Final Report

Appendix A. Background of Sonoma Water Climate Resilience Efforts

October 2021

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SECTION 1

Introduction

Sonoma Water is a regional and national leader in climate science and adaptation planning and has supported a number of efforts in both these areas. The region is susceptible to floods, droughts, wildfires and other extreme meteorological and hydrological events. The presence or absence of atmospheric rivers are a principal meteorological feature that controls the severity of these conditions. From a water management perspective, understanding and forecasting these events are key to more effective water management.

This section provides a summary of the climate-related activities that Sonoma Water has been engaged in to-date.

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SECTION 2

Climate and Hydrology Science

2.1 Climate and Hydrology Science

2.1.1 Sonoma Water-Supported Climate Science Studies

Recognizing the sensitivity of the region to climate extremes and the potential for changes in climate in the future, Sonoma Water has made considerable investments in climate science to improve understanding of, and planning for, climate changes in the region. Sonoma Water is supporting several climate science efforts in collaboration with various research agencies, such as the United States Geological Survey (USGS), Scripps Institution of Oceanography (SIO), and National Oceanic and Atmospheric Administration (NOAA). These efforts have resulted in improved understanding of the regional climate threats and have put Sonoma Water on the cutting edge of climate planning. The following is a brief review of Sonoma Water-supported programs and studies related to regional climate science.

2.1.1.1 USGS Climate Science and Watershed Hydrologic Modeling

Sonoma Water has been collaborating with the USGS on regional climate downscaling and hydrologic modeling for the Russian River watershed. A 2012 study (Flint and Flint, 2012a) was conducted to refine climate change impacts on hydrology and ecology from a global scale to a regional and local scale. A methodology was spatially developed using a gradient-inverse-distance-squared approach for hydrologic modeling applications. The methodology produced downscaled climate data and simulated hydrology using the Basin Characterization Model (BCM) at 270-meter spatial resolution.

Another study by the same authors (2012b, USGS Scientific Investigations Report 2012–5132) was conducted to investigate how climate change affects water resources and habitats in the San Francisco Bay area, specifically areas in the Russian River Valley and Santa Cruz Mountains. The BCM was applied for water balance modeling in this study. The study suggested a warming trend over the 20th century with spatial variations in the warming rate. BCM predicted reduced early and late wet season runoff during the next century when BCM was simulated using a set of downscaled climate change projections taken from Coupled Model Intercomparison Project 3 (CMIP3). The study suggested there could be higher variability in water supply due to higher variability in precipitation, however water demand is likely to increase due to increased evapotranspiration and climatic water deficit during extended summers. USGS has updated BCM simulated hydrologic projections (Micheli et al., 2016) using a set of downscaled climate change projections taken from Coupled Model Intercomparison Project 5 (CMIP5), which is the basis of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (2013).

Ongoing collaborative efforts with the USGS are focused on use of the climate and hydrologic model results in Sonoma Water's HEC-ResSim model to evaluate potential risks to reservoir operations, Russian River flows, and regional water supply.

2.1.1.2 Atmospheric River Research for Flood Control and Drought Forecasting

Atmospheric Rivers (ARs) are responsible for most, if not all, of Russian River extreme precipitation events. There is potential for ARs, the storms that are associated with most flood events in California (Ralph et al. 2006), to increase in magnitude or intensity (Dettinger et al. 2009), which is likely to affect associated flood risk. The Center for Western Weather and Water Extremes (CW3E) at SIO is conducting an assessment of ARs in California. The specific aims of this scientific assessment are to describe both the historical and projected distribution of AR characteristics that drive extreme precipitation in California. Initial findings by SIO suggest that both magnitude and frequency could be affected in the future. While changes in atmospheric river indices capture many of the most severe extreme precipitation events in the Russian River, they do not reflect all storms that could pose risk to flood infrastructure and management.

While landfalling ARs can provide a significant source of water for California following deficit years, the sudden accumulation of precipitation has the potential to induce flood events. Those located in floodplains and areas adjacent to rivers or coastlines are more vulnerable to significant flooding and are thus more likely to suffer damages as a result of flood events (Corringham et al., 2019). Corringham et al. (2019) shows that Sonoma County experienced the highest damages of any county over the 1978 to 2017 period along the western coast of the United States.

Given the large amount of variability in California's precipitation, years with extended precipitation percent well below the average can result in droughts. Because the state tends to rely on a small number of storm events to provide most of the precipitation for the year, if any number of these events circumvent the state, deficits can begin to rise. These high precipitation storms result from ARs making landfall and can make up much of the deficit created in dry years. Pineapple express events tend to follow the dips in in precipitation totals (drought events), providing ample precipitation above the mean total for roughly 2 to 3 years.

Sonoma Water has been an early and leading partner with NOAA/SIO supporting improved research on atmospheric river characterization and forecasting to improve water management in Sonoma County. Sonoma Water and CW3E formed a cooperative agreement to improve understanding and prediction of ARs and their relationship to improved water supply and reservoir operations. The NOAA/SIO's West Coast Atmospheric River Program is conducting research on ARs to help understand their processes to support water resource and flood risk planning. ARs are classified as narrow (400 to 600 kilometers wide and 1.5 kilometers above the ocean surface, on average) corridors of concentrated moisture levels in the atmosphere that can carry as much water as 15 Mississippi Rivers. Research has shown that 30 to 50% of annual precipitation on the west coast take place during just a few AR events and are significant features in the global water cycle.

Forecast Informed Reservoir Operations

In response to changes in the operation of the PVP in 2006 and experiences from the recent drought years of water years 2013 through 2015, Sonoma Water, SIO and USACE were motivated to evaluate the viability of forecast informed reservoir operations (FIRO) for Lake Mendocino to benefit water supply without impairing flood management capacity. FIRO (http://cw3e-web.ucsd.edu/firo/) is a reservoir operations strategy that better informs decisions to retain or release water by integrating additional flexibility in operation policies and rules with enhanced monitoring and improved weather and hydrological forecasts (American Meteorological Society, 2020; https://glossary.ametsoc.org/wiki/Forecast-informed_reservoir_operations). FIRO is a non-structural alternative to improving efficiency of multi-purpose reservoirs in that it seeks to modernize operations by incorporating state-of-the-art forecast information without the need of modifying existing infrastructure. The goal of FIRO at Lake Mendocino is to increase water supply reliability without reducing—and while possibly enhancing—the existing flood protection capacity of Lake Mendocino and downstream flows for fisheries habitat. Flooding and water supply in the Russian River basin are driven almost entirely by ARs, which are storms that transport large amounts of tropical and narrowly focused atmospheric moisture. Given the significance of the timing and location of where ARs make landfall, the success of FIRO at Lake Mendocino depends on research to improve AR forecasts, work that is being led by the SIO.

Operational decisions at Lake Mendocino are governed by rules in the USACE Coyote Valley Dam Water Control Manual (Water Control Manual). Those rules define the Lake Mendocino guide curve, which allocates available storage to a flood control pool at the top of the reservoir and a water supply pool below that. The USACE determines the schedule and amount of water released from Lake Mendocino during flood control operations when storage levels exceed the water supply storage pool. Rules of the Water Control Manual require the flood control pool to be empty except during periods of high flows downstream. The Lake Mendocino watershed experiences large variations in the annual amount and timing of precipitation, and the occurrence of a few large storms (often in the form of ARs) can be the difference between an ample water year and a drought (Dettinger et al., 2011). Water supply capture in Lake Mendocino is sensitive to yearly timing or distribution of rainfall due to the variable water supply pool. Given the constraints of the current guide curve, the lake must receive significant inflow in the spring (past March 1) to meet the minimum instream flow requirements and downstream demands for the remainder of the year, which has become increasingly challenging with the changes in PVP operations in 2006.

To guide the Lake Mendocino FIRO project, the Lake Mendocino Steering Committee (Steering Committee) was formed in 2014 with representatives from multiple disciplines (flood/ environmental/ water supply managers, engineers/hydrologists, and meteorologists/ atmospheric scientists) from multiple agencies including the USACE, Sonoma Water, SIO, National Oceanic & Atmospheric Agency, U.S. Geological Survey, U.S. Bureau of Reclamation, and California Department of Water Resources (DWR). A work plan was developed by the Steering Committee (2015) to establish a framework for evaluating whether FIRO is a viable strategy to safely manage storage levels, i.e., to maintain existing flood control protection while also improving storage reliability for water supply and ecosystems.

In July 2017, the Steering Committee completed a preliminary viability assessment (PVA) of FIRO for Lake Mendocino (FIRO Steering Committee, 2017). The evaluation of FIRO was enabled by the existence of forecasts of runoff throughout the Russian River watershed from the California Nevada River Forecast Center. This study found that a forecast-based decision support system could be a viable solution to meet project goals of improving the storage reliability of Lake Mendocino for water supply and ecosystems without increasing the flood risk to downstream communities.

Based on the positive outcomes of the PVA, major deviations to the Water Control Manual were requested by the Steering Committee and approved by the USACE to implement FIRO on an interim basis for water years 2019 and 2020. These major deviations implemented the Hybrid alternative evaluated in the PVA that was developed by Sonoma Water (Delaney et al., 2020), which provides 11,650 ac-ft of encroachment in the flood control pool between November 1 and the end of February. Under these major deviations, USACE operators could retain water under their discretion within this encroachment pool for water supply using FIRO decision support tools developed by Sonoma Water and Scripps, along with existing USACE procedures and protocols. However, if forecasts indicated it was unsafe, this water could be released to the existing guide curve level. Water year 2019 was a wet year with a significant flood that occurred in February, which demonstrated that a FIRO decision support system can be used to effectively manage storage levels and regulate downstream flows during flood events. Water year 2020 was a much drier year by comparison and did not result in any flood control operations of the reservoir, but two AR events in February and transfers of Eel River water through the PVP allowed reservoir storage to reach the top of the major deviation encroachment level resulting in approximately 11,000 ac-ft of additional storage when compared to the estimated storage level if the major deviation were not implemented.

The viability of FIRO was further evaluated by the Steering Committee with the final viability assessment (FVA) that was completed in February 2021 (Jasperse et al., 2021). This study built from the efforts of the PVA through the completion of detailed hourly time-step modeling of the operations, hydraulics and flood damages of four different water control plan alternatives (compared to current operations under the existing Water Control Manual) and included the simulation of extreme flood events of 200-year and 500-year recurrence frequencies. Results of this study supported the results of the PVA and found that all the alternatives evaluated could meet the project objectives with varying degrees of success for different criteria. This study also provided a review of ongoing and future research by project partners to support future improvements in reservoir operations.

A 5-year major deviation was requested by the Steering Committee and approved by the USACE in February 2021 for water years 2021 through 2026, which provides temporary implementation of the Modified Hybrid alternative. This alternative, developed by Sonoma Water, was evaluated in the FVA and demonstrated best overall performance for most criteria. The Modified Hybrid alternative is similar to the Hybrid alternative, which was implemented in the 2019 and 2020 major deviations but allows for an earlier date (from March 1 to February 15) to begin the transition of the encroachment pool for springtime operations, which expands the flood pool encroachment from February 15 to May 11.

The USACE has begun the process and studies required to permanently implement FIRO for Lake Mendocino through updating the Water Control Manual. This will likely be a multi-year effort that requires in-depth engineering and environmental review. It is anticipated the update will be completed within the next five years prior to the 2025 Plan. Consequently, for the water availability analysis, Sonoma Water is assuming the Lake Mendocino Water Control Manual update will be completed prior to the expiration of the current major deviation and FIRO will be in place for the 25-year planning horizon of the 2020 Plan.

