Climate Resilience Perspectives in the Upper San Joaquin River Region

Upper San Joaquin River

Regional Flood Management Planning

Draft April 2023

Upper San Joaquin River Regional Flood Management Plan

San Joaquin River

Flood Control Project Agency

Executive Summary

California's Central Valley is susceptible to floods and other extreme meteorological and hydrological events. This white paper identifies and assesses the projected impacts of these events and associated vulnerabilities under future climate conditions in the Upper San Joaquin River (USJR) Region. The following evaluation provides a high-level assessment of impacts to existing flood infrastructure, and it examines in-progress and proposed regional flood management projects that contributed to improved flood protection and climate resilience. Review of these existing conditions provides the basis for understanding the capacity of the USJR flood management system and its capability to adapt to and recover from changing conditions. This evaluation goes on to identify data gaps and potential areas of future study, and it concludes with recommendations for improving flood protection and climate resilience in the Region.

Projected climate trends for the USJR region and surrounding watersheds were assessed for changes to parameters of air temperature, precipitation, and hydrological responses for near-term (2042) conditions. Late-term (2072) conditions for the USJR Region were also considered based on analysis results from the 2022 Central Valley Flood Protection Plan (CVFPP) Update. In general, air temperatures are projected to increase in the near term and the late term, with higher magnitudes of warming anticipated toward the end of the century. Projected changes to annual precipitation patterns vary under future conditions, but extreme precipitation events are anticipated to increase in magnitude by up to 34% and 68% for near-term and late-term conditions, respectively. These changes will likely result in atmospheric river (AR) events that are much more severe than those recently experienced in late 2022 and early 2023. Warmer temperatures are projected to result in more precipitation falling as rain rather than snow at higher elevations in the Upper San Joaquin and Upper Merced watersheds, reducing snowpack accumulation and shifting snowmelt to earlier in the season. Consequently, peak runoff volumes are anticipated to increase in the wet season. To accommodate additional inflows to major reservoirs in the region, such Millerton Lake, greater reservoir releases and pre-releases are expected, further increasing regulated flows and stage throughout the downstream locations of USJR Region.

Risks and vulnerabilities associated with projected climatological and hydrological conditions were assessed for the Upper San Joaquin's upper watersheds, major reservoirs, rivers and floodplains, channels and levees, groundwater, and ecosystems. Risks and vulnerabilities are likely to propagate from headwaters to downstream regions as higher flows occur earlier in the season. In general, flood risks are projected to increase under changing climate conditions, particularly in river reaches and communities in and downstream of the historically snowpack-dominated Upper San Joaquin watershed. Higher flows and current 100-year equivalent flows are likely to become more frequent under future conditions, and many components of the flood control system in the region already struggle or fail to convey existing flood flows at levels less than 50-year events. This means that it is vital to protect the USJR region from existing and future more extreme flood events through several approaches: (1) Increasing the level of flood

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protection to align with current guidelines for urban areas and other disadvantaged communities, (2) addressing existing levee deficiencies, (3) funding O&M promoting proper upkeep of the flood management system, and (4) restoring lost capacity through sediment and vegetation removal.

Water supplies, both from surface sources and groundwater, are anticipated to experience additional shortages, presenting challenges to the attainment of groundwater sustainability plans and agricultural productivity in the region. Ecosystems, particularly those with vulnerable habitats and species reliant on seasonal water availability, are also likely to experience significant degradation as a consequence of increased temperatures and decreased surface water availability in summer months. However, the increased frequency of flood events in the region may provide valuable opportunities for floodplain inundation, habitat restoration, and groundwater recharge.

Regional Flood Management Plan (RFMP) projects identified in the 2015 USJR RFMP and 2021 Regional Priorities White Paper are presented to highlight key existing and proposed efforts that contribute to increased flood protection and climate resilience in the region (San Joaquin River Flood Control Project Agency 2015 and 2021). Considering these ongoing efforts, data gaps identified through the evaluation of future conditions and risks, further studies highlighted in this white paper, and regional priorities, recommendations for local, State, and federal agencies to improve flood protection and climate resilience USJR Region were developed. The following summary list provides an overview of the recommendations described at the end of this white paper:

- Implement forecast-informed reservoir operations and forecast-coordinated operations.
- Increase storage and implement adaptive reservoir rule curves in major reservoirs upstream of the USJR region.
- Improve and streamline climatological and hydrological modeling, particularly in upper watersheds of the USJR region.
- Promote improvements to the existing flood management system and climate resiliency.
- Implement long-lead flood forecasting to increase warning times in downstream areas.
- Integrate extreme weather risk with emergency response and local hazard mitigation plans.
- Improve sediment and post-fire debris management in areas upstream of the USJR Region flood management system.
- Increase adaptive storage capacity in floodplains to promote floodplain inundation, ecosystem restoration, and groundwater recharge.
- Identify opportunities to implement nature-based resilience measures alongside flood protection improvements to the existing flood management system.

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- Increase and improve areas of floodplain inundation in major river reaches and transient storage areas, and allow rivers to meander and more closely approximate natural flow regimes.
- Protect existing floodplain agricultural land and improve O&M of sloughs, creeks, and canals in support of flood conveyance, water quality, and groundwater recharge.
- Promote actions that restore geomorphic functions, increase the quantity and quality of floodplain habitats, and improve conditions for native species.
- Continue to identify and promote funding and grant opportunities that support flood protection and resiliency.

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Appendix A. Additional Climate Action and Climate Adaptation Planning Efforts

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Acronyms and Abbreviations

AEP	annual exceedance probability
AR	atmospheric river
cfs	cubic feet per second
CMIP5	Coupled Model Intercomparison Project Phase 5
CVFPP	Central Valley Flood Protection Plan
CVP	Central Valley Project
DAC	disadvantaged community
DWR	California Department of Water Resources
ET	evapotranspiration
FCO	forecast-coordinated operations
FIRO	forecast-informed reservoir operations
Flood-MAR	using flood waters for managed aquifer recharge
GCM	general circulation model
GSA	groundwater sustainability agency
GSP	groundwater sustainability plan
GVGSP	Great Valley Grassland State Park
LMA	local maintaining agency

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MID	Merced Irrigation District
NWR	National Wildlife Refuge
O&M	operations and maintenance
RCP	representative concentration pathway
RFMP	regional flood management plan
RVA	reservoir vulnerability analysis
SCADA	supervisory control and data acquisition
SGMA	Sustainable Groundwater Management Act
SSIA	State Systemwide Investment Approach
State	State of California
SWE	snow water equivalent
USJR	Upper San Joaquin River

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Introduction

This white paper provides context for historical climate trends, highlights projected changes to these trends, and identifies flood-related vulnerabilities and risks (the level of exposure to a given event or variable) in the Upper San Joaquin River (USJR) Region. This analysis also compiles priority in-progress and proposed USJR regional flood management plan (RFMP) projects that contribute to improved flood protection and climate resilience (i.e., the capacity for the USJR flood management system to adapt to and recover from changing conditions). Data gaps are identified, and additional studies and approaches are recommended to further enhance flood protection and climate resilience in the USJR Region. The structure of this white paper is as follows:

- Introduction: Provides the white paper's purpose, regional context for the Upper San Joaquin River region, and related State climate efforts.
- Projected Climate Trends: Outlines projected changes in temperature, precipitation, and hydrological responses to assess future flood events.
- Existing System Vulnerabilities and Risks: Identifies potential vulnerabilities and risks under existing and future conditions in the Upper San Joaquin River region.
- Overview of USJR RFMP Projects: Examines the list of existing and proposed regional flood management plan projects from the Upper San Joaquin River region to identify projects that contribute to increased flood protection and climate resilience.
- Data Gaps and Further Studies: Highlights existing data gaps and identifies needed further studies.
- Recommendations: Outlines actions needed to improve flood protection and climate resilience in the Upper San Joaquin Region under existing and future climate conditions.

Regional Context

The San Joaquin River watershed is located south of the Sacramento River watershed and north of the Tulare Lake watershed. It is bordered on the east by the Sierra Nevada mountains and on the west by the coastal mountains of the Diablo Range. The drainage area extends south from the southern boundaries of the Delta to include the headwaters of the San Joaquin River in Madera County and its southern drainage in Fresno County. The region is hydrologically separated from the Tulare Lake watershed by a low broad ridge that extends across the San Joaquin Valley between the San Joaquin and Kings rivers. The San Joaquin River has a historical average annual unimpaired runoff of approximately 3.2 million acre-feet, and it drains about 32,000 square miles of watershed. Major tributaries include the Calaveras, Stanislaus, Tuolumne, and Merced rivers.

At approximately 300 miles long, the San Joaquin River is one of California's longest rivers. The headwaters of the San Joaquin River begin near the 14,000-foot crest of the Sierra Nevada and

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turns northwestward on the valley floor toward the Delta, where it meets the Sacramento River.

The USJR region (Figure 1-1) covers approximately 660 square miles of the San Joaquin Valley. The region is home to some of the most productive agricultural land in California and accounts for a large portion of the state’s economy. The local economy is dependent on maintaining the quality and productivity of the region’s agriculture. The USJR region also includes a variety of habitats supporting fish and wildlife species and it includes large areas of managed wildlife refuges. Just over one-third of the region (145,000 acres) is native vegetation or riparian habitat with contiguous wetland complexes that support more than 550 identified species of birds, animals, and plants. The USJR region has promoted the recognition and consideration of natural environment and agriculture benefits when evaluating potential improvements to the flood management system (San Joaquin River Flood Control Project Agency 2015).

The region includes a diverse set of stakeholder groups that includes counties, cities, small communities, local maintaining agencies (LMAs), nongovernmental entities, landowners, wildlife refuges, and State of California (State) and federal agencies. Almost all the communities (more than 10) in the Region are considered disadvantaged communities (DACs), based on income level, and require significant financial support. The major cities within the Region include the cities of Firebaugh, Mendota, Dos Palos, Merced, and Los Banos. No known tribal lands are located within the Region (San Joaquin River Flood Control Project Agency 2015).

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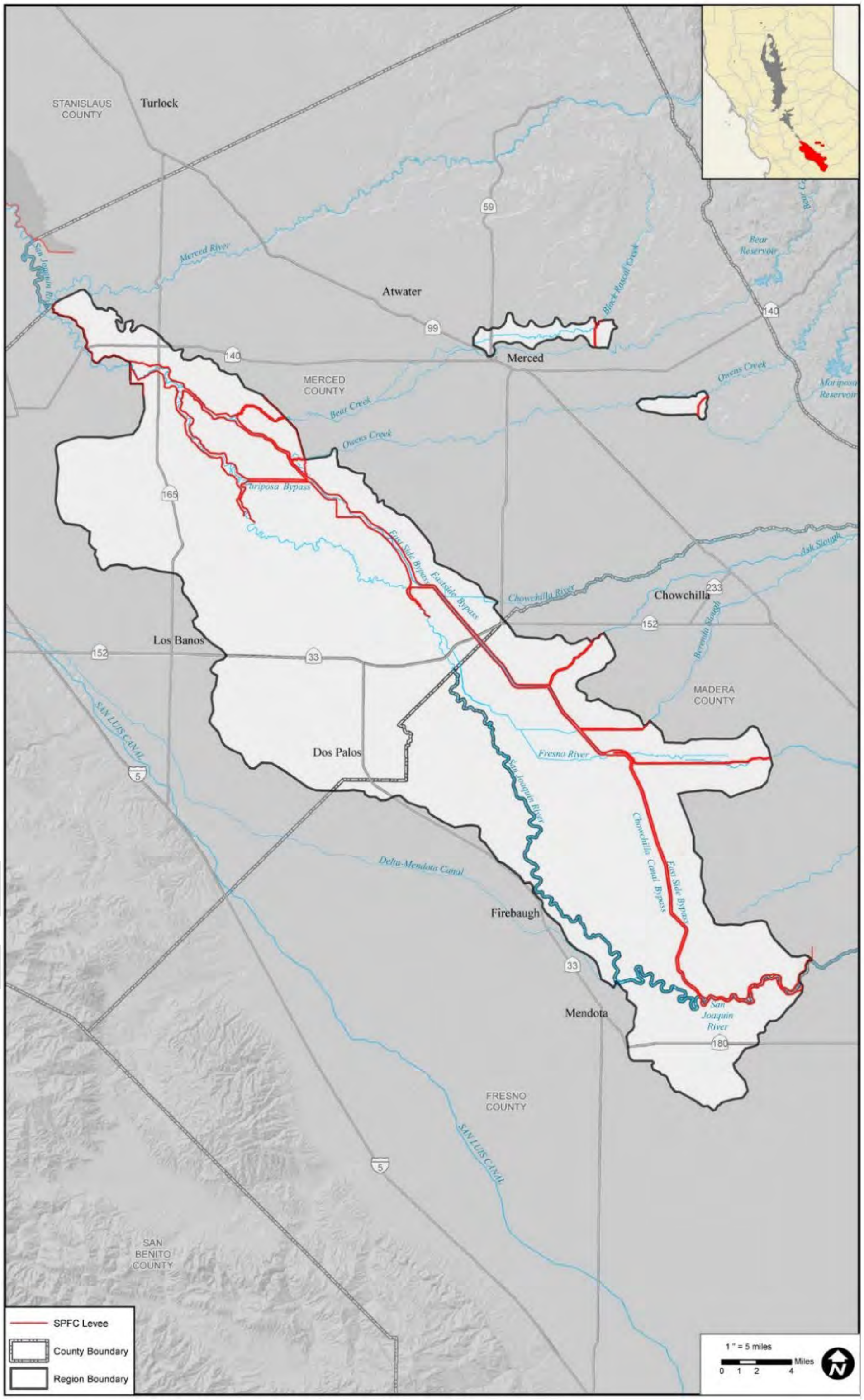
Figure 1-1. Upper San Joaquin River Regional Flood Management Planning Area



Source: San Joaquin River Flood Control Project Agency 2015

Related Climate Efforts

California’s Central Valley is susceptible to floods, droughts, wildfires, and other extreme meteorological and hydrological events. This section summarizes climate action and climate adaptation planning that the California Department of Water Resources (DWR) and other State agencies have engaged in to-date. Although many of these efforts are broader than the extent of the USJR RFMP, their resources, findings, and approaches may be relevant to future flood-related studies and flood protection projects in the region.

Additional details on other climate-related efforts, including those from local and regional agencies and entities, are provided in Appendix A, Additional Climate Action and Climate Adaptation Planning Efforts. Appendix A includes details on mitigation planning, adaptation planning, vulnerability and risk, and adaptation strategies identified in Integrated Regional Water Management (IRWM) planning regions, local hazard mitigation plans, local and regional climate adaptation plans, and groundwater sustainability plans (GSPs) of relevance in the USJR region.

Climate Action and Climate Adaptation Planning

Central Valley Flood Protection Plan

The Central Valley Flood Protection Plan (CVFPP) is the State’s blueprint for improving flood risk management in California's Central Valley. First released in 2012, following the Central Valley Flood Protection Act of 2008, the CVFPP is updated every 5 years. The 2022 CVFPP Update marks the 10th anniversary of the CVFPP and highlights three main themes: climate resilience; project implementation, accomplishments, and performance tracking; and alignment with other State efforts (California Department of Water Resources 2022d).

Climate Change Adaptation for the Conservation Strategy 2022 Update

The *Conservation Strategy 2022 Update* utilizes climate modeling analyses that have been developed for the 2022 CVFPP Update to estimate potential ecosystem responses for physical processes, habitats, species, and stressors identified in the Conservation Strategy. Risks and vulnerabilities under future climate conditions are identified, and adaptation strategies that focus on building system resiliency by restoring critical landscape-level hydrologic, geomorphic and ecological processes are recommended. Additional details are provided in Appendix H of the *Conservation Strategy 2022 Update* (California Department of Water Resources 2022f).

Reservoir Vulnerability Analysis

The reservoir vulnerability analysis (RVA) for the 2022 CVFPP Update builds on the Reservoir Climate Vulnerability and Adaptation pilot study conducted for the 2017 CVFPP Update and examines reservoir vulnerabilities under future climate conditions (California Department of Water Resources 2017). The RVA aims to determine the quantity of increased flood runoff volume under various climate projections, identify impacts to reservoir operations and downstream flood management systems, and develop possible mitigation responses (California Department of Water Resources 2022c).

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Merced River Basin Flood-MAR Reconnaissance Study

The concept of using flood waters for managed aquifer recharge (Flood-MAR) at the watershed scale was the basis for the proof-of-concept Merced River Basin Flood-MAR Reconnaissance Study. This study integrated surface and groundwater models in the Merced River watershed, and analyses are aimed to serve as a template for future studies (California Department of Water Resources 2020a).

State of California Climate Action and Climate Adaptation Planning

2021 California Climate Adaptation Strategy

The 2021 California Climate Adaptation Strategy outlines adaptation efforts through the following six climate resilience priorities:

- Strengthen flood protections for climate vulnerable communities.
- Bolster public health and safety to protect against increasing climate risks.
- Build a climate-resilient economy.
- Accelerate nature-based climate solutions.
- Strengthen climate resilience of natural systems, make decisions based on the best available climate science.
- Partner and collaborate to leverage resources.

Within each priority, a set of goals are highlighted as well as relevant planned or existing actions. Information in this update is presented through an interactive website rather than a formal document to make the information more accessible, promote understanding of current climate resilience actions, and provide prompt updates to existing information (California Natural Resources Agency 2022).

California Department of Water Resources Climate Action Plan

The Climate Action Plan serves as a guide to combating the effects of climate change within the jurisdiction of DWR. The plan is separated into three phases: greenhouse gas emissions reduction plan, climate change analysis guidance, and climate change vulnerability assessment and adaptation plan (California Department of Water Resources 2018b).

California Water Resilience Portfolio

The California Water Resilience Portfolio (WRP) contains recommended goals and actions for local and regional bodies to address water challenges throughout the state. These are divided into four main categories: maintain and diversify water supplies, protect and enhance natural ecosystems, build connections, and be prepared. The portfolio is a byproduct of Governor Newsom's Executive Order N-10-19 and was created with the following seven key principles in mind (California Department of Water Resources 2020b):

- Prioritize multi-benefit approaches that meet several needs at once.
- Use natural infrastructure such as forests and floodplains.

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- Embrace innovation and new technologies.
- Encourage regional approaches among water users sharing watersheds.
- Incorporate successful approaches from other parts of the world.
- Integrate investments, policies, and programs across State government.
- Strengthen partnerships with local, federal and tribal governments, water agencies and irrigation districts, and other stakeholders.

WRP Action 25.4 specifically seeks to “update and refine the regional flood management strategy in the Central Valley Flood Protection Plan to account for the projected impacts of climate change in order to protect vulnerable communities and infrastructure and restore floodplains along the San Joaquin River and its tributaries” (California Department of Water Resources 2020b). USJR RFMP staff have participated in the work groups to develop draft action plans for a number of topics critical to the region including subsidence, transitory storage, flood plain recharge, and modification of SPFC facilities. The 2021 Progress Report on WRP actions indicates that “DWR and the Flood Board are pursuing a San Joaquin basin regional flood strategy based on cutting-edge climate science that will consider traditional and non-traditional flood management strategies suited to the unique flood risks of the San Joaquin basin” (California Department of Water Resources 2021).

California Water Plan

The California Water Plan outlines current and future water use demands under expected climate conditions and provides guidance on managing and developing the state's water resources in a sustainable manner. The Plan is required under California Water Code Section 10005(a) and is updated every five years (California Department of Water Resources 2018a). The California Water Plan Update 2023 is in development, and the recent flood management strategy developed for WRP Action 25.4 will be included in this effort.

California’s Fourth Climate Change Assessment

California's Fourth Climate Change Assessment identifies key vulnerabilities all Californians face as a result of climate change and provides guidance for actions that can improve resiliency. The assessment informs a number of State guidelines, programs, policies, and plans that aim to promote resiliency in California (California Natural Resources Agency 2018).

