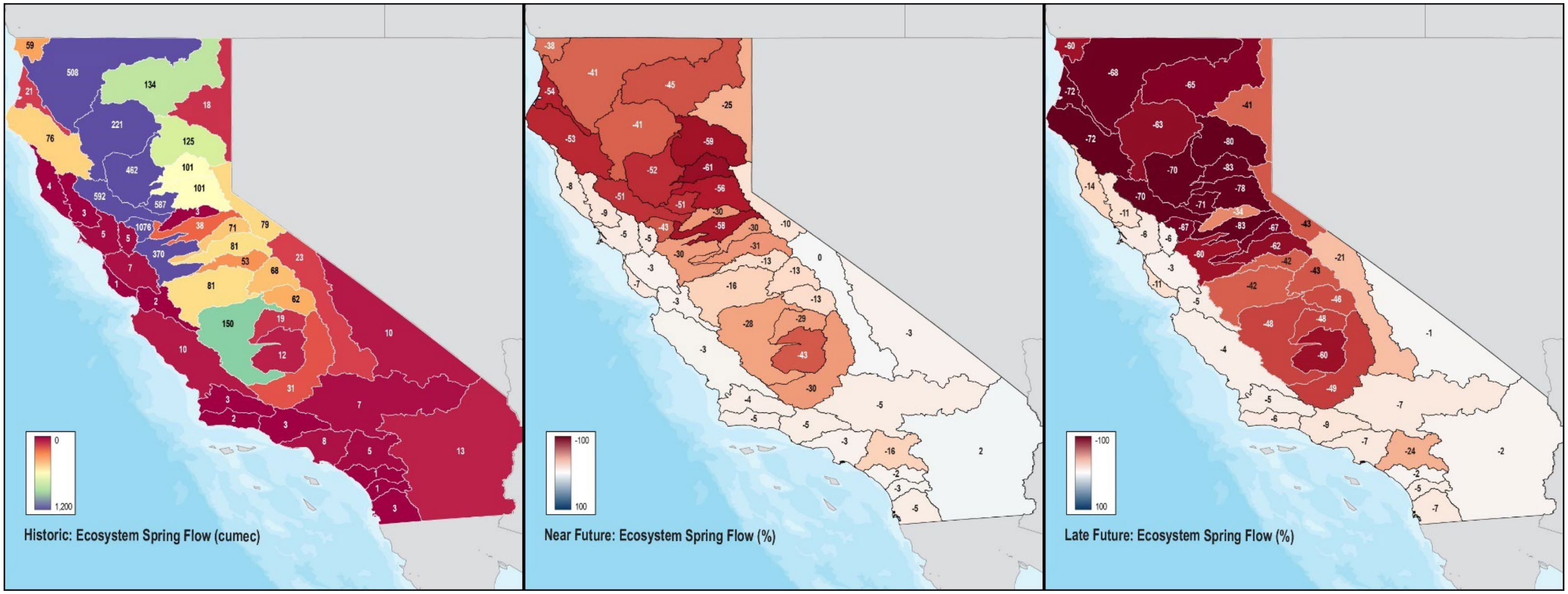
3.1.5 Ecosystem

Climate change, as projected, will cause significant changes in the seasonality (timing) and magnitude of streamflows. Changes in precipitation patterns and type (rain-snow), snowpack development and snowmelt, and changes in storm intensity all contribute to changes in streamflow. Many aquatic and terrestrial species are reliant on the seasonality and variability of flows to thrive (California Department of Fish and Wildlife 2024). For this Assessment, projected changes in seasonal low flows and variability are used to assess potential impacts to aquatic ecosystems.

Methodology: The ecosystem metric is estimated as the change in the seasonal low flow and seasonal variance for fall, winter, spring, and summer for the near and future periods with respect to the historical period. Total runoff is defined as the watershed flow which incorporates the routed flow from the upstream watersheds using the summation of surface runoff and baseflow. The low flow is calculated as the 25th percentile of the monthly total runoff simulated by the VIC model for 20 climate projections. Appendix A provides more details on methodology.

Key Results: Streamflow magnitude and duration for ecosystem support are expected to increase during the winter season and decrease during the spring season (Figure 3-7). But during fall and summer seasons, the changes are minor and spatially heterogenous.

Figure 3-7 Change in Spring season (Apr-Jun) Ecosystem Flow (25th percentile total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

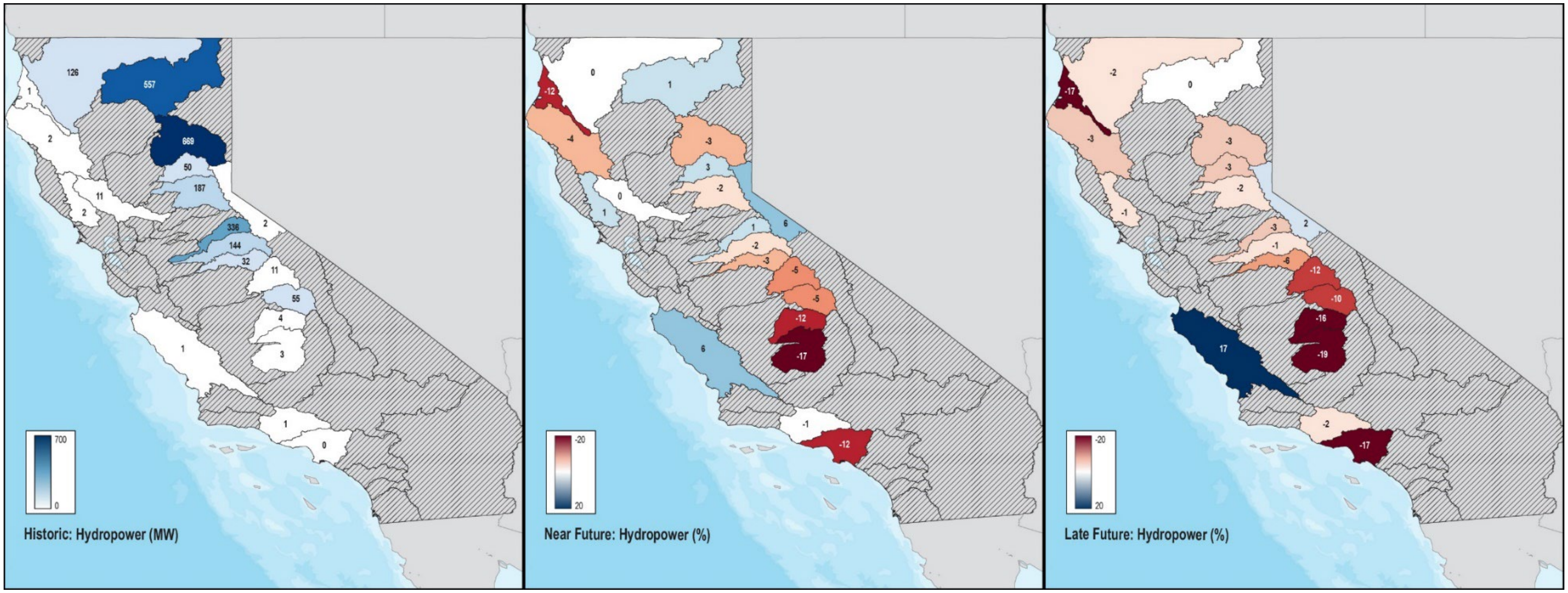
3.1.6 Hydropower

Changes in the timing of snowmelt and precipitation can also alter streamflow into major reservoirs, impacting hydropower production. Major hydroelectric generation facilities in each watershed are selected and the projected changes for inflows, storage-elevation, and generation are used to characterize the relative impact to hydropower generation (California Energy Commission 2023).

Methodology: The major dams of each watershed were used to calculate hydropower generation. The dam characteristics (e.g., storage capacity, power capacity, etc.), along with the storage-elevation, power, and energy equations, are assumed to be constant for the future periods. Using historical data, the relationship between storage, outflow, and water year index is developed. Inflow, evaporation, and water year type are used to estimate reservoir storage using the water balance equation. The dam watershed averaged monthly inflow was estimated using VIC-simulated daily total runoff from the 20 climate projections. The simulated streamflow considers shift to the earlier months as a result of earlier spring snowmelt runoff and more precipitation as liquid rain in snow dominated watersheds. Monthly hydropower generation and annual energy generation are calculated based on the water level, outflow, and storage. Watershed-scaled inflow estimates, potential energy, power, and linear storage-elevation equations are used as the alternative approaches for data-deficit dams. The change is calculated for the near and future periods with respect to the historical period and the median from the 20 climate projections is reported. Appendix A provides more details on methodology.

Key Results: Hydropower generation is expected to decrease at a majority of the dams reviewed because of future climate change (Figure 3-8). The projected high inflow during some periods is not completely transformed to hydropower generation because of restriction in reservoir storage capacity and power capacity. The inflow overwhelming the reservoir storage capacity is discharged as reservoir spill and cause a loss of potential hydropower generation. Similarly, the inflows with potential hydropower exceeding the power capacity are non-productive.

Figure 3-8 Change in Hydropower at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, megawatt)



Notes: Change is computed using the median values from 20 climate model projections. Watersheds not analyzed are marked with hatching.

3.1.7 Recreation

Increased temperatures, increased evapotranspiration rates, and more variable precipitation rates are likely to have variable impacts on recreational areas and opportunities. Projected changes in recreational opportunities in rivers, lakes, snow, and coastal areas are assessed by analyzing flows, snow depth, and sea level rise. For this assessment, recreational impacts are calculated by analyzing the following indices, intending to capture indicators for boating, fishing, snow-based recreation, and beach access and availability:

- Projected changes in river recreation opportunities.
- Projected changes in lake recreation opportunities.
- Projected changes in snow recreation opportunities.
- Projected changes in coastal recreation opportunities.

It is recognized that these indicators are coarse estimates of the recreational impacts, and that other impacts, such as wildfire and water quality changes, also impact recreational opportunities. But these measures are believed to be suitable for this level of analysis.

Methodology: River recreation opportunities are indicated by the number of days during the May-through-September period with river flows between the 25th and 75th percentiles of historic flows. Most river recreation occurs during this late spring and summer period and under moderate flow conditions. VIC-simulated total runoff (watershed flow includes the routed flow from the upstream watersheds using the summation of surface runoff and baseflow) for 20 climate projections is used to calculate the reference flow values from the historic period and estimates for river recreation days. The median changes in recreation days are calculated for the near and future periods with respect to the historical period. Appendix A provides more details on methodology.

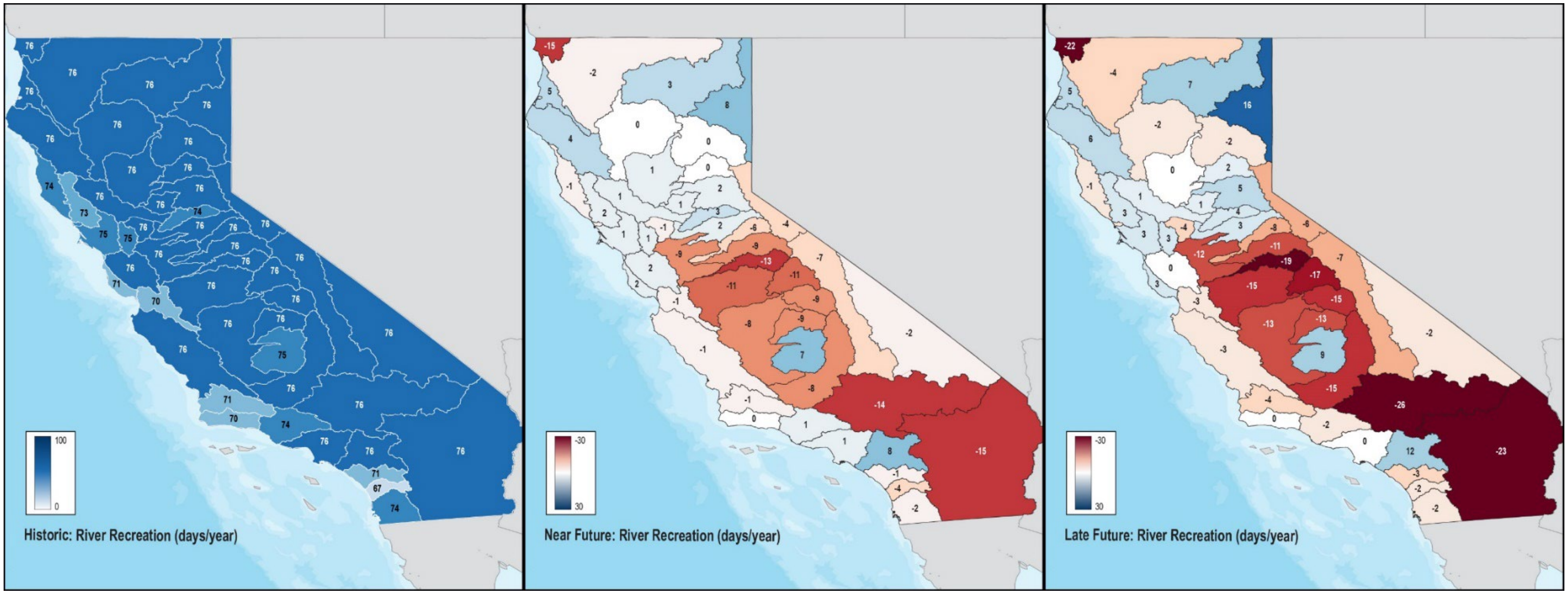
Changes in lake recreational opportunities are indicated by changes in the average water surface area of major lakes during the May-through-September period. Although lake recreation is dependent on access (e.g., boating), facilities, and other conditions, many of these conditions are correlated to the amount of lake surface area. Lake characteristics (e.g., storage capacity, surface area, etc.), along with the storage-elevation and storage-area, are assumed to be constant during the future periods. The relationship between storage, outflow, and water year type is established using historical data. Using water balance equations, inflow, evaporation, and water year type are used for estimating reservoir storage. Monthly lake surface area is calculated based on the variation in storage. Watershed-scaled inflow estimates and linear storage-area equations are used as proxies for dams lacking sufficient data. The change is calculated for the near and future periods. The median from the 20 climate projections is reported.

Snow recreation opportunities are indicated by the number of days during the November-through-June snow recreation period with SWE more than 3.9 inches (100 millimeters). Recreational days are calculated for major ski resorts for each watershed. VIC-simulated daily SWE for 20 climate projections is used to estimate the number of snow recreation days for water years. The median changes are calculated for the near and future periods.

Changes in coastal recreation opportunities are calculated using the change in the inundation area along coasts under different sea level rise scenarios. Recreation areas are estimated using the coastal zone boundary and operational landscape units (OLUs) layers extent inland of the seashore. The inundation area resulting from sea level rise ranging from 1 foot to 10 feet is clipped from the base recreation area to calculate the percentage change with respect to the base area.

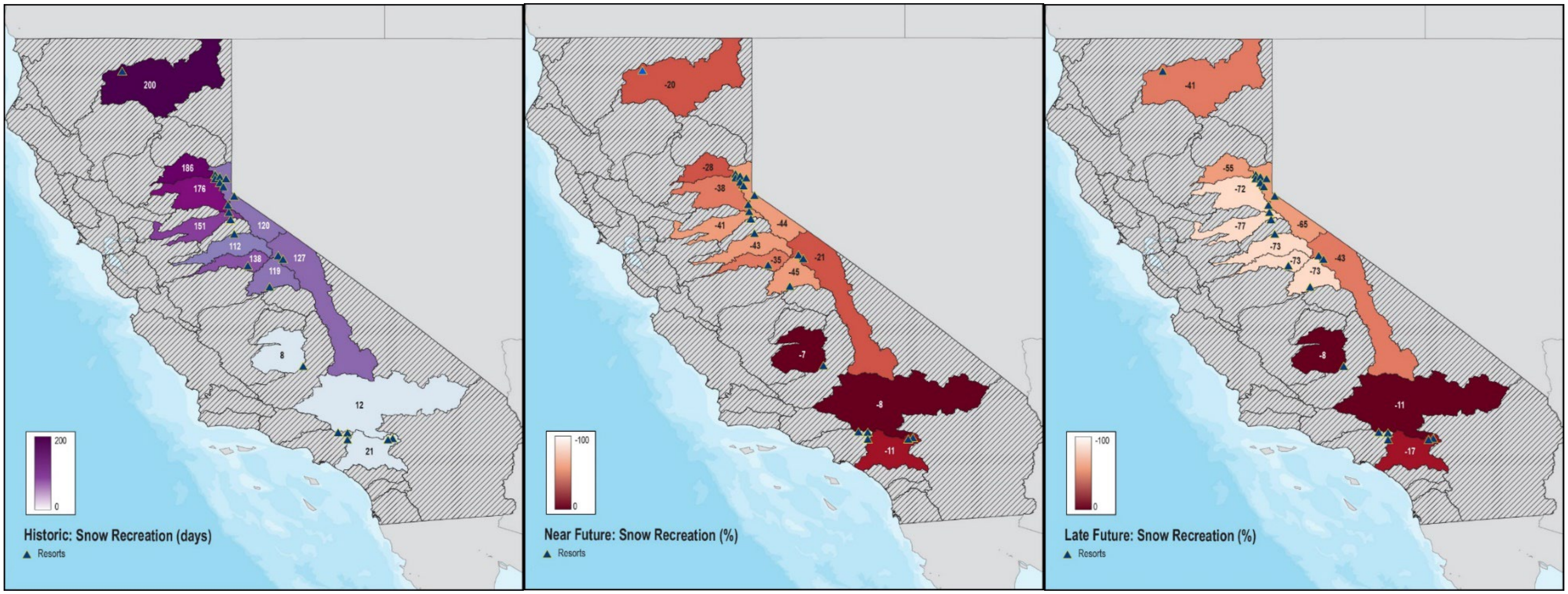
Key Results: For a majority of watersheds in Central and Southern California, river recreational opportunities are projected to decrease in the near future period and further decrease in the late future period (Figure 3-9). Snow recreational opportunities are also projected to decrease for all major ski resorts in the future periods (Figure 3-10). As a result of climate change, the lake recreational opportunities are expected to decrease for a majority of the lakes in the future periods (Figure 3-11). The projected high inflow leads to increased chance of lake spillage because the increased inflow overwhelms the storage capacity when storage is already high. Coastal recreation areas are projected to decrease for all watersheds along the coast, with the magnitude of change proportional to the amount of sea level rise (Figure 3-12).

Figure 3-9 Change in Number of River Recreation Days at Watershed Scale during Near Future (2026–2055, center, days/year) and Late Future (2056–2085, right, days/year) with respect to Historic Period (1981–2010, left, days/year)



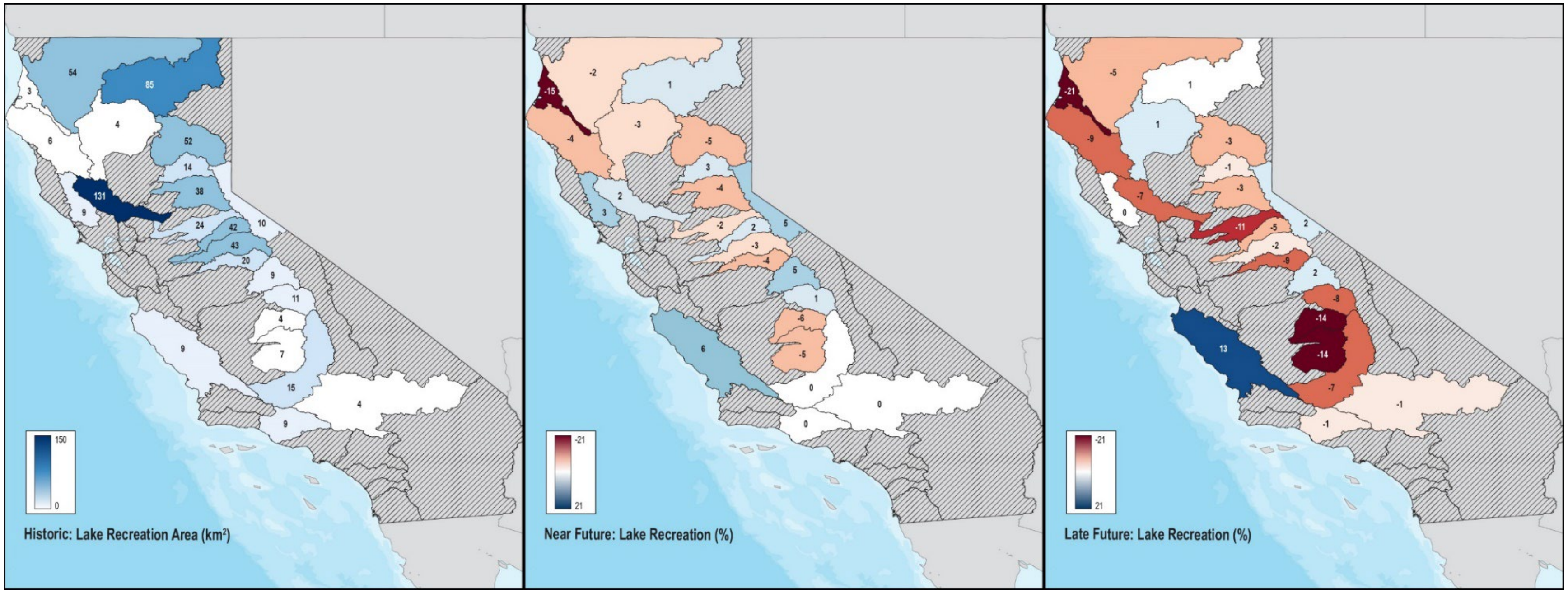
Note: Change is computed using the median values from 20 climate model projections.

Figure 3-10 Change in Number of Snow Recreation (skiing) Days at Watershed Scale during Near Future (2026-2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, days)



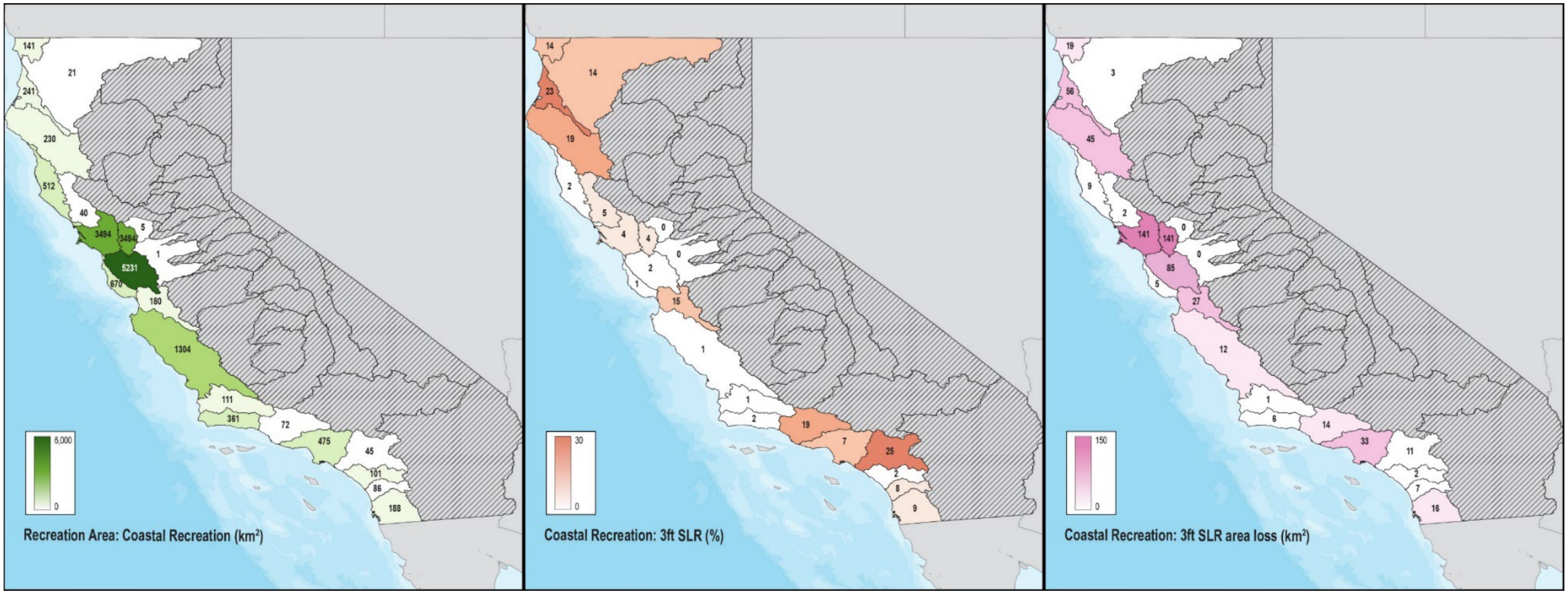
Notes: Change is computed using the median values from 20 climate model projections. Watersheds not analyzed are marked with hatching.