NOAA Hydrometeorology Testbed (HMT)

ARs previously have only been identified by measuring atmospheric moisture level content with satellite imagery. However, the issue with detecting ARs solely through satellite imagery is that the data collected omits moisture content over land and other important factors for flood forecasting, such as wind. This gap in information led to the formation of the NOAA/SIO HMT Program. The HMT is a research program that aims to improve precipitation forecasting tools to support efforts in managing water resources, flood control, and climate change adaptation. Research conducted through the testbed is directed by a collaborative team of scientists and decision makers, such as Sonoma Water, for testing new ideas, technologies, and developing predictive models for weather forecasting. A memorandum of agreement between Sonoma Water and NOAA's HMT has been signed with the first phase of research including a case study to improve the Quantitative Precipitation Information in the Russian River basin. This research is being carried out by evaluating the benefit of TV radar, determining the optimal combination of radar and gauges for hydro forecasting, and developing high resolution temperature forecasts to help reduce Russian River draw down during frost and heat wave events. The program will eventually extend these studies to more monitoring sites, as well as perform further research on atmospheric river case studies to benefit reservoir operations.

Atmospheric River Observatories (AROs), funded by DWR, were developed with the program's technologies to collect and monitor missing data on land and wind where satellite imagery left a gap (http://www.esrl.noaa.gov/psd/psd2/technology/aro.html). The observatories include a Doppler wind profiler, an S-band precipitation profiling radar, and surface-based disdrometers to study the microphysics of precipitation, and a meteorological tower to monitor AR conditions near the Earth's surface. By the end of 2016, four coastal AROs were installed along the California coast in Goleta, Point Sur, Eureka and Bodega Bay, costing roughly $1.1 million each. Tools developed from the data collected from the AROs assist weather forecasters calibrate forecasting models, predict storm and flood events, and have already improved flood mitigation by letting operators better predict when to open or close dams and other structures along reservoirs and rivers.

NOAA National Integrated Drought Information System (NIDIS)

Storage in Lake Mendocino declined to less than 32 percent capacity in 2014 due to the drought, a level not seen since the severe drought of 1977. As part of NIDIS, a grant was awarded to SIO to partner with Sonoma Water and USGS to improve understanding and prepare for droughts in the region. Specific goals of the partnership include analyzing historical data and incorporating climate change forecasts to assess how ARs play a role in ending droughts, using dendrochronology (the study of tree rings) to better understand the frequency of extreme droughts, model an extreme drought scenario for the Russian River for planning purposes, and to develop and implement a process that will identify the drought readiness of the Russian River. The outcomes of this grant produced a climate change adaptation/drought readiness report that assists water resource planners in identifying drought indicators and linked response measures to reduce drought impacts.

Sectoral Applications Research Program (SARP)/National Integrated Drought Information System (NIDIS)

The California-Nevada Applications Program (CNAP) is a NOAA and California Energy Commission funded program whose objective is to improve local climate change forecasts and provide meaningful information to stakeholders and decision makers on what the forecasts mean on a local scale. CNAP and Sonoma Water are partnering under the SARP/NIDIS to improve drought information for the Russian River. The objective of the program is to provide stakeholders, such as Sonoma Water with drought monitoring technology that is relevant to heavily regulated, imported and unmanaged water supplies. Integrating all of these water resources allows the technology to monitor not only climate and hydrometeorology indicators, but will also supplement regulatory, economic, water supply, water demand, water quality, and impact-based information. This information will provide water agencies with the ability to customize the type, format, and scale of indicators they monitor. Agencies can then use this information for extreme weather forecasting and planning, provide early warnings to reservoir regulators, as well as supplemental information for community involvement and education.

2.1.1.3 NOAA Habitat Blueprint Russian River

Habitat Blueprint is a program developed by NOAA to integrate habitat conservation throughout regions where NOAA's efforts are present. The program includes collaborations with internal and external work groups to improve ecological habitats such as rivers, coral reefs, and wetlands. Sonoma Water was awarded $690,000 in September 2014 to develop a strategy for habitat conservation in the Russian River watershed via the Habitat Blueprint framework. The Russian River watershed is the first region where the Habitat Blueprint strategy was employed. The accomplishments include:

1. Developed FIRO, an innovative management strategy that applies improved water forecasting to management of reservoirs to balance the needs of threatened and endangered fish species and people.
2. Restored breeding grounds for coho salmon.
3. Improved stream habitat to reduce flooding and recover salmon populations.
4. Incorporated water conservation measures for local landowners.

2.1.1.4 Integrated Water Resources Science and Services (IWRSS)

The USACE, USGS, and NOAA are collaborating on services, science, and tools to help support Integrated and Adaptive Water Resource Management. The purpose of this collaboration is to facilitate water resource management efforts and advance the understanding of water resource science. The collaboration also provides the capability of sharing and enhancing historical and real-time hydrologic data, high resolution water resource forecasts and flood inundation maps, data and modeling applications and software tools, and background information about authorities, policies, and programs related to water resource science and engineering efforts of each agency.

2.1.1.5 North Bay Climate Ready

Working in partnership with the Sonoma County Regional Climate Protection Authority (RCPA), the North Bay Climate Adaptation Initiative (NBCAI), and Sonoma Water, Pepperwood's Terrestrial Biodiversity Climate Change Collaborative has developed customized climate vulnerability assessments with natural resource agencies of California's Sonoma, Marin, Napa and Mendocino counties via "Climate Ready North Bay," a public-private partnership funded by the California Coastal Conservancy's Climate Ready program. The goal of Climate Ready North Bay is to engage natural resource agencies, including water agencies, parks, and open space districts, and other municipal users to collaboratively design climate vulnerability information products specific to their jurisdictions, mandates, and management priorities.

The RCPA released a report *Climate Ready Sonoma County: Climate Hazards and Vulnerabilities*. The report provides a broad depiction of the climate hazards and vulnerabilities for Sonoma County communities. As part of this effort and the related *North Bay Climate Ready* effort, future downscaled climate projections were evaluated, and specific scenarios were selected to represent the range of potential future climates for the region. As part of this work, downscaling of additional climate futures were prepared for the Russian River watershed, Petaluma, Sonoma Valley, Marin, and Napa. Metrics were identified by various user groups, including Sonoma Water, to assist in identifying vulnerabilities for resources throughout Sonoma County. Based on these scenarios and metrics, the vulnerabilities for Sonoma County resources and communities were identified at a summary level.

2.1.1.6 Sonoma Water's OneRain Site

Sonoma Water's Real-time Rainfall, River-Stream and Reservoir Data (OneRain) website, developed in response to North Bay wildfires in 2017, OneRain provides real-time and historical rainfall, river and stream levels, and reservoir levels and flow data. Data from this website is linked to the National Weather Service, which will use it in issuing weather watches, alerts, and warnings. The website has also been expanded to include all readily available rainfall and stream level data from other federal and state governmental agencies including USGS and CDEC.

2.2 Climate and Hydrologic Projections

Global climate change influences the climate of various regions of the world in differing ways. Understanding of regional climate and climate variability, regional projections, and regional impacts is important for any vulnerability assessment and adaptation plan. This section provides a synthesis of the climate science and projections of change for the Sonoma region.

2.2.1 Overview of Climate Change Science and Projections for the Sonoma County Region

Over the past several decades, air temperatures have increased globally and throughout the western United States, including California. While the Sonoma County region is complex with several microclimates, historical patterns of warming have occurred in near all monitoring stations in the region. Precipitation over most of California, including the Sonoma County region, is dominated by extreme variability, both seasonally, annually, and over decadal time scales. No significant trends in total annual precipitation are apparent from the historical records, likely the result of the dominance of natural variability in the observational periods.

Projections of future climate conditions are generally performed through general circulation models (GCMs) or regional circulation models forced with specific global greenhouse gas (GHG) emission scenarios. GCMs have relatively coarse resolution (approximately 100-kilometer grid scales) but are supported at major national climate research centers and have been simulated for a wide range of future emission scenarios. The resolution of the GCMs and the land-ocean feedbacks are continually improving. However, due to the relative coarse spatial resolution of GCMs, downscaling to the scale relevant for the study is required and biases must be corrected. Projections of future climate contain significant uncertainties. Uncertainties exist with respect to understanding and modeling of the earth systems, uncertainties with respect to future global development and GHG emission pathways, and uncertainties with respect to simulating changes at the local scale.

The summary of projections included in this section relies upon available climate projections using the models and emissions scenarios included in either the Coupled Model Intercomparison Project 3 (CMIP3) or 5 (CMIP5) (Taylor et al. 2012). These include over 200 individual downscaled climate projections that were included in the IPCC Assessment Report 4 (AR4) and 5 (AR5) (IPCC, 2007; IPCC, 2013). Additional scientific literature was reviewed to augment the information from the available projections. In addition to the climate change projections described previously, 20 individual downscaled GCM projections were selected from 10 different GCMs and 2 different Representative Concentration Pathways, RCP4.5 and RCP8.5. These 10 GCMs were chosen by the DWR Climate Change Technical Advisory Group (CCTAG) based on a regional evaluation of climate model ability to reproduce a range of historical climate conditions (DWR CCTAG, 2015). These 20 climate projections were downscaled using a statistical downscaling method called localized constructed analogs (LOCA) at 1/16th degree (approximately 6 kilometers) (3.75 miles) spatial resolution by SIO (Pierce et al., 2014, 2018). The LOCA method is a statistical scheme that uses future climate projections combined with historical analog events to produce daily downscaled precipitation and temperature time series. No additional processing of regional climate information developed by USGS was performed for the qualitative vulnerability assessment. However, the climate projections developed by USGS were processed and analyzed for the quantitative climate vulnerability assessment.

The IPCC has begun to release its Sixth Assessment Report (AR6) on the drivers and potential impacts of climate change and the ways in which human societies may respond (IPCC, 2021). Climate Change 2021: The physical science basis is the key output of IPCC’s Working Group I (WGI) and provides a contemporary understanding of the current state of the climate, how this is changing and may continue to change over shorter and longer timescales and the influence of human activity on current and future. Climate Change 2021: The physical science basis builds on the contributions of WGI to the IPCC’s Fifth Assessment Report (AR5), published in 2013 and several IPCC Special Reports published in 2018 and 2019. Its findings are broadly consistent with AR5, particularly in that it affirms that the increase of carbon dioxide, methane and nitrous oxide in the atmosphere over the industrial era is the result of human activities.

Table A-1 summarizes the available information related to the most relevant climate variables for the Russian River watershed. The projected climate changes (median and range of downscaled climate projections) included in Table A-1 are based on both the full ensemble of CMIP3 and CMIP5 projections. More detailed information related to the projections of each of these variables, and important hydrologic variables, is included in the subsequent sections. The following information has utilized to conduct the qualitative change vulnerability assessment for Sonoma Water’s water supply, flood management, and sanitation systems.

