

5. Water Resource Vulnerabilities

5.1 Introduction

The Russian River Watershed Resilience Pilot employs an integrated vulnerability assessment to evaluate how evolving climate hazards are projected to impact a series of eight water-related sectors across the planning area. These sectors include surface water supply, groundwater supply, flood management, ecosystems, water quality, recreation, hydropower, and community and equity considerations. Evaluation of sector-specific vulnerabilities to climate change supports identification of key areas of climate sensitivity and characterization of projected impacts, informing areas where subsequent adaptation strategies should be developed and prioritized.

The vulnerability assessment is characterized by both qualitative and quantitative evaluations. The qualitative vulnerability assessment employs a scoring framework to characterize effects of climate hazards on individual components of water sectors throughout the planning area in terms of sensitivity, adaptive capacity, and vulnerability. The quantitative assessment builds on these qualitative findings to identify vulnerabilities through application of a projection-based modeling framework coupled with a series of indicators and metrics for each water-related sector. This chapter provides an overview of findings and results from these evaluations; additional details on the vulnerability assessment are documented in Appendix C.

5.2 Summary of Key Vulnerabilities

In summary, eight water-related sectors across the Russian River watershed were evaluated through qualitative and quantitative methods to identify areas of high vulnerability to changing climate conditions. Table 5-1 provides an overview of key vulnerabilities that were identified through each sector-specific assessment. Brief descriptions are provided to highlight the primary drivers for these vulnerabilities. Results from these evaluations ultimately highlight areas where adaptation strategies are most needed to address the projected impacts of climate change and improve the overall resilience of the watershed to future conditions.

Table 5-1. Overview of Key Vulnerabilities Identified for Each Water-related Sector

Sector	Key Vulnerabilities
Surface Water Supply	<ul style="list-style-type: none"> ▪ Impaired water supply resiliency for Upper Russian River water users due to a higher frequency of water shortages driven by the reduction in unimpaired base flow exacerbated by reductions in Eel River transfers. ▪ Lower Lake Mendocino annual storage due to more frequent and severe drought conditions exacerbated by reduced transfers from the Eel River. ▪ Impaired water supply resiliency for Lower Russian River water users and Lake Sonoma annual storage during periods of severe drought.
Groundwater Supply	<ul style="list-style-type: none"> ▪ Reduced groundwater storage during dry periods due to increasing temperatures, higher agricultural demand, and reductions in Lake Mendocino storage that drive decreases in the contribution of streamflow in replenishing aquifers. ▪ Higher groundwater inflows during wet periods due to increases in seasonal precipitation and higher streamflow.

Sector	Key Vulnerabilities
Flood Management	<ul style="list-style-type: none"> ▪ Increased flood risk for residential communities near Santa Rosa Creek due to increasing severity of extreme precipitation events under future conditions. ▪ Increased flood risk for populated areas of Cloverdale, Healdsburg, and Guerneville due to higher peak flows along the Russian River. ▪ Increased flood risk to structures and populations near Mark West Creek and Green Valley Creek due to backwater effects from increased stages along the Russian River.
Water Quality	<ul style="list-style-type: none"> ▪ Reduced Lake Mendocino cold water pool due to warmer reservoir inflows and decreased reservoir water surface elevations. ▪ Additional stress for Russian River fisheries due to increased water temperatures and reduced dissolved oxygen. ▪ Sea level rise and seawater intrusion in estuary and Petaluma Valley and Sonoma Valley groundwater basins
Ecosystems	<ul style="list-style-type: none"> ▪ Reduced mainstem Russian River juvenile rearing due to increased water temperatures, reduced dissolved oxygen, and decreased flows in the late spring. ▪ Lower tributary over-summer survival due to a higher frequency of seasonal drying and reduced availability of wetted habitat. ▪ Risks to egg incubation during late winter and spring due to higher peak flows and increased water temperatures. ▪ Challenges for adult Chinook salmon migration due to the reduction of early fall flows. ▪ Decreased Russian River Estuary juvenile steelhead rearing and other salmonid life stages due to reductions in flows outside of the wet season, more frequent inlet closure events, and increased water temperatures.
Recreation	<ul style="list-style-type: none"> ▪ Decreased boat ramp access for recreation at Lake Mendocino due to a higher frequency of periods with lower storage. ▪ Reduced opportunities for boating and fishing along the Russian River due to a higher frequency of flows below key recreation thresholds.
Hydropower	<ul style="list-style-type: none"> ▪ Decreased hydropower production at Lake Mendocino due to more frequent lower minimum instream flow requirements..
Community and Equity	<ul style="list-style-type: none"> ▪ Heightened risk for socially vulnerable communities in Santa Rosa, Ukiah Valley, the Cloverdale-Healdsburg-Windsor corridor, and surrounding Lake Mendocino due to increased floodplain inundation footprints, more frequent wildfires, extreme heat exposure, and longer and more severe drought events.

5.3 Vulnerability Assessment Approach

The *qualitative* component of the vulnerability assessment utilizes a vulnerability matrix that provides a structured framework for evaluating climate-related risks across multiple sectors of the planning area. This matrix organizes individual components of the Russian River watershed, such as ecosystems, hydropower facilities, water supply infrastructure, flood management assets, water quality receptors, agricultural

zones, and recreation/tourism resources, against key climate stressors of extreme heat, drought, extreme precipitation and flooding, wildfire, and sea level rise, where applicable. Each entry combines concise narrative descriptions of climate sensitivities and adaptive constraints with standardized numeric ratings for sensitivity, adaptive capacity, and vulnerability to climate stressors. These narratives were informed by existing watershed management plans, agency reports, and subject-matter expertise, ensuring that local context and sector-specific drivers of risk were captured.

The qualitative assessment evaluates components of each water-related sector based on three dimensions:

- **Sensitivity** – the degree to which changes in climate stressors influence the performance, function, and integrity of a given component.
- **Adaptive capacity** – the ability to respond and recover to disruptions or impacts induced by climate stressors through operational flexibility, redundancy, or regulatory protections.
- **Vulnerability** – a measure of the threat and susceptibility to the impacts of climate stressors given the qualities and state of individual components.

Qualitative evaluations of assumed effects from climate hazards inform the subsequent ratings for sensitivity and adaptive capacity for components of each water-resources sector. Once sensitivity and adaptive capacity scores are assigned, a vulnerability rating is determined for each component, with higher vulnerabilities associated with components that are both sensitive to climate impacts and have limited capacity to adapt or recover from disruptions. This approach allows for broader identification of high vulnerability components throughout the watershed, informing areas where deeper analyses through quantitative methods are most warranted.

The *quantitative* vulnerability assessment builds upon the findings of the qualitative evaluation of potential climate impacts to water-related sectors by employing a projection-based modeling framework to explore a range of future climate conditions. This framework allows for shifts in the timing and magnitude of impacts to be evaluated under a range of plausible future conditions. Because individual climate models represent changes in temperatures, precipitation, hydrologic variability, and sea level rise differently, the quantitative vulnerability assessment approach characterizes uncertainties in future climate trajectories by considering 41 different climate projections.

For each water-related sector, a series of metrics and indicators are used to inform and evaluate climate vulnerabilities under future conditions. Indicators represent observable aspects of a given sector that can be used to characterize that sector under historical and future conditions. Metrics incorporate quantitative measurements of certain components of a given indicator. As an example, an indicator for the recreation sector is recreational uses; metrics to evaluate this indicator include reservoir water levels and river flows that are sufficient for recreational activities.

To evaluate the set of indicators and metrics for each water-related sector, a variety of analytical tools have been employed for each vulnerability assessment. Many of these analytical tools leverage outputs from the Basin Characterization Model (BCM) or other tools to simulate specific processes in the watershed, such as floodplain inundation, reservoir operations, and surface water-groundwater interactions. Table 5-1 provides an overview of each of these tools and application for relevant sector-specific assessments. For additional details related to assumptions, inputs, outputs, and limitations, please refer to the Attachment C-1: *Overview of Analytical Tools Used in the Russian River Watershed Resilience Analyses*. Quantitative analyses were performed specifically to support understanding of potential changes under a range of future climates and should not be viewed or used as definitive future outcomes.

Table 5-1. Overview of Analytical Tools by Water Sector

Tool	Use	Sector(s)*
BCM	Simulates historical and future climate unimpaired streamflows and evapotranspiration.	S, F, E, R
Russian River HEC-HMS	Simulates precipitation-runoff processes to support flood risk and reservoir operation studies for the Russian River and Santa Rosa Creek watersheds.	S, F
Santa Rosa Creek HEC-HMS	Simulates precipitation-runoff processes to support flood risk and reservoir operation studies for the Santa Rosa Creek watersheds.	S, F
Russian River HEC-ResSim	Simulates how water is stored and released from Lake Mendocino and Lake Sonoma, flows through the river system across various junctions and routing reaches, and is affected by human activities like water diversions and agricultural use.	S, R, H, E
Sonoma Water Decision Support Model	Simulates reservoir storage and releases, river diversions, aqueduct flows and capacity constraints, customer water demands, and alternative supply sources like groundwater and recycled water.	S, R, H
Russian River Integrated Hydrologic Model	An integrated surface-water and groundwater hydrology and river operations model that represents surface-groundwater interactions and uses climate forcings to estimate dynamic water use demands.	G
Potter Valley Integrated Groundwater-Surface Water Model	Simulates surface water flow, groundwater flow, groundwater-surface water interactions, evapotranspiration from shallow groundwater, and agricultural water use and irrigation dynamics for the Potter Valley Groundwater Basin.	G
Groundwater Sustainability Plan Integrated Surface and Groundwater Computer Models	Integrated surface and groundwater computer models representing surface and subsurface movement of water supplies for the Petaluma Valley, Santa Rosa, Sonoma Valley, and Ukiah Valley groundwater basins.	G
Russian River Flood HEC-ResSim	Simulates reservoir operations for Lake Mendocino and Lake Sonoma.	F
HEC-RAS	Simulates river hydraulics in the Russian River and Santa Rosa Creek watersheds.	F
HEC-ResSim Water Quality Model	Simulates water quality conditions throughout the Russian River watershed using flow, biochemical processes, and meteorological inputs.	E, Q
QCM	Simulates the hydrologic and morphologic behavior of bar-built coastal lagoons.	E, Q
Suitable Habitat Acre-day Model	Estimates the amount of suitable water-quality based juvenile salmonid habitat available within the water column at different locations with the Russian River Estuary.	E, Q
Power Tools for Hydropower	Estimates hydroelectric power generation at Lake Mendocino and Lake Sonoma using daily reservoir storage elevation and release data.	H

Tool	Use	Sector(s)*
Vulnerable Communities Platform	Identifies areas of vulnerability to various climate hazards, including extreme heat, flooding, wildfire, and drought, and overlays information related to a range of socioeconomic factors.	C

* C = Community & Equity; E = Ecosystem; F = Flood Management; G = Groundwater; H = Hydropower; Q = Water Quality; R = Recreation; S = Surface Water Supply

Notes:

HEC = Hydrologic Engineering Center

HMS = Hydrologic Modeling System

QCM = Quantified Conceptual Model

RAS = River Analysis System

ResSim = Reservoir System Simulation

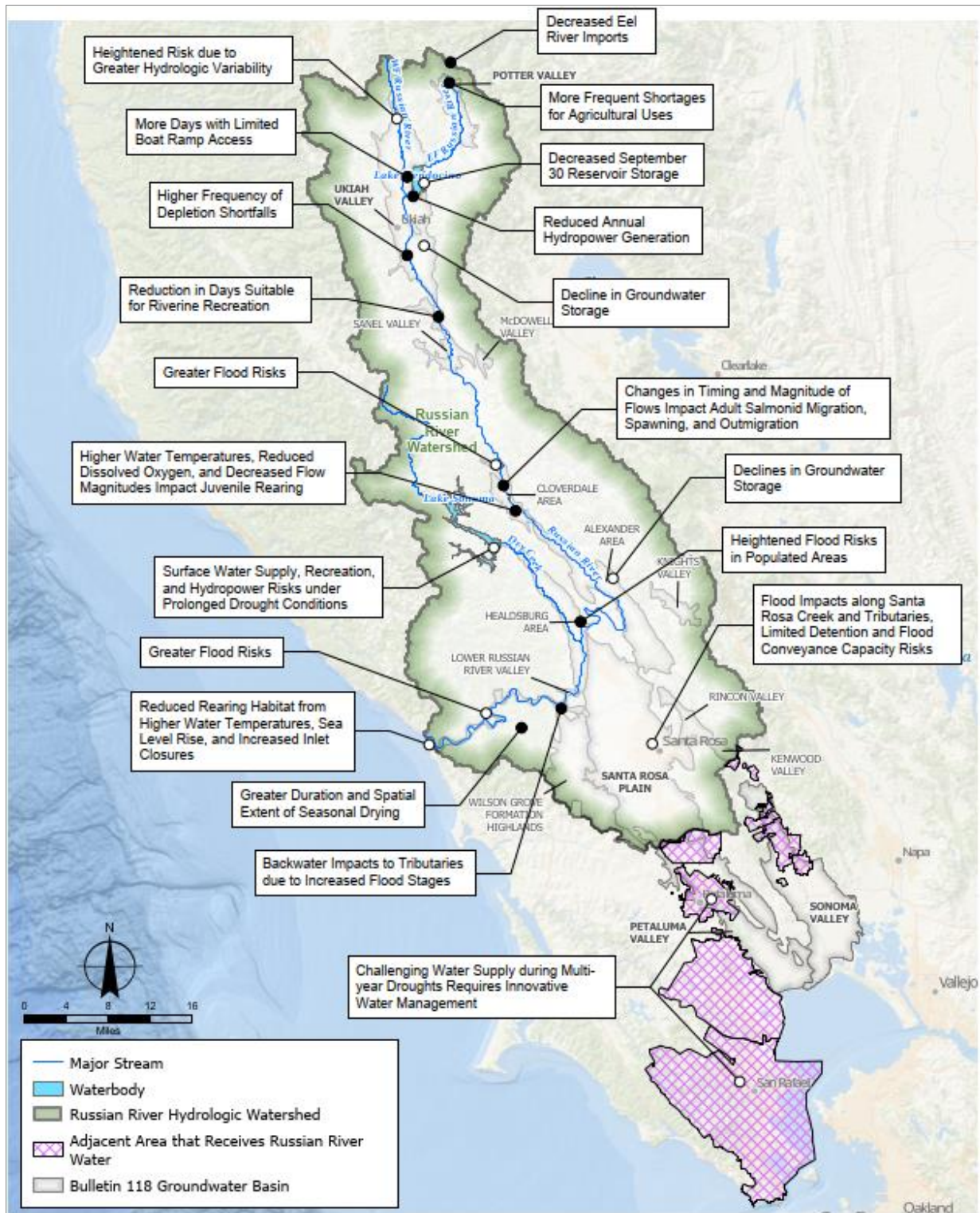
USACE = U.S. Army Corps of Engineers

5.4 Vulnerability Assessment Findings

Changes in climate are characterized by increasing ambient temperatures across the planning area, more frequent and severe extreme precipitation events, and a consolidation of precipitation during the wet season. These changes drive several responses across the watershed, including reductions in fall, spring, and summer baseflows; higher peak flows in the winter; warmer water temperatures; increased wildfire risk; and more frequent and prolonged drought events and extreme heat days. Sector-specific vulnerabilities to these changes are varied and are often influenced by existing infrastructure and operations. Results from the quantitative assessment provide a detailed evaluation of vulnerabilities across the planning area, identifying areas where thresholds are projected to be exceeded, risks are evolving, and impacts are shared or cascading across individual sectors. Ultimately, these results provide a foundation for identifying and prioritizing adaptation strategies and subsequent planning efforts to address the impacts of climate change.

Findings across the planning area that have been identified through this vulnerability assessment are summarized in Figure 5-1. Summaries of results for each water-related sector are noted in the following subsections; further information is provided in Appendix C.

Figure 5-1. Summary of Vulnerability Assessment Findings in the Russian River Watershed



5.4.1 Surface Water Supply

The surface water supply assessment evaluates how the Russian River water supply system responds to a wide range of future hydrologic, operational, and climate conditions. Using coordinated Russian River HEC-ResSim and Sonoma Water Decision Support Model simulations, the analysis examines reservoir operations, Eel River transfers, retail system performance, and the relative vulnerability of the Upper and Lower Russian River. Results highlight growing challenges in maintaining reliable supplies, particularly in the Upper Russian River, where dependence on Eel River transfers and limited storage capacity increase sensitivity to climatic and operational change.

Reduced Eel River transfers are an existing and significant driver of Russian River water supply vulnerability, and they are amplified by the climate-related impacts assessed in this study. Because future Eel River transfer volumes are uncertain following the planned decommissioning of the Potter Valley Project (PVP), climate impacts were evaluated under two plausible operational regimes: (1) No PVP, which includes full discontinuation of Eel River transfers after PVP decommissioning, and (2) NERF, which includes the transition to the New Eel-Russian Facility (NERF).

Under future climate conditions, both Eel River transfer regimes result in many years with significantly lower transfer volumes than the historical period. Even with NERF in place, Eel River transfers are expected to remain lower than historical PVP operations, a condition that is further exacerbated by climate-driven loss of snowpack in the upper Eel River watershed and greater hydrologic variability. NERF operations also shift transfer timing earlier in the water year, reducing late-spring and summer water supply availability for Potter Valley agriculture and increases the frequency of unmet depletion and minimum instream flow requirements.

In addition to changes in transfer volumes and timing impacts to Potter Valley, the portion of the transferred water that can actually be captured and retained in Lake Mendocino is also an important factor influencing system performance under future climate scenarios. Eel River water availability is greatest during the wet season, when available storage capacity in Lake Mendocino is most constrained, limiting the ability to store imported water for later use. These operational vulnerabilities compound climate-driven reductions in watershed hydrology, both the loss of dry-season water availability and the increased intensity of winter storms that can constrain Lake Mendocino's storage capacity but are not climate impacts themselves.

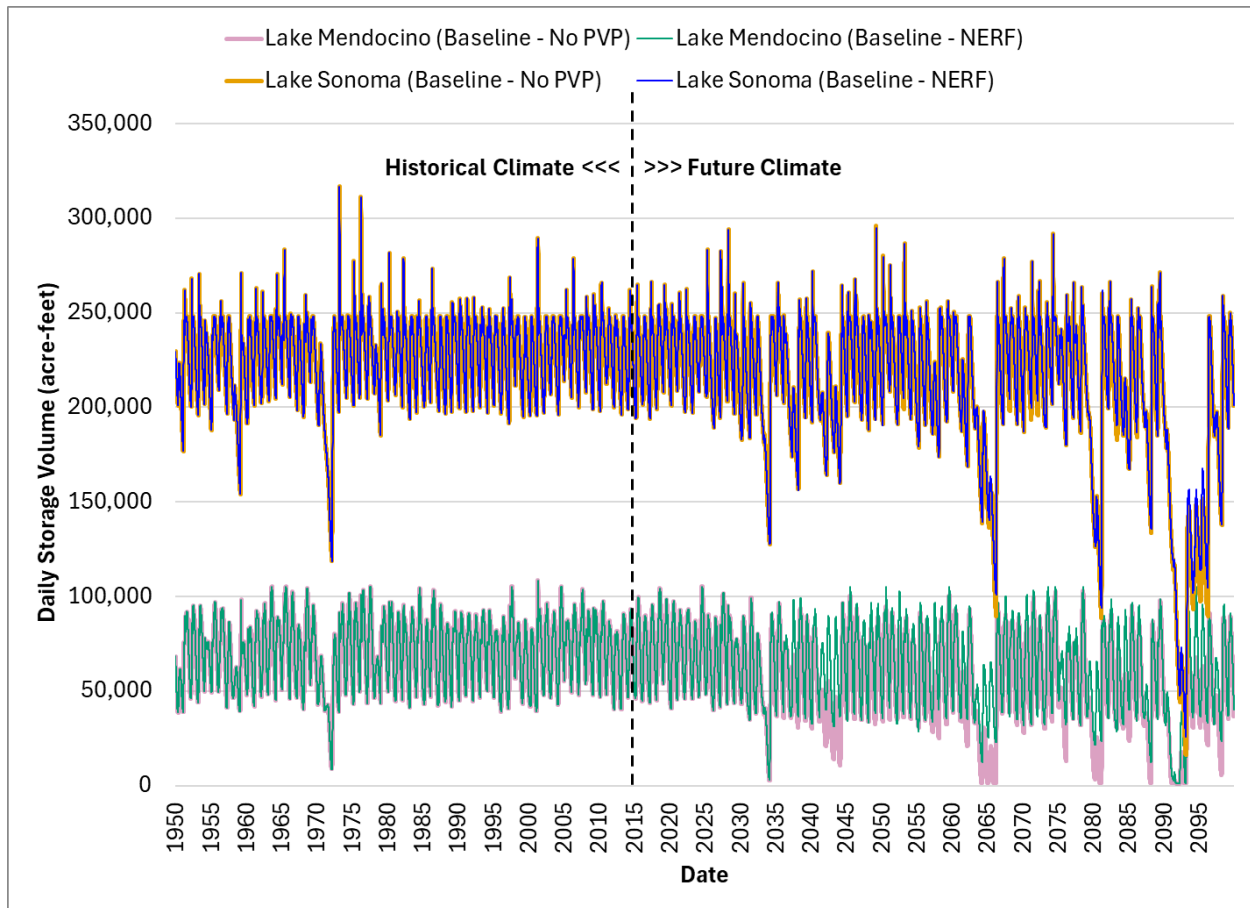
Figure 5-2 shows the simulated storage for Lake Mendocino and Lake Sonoma under one climate model projection (EC-Earth3 5-8.5) for both the No PVP and NERF scenarios. This figure illustrates a particularly notable future climate trajectory for the Russian River system in that the model produces three severe, **multiyear droughts that each persist for roughly 2 to 7 years**, placing substantial strain on both Lake Mendocino and Lake Sonoma storage within only three decades.

Under the EC-Earth3 5-8.5 climate scenario, the No PVP operational scenario (PVP through 2034 and no transfers afterwards) generally produces lower Lake Mendocino storage for most of the period from 2035

- *Reduced Eel River summer flows and transfers to the Russian River watershed are a major driver of vulnerability for water supply to agricultural and municipal users in the Upper Russian River that will be exacerbated by future climate impacts.*
- *Lake Mendocino and the Upper Russian River will become increasingly stressed due to longer and more severe droughts, reduced inflows, and greater transitional variability between wet and dry years.*
- *Lower Russian River water users experience fewer direct impacts but still face increasing pressures from longer and more severe drought conditions.*

to 2100; about 85 percent of days are lower than under the NERF scenario (PVP through 2034 and NERF from 2035). On average, Lake Mendocino storage under the NERF scenario is approximately 6.4 thousand acre-feet (KAF) higher. During late spring and summer, the storage under the NERF scenario averages about 7.2 KAF higher than the no-transfer scenario.

Figure 5-2. Lake Mendocino and Lake Sonoma Storage Volume for Future Projection EC-Earth3 5-8.5 for Two Baseline Scenarios: (1) No PVP, which ends Eel River transfers starting in 2035, and (2) NERF Operations, in which PVP transitions to NERF beginning in 2035.



This effect is especially pronounced during multi-year droughts. In the five-year drought occurring in the 2090s, storage under the no-transfer scenario never rebounds above roughly 34 KAF, remaining substantially below NERF throughout the entire drought sequence and limiting opportunities for recovery between dry years. Taken together, the sensitivity indicates that the absence of Eel River transfers can compound climate-driven stress by keeping storage lower for longer periods, reducing late-season availability, and dampening rebound potential between dry years—context for operations that sits alongside (but is distinct from) the climate-focused findings in this study.

While this scenario highlights one plausible climate pathway, it represents only a single realization within a much broader ensemble. The following figures (5-3 and 5-4) summarize the maximum, median, and minimum projected storage conditions at Lake Mendocino and Lake Sonoma across all 41 climate scenarios to better reflect the full range of uncertainty in future hydrologic conditions.

Figure 5-4. Lake Mendocino September 30 Storage Statistics for Two Baseline Scenarios: (1) No PVP, which ends Eel River transfers starting in 2035, and (2) NERF Operations, in which PVP transitions to NERF beginning in 2035.

