Sonoma Water

Final Report

Sonoma Water

Climate Adaptation Plan

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Acronyms and Abbreviations

Acronym	Definition
AlertWildfire	Fire Camera Alert System
AQPI	Advanced Quantitative Precipitation Information
AR	Atmospheric Rivers
AR4	Intergovernmental Panel on Climate Change Assessment Report 4
AR5	Intergovernmental Panel on Climate Change Assessment Report 5
AR6	Intergovernmental Panel on Climate Change Assessment Report 6
ARO	Atmospheric River Observatories
BACWA	Bay Area Clean Water Agencies
BAGS	Bedload Assessment in Gravel-bedded Streams
BCM	Bedload Assessment in Gravel-bedded Streams
BCSD	Bias-correction and spatial downscaling
BMP	Best management practices
BRIC	Building Resilient Infrastructure and Communities
CalFIRE	California Department of Forestry and Fire Prevention
CAP	Climate Adaptation Plan
CCTAG	Climate Change Technical Advisory Group
CDFW	California Department of Fish and Wildlife
CMIP3	Coupled Model Intercomparison Project 3
cfs	cubic foot (feet) per second

Acronym	Definition
CMIP5	Coupled Model Intercomparison Project 5
CNAP	California-Nevada Applications Program
CNRM-CM3	Centre National de Recherches Météorologiques Coupled Global Climate Model Version 3
CoSMoS	Coastal Storm Modeling System
CWD	Climatic water deficit
CW3E	Center for Western Weather and Water Extremes
DOC	Dissolved organic carbon
DWR	Department of Water Resources
EFO	Ensemble Forecast Operations
ESD	Equivalent Single-Family Dwelling Unit
FEMA	Federal Emergency Management Agency
FIRO	Forecast-Informed Reservoir Operations
Flood-MAR	flood-managed aquifer recharge
FVA	final viability assessment
GCM	General circulation models
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse gas
HEC-ResSim	Hydrologic Engineering Center – Reservoir System Simulation
IPCC	Intergovernmental Panel on Climate Change
I/I	Infiltration/Inflow
IWRSS	Integrated Water Resources Science and Services
LBNL	Lawrence Berkely National Laboratory
LOCA	localized constructed analogs

Acronym	Definition
Marin Water	Marin Municipal Water District
MOA	memorandum of agreement
NBCAI	North Bay Climate Adaptation Initiative
NCAR CCSM3	National Center for Atmospheric Research Community Climate System Model version 3
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OAR	Oceanic and Atmospheric Research
OCSD	Occidental County Sanitation District
OneRain	Sonoma Water's Real-time Rainfall, River-Stream and Reservoir Data
OPC	Ocean Protection Council
PCM1	NCAR Parallel Climate Model 1
PVA	preliminary viability assessment
PVP	Potter Valley Project
QPI	quantitative precipitation information
RCM	regional climate model
RCPA	Regional Climate Protection Authority
SARP	Sectoral Applications Research Program
SCADA	supervisory control and data acquisition
SCWA (or Sonoma Water)	Sonoma County Water Agency
SIO	Scripps Institution of Oceanography
Sonoma Water (or SCWA)	Sonoma County Water Agency
SOP	standard operating procedure
SSO	sanitary sewer overflow

Acronym	Definition
SWRCB	State Water Resources Control Board
UCCE	U.C. Cooperative Extension
USACE	U.S. States Army Corps of Engineers
USGS	U.S. Geological Survey
WWTP	wastewater treatment plant

Executive Summary

Sonoma Water has developed this Climate Adaptation Plan (CAP) to guide the assessment of climate risks to water supply, flood management, wastewater systems infrastructure and operations, and to serve as a roadmap for developing, evaluating, and implementing adaptation strategies to improve the resilience of its systems. Sonoma Water's mission is to protect the drinking water supply of more than 600,000 North Bay residents, manage flood control facilities in Sonoma County that impact thousands of residents and homes, and provide wastewater collection and treatment for 75,000 Sonoma County residents. Increasingly, climate risks pose a serious threat to how Sonoma Water continues to operate and maintain these services to its community.