Table A-1. Synthesis of Projected Climate and Hydrologic Changes for the Russian River Watershed Region

Change Type	Climate Variables	Projected Changes and Range	Likelihood	Reference
Temperature Changes	Annual Mean Temperature	+1.8°F (0.72 to 2.52) [+1.0°C (0.4 to 1.4°C)] by early-century from CMIP3 models +1.98°F (1.26 to 2.88) [+1.1°C (0.7 to 1.6°C)] by early-century from CMIP5 models +3.24°F (1.98 to 4.32) [+1.8°C (1.1 to 2.4°C)] by mid-century from CMIP3 models +3.78°F (2.34 to 5.58) [+2.1°C (1.3 to 3.1°C)] by mid-century from CMIP5 models +4.32°F (2.7 to 6.12) [+2.4°C (1.5 to 3.4°C)] by mid-century from CMIP3 models +5.04°F (2.88 to 8.1) [+2.8°C (1.6 to 4.5°C)] by mid-century from CMIP5 models	High degree of confidence in future warming; magnitude is uncertain within reported range	Maurer et al (2007); Brekke et al (2013); Pierce et al. (2018)
Temperature Changes	Seasonal Mean Temperature	+2.88°F (+1.6°C) in Winter by mid-century +4.14°F (+2.3°C) in Summer by mid-century	High degree of confidence in future warming; magnitude is uncertain	Pierce et al (2012)
Temperature Changes	Annual 3-day Extreme High Temperature	Approximately +3.6°F (+2°C) by mid-century across the distribution; increase in frequency of 3-day maximum temperatures above 86°F (30°C) Higher warming anticipated for inland valleys and mountain ridges.	High degree of confidence in future extreme warming; magnitude is uncertain	Pierce et al (2012); Pierce et al (2014)

Change Type	Climate Variables	Projected Changes and Range	Likelihood	Reference
Precipitation Changes	Annual Mean Precipitation	-0.6% (-14.0 to +15.0%) by early-century from CMIP3 models +1.3% (-10.5 to +12.8%) by early-century from CMIP5 models +0.2% (-14.7 to +15.1%) by mid-century from CMIP3 models +4.8% (-11.7 to +17.9%) by mid-century from CMIP5 models +0.0% (-18.7 to +13.8%) by late-century from CMIP3 models +7.0% (-8.4 to +25.0%) by late-century from CMIP5 models+6	Magnitude and direction are uncertain, although latest models suggest wetter conditions	Maurer et al (2007); Brekke et al. (2013); Pierce et al. (2018)
Precipitation Changes	Seasonal Mean Precipitation	+2.0% in Winter by mid-century -13.0% in Summer by mid-century	Magnitude and direction are uncertain, however greater confidence in direction of summer precipitation	Pierce et al (2012)
Precipitation Changes	Annual 3-day Extreme Precipitation	Maximum 3-day accumulations are expected to increase. In many instances maximum 3-day accumulations are projected far outside the historical distribution	Medium degree of confidence in increase of future extreme precipitation, magnitude is uncertain	Pierce et al (2012); Pierce et al (2014)

Change Type	Climate Variables	Projected Changes and Range	Likelihood	Reference
Sea Level Changes	Mean sea level	0.92 foot (0.4 to 1.99 feet) [+28 centimeters (12.3 to 60.8 centimeters)] by 2050 relative to the level in 2000. Probability of increases of future storm surges and high waves on the coast. By mid-century, median SLR is projected to be 0.9 foot (0.6 to 1.1) in RCP 8.5 with respect to 1991 to 2009 mean. By 2100, median probability of SLR is projected to be 1.6 feet (1.0 to 2.4 feet) and 2.5 feet (1.6 to 3.4 feet) in RCP 2.6 and RCP 8.5, respectively with respect to 1991 to 2009 mean. The H++ scenario, where high levels of ice loss from the Antarctic ice sheet are considered, projects 10 feet of sea level rise by 2100 with respect to 1991 through 2009 mean.	High degree of confidence of future sea level rise; magnitude is uncertain within reported range	National Research Council (2012); Griggs et al (2017); Ocean Protection Council (2018)
Hydrologic, Watershed Conditions Variables	Drought	Increased variability in water supply due to greater variability in precipitation, combined with warming. Potential reduction in early and late wet season runoff by end of the century, leading toward extended summer dry season.	Medium confidence in greater drought severity and frequency	Flint and Flint (2012a,b); Flint et al (2013); North Bay Climate Ready (2016)
Hydrologic, Watershed Conditions Variables	River Flooding	Potential increase for AR events, the storms that are associated with most flood events over Russian River. Increase in AR magnitude and frequency projected. By mid-century, 100-year floods are projected to be 10 to 20% higher relative to historical period	Medium degree of confidence in increase of future extreme precipitation which drive flooding risk	Dettinger (2011); DWR (2017)

Change Type	Climate Variables	Projected Changes and Range	Likelihood	Reference
Hydrologic, Watershed Conditions Variables	Wildfire	Wildfire risk is projected to increase due to warmer temperatures associated with drier conditions. Probability of one or more wildfires in Sonoma County expected to increase. Fire return intervals are projected to reduce in Sonoma by approximately 25% by late-century.	High degree of confidence due to warming and extended dry season length variability	Westerling et al (2011); Bryant and Westerling (2012); Westerling (2018); Kwawchuck and Moritz (2012)

2.2.1.1 Projected Changes in Temperature

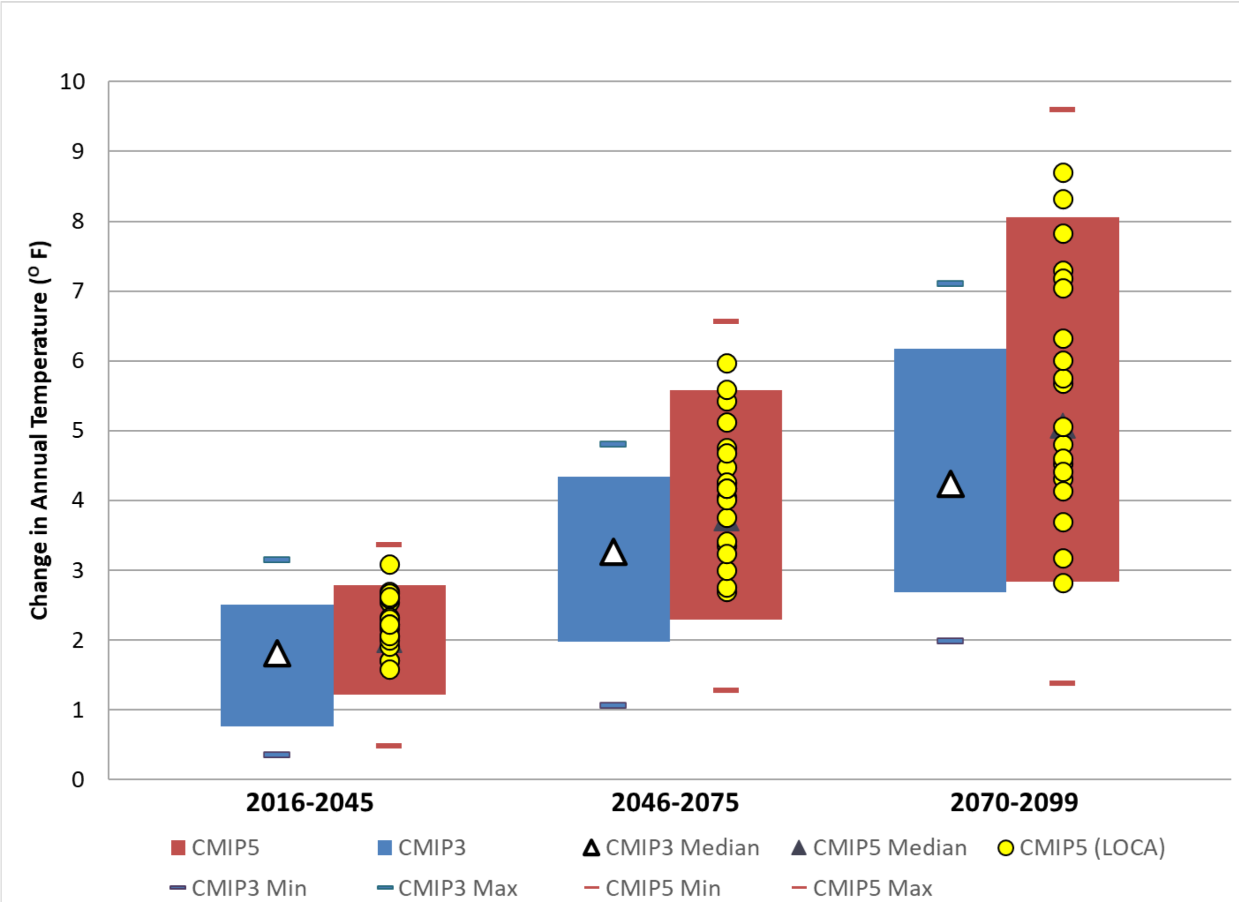
Under all available future climate scenarios, air temperatures are projected to increase in California. All projections are consistent in the direction of the temperature change (increase) but vary in terms of climate sensitivity (magnitude) (Cayan et al. 2009; Cayan et al. 2008a, 2008b, and 2008c). The median of the available climate model projections suggests up to 3.6 °F (2 °C) to 5.4 °F (3 °C) increase by 2050 for the Sonoma County region (Brekke et al. 2013). Beyond mid-century the projections of warming are strongly dependent on the GHG emission pathway and could range from 2.88 °F (1.6 °C) to 8.1 °F (4.5 °C) by end of century (Figure A-1). Climate projections selected by DWR CCTAG for California climate and water assessments approximately span the range of the broader ensemble. The 10 GCMs selected by DWR CCTAG were also used in California's Fourth Climate Change Assessment (Pierce et al., 2018).

Summer temperatures are projected to increase more than those in winter. Pierce et al (2012) analyzed seasonal changes in the projected warming and reported that winter warming was projected to increase by 2.88 °F (1.6 °C), while summer warming was projected to increase by 3.78 °F (2.1 °C). In addition, the frequency of extreme summer heat events is projected to increase significantly in the future. This finding appears to be robust for all California climate regions evaluated in the Pierce et al (2012) study. Increases of approximately 3.6 °F (2 °C) are projected for the warmest 3-day periods in the future (Figure A-2).

Figure A-3, which displays projected maximum summer air temperature from 2040 through 2069 under three climate scenarios with “business as usual” emissions conditions. Sonoma County is projected to experience an increase in maximum summer air temperature by 4.2 °F (2.33 °C) in warm and high rainfall conditions, 3.8 °F (2.11 °C) in warm and moderate rainfall conditions, and 7 °F (3.88 °C) in hot and low rainfall conditions. By late-century (as seen in Figure A-4), further warming is expected with projected increases of 7.2 °F (4 °C) in warm and high rainfall conditions, 6.3 °F (3.5 °C) in warm and moderate rainfall conditions, and 11.2 °F (6.22 °C) in hot and low rainfall conditions. While increased warming is projected for the entire region, inland valley and mountain ridges are projected to exhibit a larger increase in maximum temperatures.

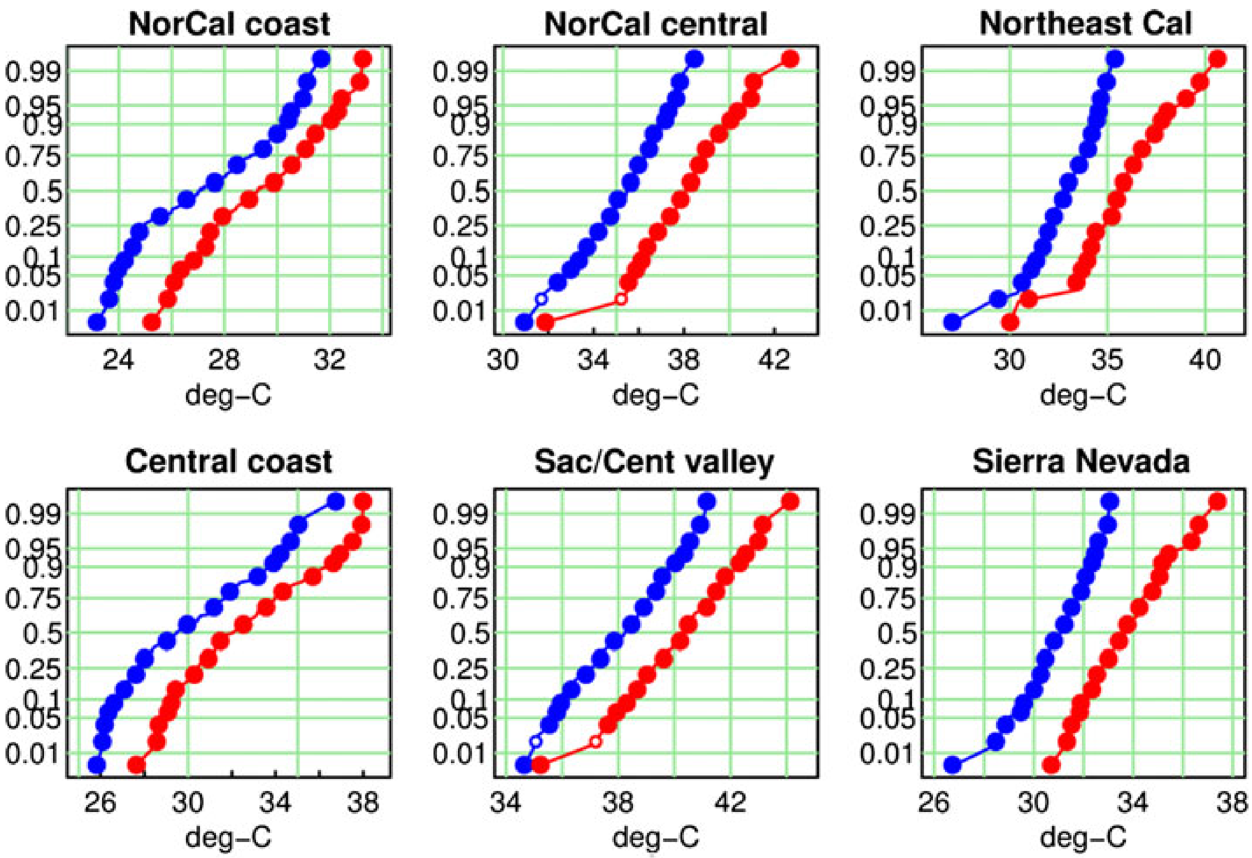
Short-term heat wave occurrence is another important metric for understanding projected changes in temperature. Figure A-5 reveals that the number of days that exceed 95 °F (35 °C) and 100°F (37.77°C) temperatures is projected to increase under future climate conditions.