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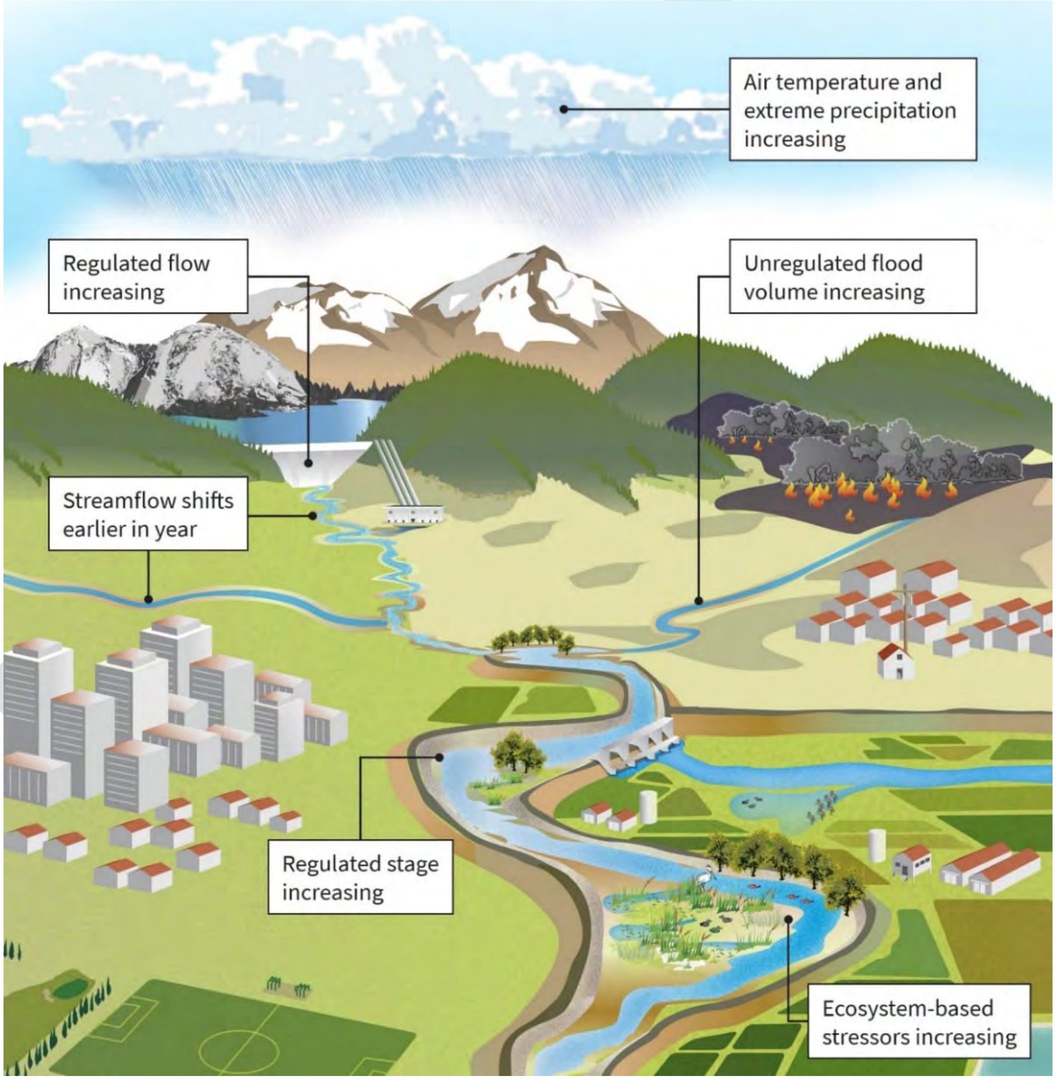
Projected Climate Trends

This section presents the projected changes to the hydrometeorological data in and near the USJR region. Figure 2-1 displays a general overview of projected climate trends and their effects in California's Central Valley regions.

Figure 2-1. Projected Climate Change Impacts on Watersheds of the Central Valley

The Upper San Joaquin River Region and downstream locations can anticipate these changes.



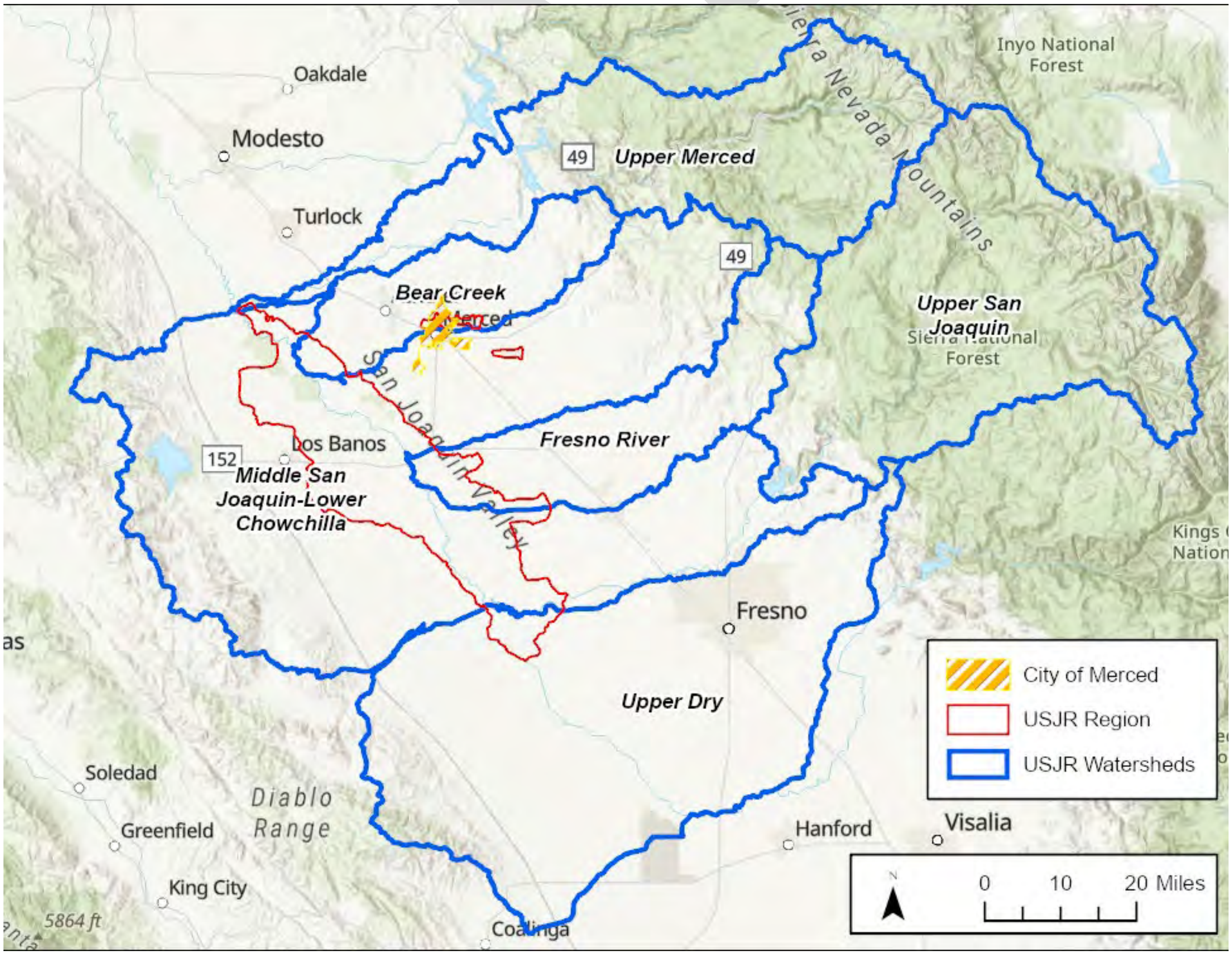
Source: Modified from California Department of Resources 2022d

Summary of Climate and Hydrology Scenarios

Projected changes to climate variables were assessed for near term (2042) and late term (2072) conditions. Near-term projections utilize climate information for the USJR RFMP boundary as well as relevant watershed areas around the Region (Figure 2-2). Late-term projections utilize 50-year climate and hydrology scenarios developed for the 2022 CVFPP Update to assess future conditions under climate change in the San Joaquin River Basin.

Included results highlight projected changes to climate variables for the USJR RFMP specifically. Climate scenarios were used to analyze changes in temperature and precipitation and drive the assessment of future snowpack, runoff, and other hydrologic factors. Hydrology scenarios consider a range of factors, such as projected population changes and future project implementation, to evaluate the flood management system under future conditions. Additional information on the development of these scenarios is available in Appendix A of the 2022 CVFPP Update Technical Analyses Summary Report (California Department of Water Resources 2022a)

Figure 2-2. Watersheds Assessed to Examine Projected 2042 Conditions



Near-term Climate Projections

Future climate projections for near-term (2042) conditions utilize climate model simulations from the model developed by Intergovernmental Panel on Climate Change called the Coupled Model Intercomparison Project Phase 5 (CMIP5). Twenty climate model projections were downscaled using the localized constructed analogs method (Pierce et al. 2014) from 10 CMIP5 general circulation models (GCMs) and two emissions scenarios, or representative concentration pathways (RCPs; RCP4.5 and RCP8.5). Near-term annual projections consider the 10th percentile, median, and 90th percentile changes for each area assessed and are intended to provide greater insight into future conditions within the next 20 years for a variety of locations. Variables that analyze changes at the monthly scale consider only the median change. No near-term scenarios or projections were available from 2022 CVFPP Update information.

Late-term Climate Projections

Climate scenarios for late-term (2072) conditions used in the 2022 CVFPP Update were developed using 64 climate model projections that were downscaled using the localized constructed analogs method (Pierce et al. 2014) from 32 CMIP5 general circulation models and RCP4.5 and RCP8.5.

Three statistically representative climate scenarios for low (drier, less warming), medium, and high (wetter, more warming) climate conditions were constructed based on the ensemble-informed climate scenarios method. Additional information on the approach used for the 2022 CVFPP Update climate analysis is included in the 2022 CVFPP Update Technical Analyses Summary Report and accompanying appendices (California Department of Water Resources 2022e).

These climate scenarios were used as inputs to hydrologic models for simulating future hydrologic conditions. Future impacts of climate change on the flood management system were examined by considering existing conditions of the system, future population change, and land use changes.

Summary of 2042 and 2072 Conditions

Table 2-1 provides a summary of projected changes to individual hydrometeorological variables under 2042 and 2072 conditions. Additional details on both historical and projected climate trends in the USJR region are provided in *Appendix B, Supplemental Climate Information*.

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Table 2-1. Summary of Projected Climate Trends

Climate Variable	Projected 2042 Conditions (USJR and Surrounding Watersheds)	Projected 2072 Conditions (2022 CVFPP Update Climate Scenarios)
Mean Annual Temperature	Increase of 1.4 to 2.4 degrees Celsius (minimum temperatures) Increase of 1.6 to 3.0 degrees Celsius (maximum temperatures)	Increase of 2.0 to 3.9 degrees Celsius
Extreme Temperature[a]	Increase of 10.2 to 36.2 annual days exceeding a temperature of 39.4 degrees Celsius (roughly 103 degrees Fahrenheit)	Increase of 24.1 to 51.6 annual days exceeding a temperature of 39.4 degrees Celsius (roughly 103 degrees Fahrenheit)
Mean Monthly Temperature	Largest increases in late summer and early autumn months, and smallest increases in early spring	Smallest and largest increases in mean monthly temperature in March and September, respectively
Mean Annual Precipitation	• 10th percentile: 1.2-inch to 3.8-inches decrease • Median: 0.2-inch decrease to 0.3-inch increase • 90th percentile: 1.3-inch to 4.3-inches increase	• Low scenario: 0.8-inch decrease • Medium scenario: 0.3-inch decrease • High scenario: 1.4-inches increase
Extreme Precipitation (99th Percentile)[a]	Increased magnitude of 23.0 to 33.8%	Increased magnitude of 25.3 to 65.5%
Mean Monthly Precipitation	Magnitude of change varies by watershed; peak increases (up to 0.8-inch) in January and peak decreases (up to-0.4 inch) in May	• Low scenario: 0.1-inch to 0.2-inch decrease across winter and spring months • Medium scenario: 0.2-inch increase in January and February • High scenario: 0.2-inch to 0.7-inch increase from December to March
Snowpack[a]	Reduced April 1 snow water equivalent (32 to 6% decrease) due to warmer temperatures causing snow to melt earlier in the year.	Reduced snowpack due to increased temperatures and more precipitation falling as rain rather than snow. Earlier spring snowmelt is also anticipated.
Runoff	Increased mean runoff in winter months, particularly in the Upper San Joaquin (up to 52% increase) and Upper Merced (up to 28% increase) watersheds, due to earlier spring snowmelt and more precipitation falling as rain rather than snow. Total mean annual runoff decreases slightly (up to 5%) for most locations.	Increased runoff volumes in winter months due to earlier spring snowmelt and more precipitation falling as rain rather than snow.
Regulated Hydrology	Not assessed.	Flood flows for 100-year events are projected to increase by up to 500% under the high climate change scenario near the Chowchilla Bifurcation Structure. The magnitude of projected changes varies by location, with most locations in the USJR region expected to experience up to a 50% increase in regulated flows under all future climate scenarios.

Note: [a] Additional discussion on projected changes under 2042 and 2072 conditions is included in Appendix B.

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Changes in Air Temperature

Warmer ambient air temperatures in the USJR region and surrounding watersheds are projected under both 2042 and 2072 conditions. Mean annual minimum and maximum temperatures for 2042 are projected to increase between 1.4 to 2.4 degrees Celsius (Figure 2-3) and 1.6 to 3.0 degrees Celsius (Figure 2-4), respectively. Mean annual temperatures for 2072 (Figure 2-5) are projected to increase between 2.0 to 3.9 degrees Celsius depending on climate scenario. Warmer temperatures are expected to reduce soil moisture and increase rates of evapotranspiration (ET), particularly under periods of sustained drought. Higher mean annual temperatures may also promote the prevalence of wildfire conditions and use of groundwater resources, particularly in years with below-average precipitation.

Figure 2-3. Projected Changes in Mean Annual Minimum Air Temperature by 2042

USJR Region and surrounding watersheds

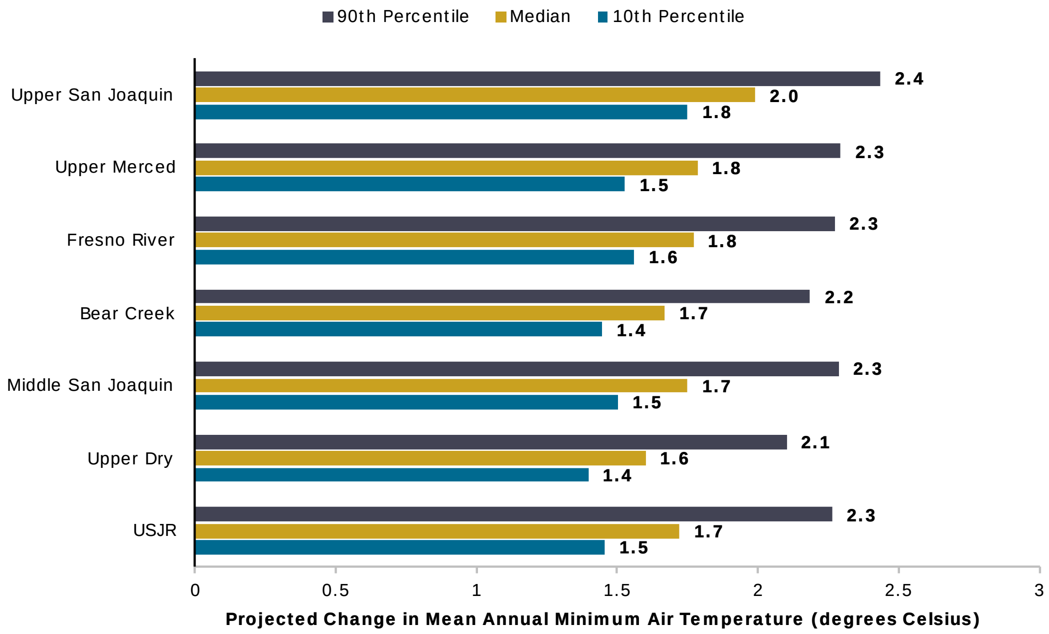


Figure 2-4. Projected Change in Mean Annual Maximum Air Temperature by 2042

USJR Region and surrounding watersheds

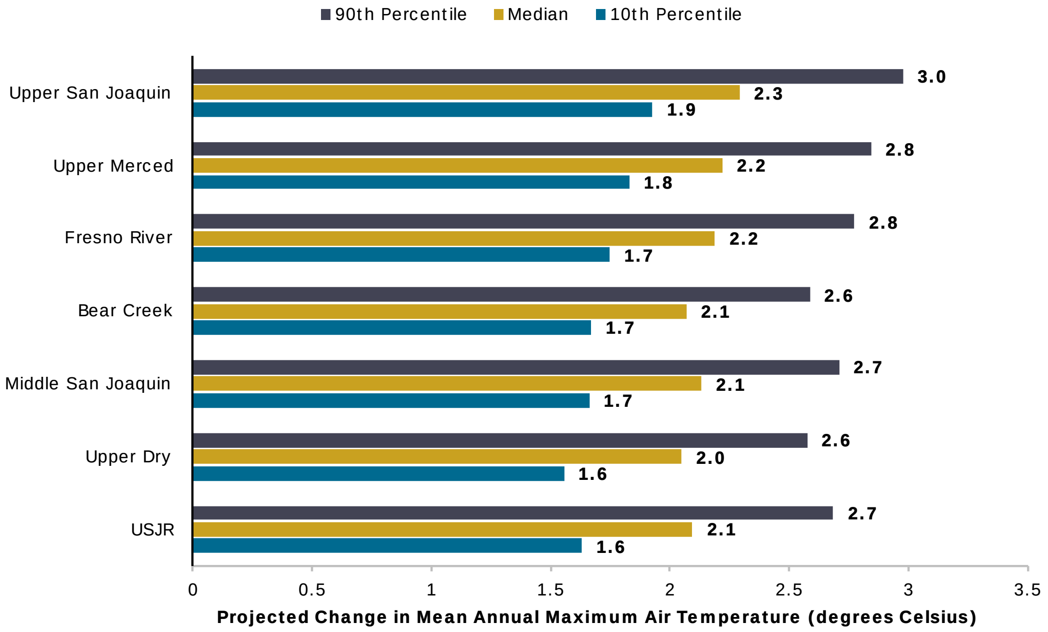
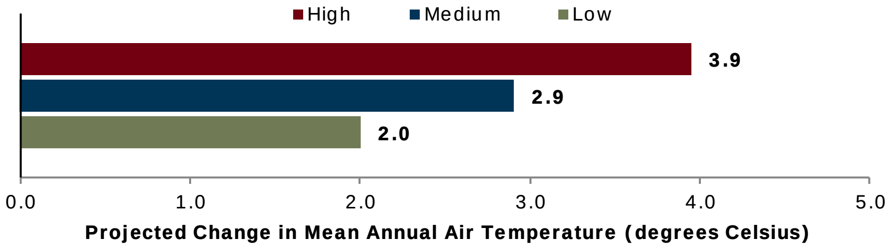


Figure 2-5. Projected Change in Mean Annual Air Temperature by 2072

USJR Region under the low, medium, and high climate scenarios



Source: Adapted from California Department of Water Resources 2022g

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At the monthly scale, mean minimum (Figure 2-6) and maximum (Figure 2-7) air temperatures under 2042 conditions in the USJR region and surrounding watersheds show a peak increase of between 2.5 to 3 degrees Celsius in August. The Upper San Joaquin watershed shows the largest change in temperature compared to other assessed watersheds. For 2072 conditions, changes in mean temperature (Figure 2-8) peaks for the high and medium climate scenarios are projected for September and August for the low climate scenario.