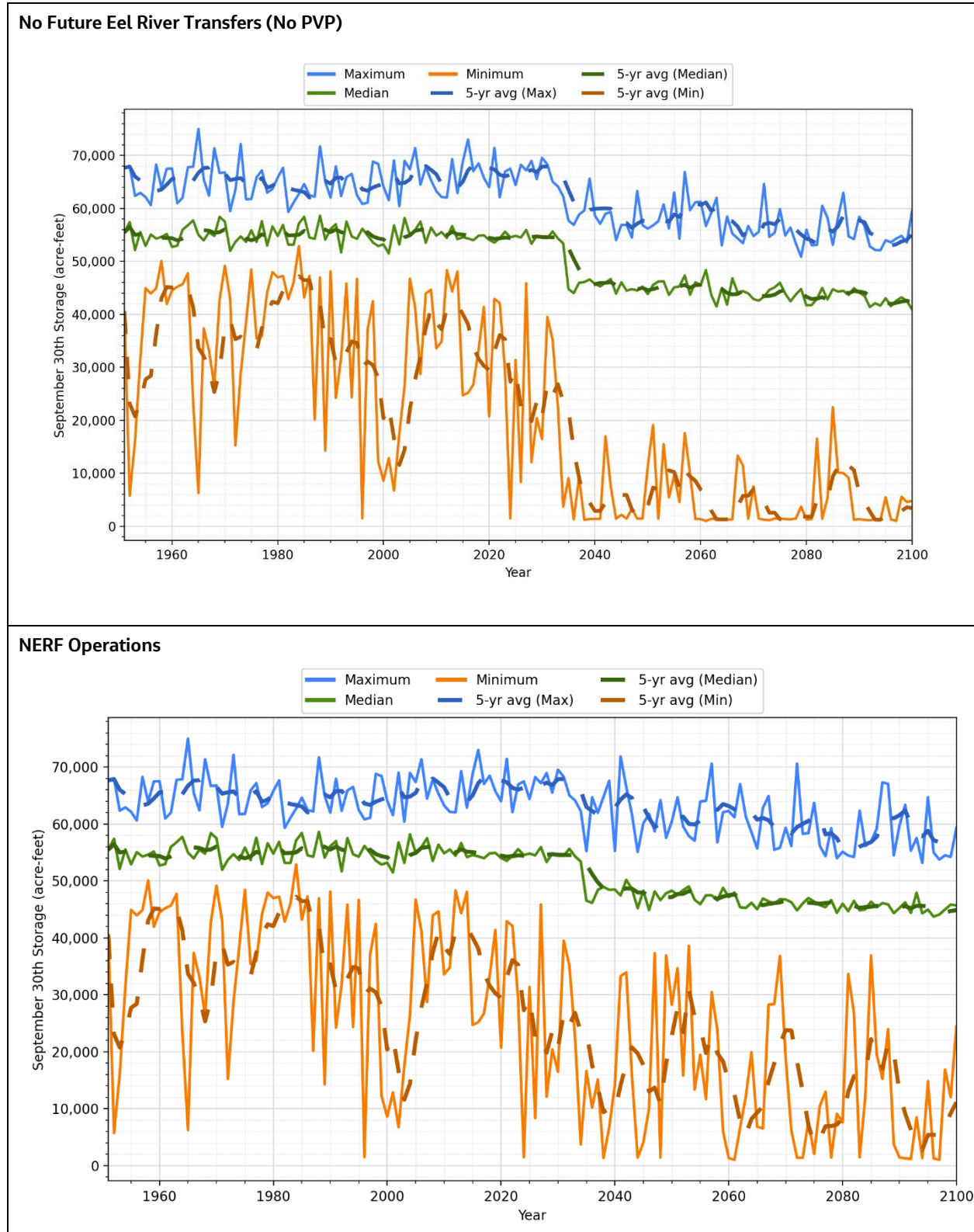


Figure 5-5. Lake Sonoma September 30th Storage Statistics



Across the full ensemble, **Lake Mendocino is increasingly stressed** in future scenarios. Annual September 30 storage declines relative to the historical period, and the frequency of years falling below critical planning thresholds increases (Figure 5-4). Longer and more severe drought sequences also emerge, reducing the ability to recover storage between dry years. As storage declines become more frequent, the ability to maintain releases for downstream water users becomes more challenging in some years. Figure 5-4 presents results for the two baseline scenarios: (1) No PVP and (2) NERF Operations. Across these scenarios, reduced or highly variable Eel River transfers further amplify storage challenges. For example, under the No PVP scenario, median September 30 storage is approximately 2 KAF lower on average after 2035. The frequency of storage dropping below 10 KAF increases substantially from 44 percent under the NERF scenario to 83 percent under No PVP.

Upper Russian River water users face the greatest increases in water supply shortage risk. Shortfalls to meet full demands increase above historical levels in both mid and late century periods, and the frequency and magnitude of shortfalls are highest under scenarios with reduced Eel River transfers. Potter Valley agricultural water supply is particularly vulnerable, with late spring and summer supplies unavailable in many future years unless significant adaptation measures are implemented.

Lower Russian River water users experience fewer direct impacts but still face increasing pressures from longer and more severe drought conditions. Lake Sonoma storage remains relatively stable across most climate and operational scenario simulations, yet several future projections include years with storage lower than historical lows (Figure 5-5). Although most model scenarios continue to meet Sonoma Water retail demands without shortages, a small number of future years show shortfalls, particularly when local Marin County surface supplies experience multi-year drought conditions and increase their reliance on Russian River water.

Across the broader surface water supply system, storage responses in Marin Water's and North Marin's reservoirs show relatively stable median conditions across historical and future periods, but with an expanding range of extreme outcomes. While average September 30 storage levels remain similar through mid- and late-century, the frequency of very low-storage years increases, particularly in the late-future period, signaling growing vulnerability during prolonged or severe drought sequences. These low-storage years are closely associated with simulated localized shortage events in Marin Water's service area. For Sonoma Water's retail customers, most modeled years show no shortages, yet a small number of future scenarios produce annual deficits, especially when multi-year drought conditions in Marin County elevate demand on Russian River supplies.

Despite these challenges, the analysis indicates that operational adaptation and water management actions can reduce impacts. Opportunities include refining reservoir operating rules, strengthening demand management, expanding local supply strategies, and improving coordination between upstream and downstream operational priorities. These strategies can help enhance system resilience and support long term water supply reliability for communities, agriculture, ecosystems, and regional partners.

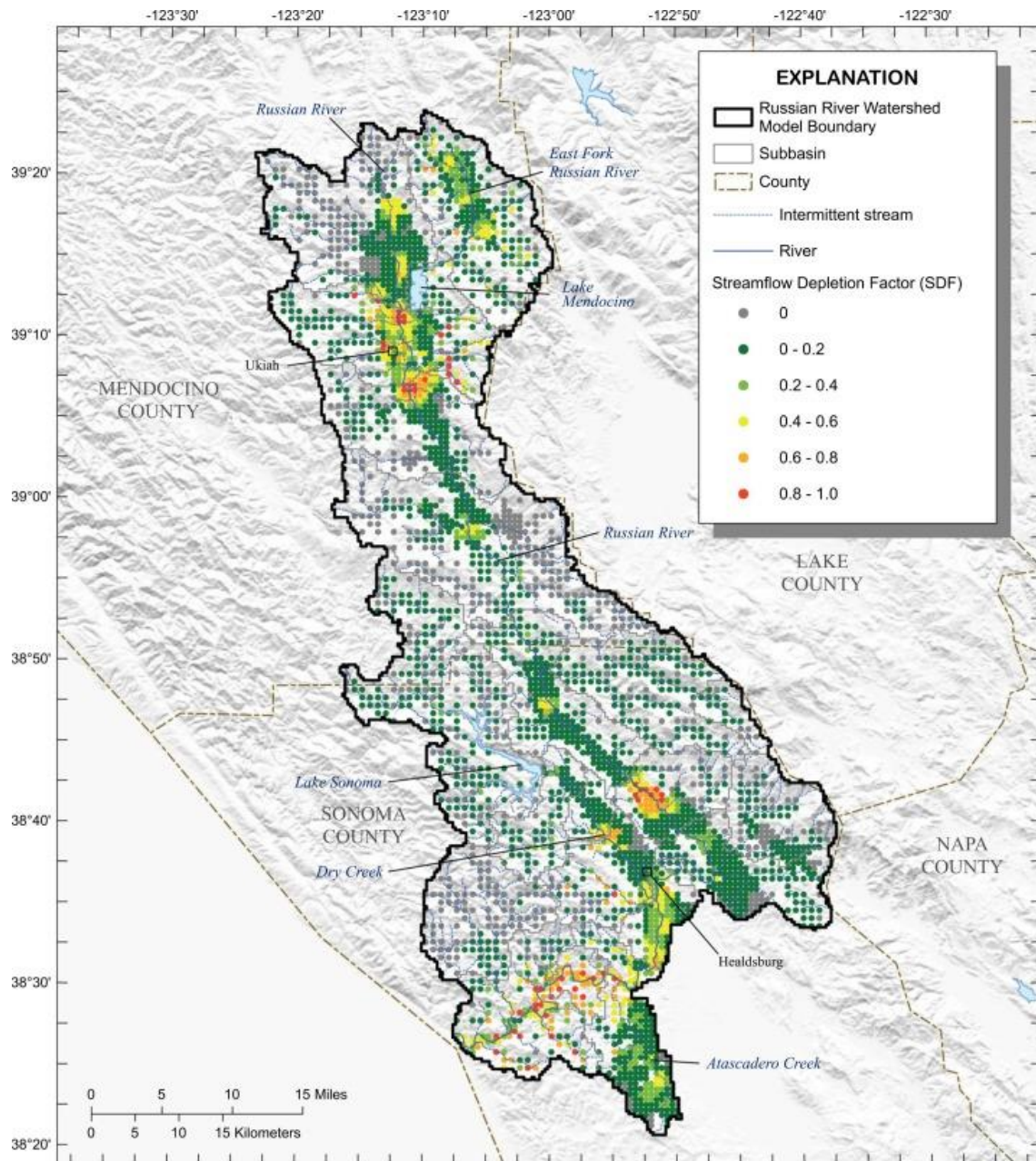
5.4.2 Groundwater Supply

Results from the Russian River Integrated Hydrologic Model (RRIHM) show the close interconnection between surface water and the alluvial aquifer systems underlying and adjacent to the Russian River within the watershed. Under historical conditions, model results suggest that aquifer systems along the Russian River have little interannual groundwater storage variability because seasonal groundwater storage losses accumulated during the dry season are typically replenished to capacity each

- *Streamflow depletion "hot spots" in alluvial aquifers in portions of Ukiah Valley, Alexander Valley, and the Lower River are most vulnerable to changing Russian River flows.*
- *Amplified seasonal changes in groundwater storage (higher in wet seasons, but lower in dry seasons) will stress summer and fall conditions and sustainable groundwater supplies.*

winter season. However, seasonal declines in groundwater storage can result in depletions of streamflow along the Russian River. In aggregate, net surface-groundwater exchange was from streams to aquifers, with 5 to 12 percent of total streamflow contributing to stream depletion to groundwater. Model results also suggest that stream depletion by groundwater pumping is a significant component of the water budget for the alluvial aquifer systems along the Russian River, with an estimated 19 percent of pumped groundwater originating from stream depletion, with particular “hot spots” for streamflow depletion occurring in alluvial aquifers in portions of the Ukiah Valley, Alexander Valley, and the Lower River (Figure 5-5). These results demonstrate the close interdependence of surface water and groundwater in the watershed and highlight their shared vulnerabilities.