Figure A-1. Projected Changes in Mean Annual Temperatures for the Sonoma County Region based on CMIP3 and CMIP5 Projections



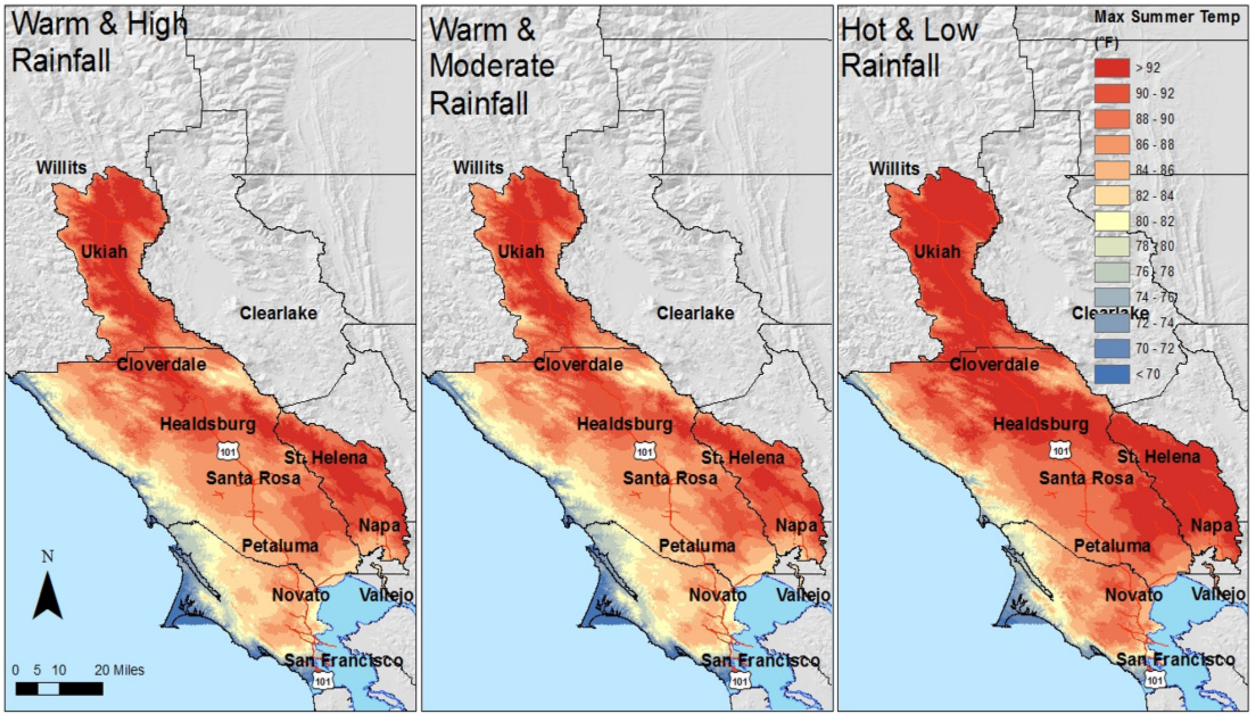
Note: The projected changes for CMIP3 and CMIP5 are computed using 112 and 178 downscaled climate model projections, simulated under Special Report on Emissions Scenarios (SRES) emission scenarios A2, A1B, and B1 for CMIP3 and simulated under Representative Concentration Pathways RCP8.5, RCP6.0, and RCP4.5 for CMIP5, used in the IPCC's AR4 and AR5, respectively. CMIP3 and CMIP5 climate model projections have been bias-corrected and spatially downscaled using bias-correction and spatial downscaling (BCSD) monthly statistical downscaling method at 1/8th degree (approximately 12 kilometers) (7.5 miles) spatial resolution (Maurer et al., 2007; Brekke et al., 2013). Changes are computed with respect to 1971 to 2000 model simulated period for both CMIP3 and CMIP5. Bars represent the range between the 10th and 90th percentiles. Circles represent the 20 climate model projections downscaled using LOCA daily statistical downscaling method at 1/16th degree (approximately 6 kilometers) (3.75 miles) spatial resolution. These 20 climate projections are from 10 GCMs and two Representative Concentration Pathways (RCP8.5 and RCP4.5) selected by DWR CCTAG for California climate and water assessments.

Figure A-2. Historical (blue) and Projected (red) 3-Day Extreme Temperature Frequency for Central and Northern California Regions (Source: Pierce et al 2012)



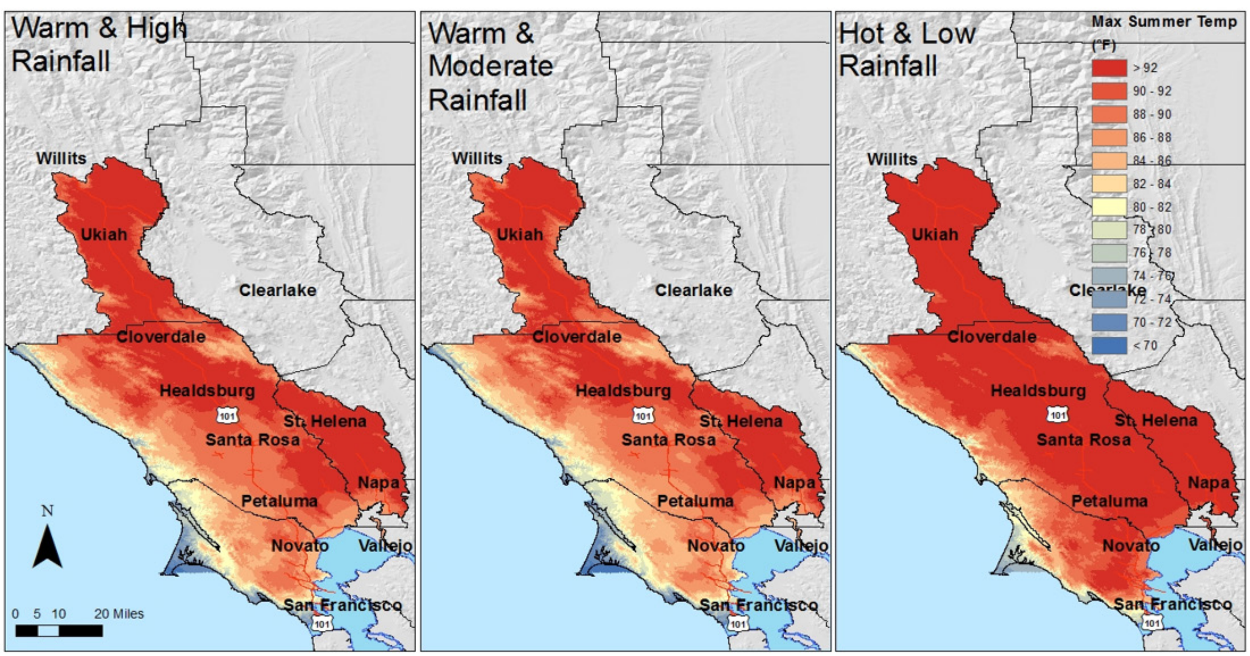
Note: The Y axis shows the probability (zero to one) of having the warmest 3 days in a year be the indicated temperature or lower. Results from the historical run are in blue; the future run is in red. Panels are plotted roughly geographically. Large solid dots show where the two curves are different at the 95 % significance level evaluated using a bootstrap technique. Data from the 9 runs with daily data was used to make the figure (adapted from Pierce et al. 2012)

Figure A-3. Mid-Century Projected Summer Maximum Air Temperature



Source: NBCAI 2016

Figure A-4. Late-Century Projected Summer Maximum Air Temperature



Source: NBCAI 2016

Figure A-5. Three-day Heat Waves for the Santa Rosa Plain Under Four Climate Simulations

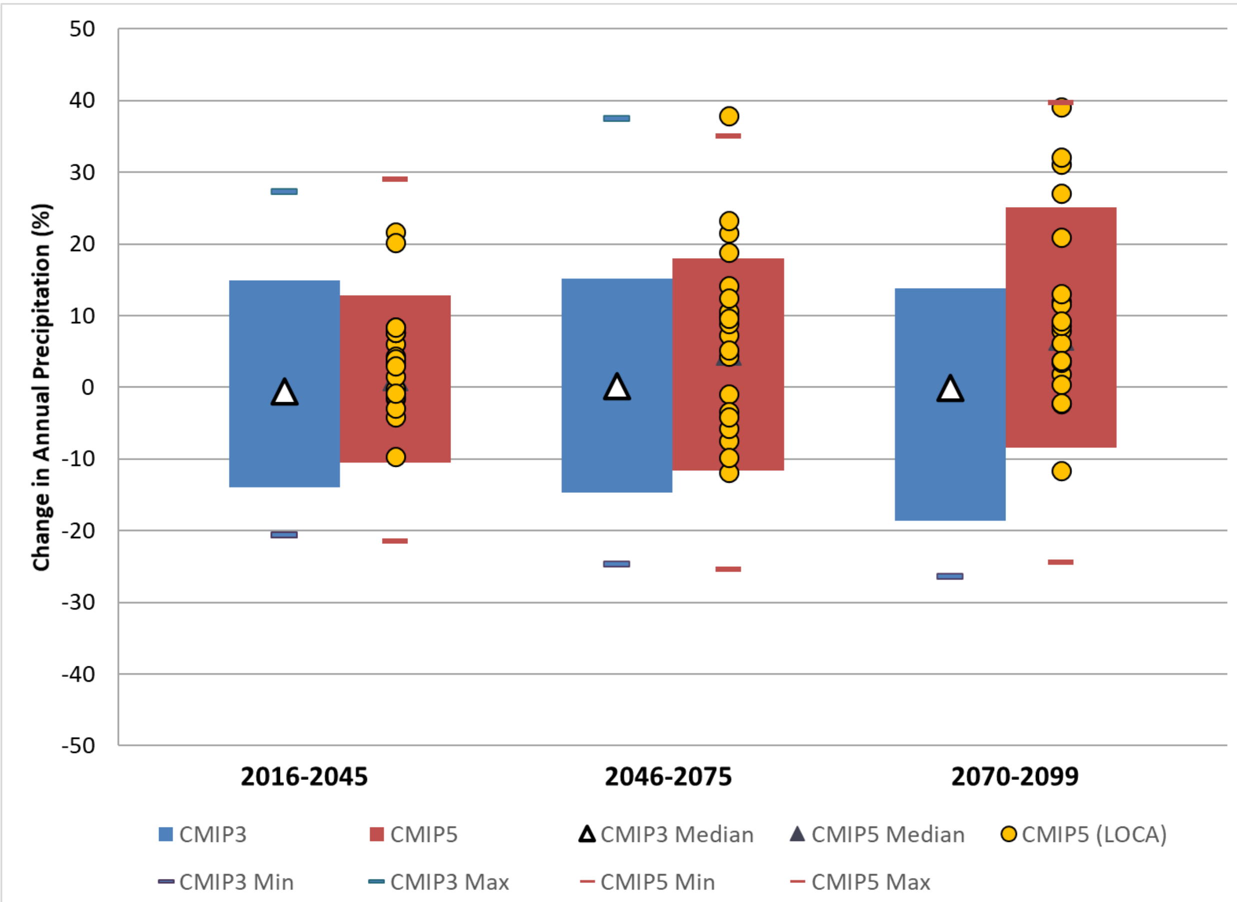
Source: NBCAI 2016

2.2.1.2 Projected Changes in Precipitation

Precipitation in most of California, including Sonoma County, is dominated by extreme variability, both seasonally, annually, and over decade time scales. The GCM simulations of historical climate capture the historical range of variability reasonably well (Cayan et al, 2009), but historical trends are not well captured in these models.