Figure 3-11 Change in Lake Recreation Opportunities at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, km²)



Notes: Change is computed using the median values from 20 climate model projections. Watersheds not analyzed are marked with hatching. km^2 = square kilometer.

Figure 3-12 Change in Coastal Recreation Area (center, %; right, km²) at Watershed Scale resulting from 3-foot Sea Level Rise with respect to Base Recreation Area (left, km²)



Notes: Watersheds not analyzed are marked with hatching. km^2 = square kilometer.

3.1.8 Wildfires

Increases in hot, dry weather and prolonged dry periods can cause extreme low soil moisture and increases the risk of wildfires. Climate change can increase drought risks (e.g., vegetative desiccation and dieoff), and higher temperatures create ideal conditions for fires to start and spread. Recent historical trends have demonstrated increases in the size and occurrence of destructive wildfires. Projected changes in future wildfires are calculated by analyzing the following indices:

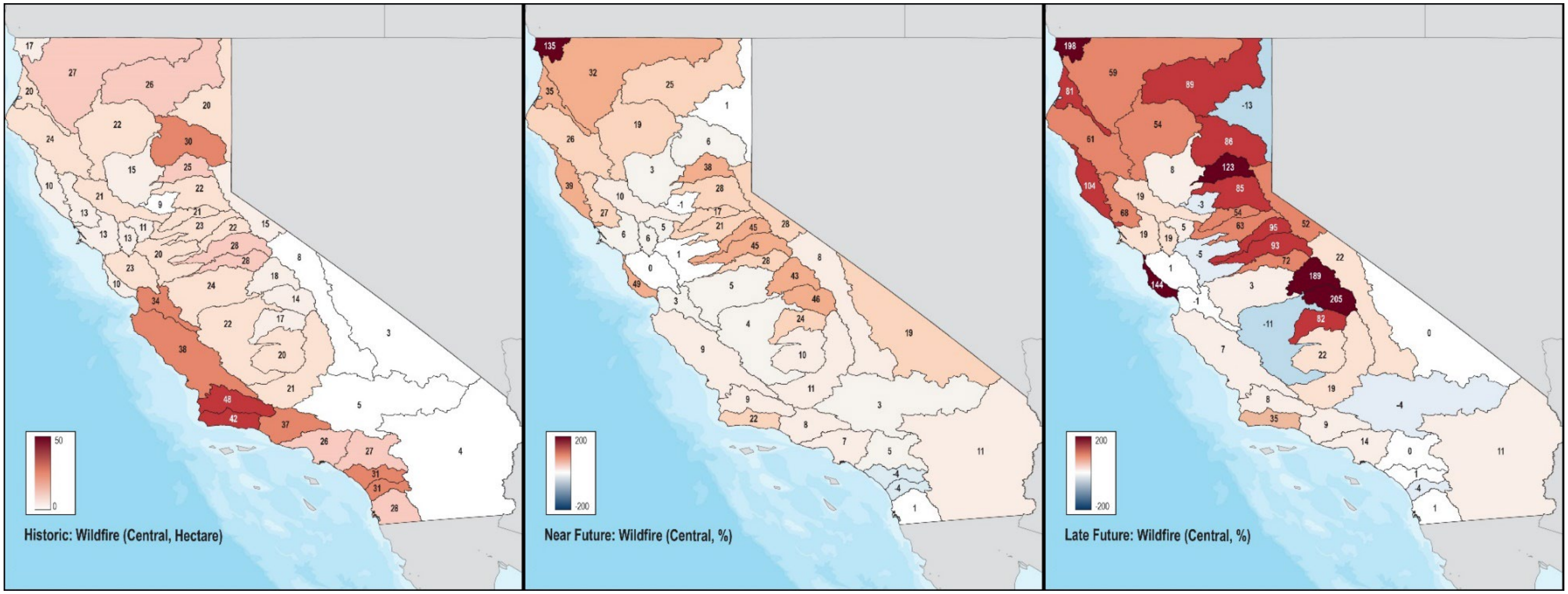
- Projected changes in area burned.
- Projected changes in decadal wildfire probabilities.

Area burned is defined as the area projected to be at risk of burning in a given year. Decadal wildfire probability is the probability of occurrence of one or more fires in any area during the decade.

Methodology: Wildfire indices are estimated using the annual wildfire burned area and data for three population scenarios and four climate models under Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 from the Cal-Adapt database. The burn area and the decadal wildfire probabilities for each watershed are calculated for the historic and future periods. Grids with missing data are excluded during the calculation for burn area, probability, and watershed area. The median changes are calculated for the near and future periods relative to the historical period. Appendix A provides more details on methodology.

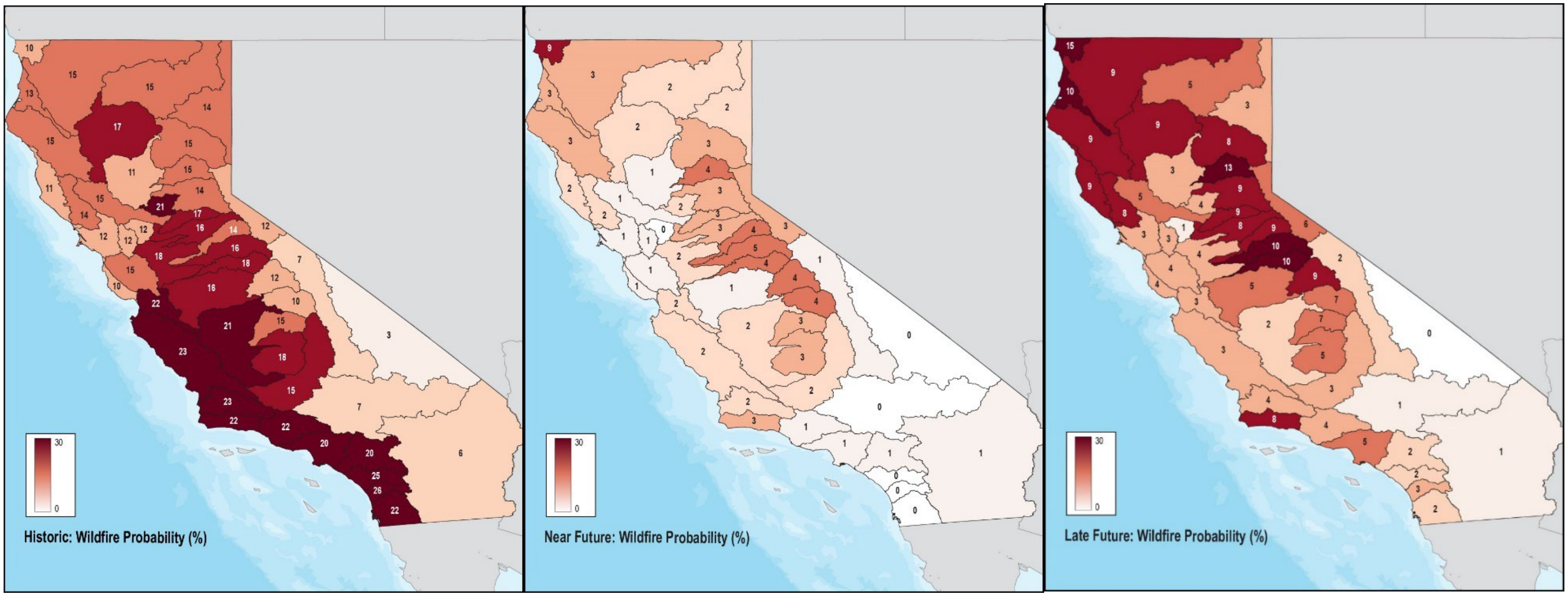
Key Result: Wildfire burn area and decadal probability are projected to increase for the near and late future periods (Figures 3-13 and 3-14). The increase is greater for the watersheds that have a greater amount of wildfire fuels.

Figure 3-13 Change in Burned Area Resulting from Wildfire at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, hectare) for Central Population Growth Scenario



Note: Change is computed using the median values from eight climate model projections.

Figure 3-14 Change in Wildfire Probability at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, %) for Central Population Growth Scenario



Note: Change is computed using the median values from eight climate model projections.

3.1.9 Summary Vulnerability Ratings

Table 3-2 provides a summary of the vulnerability indicators, metrics, and rating scales used in this Assessment. These rating scales and associated relative changes were derived by evaluating the range of projected changes across California's watersheds over the next century and provide a useful scale for describing low and high changes that may impact individual watersheds. The vulnerability ratings should not be interpreted as "definitive" impacts to all watersheds, but rather should be used as "indicative" of potential impacts. The percent changes for vulnerability ratings across the state are not fully consistent because they are computed based on historical value for each watershed, which differs among the watersheds.

Table 3-2 Vulnerability Indicators, Metrics, and Rating Scales

No.	Vulnerability Indicator	Vulnerability Metric	Threshold Value for Rating				
			Low (rating = 1)	**Low-Moderate (rating = 2)**	**Moderate (rating = 3)**	**Moderate-High (rating = 4)**	**High (rating = 5)**
1	Temperature	Annual change (ºC)	< 1 ºC	> 1 ºC	> 2 ºC	> 3 ºC	> 4 ºC
2	Precipitation	Annual change (%)	> 0%	< 0%	< -5%	< -10%	< -15%
3	Water Supply	**Change in Lowest Quartile Annual Flow (%)**	> 0%	< 0%	< -10%	< -20%	< -30%
		Drought Severity Change (%)	< 0%	> 0%	> 10%	> 30%	>50%
		Drought Duration (years)	< 0	> 0	> 1	> 2	> 3
4	Flood Management	**Change in Annual Peak 3-day Flood Volume**	< 0%	> 0%	> 10%	> 30%	>50%
5	Groundwater	**Annual Recharge Change (%)**	> 0%	< 0%	< -10%	< -20%	< -30%
6	Water Quality	**Change in Summer Stream Temperature (ºC)**	< 1 ºC	> 1 ºC	> 2 ºC	> 3 ºC	> 4 ºC
		Change in Summer Dissolved Oxygen (mg/L)	> 0	< 0	< 0.25	< 0.5	< 0.75
7	Ecosystem	**Change in Spring Lowest Quartile Flow (%)**	> 0%	< 0%	< -10%	< -30%	< -50%
8	Hydropower	**Change in Annual Generation (%)**	> 0%	< 0%	< -10%	< -20%	< -30%

No.	Vulnerability Indicator	Vulnerability Metric	Threshold Value for Rating				
			Low (rating = 1)	Low-Moderate (rating = 2)	Moderate (rating = 3)	Moderate-High (rating = 4)	High (rating = 5)
9	Recreation	**Change in Days Suitable for River Recreation (days)**	> 0 d	< 0 d	< -10 d	< -20 d	< -30 d
		Change in May-Sep Lake Surface Areas (%)	> 0%	< 0%	< -10%	< -20%	< -30%
		Change in Days in Nov-Jun Suitable for Snow Recreation from Natural Snow (days)	> 0 d	< 0 d	< -15 d	< -30 d	< -45 d
		Change in Coastal Zone Areas (%)	> 0%	< 0%	< -10%	< -20%	< -30%
10	Wildfire	**Change in Wildfire Burn Probability (%)**	< 0%	> 0%	> 5%	> 10%	>15%
		Change in Wildfire Burn Area (%)	< 0%	> 0%	> 50%	> 75%	>100%
11	Drought	**Drought Severity Change (%)**	< 0%	> 0%	> 10%	> 30%	>50%
		Drought Duration (years)	< 0	> 0	> 1	> 2	> 3

Notes: ºC = degrees Celsius; mg/L = milligram per liter; d = days.

Watershed climate vulnerability can be viewed by evaluating the potential impacts from each of the indicators above or collectively by combining vulnerability scores. For an integrated assessment and summary rating, the primary metrics bolded in Table 3-2 are used.

3.2 Preparedness Assessment

Preparedness – a critical metric for evaluating California watersheds – is another component to consider when o comprehensively assessing watershed resilience. Resiliency capacity is a significant component of watershed preparedness as it involves both internal and external resources to adapt to future climate resiliency risks. Climate preparedness describes how well-equipped watershed managers are to understand current and future risks and act to improve watershed resiliency, to collaborate with regional science and watershed partners, and to identify, develop, and implement effective adaptation strategies. Resiliency planning capacity varies dramatically across the state. Some regions and water agencies have had the resources and motivation to invest significant resources in both staff and outside support to evaluate their risks and develop adaptation strategies. And other regions have limited capacity and opportunity to invest in evaluating and addressing climate risks.

This section describes the process followed to evaluate the preparedness of watersheds for addressing the climate resiliency challenges.

3.2.1 Climate and Water Management Plans Reviewed

The assessment of climate preparedness was prepared by reviewing available studies, plans, and projects related to each watershed's climate resilience. More than 800 individual plans were reviewed as part of this Assessment to develop a common and consistent understanding of the level of climate preparedness in the state's watersheds. Documents chosen as part of this Assessment were generally completed in all regions across the state. In total, 11 different plan types were considered for evaluating watershed climate preparedness. Table 3-3 summarizes the primary plans reviewed for this Assessment. The most relevant plans were the integrated regional water management plans, basin studies, locally developed climate action and adaptation plans, groundwater sustainability plans, urban water management plans, and local hazard management plans. Several of these plans included qualitative climate impact assessments. But most plans were limited in the scope of water resources that were considered and few included quantitative vulnerability assessments or targeted adaptation strategies. In general, sources were selected based on their relevance to water-based climate resiliency efforts, scope and scale of relevant interested parties and organizations within each watershed, and level of accessibility.

Table 3-3 Summary of Climate and Water Management Plans Reviewed

Plan	Summary of Content Related to the Assessment	No. of Available Plans	Included in Assessment
Groundwater Sustainability Plans	Plans are required in all groundwater basins classified as “medium” or “high priority.” Defines framework for sustainable groundwater management in accordance with Sustainable Groundwater Management Act.	100	Yes
Integrated Regional Water Management Plan (IRWMP)	Collaborative effort to identify water management solutions to promote regional self-reliance and reduce conflict to manage water to promote sustainable management of local water resources in California. All 48 watersheds had at least one IRWMP developed.	48	Yes
Urban Water Management Plan (UWMP)	Required by every urban water supplier that provides more than 3,000 acre-feet of water annually. Each UWMP must include a 5-year drought water reliability assessment, drought risk assessment, seismic risk assessment, water shortage contingency plan, and other coordination with groundwater sustainability plans.	286	Yes
Local Hazard Mitigation Plan	Required by all local jurisdictions to identify hazard vulnerabilities and assess mitigation actions.	210	Yes
Reclamation Basin Study	A total of seven basin studies have been conducted in California to evaluate their respective water supply and demand to ensure water supplies in the basin for the future period. Although the number of documents is small, the documents reviewed covered 28 of 48 of the watersheds.	10	Yes
Climate Action and Adaptation Plan	Provides a framework for quantifying and reducing greenhouse gas emissions and climate impacts.	154	Yes

Plan	Summary of Content Related to the Assessment	No. of Available Plans	Included in Assessment
Agriculture Water Management Plan	Required for any agricultural water supplier serving more than 25,000 irrigated acres. The plan helps agricultural producers analyze risk through water supply diversification and natural resource conservation practices. Plans were not considered as relevant as others with respect to climate impacts and vulnerabilities.	33	No
Landscape Conservation Cooperative	Management-science partnership that supports ecosystems through cooperative conservation partnerships (network of 22 regional conservations groups(?)). The purpose is to address the impacts of climate change across ecosystems.	1	No
Regional Climate Collaborative	Provides grants for under-resourced communities to facilitate communication across regional partners to develop processes and projects for climate change. Not enough documents were provided encompassing all watersheds to include in the Assessment.	3	No
County General Plans	Provides a plan for meeting community's long-term plans for land use, open space, conservation, circulation, noise, and safety. Content within these plans was not always relevant to watershed resilience.	N/A	No
Resource Conservation Districts	Special districts that can implement projects on public and private land to help achieve sustainable watershed planning and management, water conservation, water quality protection, agricultural land conservation, and wildlife habitat enhancement. Content within these plans was not always relevant to watershed resilience.	N/A	No

3.2.2 Climate Preparedness Rating Process

The plans were independently reviewed for their relevance and strength for effective watershed resilience planning. Each plan was rated in accordance with six main elements that support resilience planning capacity: (1) collaboration with regional climate groups, academic, and research Institutions; (2) staffing dedicated to watershed resilience or sustainability planning; (3) identified watershed climate impacts; (4) developed climate vulnerability and/or risk assessments; (5) developed climate adaptation strategies; and (6) identified implementation and funding approaches.

These elements are considered in many climate adaptation planning processes (e.g., Water Utility Climate Alliance guides) and are fundamental to the watershed resilience planning activities that DWR promotes. Table 3-4 defines the rating system by which each plan is assessed. The table includes indicators that generally follow the proposed watershed resilience planning framework and provides an indication of how advanced the planning for resilience is at the watershed scale. These six elements were determined to be significant indicators of climate preparedness.

Table 3-4 Resilience Planning Capacity Metrics for Statewide Watershed Resilience Planning

Resiliency Planning Capacity Metric	Low (rating = 1)	Moderate (rating = 3)	High (rating = 5)
Collaboration with Regional Climate Groups, Academic, and Research Institutions	Some regional collaboration may be present but not been active in climate risk planning efforts.	Regional collaboration forum exists and some interaction and engagement in preparation of climate risk planning efforts has occurred.	Regional collaboration forum exists and has been actively engaged in preparation of climate risk planning efforts.
Staffing Dedicated to Watershed Resilience or Sustainability Planning	Limited climate resilience staff at water/watershed management agencies. These staff may be indicated as sustainability coordinators or other titles.	Climate resilience staff exist at some water/watershed management agencies; engagement in resiliency planning, but not fully dedicated to watershed resiliency.	Dedicated climate resilience staff exist at primary water/watershed management agencies; fully engaged in resiliency planning efforts at watershed scale.

Resiliency Planning Capacity Metric	Low (rating = 1)	Moderate (rating = 3)	High (rating = 5)
Identified Watershed Climate Impacts	Climate impacts identified but not evaluated; some sectors may be missing.	Climate impacts have been identified for some sectors, but only qualitatively described, or quantitatively for only a few sectors.	Climate impacts have been identified for all sectors, and quantitatively evaluated for all.
Developed Climate Vulnerability/Risk Assessments	Vulnerability or risk of sectors identified but no assessment prepared.	Vulnerability assessment for some sectors has been developed, but largely qualitative; no risk assessment.	Complete vulnerability and risk assessments prepared and documented for all sectors.
Developed Climate Adaptation Strategies	Climate adaptation strategies have not been developed for most sectors, or adaptation measures are identified but not linked to climate change.	Climate adaptation strategies have been developed for some sectors, largely conceptual.	Complete adaptation strategies have been developed for all sectors; primary strategies have some feasibility assessment.
Identified Implementation and Funding Approaches	Funding sources identified for climate adaptation efforts but implementation and funding approaches not prepared.	Funding opportunities have been applied for and obtained but implementation status not provided.	Funding strategy is well-developed and implementation progress is documented.

Collaboration is an essential component of general watershed management and resiliency planning. Effective collaboration should include interested parties on the local, regional, and governmental level; Tribes and vulnerable communities, and scientific input. The ratings assessed the agencies or entities involved; presence of a structured working group or shared responsibilities for resiliency planning; and scientific engagement through collaboration with academia, government agencies, or the private sector.

Staffing is another key element for achieving resilience capacity on a local and regional level. Adequate staffing efforts are necessary to determine the impacts of climate change on a local and regional level and to identify and develop effective adaptation strategies. Ratings included scoring for identifying interested parties with climate devoted staff, staff with shared responsibilities for climate resiliency, and the level of internal staffing efforts for climate change resiliency.

To effectively plan for climate change resiliency, the impacts of climate change must first be understood. As discussed above, key water resources sectors selected for assessment are water supply, flood, groundwater, water quality, ecosystem, hydropower, and recreation. Ratings include scoring for identifying the climate change impacts to these key sectors, providing qualitative discussion, and providing quantitative evaluation.

After identifying climate change impacts for key sectors, the next step is assessing the level of vulnerability to those impacts. Ratings were based on identifying climate change vulnerabilities of the key sectors, with additional points for qualitative discussion and quantitative evaluation. A quantitative risk assessment provided full points because this level of assessment informs formulation of adaptation strategies for a watershed.

Adaptation strategies range from specific projects to programmatic efforts and should reflect the impacts and vulnerabilities specific to each key sector within each watershed. Ratings accounted for general adaptation strategies, strategies specific to key sectors, providing details such as timelines and priority ranking, and assessing the extent that strategies would reduce vulnerability and promote resiliency.

Identifying and obtaining funding is a crucial component of the planning cycle. Funding opportunities for climate resiliency efforts can come from a variety of sources, including agency revenues or State and federal grants. Ratings include scores for identifying specific funding opportunities, obtaining funding, and providing the status of implementation progress for adaptation actions.

3.2.3 Summary and Relevance of Plans

This section provides a high-level summary of the climate and water management plans and relevance for this climate preparedness assessment. During the assessment process, certain plans were determined to be more relevant than others for watershed resilience assessments; for example, some plans are available and cover all watersheds of the state, but others were not mandated statewide and only specific regions have produced these plans. It is important to acknowledge that supporting this watershed resilience assessment was not a specific purpose of any of the climate and water management plans. Although when taken as a whole, these plans are the best representation of climate preparedness that could be consistently assessed for each watershed throughout the state.

3.2.3.1 Integrated Regional Water Management Plans

As part of the integrated regional water management process, integrated regional water management plans (IRWMPs) are required to address climate change impacts, a requirement largely reflected in documents reviewed. Although the level of detail varied widely, IRWMPs covered many climate change components across various sectors and were the most comprehensive of the document types reviewed.

3.2.3.2 Urban Water Management Plans

Urban water management plans (UWMPs) are structured plans and are required to address drought vulnerability and contain a water shortage contingency plan. Although several components of the UWMPs inherently contribute to resiliency planning capacity, the plans were largely found to lack a strong connection between water conservation efforts and climate change. Additionally, these plans were primarily structured to address water supply and demand conditions in the future but are not inclusive of other water management sectors.

3.2.3.3 Local Hazard Mitigation Plans

Local hazard mitigation plans (LHMPs) are less structured and are intended to cover all hazards for the city, county, or entity preparing the plan. The level of detail related to climate impacts, and specifically impacts to the water sector, was found to vary greatly. Although several plans addressed climate change, there was a general lack of consistency across plans and regions.

3.2.3.4 Groundwater Sustainability Plans

Groundwater sustainability plans (GSPs) are structured plans intended to cover water supply, demand, and quality concerns for groundwater basins. Because of the structure of these plans, the majority of other sectors are not addressed and the connection of sustainability measures to climate change is not generally well enumerated. Additionally, many watersheds either do not have a groundwater basin or the local authorities managing the groundwater basin(s) within that watershed are not required to submit a GSP. For this reason, most watersheds of the state do not have any GSPs. The GSPs were found to be useful in some watersheds, but were generally too narrowly focused (by design) on one water resource sector and only exist for specific groundwater basins.

3.2.3.5 U.S. Bureau of Reclamation Basin Studies

U.S. Bureau of Reclamation basin studies largely covered all elements necessary for watershed resiliency planning capacity except funding for adaptation strategies. However, approximately half the watersheds in the state are not covered by a basin study, and several of the studies were developed for multiple hydrologic regions such that the scale is not well-aligned with the more detailed watersheds.

3.2.3.6 Climate Adaptation and Action Plans

Climate adaptation/action plans were highly variable in their subject matter, and the majority of climate action plans (CAPs) reviewed were focused on climate change mitigation efforts to reduce emissions, as opposed to adaptation measures to respond to the impacts of climate change. Yet, despite the inconsistency in relevancy across plans, the plans have largely been prepared for all regions in the state.