Plan Objectives

The key objectives of the CAP are to:

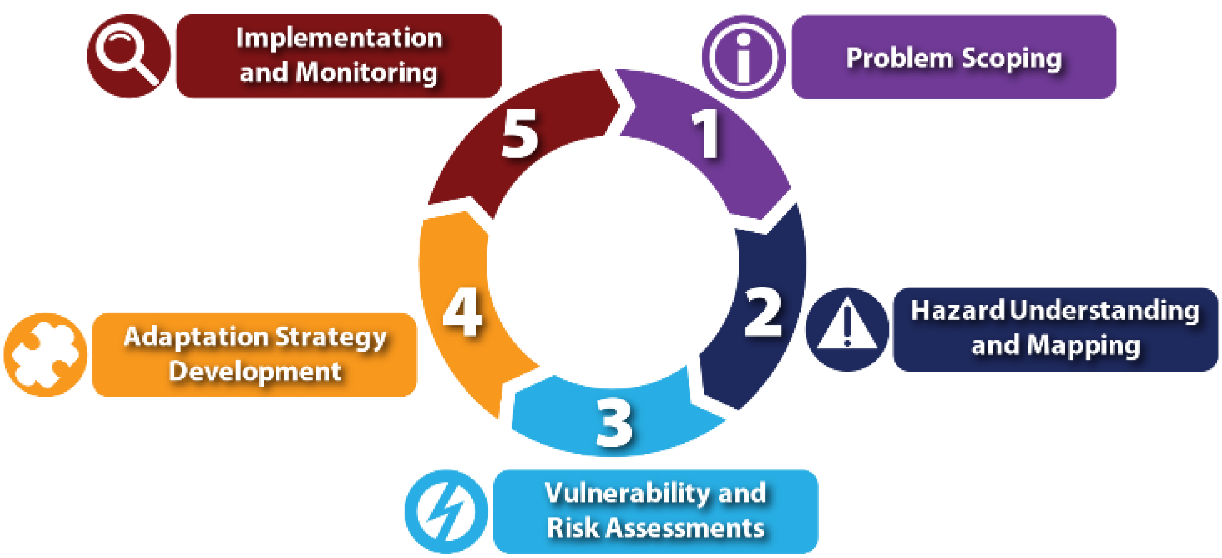
- **Improve the understanding** of the relationship between climate variability and change and regional water supply, flood management, and sanitation systems.
- **Document and describe** the historical and projected **climate and hydrologic threats** to Sonoma Water's water supply, flood management, and sanitation infrastructure and operations.
- **Assess the vulnerability** of Sonoma Water's **water supply, flood management, and sanitation infrastructure and operations** to past and future projected climate conditions.
- **Identify high-risk infrastructure and operations** and identify inter-related risks between critical system components.
- **Identify, prioritize, and cost adaptation measures** to improve the system resiliency.
- **Develop a strategy for improving the resilience** of Sonoma Water's infrastructure and operations, and to assist in guiding future operations and infrastructure investments.

Robust Resiliency Planning Framework

Sonoma Water has applied a robust five-step resiliency planning framework that has helped organize and guide the planning process (Figure ES-1). This structured approach has been widely used in climate adaptation and resiliency planning efforts. Through this approach, Sonoma Water can be certain the resulting plan addresses the major climate risks affecting its systems and provides a framework to implement resilience through Sonoma Water activities and regional partnerships. The five distinct steps are linked through a cycle, or adaptive planning process. The planning process involves:

1. Problem scoping – Frame the questions to be addressed and systems and bounds of study.
2. Hazard understanding and mapping – Understand historical and future climate influences on system.
3. Vulnerability and risk assessments – Assess system vulnerability and risks to a range of future climate projection.
4. Adaptation strategy development – Identify and develop strategies to address climate-related risks to the systems.
5. Implementation and monitoring – Recommend approaches to implement strategies and monitoring to support adaptive management.