Figure 5-5. Spatial Distribution of Streamflow Depletion Factors, Simulated for the 1990-2015 Period

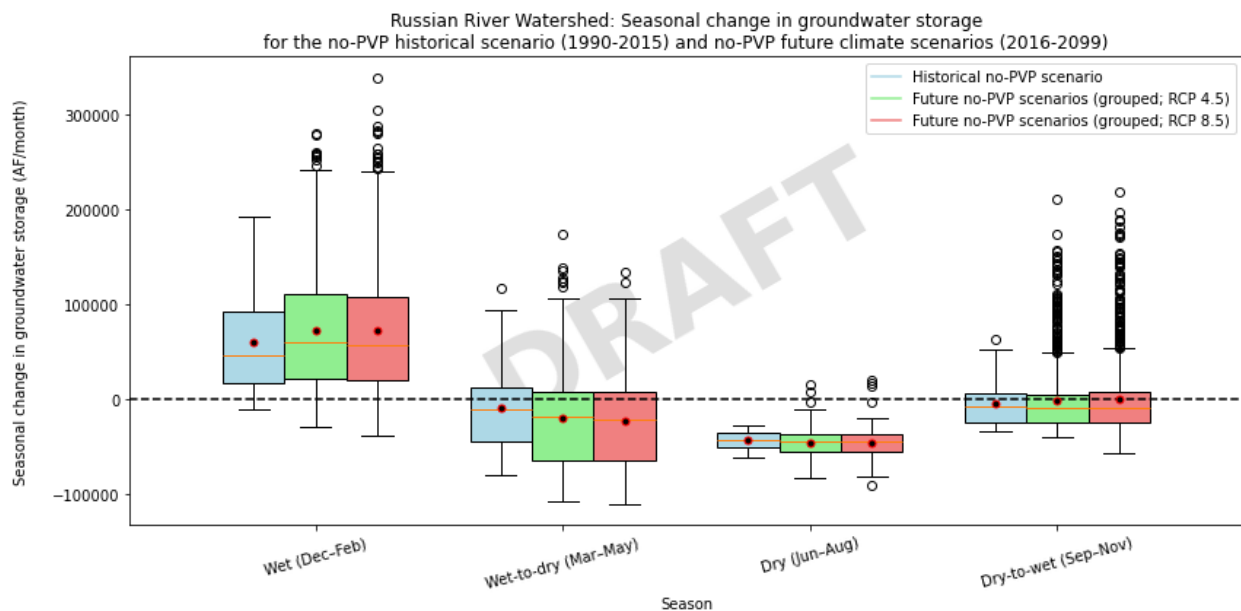


Note: from Adera et al. 2026

Future climate change simulations of the Russian River watershed show both greater seasonal and interannual hydrologic variability, with droughts occurring more frequently and with greater intensity. Given the close interconnection between the Russian River and the alluvial aquifer systems along the river’s corridor, groundwater response follows these shifts, generally amplifying seasonal swings in storage, with greater increases in storage during the wet season and greater reductions in storage in wet-to-dry and dry seasons. Under the combined future stressors of intensified drought conditions and potential cessation of interbasin transfers of Eel River water, Lake Mendocino reliability is potentially reduced. Under conditions where Lake Mendocino drops below dead pool storage and releases cannot be made into the upper Russian River, groundwater replenishment from stream depletion is effectively cut off, amplifying dry-season groundwater storage declines and contributing to year-over-year storage declines in aquifer systems along the Upper Russian River. For aquifer systems along Dry Creek, where releases from the significantly more reliable Lake Sonoma sustain year-around flows, large year-over-year groundwater storage declines do not occur during the same simulated drought periods, highlighting the importance of surface water replenishment of groundwater in these systems.

Given the close interconnection between the Russian River and the alluvial aquifer systems along the river’s corridor, increases in hydrologic volatility and attendant changes in streamflow response under climate change have follow-on impacts on groundwater resources. In general, groundwater response shows amplified seasonal swings in storage, with greater increases in storage during the wet season and greater reductions in storage in wet-to-dry and dry seasons (Figure 5-6). These larger-amplitude seasonal swings are driven by greater wet-season stream leakage and greater groundwater discharge to streams in wet-to-dry and dry seasons.

Figure 5-6. Seasonal Changes in Groundwater Storage Volumes under a Hypothetical Drought for the HadGEM2-ES RCP 8.5 Future Climate Scenario for the Upper Russian River and Dry Creek Subwatersheds



Based on the evaluations performed to support Groundwater Sustainability Plan (GSP) development, changes in groundwater storage are sensitive to climate and hydrologic conditions where increases in groundwater storage occur during the wet periods when recharge from precipitation and streamflow tends to be higher. Decreases in groundwater storage tend to occur during drier periods when recharge from precipitation and streamflow tends to be lower and when groundwater pumping to meet agricultural demands is higher due to increased temperatures. In summary, groundwater inflows are generally larger

during wet years and smaller during drier years, which has a larger influence on the change in groundwater storage over time. Additionally, increased temperature and decreased precipitation cause an increase in agricultural demand which can lead to increased groundwater pumping causing larger declines in groundwater storage during the drier periods. For the Petaluma Valley and Sonoma Valley, which are adjacent to San Pablo Bay, projected sea-level rise assumptions were incorporated in the groundwater modeling used to support development of the GSP. Projected groundwater budgets for the Petaluma Valley and Sonoma Valley both suggest that inflow from the tidally influence Petaluma River and San Pablo Bay are projected to increase due to impacts of sea-level rise. Increased inflow from San Pablo Bay could cause seawater to advance inland, however, available data does not indicate increasing trends in salinity at wells near San Pablo Bay.

5.4.3 Flood Management

Flood modeling was conducted to assess vulnerabilities associated with changing rainfall intensity and magnitudes suggested by future climate models. An integrated modeling suite comprised of hydrologic (HEC-HMS), reservoir operations (ResSim), and river hydraulic models (HEC-RAS) was applied to approximate potential future changes in flood risk. This suite of models is useful for approximating comparative changes in flood risk for historical and future climate. Spatial analyses of modeled future flood conditions (Figure 5-7) can inform our understanding of the relative shifts in flood risk from current to future climates and lead toward improved understanding of measures to reduce these risks. Simulations with the integrated modeling suite were conducted for current conditions and for future climate consisting of increased rainfall magnitude and intensity. It is important to note that the flood modeling was performed specifically to support understanding of potential changes under a range of future climates and should not be viewed or used as definitive future outcomes. This flood analysis did not include updates to elevation mapping or refinements to models and should not be used to assess specific property risks. Flood risk management responsibilities are spread amongst multiple agencies in Mendocino and Sonoma Counties and many of these are coordinating to advance analysis and response.

Along the Russian River, future climate is projected to nearly double the number of residences vulnerable to 100-year flood inundation. For the 100-year flood event, increases under future climate could reach 24 percent by mid-future and 97 percent by late future (Figure 5-8). For the 25-year flood event, model results indicate that approximately 20 percent more structures in the Russian River watershed may flood under the mid future scenario and 47 percent more in the late future scenarios. The majority of impacted residences are in the lower Russian River, where homes are situated in closer proximity to the river.

Projected flood impacts to residences in the Santa Rosa Creek watershed are significantly higher as Santa Rosa Creek does not have the conveyance capacity required to transport even the current lower flood flows without overtopping its banks. In the mid-future, models predict a 600 percent increase in the number of structures flooded by the 25-year flood event. In late-future conditions, results show a 1,200 percent increase in residences impacted (Figure 5-9). At the 100-year flood level, the increases are smaller in percentage terms but larger in number of structures impacted, increasing from roughly 2,600 in the baseline to 11,600 in mid-future and 15,700 in late future conditions. The Santa Rosa Creek watershed is more densely populated than the Russian River watershed, hence the large increases with increased flows under future climate scenarios. Backwater impacts of increased stages in the Russian River are also seen in Mark West Creek and Green Valley Creek.

Figure 5-7. Sample of Structures at Risk with Modeled Increased Inundation under Future Climate (Baseline, Mid-Future, and Late Future 100-year event)