Projections of future precipitation are much more uncertain than those for temperature. While it is difficult to discern strong trends from the full range of climate projections, the median of the projections suggest neutral to wetter futures. While the median of the future climate projections included in CMIP3 ensemble, suggests a slight increase or no change in annual precipitation, the median of the projections in CMIP5 ensemble suggest an increase by about 5% by mid-century and about 8% by end of century (Brekke et al. 2013) (Figure A-6). Climate projections selected by DWR CCTAG for California climate and water assessments approximately span the range of the broader ensemble.

Figure A-6. Projected Changes in Mean Annual Precipitation for the Sonoma County Region based on CMIP3 and CMIP5 Projections

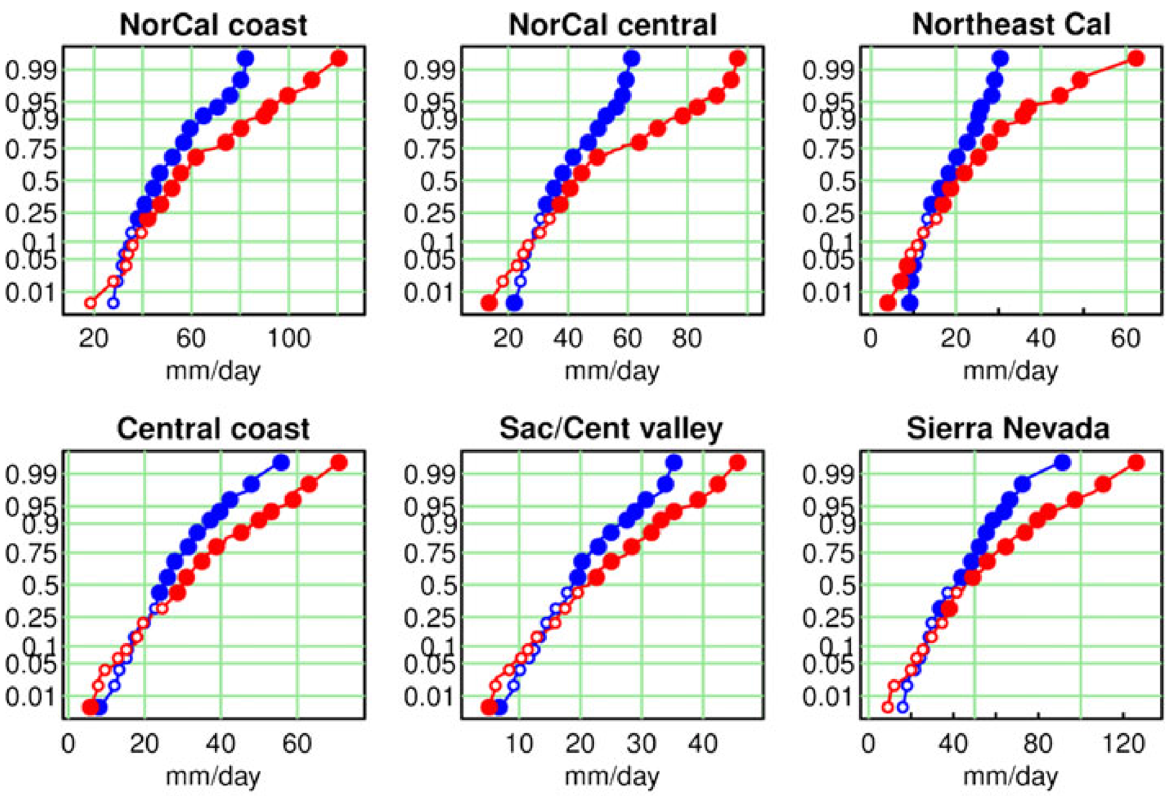


Note: The projected changes for CMIP3 and CMIP5 are computed using 112 and 178 downscaled climate model projections, simulated under SRES emission scenarios A2, A1B, and B1 for CMIP3 and simulated under Representative Concentration Pathways RCP8.5, RCP6.0, and RCP4.5 for CMIP5, used in the IPCC's AR4 and AR5, respectively. CMIP3 and CMIP5 climate model projections have been bias-corrected and spatially downscaled using BCSD monthly statistical downscaling method at 1/8th degree (approximately 12 kilometers) (7.5 miles) spatial resolution (Maurer et al., 2007; Brekke et al., 2013). Changes are computed with respect to 197 to 2000 model simulated period for both CMIP3 and CMIP5. Bars represent the range between the 10th and 90th percentiles. Circles represent the 20 climate model projections downscaled using LOCA daily statistical downscaling method at 1/16th degree (approximately 6 kilometers) (3.75 miles) spatial resolution. These 20 climate projections are from 10 GCMs and two Representative Concentration Pathways (RCP8.5 and RCP4.5) selected by DWR CCTAG for California climate and water assessments.

Changes in intensity and frequency of heavy precipitation are uncertain, but some projections show greater atmospheric river presence and possible increased "stalling" of storms. Pierce et al (2012) based on daily downscaled data from 9 runs from the Centre National de Recherches Météorologiques Coupled Global Climate Model version 3 (CNRM-CM3), Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1, National Center for Atmospheric Research Community Climate System Model version 3 (NCAR CCSM3), and NCAR Parallel Climate Model 1 (PCM1) models (Table 1 in Pierce et al., 2012) found significant increases in the frequency of the most extreme precipitation events for all regions of California (Figure A-7). More than half of annual maximum 3-day precipitation projections, a common driver of flooding, suggest increases in annual maximum 3-day precipitation in early current century (Figure A-8). By end of century, the median change in 3-day annual maximum precipitation in Sonoma County is projected to be 20 percent greater than historical.

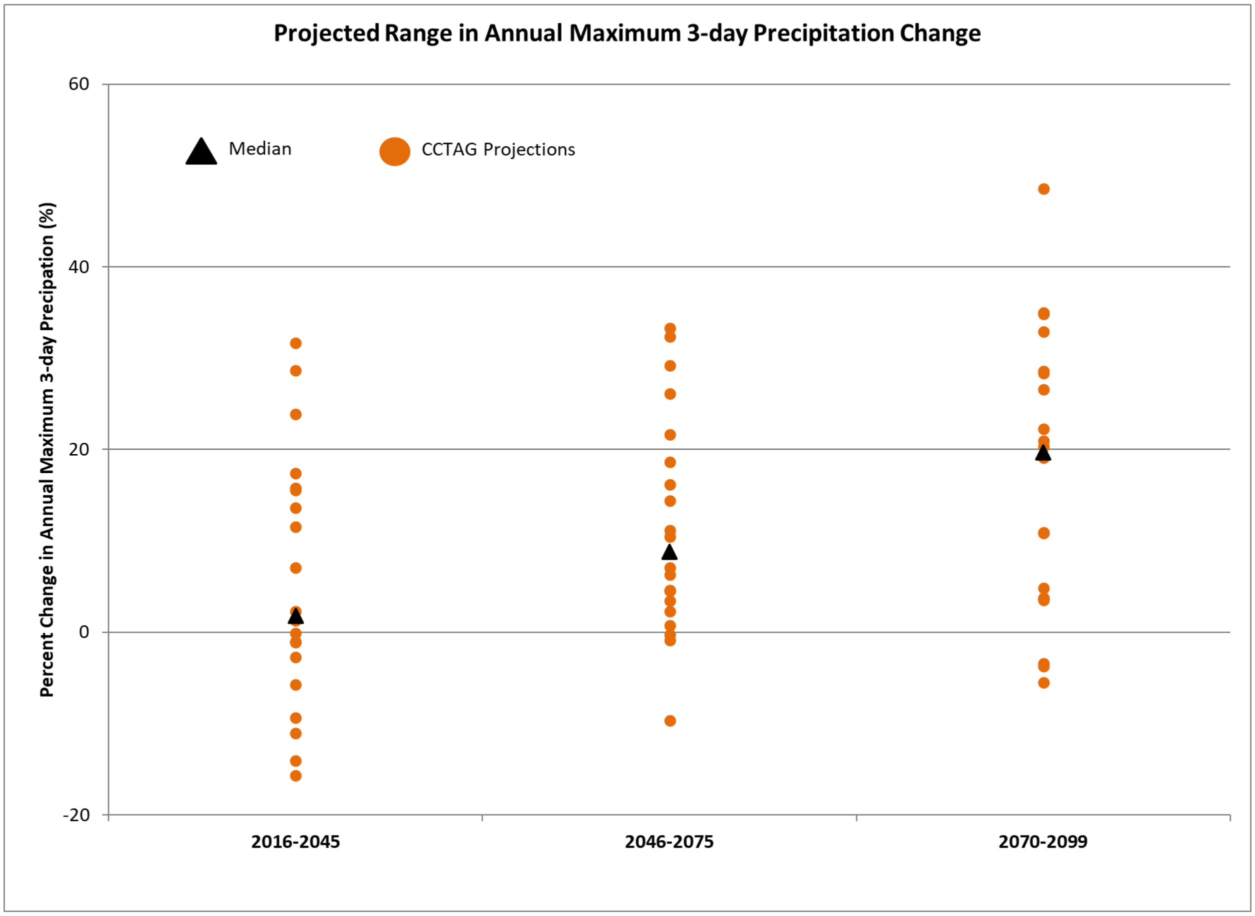
Sonoma Water, CW3E, and The Office of Oceanic and Atmospheric Research at NOAA are partnering to improve the assessment of future changes in atmospheric river conditions. ARs are responsible for most if not all of Sonoma County extreme precipitation events. Figure A-9 shows the projected changes in AR intensities for different annual exceedance probability (AEP) events, as computed using data from seven global climate model simulations under SRES A2 emission scenario. For example, for the 1 percent AEP event, simulations suggest a range of average AR intensities from 94 percent to 125 percent of historical events using the 2046 through 2065 period relative to a baseline from 1961 through 2000.