Figure 2-6. Projected Change in Mean Monthly Minimum Air Temperature by 2042

USJR Region and surrounding watersheds

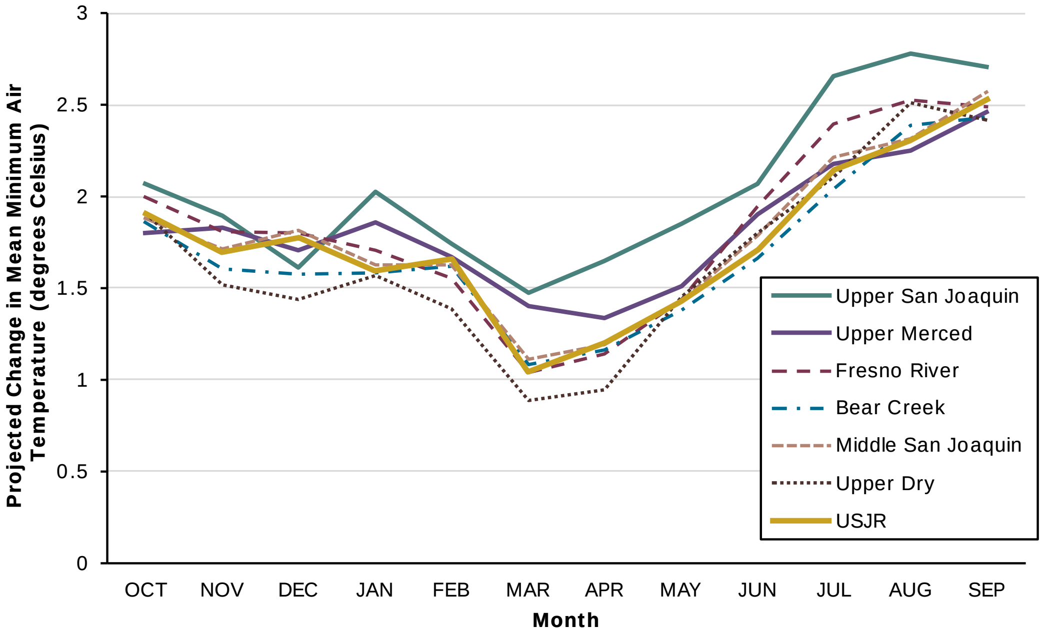

Figure 2-7. Projected Change in Mean Monthly Maximum Air Temperature by 2042

USJR Region and surrounding watersheds

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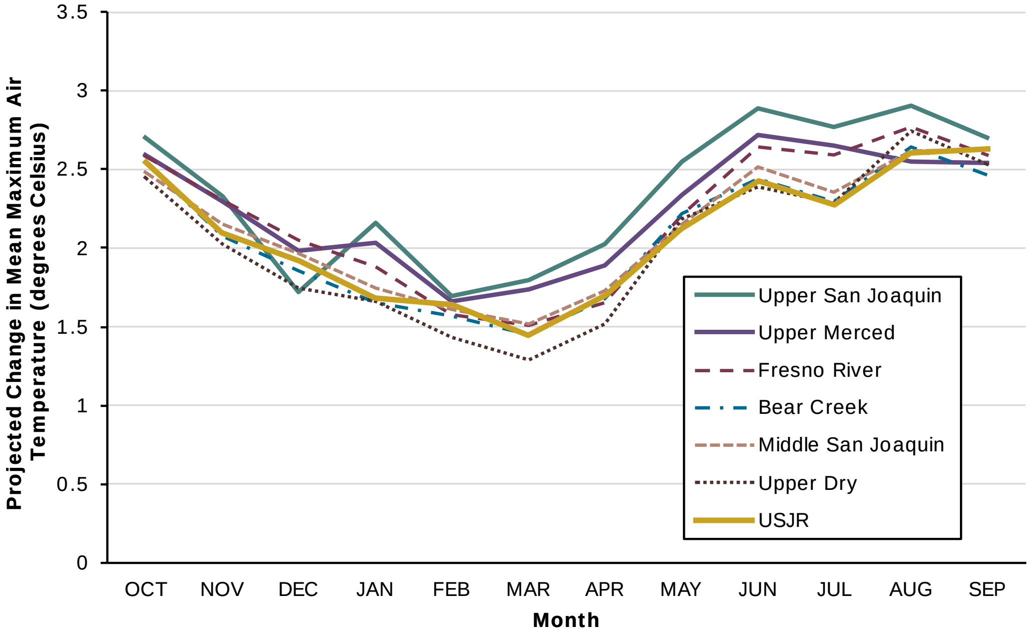
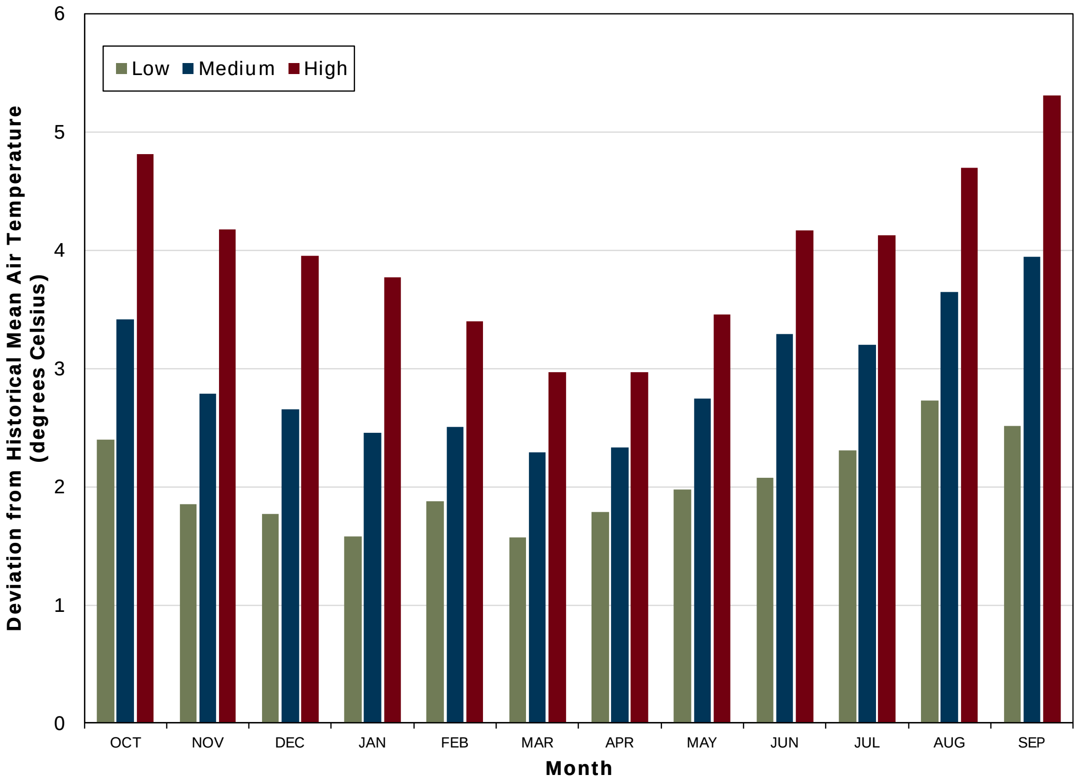


Figure 2-8. Projected Change in Mean Monthly Air Temperature by 2072

USJR Region under the low, medium, and high climate scenarios



Source: Adapted from California Department of Water Resources 2022g

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Changes in Precipitation

Projected changes in mean annual precipitation vary greatly depending on the metric (e.g., median versus 90th percentile) and scenario used. Figures 2-9 and 2-10 present the projected change in mean annual precipitation under 2042 and 2072 conditions, respectively. In the near term, mean annual precipitation trends vary depending on watershed, with most locations showing relatively no change. Tenth and 90th percentile changes for 2042 show a decrease of between 1.2 to 3.8 inches and an increase of between 1.3 to 4.3 inches, respectively. For 2072 conditions under the low and medium climate scenarios, a decrease between 0.3 to 0.8 inch in mean annual precipitation is projected; however, under the high climate scenario, a 1.4-inch increase is projected. Ultimately, the range of projected changes to mean annual precipitation is relatively small, particularly for watersheds at lower elevations. Differences between projected changes show the variability in assessment of precipitation under 2042 conditions across the 20 climate models used. This is similar to the characterization of the 2072 scenarios: warmer and wetter models (i.e., those showing an increase in annual precipitation) are more representative of the high climate scenario and drier and less warm models (i.e., those showing a decrease in annual precipitation) are captured in the low scenario. Higher elevation watersheds display a greater range of changes between 10th and 90th percentiles due to the greater prevalence of precipitation at these locations.

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Figure 2-9. Projected Change in Mean Annual Precipitation by 2042

USJR Region and surrounding watersheds

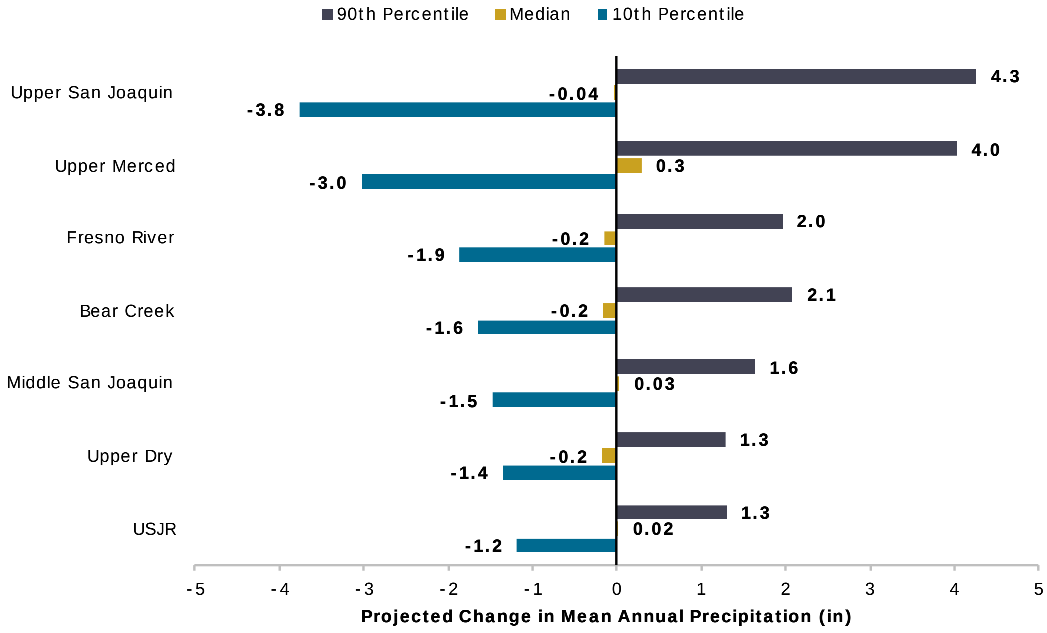
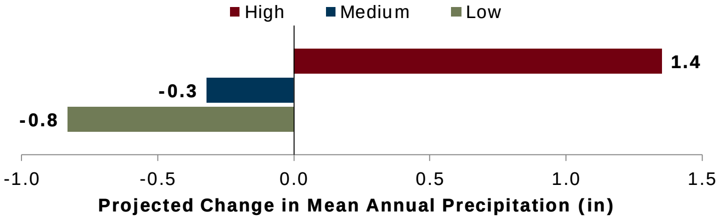


Figure 2-10. Projected Change in Mean Annual Precipitation by 2072

USJR Region under the low, medium, and high climate scenarios



Source: Adapted from California Department of Water Resources 2022g

Figures 2-11 and 2-12 highlight the change in average monthly precipitation under 2042 and 2072 conditions, respectively. During wetter months (December through February) in the near term, most locations show a relative increase in average precipitation, with upper watersheds showing the greatest projected change. These increases in winter months are immediately followed by decreases in average precipitation in the late spring to early summer. The Upper Merced and Upper San Joaquin watersheds show the most dramatic change from historical conditions, with an average increase of 0.6 to 0.8 inch in January and an average decrease of 0.3 to 0.5 inch in May. These changes are related to the higher elevation of these watersheds and the greater prevalence of precipitation events. However, for all locations, increases in winter months are offset by decreases in the late spring and early summer, resulting in a relatively minor change to mean annual precipitation (as shown for the median in Figure 2-9).

For 2072, the high and medium scenarios show the greatest increases in mean precipitation from historical conditions during wetter months, while the low scenario shows reductions during this period. The high and low scenarios are composed of “wetter” and “drier” climate models, respectively. Trends for the medium scenario generally follow those presented for the USJR area in the near term. In addition, most scenarios show a decrease in monthly mean precipitation from April to June and from October to November. For the medium scenario, this suggests both an overall decrease in mean annual precipitation (as shown in Figure 2-10) and more condensed precipitation events in winter months. With the high climate change scenario, the precipitation extremes in the winter months make up for the loss of precipitation at other points throughout the year to result in a net increase to annual precipitation.

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Figure 2-11. Projected Change in Mean Monthly Precipitation by 2042

USJR Region and surrounding watersheds

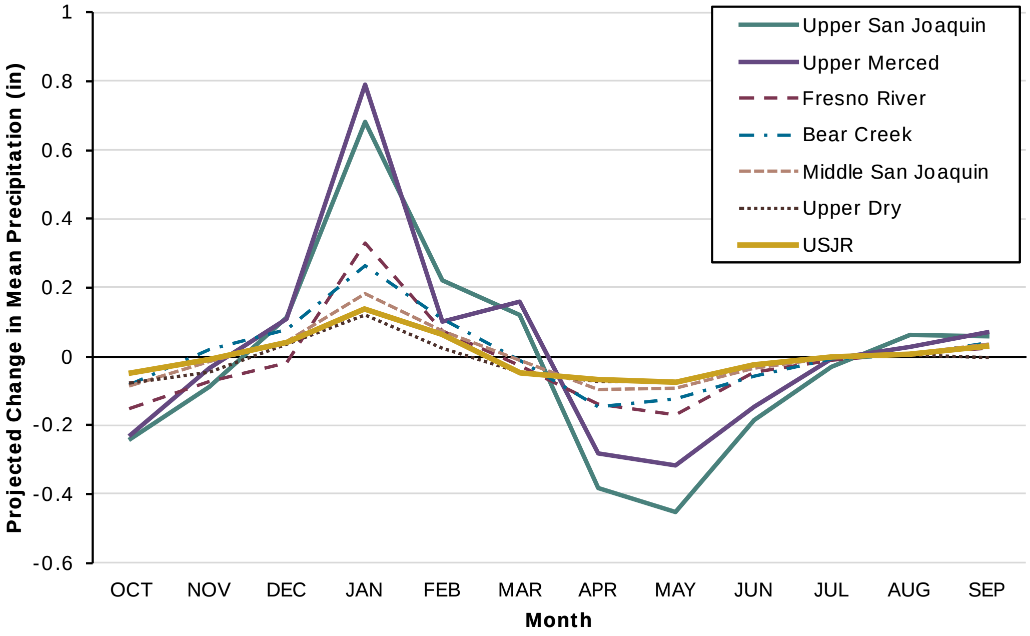
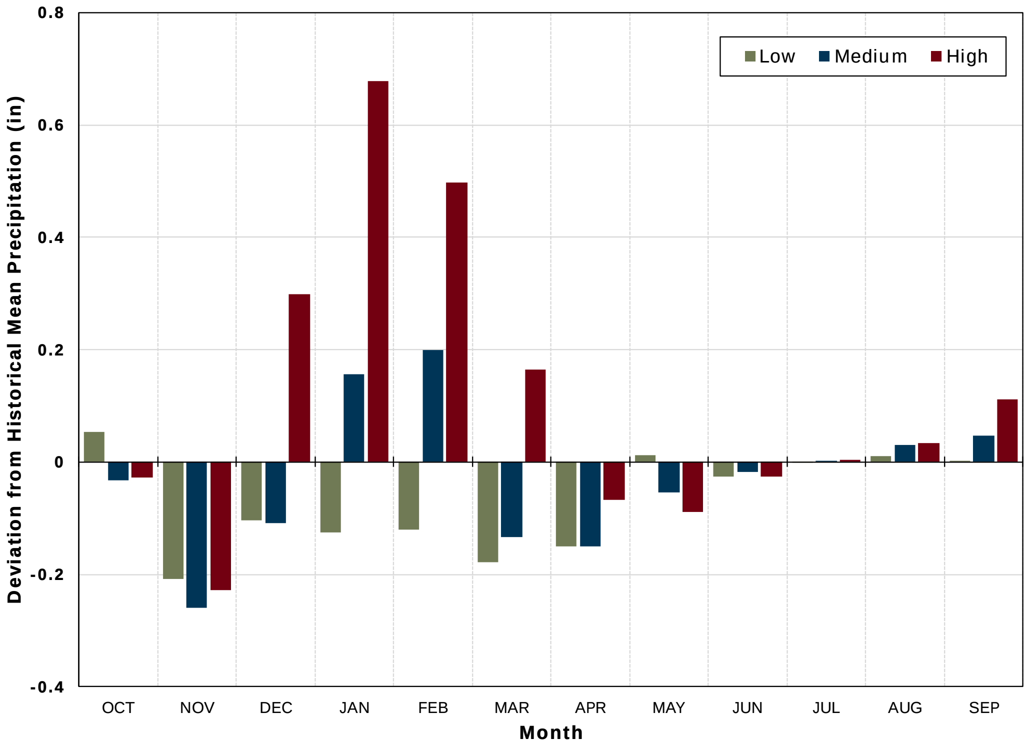


Figure 2-12. Projected Change in Mean Monthly Precipitation by 2072

USJR Region under the low, medium, and high climate scenarios



Source: Adapted from California Department of Water Resources 2022g

Hydrological Responses to Climate Change

Snowpack and the timing of snowmelt are key components of the hydrologic system in California. While covering approximately 25% of the total land area in the state, the Sierra Nevada region provides roughly 60% of California's water, much of which originates from snowpack (Reich et al. 2018). Historically, snowpack in the San Joaquin River Basin has typically developed at higher elevations from November through March (California Department of Water Resources 2022a). As temperatures begin to rise in the spring, snowpack gradually melts, supplying water to communities, ecosystems, and agriculture through the spring and summer.

For the San Joaquin River Basin, the historical freezing elevation is slightly higher than 8,000 feet. Under the low, medium, and high climate change scenarios, this elevation is projected to increase to approximately 9,500, 10,200, and 11,500 feet, respectively. These findings indicate that warmer temperatures are projected to shift the composition of precipitation from snow to rain at higher elevations (California Department of Water Resources 2022a). Precipitation that is no longer captured in snowpack will travel downstream as runoff, and higher temperatures will likely increase the rate and timing of snowmelt that does accumulate.

Furthermore, increasing temperatures and changes to snowpack composition will impact snow water equivalent (SWE, the volume of liquid water contained in snowpack) at different elevations. SWE volumes are projected to dramatically decrease from baseline conditions, particularly under the high climate change scenario (California Department of Water Resources 2022a). In the near term, these changes are reflected by the change in April 1 SWE for the Upper San Joaquin and Upper Merced Watersheds, the historically snowpack-dominated watersheds in the area (Figure B2-5 in Appendix B). For both locations, a decrease between roughly 6 to 32% is projected depending on the statistic, likely due to increased minimum temperatures causing snowpack to melt earlier in the year.

As a result of the overall decrease in snowpack, SWE, and timing of snowmelt, the water system is projected to experience higher runoff flows earlier in the year, likely inducing increased flood risks and changes to water management operations. Under the high climate change scenario, runoff volumes are projected to increase across all elevations in the San Joaquin River Basin. Under all climate change scenarios, runoff volumes are projected to increase at elevations greater than 6,000 feet.

In the near term, 2042 projected changes to mean annual (Appendix B, Figure B2-6) and monthly (Figure 2-13) unregulated (unimpaired) runoff are similar to those presented for precipitation. Increased runoff in winter to early spring are offset by decreases in the summer months as more precipitation falls as rain rather than snow and snowmelt shifts to earlier in the year. This results in a minor (less than roughly 5%) decrease in annual average runoff for the majority of assessed watersheds. Historically snowpack-dominated watersheds (Upper Merced and Upper San Joaquin) show the most dramatic shift form historical conditions, with nearly a 20 to 50% increase in runoff from November through April. These shifts are offset by a roughly 60 to 70% decrease in runoff in July and August. Other, lower-elevation watersheds show

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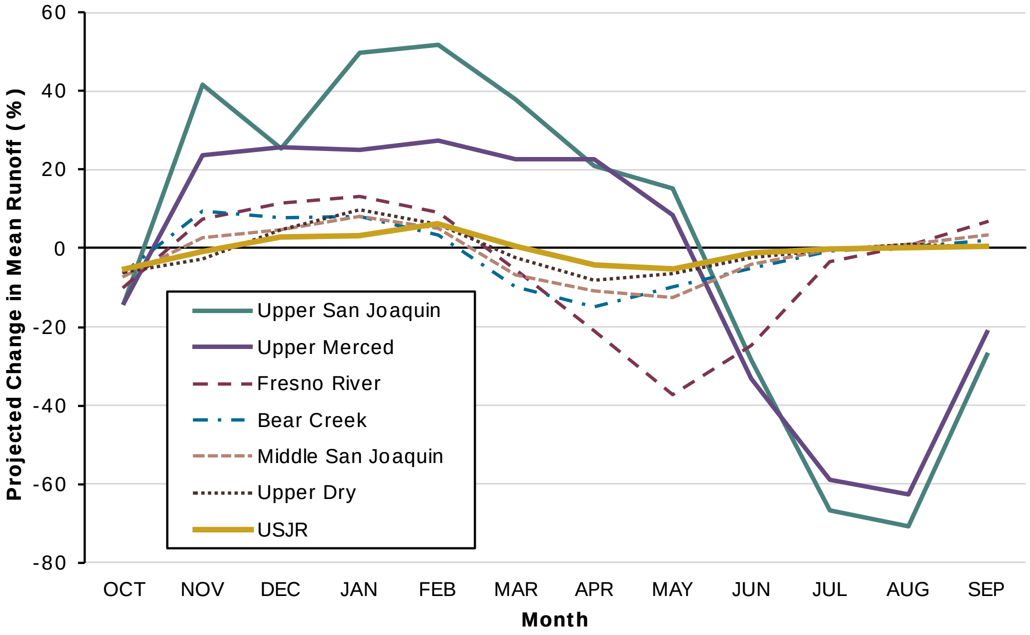
somewhat similar trends, with up to 10% increases between November to February. However, decreases in runoff begin much earlier in the year (March) than the upper watersheds due to the lack of snowpack at these locations.

Figure 2-13. Projected Change in Mean Monthly Runoff by 2042

USJR Region and surrounding watersheds



To examine changes in peak flood events, projected changes of regulated (altered by human intervention such as reservoir operations) hydrology were assessed at several locations throughout the Central Valley. Figure 2-14 presents the spatial patterns of change in peak regulated flows throughout the Central Valley for a 1% annual exceedance probability (AEP; 100-year flood event) under each of the three climate change scenarios. The San Joaquin River Basin, and many of the upstream locations in the USJR region, show substantial increases in peak flows under these conditions, with roughly a 500% increase near the Chowchilla Bifurcation Structure. In general, 100-year event flows will increase across most locations along the San Joaquin River under 2072 conditions, and equivalent flows (i.e., what is currently considered a 100-year event flow) will become more frequent.