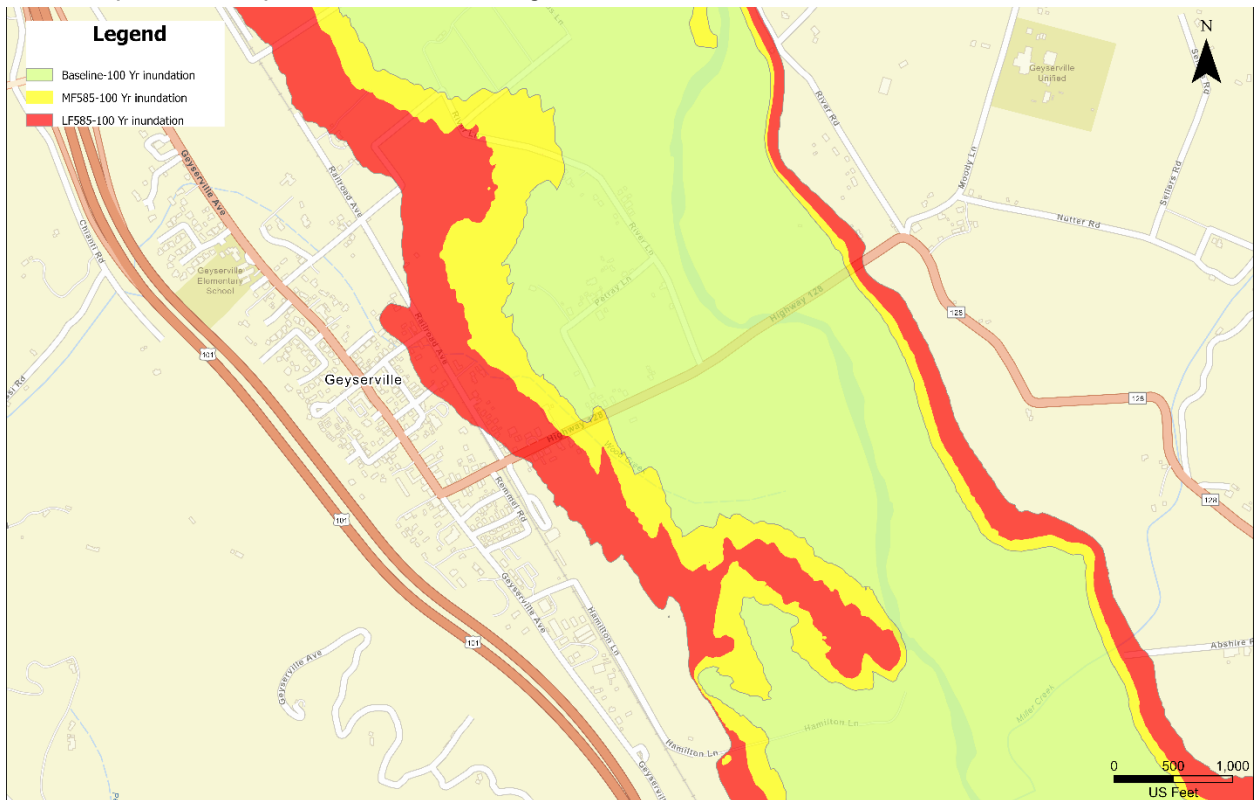


Figure 5-8. Simulated Increase in Residences at Risk in Russian River Watershed

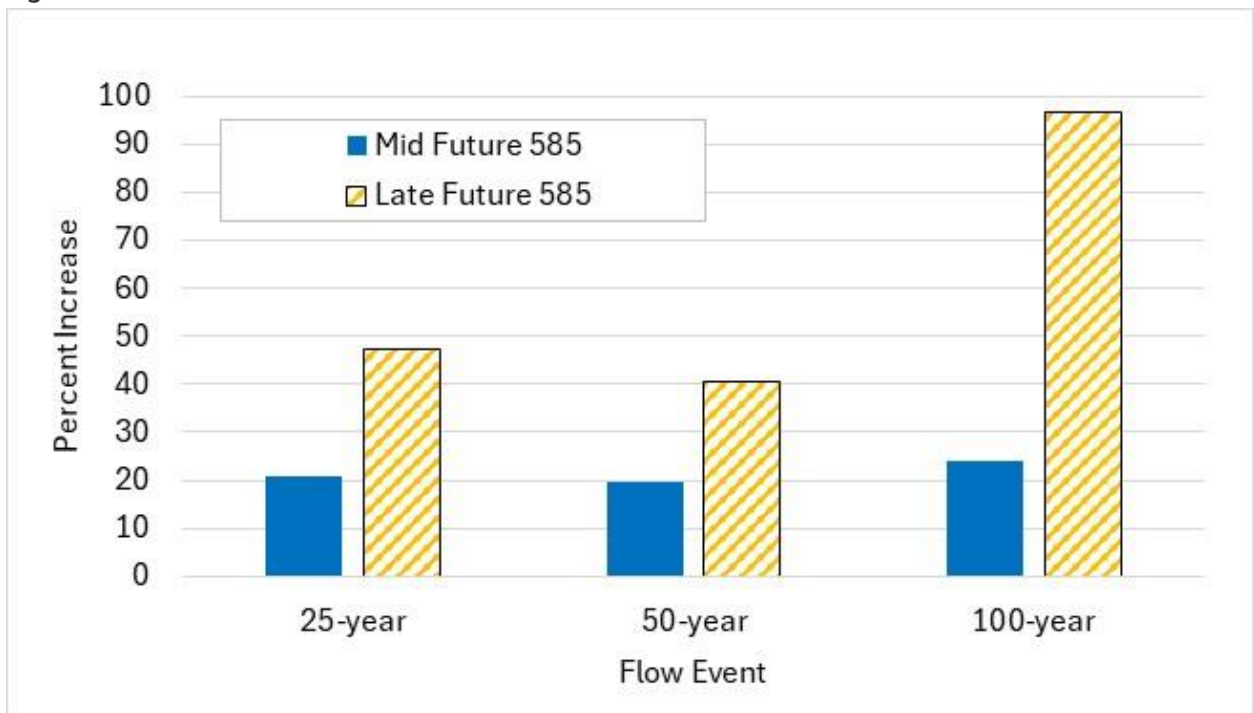
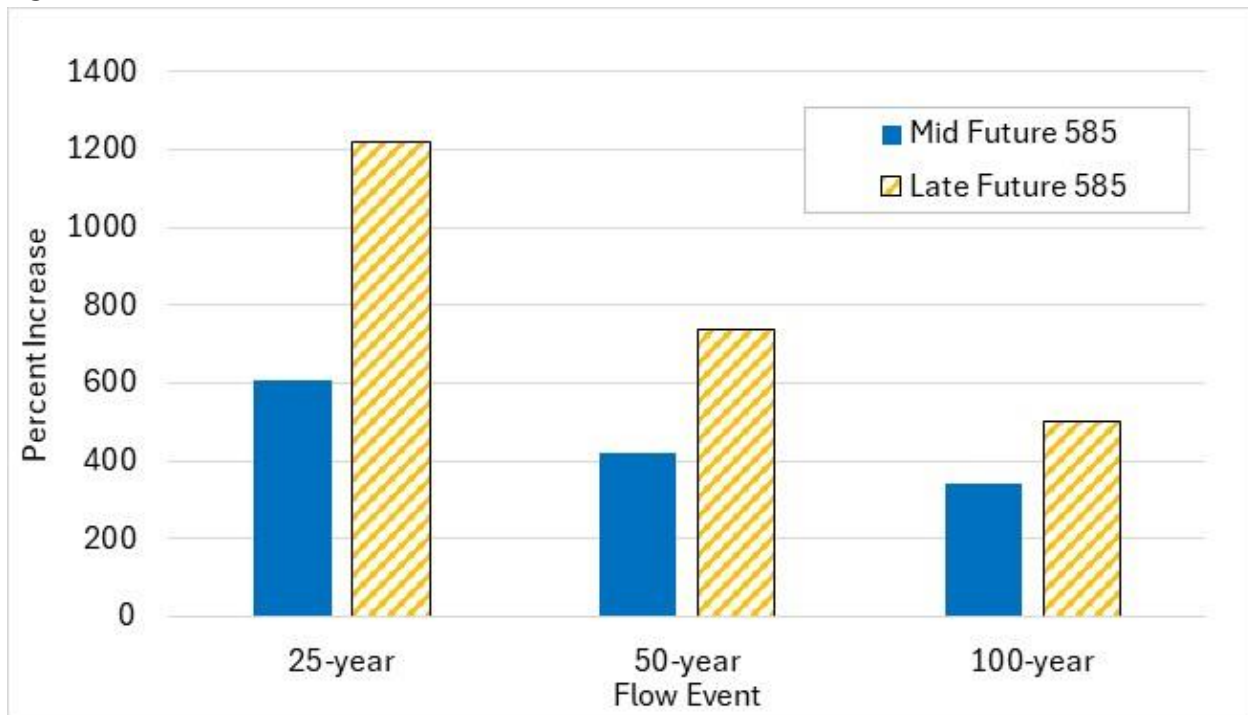


Figure 5-9. Simulated Increases in Residences at Risk in the Santa Rosa Creek Watershed



Flood vulnerabilities under future climate are significant in residential areas near Santa Rosa Creek. While such residences are not within the current 100-year floodplain, increased runoff from projected future storm events is expected to result in a larger 100-year floodplain (Figure 5-7). Impacts are also seen in more populated areas along the Russian River, such as Guerneville and Healdsburg. Backwater impacts of increased stages in the Russian River are also seen in Mark West Creek and Green Valley Creek.

Numerical models provide useful estimates of future conditions, but results must be interpreted with an understanding of potential limitations of the modeling analysis, including those associated with assumptions adopted by the model. The full modeling suite has not been calibrated to historic events as part of this analysis, and a cursory comparison to larger historic events indicates that the model underestimates peak flows and stages. This would likely lead to an underestimation of the structures and population at risk under future climate. A full calibration of the HEC-HMS and HEC-RAS models should be incorporated into future studies.

- *Along the Russian River, future climate is projected to nearly double the number of residences vulnerable to 100-year flood inundation.*
- *Projected flood impacts to residences in the Santa Rosa Creek watershed are significantly higher as Santa Rosa Creek does not have the conveyance capacity required to transport even the current lower flood flows without overtopping its banks.*
- *Backwater impacts of increased stages in the Russian River are also seen in Mark West Creek and Green Valley Creek.*

5.4.4 Water Quality

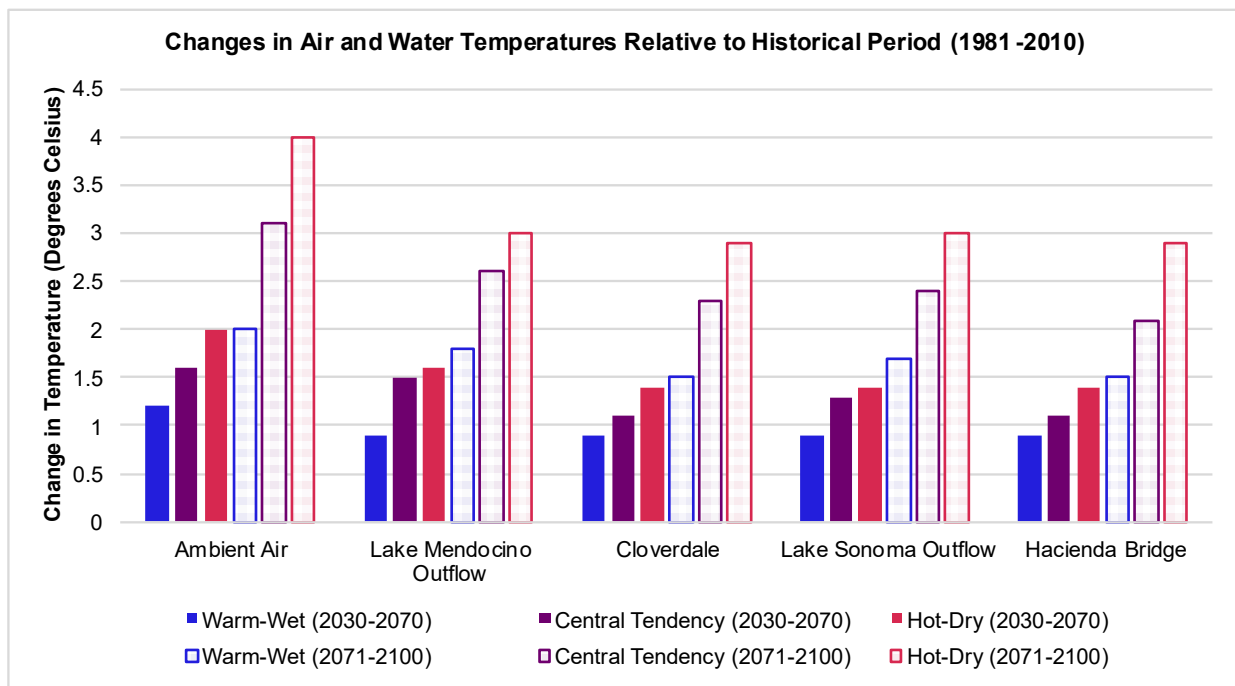
The water quality vulnerability assessment evaluates projected changes in water quality under three future climate scenarios, representing a subset of the full suite of 41 climate projections: hot-dry, warm-wet, and central tendency. To estimate these changes, the Russian River HEC-ReSim Water Quality Model (RRWQM) was utilized to simulate different water quality parameters under varying hydrologic and meteorological

inputs. For this assessment, water temperature and dissolved oxygen model outputs were analyzed at Lake Mendocino and Lake Sonoma reservoirs and along the mainstem of the Russian River to determine the water quality-related vulnerabilities of Russian River watershed.

Results indicate that **under all evaluated future climate scenarios the water temperature being released from Lake Mendocino and Lake Sonoma is expected to increase due to warmer inflows from increased air temperature (Figure 5-10)**. Specifically for Lake Mendocino, there is projected increase in the frequency of fall water temperature spikes due to the depletion of cold-water pool earlier in the season from lower reservoir storage. These increases in water temperature from reservoir releases may have an impact on Coyote Valley Dam hatchery operations as well as salmon and steelhead lifecycle stages downstream.

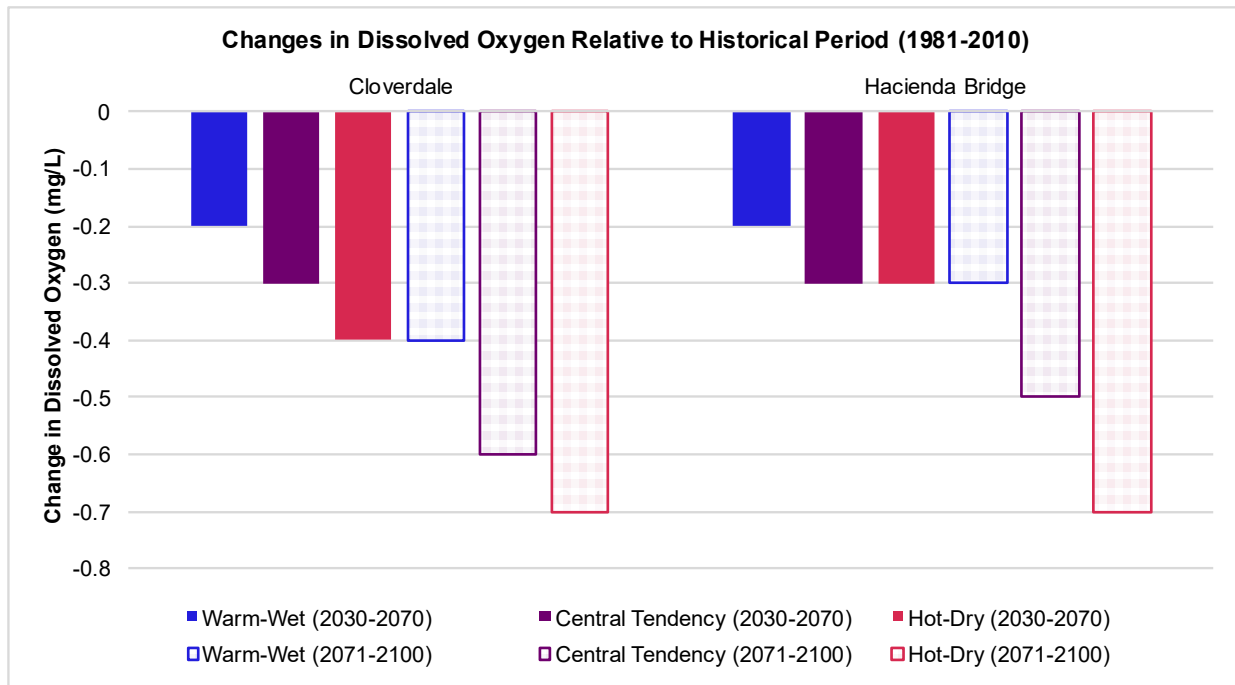
- *Water temperatures are projected to increase along the Russian River, Dry Creek, and other tributaries due to increasing air temperatures, warmer reservoir releases, and greater heat absorption.*
- *The Russian River is expected to experience decreasing dissolved oxygen due to higher water temperatures and lower summer and fall river flows.*
- *Increasing water temperature and decreasing dissolved oxygen have the potential to impact salmon and steelhead rearing and spawning in the Russian River by decreasing the availability of suitable habitat*

Figure 5-10. Change in Air and Water Temperature Results for Various Model Locations



For the Russian River, both Cloverdale in the Upper Russian River and Hacienda Bridge in the Lower Russian River are projected to experience an increase in water temperature through the whole year due to warmer local natural flow from increasing air temperatures, warmer reservoir releases, and greater heat absorption while flowing downstream from increasing air temperatures (Figure 5- 11). Both locations are also expected to experience decreasing dissolved oxygen in the river due to higher water temperatures and lower river flows. These changes also have the potential to impact salmon and steelhead rearing and spawning in the Russian River by decreasing the availability of suitable habitat.