Figure A-7. Historical (blue) and Projected (red) 3-Day Extreme Precipitation Frequency for Central and Northern California Regions (Source: Pierce et al 2012)



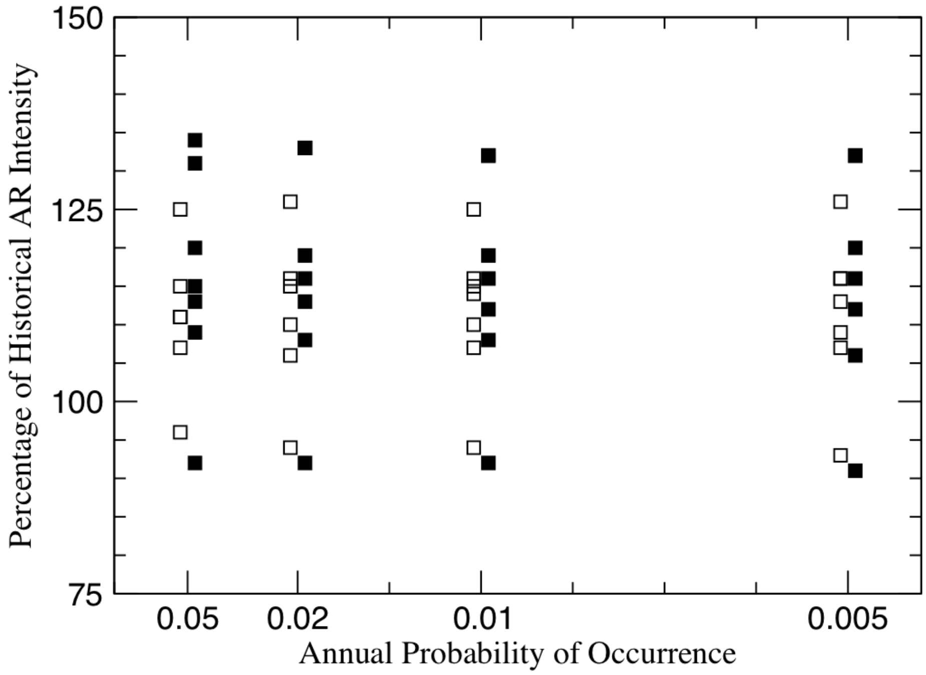
Note: Regions are plotted roughly geographically. Y axis is probability (0–1) of experiencing the indicated average 3-day precipitation rate (mm/day), or lower. Large solid dots show where the two curves are different at the 95 % significance level, evaluated using a bootstrap technique. Open circles indicate statistically indistinguishable values. Data from the 9 runs with daily data was used to make the figure (adapted from Pierce et al. 2012)

Figure A-8. Projected Range in Annual Maximum 3-day Precipitation Change



Notes: The projected changes were computed based on 20 downscaled climate projections using LOCA daily statistical downscaling method at 1/16th degree (approximately 6 kilometers) (3.75 miles) spatial resolution. These climate projections are from 10 GCMs and two RCPs (RCP8.5 and RCP4.5) selected by DWR CCTAG for California climate and water assessments. Changes are computed with respect to 1981 to 2010 model simulated period. GCMs Selected by CCTAG: ACCESS-1.0, CCSM4, CESM1-BGC, CMCC-CMS, CNRM-CM5, CanESM2, GFDL-CM3, HadGEM2-CC, HadGEM2-ES, MIROC5.

Figure A-9. Climate change simulations by seven global climate models using the SRES A2 emissions scenario (adapted from DWR, 2012 CVFPP Attachment 8K, Climate Change Analysis)



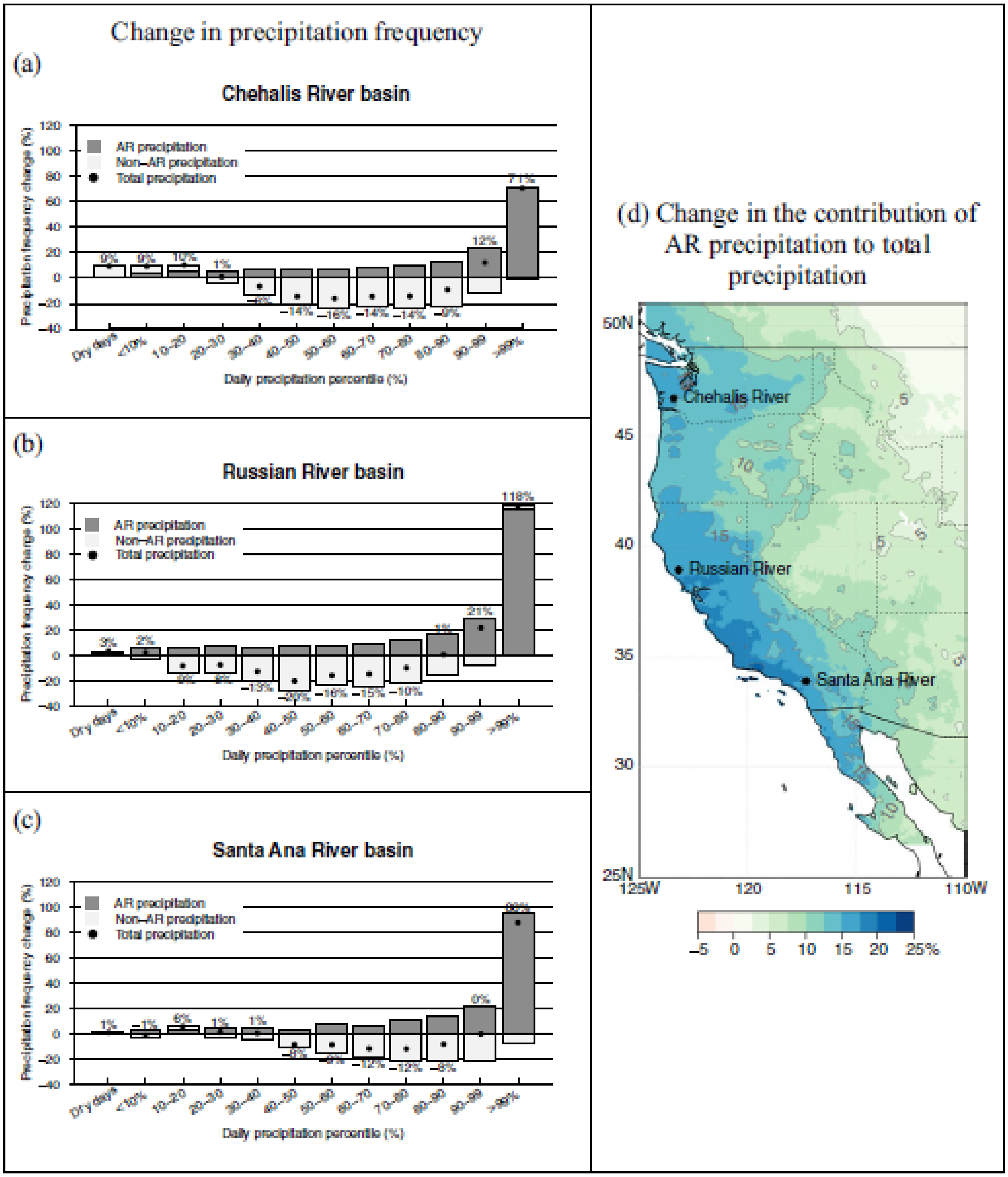
Note

Solid: Changes in AR Intensities, 2081–2100 vs 1961–2000

Open: Changes in AR Intensities, 2046–2065 vs 1961–2000

While projected changes in precipitation are less certain, the increased warming from climate change will likely result in more intense AR events (Huang et al., 2020). Figure A-10 presents the changes in precipitation frequencies for both atmospheric river and non-atmospheric river precipitation in the Chehalis, Russian, and Santa Ana river basins. The black dots in each bin represent the total change in the projected shift from historical precipitation frequencies, with the dark grey and light grey boxes discerning between AR and non-AR events, respectively (Gershunov et al., 2019). In each of these cases, non-AR precipitation events are expected to decrease in frequency for medium intensity precipitation (between 30th and 90th percentiles). Changes to low intensity precipitation (between dry days and 30th percentiles) vary between each of the inspected river basins, with the Chehalis and Santa Ana river basins projecting increases in both non-AR and AR events for the majority of the bins and the Russian River basin showing a decrease in non-AR events and an increase in AR events in the latter two bins. High intensity precipitation (90th to >99th percentiles) are dominated by an increase in AR events. Overall, AR precipitation events increase across the range of precipitation intensities, suggesting a shift in rainfall contribution from non-AR precipitation. Figure A-10, panel d, furthers this point, by displaying the change in contribution of AR precipitation to total precipitation on the western coast of the United States. High increases in contribution (roughly 20%) can be seen along the coast and that steadily decrease moving inland.

Figure A-10. Future changes in daily precipitation frequency binned by percentile ranges of daily intensity (% of historical climatology).



Source: Gershunov et.al., (2019)

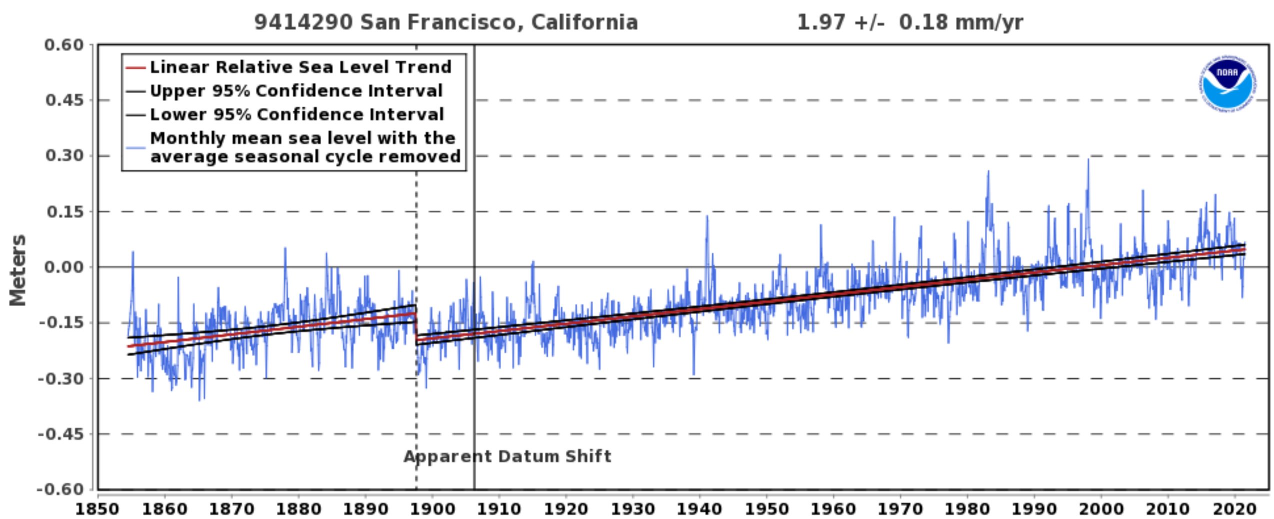
Note: Results represent ensemble averages for the Real-5 LOCA downscaled GCMs for the Chehalis, Russian and Santa Ana river basins (a through c, respectively). Changes in total precipitation are denoted by dots and associated values; AR-related precipitation (for each AR day and the following day) – dark grey bars; and non-AR precipitation – light grey bars. Panel (d) illustrates Real-5 ensemble average change in the contribution of AR-related precipitation to total precipitation.

2.2.1.3 Projected Changes in Sea Level

Global and regional sea levels have been increasing over the past century and are expected to continue to increase throughout this century. Over the past several decades, sea level measured at tide gauges along the California coast has risen at rate of about 0.56 ft – 0.66 ft

(17 - 20 centimeters) (cm) per century (Cayan et al 2009). There is considerable variability amongst tide gauges along the Pacific Coast, primarily reflecting local differences in vertical movement of the land and length of gauge record. Figure A-11 shows the mean sea level trend for the NOAA tide gauge at San Francisco, California (NOAA Tide Gauge No 9414290). The mean sea level trend is 0.078 inch/year (1.97 mm/year) with a 95% confidence interval of +/- 0.007 inch/year (+/- 0.18 mm/year) based on monthly mean sea level data from 1897 to 2020 which is equivalent to a change of 0.65 foot (19.8 centimeters) in 100 years.