3.2.4 Summary Preparedness Ratings

For each plan reviewed, ratings (ranging from 1 to 5) were provided for each of the six elements defined in Table 3-4. These ratings were then averaged to arrive at an overall plan rating. In some cases, multiple plans may be included for a single watershed. For example, three UWMPs exist within the American-Bear watershed. In this case, overall plan ratings were averaged to provide a single watershed rating for each plan type. The summary preparedness ratings for each watershed and plan type are presented in Appendix B.

In evaluating the plans in more detail and attempting to arrive at a consolidated rating for each watershed's climate preparedness, several weighting schemes were attempted. It was determined that the IRWMPs and CAPs had the most consistent coverage throughout the state and represented many of the water sectors. Combining the ratings of these two plans resulted in the most representative and uniform assessment of climate preparedness for the state's watersheds. Including an average of all plans resulted in lower overall climate preparedness ratings for some watersheds simply based on a single low-scoring plan or a plan that was not required in that watershed (e.g., GSPs or basin studies). In many cases, low ratings for certain plans represent differences in the objective and requirements of a specific plan relative to the informational needs of this watershed resilience assessment effort.

The ratings for each independent plan for each watershed are provided in Appendix B.

4. Climate Risk Synthesis

Application of the vulnerability assessment and preparedness assessment approaches allows for an improved understanding of the State's current engagement with watershed climate resilience (Federal Emergency Management Agency 2023; National Oceanic and Atmospheric Administration 2023; State Water Resource Control Board 2023). Climate risk is the result of combining vulnerability and preparedness ratings.

Several key findings can be summarized from the watershed climate vulnerability assessment.

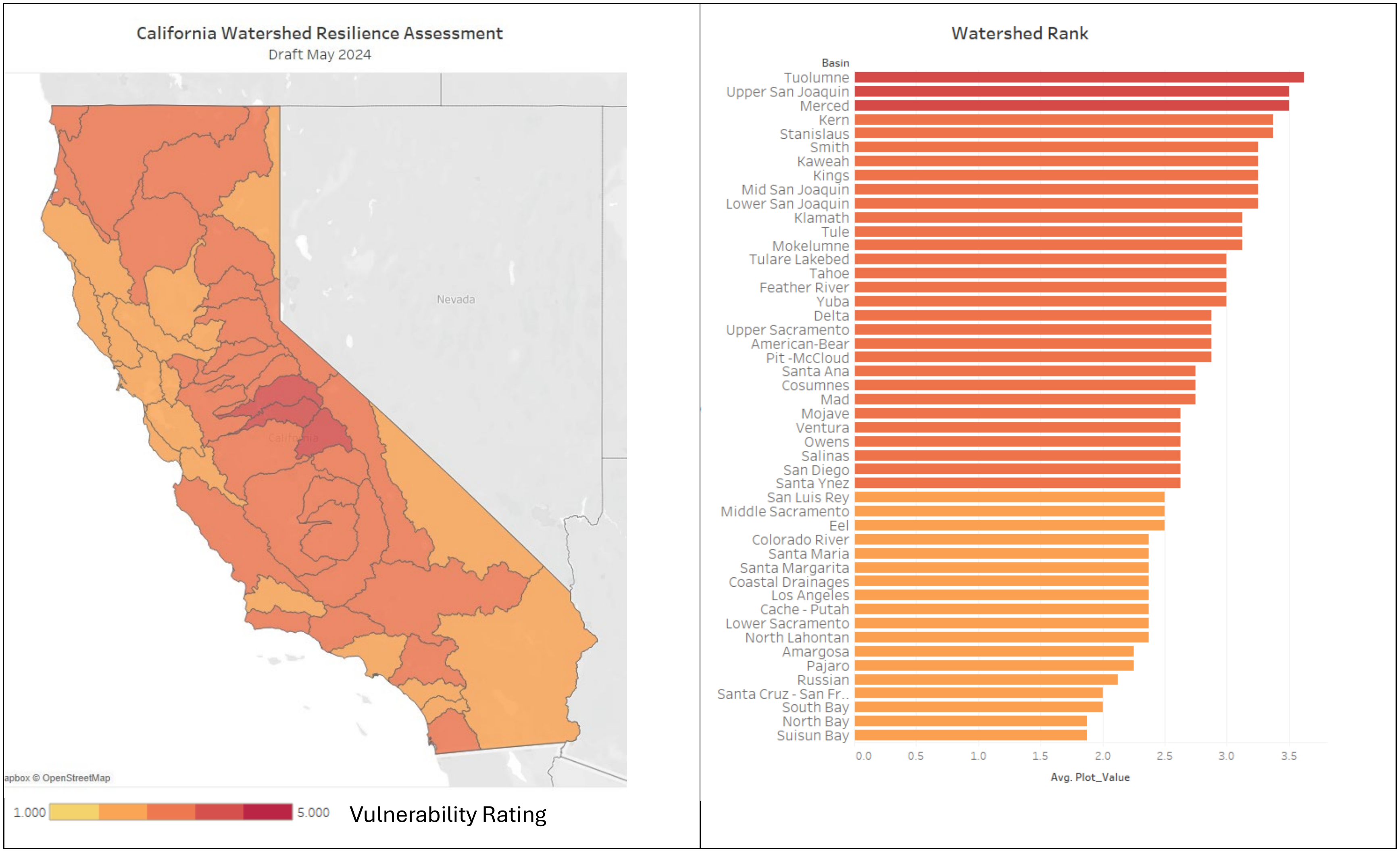
- Increases in average annual water supply are expected to be greater in the late future period compared to the near future period. Some watersheds in Southern California are projected to exhibit reduced water availability. Water availability is projected to increase during the fall and winter seasons but decrease for spring and summer seasons. Drought severity and duration are also expected to increase in the future period.
- Extreme precipitation events are projected to increase in both frequency and intensity in the near future period (2026–2055) and be further amplified during the late future period (2056–2085).
- Groundwater recharge changes show spatial heterogeneity with decreases in Sierra Nevada, Southern, and Northern California watersheds. Groundwater infiltration is projected to further decrease during the late future period.
- Stream temperature and dissolved oxygen content is strongly correlated with average air temperature during the summer and early fall. Stream temperature is expected to increase and dissolved oxygen content is expected to decrease for all watersheds in California.
- Ecologically important flows are expected to increase during the winter season and decrease during the spring season. But during fall and summer seasons, the changes are minor and spatially heterogenous.
- Hydropower generation potential is expected to decrease at a majority of dams in the future because of climate change. Projected high inflow leads to increased chance of reservoir spillage and lost generation potential either because the increased inflow overwhelms the capacity to store when storage is already high, or the potential power generation exceeds the power capacity.
- For a majority of watersheds in Central and Southern California, river recreational opportunities are projected to decrease in the near future period

and further decrease in the late future period. Snow recreational opportunities are also projected to decrease for the future periods. Lake recreational opportunities are expected to decrease for a majority of lakes in the future due to climate change. Coastal recreation areas are projected to decrease for all watersheds along the coast, with the magnitude of change proportional to the amount of sea level rise.

- Wildfire burn area and decadal probability are projected to increase for both near and late future periods. The increase is greater for the watersheds that have a greater amount of wildfire fuels.

Figure 4-1 shows the summary watershed climate vulnerability ratings for all watersheds. This summary vulnerability rating includes the combined (average) assessment scores from water supply, flood management, groundwater, water quality, ecosystem, hydropower, recreation, and wildfire resource areas. The highest combined climate vulnerabilities occur in watersheds of the San Joaquin River, Tulare Lake, and North Coast hydrologic regions. These vulnerabilities are driven by large reductions in ecosystem flows in spring, increased flood flows, increased drought severity, and increased wildfire probability. Other watersheds have more distinct vulnerabilities. Some coastal watersheds (e.g., Pajaro, Ventura, San Diego) have significant vulnerabilities associated with sea level rise and increased flood risks but are less impacted by seasonal changes in ecological flows.

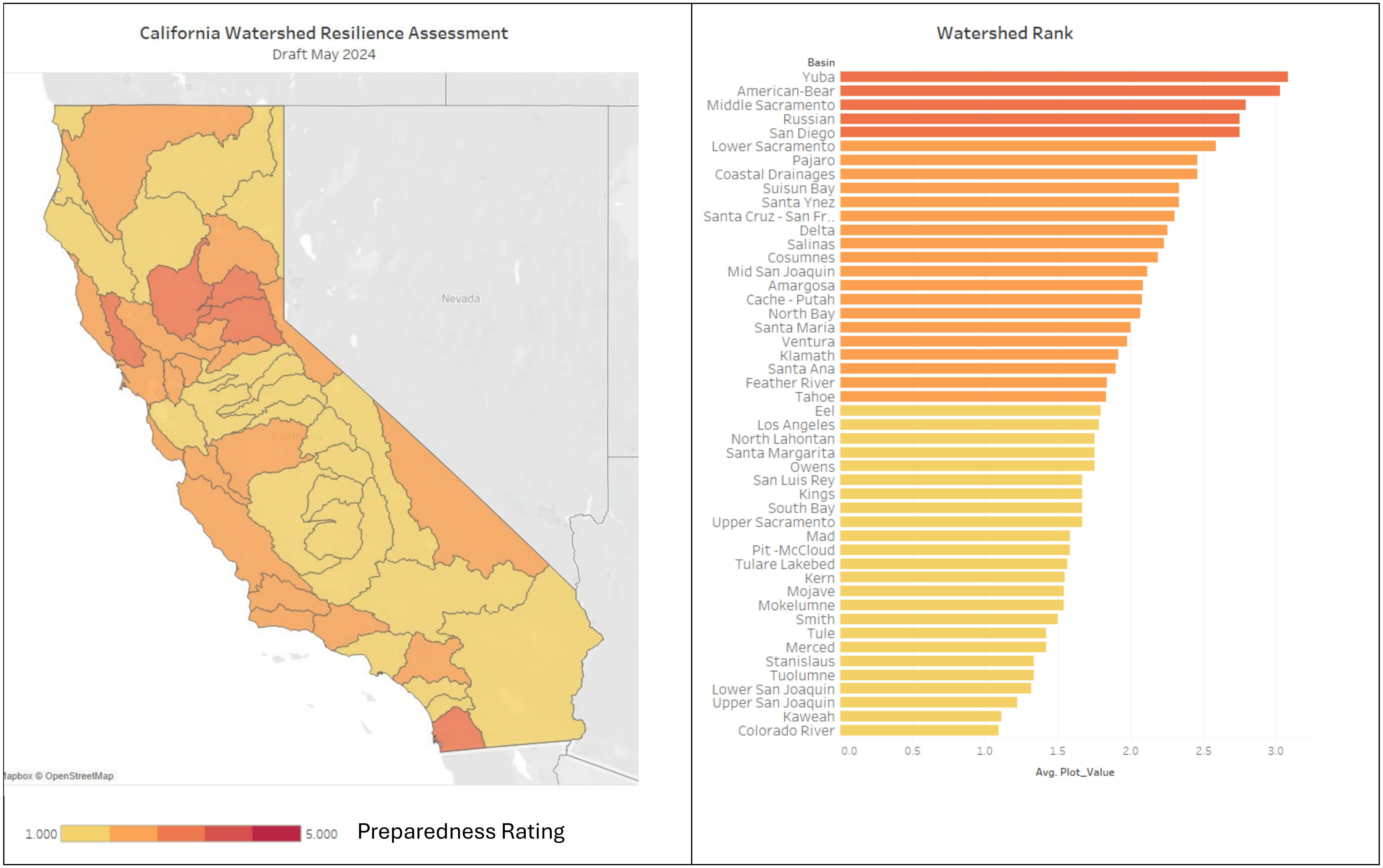
Figure 4-1 Summary Watershed Climate Vulnerability Assessment Ratings



Note: Higher score indicates higher level of climate vulnerability.

Figure 4-2 shows the summary watershed climate preparedness ratings for all watersheds. This summary rating includes the combined (average) assessment of IRWMPs and CAPs scores. IRWMPs and CAPs in some watersheds have taken a more robust consideration of climate change, impacts, and adaptations. For example, the Yuba, American-Bear, Russian, and San Diego River watersheds had higher rated plans for climate change preparedness. Many of the San Francisco Bay, Central Coast, and South Coast watersheds rated higher with respect to preparedness. But it should be noted that more than half of the state's watersheds scored less than 2 (out of a 5-point scale) and only two watersheds rated higher than a 3 (on the same 5-point scale). Although there is a great disparity in the level of preparedness across the state, all watersheds are in need of further advancements to increase resiliency.

Figure 4-2 Summary Watershed Climate Preparedness Assessment Ratings



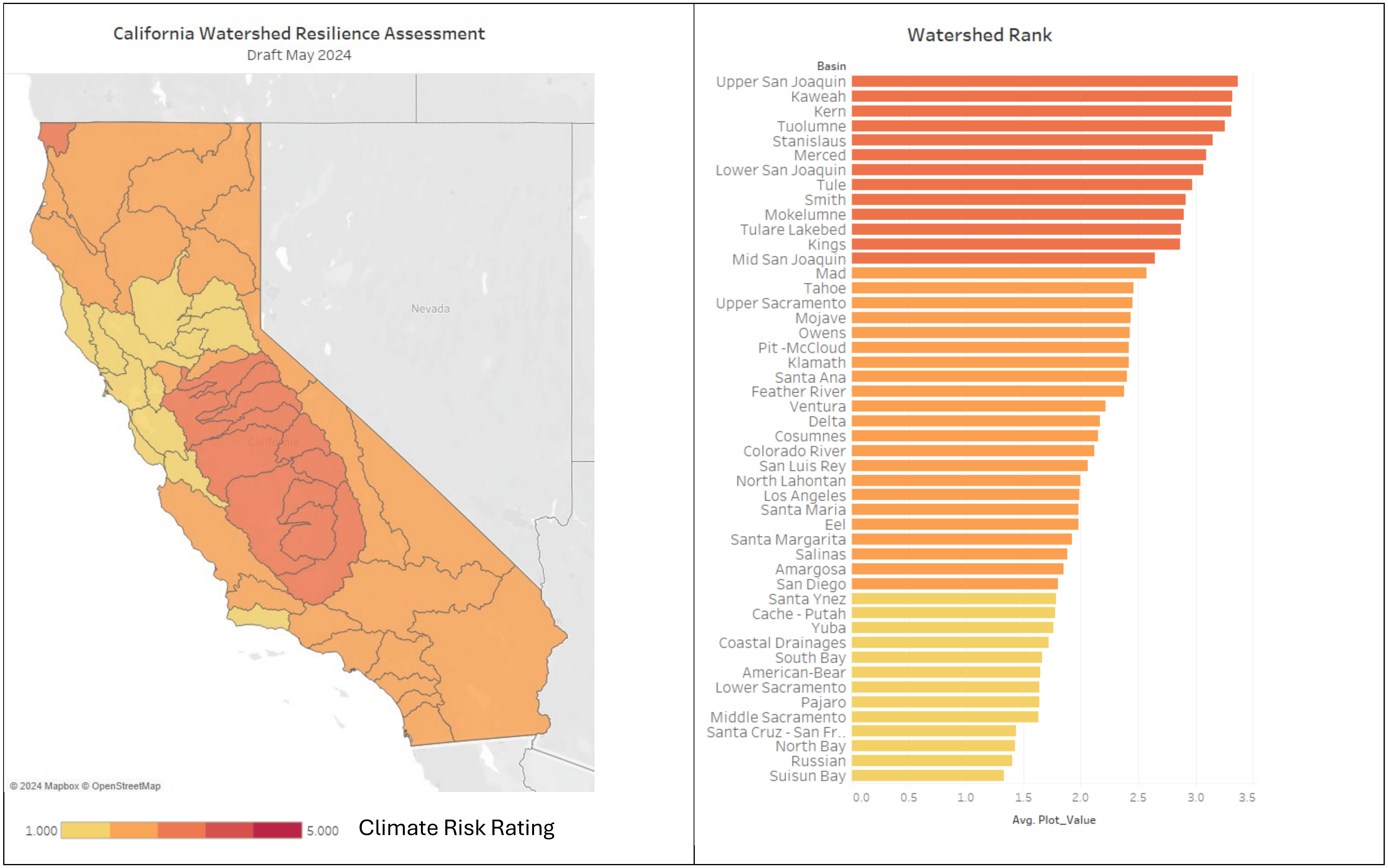
Note: Higher score indicates higher level of climate preparedness.

Figure 4-3 shows the summary watershed climate risk ratings for all watersheds. This summary climate risk rating is a combination of the watershed vulnerability and preparedness assessments. Climate risk is computed as the product of vulnerability rating (1 through 5) and preparedness rating (1 through 5) and normalized to a 1 through 5 rating. The mathematical calculation of the risk rating is shown below:

Risk Rating = [Vulnerability Raring x (6 – Preparedness Rating)] / 5

Watersheds with high levels of vulnerability and low preparedness are indicated with high climate risk. Other areas with higher preparedness and lower vulnerabilities result in low climate risk. Watersheds in the San Joaquin and Tulare Lake hydrologic regions exhibit some of the highest climate risk, associated with high vulnerability and low preparedness. It should be noted that climate risk, as shown in Figure 4-3, is associated with the combined vulnerability ratings. Maps of specific climate vulnerabilities, such as those with a focus on flood risk, drought severity, wildfire, or snow-based recreation, will show different patterns of climate risks.

Figure 4-3 Summary Watershed Climate Risk Assessment Ratings



Note: Higher score indicates higher level of climate risk.

5. Visualization

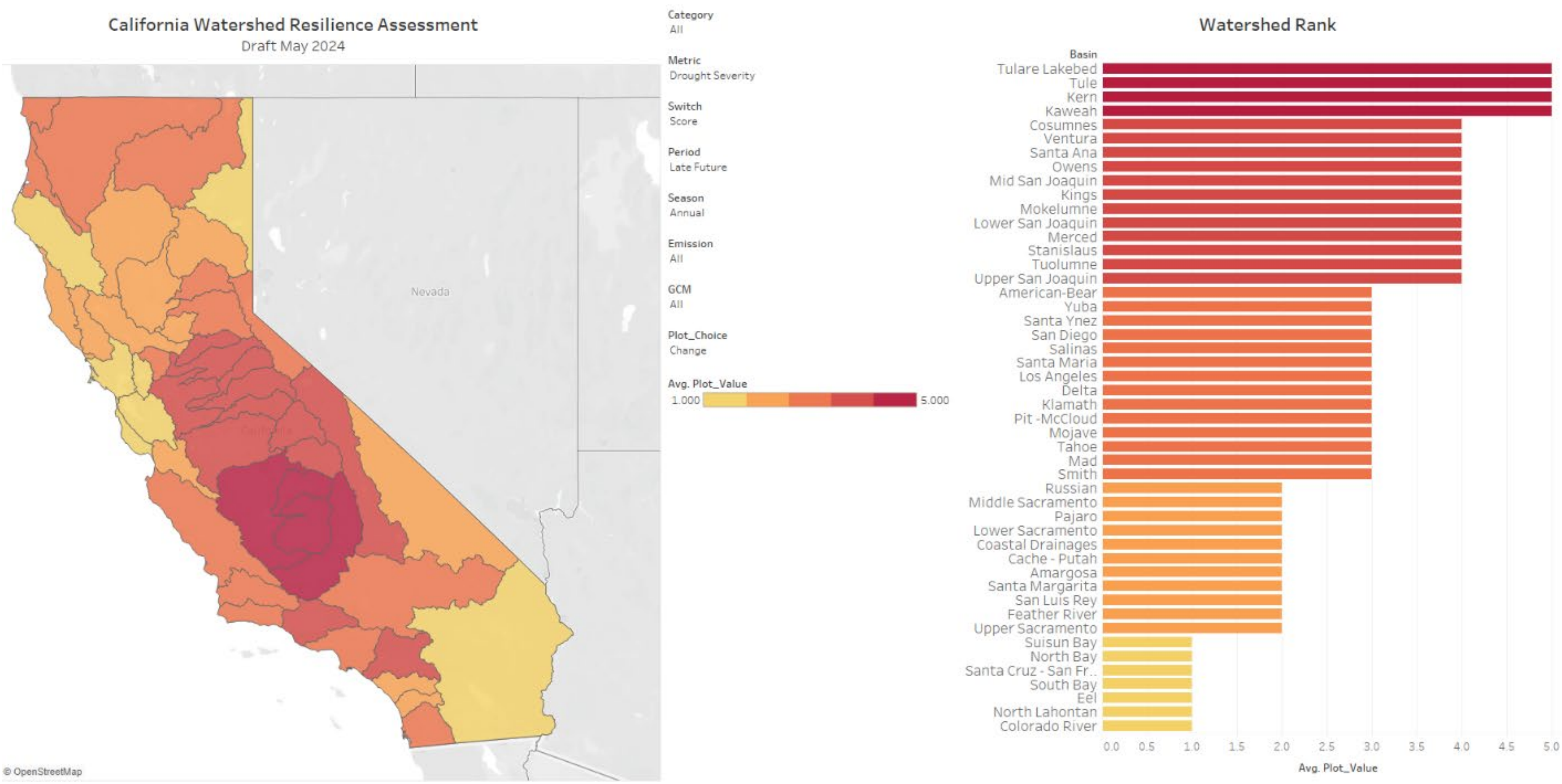
The results of the Assessment have been presented in a Tableau dashboard for visualization and review. The dashboard includes selections for either vulnerability parameters, preparedness parameters, or a combined climate risk parameter. The watershed map indicates the relative 1 (low) through 5 (high) score and the bar chart ranks the watersheds based on the selected metric.

Within the dashboard, visualizations can be explored based on the following parameters:

- Climate and preparedness metrics.
- Annual or seasonal periods.
- Two future time periods (mid- and late-century periods).
- Emission scenarios (RCPs 4.5 and 8.5).
- Ten GCM projections.

A screen capture of the visualization tool is shown in Figure 5-1.

Figure 5-1 Visualization Tool for Watershed Climate Resilience



Note: Higher score indicates higher level of climate vulnerability (drought severity vulnerability shown).

6. Limitations and Next Steps

This section discusses key limitations and next steps in the formation of the Assessment.

6.1 Climate Vulnerability

Climate vulnerability assessment was performed using the statewide available climate data and hydrologic model simulated data. The goal of this Assessment is to provide high-level, statewide, consistent information that describes indications of climate vulnerabilities rather than definitive vulnerabilities at the watershed scale. The list below describes the estimations and limitations associated with each metric.

- Water supply metrics do not reflect water imports, transfers, or any additional external sources of water, but instead are based on locally derived water sources from natural runoff.
- The VIC hydrologic model results were utilized to support many of the water supply and ecosystem vulnerability metrics. These results are provided at approximately 6-km scale statewide. Hydrological modeling at these scales cannot capture the dynamics of specific river or stream reaches and is best suitable for regional analysis. The computation of the flow and total runoff estimates was performed using the region within the watershed, and connected upstream watersheds and hydrologic routing was available.
- Uniform climate metrics were used for analyzing each water sector across the state. It is acknowledged that regionally specific metrics would provide more detailed insight. The flood management metric was developed using the 1-percent exceedance value of the three-day daily maxima runoff. Flood-frequency analysis using approaches, such as peak flow quantiles, was not used because of the Assessment’s level of analysis and difficulty in characterizing extreme statistical changes with climate change.
- The indices analyzed under the water quality metric were stream water temperature and dissolved oxygen. The stream water temperature was developed using the linear regression relationship between air temperature and stream water temperature. The dissolved oxygen was developed using the linear regression relationship between stream water temperature and dissolved oxygen. These correlations have been applied for regional efforts. But these correlations are not sufficient for detailed analysis that is commonly implemented water quality models. Other water quality indices (for example, sediments and nutrients) were not analyzed in this assessment.

- For the dams and lakes situated outside the Central Valley, simplified approaches involving watershed average runoff, basic power and potential energy equations, linear relationship between storage, elevation, and surface area were used. Both the hydropower and lake recreation metrics were developed by identifying the representative dams and lakes for the watershed based on power capacity, storage capacity, surface area, available data.
- Estimation of the snow recreation metric was developed using data from the major ski resorts in California. The climatological and hydrological data was applied for the entire 12-km VIC grid overlying the ski resorts.
- To develop the base recreational area map for coastal recreational areas, coastal zone boundary and OLUs were merged and distributed at the watershed scale along the coast.
- To summarize climate vulnerabilities and risk across the state's watersheds, it was necessary to normalize projected climate changes into rating scores. One limitation with this approach is that some details associated with each watershed's distinct vulnerabilities are not illuminated. The visualization tool, however, permits this level of detailed to be evaluated for further analysis.