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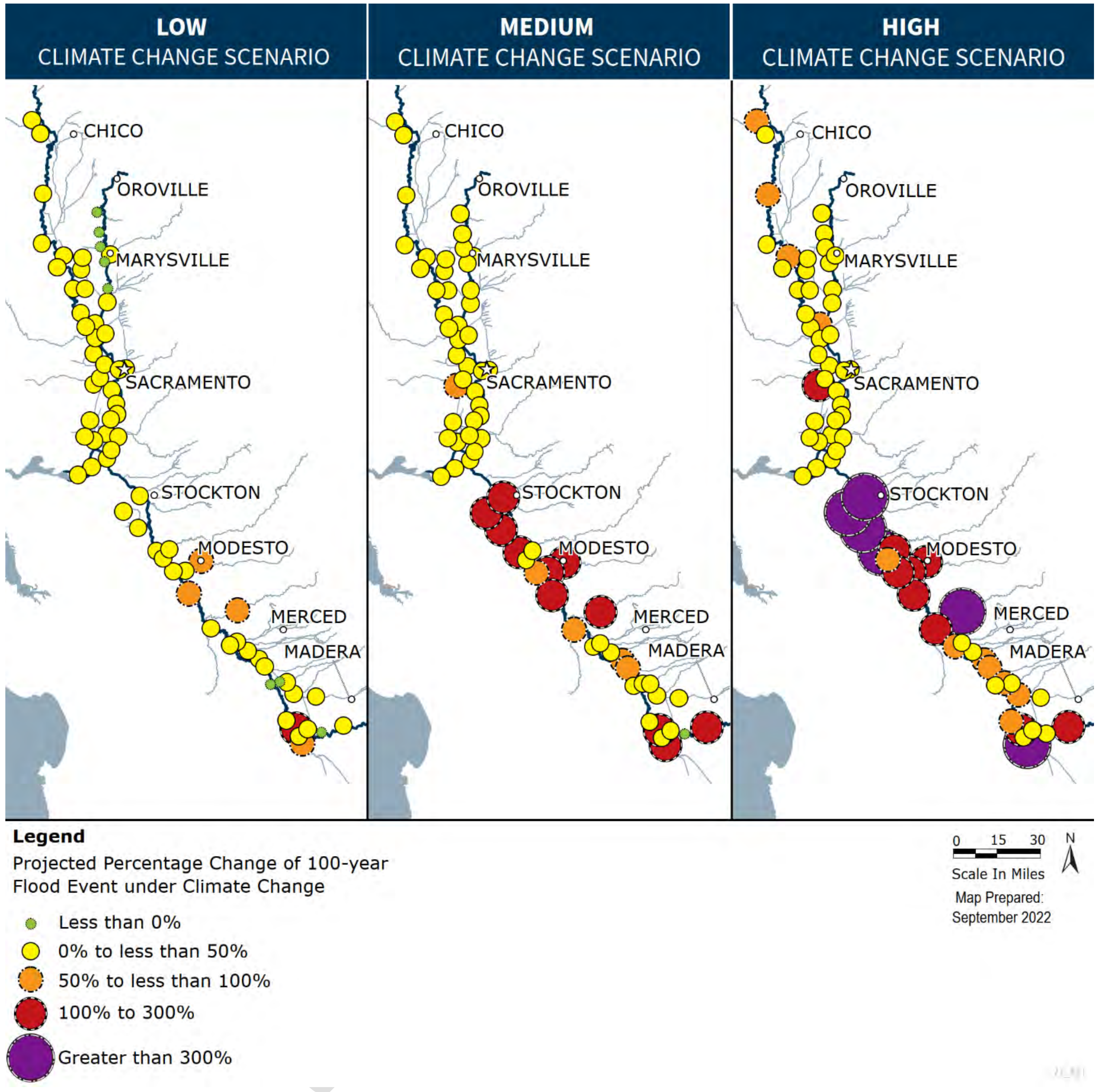
Figure 2-14. Spatial Patterns of Change in Peak Regulated Flows Representing the 100-Year Flood or 1% Annual Exceedance Probability under 2022 CVFPP Climate Change Scenarios

Central Valley under the low, medium, and high climate change scenarios



Source: California Department of Resources 2022d

Existing System Vulnerabilities and Risks

Summary of Climate Vulnerabilities and Risk

The flood management system of the USJR region experiences a number of challenges that makes managing existing flood events, let alone projected changes to these events, difficult. These challenges include subsidence, insufficient or aging infrastructure, seepage, loss of hydraulic capacity due to sedimentation and vegetation encroachment, complex system operations, and lack of adequate funding. Additionally, complex institutional and onerous permitting and compliance issues make the implementation of flood management actions, and even routine operations and maintenance (O&M), difficult, particularly in the numerous DACs encompassed in the region. Together, these issues make the USJR particularly susceptible to flooding, property damage, and potential loss of life under existing conditions and future conditions.

The projected changes to climate variables described in the previous section are likely to compound existing vulnerabilities and risks (the level of exposure to a given event or variable) in the USJR region. These risks and vulnerabilities will propagate from headwaters to downstream regions, and changing conditions will present additional stress (such as the amount of pressure or strain placed on a given resource or infrastructure component under certain conditions) on flood management infrastructure and operations throughout the region. Figure 3-1 and Table 3-1 summarize climate vulnerabilities and risks for the geographical areas outlined in this section; additional detail is included in the following subsections.

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Figure 3-1. Projected Climate Vulnerabilities and Risks in the Central Valley’s Watersheds

The USJR region and downstream locations will experience the greatest of these climate-related risks.

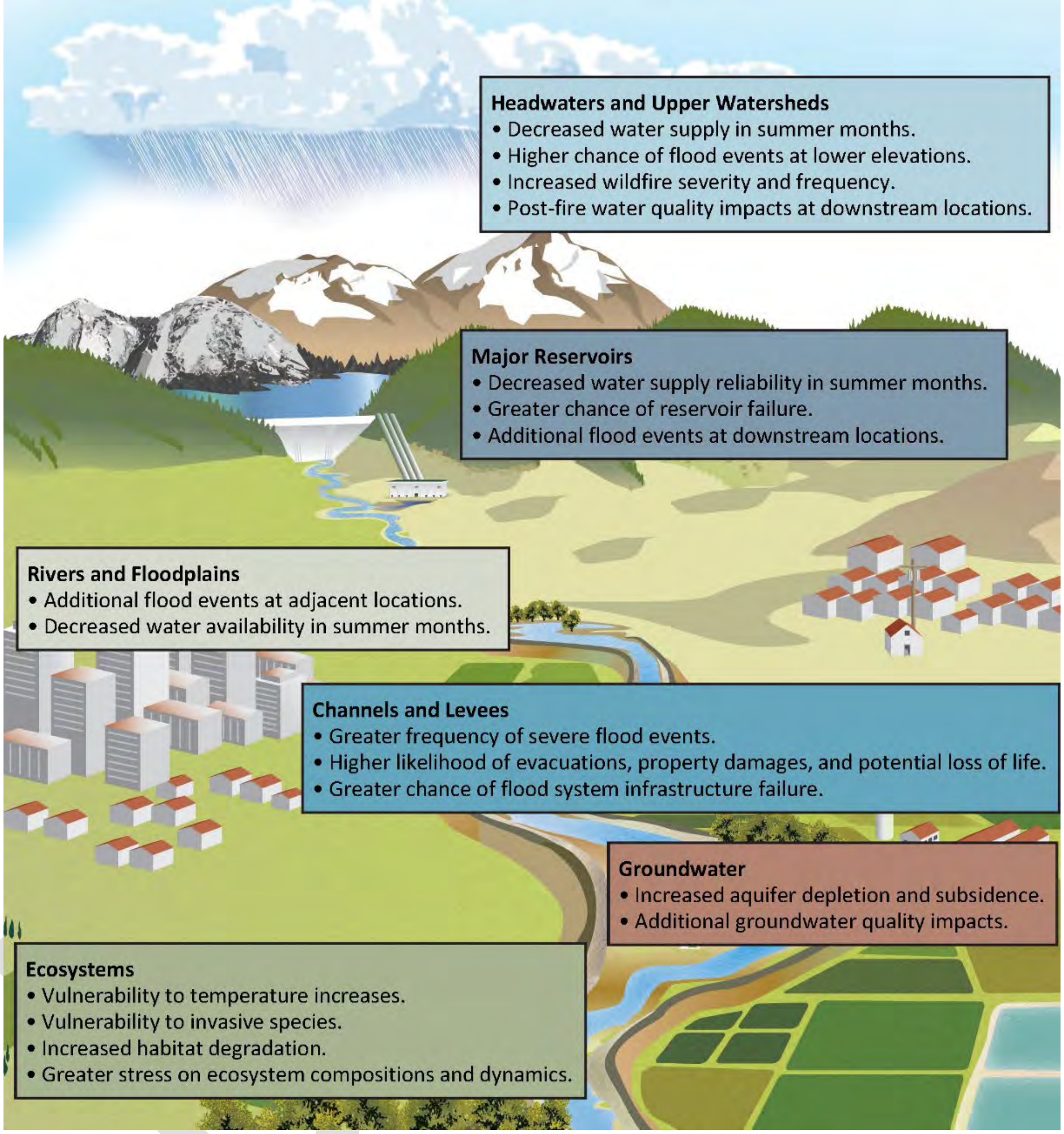

Table 3-1. Summary of Climate Vulnerabilities and Risks

Geographical Area	Vulnerabilities and Risks
Upper Watersheds	Reduced snowpack volume and earlier spring snowmelt from increasing temperatures will shift unregulated flow volumes to earlier in the year and may reduce water supplies in summer months. Less frequent, more severe extreme precipitation events from landfalling atmospheric rivers (AR) will further increase flood risks at select locations.
Major Reservoirs	Larger unregulated inflow volumes under extreme precipitation conditions are likely to increase flood risk at reservoir locations. Reservoirs without ample storage and release capacity may be vulnerable to overtopping or other failures. Water supply reliability is also projected to decrease in summer months due reduced reservoir storage as inflows concentrate into winter months.
Rivers and Floodplains	Higher regulated peak flows and stage in the wet season will increase flood risks at locations adjacent to rivers and floodplains. Lower flow volumes in summer months will likely decrease water supplies as annual runoff volumes become concentrated into wet season months. Rivers with severe sediment or vegetation encroachments will have a loss of conveyance capacity resulting in increased flooding.
Channels and Levees	Increased potential seepage and failure of channels, levees, and other flood system infrastructure in wet season months will result from longer duration and higher regulated peak flows and stage. Levees and channels with existing deficiencies or capacity losses (such as sedimentation or vegetation encroachments) may be particularly vulnerable.
Groundwater	Increased groundwater demand in summer months when surface flows decrease may lead to further subsidence in the region, depending on the implementation of the Sustainable Groundwater Management Act (SGMA) by local Groundwater Sustainability Agencies.
Ecosystems	Species and habitats are likely to experience temperatures and surface water shortages outside of a survivable threshold, resulting in the degradation of ecosystem processes and composition.

Upper Watersheds

In upper watersheds, changes in temperatures, snowpack, and hydrology are the primary drivers for increased climate risk and vulnerabilities. Warmer temperatures in the USJR region and surrounding watersheds are projected to increase the amount of precipitation falling as rain rather than snow and to shift snowmelt earlier in the year. In the near term (2042) for the Upper San Joaquin and Upper Merced watersheds, April 1 SWE is projected to decrease by roughly 6 to 32%. By the end of the century, it is estimated that the total annual snowpack will decrease between 58 and 84% (Fernandez-Bou et al. 2021). Coupled with greater magnitude extreme precipitation events, such as landfalling ARs, these changes have the potential to

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dramatically increase flood risks in lower-elevation and downstream locations during wet season months. Locations without adequate storage for accommodating increased peak runoff volumes are likely to be particularly vulnerable to these changing conditions.

In comparison to the Sacramento River watershed, the San Joaquin River watershed is expected to experience more dry years and less wet years because of differences in geography and hydrological climates (He et al. 2021). As a result, water supplies in the San Joaquin River watershed are likely to be much more vulnerable to the effects of climate change, especially under drought conditions and in summer months as runoff flows are shifted into winter months. Table 3-2 highlights modeled changes in mean annual flows for various watersheds in and around the USJR region under a variety of ambient temperature increases (T2, T4, and T6 represent uniform increases in air temperature of 2, 4, and 6 degrees Celsius, respectively). Increased temperatures result in decreased modeled mean annual flow, resulting in impacts to the management of reservoirs and downstream releases to rivers throughout the region (San Luis and Delta-Mendota Water Authority 2019). This generally corresponds to the minor decreases (less than 5%) in mean annual runoff for the Upper Merced and Upper San Joaquin watersheds described in Section 2.

Table 3-2. Modeled Mean Annual Flow for the Merced and San Joaquin Watersheds

Projected changes in annual average flow under various ambient temperature (T2, T4, and T6 represent uniform increases in air temperature of 2, 4, and 6 degrees Celsius, respectively) increases in the Merced and San Joaquin watersheds.

Watershed	Annual Average Flow (MAF)				Change from Base Case (%)		
	Base Case	T2	T4	T6	T2	T4	T6
Merced	1.09	1.06	1.03	1.00	-3.0	-5.6	-8.2
San Joaquin	1.86	1.84	1.81	1.78	-1.3	-2.6	-4.1

Source: Modified from San Luis and Delta-Mendota Water Authority 2019

Increased temperatures in upper watersheds are also projected to result in more frequent and severe wildfire events. The annual average area burned in the Sierras is projected to increase by two to four times that of late 1900s averages by the end of the century, substantially increasing wildfire risk (Westerling 2018). These risks are likely to threaten the safety of ecosystems, property, and residents in these areas, and post-fire runoff has historically been associated with higher peak flows and water quality impacts on downstream locations. As such, flood risks are likely to increase at these locations, and additional water treatment efforts may be needed to reduce water quality impacts on water supplies.

Major Reservoirs

Reservoirs serve as vital water management infrastructure to capture inflows from headwaters and upper watersheds, provide surface water storage throughout the year, and regulate downstream releases. Major reservoirs upstream of the USJR region include Lake McClure,

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Millerton Lake, Eastman Lake, and Hensley Lake. Bear, Owens, Burns, and Mariposa reservoirs include dry flood dams that are also present upstream of the region. The vulnerabilities of major reservoirs arise primarily from unregulated inflow characteristics under future climate conditions, the overall storage capacity of the reservoir itself, and the capacity to release outflows downstream. With increased inflows during extreme precipitation events and larger runoff volumes earlier in the year, major reservoirs are likely to experience greater operational challenges. Larger and more frequent reservoir releases and event pre-releases will likely be needed to accommodate the increased inflows and prevent downstream flooding.

Additionally, unregulated inflows primarily originate from the snowmelt runoff from the Sierra Nevada Mountains (MIRWMA 2019). Table 3-3 provides an overview of projected average unregulated inflows for reservoirs in or upstream of the USJR region under 1997 flood event patterns for the 2022 CVFPP Update baseline and future climate change scenarios (California Department of Water Resources 2022c). Substantial increases in average unregulated inflows are projected under the high climate change scenario. With increasing temperatures and the projected hydrologic changes in the region, reservoirs may reach maximum capacity early in the year, prompting earlier downstream releases. These earlier release schedules can lead to water supply shortages and lower reservoir storage in summer months (MIRWMA 2019). In the USJR region, decreased reservoir storage will increase dependency on groundwater resources, particularly for agriculture.

Table 3-3. Projected Changes to 100-Year San Joaquin System Reservoir Unregulated Inflows under 1997 Flood Event Patterns in Cubic Feet per Second (cfs)

Reservoir	Average Interval (days)	Baseline (cfs)	Low Scenario (cfs)	Low Scenario (percent increase)	Medium Scenario (cfs)	Medium Scenario (percent increase)	High Scenario (cfs)	High Scenario (percent increase)
Millerton Lake	15	16,000	20,000	25%	26,000	63%	38,000	138%
Hensley Lake	3	5,000	7,000	40%	9,000	80%	12,000	140%
Eastman Lake	3	5,000	7,000	40%	9,000	80%	12,000	140%
Owens Reservoir	3	300	400	33%	500	67%	700	133%
Bear Reservoir	3	1,000	2,000	100%	2,000	100%	3,000	200%
Burns Reservoir	3	1,000	1,000	0%	2,000	100%	3,000	200%
Lake McClure	15	13,000	17,000	31%	21,000	62%	31,000	138%

Source: Adapted from California Department of Water Resources 2022c

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Rivers and Floodplains

Major rivers in the USJR region include the Merced River, Bear Creek, Owens Creek, Chowchilla River, Fresno River, and San Joaquin River. Runoff from heavy storm events, earlier snowmelt in spring months, decreased snowpack, shifting reservoir release schedules, loss of capacity from sediment accumulation and vegetation encroachment, and the relatively flat topography of the region, can result in a greater magnitude flood events throughout the region (MIRWMA 2019). As outlined in Section 2, peak regulated flows and stage are projected to increase in the USJR region, significantly increasing flood risks in areas adjacent to rivers and floodplains. Areas without intact floodplains, existing levee deficiencies, and inadequate freeboard are likely to be particularly vulnerable.

Channels and Levees

Future conditions are projected to increase flood risk in downstream reaches of the USJR region primarily through increased regulated flows and stage. Flooding is more likely to occur during extreme storm events, such as landfalling ARs, potentially leading to widespread flooding throughout the region. Recent AR events in late 2022 and early 2023 have contributed a significant amount of rainfall to the USJR region and Central Valley as a whole, resulting in widespread flooding, evacuations, and property damage.

Major flood management system infrastructure in the USJR region includes facilities developed under the San Joaquin River Flood Control Project and the Merced County Streams Project. Twenty-five miles of levees along the Fresno River and Ash Slough are also present in Madera County. Federal and State authorizations for these projects began in 1944 and 1955, respectively (San Joaquin River Flood Control Project Agency 2015). Table 3-4 provides an overview of components of the Upper San Joaquin River Flood Control System. Similarly, Table 3-5 provides an overview of components of the Merced and Madera flood control systems.

Table 3-4. Summary of Components of the Upper San Joaquin Flood Control System

Component Type	Component	Description
Levees	Private Levees	Private levees were constructed by individual landowners to protect localized areas (private properties).
	Project Levees	Constructed as part of the San Joaquin River Flood Control Project, project levees were designed to provide 50-year flood protection.
Diversion Structures	Chowchilla Bifurcation Structure	The structure controls the diversion of flows from San Joaquin River into the Chowchilla Canal Bypass.
	Eastside Bypass Control Structure	The structure controls flow in the Eastside Bypass downstream of the Mariposa Bypass.

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Component Type	Component	Description
	Sand Slough Control Structure and San Joaquin River Control Structure	The structure diverts San Joaquin River flows into Reach 4B. The gates in the structure are currently closed, and flood flows have not been released into Reach 4B in many years.
	Mariposa Bypass Structure	The structure diverts flow from Eastside Bypass into the Mariposa Bypass and the San Joaquin River.
Bypass Channels	Fresno Slough	The channel conveys high flows from Kings River to Mendota Pool.
	Chowchilla Canal Bypass	The channel conveys high flows from Chowchilla Bifurcation Structure to Eastside Bypass.
	Eastside Bypass	Conveys flows from Chowchilla Canal Bypass to Mariposa Bifurcation Structure and Bear Creek (both of which convey flows back into San Joaquin River).
	Mariposa Bypass	Conveys water from the Mariposa Bypass Bifurcation Structure into the San Joaquin River.

Source: Modified from San Joaquin River Flood Control Project Agency, 2015

Table 3-5. Summary of Components of the Merced and Madera Flood Control Systems

Facility Type	Facility	Year Constructed	Capacity (AF)
Merced Facilities	Burns Reservoir	1957	6,800
	Bear Reservoir	1957	7,700
	Owens Reservoir	1957	3,600
	Mariposa Reservoir	1957	15,000
	Castle	1992	6,400
Merced Channel Improvements and Diversions	Black Rascal Creek to Bear Creek	1958	3,000
	Owens Creek to Mariposa Creek Reservoir	1958	400
Madera County	Levees on Fresno River	1977	5,000
	Levee on Berenda Slough	1977	2,000
	Levee on Ash Slough	1977	5,000
	Eastman Lake	1975	150,000
	Hensley Lake	1975	90,000

Source: Modified from San Joaquin River Flood Control Project Agency, 2015

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The San Joaquin River Flood Control Project and much of the flood system were constructed—not engineered—in the mid-1900s using native material and were intended to protect against a 50-year flood event. Since then, substantial sediment accumulation, vegetation encroachment, unaddressed levee deficiencies, and subsidence have severely reduced the ability for the existing system to convey flood flows. As highlighted in Section 2, regulated flows for 100-year flood events under 2072 conditions are projected to increase dramatically (up to 500%), particularly near the Chowchilla Bifurcation Structure. While near-term changes to regulated flows could not be assessed at the time, the relative trend toward higher flows and current 100-year equivalent flows becoming more frequent is likely consistent, although with lesser magnitude. Many of these areas already struggle or fail to convey existing flood flows for less than 50-year events.