Figure A-11. Monthly Mean Sea Level and Trend at San Francisco Tide Gauge (NOAA Gauge No. 9414290)



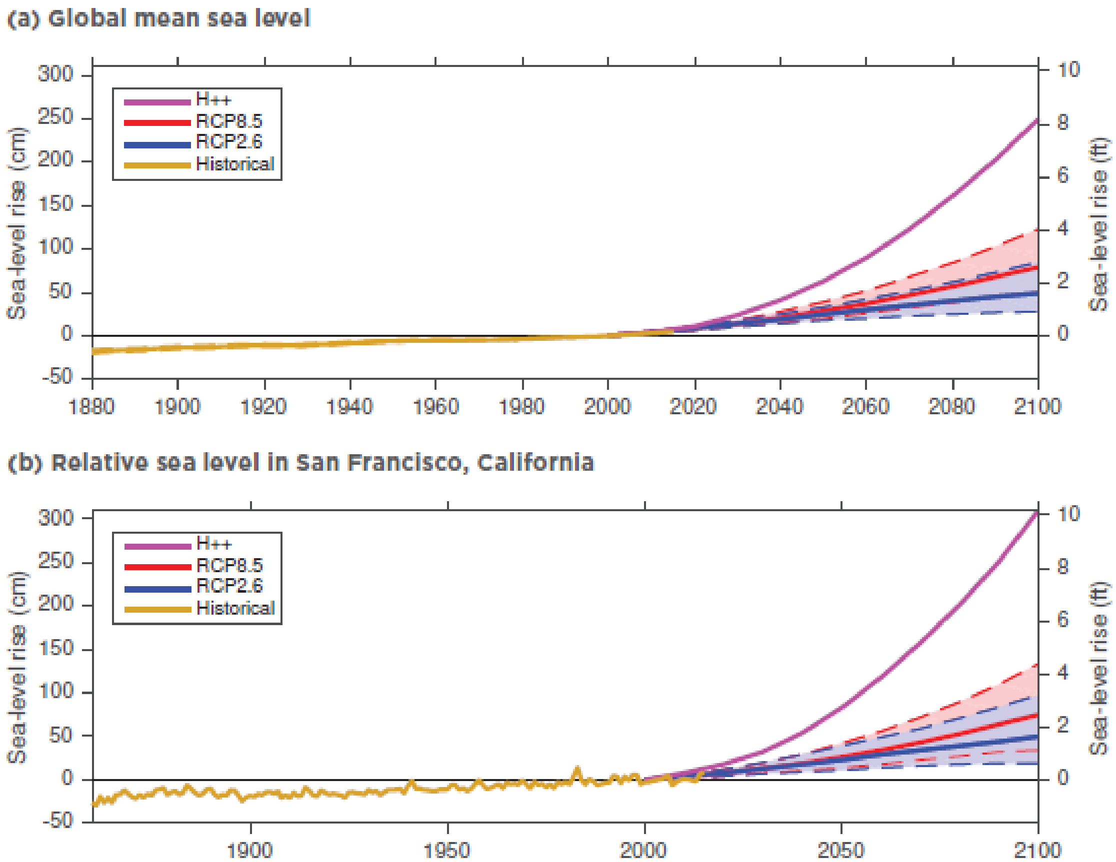
Source: NOAA, 2021

Global mean sea levels have risen in the past century because of melting ice sheets and glaciers as well as the thermal expansion of seawater associated with increased global temperatures. Development of sea-level rise projections is typically performed by incorporating emissions pathways (i.e., RCPs) to model the physical processes associated with sea-level rise. For example, work by Kopp et al. (2014) applies RCP2.6, RCP4.5, and RCP8.5 while incorporating CMIP5 GCMs, tide gauge data, and historical extrapolation to characterize land water storage, ice sheet melt, glacier and ice caps melt, oceanographic processes, and localized non-climatic effects to quantify future changes to local sea levels at the global scale. This framework has been adopted and modified in other works and reports, such as California's Fourth Climate Change Assessment, where an additional scenario characterized by extreme sea-level rise under rapid ice sheet loss was included (Pierce et al., 2018; Griggs et al., 2017).

Projections for future sea-level rise from local to global scales have been included in several reports in recent years, such as California's Fourth Climate Change Assessment, the Fourth National Climate Assessment, and IPCC's AR6 (Bedsworth et al., 2019; USGCRP, 2017; IPCC, 2021).

An April 2017 report titled Rising Seas in California: An Update on Sea-Level Rise Science provides the projections of sea-level rise in the San Francisco Bay (Griggs et al. 2017). Comparisons between different projections on both global mean sea level and relative sea level in San Francisco, California can be seen in Figure A-12. The projections of sea-level rise for RCP 8.5 and RCP 2.6 are estimated using the methodology of Kopp et al. (2014).

Figure A-12. Projections of: (a) Global mean sea level, and (b) Relative sea level in San Francisco, California.



Source: Griggs, et.al. (2017)

Note: Sea-level rise projections for RCP 8.5 and RCP 2.6 are calculated using the methodology of Kopp et al., 2014. The shaded areas bounded by the dashed lines denote the 5th and 95th percentiles. The H++ scenario corresponds to the Extreme scenario of Sweet et al. (2017) and represents a world consistent with rapid Antarctic ice sheet mass loss. Note that the behavior of the Antarctic ice sheet early in this century is governed by different processes than those which would drive rapid mass loss; although the world is not presently following the H++ scenario, this does not exclude the possibility of getting onto this path later in the century. The historical global mean sea level curve in (a) is from Hay et al. (2015).

Table A-2 presents an overview of probabilistic sea-level rise projections developed for the State of California Sea-Level Rise Guidance 2018 Update. This provides the most recent projections of SLR in the San Francisco Bay. Projections are presented with respect to the average relative sea level between 1991 and 2009. High and low emissions are representative of RCP8.5 and RCP2.6, respectively. The H++ scenario presented in the last column corresponds to the extreme sea-level rise under rapid ice sheet loss scenario described previously. Recommended projections depending on risk aversion are identified with bold bordering (Ocean Protection Council, 2018). The State of California Sea-Level Rise Guidance 2018 Update relies on the scientific findings documented by Griggs et al. (2017).

Table A-2. Projected Sea-Level Rise (in feet) for San Francisco (based on Kopp et al. 2014)

Emissions	Year	Median 50% probability sea-level rise meets or exceeds…	Likely Range 66% probability sea-level rise is between… (max value is low risk aversion)	1-in-20 Chance 5% sea-level rise meets or exceeds…	1-in-200 Chance 0.5% probability sea-level rise meets or exceeds. (Medium High Risk Aversion)	H++ scenario (Sweet et al. 2017 *Single scenario) (Extreme Risk Aversion)
High	2030	0.4	0.3and0.5	0.6	0.8	1
	2040	0.6	0.5and 0.8	1	1.3	1.8
	2050	0.9	0.6 and1.1	1.4	1.9	2.7
Low	2060	1	0.6 and1.3	1.6	2.4	3.9
High	2060	1.1	0.8 and1.5	1.8	2.6	
Low	2070	1.1	0.8 and1.5	1.9	3.1	5.2
High	2070	1.4	1 and1.9	2.4	3.5	
Low	2080	1.3	0.9 and1.8	2.3	3.9	6.6
High	2080	1.7	1.2 and2.4	3	4.5	
Low	2090	1.4	1 and2.1	2.8	4.7	8.3
High	2090	2.1	1.4 and2.9	3.6	5.6	
Low	2100	1.6	1 and2.4	3.2	5.7	10.2
High	2100	2.5	1.6 and 3.4	4.4	6.9	

Source: adapted from Ocean Protection Council, 2018

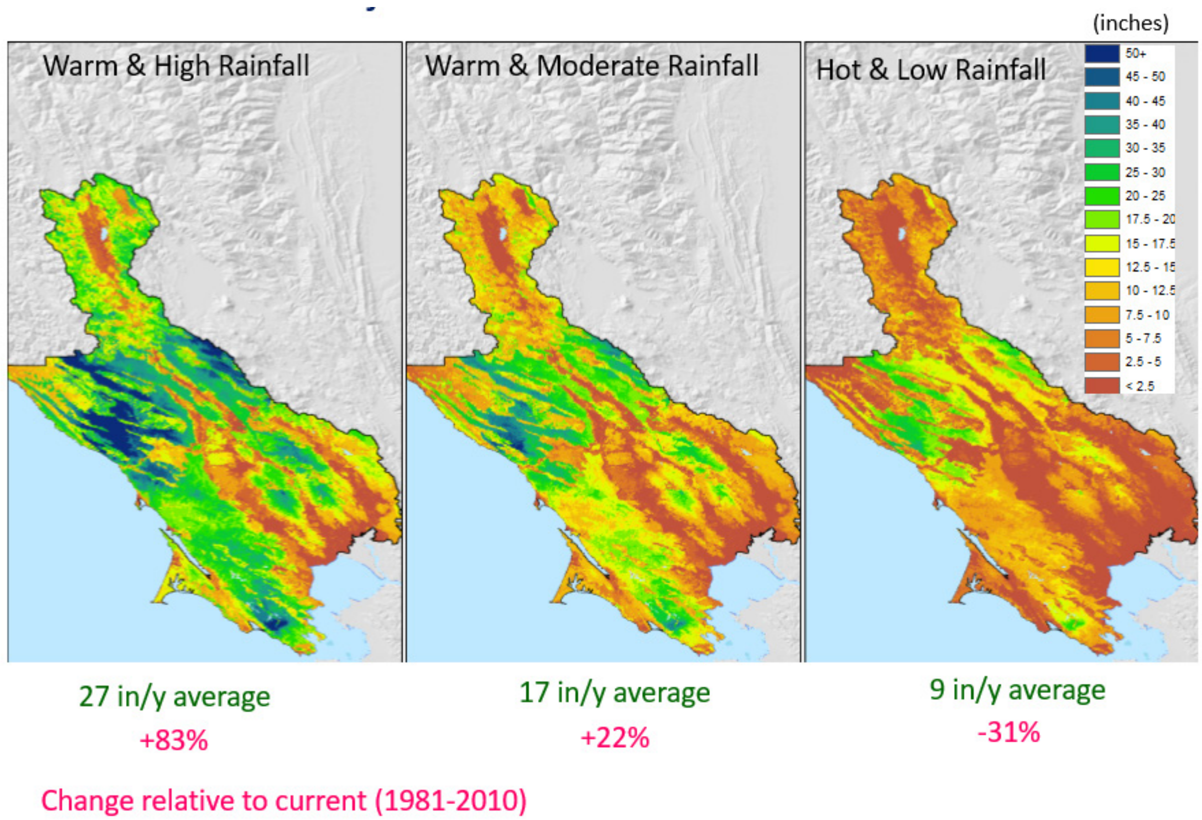
Sonoma Water has supported modeling of the sea-level rise and storm surge impacts to the North Bay through the Coastal Storm Modeling System (CoSMoS). The CoSMoS study was part of the NOAA Russian River Blueprint Habitat and included an assessment of the effects of sea-level rise and the impacts of winter storm surge and wave impacts that can elevate the coastal water levels and contribute to coastal vulnerabilities. The CoSMoS results for the North coast were used in the qualitative vulnerability assessment.

2.2.1.4 Projected Changes in Droughts

Droughts are often characterized by prolonged periods of below average precipitation and above average temperatures, resulting in prolonged periods of water deficits.

Figure A-13 translates projected changes in precipitation to runoff through a water balance in the BCM simulation at 270-meter resolution in Sonoma County. Increases in runoff are expected to be seen in warm and high rainfall and warm and moderate rainfall scenarios but not in hot & low rainfall scenarios, with an average of 27, 17, and 9 inches/year of runoff over the future period 2070 to 2099, respectively. This represents an 83% increase, 22% increase, and 31% decrease, respectively, from 1981 through 2010 runoff levels.