Figure 5-11. Changes in Daily Average Dissolved Oxygen Results for Cloverdale and Hacienda Bridge Model Locations



This analysis does not evaluate specific vulnerabilities to fisheries in the Russian River but instead provides general trends in water quality and an interpretation of the causes based on the RRWQM. The ecosystem vulnerability assessment explores associated water quality impacts to fisheries in more detail.

5.4.5 Ecosystems

The ecosystem vulnerability assessment employs separate methodologies and analytical tools for the mainstem Russian River and its tributaries as well as the Russian River Estuary.

5.4.5.1 Mainstem Russian River and Tributaries

For the mainstem Russian River and its tributaries, the ecosystem vulnerability assessment evaluated projected climate-driven changes in hydrology, temperature, and dissolved oxygen in the mainstem Russian River and Dry Creek; total watershed averaged flow metrics for tributary watersheds to the Russian River and Dry Creek; and hydrologic connectivity in select tributaries of the Russian River watershed using ensemble climate simulations and literature-supported habitat relationships. Daily reservoir and river flows were modeled across historical (1981 to 2010), mid-future (2041 to 2070), and late-future (2071 to 2100) periods. Modeled discharge was interpreted qualitatively in relation to salmonid depth-velocity suitability preferences and migration thresholds at known passage for critical riffles at four locations in the HEC-ResSim model (Cloverdale, Healdsburg, Dry Creek at the Russian River, and Hacienda). Water temperature and dissolved oxygen projections were evaluated relative to species- and life stage-specific tolerance limits at a subset of these locations (Cloverdale, Dry Creek, Hacienda). Total watershed averaged flow outputs for identified tributary watersheds were generated using 41 simulations from the Russian River and Upper Eel River BCM. A complementary review of tributary wet-dry mapping and empirical survival studies was also conducted to assess sensitivity to seasonal flow disconnection.

Results indicate that **climate change is expected to intensify seasonal habitat constraints and increase vulnerability for multiple listed salmonid life stages**, particularly under late-future conditions. In the mainstem Russian River, projected reduced early-fall flows increase the risk of delayed adult migration at critical riffles, especially for Chinook salmon (*Oncorhynchus tshawytscha*) (Figure 5-11). Higher and more variable winter peak flows elevate the likelihood of streambed and redd (spawning nests) scour for Chinook salmon, and to a lesser degree, steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). Warmer late-winter and early-spring temperatures advance incubation threshold exceedances, shortening the window of suitable egg development conditions at upstream locations, such as Cloverdale.

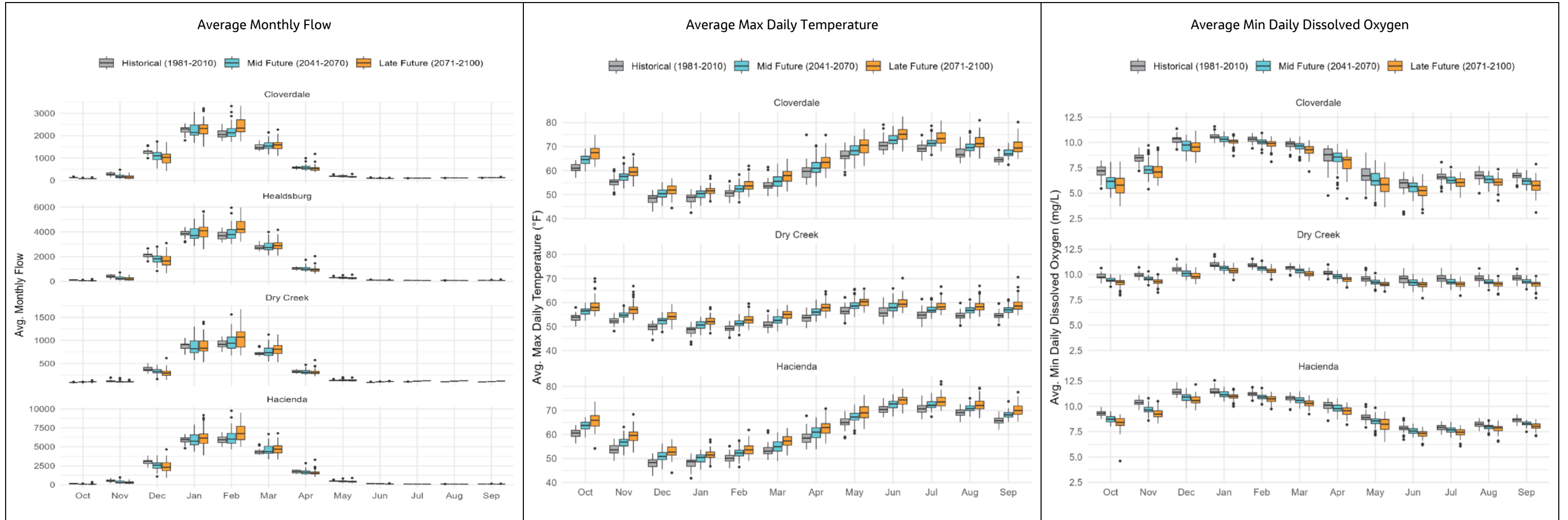
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- *Climate change is expected to intensify seasonal habitat constraints and increase vulnerability for multiple listed salmonid life stages*
 - *The most consistent and severe vulnerability is projected during juvenile rearing where mainstem summer temperatures already approach or exceed thermal thresholds under historical conditions and increase under future conditions.*
 - *Projected warming and declining baseflows are expected to increase the duration and spatial extent of seasonal drying in tributaries, particularly in lower alluvial reaches*
 - *Seasonal thermal stress, low-flow passage constraints, and tributary connectivity loss are the dominant drivers of future climate vulnerability for listed salmonids in the watershed*
 - *Suitable habitat conditions for juvenile steelhead in the Russian River estuary are vulnerable due to increased closure duration (sea level rise and river flows) and higher river temperatures are projected to reduce suitable juvenile steelhead rearing habitat during rearing months*
-

The most consistent and severe vulnerability is projected during juvenile rearing. Mainstem summer temperatures already approach or exceed thermal thresholds under historical conditions and increase under mid- and late-future conditions. At Cloverdale, projected late-future dissolved oxygen concentrations fall below 6 milligrams per liter (mg/L) beginning in early May and remain depressed through summer, compounding potential for thermal stress. Reduced late-spring flows may further constrain juvenile outmigration and rearing habitat and associated survival to the Pacific Ocean.

Tributaries of the Russian River watershed represent an additional critical vulnerability. Empirical evidence identifies longitudinal disconnection and reduced wetted habitat as primary drivers of juvenile mortality, with “days of disconnection” strongly associated with survival. Projected warming and declining baseflows are expected to increase the duration and spatial extent of seasonal drying, particularly in lower alluvial reaches. Although groundwater-supported pools provide localized refugia, their persistence may diminish under intensified drought conditions. BCM-generated total watershed averaged flow results for tributary watersheds indicate a consolidation of flows into the winter season at the loss of total flow volumes in the fall and spring, signaling vulnerabilities for upstream migration in the fall and outmigration in the spring.

Overall, the most climate-sensitive components of the system are mainstem juvenile rearing, tributary over-summer survival, and egg incubation during late winter and spring. Adult Chinook salmon migration is vulnerable primarily during low-flow fall periods but is comparatively less constrained by temperature. These findings identify seasonal thermal stress, low-flow passage constraints, and tributary connectivity loss as the dominant drivers of future climate vulnerability for listed salmonids in the watershed.

Figure 5-11. Simulated Average Monthly Flow, Average Maximum Daily Temperature, and Average Minimum Daily Dissolved Oxygen at Various Locations along the Russian River and Dry Creek

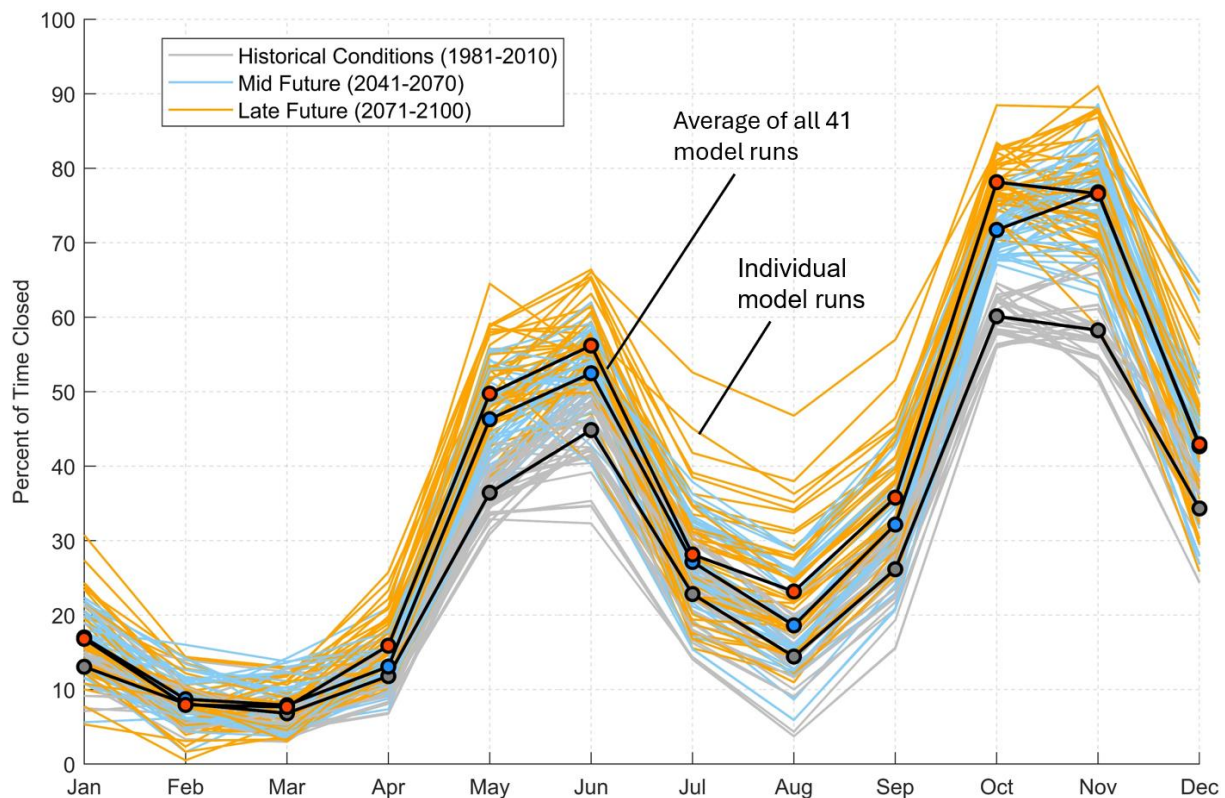


5.4.5.2 Russian River Estuary

For the Russian River estuary, projected changes in hydrology and water quality were evaluated to determine how habitat conditions for federally listed salmonids in the estuary may be affected. Changes in suitable habitat availability were assessed across the historical, mid-future, and late-future periods. Separate lagoon hydrology and habitat models were integrated to simulate future conditions, taking into account changes in boundary conditions driven by climate change, including altered river temperature, sea level rise, ocean tides, and wave conditions. The QCM simulates river mouth closure dynamics, and the Suitable Habitat Acre-Day (SHAD) analysis quantifies spatial and temporal changes in juvenile steelhead rearing habitat under varying inlet conditions. River and reservoir operations were simulated separately using HEC-ResSim, and future tidal conditions follow State of California sea level rise guidance.