Figure ES-1. Climate Adaptation Planning Framework Used to Guide Planning Process



As more information is gained on new science or monitoring, the process should be revisited and updated to address the changing understanding of risk.

Science-based Approach to Regional Climate Change

The CAP has evaluated the historical climate trends and a range of future climate projections to develop scenarios of climate threats in the region. Building on global climate model projections, statewide assessments, and regional downscaling, the CAP summarizes the state of climate science and uses consistent, best-available science projections to develop scenarios of increasing temperature, rising sea levels, increases in extreme precipitation and river flooding, and changes in drought and wildfire frequency and severity. Table ES-1 summarizes the range of climate change considered in the CAP.

Table ES-1. Summary of the Range of Climate Change Considered in CAP

Hydroclimate Variables		Projected Trends
	Temperature	• Increases up to 1.3 to 3.1°C by mid-century • Increased frequency of temperature extremes (days hotter than 30°C or 86°F)
	Sea Level Rise	• MSL increases by 0.1 to 0.6 meter (0.3 to 2 feet) by mid-century • Storm surge will cause additional increases
	Precipitation	• Extreme precipitation increases (ARs) by 15% • Increased winter, decreased summer precipitation (more variability)
	Drought	• Increasing intensity of drought conditions • Increasing frequency and duration of dry weather conditions
	Wildfire	• More frequent and intense wildfires due to warmer temperatures and drier conditions • Increase in probability of wildfires by 15 to 33%
	River Flooding	• Potential increase in AR-driven floods on Russian River • 100-year flood magnitudes could increase by 10 to 20%

System Vulnerabilities and Risks

Climate threats to Sonoma Water's water supply, flood management, and sanitation systems were comprehensively assessed. Climate change maps were developed; water supply and flood modeling were conducted on the Russian River and Santa Rosa Creek; and major facilities were visited and studied to assess vulnerabilities to future climate change. Vulnerability and risk assessments were conducted for the systems' major components. The CAP identified the following major areas of risk:

Water Supply – Extreme drought on the Russian River; river flooding and wildfire risk at the Mirabel and Wohler diversion facilities; river flooding and extreme precipitation risk at the River Road and Wohler chlorination facilities; and extreme precipitation risk at the Ely and Kawana Booster Stations

Flood Management – Extreme precipitation, river flooding, and wildfire risk at Central Sonoma Watershed Project infrastructure; sea level rise and river flooding risk on the Petaluma River and on Sonoma Creek; river flooding risk on the upper Russian River; and sea level rise and river flooding risk on the lower Russian River and estuary

Sanitation – Extreme precipitation, river flooding, and sea level rise risks at wastewater treatment plants (WWTPs), collection systems, and reclamation systems

Table ES-2 summarizes the climate vulnerabilities identified in the CAP

Table ES-2. Summary of Climate Vulnerabilities to Sonoma Water's Water Supply, Flood Management, and Sanitation Systems

System	System Component	Temperature	Sea Level Rise	Extreme Precipitation	River Flooding	Drought	Wildfire
Water Supply	Upper Russian River Supply (Watershed and Lake Mendocino)	Moderate	N/A	N/A	N/A	High	Moderate
Water Supply	Lake Sonoma	Moderate	N/A	N/A	N/A	Moderate	Moderate
Water Supply	Mirabel Diversion Facilities	N/A	N/A	N/A	High	Moderate	High
Water Supply	Wohler Diversion Facilities	N/A	N/A	N/A	High	Moderate	High
Water Supply	Wohler Chlorination and Corrosion Control	N/A	N/A	Moderate/ High	Moderate/ High	Moderate	Moderate/ High
Water Supply	Mirabel Chlorination and Corrosion Control	N/A	N/A	Low	Low	N/A	Low
Water Supply	River Road Chlorination	N/A	N/A	Moderate/ High	High	N/A	N/A
Water Supply	Ely Booster	N/A	N/A	High	N/A	N/A	N/A
Water Supply	Kawana Booster	N/A	N/A	Moderate	N/A	N/A	N/A
Flood Management	Central Sonoma Watershed Project (Zone 1A) – Detention Basins	N/A	N/A	High	High	N/A	Moderate
Flood Management	Central Sonoma Watershed Project (Zone 1A) – Triple Box Culvert	N/A	N/A	High	High	N/A	Moderate
Flood Management	Central Sonoma Watershed Project (Zone 1A) – Channels	N/A	N/A	High	High	N/A	Moderate