Figure A-13. Projected Runoff in Sonoma County Under Three Climate Scenarios over the Future Period 2070 to 2099



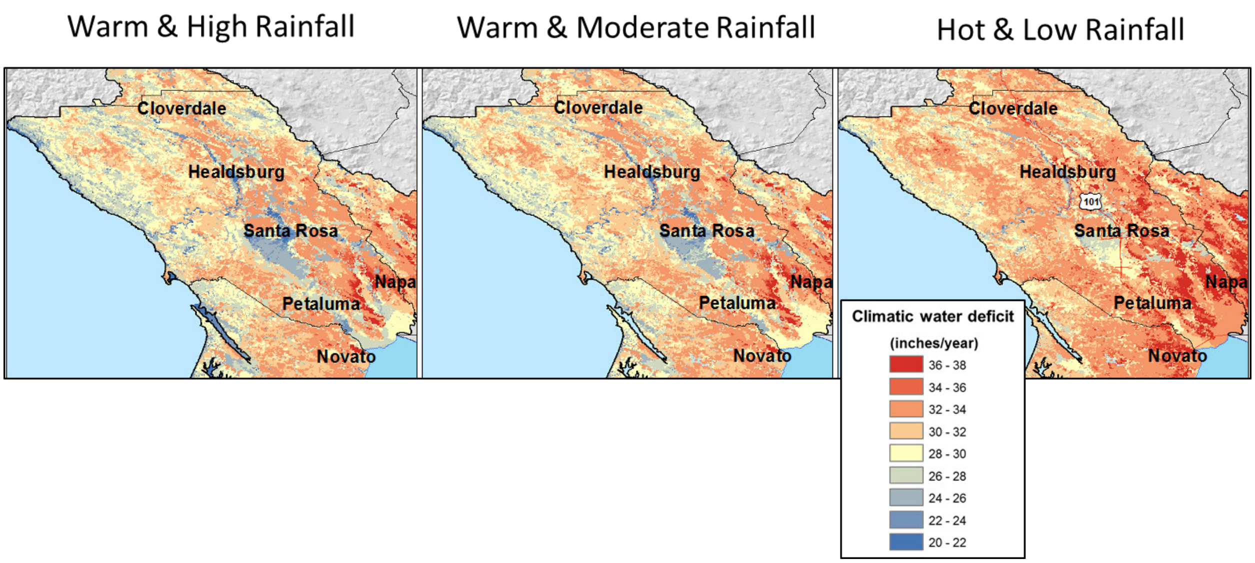
Source: NBCAI, 2016

Future changes in climate, even with average increases in precipitation, can result in increases in drought severity or frequency. Flint and Flint (2012b) suggested a warming trend in the Russian River Valley and Santa Cruz Mountains over the 20th century with reduced early and late wet season runoff using a set of downscaled climate change projections taken from CMIP3. Warming during the spring, summer, and fall can increase the evapotranspiration of vegetation in the watershed and when combined with extended periods of reduced precipitation can result in climatic water deficit during extended summers. These conditions are the result of increases in evapotranspiration and subsequent reductions in soil moisture. Subsequent rainfall events often result in lower runoff as water infiltrates and is stored as soil moisture. This soil moisture deficit is also likely to reduce groundwater recharge as more water is retained in the upper soil layers.

Definitions of drought vary and are most often expressed in terms of the condition for which water systems are most sensitive. These conditions will need to be explored further for Sonoma Water's water supply system vulnerabilities but could be expressed as both climatic indicators (precipitation minus potential evapotranspiration) and hydrologic indicators.

One metric for drought is climatic water deficit (CWD). CWD correlates to irrigation demand, landscape stress, and vegetation distributions. In Figure A-14 (from NBCAI, 2016), it is apparent that CWD is projected to increase by mid-century due to increases in air temperature and evapotranspiration for all scenarios. Increases are most apparent in lower elevation locations in the southern-most parts of Sonoma County.

Figure A-14. Projected Climatic Water Deficit 2040 throigh-2069 Under Different Climate Change Scenarios



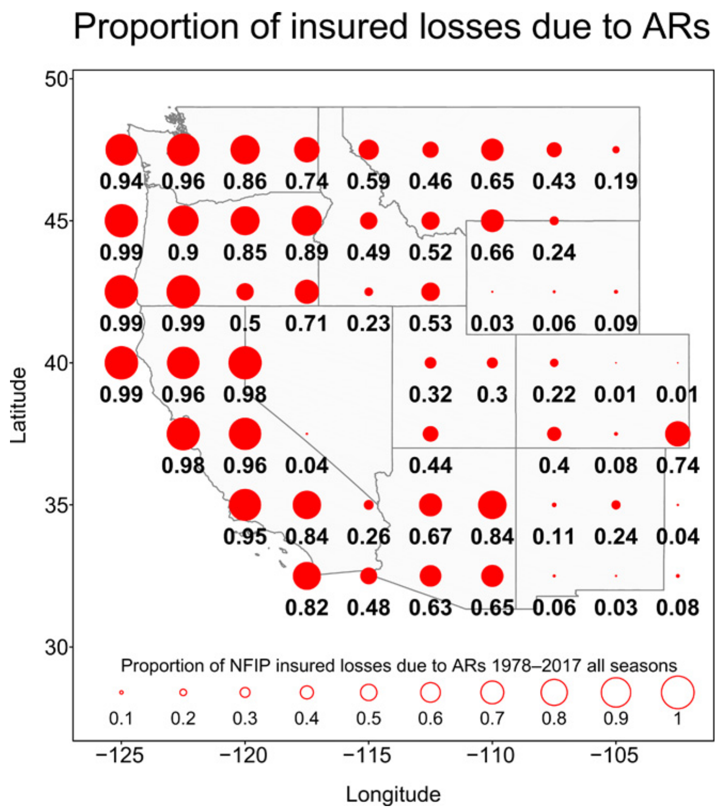
Source: NBCAI, 2016

2.2.1.5 Projected Changes in Floods

Most significant flooding events on the Russian River are associated with AR events. Ralph et al. (2006) found that AR conditions were present and caused heavy rainfall through orographic precipitation for all seven floods between 1 October 1997 and 28 February 2006 on the Russian River.

Corringham et al. (2019) highlights the proportion of insured flood losses due to ARs, with an upwards of 99% along the western coast of the United States. Corringham et al. (2019) shows that Sonoma County experienced the highest damages of any county over the 1978 to 2017 period along the western coast of the United States (Figure A-15).

Figure A-15. From 1978 to 2017, ARs accounted for 84.2% of all insured flood losses in the 11 western states across all seasons. In many areas in coastal northern California and the Pacific Northwest, ARs accounted for over 95% of insured flood losses.



Source: Corringham et.al., (2019)

As discussed under extreme precipitation, the frequency and/or magnitude of AR storms are projected to increase (Dettinger et al. 2009). Increases in AR events will almost certainly cause increases in flooding in the Sonoma region and increase flood risk. Sonoma Water and SIO are currently partnering to improve the assessment of future changes in atmospheric river conditions. This remains an area of active research.

Work performed by Jacobs for the DWR, evaluated flood risks for all major watersheds in the Central Valley associated with projected changes in extreme precipitation and warming (DWR, 2017). Hydrologic modeling simulated changes in flood volumes associated with projected changes in extreme precipitation and temperature. For watersheds with little or no snow accumulation, changes in the 3-day, 100-year flood volumes increased from 10% to 20%. Changes were substantially larger for high elevation watersheds with significant historical snow accumulations.

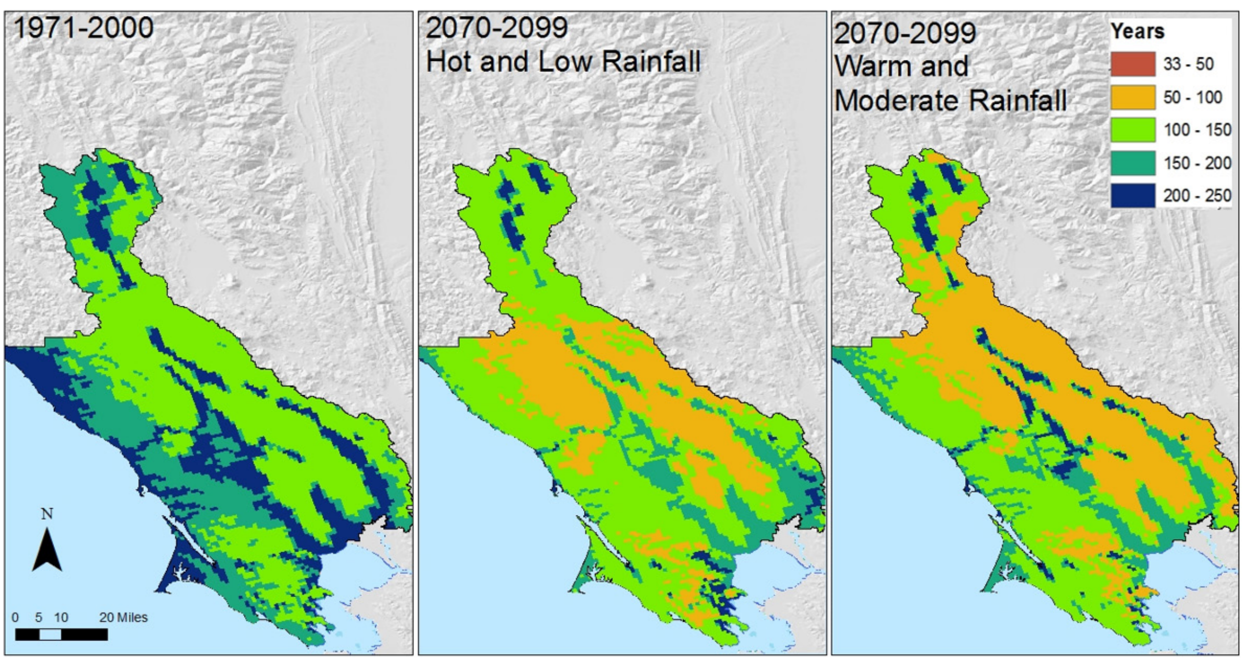
2.2.1.6 Projected Changes in Wildfires

Wildfires are a common occurrence in many parts of California and Sonoma and Napa Counties have had much higher historical wildfire risk than other North Bay counties (Krawchuk and Moritz, 2012). The Sonoma Complex Fires which include the Tubbs, Nuns, Pocket, Atlas, and Redwood Valley fires substantially impacted Sonoma County in October 2017 (http://sonomavegmap.org/firestory/index.html). Climate change is generally expected to increase the wildfire risk in the Sonoma region, through increased incidence of dry conditions (drought) and higher temperatures over a longer and longer fire season (Westerling, 2018). However, significant other factors that contribute to wildfire risk include urban development and vegetation structure and abundance. The acreage of forested areas in northern California burned by wildfires is expected to increase substantially in the future (Westerling et al., 2011, Bryant and Westerling, 2012; Westerling, 2018; Cal-Adapt, 2021). However, the risk is strongly dependent on the land use and development conditions. The most extreme increases in residential fire risks occurred as the result of high growth, high sprawl, and extreme climate scenarios (Bryant and Westerling 2012). Accordingly, little increase in wildfire risk was projected under future climate scenarios in areas with low growth and little or no increase in the interface between wildland and urban areas.

As described in NBCAI (2016), the average historic probability of burning with a 30-year period was 17 percent over the 1971 to 2000 period. The probability of burning occurring one or more times within 30 years is projected to double in some locations over the 2070 to 2099 period, with the probability throughout the region projected to increase to 23 percent under both the warm, moderate rainfall and hot, low rainfall scenarios. Figure A-16 shows projected reduction in fire return intervals in Sonoma by approximately 25% by late-century (NBCAI 2016).

Areas burned by wildfires could cause increases in soil erosion rates within watersheds, which can increase sedimentation in downstream rivers and reservoirs. As noted in Sankey et al. (2017), increased sedimentation could negatively impact water supply and quality for some communities, in addition to affecting stream channel stability and aquatic ecosystems.

Figure A-16. Change in Projected Fire Return Interval Under Different Climate Change Scenarios



Source: NBCAI, 2016

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