While immediate near-term (within the next 20 years) risks depend on upstream management and regulation of reservoir releases, changes in mean monthly runoff can provide (highlighted in Section 2) a spatial assessment of relative projected impacts in areas of the USJR region. A conceptual assessment of near-term projected impacts by watershed for levees of relevant channels in the USJR region are highlighted in Table 3-6. Increasing the level of flood protection for urban areas and disadvantaged communities, addressing existing levee deficiencies, funding O&M of the flood management system, and restoring lost capacity through sediment and vegetation removal are vital to protecting the USJR region from existing and future more extreme flood events.

Table 3-6. Conceptual Assessment Based on Relative Magnitude Change in Total Projected 2042 Runoff in the USJR Region Flood System

Channel	Responsible Agencies	Peak Change in Mean Monthly Runoff by Watershed [a]
San Joaquin River	LSJLD, Nonproject	• Upper San Joaquin: 52% (Feb) • Middle San Joaquin: 8% (Jan) • Upper Dry: 10% (Jan) • Fresno River: 13% (Jan) • Bear Creek: 9% (Nov) • Upper Merced: 28% (Feb)
Chowchilla Canal Bypass	LSJLD	• Upper San Joaquin: 52% (Feb) • Fresno River: 13% (Jan)
Eastside Bypass	LSJLD	• Fresno River: 13% (Jan)
Fresno Slough	Nonproject	• Upper Dry: 10% (Jan)
Fresno River	Madera County	• Fresno River: 13% (Jan)
Berenda Slough	Madera County, LSJLD	• Fresno River: 13% (Jan)
Ash Slough	Madera County, LSJLD	• Fresno River: 13% (Jan)
Chowchilla River	Madera County	• Middle San Joaquin: 8% (Jan)

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Channel	Responsible Agencies	Peak Change in Mean Monthly Runoff by Watershed [a]
Owens Creek	MSG, LSJLD	• Middle San Joaquin: 8% (Jan)
Black Rascal Creek	MSG	• Bear Creek: 9% (Nov) • Upper Merced: 28% (Feb)
Bear Creek	MSG, LSJLD	• Bear Creek: 9% (Nov) • Upper Merced: 28% (Feb)

Notes:

[a] Values represent the peak median projected change under 2042 conditions for mean monthly runoff for relevant watersheds. This information is also presented in Figure 2-20. Runoff does not translate to actual regulated flows at downstream locations due to upstream operations. However, this information does present the relative magnitude change in the total projected runoff for relevant watersheds upstream or adjacent to a given channel.

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Groundwater

Three groundwater aquifers are located within the USJR region: the Chowchilla, Merced, and Turlock subbasins. The Chowilla Subbasin lies south of Merced Subbasin while the Turlock Subbasin lies to the north of the Merced Subbasin. Groundwater levels in the region have been steadily declining due to overdraft conditions, leading to subsidence. This perpetuates flood conditions due to the relative decrease in conveyance capacity, causing flows and sediment to settle in areas with lower elevation. Under future conditions, groundwater basins in the USJR region have the potential for increased over drafting, particularly with increased temperatures and shifting annual water supply availability in summer months. If surface water supplies are not able to meet demands, municipal, residential, and agricultural users will need to rely on additional water from groundwater basins (MIRWMA 2019).

The passing of SGMA in 2014 required local agencies to form groundwater sustainability agencies (GSAs) in critically overdrafted basins or subbasins and develop GSPs to address overdraft within the next 20 years (California Department of Water Resources 2022h). With warmer temperatures, increased extreme heat days, and shifting surface water availability throughout the year, it may be difficult for GSAs in the region to implement GSPs within the next 20 years and continue sustainable groundwater use into the late century. However, future high-flow events will provide recharge opportunities to restore groundwater supplies in the region using the Flood-MAR concept, which has been pilot tested in several locations and will be critical to managing local water supplies under future conditions.

Ecosystems

Approximately 95% of the original wetlands in the San Joaquin Valley have been lost due to agriculture development, changing climate conditions, or other sources (Fernandez-Bou et al.

2021). Future climate conditions can disrupt and cause greater stress on the ecosystems and habitats in the USJR region and surrounding area (Madera County 2017). Warmer ambient air temperatures will lead to increased water temperatures throughout the USJR region, resulting in impaired water quality from decreased dissolved oxygen levels and increased the concentrations of algal blooms (California Department of Water Resources 2008). These changes can cause further stress on aquatic ecosystems and habitats (MIRWMA 2019).

Many of the natural ecosystems in the San Joaquin Valley are riparian or grassland habitats such as freshwater marshes, valley sink scrub, and grassland vernal pool habitats (San Luis and Delta-Mendota Water Authority 2019), each of which are particularly vulnerable to shifting hydrologic processes throughout the year. Similar to opportunities for recharge described above, increased flows under future conditions may present opportunities for floodplain inundation and ecosystem restoration. Setback levees can increase the capacity of rivers and floodplains in the region and restore geomorphic and ecosystem processes. Strategic levee breaks or removals can also create areas of intentional inundation, further promoting restoration of ecosystem processes and habitats.

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Overview of USJR RFMP Projects

As described in the preceding sections, the USJR region has experienced major flood events in recent history; these events are likely to become more frequent and damaging in the coming decades under future climate conditions and an already degraded flood management system. Significant improvements to the existing flood management system are needed to combat both current and future flood risk in the region, but lack of adequate funding from State and federal sources has been a substantial barrier to the development, permitting, and implementation of flood risk reduction projects. Despite these challenges, several projects are currently ongoing or have been identified to improve the condition of the flood management system in the region.

To highlight current and proposed USJR RFMP projects that contribute to improved flood protection and public safety under existing and future extreme weather events, the list of 169 regionally identified projects (as of 2021) was considered for this assessment. The USJR Region identified the following projects as high priority:

- Flood-MAR
- Develop Emergency Response Plans
- Upper San Joaquin Sediment Study
- Le Grand Canal Flood Control Structure at Black Rascal Creek
- Los Banos Creek Recharge and Recovery
- Los Banos Creek Detention Reservoir Regulation and Storage
- Black Rascal Creek Flood Control Project
- Del Puerto Canyon Reservoir
- Chowchilla Bypass Flood Flow Recharge
- Western Madera and Merced County Subsidence Solution
- Fresno Slough South Levee Repair and Floodplain Enhancement Project
- San Luis National Wildlife Refuge West Bear Creek Project
- Bridge Enlargement over Eastside Bypass at Sandy Mush Road
- Enlarge Chowchilla Canal Bypass Control Structure
- Enlargement of Burns, Bear, Mariposa, and Owens Reservoirs
- Miscellaneous Vegetation and Sediment Removal Projects
- Levee Improvements for City of Firebaugh to Protect Wastewater Treatment Plant and Critical Infrastructure

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The following brief descriptions elaborate on each project's focus and how it can beneficially contribute toward flood management improvements and climate adaptation in the USJR Region:

- **Flood-MAR**: includes the development and implementation of a voluntary flood managed aquifer recharge program to divert surplus flows during the winter onto farms and fields, reducing the burden on flood management infrastructure (by decreasing peak flows within the channel and downstream areas) while providing groundwater recharge.
- **Develop Emergency Response Plans:** provides a low-cost, high-benefit approach to prevent the loss of life, reduce physical damages, decrease recovery times, and improve disaster management and communication during floods and other emergencies.
- **Upper San Joaquin Sediment Study:** consists of conducting a sediment study to identify upstream sources of sediment in the USJR region and developing regional mitigation efforts to improve sediment management and prevent loss of channel capacity.
- **Le Grand Canal Flood Control Structure at Black Rascal Creek:** consists of adding a control structure connected to Merced Irrigation District's (MID) supervisory control and data acquisition (SCADA) system to Le Grand Canal at the intersection with Black Rascal Creek, increasing the flexibility of operations and flood management.
- **Los Banos Creek Recharge and Recovery:** includes construction of 103 acres of recharge ponds and 6 recovery wells, and provides groundwater recharge opportunities and greater operational flexibility of surface water flows, particularly during high-flow events.
- **Los Banos Creek Detention Reservoir Regulation and Storage:** provides a long-term solution to flooding, drought resilience, groundwater overdraft, and subsidence risks as well as an average annual increase in water supplies of 8,000 acre-feet per year.
- **Black Rascal Creek Flood Control Project:** includes construction of a detention basin in the Black Rascal Creek watershed that will provide 200-year flood protection for the City of Merced and the Community of Franklin-Beachwood.
- **Del Puerto Canyon Reservoir:** project includes construction of an 82,000 acre-feet reservoir to capture and store water during excess conditions as well as release water for beneficial use during shortfalls of Central Valley Project (CVP) allocations of surface water. The average annual yield is anticipated to be between 55,000 to 60,000 acre-feet.
- **Chowchilla Bypass Flood Flow Recharge:** includes construction and operation of diversion and conveyance facilities and basins to recharge an anticipated average of roughly 38,000 acre-feet using flood flows within the western portion of the Madera Subbasin.
- **Western Madera and Merced County Subsidence Solution:** combined groundwater banking and overdraft correction program in the Red Top and El Nido areas east of the San

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Joaquin River. Improvements include development of several acres of recharge ponds, shallow water wells, detention basins, and surface water distribution. It is anticipated that this project will provide over 120,000 acre-feet of groundwater storage potential in the area, reduce subsidence, extend surface water availability, and reduce San Joaquin River flows during flood events.

- **Fresno Slough South Levee Repair and Floodplain Enhancement Project**: includes several improvements and enhancements through modifications of existing levees, improving the flow over the land and reducing pressure on nearby levees during flood events.

- **San Luis National Wildlife Refuge West Bear Creek Project:** restoration of wetland slough channel connectivity with the San Joaquin River to better accommodate flood flows.

- **Bridge Enlargement over Eastside Bypass at Sandy Mush Road:** includes lengthening of the existing bridge to reduce the constriction of flood flows and upstream freeboard encroachment. Installing culverts in the existing embankments is being considered as an alternative option.

- **Enlarge Chowchilla Canal Bypass Control Structure:** installation of two additional gate bays to minimize upstream seepage and levee failure, increasing emergency flow capacity and operational flexibility of the structure.

- **Enlargement of Burns, Bear, Mariposa, and Owens Reservoirs:** increase storage for flood capacity of Burns, Bear, Mariposa, and Owens reservoirs as well as downstream levee and channel modifications. Each of these reservoirs was originally constructed to provide protection for up to a 50-year event; improvements would meet requirements for flood protection of urban areas.

- **Miscellaneous Vegetation and Sediment Removal Projects:** several projects have been identified by the USJR region to remove channel vegetation and accumulated sediment. Channel vegetation, especially those invasive in nature, and sediment are key drivers for the loss of channel capacity, limiting the ability to convey flows during flood events.

- **Levee Improvements for City of Firebaugh to Protect Wastewater Treatment Plant and Critical Infrastructure:** several projects have been identified to mitigate flood risk for the City of Firebaugh, including bank stabilization of the San Joaquin River and construction of earthen levees near the rodeo grounds, and to protect the city wastewater treatment plant during high river flow events.

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Data Gaps and Further Studies

Flood management challenges in the USJR region include subsidence, insufficient or aging infrastructure, seepage, loss of hydraulic capacity due to sedimentation and vegetation encroachment, complex system operations, and lack of adequate funding. Complex institutional and onerous permitting and compliance issues make the implementation of flood management actions, and even routine operations and maintenance (O&M), difficult. These issues and deficiencies challenge the function and reliability of the flood management system and make addressing immediate flood management concerns and future climate change impacts difficult. This section identifies data gaps and potential further studies and efforts that are needed to formulate approaches to improving the flood management system in the USJR region under existing and future conditions.

Data Gaps

The analysis conducted in this white paper is a high-level assessment of future trends in temperature, precipitation, and hydrology for the USJR region. Further efforts could be conducted in the future to better determine the potential impacts of future climate conditions. For example, regulated flows under 2042 conditions could not be assessed as no hydrologic modeling was performed, and unrouted runoff changes were used to as a proxy to determine projected impacts to the flood management system. Consideration of additional climate trends, such as changes to wildfires and the subsequent impact to peak flows, could also benefit the identification of potential impacts to the USJR region.

An in-depth review of the existing capacity of the flood management system to convey flood flows is needed to better understand the conditions of the system under future conditions. Identified vulnerabilities consider individual infrastructure components, but a holistic assessment and consideration of current capacity losses (e.g., from sediment accumulation) and deficiencies would provide a more robust estimation of existing flood flow conveyance capabilities.

Some of the projected impacts and vulnerabilities outlined in this white paper leverage the work conducted in the 2022 CVFPP Update and supporting documents. In these cases, the analyzed impacts are limited to the study area conducted by the 2022 CVFPP Update technical analysis. Most notably, this analysis excludes the City of Merced and much of the surrounding area, the largest urban area in the USJR region. Supporting literature, as referenced in Appendix A, also provide valuable perspectives on potential climate change impacts and vulnerabilities in the region, but they may be slightly broader (e.g., at the county scale) than the extent of the USJR region.

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Further Studies

The 2015 USJR RFMP outlines several future studies that are recommended for further evaluation. These efforts were not pursued due to limited resources and the schedule constraints during the RFMP planning process, but they remain relevant approaches that need to be considered in the future. Brief descriptions of these proposed studies follow:

- **Forecast-Coordinated Operations**: enhances upstream reservoir operations through increased coordination among operating entities, utilization of forecasting information, broader communication with others, improved and more accessible gauging, and updated flood management manuals.
- **Forecast-Based Operations:** use hydrologic forecasts to inform operational regimes. This approach could allow greater reservoir releases in advance of large storms, reducing peak flows at downstream locations, and encroaching on flood storage space to save water if forecasts anticipate minimal runoff for the forecast period.
- **Evaluation of Upstream Storage:** develop additional upstream reservoir storage could provide potential flood protection and water supply benefits to the USJR region. Several projects identified in the previous section of this white paper include these elements.
- **Regional Sediment Study:** conduct a basin-wide study of sediment management for the entire San Joaquin River basin to analyze transport processes and develop a sediment management strategy for the whole basin to restore channel capacity and improve conveyance of flood flows.
- **Improved Governance and Sustainable Funding:** several governance issues exist in the USJR region. Local maintaining agencies (LMAs) in the region also need formalized emergency management plans and improved funding sources to implement flood risk reduction and routine O&M actions (SJRFCPA 2015).

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Recommendations

The list of in-progress and planned USJR RFMP projects primarily consist of (1) flood system infrastructure improvements; (2) groundwater recharge opportunities; (3) operations, maintenance, repair, rehabilitation, and replacement actions such as sediment and vegetation removal; and (4) ecosystem restoration efforts. The following priorities for the USJR region were identified in the 2021 Regional Priorities White Paper include (San Joaquin River Flood Control Project Agency 2021):

- Restore federal authorization for the SJRFCP.
- Improve O&M and ability to obtain permits.
- Restore the flood system to the original design capacity or increased capacity where it is feasible and reasonable to do so.
- Provide 200-year flood protection per SB 5 for urban areas (Merced).
- Provide 100-year flood protection per SB 5 for small communities of Franklin-Beachwood, Firebaugh, and Dos Palos.
- Facilitate the modification or removal of levees from the SPFC.
- Preserve the unique and historical agricultural community.
- Expedite the permitting and construction of infrastructure improvements.

With these previously identified priorities considered, the following set of recommendations is intended to supplement existing flood protection and climate resilience actions.

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Flood System Operations

Major reservoir operations typically lie outside of the jurisdiction of local and regional agencies within the USJR RFMP, but re-operation and pre-release of flows in anticipation of extreme storm events may provide significant downstream benefits. The following recommendations are potential flood system operations approaches that may be pursued through partnerships with State and federal entities:

- **Implement Forecast-informed Reservoir Operations (FIRO) and Forecast-coordinated Operations (FCO)**: As highlighted in the further studies described above, FIRO and FCO can be implemented to improve flood management and water supply operations by coordinating downstream reservoir releases (from Lake McClure or Lake Millerton, for example) and other infrastructure operations with forecasting technology and modeling. Preemptive releases ahead of extreme weather events may help to reduce peak flows at downstream locations and reduce pressure on the existing flood management system in the region, particularly in areas that currently experience a significant reduction in the original design capacity. Additionally, while increases to reservoir storage and release capacities can be vital to improving management of potential flood flows in downstream reaches (as described in Section 3), more flexible operation could potentially reduce the immediate need for improvements of this type.

- **Increase storage and implement adaptive reservoir rule curves in major reservoirs upstream of the USJR region:** Increased reservoir storge, particularly in major reservoirs in the Upper Merced (Lake McClure) and Upper San Joaquin (Millerton Lake) watersheds can help to reduce the magnitude of downstream releases during extreme events, lowering some of the risk of flooding for communities in the USJR region. Reservoir rule curves are used to control the release of water downstream according to certain criteria. Similar to FIRO and FCO, adaptive rule curves can increase the flexibility of operations by imposing more variable release criteria depending on characteristics of certain water years. Ultimately, future conditions are projected to swing more frequently between droughts and flood events; incorporating operational flexibility into upstream reservoirs operations can help increase resilience during these events.

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Prediction, Modeling, and Forecasting

Prediction, modeling, and forecasting efforts improve the characterization of climate impacts and vulnerabilities, enhance the assessment of the timing and severity of potential weather events, and support key emergency preparedness and management actions. Much of the analysis presented in the sections above relied on qualitatively relating future conditions to conditions of the existing flood management system. More-detailed modeling approaches can improve this assessment and identify and prioritize areas where improvements are needed. Recommendations related to these types of actions are as follows:

- **Improve and streamline climatological and hydrological modeling, particularly in upper watersheds of the USJR region**: Improved and streamlined climatological and hydrological modeling enhance the ability to assess future climate change trends, impacts, and potential risks. As described above, historically snowpack-dominated watersheds upstream of the USJR region are key drivers for flood conditions in downstream areas. Improved modeling of these areas that utilize the best available science and approaches can better inform threats to downstream areas in the region. Furthermore, a streamlined approach to climatological and hydrological modeling could increase modeling consistency and accessibility.

- **Promote improvements to the existing flood management system and climate resiliency:** Performance tracking is an important tool that helps identify not only progress made, but also existing gaps in flood management system improvements as well as climate resiliency. Defining clear goals and methods for tracking progress and can be used to prioritize areas where improvements are most needed; much of this work can be informed through the improved modeling described in the bullet above.
- **Implement long-lead flood forecasting to increase warning times in downstream areas**: Long-lead flood forecasting can improve the amount of warning time that individuals and communities in the USJR region have before a flood event occurs, promoting more effective

evacuation orders and flood response efforts while reducing potential property damage and loss of life. Increasing the lead time of flood forecasting can be accomplished with improved climatological and hydrological modeling and forecasting. Flooding is likely to continue in the area until significant system improvements are implemented and much of the region is able to attain relevant 100-year or 200-year level of flood protection goals. However, promoting earlier warning times can greatly reduce the threat to individuals in the USJR region while other, physical approaches are considered for implementation.

Emergency Management

Emergency management approaches often provide significant benefits at lower cost. Given the systemic challenges associated with funding for system improvements in the USJR region, actions of this type may be particularly effective and more easily implemented than some of the other recommendations highlighted in this section. Relevant recommendations related to improving flood response and climate resilience are as follows:

- **Integrate extreme weather risk with emergency response and local hazard mitigation plans**: Integrating extreme weather risk into emergency response plans and procedures as well as local hazard mitigation plans can better inform the range of potential impacts to individuals and communities in the USJR region and promote strategies to minimize damages or other losses during extreme events. Several communities in the region do not have formally developed emergency response plans or local hazard mitigation plans, or they are outdated. Developing these plans and identifying impacts to individual communities from extreme weather events can help to establish clear procedures and response actions for when these events occur.

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Watershed and Floodplain Management

Watershed and floodplain management approaches can provide flood risk reduction and other benefits such as recharge, ecosystem restoration, and enhanced natural processes under future climate conditions. Recommendations of this type are as follows:

- **Improve sediment and post-fire debris management in areas upstream of the USJR Region flood management system**: The USJR region has historically experienced a significant loss in design capacity as a result of sediment accumulation and vegetation encroachment. With wildfire conditions likely to be more prevalent in upper watersheds (such as the Upper Merced and Upper San Joaquin) under future conditions, post-fire debris may become another threat to channel capacity in the future. Improving sediment and post-fire debris management through construction of detention ponds, reduction in upstream erosion, and ecosystem restoration can reduce future O&M costs, reduce the further decrease of hydraulic capacity, and support flood risk reduction in areas with already decreased capacity.