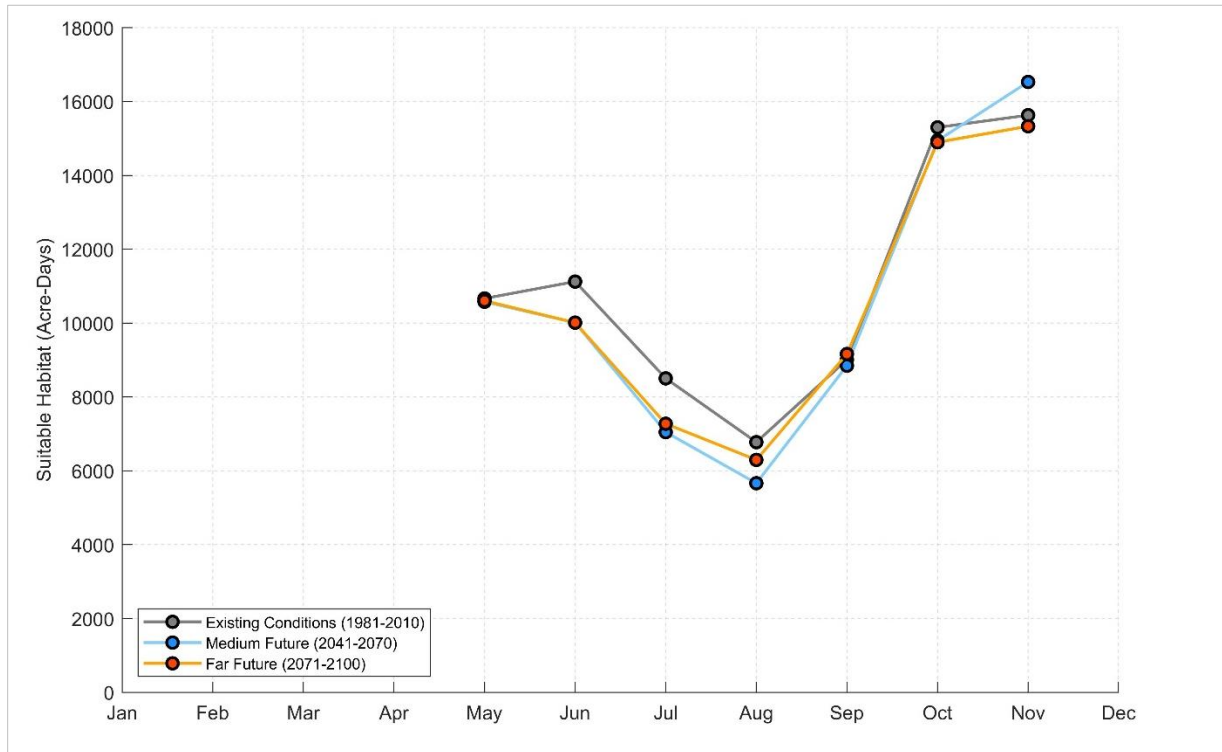
Vulnerability assessment results indicate that future climate conditions increase risk to multiple salmonid life stages. Both mid- and late-future conditions show reduced early fall, early winter, and spring flows and longer or more frequent inlet closure events. Late-future conditions also project higher winter peak flows. Projected increases in air temperature are expected to elevate river temperatures entering the estuary, and monitoring data confirm that estuary temperatures closely track upstream river conditions, particularly during closed-mouth periods. Increased closure duration and higher river temperatures are projected to reduce suitable juvenile steelhead rearing habitat during rearing months (May through November), as demonstrated in Figure 5-12.

Figure 5-12. Modeled Inlet Closure Seasonality Within Each Epoch (Historical [1981–2010], Mid Future [2041–2070], Late Future [2071–2100])



Note: The thin lines in the background represent individual model runs, and show the percent of each month of the year that the Russian River inlet is predicted to be closed (e.g. 100% closed means that the river was closed for the full month). Different colors represent the different epochs. Thick lines in the foreground represent averages of all 41 model runs.

Figure 5-13. Suitable Steelhead Rearing Habitat Availability per Month



Overall, the estuary is expected to retain its typical seasonal open/closed dynamics, but with intensified drought sensitivity and temperature-related stress. These findings support continued use of adaptive management strategies that protect thermal refugia to sustain salmonid rearing and migration under future conditions.

5.4.6 Recreation

The Russian River, Lake Mendocino, and Lake Sonoma offer opportunities for recreation within the planning area. These opportunities are dependent on annual surface water supplies, reservoir management, and downstream diversions. Under future climate conditions, shifts in the timing and magnitude of unimpaired inflows to reservoirs and decreases in the total annual surface water supplies may affect the quality and availability of recreational activities, particularly in summer months.

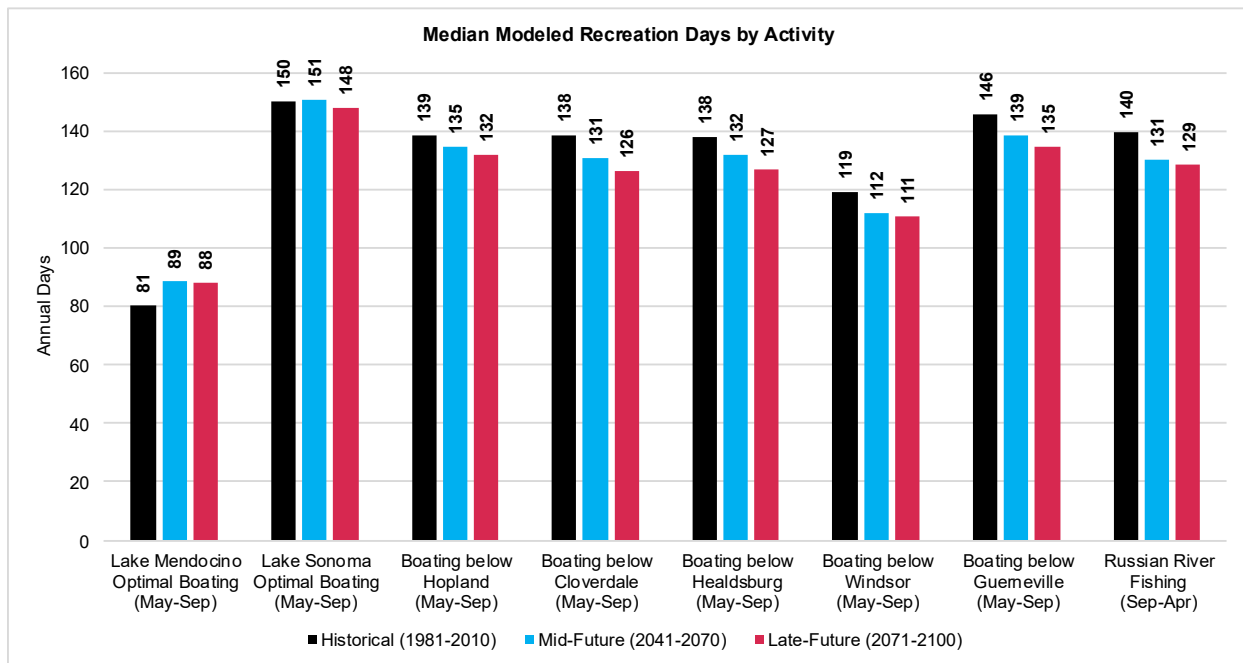
Vulnerabilities to climate change were assessed for both lake and riverine recreation using daily Sonoma Water DSM outputs at Lake Sonoma, Lake Mendocino, and various locations along the Russian River. Key reservoir elevation and riverine flow thresholds identified in the *Fish Habitat Flows and Water Rights Project Draft EIR* (Sonoma Water 2016b) were utilized and supplemented with additional thresholds to expand coverage to upstream portions of the Russian River above Rio Linda Academy. Simulated reservoir elevation and Russian River flow timeseries under historical (1981-2010), mid-future (2041-2070), and late-future (2071-2100) conditions were compared to identified thresholds to estimate the number of annual days sufficient for the range of recreational activities considered. For Lake Sonoma and Lake Mendocino, changes in the availability of motorized boating, non-motorized boating, and camping were considered between May 1 and September 30. For the Russian River, non-motorized boating and public access were considered between the same time period. Fishing along the Russian River was also evaluated between September 1 and April 30.

Findings from the analysis are summarized for median conditions in Figure 5-14. For Lake Mendocino, the number of days with optimal (i.e., no negative impact on any recreational activities) conditions for recreation increases by approximately 8 days (mid-future) and 7 days (late-future)

- *Optimal days for lake recreation at Lake Mendocino is projected to decrease with boating closures increased by up to two weeks under future climate.*
- *Recreationally suitable days decreases by up to 12 days along the Upper Russian River, with smaller impacts along the Lower River.*

annually relative to historical trends. However, the **annual frequency of closures that fully prohibit motorized boating increase by roughly 14 days each year for the mid-future and 17 days for the late-future** due to a higher prevalence of lower reservoir storage under future conditions. For Lake Sonoma, median conditions are relatively unchanged by future climate conditions, with only a 1-day increase to 2-day reduction in optimal reservoir elevations, depending on analysis period, that result in access limitations at only one of the three boat ramps. For both Lake Mendocino and Lake Sonoma, sufficient adaptive capacity exists to maintain the availability of recreational opportunities at these locations. While Lake Mendocino is more vulnerable to future climate conditions and displays a decreasing trend in annual storage, lightweight crafts can still be hand-launched to access the lake and the reduction in storage results in a decreased frequency of events that inundate surrounding campgrounds and parking lots. For Lake Sonoma, alternative boat ramps can still be utilized during periods of lower reservoir elevations to access the lake.

Figure 5-14. Summary of Recreation Vulnerability Assessment Findings



Along the Russian River, the median frequency of recreationally suitable days decreases between 4 to 9 days for mid-future conditions and 7 to 12 days for late-future conditions, depending on location and activity. The decrease in days that flows are above identified thresholds at these locations is driven by reductions in storage at Lake Mendocino between May and February. The reduction in storage results in a decrease in surface water supplies that can be released downstream, resulting in a higher frequency of days with flows below thresholds suitable for recreation. Additionally, while Lake Sonoma storage appears to be more resilient to future climate conditions, this stability does not offset the impacts to flows caused

by the reduction in Lake Mendocino storage in areas below the confluence with Dry Creek. **Along the Upper Russian River, riverine recreation is particularly vulnerable to the reduction in annual water supplies at Lake Mendocino as no infrastructure currently exists to manipulate water surface elevations.** For the Lower Russian River, where most of the recreation in the watershed is consolidated, operation of the instream summer dams has a greater impact on the prevalence of recreational activities in these areas. If instream dams continue to operate as normal and create sufficient water surface elevations for swimming, boating, and public access, the impacts of higher frequencies of low-flow occurrences can be partially mitigated.

5.4.7 Hydropower

Releases from Coyote Valley Dam at Lake Mendocino and Warm Springs Dam at Lake Sonoma are used to generate hydropower in the Russian River watershed. Changes in the magnitude and distribution of reservoir inflows throughout the year can influence the quantity of hydropower production and the reliability of these energy supplies for municipalities and residents within the watershed. Hydropower vulnerabilities at Lake Mendocino and Lake Sonoma were evaluated using daily turbine flow and hydropower generation timeseries between 1950 and 2100. These time series were generated by incorporating a python-based tool developed by Sonoma Water for estimating hydropower production into Sonoma Water DSM, a regional water supply model that simulates reservoir and diversion operations within Sonoma Water's service area. Historical trends between 1981 and 2010 were compared with mid-future (2041-2070) and late-future (2071-2100) climate conditions to evaluate vulnerabilities to hydropower generation at Lake Mendocino and Lake Sonoma.