6.2 Climate Preparedness

Limitations in the climate preparedness portion of this Assessment include document availability, document quantity, and document content. In terms of document availability, all available documents as of spring 2023 were compiled and scored. Documents published or posted after spring 2023 are not used in this assessment.

Among the plans scored, some documents could not be found or were not accessible. In some cases, this was because of restricted access, and in others, invalid or outdated links. Despite a handful of inaccessible or unavailable documents, the assessment scored a total of 834 plans, providing a comprehensive review of climate preparedness of watersheds.

Although some documents were inaccessible, others were not relevant to a particular watershed. For example, several watersheds did not have groundwater basins or did not have basins at a high enough risk level to require a GSP by the Sustainable Groundwater Management Act. In other cases, some watersheds did not have large enough urban populations to require a UWMP. In these cases, fully consistent plans were not available in all watersheds. Updates to the rating approach for climate preparedness assessment have attempted to minimize any rating bias associated with inconsistency in plan coverage.

Although some documents were not available, and some documents did not have fully relevant content, this Assessment includes a large sampling of plans that are believed to provide a robust assessment of climate preparedness.

6.3 Next Steps

This Assessment provides a unique overview of the status of watershed climate resilience in California. The Assessment and interactive tool can be used to identify "priority areas" of higher climate vulnerability and to focus attention and support for watersheds as water managers continue to increase climate resiliency. The information in the Assessment can be used by DWR to help tailor supportive resources. It also can be used by watershed managers to understand and improve analyses for a more robust assessment at the individual watershed level.

7. References

California Energy Commission. 2023. "Hydroelectric Power." [Website.] Viewed online at: https://www.energy.ca.gov/data-reports/california-power-generation-and-power-sources/hydroelectric-power. Accessed: June 13, 2024.

California Department of Fish and Wildlife. 2024. "Science: California's Biodiversity." [Website.] Viewed online at: https://wildlife.ca.gov/Biodiversity#:~:text=California%20is%20the%20most%20biodiverse,covers%2046%25%20of%20the%20state. Accessed: June 13, 2024.

California Department of Water Resources. 2013. *California's Flood Future. Recommendations for Managing the State's Flood Risk. Final. November 2013.* 152 pp. [Government Report.] Viewed online at: https://cawaterlibrary.net/wp-content/uploads/2017/05/California_Flood_Future.pdf. Accessed: June 13, 2024.

California Department of Water Resources Climate Change Technical Advisory Group (CCTAG). 2015. *Perspectives and guidance for climate change analysis. August 2015.* 142 pp. [Government Report.] Viewed online at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Program-Activities/Files/Reports/Perspectives-Guidance-Climate-Change-Analysis.pdf. Accessed: June 13, 2024.

California Department of Water Resources. 2020. California Department of Water Resources' Climate Action Plan. [Website.] Viewed online at: https://water.ca.gov/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan. Accessed: June 13, 2024.

California Department of Water Resources. 2022. 2022 Central Valley Flood Protection Plan Update. 298 pp. [Government Report.] Viewed online at: http://cvfpb.ca.gov/wp-content/uploads/2022/12/Central_Valley_Flood_Protection_Plan_Update_2022_ADOPTED.pdf. Accessed: June 13, 2024.

California Department of Water Resources. 2023. Water Basics. "Groundwater." [Website.] Viewed online at: https://water.ca.gov/water-basics/groundwater. Accessed: June 13, 2024.

California Natural Resources Agency. 2021. "California Climate Adaptation Strategy." [Website.] Viewed online at: https://resources.ca.gov/Initiatives/Building-Climate-Resilience/2024-State-Adaptation-Strategy-Update. Accessed: June 13, 2024.

California Natural Resources Agency, California Governor's Office of Planning and Research, State of California Energy Commission. 2018. "California's Fourth Climate Change Assessment." [Website.] Viewed online at: https://www.climateassessment.ca.gov/state/overview/. Accessed: June 13, 2024.

California Natural Resources Agency and California Ocean Protection Council. 2018. *State of California Sea Level Rise Guidance 2018 Update*. 84 pp. [Government Report.] Viewed online at: https://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf. Accessed: June 13, 2024.

California Water Quality Monitoring Council. 2023. "Healthy Watersheds Partnership Assessment." [Website.] Viewed online at: https://mywaterquality.ca.gov/monitoring_council/healthy_watersheds/assessment.html. Accessed: June 13, 2024.

Delta Stewardship Council. 2021. *Delta Adapts: Creating a Climate Resilient Future. Sacramento–San Joaquin Delta Climate Change Vulnerability Assessment*. 223 pp. [Government Report.] Viewed online at: https://deltacouncil.ca.gov/pdf/delta-plan/2021-06-25-delta-adapts-vulnerability-assessment.pdf. Accessed: June 13, 2024.

Espinoza V, Waliser DE, Guan B, Lavers DA, Ralph FM. 2018. "Global Analysis of Climate Change Projection Effects on Atmospheric Rivers." Geophysical Research Letters Volume 45 (Issue 9): Pages 4,299–4,308. [Journal.] Viewed online at: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2017GL076968. Accessed: June 13, 2024.

Federal Emergency Management Agency. 2023. "National Risk Index for Natural Hazards." [Website.] Viewed online at: https://www.fema.gov/flood-maps/products-tools/national-risk-index. Accessed: June 13, 2024.

Gershunov A, Shulgina T, Clemesha RES, Guirguis K, Pierce DW, Dettinger MD, Lavers DA, Cayan DR, Polade SD, Kalansky J, Ralph FM. 2019. "Precipitation regime change in Western North America: The role of Atmospheric Rivers." Scientific Reports Volume 9 (9944). [Journal.] Viewed online at: https://www.nature.com/articles/s41598-019-46169-w. Accessed: June 12, 2024.

Greenberg A, Clesceri L, Eaton A. 1992. Standard Method for the Examination of Water and Wastewater. 18th Edition. Washington DC: American Public Health Association. 1100 pg. [Book] Viewed online at: hnb24.tmp (deu.edu.tr). Accessed: June 20, 2024.

Huang X, Swain DL, Hall AD. 2020. "Future precipitation increase from very high resolution ensemble downscaling of extreme atmospheric river storms in California." Science Advances Volume 6 (Issue 29). [Journal.] Viewed online at: https://www.science.org/doi/10.1126/sciadv.aba1323. Accessed: June 12, 2024.

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. 2006. "World Map of the Köppen-Geiger climate classification updated." Meteorologische Zeitschrift Volume 15 (Issue 3): Pages 259–263. [Journal.] Viewed online at: https://opus.bibliothek.uni-augsburg.de/opus4/frontdoor/deliver/index/docId/40083/file/metz_Vol_15_No_3_p259-263_World_Map_of_the_Koppen_Geiger_climate_classification_updated_55034.pdf. Accesses: June 12, 2023.

Mohseni O, Stefan H, Erickson T. 1998. "A non-linear regression model for weekly stream temperatures", Water Resources Research Volume 34 (Issue 10): Pages 2685–2693. [Journal.] Viewed online at: A nonlinear regression model for weekly stream temperatures - Mohseni - 1998 - Water Resources Research - Wiley Online Library. Accessed: June 20, 2024.

National Oceanic and Atmospheric Administration. 2023. "U.S. Climate Resilience Toolkit. Meeting the Challenges of a Changing Climate." [Website.] Viewed online at: https://toolkit.climate.gov/. Accessed: June 13, 2024.

Pierce, D.W., Cayan, D.R., Thrasher, B.L. 2014. "Statistical downscaling using localized constructed analogs (LOCA)." Journal of Hydrometeorology Volume 15: Pages 2,558–2,585. [Journal.] Viewed online at: https://journals.ametsoc.org/view/journals/hydr/15/6/jhm-d-14-0082_1.xml. Accessed: June 13, 2024.

State Water Resource Control Board. 2023. "Basin Plan Portal." [Website.] Viewed online at: https://www.waterboards.ca.gov/resources/data_databases/|basin_plan_portal.html. Accessed: June 13, 2024.

University of California, Berkeley, and the California Energy Commission (CEC). 2023. "Explore and analyze climate data from California's Climate Change Assessments." [Website.] Viewed online at: https://cal-adapt.org/. Accessed: June 13, 2024.

U.S. Bureau of Reclamation. 2012. *Reclamation, Managing Water in the West*. *Colorado River Basin Water Supply and Demand Study*. *Technical Report B – Water Supply Assessment*. 103 pp. [Government Report.] Viewed online at: https://www.usbr.gov/lc/region/programs/crbstudy/finalreport/Technical%20Report%20B%20-%20Water%20Supply%20Assessment/TR-B_Water_Supply_Assessment_FINAL.pdf. Accessed: June 13, 2024.

Useful Web Links

Table 3-1

Cal-Adapt

https://cal-adapt.org/tools/local-climate-change-snapshot/

California Data Exchange Center
https://cdec.water.ca.gov/

National Oceanic and Atmospheric Administration
https://coast.noaa.gov/slrdata/

State of California Sea-Level Rise Guidance
https://www.opc.ca.gov/updating-californias-sea-level-rise-guidance/

Variable Infiltration Capacity
https://cal-adapt.org/data/download/

Appendix A
Vulnerability Assessment

A.1 Water Supply

Water supply impacts resulting from climate change were evaluated. The water supply vulnerability is assessed by analyzing the runoff and water deficit conditions in the watershed. The metric is calculated by analyzing the following indices:

1. Projected changes in average and lower quartile annual and seasonal available water supply.
2. Projected changes in drought severity and duration (as determined by routed runoff deficit).

A.1.2 Approach

1. Average and Lower Quartile Annual and Seasonal Available Water Supply

a) VIC-simulated daily total runoff for the 1/16th localized constructed analog (LOCA) grids in California was estimated by grid-wise summation of the surface runoff and baseflow from each of the 20 climate projections.

b) The watershed-averaged daily total runoff was estimated for the individual watersheds using the area-weighted approach from gridded runoff. The total runoff was calculated as the sum of the local watershed flow and routed flow from the upstream watershed.

c) The daily total runoff was accumulated at different temporal scales for estimating the following index values during the historic (1981–2010), near (2026–2055), and late (2056–2085) future periods:

   i. Seasonal: October to June.
   ii. Annual: Water year (October to September).
   iii. Annual low quartile: 25th percentile of the annual total runoff.
   iv. Fall season: October to December.
   v. Winter season: January to March.
   vi. Spring season: April to June.
   vii. Summer season: July to September.

d) The absolute values of the seasonal, annual, annual low-quartile, and four seasons' indices during the historic, near and late future periods were utilized to calculate the percentage change for the future periods for 20 climate projections.

e) The projected change in the available water supply was reported as the median change of the seasonal, annual, annual low-quartile, and four seasons' indices from the 20 climate projections during the near and late future periods.

2. Drought Severity and Duration

a) VIC-simulated daily total runoff for the 1/16th LOCA grids in California was estimated by grid-wise summation of the surface runoff and baseflow from each of the 20 climate projections.

b) The watershed-averaged daily total runoff was estimated for the individual watersheds using the area-weighted approach from gridded total runoff. The total runoff was calculated as the sum of the local watershed flow and routed flow from the upstream watershed.

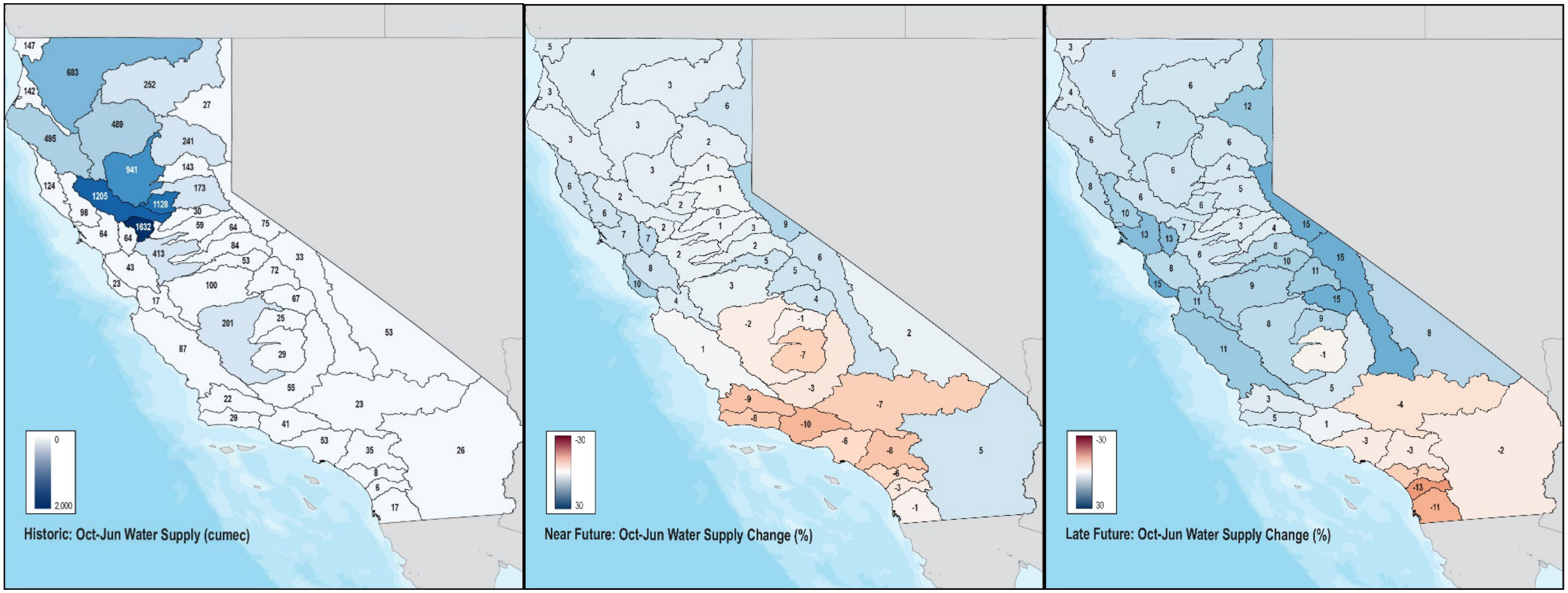
c) The daily values were accumulated at annual water year scale for the estimation of the historic annual mean for the historic (1951–2000), near (2001–2050), and late (2050–2099) future periods. Runoff deficit (when annual value minus long-term historic value is negative) was calculated for each year for the near and late future periods using the historical annual value as threshold.

d) The years with the positive deficit value were assigned 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 runoff deficit for the historic, near, and late future periods.

e) The relative percentage change in the drought severity and absolute change in the drought duration were calculated during the historic, near and late future periods for 20 climate projections.

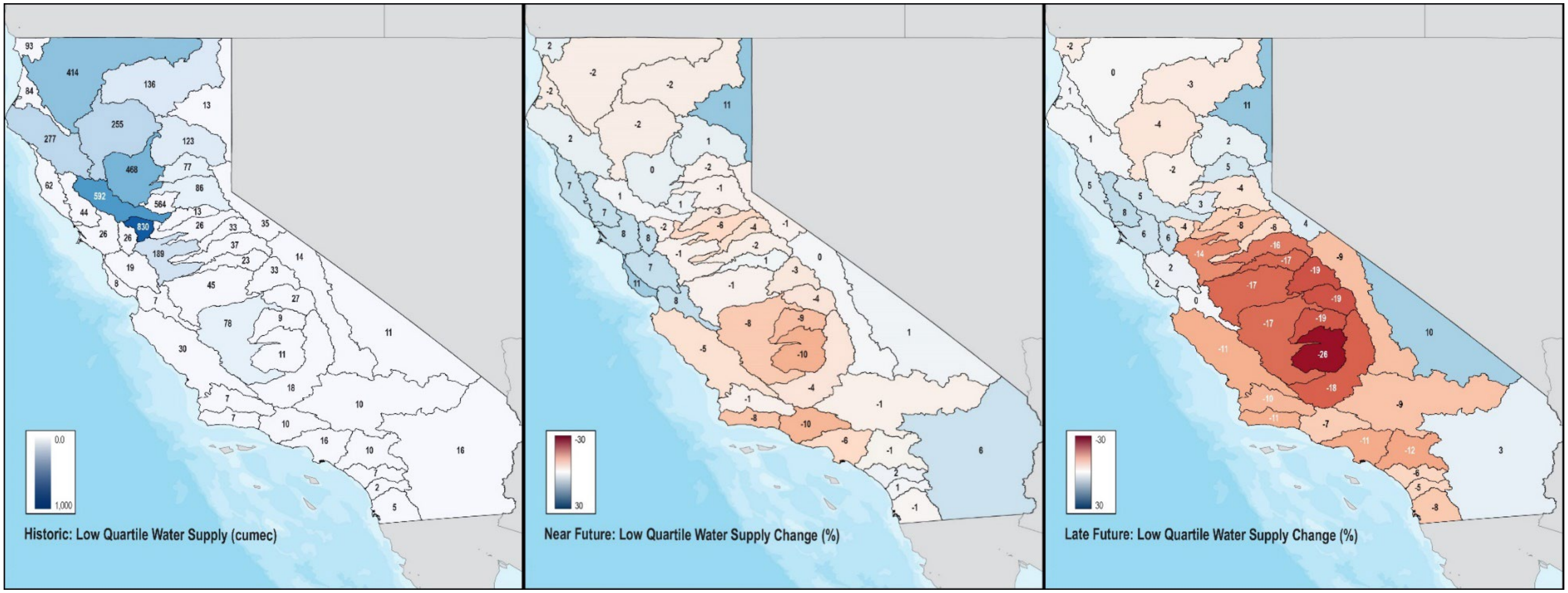
f) The projected change in the drought severity and drought duration was reported as the median change of the seasonal, annual, annual low-quartile, and four seasons' indices from the 20 climate projections during the near and late future periods.

Figure A.1-1 Change in Oct-Jun Water Supply (total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



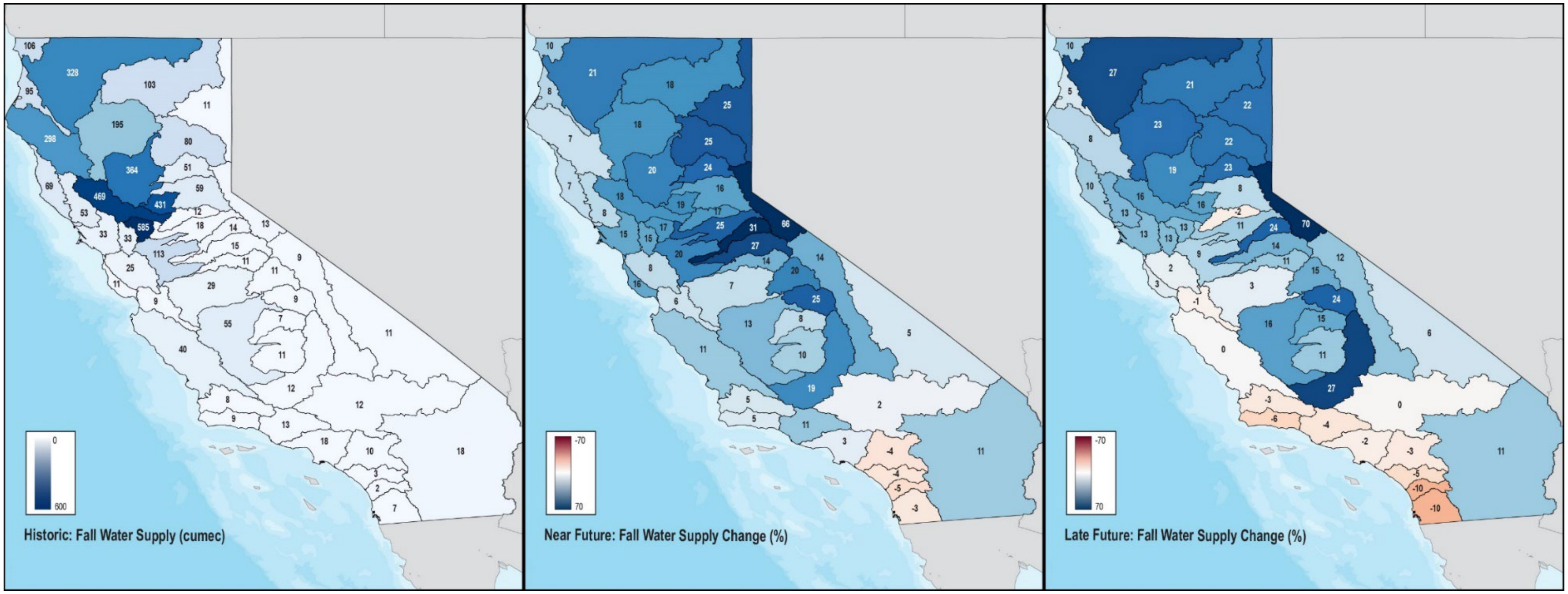
Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure A.1-2 Change in Low-Quartile Water Supply (total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



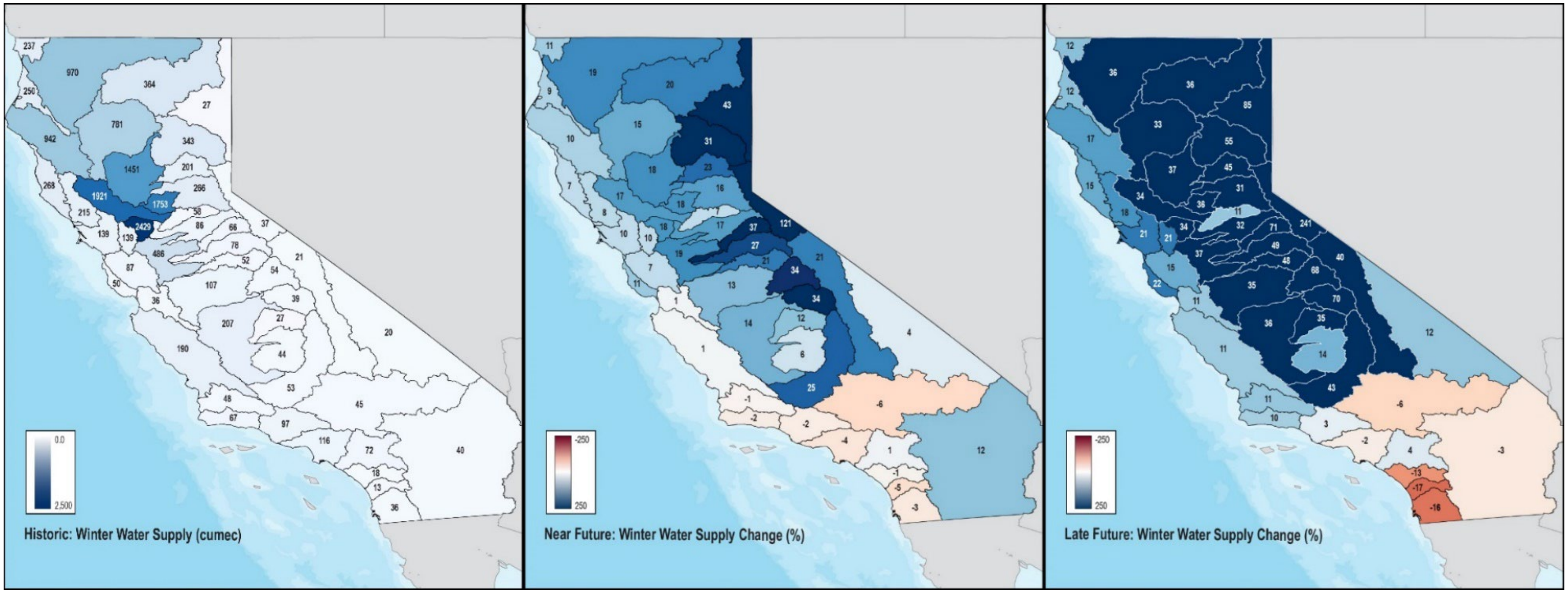
Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure A.1-3 Change in Fall Season (Oct-Dec) Water Supply (total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