- **Increase adaptive storage capacity in floodplains to promote floodplain inundation, ecosystem restoration, and groundwater recharge:** As previously described, floodplains can offer a variety of benefits for the USJR region, such as groundwater recharge, ecosystem restoration, and flood storage. With peak flows projected to increase under future conditions, increasing floodplain storage through strategic levee breaks, setback levees, and other approaches such as Flood-MAR can improve flood management to reduce strain on existing flood management infrastructure in the region. These approaches can also help to promote the implementation of GSPs in the region and promote restoration of natural processes.
- **Identify opportunities to implement nature-based resilience measures alongside flood protection improvements to the existing flood management system**: Nature-based solutions, including green infrastructure measures, can support flood and climate risk-reduction strategies while providing multiple benefits across a variety of areas such as restored ecosystem functions. These approaches directly align with the USJR region's recognition and consideration of natural environment and agriculture benefits when evaluating potential improvements to the flood management system.

Ecosystem Management

While several ecosystem restoration actions are included in the list of USJR RFMP projects, additional recommendations to further improve the resiliency of ecosystems and natural processes while providing benefits to flood management are as follows:

- **Increase and improve areas of floodplain inundation in major river reaches and transient storage areas, and allow rivers to meander and more closely approximate natural flow regimes**: The frequency, magnitude, duration, timing, and rate of change of flows are key factors for riverine geomorphic processes and floodplain inundation that ultimately benefit target habitats and species. As highlighted in Section 2, these processes are likely to be further stressed from increased temperatures and shifting water availability under future conditions. Maintaining and restoring these processes in the USJR region can provide opportunities to better manage increased flows through floodplain inundation and groundwater recharge. Setback levees allow for natural meandering of rivers while improving the capacity of flood management in these areas.

- **Protect existing floodplain agricultural land and improve O&M of sloughs, creeks, and canals in support of flood conveyance, water quality, and groundwater recharge:** Agricultural lands, particularly those situated in existing floodplains, are key components of the USJR region. Promoting protection of these areas as along with adjoining drainage canals and ditches through sediment management, vegetation control, and system improvements can provide benefits for not only native species, but water quality and groundwater recharge. Implementation of GSPs in the region will likely rely heavily on recharge opportunities in existing floodplain agricultural lands to offset groundwater overdraft.

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- **Promote actions that restore geomorphic functions, increase the quantity and quality of floodplain habitats, and improve conditions for native species**: Native habitats (such as riparian and grassland habitats) and species in the USJR region are likely to experience significant stress under future climate conditions, particularly those reliant on floodplains or seasonal water availability. Enhancing existing floodplains as well as restoring historical floodplain areas in the region can greatly improve the resilience of ecosystems under future climate conditions. Floodplains also offer valuable storage for flood waters during highwater events and can help to recharge groundwater supplies (e.g., through Flood-MAR).

Funding and Grants

Adequate funding and grant opportunities are critical to supporting increased flood protection and climate resilience for the USJR region. Historically, lack of adequate funding in the region has impaired the implementation of flood system improvements, increased the backlog of deferred maintenance, and further compromised the aging and insufficient flood management system. Funding and grant opportunities are key for implementation of in-progress and proposed projects, regional priorities, and the recommendations described in the preceding subsections. Recommendations related to funding and grants are as follows:

- **Continue to identify and promote funding and grant opportunities that support flood protection and resiliency**: State and federal funding opportunities and resources have been compiled by the USJR RFMP region and are available on the regional website; continuing to update these resources is vital for identifying when new funding and grant opportunities become available. Additionally, promoting application of these opportunities through additional funding and additional resources, where available, will benefit local disadvantaged communities and agencies who have historically struggled to complete funding and grant applications. Lower local cost-shares on funding that is awarded enables, and provides much greater flexibility for, local agencies to implement more substantial and much needed flood protection improvement actions in the region.

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Appendix A

Additional Climate Action and Climate Adaptation Planning Efforts

A. Additional Climate Action and Climate Adaptation Planning Efforts

Several regional, county, and other local climate action and climate adaptation planning efforts are relevant to or related to the USJR Region's need for improved flood management and climate resilience. The following categories of plans were reviewed:

- Integrated Regional Management Planning (5 regional plans)
- Local Hazard Mitigation Plans (4 county plans)
- Groundwater Sustainability Plans (1 State-mandated plan)

Overviews of each plan are briefly summarized by the following information to help reveal existing efforts to identify, mitigate, and/or adapt to future climate conditions in and around the USJR Region.

1. Document
2. Source
3. Summary of Findings
4. Mitigation Planning
5. Adaptation Planning
6. Vulnerability and Risk
7. Adaptation Strategies

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Integrated Regional Water Management Planning

Document	Source	Summary of Findings	Mitigation Planning	Adaptation Planning	Vulnerability and Risk	Adaptation Strategies
2019 Westside-San Joaquin Integrated Regional Water Management Plan	https://sldmwa.org/OHTDocs/pdf_documents/Groundwater/WSJ_IRWMP_2019_Final_w_appendices.pdf	Early snowmelt can increase the region's vulnerability to flooding by consolidating runoff flows in the wet season. More intense storms are also predicted. Some general flood management strategies include improving existing levee systems. The region's vulnerability to floods is considered significant because of past critical flooding events with great consequences for the economy, infrastructure, assets, and residents, even in the relatively recent past.	Mitigation planning strategies identified are flood control enhancement, improvements to levee systems (e.g., floodwalls or setback levees), installation of pervious pavement, protection and enhanced management of floodplains, and construction of regional flood control infrastructure.	Adaptation planning strategies identified are improved Delta, regional, and local conveyance; system reoperation; ecosystem restoration; enhanced forest management; and future land use planning.	A flood management system vulnerability assessment was conducted, and the technical feasibility of addressing identified vulnerabilities was categorized as feasible. Some strategies identified are riparian habitat restoration, low-impact development (LID) stormwater runoff, and levee improvements.	Highlighted adaptation strategies include riparian restoration, LID, stormwater runoff management, and levee improvements.
Southern Sierra Integrated Regional Water Management Plan	https://www.southernsierrarwmg.org/uploads/7/4/7/8/74782677/november_2018_southern_sierra_irwmp_final_1.pdf	In terms of flooding, heavy winter rainstorms, earlier snowmelt, and dam failures could cause widespread flooding in the area. Over 30 reservoirs provide water storage, flood control, and infrastructure protection for this region. Higher magnitude storms, more rain-on-snow events, greater runoff flows, and increased risk of landslides contribute to a greater likelihood for flood events.	Mitigation planning strategies outlined are address climate impacts from flooding, integrate flood management with other activities, restore floodplain connectivity, and increase water storage capacity (through approaches such as targeted groundwater recharge). One goal of integrated flood management is to integrate land and water resources development to maximize the efficient use of floodplains. This plan states that this can be accomplished by integrating flood management with transportation, land development, resource management, and water resources projects.	Adaptation planning is not mentioned.	Examples of flood risk management approaches include levees, floodwalls, floodplain zoning, floodplain function restoration, disaster preparedness, and flood emergency response. For this region, FEMA does not maintain flood risk maps due to the lack of flood potential.	Identified adaptation strategies in this plan include watershed protection, forest restoration, riparian and floodplain habitat restoration and protection, risk analysis and mapping, and contingency planning. These strategies to help mitigate flood risk and minimize damage caused by future flood events. Increasing storage capacity can also provide greater water reserves on a short- and long-term basis while providing improved flood protection.
Yosemite-Mariposa Integrated Regional Water Management Plan	https://drive.google.com/file/d/1lBKveFvB1zSr4xm4iakInnDhKlD7P5xx/view	The Mariposa, El Portal, Coulterville, Wawona, and Hornitos areas are likely to experience increased flooding under future climate conditions. Some efforts to mitigate future flood impacts include removal of nonessential infrastructure from high flood risk areas.	The goal of this plan is to mitigate flood risk associated with future climate conditions by cooperating with local hazard mitigation planning efforts. Some mitigation strategies include encouraging permeable paving, increasing groundwater recharge, repairing road-stream crossings, encouraging meadow restoration in flood-prone areas, clearing debris and vegetation, and mitigating damage associated with vegetation loss to prevent mudslides and siltation.	Highlighted adaptation planning approaches include cooperating with local hazard mitigation efforts and raising public awareness of potential flood impacts.	In terms of risk and vulnerability, the region has limited floodplain areas due to the steep terrain. Some flooding danger in and downstream of the region is usually most prevalent during the spring months when snowmelt is typically at its peak.	One adaptation strategy mentioned is to encourage permeable paving or hardscape areas to improve water infiltration, flood control, and groundwater recharge.

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Document	Source	Summary of Findings	Mitigation Planning	Adaptation Planning	Vulnerability and Risk	Adaptation Strategies
2018 Merced Integrated Regional Water Management Plan Update	https://www.mercedirwmp.org/files/Merced%20IRWMP%20Final_w%20Appendices_smaller%20file.pdf	Flooding in the region is typically caused by infrequent, severe winter storms combined with snowmelt runoff from the foothills east of Merced County. Some flood management techniques include managing flood flows and stormwater runoff for public safety, water supply, groundwater recharge, and natural resource management.	In terms of mitigation planning, some creeks, such as Black Rascal Creek, have little or no flood control infrastructure. A mitigation strategy for that area could be improved flood management coordinated with surface storage and/or recharge facilities to maximize use of local supplies. For example, flood flows could be diverted to agricultural lands or to recharge areas in the southeastern portion of the region, which has sandy soils. The region currently employs groundwater recharge basins; similar projects could be implemented to provide additional flood control benefits.	Adaptation planning described includes managing flood flows and stormwater runoff, and controlling the volume of flood water stored and/or recharged to decrease flood-related damages.	Vulnerable areas include Bear Creek, Black Rascal Creek, Deadman Creek, Dry Creek, Fahrenheit Creek, Lake Yosemite, Mariposa Creek, Merced River, and San Joaquin River.	Structural adaptation strategies include setting back levees, modifying channels to include lining, high flow diversions, improved coordination of flood operations, maintaining facilities to secure the long-term preservation of flood management assets. Land use management approaches include floodplain function restoration to preserve and/or restore the natural ability of undeveloped floodplains to absorb, hold, and release floodwaters. Disaster strategies include information and education, disaster preparedness, and post-flood recovery.
Madera Integrated Regional Water Management Plan Proposition 1 Update	https://www.maderacountywater.com/wp-content/uploads/2019/09/Madera-Integrated-Regional-Water-Management-Plan-2019-Prop-1-Update.pdf	Flood events can cause major damage in Madera County. The impacts of these events can be mitigated by improving building ordinances, water storage, and flood conveyance. Future climate conditions could also alter the timing, frequency, and magnitude of flooding.	Mitigation planning is not mentioned.	The IRWMP states that one form of flood adaptation planning could be flood control with better building ordinances, water storage, and flood conveyance. Identified vulnerabilities can be addressed by increasing flood channel capacity and constructing additional storage facilities.	Higher flows in Madera County under future conditions could exacerbate future flooding unless sufficient upstream storage is constructed. As a result, floodplain zoning and decreasing the number of high value (more expensive) development could help the area mitigate projected flooding issues.	Some strategies outlined in the plan include conveying flood water into public irrigation canals to increase the quantity of surface water delivered from the San Joaquin River. Many sloughs, streams, flood bypass channels, irrigation canals, and rivers convey excess flood water during storm events. Increasing the capacity of each of these channels can also improve the conveyance of flood waters through the county.

Local Hazard Mitigation Plans

Document	Source	Summary of Findings	Mitigation Planning	Adaptation Planning	Vulnerability and Risk	Adaptation Strategies
Fresno County Multi-Hazard Mitigation Plan	https://www.co.fresno.ca.us/home/showdocument?id=24743	Primary flood control measures in Fresno include flood control reservoirs and levee systems.	Mitigation planning strategies include replacing old drainage systems, conducting feasibility studies for flood detention facilities, and analyzing flood water conveyance facilities.	Adaptation planning is not mentioned.	The region is likely to experience additional flood events under future climate conditions. The plan also conducts a vulnerability assessment to evaluate levee failure and potential impacts adjacent communities. Fresno has the largest population living in a 500-year flood zone, and Firebaugh has the largest population living in a 200-year flood hazard zone.	Adaptation strategies include implementation of a flood awareness program and replacement of outdated storm drawings.

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Document	Source	Summary of Findings	Mitigation Planning	Adaptation Planning	Vulnerability and Risk	Adaptation Strategies
Madera County Local Hazard Mitigation Plan	https://www.maderacounty.com/home/showdocument?id=362	In Madera County, increased heat and precipitation events can increase the frequency and magnitude of flooding. The plan conducts a flood risk assessment and develops mitigation approaches for future flood events.	Much of the population growth of Madera County occurs in urban areas. Slowing population growth in areas subjected to localized flooding may help to mitigate future flood risk.	Adaptation planning is not mentioned.	Hidden Lake Dam does not provide adequate protection for a 500-year flood event. During flood flows, Friant Dam can release water into the Friant-Kern Canal and Madera Canal if both canals have sufficient capacity. The plan conducts a vulnerability assessment to evaluate vulnerabilities and risks from 100-year and 500-year flood events. The number of parcels at risk in a 100-year event is 4,336, and in a 500-year event is 3,215.	As part of its flood management strategy, Madera County is engaging in flood mapping efforts to better evaluate potential threats to existing communities.
Merced County Multi-Jurisdictional Hazard Mitigation Plan	https://web2.co.merced.ca.us/pdfs/oes/Merced_MJHMP_2021_Draft.pdf	Historically, Merced County has had the highest risk of flooding during the winter and spring months. The county's plan conducts a hazard analysis and risk summary for flood and levee failure in the area. Mitigation strategies are continued compliance with the National Flood Insurance Program.	Mitigation strategies include ensuring compliance with the National Flood Insurance Program, increasing water storge to mitigate flooding and drought, and incorporating flood mitigation into local planning efforts.	A flood vulnerability assessment was performed on Merced County. The analysis estimated that the City of Merced has the largest estimated damages at $736 million. Among all jurisdictions, the total estimated damages are $1.24 billion.	Findings from the flood vulnerability assessment indicate that flood hazards are considered "extensive" in terms of geographic area, "likely" in terms of probability, "catastrophic" in terms of magnitude, and "high" in overall significance. Approximately 50,000 people in Merced County live in a 100-year flood hazard zone and 11,000 people live in a 500-year flood hazard zone.	Adaptation strategies include consideration of extreme weather and associated risks during future development planning.
Mariposa County Local Hazard Mitigation Plan	http://www.mariposacounty.org/DocumentCenter/View/80852/Public-Draft-LHMP_Jan-6-2020_compiled-	Mariposa County is subjected to localized flooding. There are roughly 27 square miles with a 1% annual chance of flooding. Localized flooding areas are generally flat urbanized areas. Hazard identification and risk assessment was conducted for flooding in Mariposa County. Some mitigation strategies include participation in national flood insurance programs.	Mitigation planning approaches include retrofitting structures and facilities to minimize damage from high winds, earthquakes, floods, and wildfires. Other strategies include implementation of vegetative management programs and localized flood control projects(ring levees and floodwall systems, for example).	Adaptation planning is not mentioned.	There are roughly 27 square miles in Mariposa County with a 1% chance of flooding. These areas include Mariposa Creek, Mariposa River, and the Merced River. Localized flooding areas are typically flat urbanized areas such as the towns of Mariposa, El Portal, Coulterville, Wawona, and Hornitos.	Adaptation strategies are not mentioned.

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Groundwater Sustainability Plans

Document	Source	Summary of Findings	Mitigation Planning	Adaptation Planning	Vulnerability and Risk	Adaptation Strategies
Groundwater Sustainability Plan-Delta Mendota	https://sgma.water.ca.gov/portal/gsp/preview/38	Flood events present the highest threat to urban areas along the San Joaquin River. The flood management system in the region consists of reservoirs to regulate runoff, bypasses to channel flows at lower elevations, and levees that line major rivers to protect adjacent communities.	Mitigation planning is not mentioned.	The Mendota GSP plans to implement flood water capture projects.	A flood-related vulnerability assessment was not conducted.	Adaptation strategies are not mentioned.

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Appendix B
Supplemental Climate Information

B. Supplemental Climate Information

Historical Climate Trends

Temperature

From 1961 to 1990, the average maximum temperature in Merced County was 75 degrees Farenheit (°F) while the average maximum temperature in Madera County was 68 °F (Fernandez-Bou et al. 2021). The average minimum temperature in Merced County was 47.3 °F while the average minimum temperature in Madera County was 40.8 °F (Fernandez-Bou et al. 2021).

Extreme Temperature

From 1961 to 1990, the number of extreme days (defined as days with a maximum daily temperature greater than 101.6 °F) was estimated to be 4 days for both Merced and Madera Counties (Fernandez-Bou et al. 2021). In Merced County, on average, there roughly 98 days above 90 °F and 30 days where minimum temperatures are below freezing (Merced County 2021).

Precipitation

The average annual precipitation from 1961 to 1990 was estimated to be 12.2 inches for Merced County and 26 inches for Madera County (Fernandez-Bou et al. 2021). Annual average precipitation in the Westside-San Joaquin Integrated Regional Water Management (IRWM) region (spanning the San Joaquin, Stanislas, Merced, Madera, Fresno, and Kings counties) was between 9 and 11 inches (San Luis and Delta-Mendota Water Authority 2019). Monthly annual average precipitation between 1899 and 2016 at the Merced Municipal Airport weather station is presented in Figure B1-1. Daily average and extreme precipitation depths at the same location are presented in Figure B1-2.

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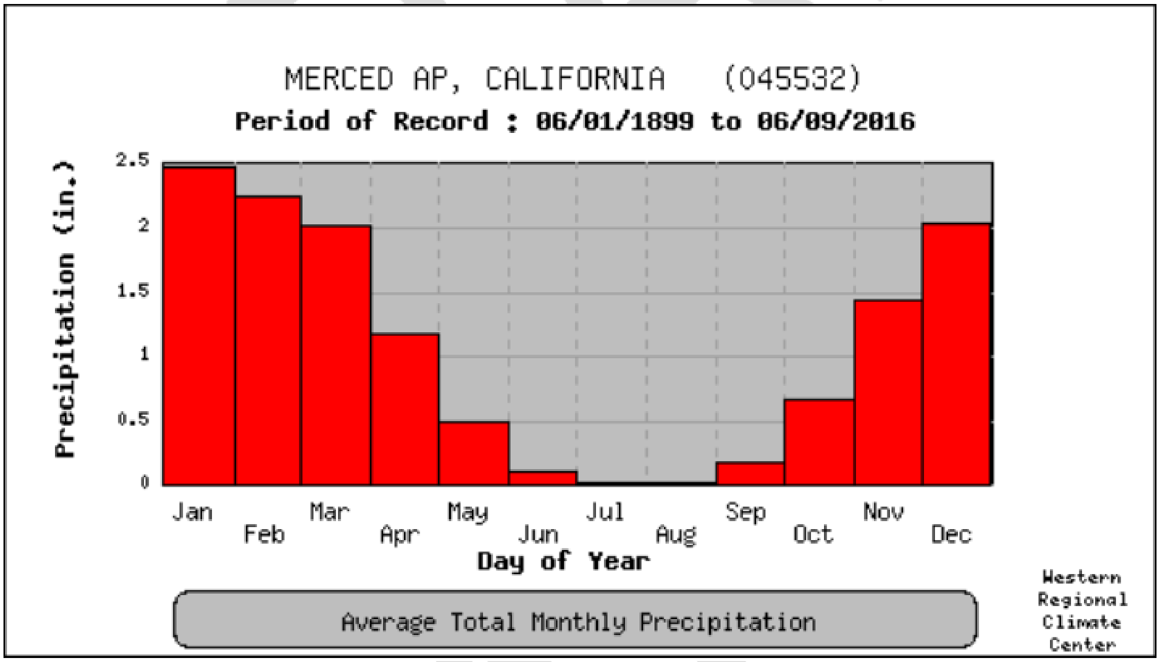
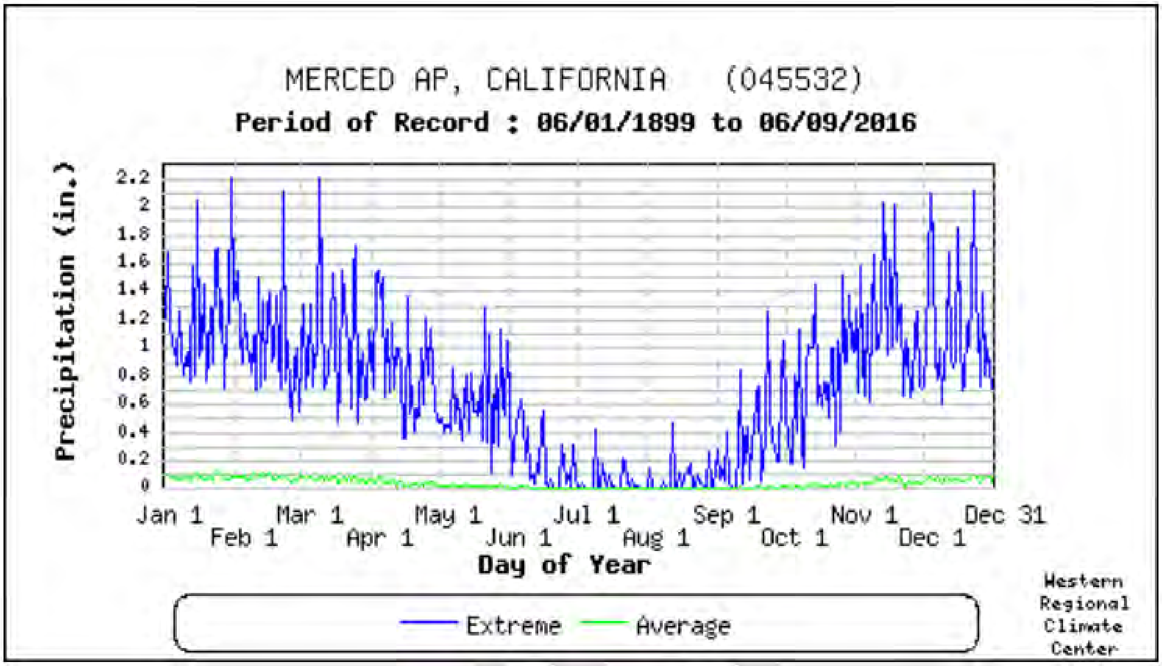
Figure B1-1. Monthly Average Total Precipitation from 1899 to 2016 from Merced Municipal Airport Weather Station



Source: Merced County 2021

Figure B1-2. Daily Precipitation Average and Extreme from 1899 to 2016 from Merced Municipal Airport Weather Station



Source: Merced County 2021

Extreme Precipitation

Extreme precipitation events in the Southern Sierra IRWM region (spanning a portion of Fresno, Tulare, and Madera counties) have historically caused 10 to 20 inches of rain and excess peak flows of 50,000 cubic feet per second (Southern Sierra Regional Water Management Group 2018). In Merced County, heavy rainstorms have been a source of widespread flooding. Based on available National Centers for Environmental Information (NCEI) data, 23 heavy rain incidents have occurred from 1998 to 2018, totaling approximately $2 million in property damage and $15 million in crop damages (Merced County 2021).