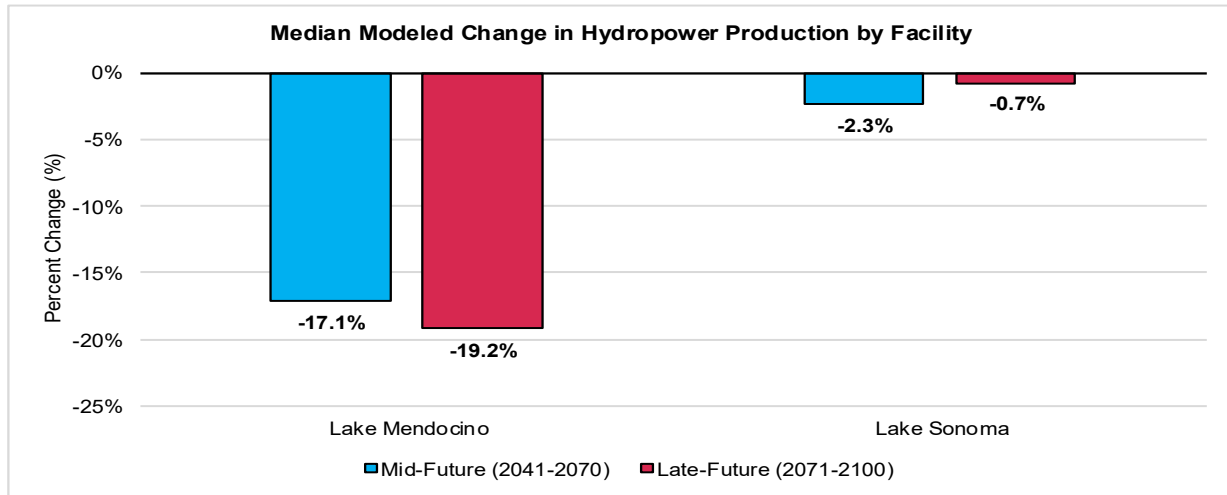
Lake Mendocino annual total hydropower generation is projected to decrease by roughly 17 percent and 19 percent under median mid-future and late-future conditions, respectively (Figure 5-15). These changes are primarily driven by a significant reduction in reservoir releases to hydroelectric turbines in October through January. The reduction in turbine flow for these months is caused by a decrease in reservoir inflows to Lake Mendocino

between spring and early winter as a result of reduced Eel River transfers. Given that Lake Mendocino hydroelectric supplies are primarily utilized by the City of Ukiah, alternative, local energy sources may need to be considered between October and January to compensate for the reduction in power production during these months.

- *Lake Mendocino annual total hydropower generation is projected to decrease by roughly 17 percent and 19 percent under median mid-future and late-future conditions*
- *Lake Sonoma annual total hydropower generation demonstrates high resilience to future climate conditions, with only modest decreases under future climate.*

Lake Sonoma annual total hydropower generation demonstrates high resilience to future climate conditions, with a 2 percent decrease under median mid-future conditions and a 1 percent decrease under median late-future conditions relative to historical trends (Figure 5-15). Monthly trends are projected to vary slightly from month-to-month on average, but any decreases in some months are largely offset by increases in others, particularly under late-future conditions. Ultimately, shifts in reservoir inflows at Lake Sonoma have a relatively muted effect on annual reservoir storage, and reservoir operations appear to be capable of maintaining historical hydropower generation trends under future conditions. Between late spring and early fall under late future conditions, Lake Sonoma hydropower production increases slightly relative to historical conditions, resulting in a minor overall increase in hydroelectric generation during this period. This change is driven by an increase in Lake Sonoma releases to compensate for the reduction in releases from Lake Mendocino during this period and ensure minimum instream flow requirements in the Russian River are being met.

Figure 5-15. Summary of Hydropower Vulnerability Assessment Findings



5.5 Understanding Hazards with an Equity Lens

Advancing equity in climate and watershed planning requires an understanding of the current vulnerabilities and sensitivities of the existing population and understanding how projected future hazards will impact those populations.

Community vulnerability in the watershed is assessed by overlaying climate hazard information with social vulnerability indicators to determine if community members with higher sensitivity to hazards are disproportionately exposed. To understand current sensitivity, we leveraged the sensitivity indicators developed by the Vulnerable Communities Platform (VCP) (Office of Land Use and Climate Innovation). The VCP aggregates multiple demographic and access related indicators to develop four unique sets of sensitivity indicators for specific climate hazards: Water Supply, Wildfire, Extreme Heat and Flooding. Subsequently, the projected climate hazards specific to Russian River watershed were overlaid with the community sensitivity to understand who is impacted by the projected climate impacts.

- Flood exposure increases by approximately 15 percent in the projected late-century, rising from approximately 13,000 residents to more than 15,000, with one third of exposed residents in the highest sensitivity tier.
- The risk of wildfire expands dramatically, with nearly the entire watershed exceeding a 15 percent decadal burn probability under late century conditions, affecting many mid-valley communities that historically experienced lower risk.
- Extreme heat exposure intensifies most sharply, with up to over 40 additional days above 95°F projected in inland areas by late century. Because 30 percent of residents, including outdoor workers and others with occupational heat exposure, are already in the highest heat sensitivity tier, exposure among heat sensitive populations increases by roughly 40 to 50 percent under future conditions.
- Future water supply vulnerability is similarly widespread, with roughly 50 percent of all residents expected to experience high water supply vulnerability.

5.5.1 Existing Population Sensitivity to Climate Hazards

Figure 5-16 illustrates how current sensitivity to drought, wildfire, heat, and flood is distributed across the Russian River watershed, revealing clear north–south contrasts: clusters of higher sensitivity (shown in reds and blues) occur most prominently in the northern portion of the basin, while lower and moderate sensitivity populations (greens, yellows, and purples) appear more frequently in the south. Together, these patterns highlight the uneven distribution of climate-related burdens across the watershed and underscore the need for place-specific strategies that address both environmental exposure and underlying social vulnerability.

Figure 5-16. Distribution of Population Sensitivity to Climate-Related Impacts (Left to Right: Water Supply Vulnerability, Wildfire, Extreme Heat, Flooding)

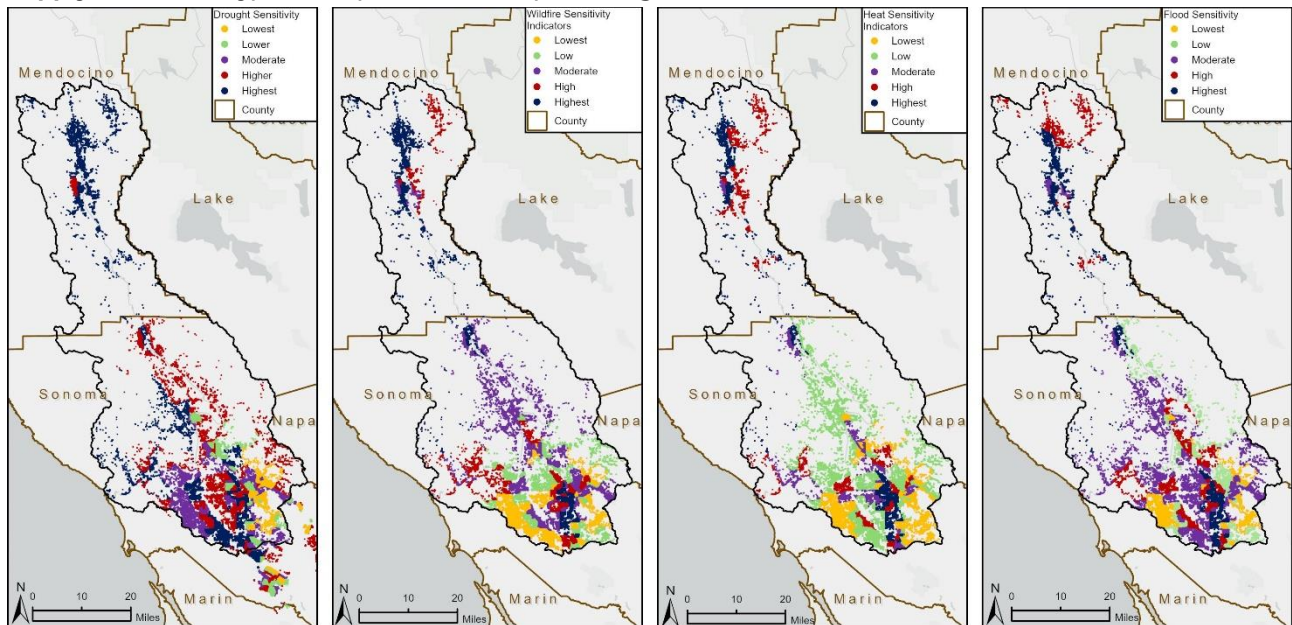
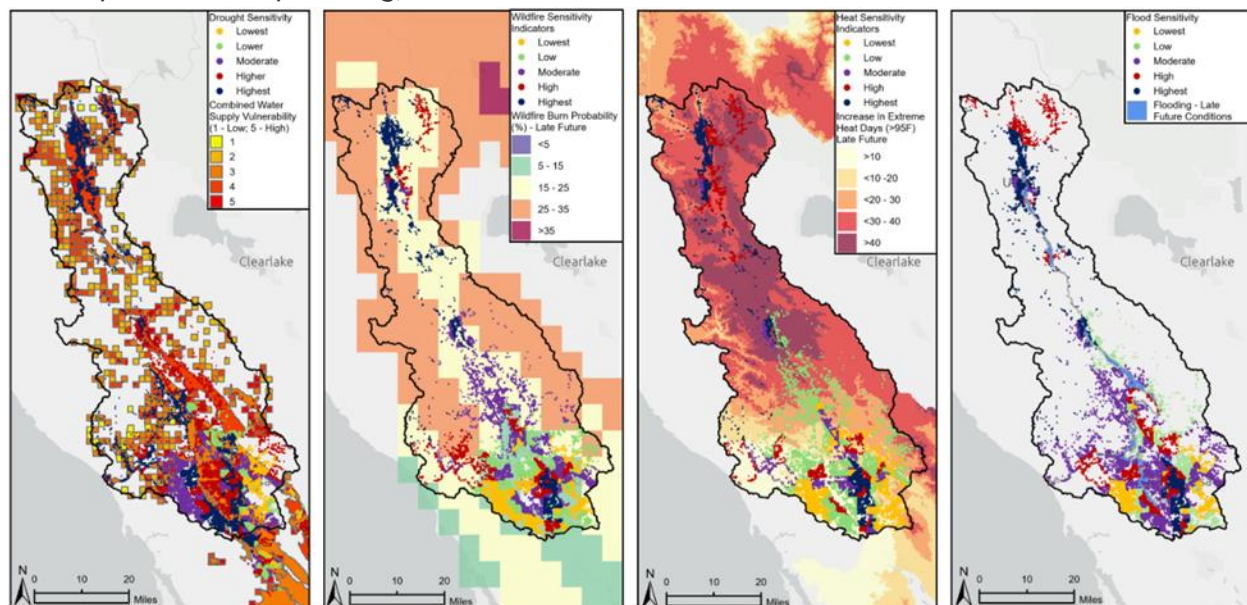


Figure 5-17 shows that in the late century climate scenario the population sensitivity to climate hazards is unevenly distributed across the Russian River watershed, with 40 to 50 percent of residents falling into moderate to highest levels of sensitivity, depending on the hazard. Across all four hazard types, the northern watershed consistently displays extensive clusters of high sensitivity, reflected in the dominance of blue (highest) and red (second-highest) sensitivity tiers.

Figure 5-17. Late-Future Conditions Climate Impacts Mapping (Left to Right: Drought Sensitivity, Wildfire, Extreme Heat, Flooding)



Many of the people who are most socially vulnerable live in places that currently face the greatest climate hazards, which means they experience disproportionate exposure today and will experience greater exposure in the future. Findings from the community and equity vulnerability assessment include:

- Flood exposure increases by approximately 15 percent in the projected late-century scenario, rising from approximately 13,000 residents to more than 15,000, with one third of exposed residents in the highest sensitivity tier.
- In the late future scenario, the risk of wildfire expands dramatically, with nearly the entire watershed exceeding a 15 percent decadal burn probability under late century conditions, affecting many mid-valley communities that historically experienced lower risk. Currently, about 20 percent of all watershed residents fall within the highest wildfire sensitivity tier.
- Extreme heat exposure intensifies most sharply, with up to over 40 additional days above 95°F projected in inland areas by late century. Because 30 percent of residents, including outdoor workers and others with occupational heat exposure, are already in the highest heat sensitivity tier, exposure among heat sensitive populations increases by roughly 40 to 50 percent under future conditions.
- Future water supply vulnerability is similarly widespread, with many residents expected to experience moderate to high water supply vulnerability.

Together, these findings underscore that hazard intensity, geographic reach, and exposure among high-sensitivity communities all increase substantially across future climate projections. Results of this assessment indicate that the people and neighborhoods of Santa Rosa, the Ukiah Valley, the Cloverdale-Healdsburg-Windsor corridor, the communities surrounding Lake Mendocino, and the lower Russian River corridor face the most significant and compounding climate pressures in the Russian River watershed.