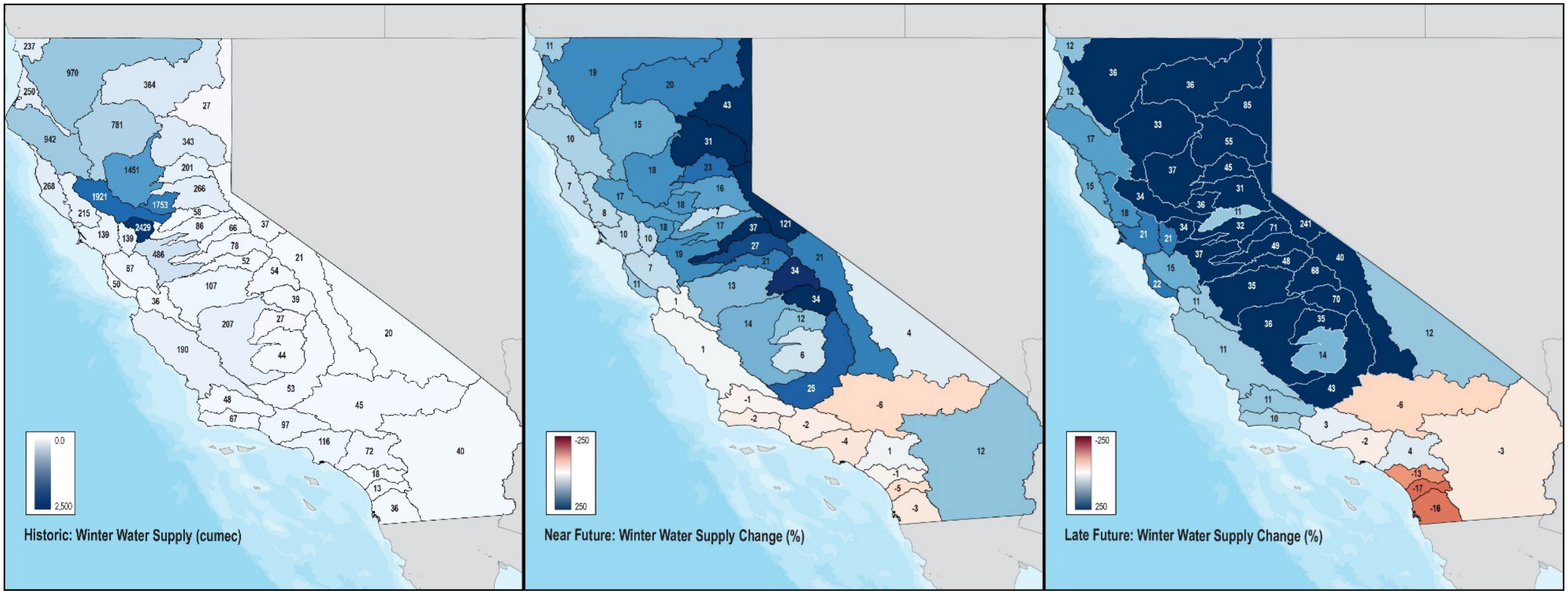
Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure A.1-4 Change in Winter Season (Jan-Mar) Water Supply (total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



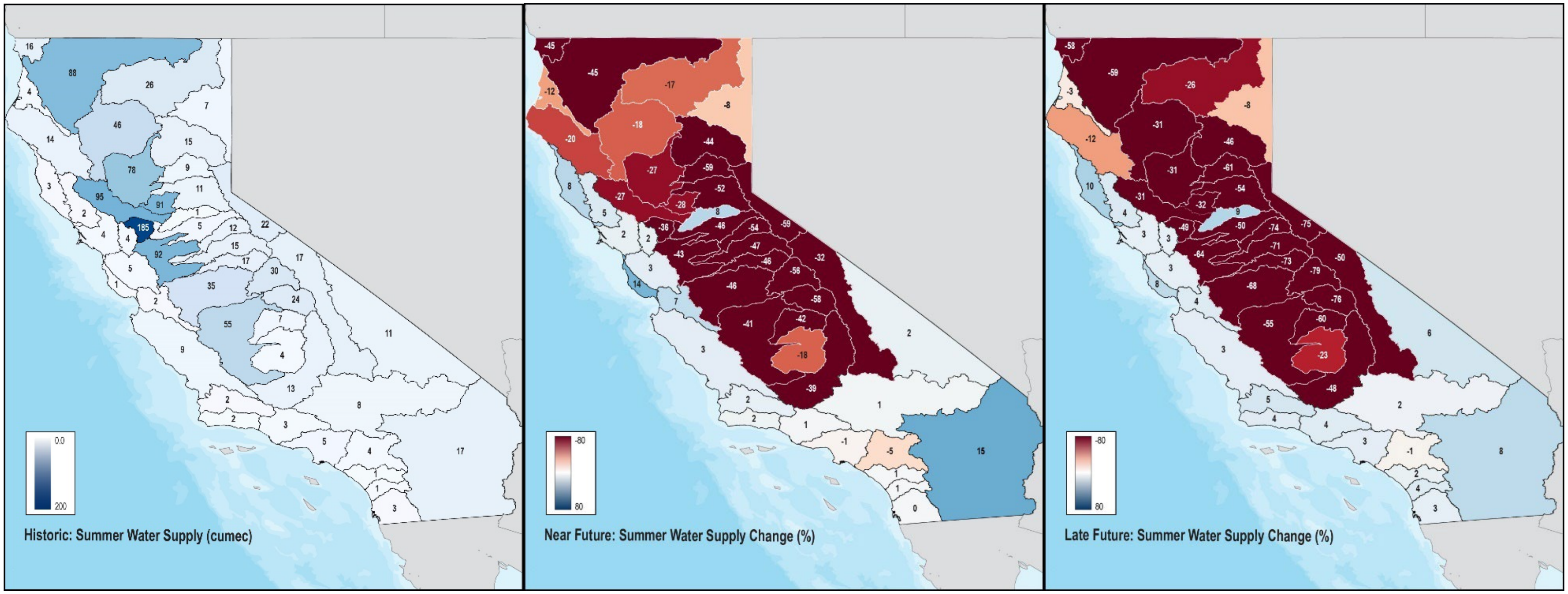
Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure A.1-5 Change in Spring Season (Apr-Jun) Water Supply (total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



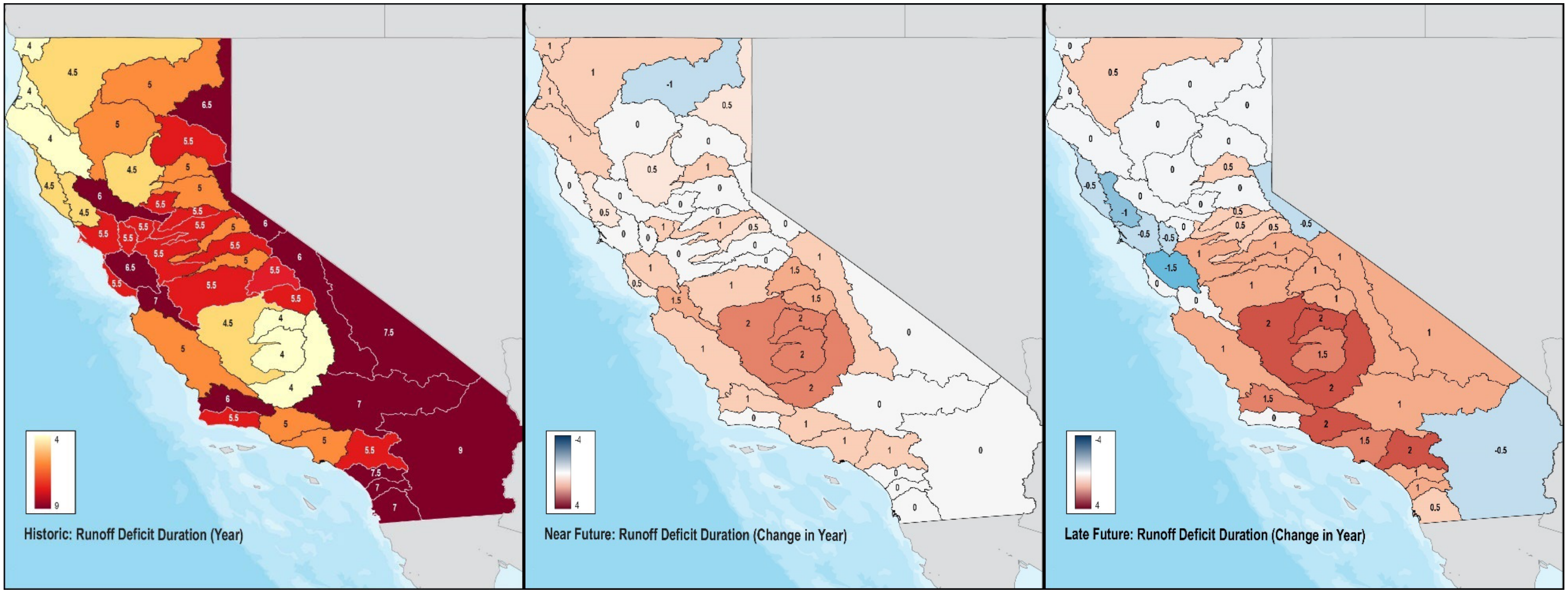
Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure A.1-6 Change in Summer Season (Jul-Sep) Water Supply (total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure A.1-7 Change in Drought Duration at Watershed Scale during Near Future (2001–2050, center, year) and Late Future (2050–2099, right, year) with respect to Historic Period (1951–2000, left, year)



Notes: Change is computed using the median values from 20 climate model projections. Positive values indicate an increase in dryness.

A.2 Flood Management

Flood management changes resulting from climate change were evaluated. Flood impacts are estimated by forecasting the impacts of flood events for the future period. The projected changes in 1-percent annual exceedance probability flows at watershed outlets is calculated based on three-day unimpaired flow in the future period compared to the historical period.

A.2.1 Approach

a) VIC-simulated daily total runoff for the 1/16th LOCA grids in California was estimated by grid-wise summation of the surface runoff and baseflow from each of the 20 climate projections.

b) The watershed-averaged daily total runoff was estimated for the individual watersheds using the area-weighted approach from gridded total runoff. The total runoff was calculated as the sum of the local watershed flow and routed flow from the upstream watershed.

c) The daily total runoff was utilized for estimating the three-day moving average total runoff and annual maxima three-day total runoff for estimating the 99th percentile values during the historic (1951–2000), near (2001–2050), and late (2050–2099) future periods.

d) The absolute values of the 99th percentile values of the three-day maxima total runoff during the historic, near, and late future periods were utilized to calculate the percentage change for the future periods for 20 climate projections.

e) The projected change in the flood management was reported as the median change of the indices from the 20 climate projections during the near and late future periods.

A.3 Groundwater

Groundwater recharge changes resulting from climate change were evaluated. Climate change impacts on groundwater recharge are estimated as the change in precipitation infiltration to deep soil layers. Percolation is calculated as the net balance between precipitation, actual evapotranspiration, and total runoff. Projected changes in average and lower quartile groundwater recharge are estimated for the future period compared to the historical period.

A.3.1 Approach

a) VIC-simulated daily precipitation, actual evapotranspiration, and total runoff (summation of surface runoff and baseflow) values for the 1/16th LOCA grids in California was estimated from each of the 20 climate projections for estimating the groundwater recharge. The infiltration, representing the groundwater recharge, is estimated as the net balance of precipitation minus actual evapotranspiration and runoff.

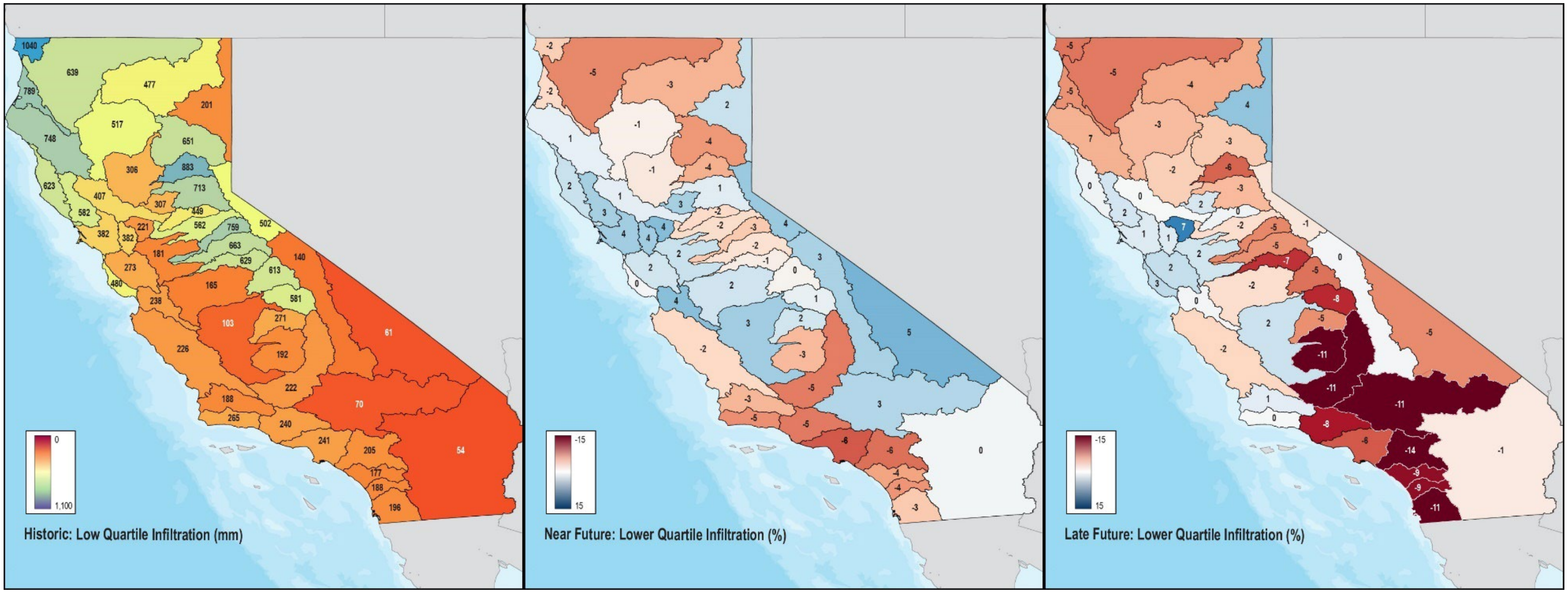
b) The watershed-averaged daily groundwater recharge values were estimated for the individual watersheds using the area-weighted approach.

c) The daily values were accumulated at annual water year scale for estimating the annual average and low-quartile (25th percentile) values during the historic (1981-2010), near (2026-2055), and late (2056-2085) future periods.

d) The relative percentage change in the annual average and low-quartile values of the groundwater recharge were calculated during the historic, near, and late future periods for 20 climate projections.

e) The projected change in the groundwater recharge was reported as the median change of the annual average and low-quartile values from the 20 climate projections during the near and late future periods.

Figure A.3-1 Change in Low-Quartile Groundwater Infiltration at Watershed Scale during Near Future (2026-2055, center, %) and Late Future (2056-2085, right, %) with respect to Historic Period (1981-2010, left, mm)



Notes: Change is computed using the median values from 20 climate model projections. mm = millimeter.

A.4 Water Quality

Water quality impacts resulting from climate change was evaluated. Rising temperatures can increase water temperature of watersheds and reduce the relative percentage of dissolved oxygen. Based on the correlation matrices with air temperature and snowmelt, stream temperature changes are estimated for the historic and future periods. The metric is calculated by analyzing the following indices:

1. Projected changes in stream temperature.
2. Projected changes in dissolved oxygen.

A.4.1 Approach

1. Stream Temperature

a) VIC-simulated daily average temperature for the 1/16th LOCA grids in California was estimated by grid-wise average of maximum and minimum temperature from each of the 20 climate projections.

b) The watershed-averaged daily average temperature was estimated for the individual watersheds using the area-weighted approach from gridded total runoff.

c) The daily stream temperature was estimated using the Köppen Climate Classification System (Kottek et al. 2006) and a nonlinear regression model equation between the stream temperature and air temperature (Mohseni et al. 1998):

$$T_{\text{water}} = \frac{C_0}{[1 + e^{(C_1 T_{\text{air}} + C_2)}]},$$

where C_0, C_1, and C_2 are the coefficients based on climate zone.

d) The daily stream temperature was accumulated at different temporal scales for estimating the following index values during the historic (1981–2010), near (2026–2055), and late (2056–`2085) future periods:

   i. Fall season: October to December.
   ii. Winter season: January to March.
   iii. Spring season: April to June.
   iv. Summer season: July to September.

e) The absolute values of the indices during the historic, near, and late future periods were utilized to calculate the percentage change for the future periods for 20 climate projections.

f) The projected change in the stream temperature was reported as the median change of the four seasons' indices from the 20 climate projections during the near and late future periods.

2. Dissolved Oxygen

a) The watershed-averaged daily stream temperature was estimated for the individual watersheds using the maximum and minimum temperature from each of the 20 climate projections.

b) The daily dissolved oxygen was estimated using the stream temperature by employing the equation developed by the American Public Health Association (Greenberg et al. 1992):

$$\mathrm{Ox}_{\mathrm{sat}} = \exp\left[-139.3441 + \frac{1.575701 \times 10^{5}}{T_{\mathrm{wat},K}} - \frac{6.642308 \times 10^{7}}{(T_{\mathrm{wat},K})^{2}} + \frac{1.243800 \times 10^{10}}{(T_{\mathrm{wat},K})^{3}} - \frac{8.621949 \times 10^{11}}{(T_{\mathrm{wat},K})^{4}}\right],$$

where T_{wat} is the stream temperature.

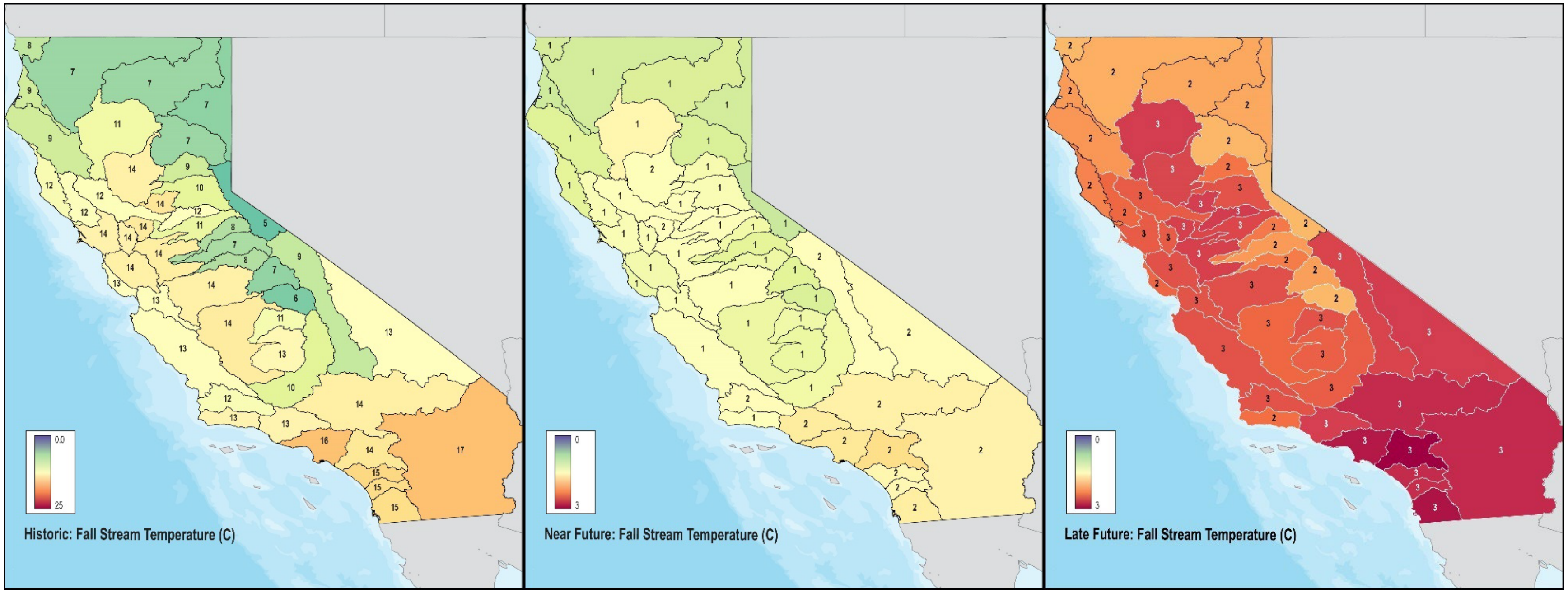
c) The daily dissolved oxygen was accumulated at different temporal scales for estimating the following index values during the historic (1981–2010), near (2026–2055), and late (2056–2085) future periods:

i. Fall season: October to December.
ii. Winter season: January to March.
iii. Spring season: April to June.
iv. Summer season: July to September.

d) The absolute values of the indices during the historic, near, and late future periods were utilized to calculate the percentage change for the future periods for 20 climate projections.

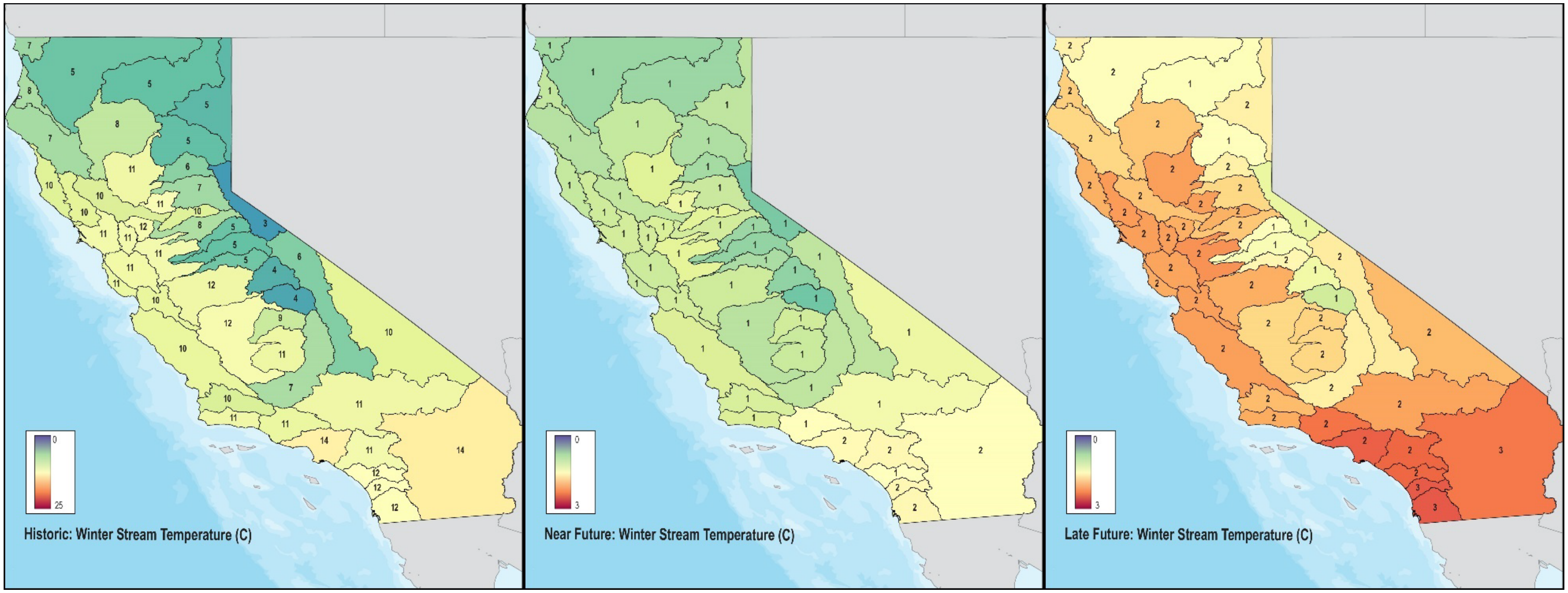
e) The projected change in the dissolved oxygen was reported as the median change of the four seasons' indices from the 20 climate projections during the near and late future periods.