Flooding

According to the Federal Emergency Management Agency (FEMA), approximately 380,000 acres in Merced County are located within a 100-year floodplain. In general, flooding in this region is caused by extreme precipitation events in combination with snowmelt runoff (Merced Integrated Region Water Management Authority 2019).

In Merced County, heavy rainstorms have caused widespread flooding that has led to severe drainage issues. Historically, flooding has occurred in Merced County approximately every five years (Merced County 2021). For the City of Merced in particular, flooding can be attributed to increased flood stage that exceeds the northern and southern banks of Bear Creek. According to the National Oceanic and Atmospheric Administration (NOAA) database, 54 flash flood events occurred in Merced County between 1950 and 2020. FEMA's Flood Insurance Study indicates that Merced County had 9 flood events between 1969 and 2017 (Merced County 2021).

Madera County has been particularly susceptible to flooding due to the region's relatively flat topography. In Madera County, most of the historical flooding can be attributed to the Fresno and Chowilla rivers. Historical flooding can be attributed to natural obstruction of flows, decreased channel capacity, and levee failure (Merced Integrated Region Water Management Authority 2019). In Fresno County, levee failures have occurred several times between 1955 and 2017.

Land Subsidence

Land subsidence in the San Joaquin region has resulted from groundwater overdrafting from the deep confined aquifers (Madera Regional Water Management Group 2019). From 1920 to 1983, soils in the Los Banos region subsided roughly 4 feet in some locations. In Madera County, land subsidence has reduced the flow capacity of several canals (Madera Regional Water Management Group 2019). Figure B1-3 shows the spatial distribution of subsidence in the Merced area.

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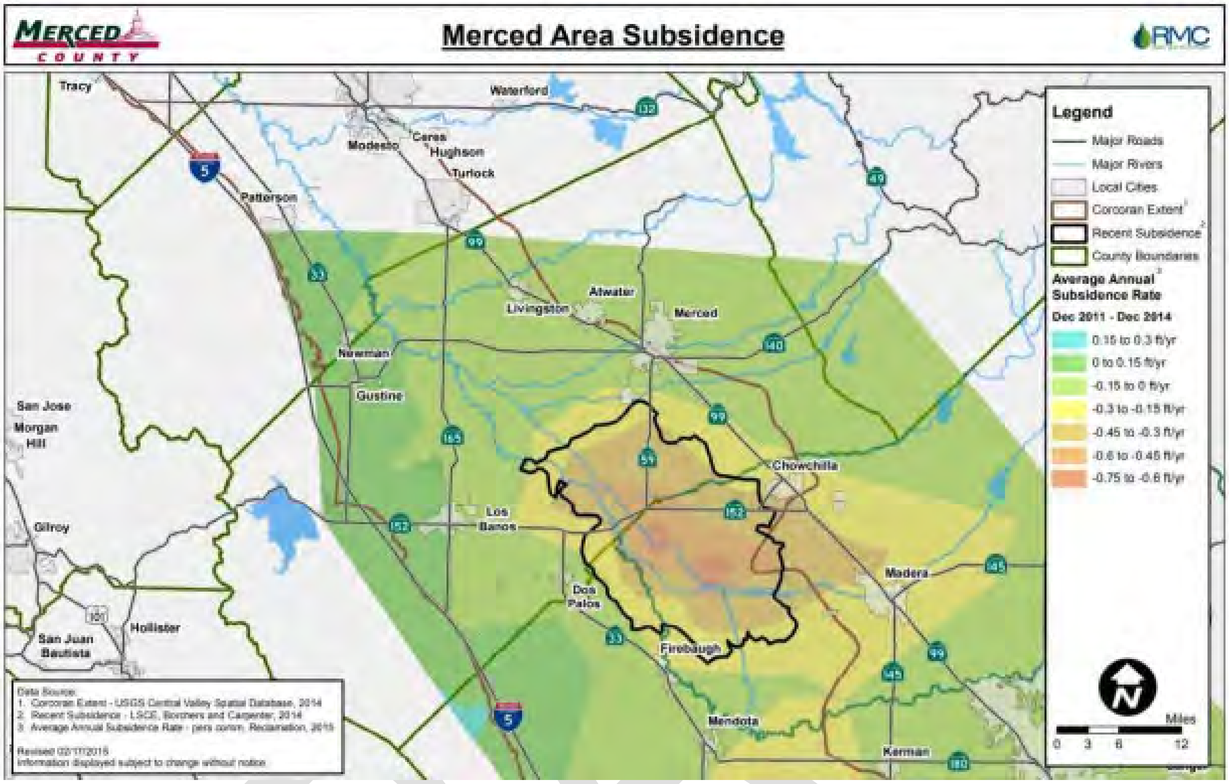
Figure B1-3. Land Subsidence in Merced County Area

Average annual subsidence rates for the Merced County area between December 2011 and 2014.



Source: Merced County 2021

Groundwater

According to the California Department of Water Resources, the groundwater basins in the Upper San Joaquin River (USJR) Region are categorized as a critically over drafted or high priority (Hanak 2019). For the San Joaquin Valley in general, groundwater overdraft has accelerated over the past decade. Between 1988 and 2002 the average overdraft was approximately 1.3 million acre-feet (MAF) per year. From 2003 to 2017, groundwater overdraft increased to 2.4 MAF per year (Hanak 2019).

In the Merced Subbasin, groundwater storage has decreased by approximately 45.3 MAF over the last 20 years. In Figure B1-4 below, the cumulative change in groundwater storage shows a projected decrease of roughly 2.5 MAF from 1995 to 2015 (Merced Integrated Region Water Management Authority 2019).

Groundwater in the Westside-San Joaquin IRWM region (spanning the San Joaquin, Stanislas, Merced, Madera, Fresno, and Kings counties) has increased by 2.2 feet from 1970-2000 (San Luis and Delta-Mendota Water Authority 2019). According to the 2008 Groundwater

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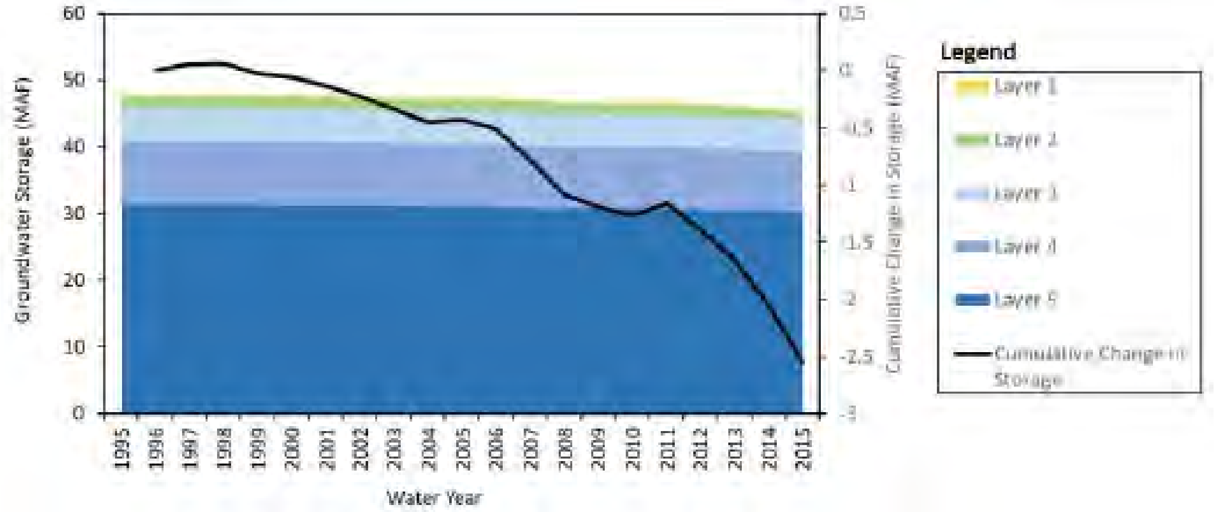
Management Plan Update, groundwater levels in the Merced Subbasin declined 3.7 feet between 1995 and 2007 (Madera Regional Water Management Group 2019).

Figure B1-4. Historical Modeled Change in Storage of the Merced Subbasin from 1995 to 2015

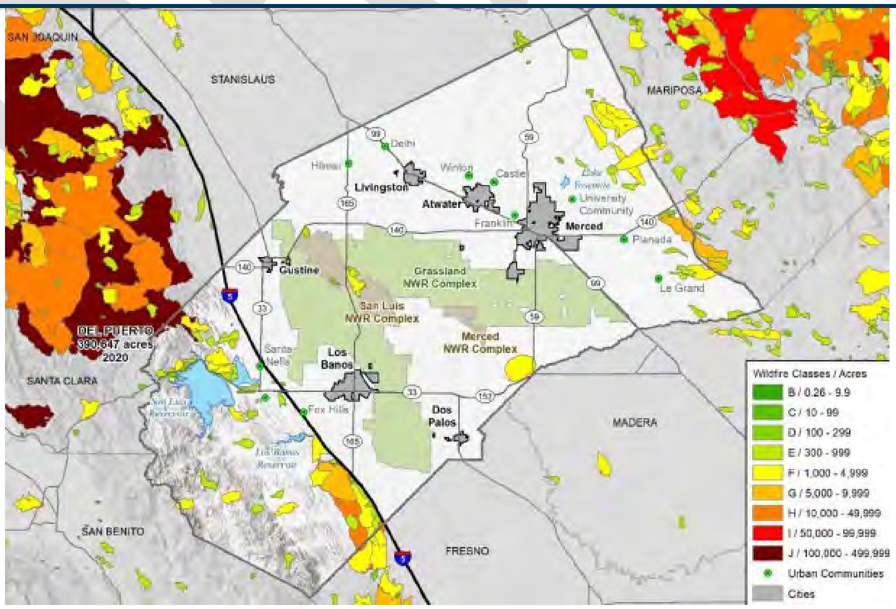


Source: Madera Regional Water Management Group 2019

Wildfires

In Merced County, there have been 101 wildfires from 1950 to 2018, resulting in roughly 110,000 acres burned. Figure B1-5 depicts Merced County's fire history from 1911 to 2020.

Figure B1-5. Merced County's Historical Burned Areas from 1911 to 2020



Source: Merced County 2021

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Supplemental 2042 and 2072 Climate Trends

Changes in Extreme Temperature

To assess projected changes to extreme temperatures, a threshold temperature was determined using the 98th percentile of daily maximum temperature over the historical reference period (between January 1, 1971 and December 31, 2000) for the USJR Region, consistent with the 2022 CVFPP Update approach. This threshold temperature (39.4 degrees Celsius [roughly 103 degrees Farenheit]) was compared with daily maximum temperatures for the historical reference period and projected future period (e.g., centered on 2042 or 2072). Days determined to be greater than or equal to the threshold temperature were summed for each water year (October 1 to September 30). The average number of additional days per year exceeding the threshold temperature are presented in Figures B2-1 (2042 conditions) and B2-2 (2072 conditions). The Upper Merced and Upper San Joaquin watersheds have been excluded from Figure B2-1 due to lack of days exceeding this temperature threshold.

Figure B2-1. Projected Deviation from Historical Days Exceeding Threshold Maximum Temperature by 2042

USJR Region and surrounding watersheds

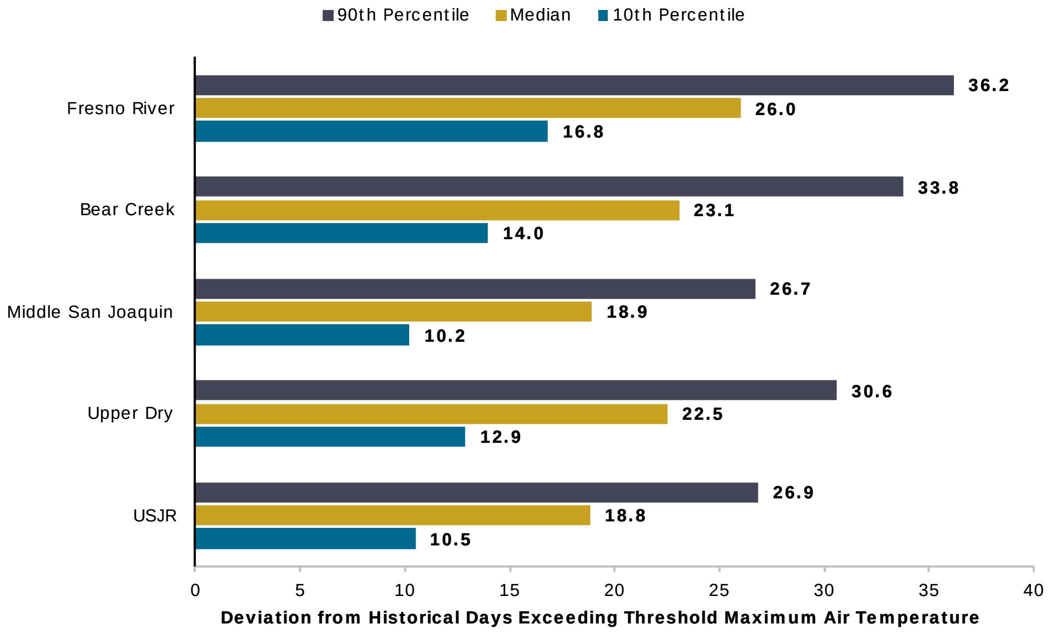
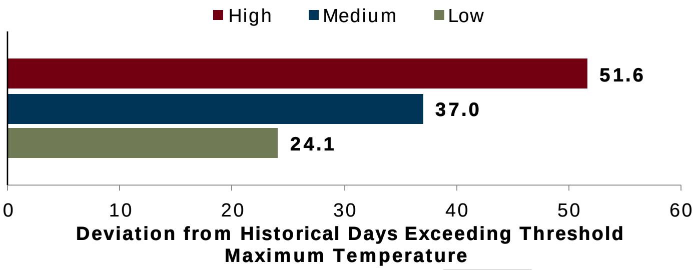


Figure B2-2. Projected Deviation from Historical Days Exceeding Threshold Maximum Temperature by 2072

USJR Region under the low, medium, and high climate scenarios



Source: Adapted from California Department of Water Resources 2022

Changes in Extreme Precipitation, Snowpack, and Runoff

Projected changes to mean 3-day annual maximum precipitation amounts were assessed for 2042 (Figure B2-3) and 2072 (Figure B2-4) conditions to examine shifts in extreme precipitation events. Average and 99th percentile changes to mean 3-day annual maximum precipitation were calculated. Near-term changes show an average increase between 5.1 to 8.8% and a 99th percentile increase between 23 to 33.8%. In the late term, the magnitude of these changes increases dramatically under the high climate scenario, with the medium and low scenarios somewhat reflecting near-term projections for the 99th percentile. Late-term average changes to the medium and low scenarios show a roughly 3% increase and decrease, respectively.

The increase in mean 3-day 99th percentile annual maximum precipitation can be attributed to more intense atmospheric river (AR) precipitation events. AR events have historically contributed between roughly one-third and one-half of California's annual precipitation (Florsheim and Dettinger 2015); however, increased warming from climate change will likely result in less frequent, more severe AR events, leading to an increased prevalence of AR conditions (Espinoza et al. 2018; Huang et al. 2020). Furthermore, AR storms are projected to contribute to a greater amount of total annual precipitation under future conditions (Gershunov et al. 2019; California Department of Water Resources 2022). Recently, AR events in late 2022 and early 2023 have contributed a significant amount of rainfall to the USJR region and Central Valley as a whole, resulting widespread flooding, evacuations, property damages, and loss of life.

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Figure B2-3. Projected Change in Mean 3-Day Annual Maximum Precipitation by 2042

USJR Region and surrounding watersheds

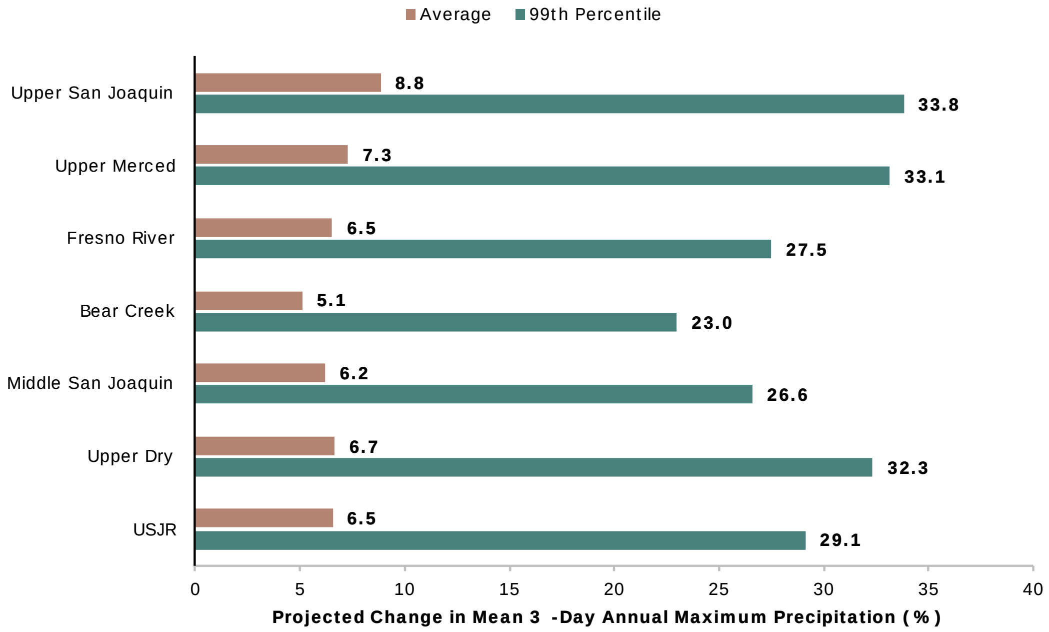
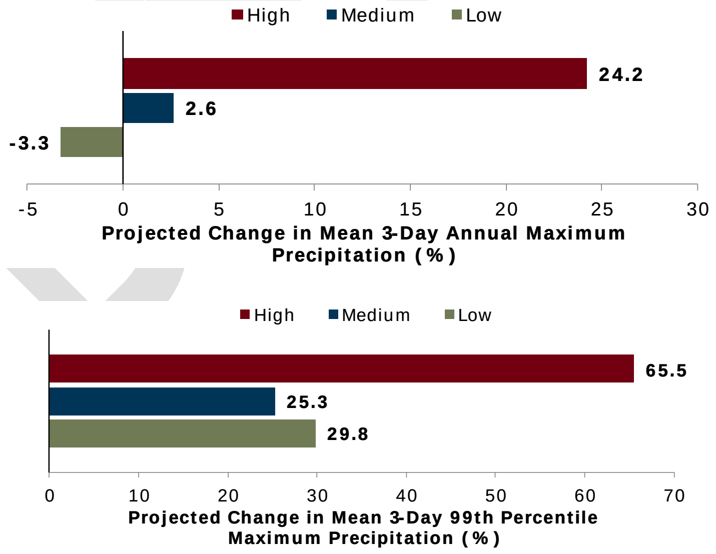