Figure A.4-1 Change in Fall Season (Oct-Dec) Stream Water Temperature at Watershed Scale during Near Future (2026-2055, center, °C) and Late Future (2056-2085, right, °C) with respect to Historic Period (1981-2010, left, °C)



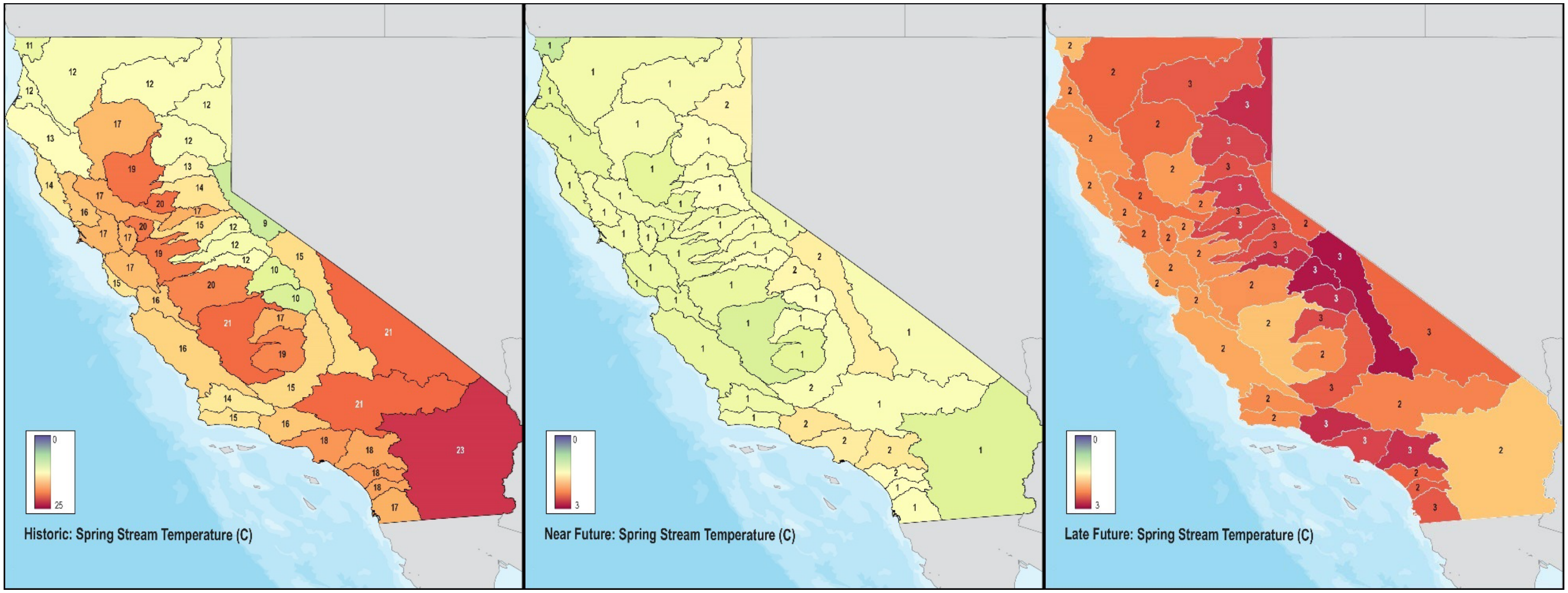
Notes: Change is computed using the median values from 20 climate model projections. °C = degrees Celsius.

Figure A.4-2 Change in Winter Season (Jan-Mar) Stream Water Temperature at Watershed Scale during Near Future (2026–2055, center, °C) and Late Future (2056–2085, right, °C) with respect to Historic Period (1981–2010, left, °C)



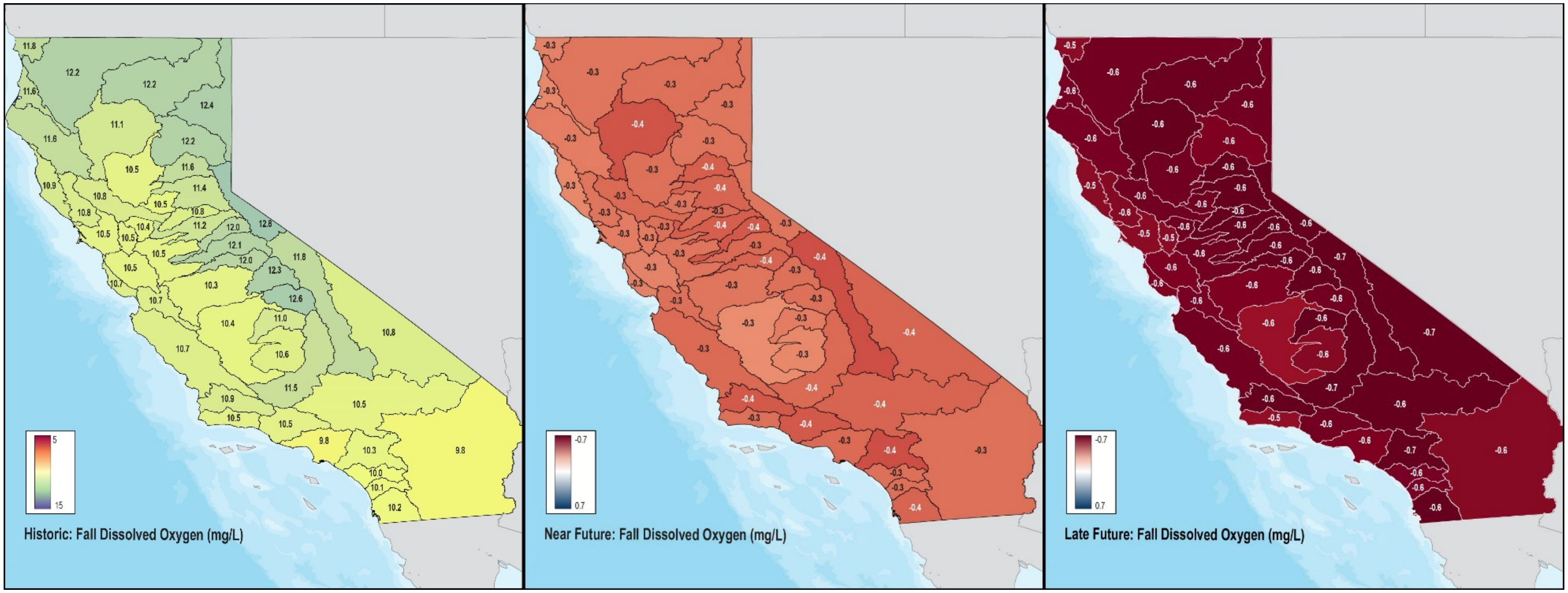
Notes: Change is computed using the median values from 20 climate model projections. °C = degrees Celsius.

Figure A.4-3 Change in Spring Season (Apr-Jun) Stream Water Temperature at Watershed Scale during Near Future (2026–2055, center, °C) and Late Future (2056–2085, right, °C) with respect to Historic Period (1981–2010, left, °C)



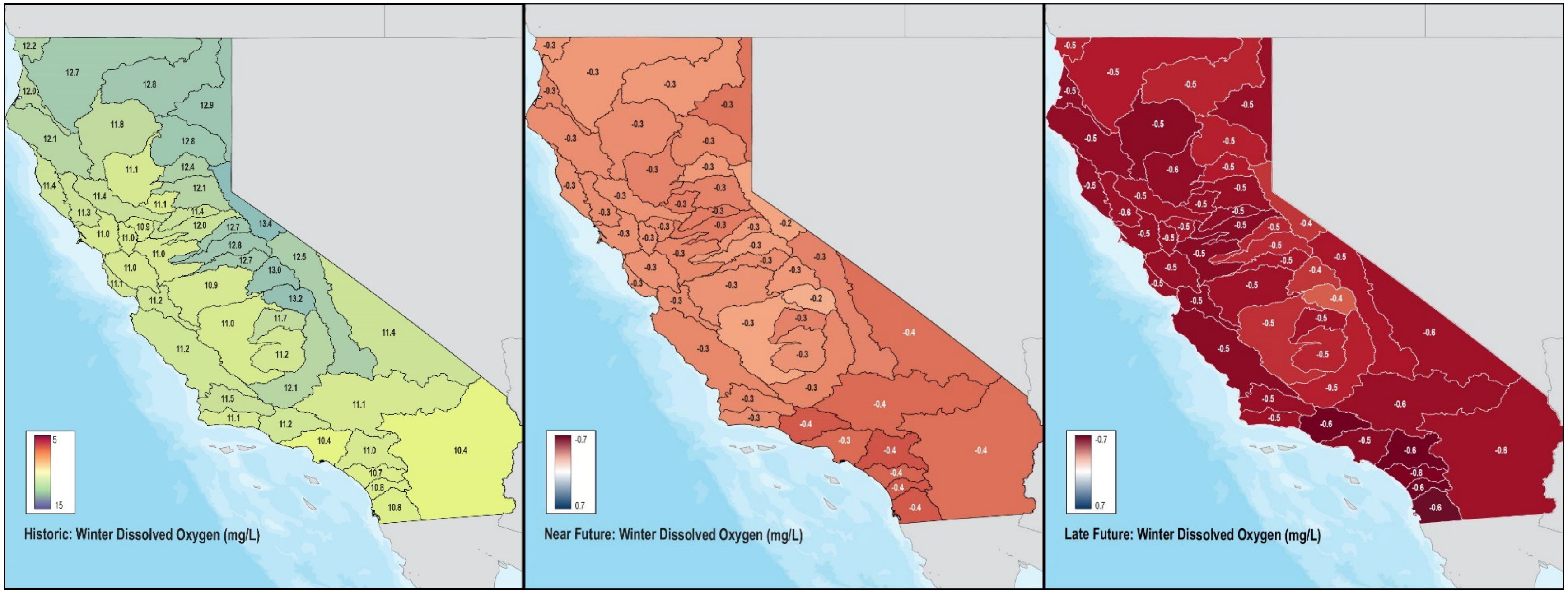
Notes: Change is computed using the median values from 20 climate model projections. °C = degrees Celsius.

Figure A.4-4 Change in Fall Season (Oct-Dec) Dissolved Oxygen at Watershed Scale during Near Future (2026–2055, center, mg/L) and Late Future (2056–2085, right, mg/L) with respect to Historic Period (1981– 2010, left, mg/L)



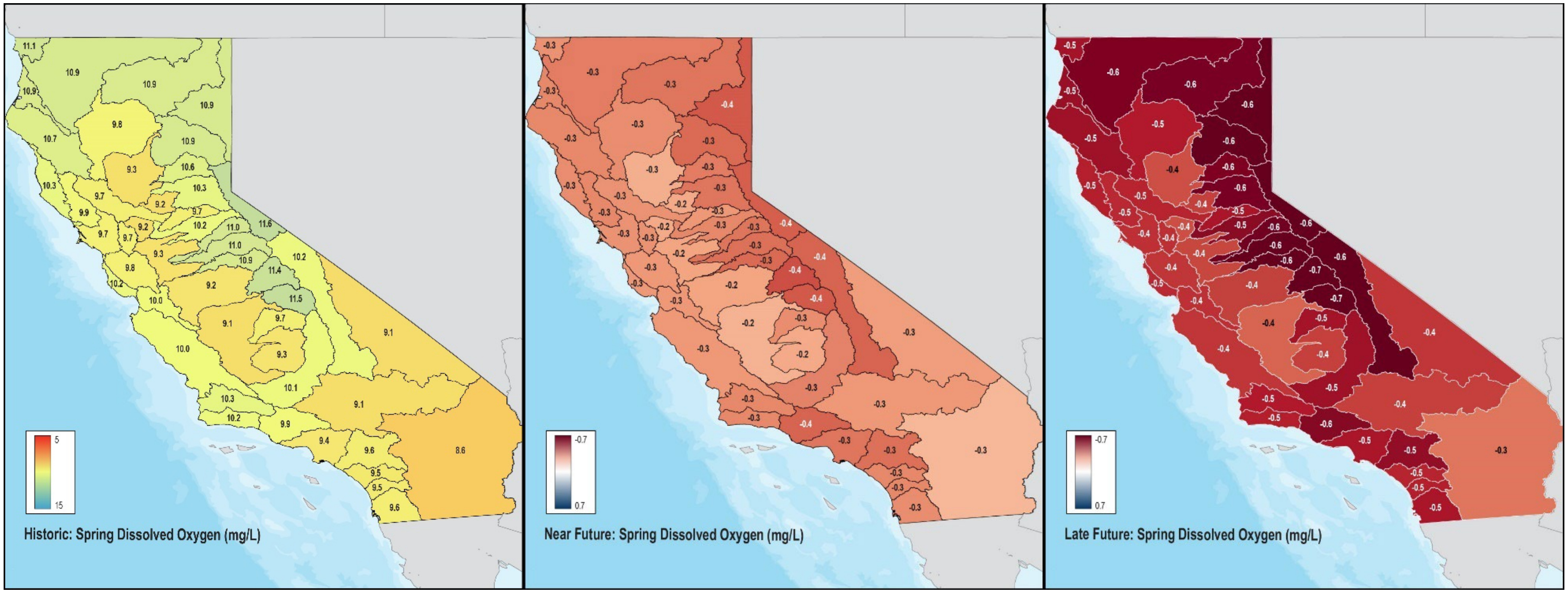
Notes: Change is computed using the median values from 20 climate model projections. mg/L = milligrams per liter.

Figure A.4-5 Change in Winter Season (Jan-Mar) Dissolved Oxygen at Watershed Scale during Near Future (2026–2055, center, mg/L) and Late Future (2056–2085, right, mg/L) with respect to Historic Period (1981–2010, left, mg/L)



Notes: Change is computed using the median values from 20 climate model projections. mg/L = milligrams per liter.

Figure A.4-6 Change in Spring Season (Apr-Jun) Dissolved Oxygen at Watershed Scale during Near Future (2026–2055, center, mg/L) and Late Future (2056–2085, right, mg/L) with respect to Historic Period (1981–2010, left, mg/L)



Notes: Change is computed using the median values from 20 climate model projections. mg/L = milligrams per liter.

A.5 Ecosystem

Ecosystem changes resulting from climate change were evaluated. Climate change can alter the minimum flow requirements, negatively affecting ecosystems and aquatic inhabitants. Projected changes in seasonal low flows and variability are defined by the lowest quartile and are estimated for the future periods compared to the historic period.

A.5.1 Approach

a) VIC-simulated daily total runoff for the 1/16th LOCA grids in California was estimated by grid-wise summation of the surface runoff and baseflow from each of the 20 climate projections.

b) The watershed-averaged daily total runoff was estimated for the individual watersheds using the area-weighted approach from gridded total runoff. The total runoff was calculated as the sum of the local watershed flow and routed flow from the upstream watershed.

c) The daily total runoff was accumulated at monthly temporal scales for estimating the 25th percentile for the following seasons during the historic (1981–2010), near (2026–2055), and late (2056–2085) future periods:

    i. Fall season: October to December.

    ii. Winter season: January to March.

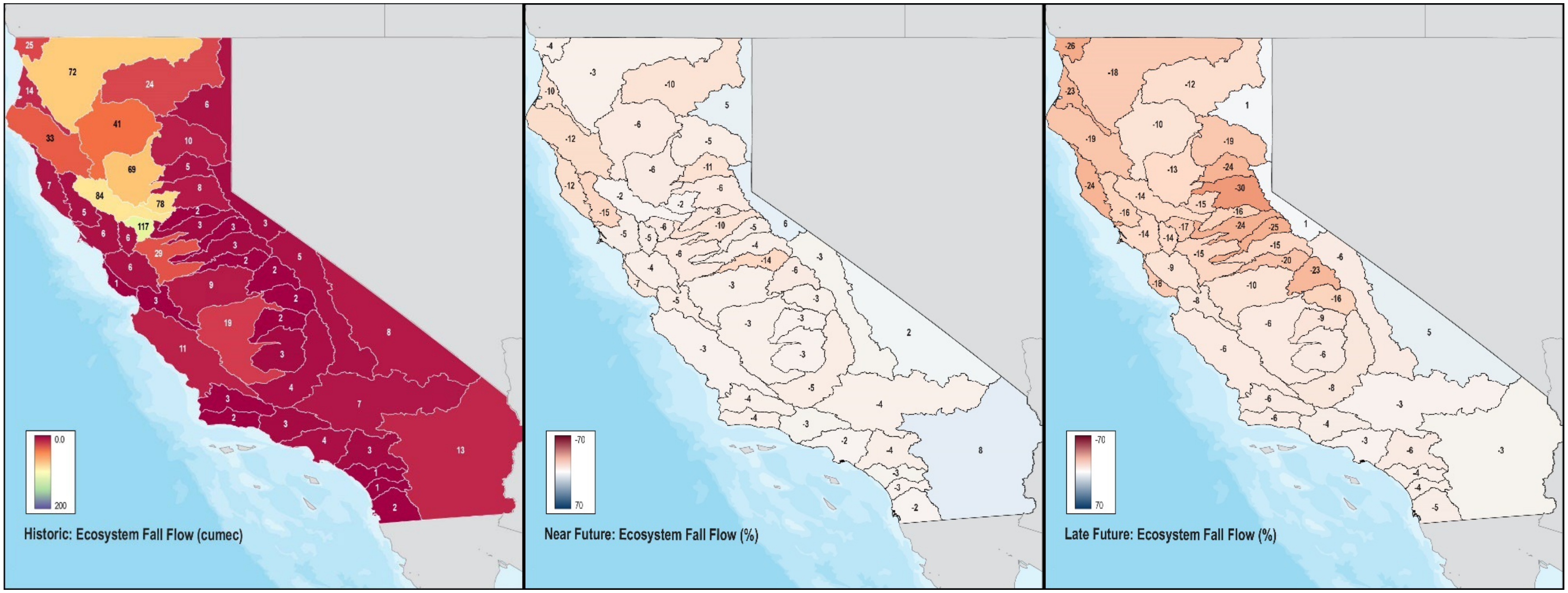
    iii. Spring season: April to June.

    iv. Summer season: July to September.

d) The absolute values of the four seasons' indices during the historic, near and late future periods were utilized to calculate the percentage change for the future periods for 20 climate projections.

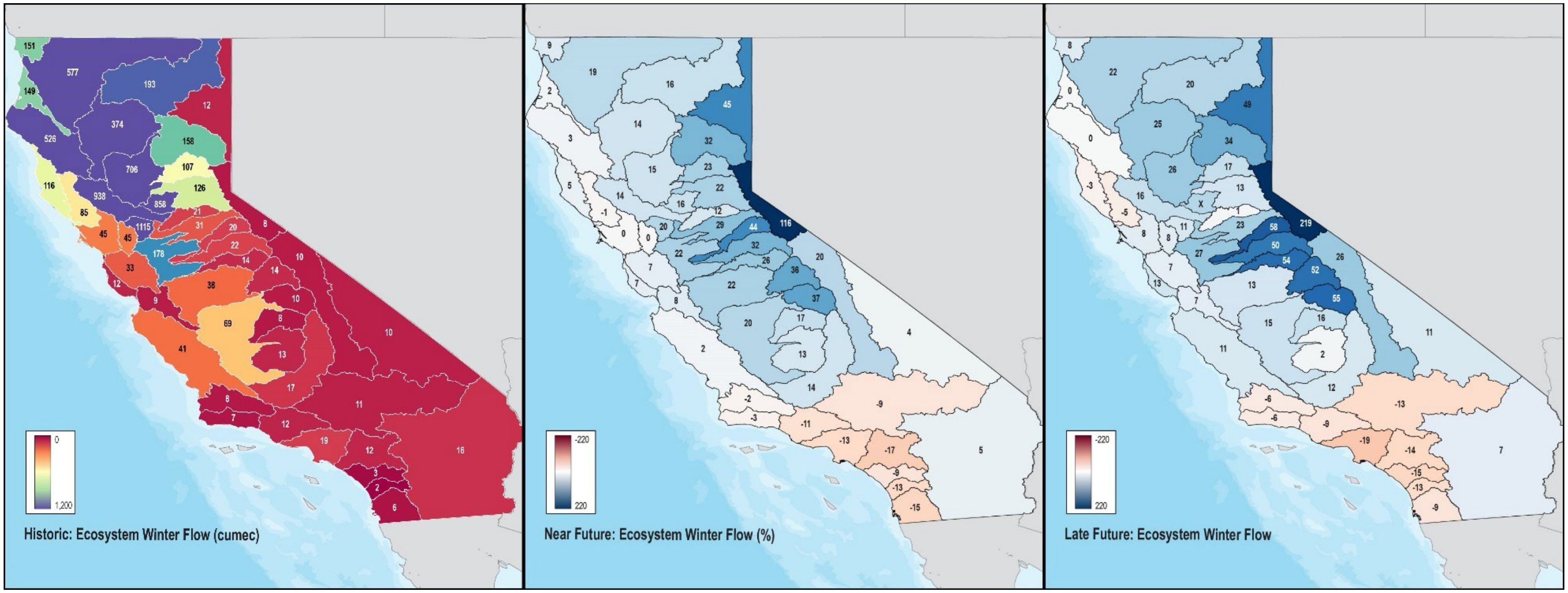
e) The projected change in the ecosystem flow was reported as the median change of the four seasons' indices from the 20 climate projections during the near and late future periods.

Figure A.5-1 Change in Fall season (Oct-Dec) Ecosystem Flow (25th percentile total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



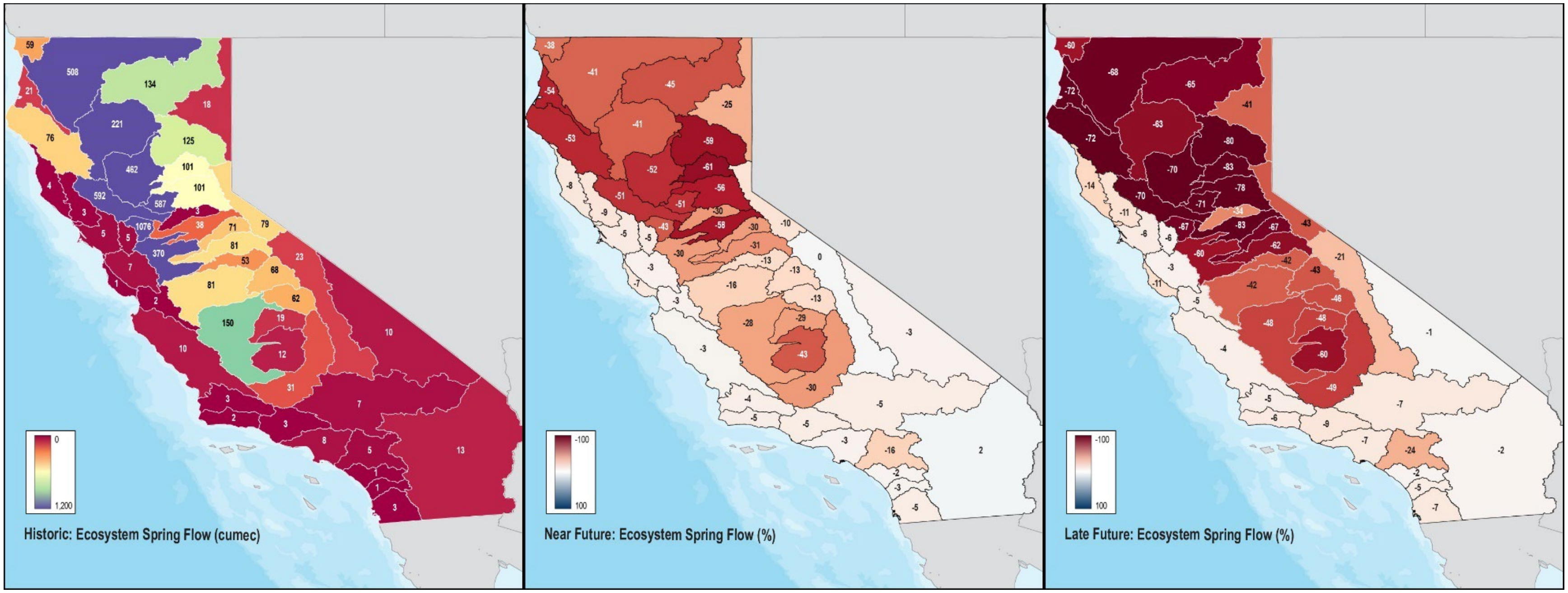
Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure A.5-2 Change in Winter Season (Jan-Mar) Ecosystem Flow (25th percentile total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

Figure A.5-3 Change in Spring season (Apr-Jun) Ecosystem Flow (25th percentile total runoff) at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, cumec)



Notes: Change is computed using the median values from 20 climate model projections. cumec = cubic meters per second.