Figure B2-4. Projected Change in Mean 3-Day Annual Maximum Precipitation by 2072

Projected percent change in mean 3-day average (top bar chart) and 99th percentile (bottom bar chart) annual maximum precipitation in the Upper San Joaquin River region under the low, medium, and high climate scenarios



Source: Adapted from California Department of Water Resources 2022

Figure B2-5. Projected Change in April 1 Snowpack by 2042

Upper San Joaquin and Upper Merced watersheds

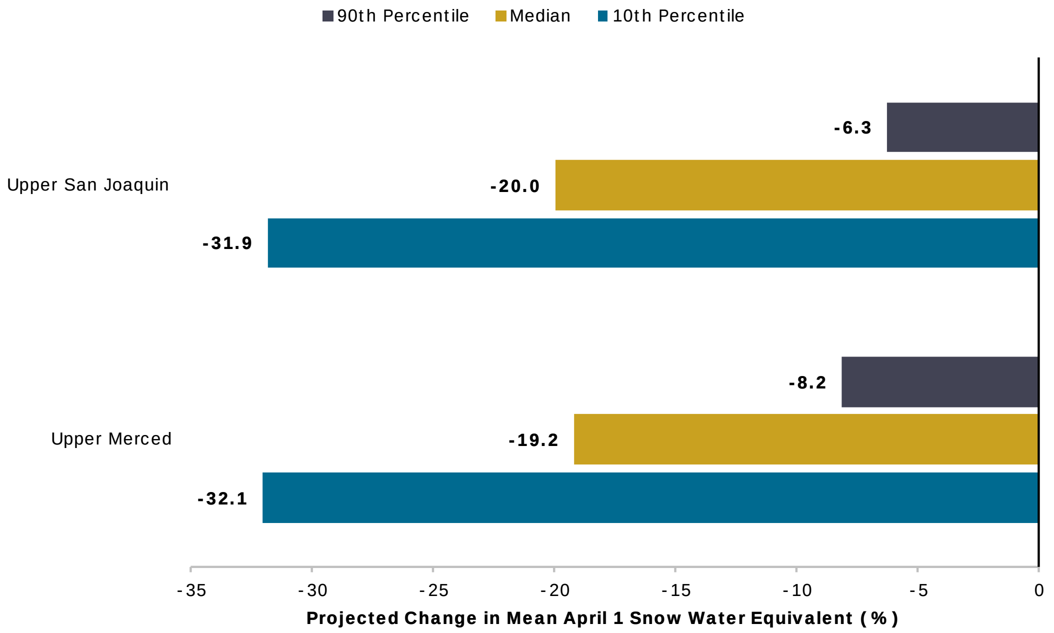


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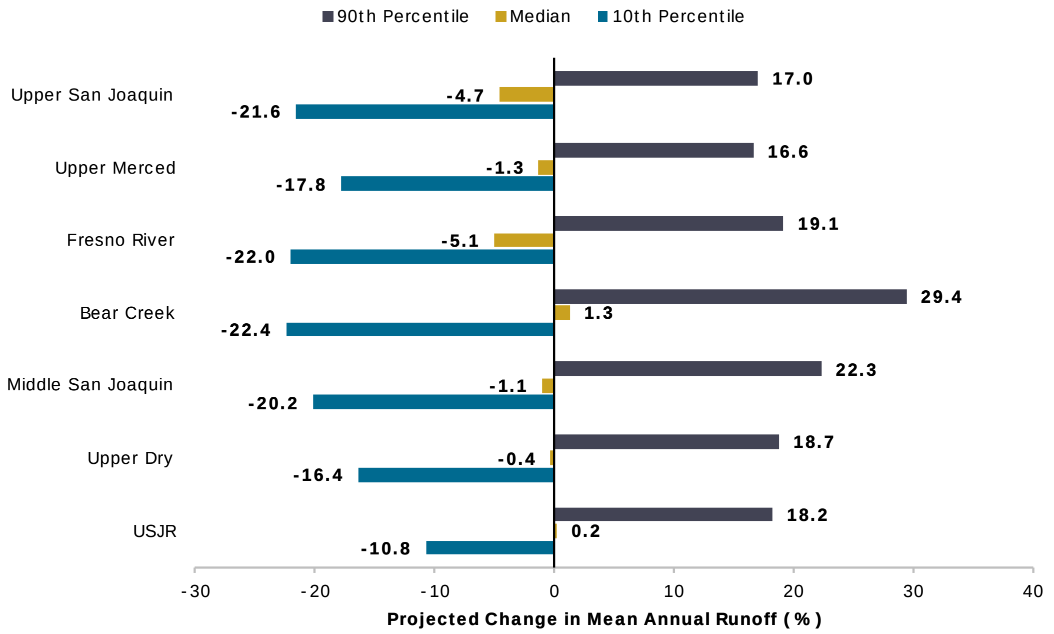
Figure B2-6. Projected Change in Mean Annual Runoff by 2042

USJR Region and surrounding watersheds



Supplemental Findings from Supporting Literature

Temperature

In both Merced and Madera counties, annual maximum temperatures and annual minimum temperatures are expected to increase across all emissions scenarios into the end of the century.

Annual Maximum Temperature

In Merced County, mid-century (2035 to 2064) average annual maximum temperatures are projected to increase between 4 to 5 °F under both the medium (Representative Concentration Pathway [RCP] 4.5) and high (RCP 8.5) emissions scenario from the historical average. By the end of the century (2070 to 2099), annual maximum temperatures are projected to increase between 5 to 8.5 °F under both the medium and high emissions scenarios (Fernandez-Bou et al. 2021).

In Madera County, mid-century (2035 to 2064) average annual maximum temperatures are projected to increase between 4.2 to 5.2 °F under both the medium and high emissions scenario from the historical average. End of the century (2070 to 2099) average annual maximum temperatures are projected to increase between 5.4 to 8.9 °F under both the medium and high emissions scenarios (Fernandez-Bou et al. 2021).

Annual Minimum Temperature

In Merced County, mid-century (2035 to 2064) average annual minimum temperatures are projected to increase by 3.4 to 4.3 °F under both the medium and high emissions scenarios from the historical average. By the end of the century (2070 to 2099), annual minimum temperatures are projected to increase from 4.4 to 7.7 °F under both the medium and high emissions scenario (Fernandez-Bou et al. 2021).

In the Madera County, mid-century (2035 to 2064) average annual minimum temperature is projected to increase by 3.5 to 4.5 °F under both the medium and high emissions scenarios from the historical average. By the end of the century (2070 to 2099), average annual minimum temperatures are projected to increase from 4.6 to 8 °F under both the medium and high emissions scenario (Fernandez-Bou et al. 2021).

Extreme Temperature

Extreme temperature days are expected to increase in both the Merced and Madera counties. In Merced County the number of extreme heat days is expected to increase between 18 and 25 days compared to the historical average under the medium and high emissions scenarios between 2035 and 2064. In Madera County the number of extreme heat days is also expected

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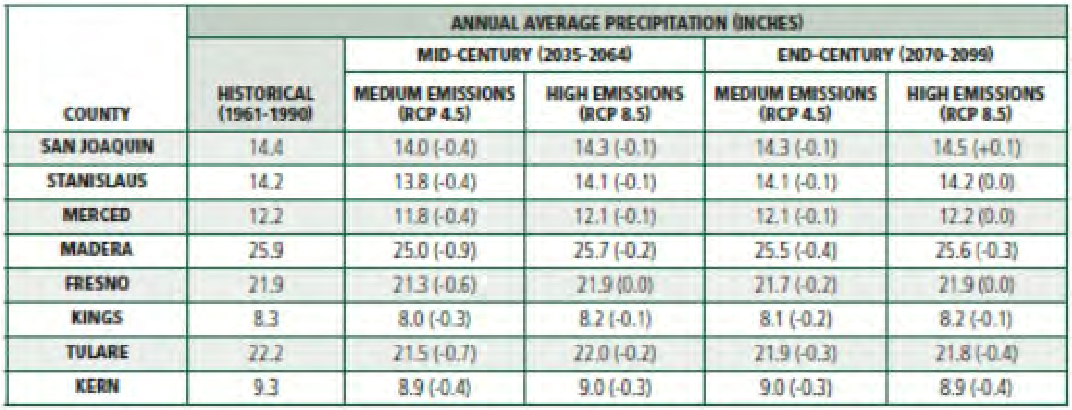
to increase between 21 and 29 days compared to the historical average under the medium and high emission scenarios between 2035 and 2064 (Fernandez-Bou et al. 2021).

By the end of the century (between 2070 to 2099) the number extreme heat days in Merced County is expected to increase between 26 and 52 days under the medium and high emissions scenarios. In Madera County, the number of extreme heat days into the end of the century is also expected to increase between 31 and 60 days under the medium and high emissions scenarios (Fernandez-Bou et al. 2021).

Precipitation

Annual precipitation is expected to decrease compared to historical trends for both Merced and Madera Counties under the medium and high emissions scenarios. In Merced County between 2035 to 2064, the annual average precipitation expected to decrease between 0.4 to 0.1 inches under the medium and high emissions scenarios, respectively. In Madera County between the same time period, the annual average precipitation is also expected to decrease between 0.9 to 0.1 inches under the medium and higher emission scenarios, respectively (Fernandez-Bou et al. 2021). Figure B3-1 describes the projected changes in annual average precipitation for both the Merced and Madera Counties.

Figure B3-1. Annual Average Precipitation by County in the San Joaquin Region



COUNTY	ANNUAL AVERAGE PRECIPITATION (INCHES)				
		MID-CENTURY (2035-2064)		END-CENTURY (2070-2099)	
	HISTORICAL (1961-1990)	MEDIUM EMISSIONS (RCP 4.5)	HIGH EMISSIONS (RCP 8.5)	MEDIUM EMISSIONS (RCP 4.5)	HIGH EMISSIONS (RCP 8.5)
SAN JOAQUIN	14.4	14.0 (-0.4)	14.3 (-0.1)	14.3 (-0.1)	14.5 (+0.1)
STANISLAUS	14.2	13.8 (-0.4)	14.1 (-0.1)	14.1 (-0.1)	14.2 (0.0)
MERCED	12.2	11.8 (-0.4)	12.1 (-0.1)	12.1 (-0.1)	12.2 (0.0)
MADERA	25.9	25.0 (-0.9)	25.7 (-0.2)	25.5 (-0.4)	25.6 (-0.3)
FRESNO	21.9	21.3 (-0.6)	21.9 (0.0)	21.7 (-0.2)	21.9 (0.0)
KINGS	8.3	8.0 (-0.3)	8.2 (-0.1)	8.1 (-0.2)	8.2 (-0.1)
TULARE	22.2	21.5 (-0.7)	22.0 (-0.2)	21.9 (-0.3)	21.8 (-0.4)
KERN	9.3	8.9 (-0.4)	9.0 (-0.3)	9.0 (-0.3)	8.9 (-0.4)

Source: Fernandez-Bou et al. 2021

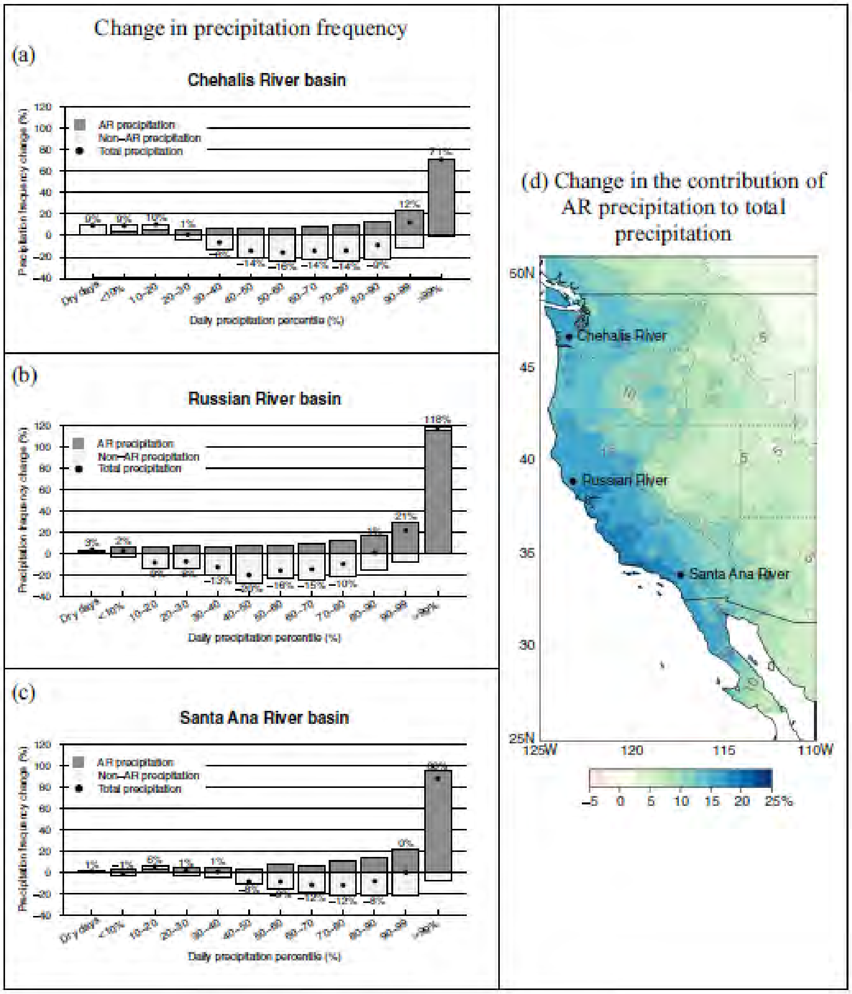
Extreme Precipitation

Historically, AR events have contributed approximately one-third to one-half of California’s annual precipitation (Florsheim and Dettinger 2015); however, increased warming under future climate conditions is anticipated to 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). ARs are projected to contribute to a greater amount of total annual precipitation under future conditions (Gershunov et al. 2019). Additionally, short-duration rainfall extremes are likely to lead to an increase in flash flood events under future conditions (Fowler et al. 2021).

To illustrate this change in example watersheds outside of the San Joaquin River Basin, Figure B3-2 presents the changes in precipitation frequencies for both atmospheric river and non-atmospheric river precipitation in the Chehalis, Russian, and Santa Ana River Basins. For each basin, non-atmospheric river precipitation events are expected to decrease in frequency for medium intensity precipitation. High intensity precipitation projections appear to be dominated by an increase in atmospheric river events. Overall, atmospheric river precipitation events increase across the range of precipitation intensities, suggesting a shift in rainfall contribution from non-atmospheric river precipitation (Gershunov et al. 2019).

Figure B3-2. Projected Trends in Atmospheric River Precipitation

Future changes in daily precipitation frequency binned by percentile ranges of daily intensity (% of historical climatology) for the Chehalis, Russian, and Santa Ana river basins (left panels). The right panel illustrates the average change in the contribution of AR-related precipitation to total precipitation.

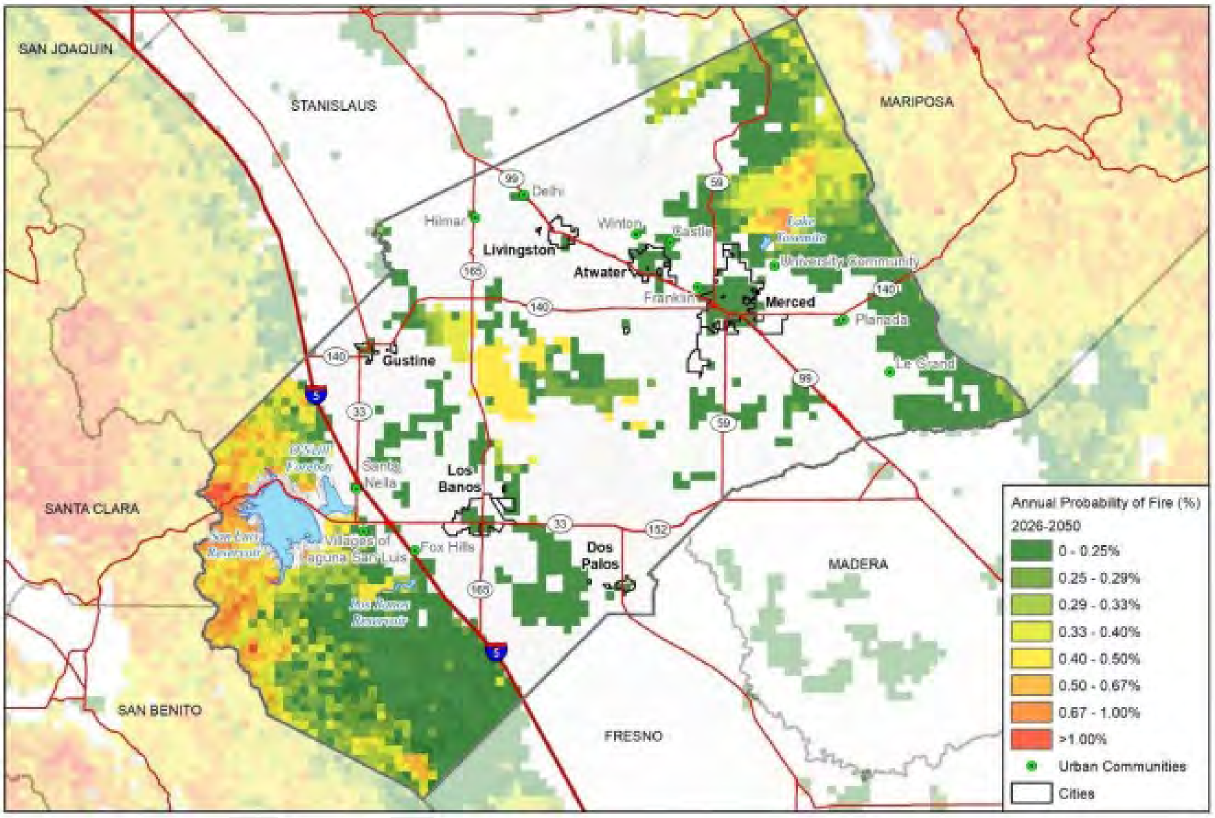


Source: Gershunov et.al. 2019

Wildfire

Mid-century projections (2035 to 2064) estimate that the annual average area burned is anticipated to increase between 788 to 1,564 acres under the medium and high emissions scenario for the San Joaquin Valley compared to historical values. End of century projections (2070 to 2099) estimate that the annual average area burned is estimated to increase between 470 to 611 acres under the medium and high emissions scenarios for the San Joaquin Valley compared to historical values (Fernandez-Bou et al. 2021). Figure B3-3 shows the spatial distribution of annual wildfire probabilities in Merced County from 2026 to 2050.

Figure B3-3. Merced County Annual Probability of Fire from 2026 to 2050



Source: Merced County 2021

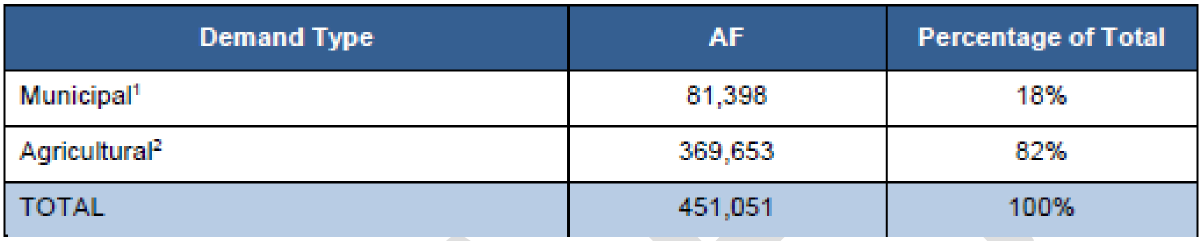
Water Quality

Surface water quality can be vulnerable due to increased flow duration and heavy precipitation events. Groundwater quality can be vulnerable due to increased pressure on aquifers during water supply shortages (San Luis and Delta-Mendota Water Authority 2019). Post-wildfire runoff can also introduce pollutants into waterbodies, degrading surface water quality (Merced Integrated Region Water Management Authority 2019).

Water Supply

Under future climate conditions, decreased surface water availability in the region are likely to result in increased groundwater pumping. The water demand in the Merced IRWM Region is projected to be 450,000 AF per year by 2040. Figure B3-4 provides an overview of municipal and agricultural water demand projections for the Merced Subbasin under 2040 conditions. With decreased summertime flows and projected temperature increases, increased water use can exacerbate low flow conditions (Merced Integrated Region Water Management Authority 2019)

Figure B3-4. Projected Water Demand in the Merced Subbasin under 2040 Conditions



Demand Type	AF	Percentage of Total
Municipal[1]	81,398	18%
Agricultural[2]	369,653	82%
TOTAL	451,051	100%

Source: Merced Integrated Region Water Management Authority 2019

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