A.6 Hydropower

Changes in hydropower generation resulting from climate change were evaluated. Changes in the timing of snowmelt and precipitation can alter streamflow into reservoirs, impacting hydropower production. Major hydroelectric generation facilities in each watershed are selected and the projected changes for inflows, storage-elevation, and generation are used to characterize the relative impact to hydropower generation.

A.6.1 Approach

a) The dam characteristics (e.g., storage capacity, power capacity, turbines), observed inflow, outflow, evaporation, and water year index was accessed from the California Data Exchange Center (CDEC), United States Geological Survey (USGS), and open sources database.

b) VIC-simulated daily total runoff for the 1/16th LOCA grids in California was estimated by grid-wise summation of the surface runoff and baseflow from each of the 20 climate projections. The dam catchment-averaged monthly inflow was estimated for the individual dams using the area-weighted approach from gridded total runoff. The water year index was developed for the future period.

c) A power model developed along with applying CalSim II was used for estimating the hydropower generation of the dams located within the Central Valley. The storage-elevation relation, power, and energy equations developed in the power model was utilized. A generalized approach was used for dams situated in the other regions in California.

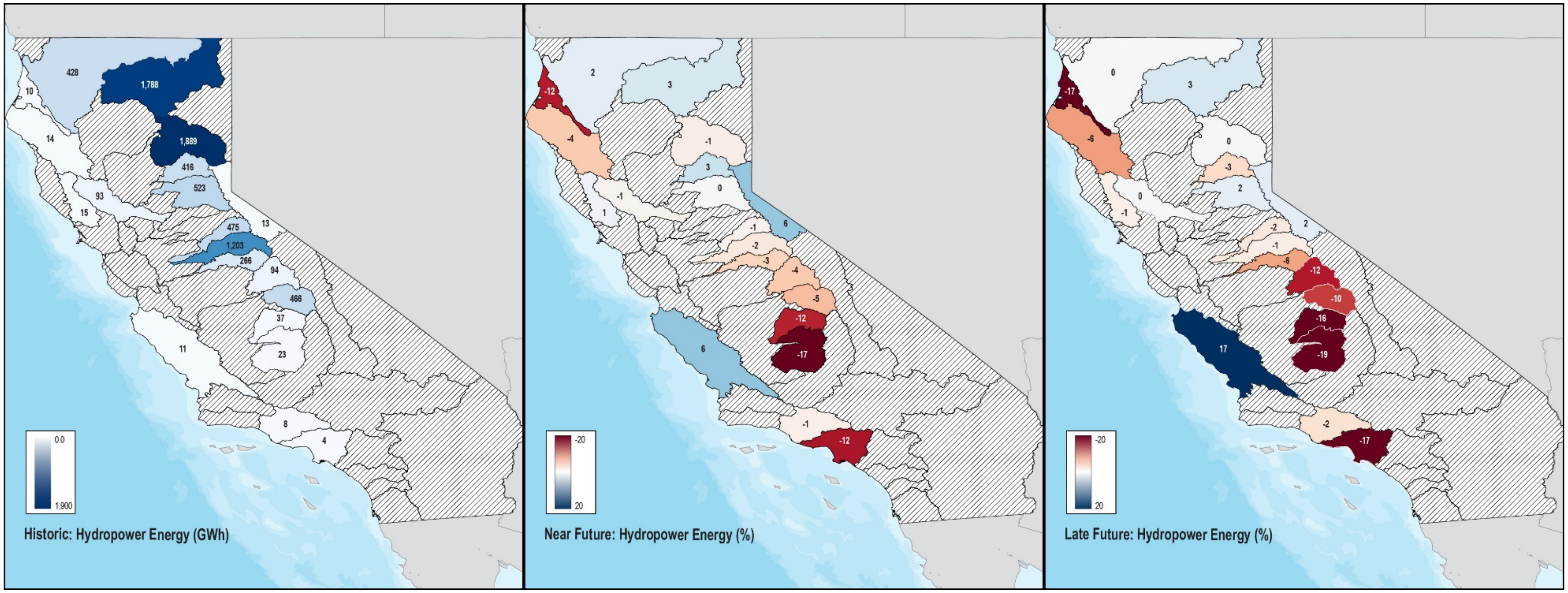
d) Using observed data, the relationship between storage, outflow, and water year index was developed for the individual dams located outside the Central Valley.

e) Inflow, evaporation, storage-release relationship, and water year type were used to estimate reservoir storage using the water balance equation. Monthly hydropower generation and annual energy generation were calculated based on the water level, outflow, and storage for the historic (1981–2010), near, (2026–2055), and late (2056–2085) future periods.

f) The absolute values of the monthly hydropower generation and annual energy generation during the historic, near, and late future periods were utilized to calculate the percentage change for the future periods for 20 climate projections.

g) The projected change in the hydropower was reported as the median change from the 20 climate projections during the near and late future periods.

Figure A.6-1 Change in Hydropower Energy at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, gigawatt hours)



Notes: Change is computed using the median values from 20 climate model projections. Watersheds not analyzed are marked with hatching.

A.7 Recreation

Changes in recreational opportunities resulting from climate change were evaluated. Increased temperatures, increased evapotranspiration rates, and more variable precipitation rates are likely to have various impacts on recreational areas and opportunities. Projected changes in recreational opportunities are assessed by analyzing flows, snow depth, and sea level rise. Recreation is calculated by analyzing the following indices:

1. Projected changes in river recreation opportunities.
2. Projected changes in lake recreation opportunities.
3. Projected changes in snow recreation opportunities.
4. Projected changes in coastal recreation opportunities.

A.7.1 Approach

1. River Recreation Opportunities

a) VIC-simulated daily total runoff for the 1/16th LOCA grids in California was estimated by grid-wise summation of the surface runoff and baseflow from each of the 20 climate projections.

b) The watershed-averaged daily total runoff was estimated for the individual watersheds using the area-weighted approach from gridded total runoff. The total runoff was calculated as the sum of the local watershed flow and routed flow from the upstream watershed.

c) The 25th and 75th percentile values of the daily total runoff between May and September were estimated for the historic period (1981–2010).

d) The river recreational days were calculated as the number of days between May and September with daily total runoff value between the historic 25th and 75th percentile values during the historic (1981–2010), near (2026–2055), and late (2056–2085) future periods.

e) The absolute values of the river recreation days per year during the historic, near, and late future periods were utilized to calculate the change for the future periods for 20 climate projections.

f) The projected change in the river recreation opportunity was reported as the median change of the seasonal, annual, annual low-quartile, and four seasons' indices from the 20 climate projections during the near and late future periods.

2. Lake Recreation Opportunities

a) The lake characteristics (e.g., storage capacity, surface area), observed inflow, outflow, evaporation, and water year index was accessed from the CDEC, USGS, and open sources database.

b) VIC-simulated daily total runoff for the 1/16th LOCA grids in California was estimated by grid-wise summation of the surface runoff and baseflow from each of the 20 climate projections. The dam catchment-averaged monthly inflow was estimated for the individual dams using the area-weighted approach from gridded total runoff. The water year index was developed for the future period.

c) A power model developed along with CalSim II was used for estimating the surface area variation of the lakes located within the Central Valley. The storage-elevation relation, and storage-area relation developed in the power model was utilized. A generalized approach was used for the lakes situated in the other regions in California.

d) Using observed data, the relationship between storage, outflow, and water year index was developed for the individual dams located outside the Central Valley.

e) Inflow, evaporation, storage-release relationship, and water year type were used to estimate lake storage using the water balance equation. Monthly lake surface area variation was calculated based on the storage for the historic (1981–2010), near (2026–2055), and late (2056–2085) future periods.

f) The absolute values of the monthly lake surface area between May and September during the historic, near, and late future periods were utilized to calculate the percentage change for the future periods for 20 climate projections.

g) The projected change in the lake surface area was reported as the median change from the 20 climate projections during the near and late future periods.

3. Snow Recreation Opportunities

a) VIC-simulated daily snow water equivalent (SWE) values for the 1/16th LOCA grids in California were extracted from each of the 20 climate projections.

b) The LOCA grids representing the major selected ski resorts were identified.

c) Ski recreational days were calculated as the number of days with SWE of more than 100 millimeters (3.9 inches) between November and June during the historic (1981–2010), near (2026–2055), and late (2056–2085) future periods.

d) The absolute values of the ski recreation days during the Historic, Near and Late future periods were utilized to calculate the percentage change for the future periods for 20 climate projections.

e) The projected change in the ski recreation opportunity was reported as the median change from the 20 climate projections during the near and late future periods.

4. Coastal Recreation Opportunities

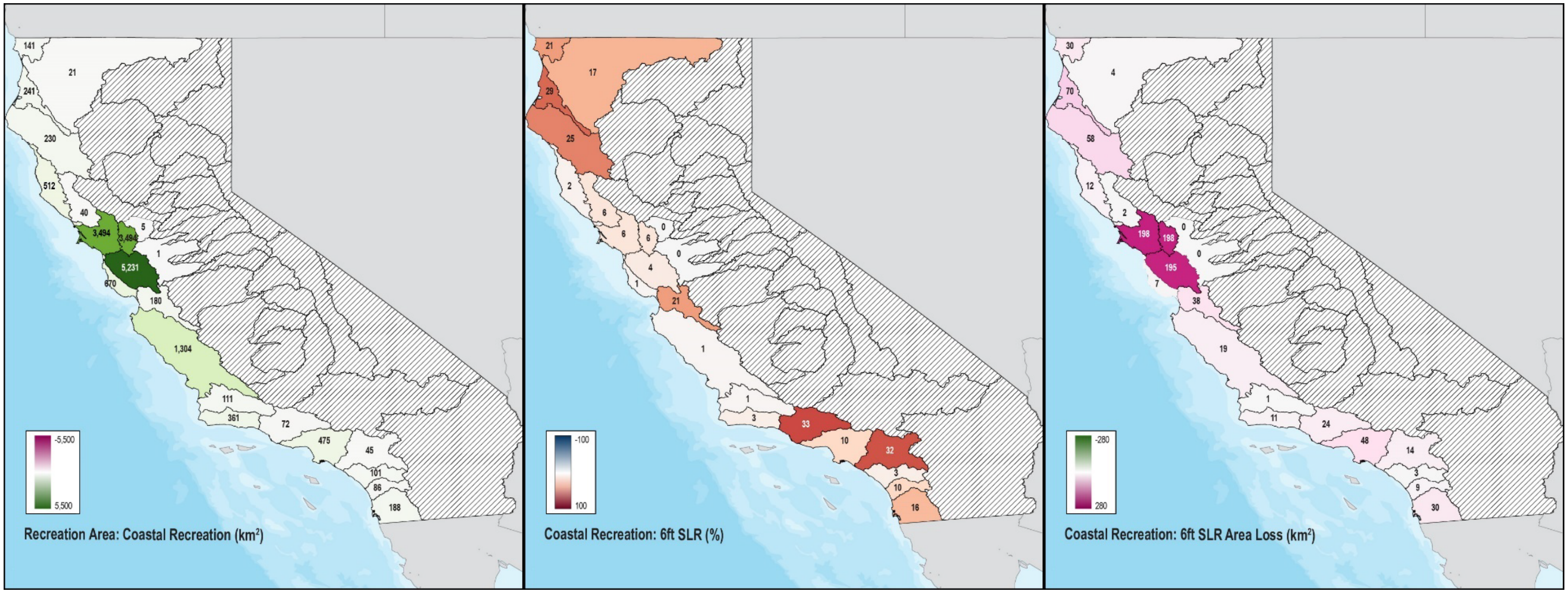
a) For watersheds along the coast, coastal recreation areas were estimated using the coastal zone boundary and operational landscape units (OLUs) layers that extend inland of the seashore.

b) Inundation areas resulting from sea level rise at 1-foot increments between 1 foot to 10 feet were downloaded from the National Oceanic and Atmospheric database.

c) The reduction in the coastal recreation area was estimated as the difference between the base recreation area and the inundation area affected by sea level rise from 1 foot to 10 feet.

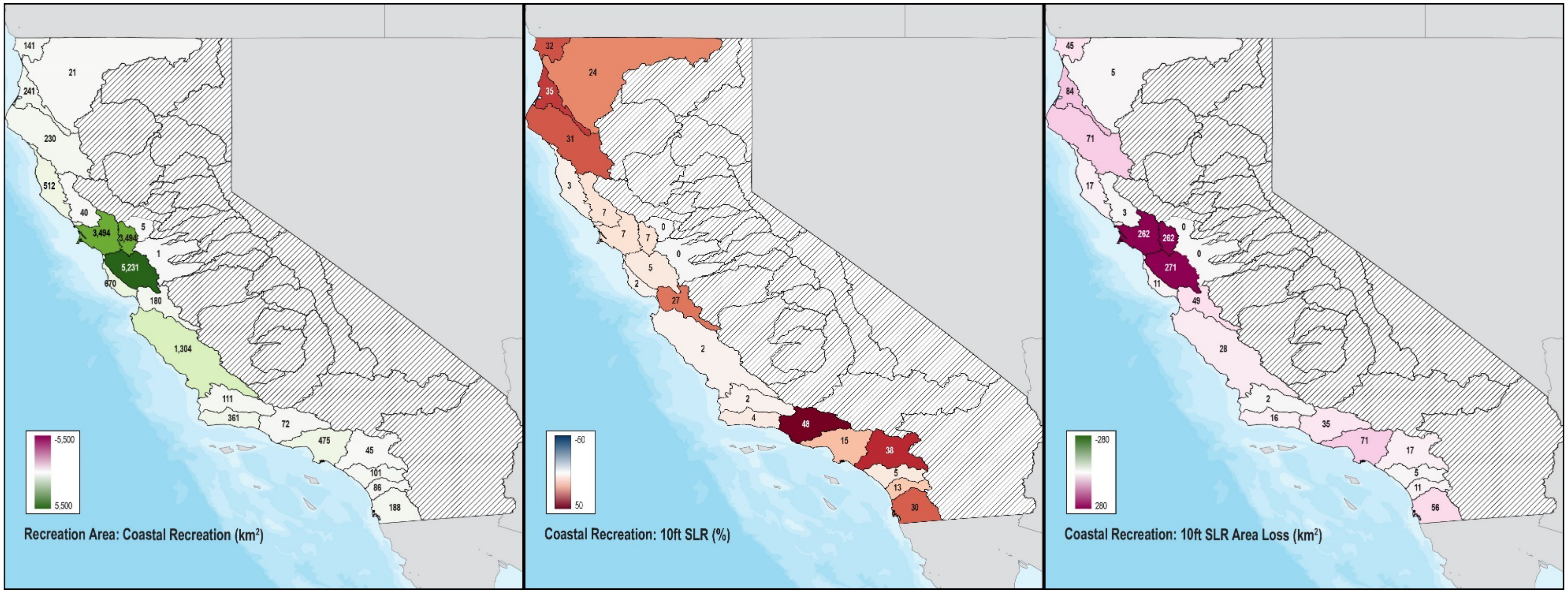
d) The absolute values of the loss in coastal recreation area and relative percentage change with respect to base recreational area was reported for different sea-level-rise scenarios.

Figure A.7-1 Change in Coastal Recreation Area (center, %; right, km²) at Watershed Scale resulting from 6-foot Sea Level Rise with respect to Base Recreation Area (left, km²)



Notes: Watersheds not analyzed are marked with hatching. km^2 = square kilometer.

Figure A.7-2 Change in Coastal Recreation Area (center, %; right, km²) at Watershed Scale resulting from 10-foot Sea Level Rise with respect to Base Recreation Area (left, km²)



Notes: Watersheds not analyzed are marked with hatching. km^2 = square kilometer.

A.8 Wildfire

Increased wildfire danger as a result of climate change was evaluated. 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 indices:

1. Projected changes in area burned.
2. Projected changes in decadal wildfire probabilities.

A.8.1 Approach

1. Wildfire Area Burned

a) Annual wildfire burned area data for three population growth scenarios and four climate models under representative concentration pathway (RCP) 4.5 and RCP 8.5 for the 1/16th LOCA grids in California was accessed from the Cal-Adapt database. Population projections are developed for three growth scenarios — central, low, and high. These population growth scenarios were used to drive a land use change simulation model (LUCAS). The land use/land cover scenarios represent changes in a suite of classes of land use and land cover related to urbanization, agricultural expansion and contraction, forest harvest, wildfire, and other processes. The LUCAS scenarios were converted to estimate proportion of the 1/16th grid cells that were vegetated (i.e., burnable wildland fuel).

b) The watershed-averaged annual wildfire burned area was estimated for the individual watersheds using the area-weighted approach. The grids with the missing values were excluded and burned area estimates were normalized by watershed area.

c) The absolute values of the wildfire burned area during the historic (1981–2010), near (2026–2055), and late (2056–2085) future periods were utilized to calculate the percentage change for the future periods for eight climate projections.

d) The projected change in the wildfire burned area was reported as the median change from the eight climate projections during the near and late future under three population scenarios.

2. Decadal Wildfire Probabilities

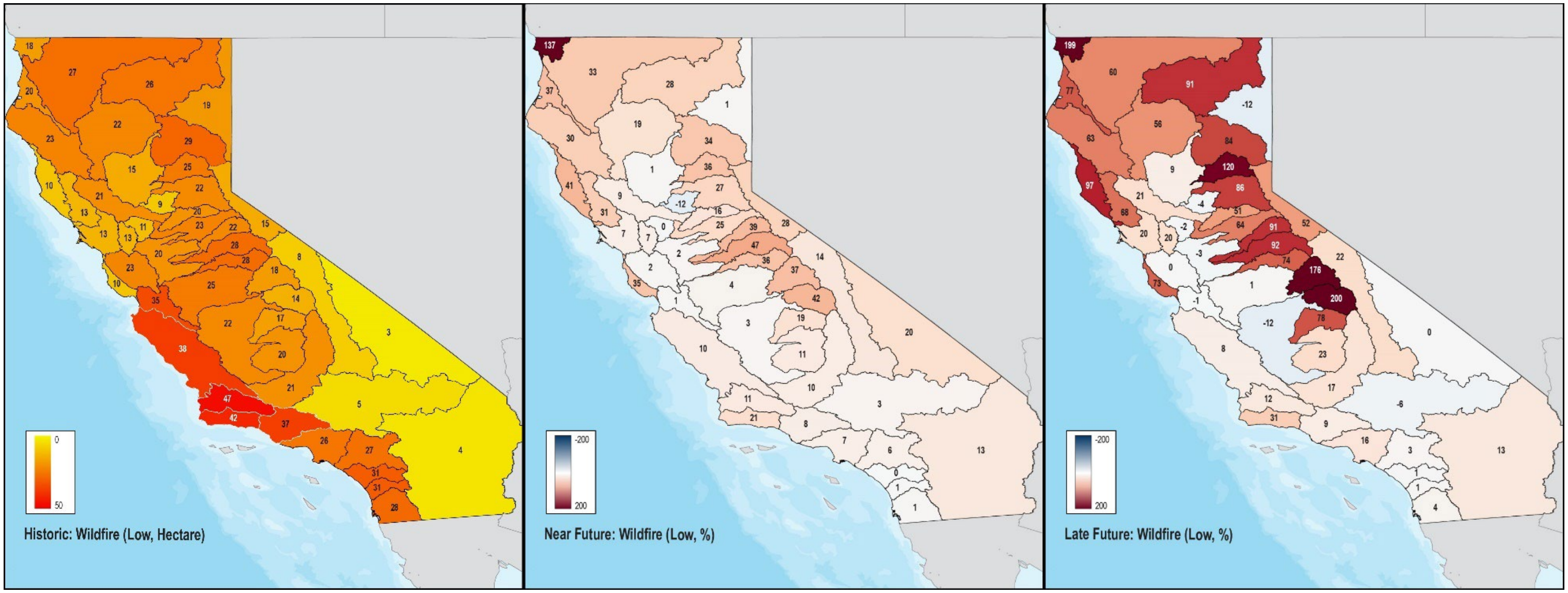
a) Decadal wildfire probabilities data for central population growth scenarios from four climate models under RCP 4.5 and RCP 8.5 for the 1/16th LOCA grids in California were accessed from the Cal-Adapt database. Population projections are developed for three growth scenarios — central, low, and high.

b) The watershed-averaged decadal wildfire probabilities were estimated for the individual watersheds using the area-weighted approach. The grids with the missing values were excluded from the calculation.

c) The absolute change in the decadal wildfire probabilities were estimated for the near (2026–2055) and late (2056–2085) future periods with respect to the historic (1981–2010) period for eight climate projections.

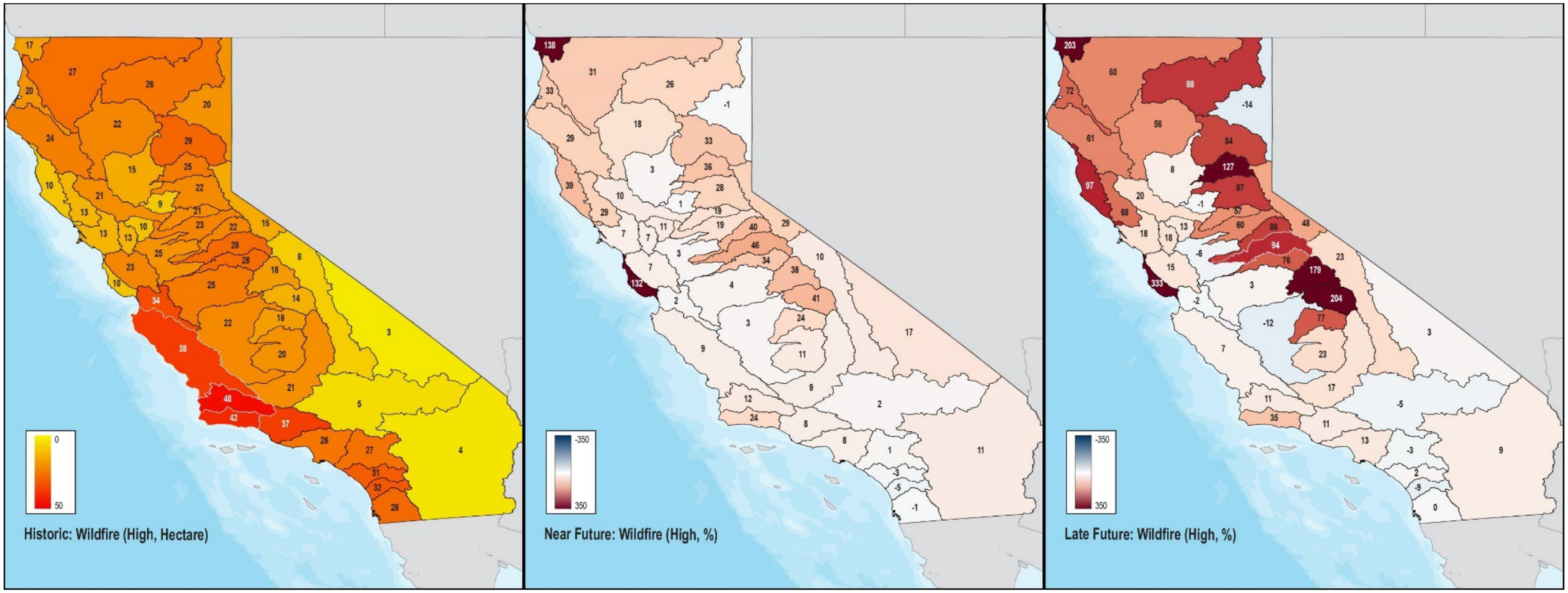
d) The projected change in the decadal wildfire probabilities was reported as the median change from the eight climate projections during the near and late future periods under central population scenario.

Figure A.8-1 Change in Burned Area resulting from Wildfire at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, hectare) for Low Population Growth Scenario



Note: Change is computed using the median values from eight climate model projections.

Figure A.8-2 Change in Burned Area resulting from Wildfire at Watershed Scale during Near Future (2026–2055, center, %) and Late Future (2056–2085, right, %) with respect to Historic Period (1981–2010, left, hectare) for High Population Growth Scenario



Note: Change is computed using the median values from eight climate model projections.

Appendix B
Preparedness Assessment

Table B-1 Watershed Plan and Summary Ratings

Watershed	Average GSP Rating	Average LHMP Rating	Average UWMP Rating	Average IRWMP Rating	Average Basin Studies Rating	Average Climate Adaptation Rating	Average Summary Rating
Amargosa	N/A	2.42	N/A	3.00	N/A	1.17	2.76
American-Bear	0.33	2.50	0.83	3.61	2.42	2.44	2.58
Cache - Putah	0.83	2.29	0.56	2.78	2.42	1.38	2.09
Coastal Drainages	N/A	1.25	N/A	2.33	N/A	1.92	2.07
Colorado River	0.50	0.61	0.75	1.94	1.17	0.25	1.30
Consumnes	N/A	2.28	0.83	2.94	2.42	1.44	2.37
Delta	1.00	2.17	0.92	2.75	4.17	1.76	2.23
Eel	0.33	1.33	0.50	2.58	N/A	0.67	1.72
Feather River	0.33	2.58	0.83	3.17	4.17	0.50	2.36
Kaweah	0.29	0.33	0.67	2.06	4.17	0.17	1.42
Kern	0.54	0.75	0.83	2.42	4.17	0.67	1.74
Kings	0.42	0.83	0.42	2.67	4.17	0.67	1.80
Klamath	0.58	1.13	1.17	2.33	3.25	0.83	1.77
Los Angeles	0.33	0.51	1.12	2.25	1.33	0.48	1.49
Lower San Joaquin	0.56	0.88	0.78	1.94	4.17	0.61	1.51
Mad	N/A	1.00	0.60	2.33	N/A	0.17	1.66
Merced	N/A	1.50	N/A	2.17	4.17	0.67	2.07
Lower Sacramento	0.50	2.97	0.52	3.00	2.42	2.17	2.30
Middle San Joaquin	0.37	1.13	0.54	2.13	4.17	2.00	1.66
Middle Sacramento	0.54	1.95	1.00	3.50	2.42	2.08	2.47
Mojave	N/A	1.06	0.85	2.46	N/A	0.50	1.81
Mokelumne	N/A	1.33	1.00	2.58	4.17	0.50	2.08

Watershed	Average GSP Rating	Average LHMP Rating	Average UWMP Rating	Average IRWMP Rating	Average Basin Studies Rating	Average Climate Adaptation Rating	Average Summary Rating
North Bay	0.50	0.69	0.87	2.67	N/A	1.13	1.76
North Lahontan	N/A	0.83	N/A	3.00	N/A	0.50	2.36
Owens	0.00	1.75	0.67	3.00	N/A	0.50	1.99
Pajaro	1.25	1.67	1.53	3.42	N/A	1.50	2.51
Pit-McCloud	0.33	0.50	1.08	2.67	4.17	0.50	1.84
Russian	0.50	0.81	0.81	2.33	N/A	2.50	1.67
Salinas	0.98	1.75	0.90	3.61	N/A	0.85	2.47
San Diego	0.67	0.83	0.42	2.83	1.17	2.33	1.83
San Luis Rey	0.67	0.83	1.09	2.83	N/A	0.17	1.87
Santa Ana	1.03	0.53	0.98	2.83	1.00	0.30	1.81
Santa Cruz - San Francisco Coastal	1.17	1.29	1.17	3.67	N/A	0.94	2.49
Santa Margarita	N/A	0.08	1.17	3.06	N/A	0.33	2.04
Santa Maria	0.50	0.67	0.50	2.83	N/A	1.17	1.79
Santa Ynez	1.17	0.67	0.97	2.83	N/A	1.83	1.97
Smith	N/A	1.67	0.33	2.33	N/A	0.00	1.73
South Bay	0.17	1.10	1.42	2.58	N/A	0.75	1.81
Stanislaus	N/A	0.33	0.83	2.17	4.17	0.50	1.66
Suisun Bay	N/A	1.17	1.31	3.00	N/A	1.67	2.30
Tahoe	N/A	2.33	0.72	2.83	3.67	0.83	2.33
Tulare Lakebed	0.35	0.56	0.33	2.13	4.17	1.00	1.49
Tule	0.24	0.75	0.42	2.17	4.17	0.67	1.52
Tuolumne	N/A	0.00	0.83	2.17	4.17	0.50	1.60

Watershed	Average GSP Rating	Average LHMP Rating	Average UWMP Rating	Average IRWMP Rating	Average Basin Studies Rating	Average Climate Adaptation Rating	Average Summary Rating
Upper Sacramento	0.67	1.19	1.11	2.83	4.17	0.50	2.06
Upper San Joaquin	N/A	1.25	N/A	2.11	4.17	0.33	1.96
Ventura	0.77	1.00	1.60	2.83	N/A	0.39	2.00
Yuba	0.33	2.56	1.17	4.17	4.17	2.00	2.98

Notes: GSP = groundwater sustainability plan; IRWMP = integrated regional water management plan; LHMP = local hazard mitigation plan; UWMP = urban water management plan.

Table B-2 Groundwater Sustainability Plan Component Ratings

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Cache - Putah	2.00	0.00	2.00	0.00	1.00	0.00
Colorado River	0.00	0.00	2.00	0.00	0.00	1.00
Delta	2.50	0.00	2.00	0.00	1.00	0.50
Eel	0.00	0.00	2.00	0.00	0.00	0.00
Feather River	0.00	0.00	2.00	0.00	0.00	0.00
Kaweah	0.50	0.00	1.25	0.00	0.00	0.00
Kern	0.25	0.50	2.00	0.00	0.25	0.25
Kings	0.50	0.00	2.00	0.00	0.00	0.00
Klamath	1.00	0.00	2.00	0.00	0.50	0.00
Los Angeles	0.00	0.00	2.00	0.00	0.00	0.00
Lower San Joaquin	1.33	0.00	2.00	0.00	0.00	0.00
Lower Sacramento	0.00	0.00	2.00	1.00	0.00	0.00
Middle San Joaquin	0.44	0.00	1.78	0.00	0.00	0.00
Middle Sacramento	0.75	0.00	2.00	0.00	0.25	0.25
North Bay	1.00	0.50	1.25	0.00	0.25	0.00
Owens	0.00	0.00	0.00	0.00	0.00	0.00
Pajaro	1.50	1.00	1.50	1.00	1.50	1.00
Pit-McCloud	0.00	0.00	2.00	0.00	0.00	0.00
Russian	0.50	0.50	2.00	0.00	0.00	0.00
Salinas	1.75	0.00	2.00	0.25	1.00	0.88
San Diego	2.00	0.00	1.00	0.00	0.00	1.00
San Luis Rey	2.00	0.00	2.00	0.00	0.00	0.00
Santa Ana	2.00	0.40	2.00	0.20	0.40	1.20

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Santa Cruz - San Francisco Coastal	2.00	1.00	1.00	0.00	1.00	2.00
Santa Maria	0.50	0.00	2.00	0.00	0.50	0.00
Santa Ynez	2.00	1.00	2.00	1.00	1.00	0.00
South Bay	0.00	0.00	1.00	0.00	0.00	0.00
Tulare Lakebed	0.55	0.00	1.45	0.00	0.09	0.00
Tule	0.22	0.00	1.22	0.00	0.00	0.00
Upper Sacramento	2.00	0.00	2.00	0.00	0.00	0.00
Ventura	0.88	0.25	2.00	0.25	0.25	1.00
Yuba	0.00	0.00	2.00	0.00	0.00	0.00

Notes: The groundwater sustainability plan (GSP) summary results are shown for all watersheds. A total of 103 GSP plans were rated in this Assessment.

Table B-3 Local Hazard Mitigation Plan Component Ratings

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Amargosa	3.00	1.00	2.50	3.00	4.00	1.00
American-Bear	1.50	2.25	4.50	4.50	2.25	0.00
Cache - Putah	2.71	2.00	2.86	2.57	1.29	2.29
Coastal Drainages	0.00	0.00	2.00	2.00	3.00	0.50
Colorado River	0.67	0.00	0.67	1.00	1.00	0.33
Consumnes	2.33	1.33	3.00	2.67	2.00	2.33
Delta	3.00	2.50	1.50	3.00	1.50	1.50
Eel	0.00	1.00	2.33	2.33	1.33	1.00
Feather River	1.50	1.00	3.50	3.00	2.50	4.00
Kaweah	0.00	0.00	1.00	0.50	0.50	0.00
Kern	0.00	0.00	1.50	1.50	1.00	0.50
Kings	0.00	0.00	3.00	2.00	0.00	0.00
Klamath	0.00	0.20	2.20	2.20	1.40	0.80
Los Angeles	0.08	0.17	1.08	1.00	0.42	0.29
Lower San Joaquin	0.50	0.25	1.50	1.50	1.00	0.50
Mad	0.00	0.50	2.00	1.50	1.00	1.00
Merced	2.00	0.00	2.00	2.00	2.00	1.00
Lower Sacramento	3.60	3.40	3.40	2.60	2.00	2.80
Middle San Joaquin	0.75	0.00	2.00	2.00	1.50	0.50
Middle Sacramento	1.43	1.57	2.86	2.29	1.71	1.86
Mojave	0.67	0.00	1.33	2.00	1.67	0.67
Mokelumne	1.00	0.67	1.67	1.67	1.67	1.33
North Bay	0.81	0.19	0.94	0.75	0.94	0.50

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
North Lahontan	0.00	0.00	2.00	2.50	0.00	0.50
Owens	2.00	1.00	3.00	1.50	2.50	0.50
Pajaro	2.00	0.00	2.67	2.67	2.00	0.67
Pit-McCloud	0.00	0.00	1.50	1.00	0.00	0.50
Russian	0.14	0.00	1.29	1.29	1.71	0.43
Salinas	2.50	1.50	2.00	1.50	2.00	1.00
San Diego	1.00	0.00	1.00	1.00	1.00	1.00
San Luis Rey	1.00	0.00	1.00	1.00	1.00	1.00
Santa Ana	0.45	0.29	0.68	0.86	0.48	0.45
Santa Cruz - San Francisco Coastal	1.75	0.75	1.75	1.50	1.25	0.75
Santa Margarita	0.00	0.00	0.00	0.25	0.00	0.25
Santa Maria	1.00	1.00	1.00	1.00	0.00	0.00
Santa Ynez	1.00	1.00	1.00	1.00	0.00	0.00
Smith	0.00	0.00	3.00	3.00	3.00	1.00
South Bay	1.53	0.24	1.53	1.47	1.41	0.41
Stanislaus	0.33	0.00	0.67	0.67	0.33	0.00
Suisun Bay	1.43	1.00	1.29	1.71	1.00	0.57
Tahoe	1.33	2.00	4.33	4.33	2.00	0.00
Tulare Lakebed	0.00	0.00	1.33	1.33	0.33	0.33
Tule	0.00	0.00	1.50	1.50	1.00	0.50
Tuolumne	0.00	0.00	0.00	0.00	0.00	0.00
Upper Sacramento	0.33	0.50	2.33	1.83	0.83	1.33
Upper San Joaquin	0.50	0.00	2.50	2.50	1.50	0.50

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Ventura	1.33	1.33	1.33	1.00	0.00	1.00
Yuba	1.33	2.00	4.33	4.00	2.67	1.00

Notes: The local hazard mitigation plan (LHMP) summary results are shown for all watersheds. A total of 210 LHMP plans were rated in this Assessment.

Table B-4 Urban Water Management Plan Component Ratings

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
American-Bear	1.00	1.00	2.33	0.33	0.33	0.00
Cache - Putah	0.56	1.00	1.11	0.44	0.11	0.11
Colorado River	0.33	1.17	1.33	0.67	0.67	0.33
Consumnes	2.00	1.00	2.00	0.00	0.00	0.00
Delta	2.00	1.25	1.25	0.75	0.25	0.00
Eel	0.00	1.00	2.00	0.00	0.00	0.00
Feather River	2.00	1.00	1.00	1.00	0.00	0.00
Kaweah	1.00	1.00	1.50	0.50	0.00	0.00
Kern	0.80	1.40	2.00	0.80	0.00	0.00
Kings	0.00	1.00	1.50	0.00	0.00	0.00
Klamath	0.00	1.00	2.00	4.00	0.00	0.00
Los Angeles	1.33	1.02	1.49	1.89	0.55	0.43
Lower San Joaquin	0.92	1.00	1.33	0.58	0.75	0.08
Mad	0.00	1.00	1.20	1.20	0.20	0.00
Lower Sacramento	0.63	1.00	1.38	0.00	0.13	0.00
Middle San Joaquin	0.00	1.25	0.50	0.75	0.75	0.00
Middle Sacramento	1.40	1.60	1.80	1.00	0.20	0.00
Mojave	0.55	1.09	1.82	1.09	0.36	0.18
Mokelumne	1.00	1.00	2.00	2.00	0.00	0.00
North Bay	1.33	1.00	1.22	0.56	0.44	0.67
Owens	0.50	1.00	1.00	0.50	1.00	0.00
Pajaro	1.83	1.50	2.17	1.83	1.33	0.50
Pit-McCloud	0.50	1.00	3.00	1.00	1.00	0.00

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Russian	1.00	1.00	1.83	0.67	0.33	0.00
Salinas	0.75	1.25	1.50	1.25	0.67	0.00
San Diego	0.30	1.00	0.40	0.50	0.20	0.10
San Luis Rey	1.00	1.00	2.22	1.78	0.44	0.11
Santa Ana	0.63	1.00	1.71	1.63	0.54	0.38
Santa Cruz - San Francisco Coastal	2.00	1.00	2.17	1.50	0.17	0.17
Santa Margarita	1.75	1.00	1.50	1.25	0.75	0.75
Santa Maria	0.00	1.00	0.67	0.67	0.67	0.00
Santa Ynez	1.17	1.00	1.33	1.17	0.83	0.33
Smith	0.00	1.00	1.00	0.00	0.00	0.00
South Bay	2.32	1.32	1.68	1.96	0.61	0.61
Stanislaus	0.00	1.00	2.00	1.00	1.00	0.00
Suisun Bay	2.43	1.29	1.86	1.29	0.57	0.43
Tahoe	0.00	1.00	1.67	1.00	0.67	0.00
Tulare Lakebed	0.00	1.00	1.00	0.00	0.00	0.00
Tule	0.00	1.00	1.00	0.50	0.00	0.00
Tuolumne	0.00	1.00	2.00	1.00	1.00	0.00
Upper Sacramento	1.00	1.33	2.67	1.00	0.67	0.00
Ventura	1.40	1.20	2.60	2.00	1.40	1.00
Yuba	1.00	1.50	3.00	0.50	1.00	0.00

Notes: The urban water management plan (UWMP) summary results are shown for all watersheds. A total of 286 UWMP plans were rated in this Assessment.

Table B-5 Integrated Regional Water Management Plan Component Ratings

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Amargosa	2.00	2.00	4.00	3.00	4.00	3.00
American-Bear	5.00	3.00	4.00	3.67	3.67	2.33
Cache - Putah	4.33	1.67	3.00	2.67	1.33	3.67
Coastal Drainages	3.00	1.00	2.00	4.00	2.00	2.00
Colorado River	2.00	0.67	2.33	3.33	2.67	0.67
Consumnes	4.67	2.00	3.33	3.00	3.00	1.67
Delta	4.50	1.00	3.00	2.50	1.50	4.00
Eel	3.50	2.00	2.50	3.50	1.50	2.50
Feather River	3.00	1.00	5.00	4.00	3.00	3.00
Kaweah	3.00	0.67	2.67	3.33	2.33	0.33
Kern	3.00	1.00	3.00	3.50	3.00	1.00
Kings	4.00	1.00	3.00	4.00	3.00	1.00
Klamath	3.00	1.00	2.00	4.00	2.00	2.00
Los Angeles	2.00	2.50	2.00	2.50	3.00	1.50
Lower San Joaquin	2.00	1.17	1.50	3.00	2.83	1.17
Mad	3.00	1.00	2.00	4.00	2.00	2.00
Merced	1.50	0.50	2.00	4.00	3.00	2.00
Lower Sacramento	4.50	2.00	3.25	3.00	2.25	3.00
Middle San Joaquin	2.00	0.80	1.80	3.80	3.00	1.40
Middle Sacramento	4.33	3.00	3.67	3.67	2.67	3.67
Mojave	3.75	0.75	3.25	3.00	3.00	1.00
Mokelumne	4.50	1.50	3.00	2.50	2.00	2.00
North Bay	4.00	1.50	2.00	4.00	2.50	2.00

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
North Lahontan	3.00	1.00	4.00	4.00	4.00	2.00
Owens	2.00	2.00	4.00	3.00	4.00	3.00
Pajaro	4.00	2.50	3.50	3.50	3.50	3.50
Pit-McCloud	2.00	1.00	3.00	2.00	5.00	3.00
Russian	3.00	1.00	2.00	4.00	2.00	2.00
Salinas	4.67	2.67	3.33	3.33	3.67	4.00
San Diego	3.00	2.00	3.00	3.00	3.00	3.00
San Luis Rey	3.00	2.00	3.00	3.00	3.00	3.00
Santa Ana	2.00	3.00	3.00	3.00	3.00	3.00
Santa Cruz - San Francisco Coastal	5.00	3.00	4.00	4.00	3.00	3.00
Santa Margarita	3.67	2.33	3.33	3.00	3.00	3.00
Santa Maria	5.00	2.00	2.00	4.00	3.00	1.00
Santa Ynez	5.00	2.00	2.00	4.00	3.00	1.00
Smith	3.00	1.00	2.00	4.00	2.00	2.00
South Bay	3.50	1.50	2.00	3.50	3.50	1.50
Stanislaus	3.00	2.00	3.00	2.00	3.00	0.00
Suisun Bay	5.00	2.00	2.00	4.00	3.00	2.00
Tahoe	2.50	1.50	3.50	2.50	3.00	4.00
Tulare Lakebed	2.80	0.60	2.60	3.40	2.60	0.80
Tule	3.00	0.80	2.80	3.40	2.20	0.80
Tuolumne	3.00	2.00	3.00	2.00	3.00	0.00
Upper Sacramento	4.00	3.00	3.00	3.00	1.00	3.00
Upper San Joaquin	2.33	0.67	2.00	3.67	3.00	1.00

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Ventura	3.33	1.67	3.33	3.00	3.33	2.33
Yuba	5.00	4.00	4.50	4.50	5.00	2.00

Notes: The integrated regional water management plan (IRWMP) summary results are shown for all watersheds. A total of 48 IRWMP plans were rated in this Assessment.

Table B-6 Reclamation Basin Studies Component Ratings

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
American-Bear	4.00	2.50	3.00	2.50	2.50	0.00
Cache - Putah	4.00	2.50	3.00	2.50	2.50	0.00
Colorado River	1.50	0.00	3.00	2.00	0.50	0.00
Consumnes	4.00	2.50	3.00	2.50	2.50	0.00
Delta	5.00	5.00	5.00	5.00	5.00	0.00
Feather River	5.00	5.00	5.00	5.00	5.00	0.00
Kaweah	5.00	5.00	5.00	5.00	5.00	0.00
Kern	5.00	5.00	5.00	5.00	5.00	0.00
Kings	5.00	5.00	5.00	5.00	5.00	0.00
Klamath	3.00	2.50	5.00	4.00	5.00	0.00
Los Angeles	2.00	0.00	2.00	3.00	1.00	0.00
Lower San Joaquin	5.00	5.00	5.00	5.00	5.00	0.00
Merced	5.00	5.00	5.00	5.00	5.00	0.00
Lower Sacramento	4.00	2.50	3.00	2.50	2.50	0.00
Middle San Joaquin	5.00	5.00	5.00	5.00	5.00	0.00
Middle Sacramento	4.00	2.50	3.00	2.50	2.50	0.00
Mokelumne	5.00	5.00	5.00	5.00	5.00	0.00
Pit-McCloud	5.00	5.00	5.00	5.00	5.00	0.00
San Diego	2.00	0.00	2.00	1.00	2.00	0.00
Santa Ana	1.00	0.00	1.00	3.00	1.00	0.00
Stanislaus	5.00	5.00	5.00	5.00	5.00	0.00
Tahoe	5.00	5.00	5.00	4.00	3.00	0.00
Tulare Lakebed	5.00	5.00	5.00	5.00	5.00	0.00

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Tule	5.00	5.00	5.00	5.00	5.00	0.00
Tuolumne	5.00	5.00	5.00	5.00	5.00	0.00
Upper Sacramento	5.00	5.00	5.00	5.00	5.00	0.00
Upper San Joaquin	5.00	5.00	5.00	5.00	5.00	0.00
Yuba	5.00	5.00	5.00	5.00	5.00	0.00

Notes: The Reclamation Basin Studies summary results are shown for all watersheds. A total of 11 Reclamation Basin plans were rated in this Assessment.

Table B-7 Climate Action/Adaptation Plan Component Ratings

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Amargosa	1.00	0.00	2.00	3.00	1.00	0.00
American-Bear	1.67	1.67	2.67	3.67	4.00	1.00
Cache - Putah	3.00	1.75	1.25	0.75	1.25	0.25
Coastal Drainages	2.50	2.50	2.25	2.25	1.50	0.50
Colorado River	0.00	0.00	1.00	0.00	0.50	0.00
Consumnes	1.67	0.67	2.33	1.67	2.00	0.33
Delta	3.14	2.14	1.57	1.71	1.43	0.57
Eel	1.00	1.00	2.00	0.00	0.00	0.00
Feather River	0.00	0.00	2.00	1.00	0.00	0.00
Kaweah	0.00	0.00	1.00	0.00	0.00	0.00
Kern	0.00	1.00	1.00	0.00	2.00	0.00
Kings	0.00	0.00	2.00	0.00	2.00	0.00
Klamath	0.00	0.00	1.00	0.00	4.00	0.00
Los Angeles	0.50	0.20	0.80	0.70	0.70	0.00
Lower San Joaquin	0.50	0.50	1.50	0.00	1.00	0.17
Mad	0.00	0.00	0.00	0.00	1.00	0.00
Merced	0.00	0.00	2.00	0.00	1.00	1.00
Lower Sacramento	3.00	2.33	2.33	2.33	2.67	0.33
Middle San Joaquin	5.00	3.00	1.00	1.00	2.00	0.00
Middle Sacramento	2.75	1.75	2.00	2.75	2.50	0.75
Mojave	1.00	1.50	0.50	0.00	0.00	0.00
Mokelumne	0.00	0.00	2.00	0.00	1.00	0.00
North Bay	1.70	1.30	1.50	0.70	1.20	0.40

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
North Lahontan	0.00	0.00	2.00	0.00	1.00	0.00
Owens	0.50	0.00	1.00	1.00	0.50	0.00
Pajaro	2.00	1.00	3.00	2.00	1.00	0.00
Pit-McCloud	0.00	0.00	2.00	0.00	1.00	0.00
Russian	3.67	3.33	2.67	2.33	2.33	0.67
Salinas	0.75	2.00	1.00	0.33	1.00	0.00
San Diego	2.00	3.00	3.00	4.00	2.00	0.00
San Luis Rey	0.33	0.00	0.33	0.00	0.33	0.00
Santa Ana	0.43	0.14	0.64	0.14	0.14	0.29
Santa Cruz - San Francisco Coastal	0.67	0.33	1.67	1.00	1.33	0.67
Santa Margarita	0.00	0.00	2.00	0.00	0.00	0.00
Santa Maria	1.00	2.00	2.00	0.00	1.00	1.00
Santa Ynez	2.00	2.00	2.50	1.50	2.00	1.00
Smith	0.00	0.00	0.00	0.00	0.00	0.00
South Bay	0.74	0.67	1.19	0.69	0.85	0.37
Stanislaus	0.00	0.00	2.00	0.00	1.00	0.00
Suisun Bay	2.80	1.20	2.00	1.80	2.00	0.20
Tahoe	0.00	0.00	3.00	2.00	0.00	0.00
Tulare Lakebed	2.00	2.00	1.00	0.00	1.00	0.00
Tule	0.00	0.00	2.00	0.00	2.00	0.00
Tuolumne	0.00	0.00	2.00	0.00	1.00	0.00
Upper Sacramento	0.33	0.00	2.00	0.00	0.67	0.00
Upper San Joaquin	0.00	0.00	0.00	2.00	0.00	0.00

Watershed	Average of Collaboration Rating	Average of Staffing Rating	Average of Impacts Rating	Average of Vulnerability Rating	Average of Strategies Rating	Average of Funding Rating
Ventura	1.00	0.00	0.67	0.00	0.00	0.67
Yuba	1.00	0.00	2.00	5.00	3.00	1.00

Notes: The climate action/adaptation summary results are shown for all watersheds. A total of 155 plans were climate action/adaptation rated in this Assessment.

DEPARTMENT OF WATER RESOURCES • STATE OF CALIFORNIA •