System	System Component	Temperature	Sea Level Rise	Extreme Precipitation	River Flooding	Drought	Wildfire
Flood Management	Petaluma River (Zone 2A)	N/A	High	High	High	N/A	N/A
Flood Management	Sonoma Creek (Zone 3A)	N/A	Moderate	Moderate	Moderate	N/A	N/A
Flood Management	Upper Russian River (Zone 4A)	N/A	N/A	N/A	Moderate	N/A	N/A
Flood Management	Lower Russian River (Zone 5A)	N/A	Moderate	N/A	Moderate	N/A	N/A
Sanitation	Russian River CSD - WWTP	N/A	N/A	High	High	N/A	Moderate
Sanitation	Russian River CSD - Collection	N/A	N/A	High	High	N/A	Moderate
Sanitation	Sonoma Valley CSD - WWTP	N/A	Moderate/ High	Moderate	Moderate	N/A	Moderate/ Low
Sanitation	Sonoma Valley CSD – Collection	N/A	N/A	High	High	N/A	Moderate
Sanitation	Penngrove SZ – Collection	N/A	Low	High	High	N/A	Moderate/ Low
Sanitation	Occidental County SZ – WWTP & Collection	N/A	N/A	Moderate	N/A	N/A	Moderate
Sanitation	Geyserville SZ - WWTP	N/A	N/A	Moderate	Moderate	N/A	N/A
Sanitation	Geyserville SZ – Collection	N/A	N/A	High	High	N/A	N/A
Sanitation	Airport SZ – WWTP	N/A	N/A	Moderate	Moderate	N/A	N/A
Sanitation	Airport SZ - Collection	N/A	N/A	Low	N/A	N/A	Moderate

Adaptation Strategies

Sonoma Water's CAP team identified a range of adaptation project concepts and strategies to improve resilience through a series of interactive workshops. Over 250 specific concepts were initially suggested and through synthesis, about 80 concepts were retained and evaluated. Adaptation strategies and portfolios of projects were developed for water supply, flood management, and sanitation systems to improve climate resiliency.

Adapting to the impacts of climate change often involves the recognition that no single action can address every adaptation need or be robust enough to respond to the future conditions. Essentially, there is no single silver bullet, even when considering only one system. The substantial and diverse set of climate risks to Sonoma Water's systems necessitated the development of an equally diverse set of potential adaptation responses.

The CAP team developed portfolios of adaptation strategies for water supply, flood management and sanitation that considered several factors. Each major action associated with an adaptation strategy is represented with several promising concepts that, if achieved, would reduce risks and/or improve resiliency. *Anchor* project concepts were linked to each major action and reflect the hallmark concept(s) that would substantially "move the needle" on climate adaptation, could be substantially directed by Sonoma Water, and have targeted funding sources. These anchor project concepts are combined with several *supporting* concepts to help achieve the goals.

Water Supply Adaptation Strategy

The recommended water supply adaptation strategy consists of five major actions that are believed to best put Sonoma Water on a path for adapting to climate change (Figure ES-2):

1. **Improve Resilience of Water Supply Infrastructure** – The anchor project for this action is the development of a *Water Diversion Facilities Protection Program* to protect Wohler and Mirabel diversion infrastructure and access during flood and wildfires.

2. **Increase Operational Flexibility of Water Management Facilities** – The anchor project for this action is an expanded *Forecast-Informed Reservoir Operations Program* to consolidate of Forecast-Informed Reservoir Operations (FIRO) efforts related to Lake Mendocino, Lake Sonoma, and flood control structures into a combined program to improve water supply and flood management operations.

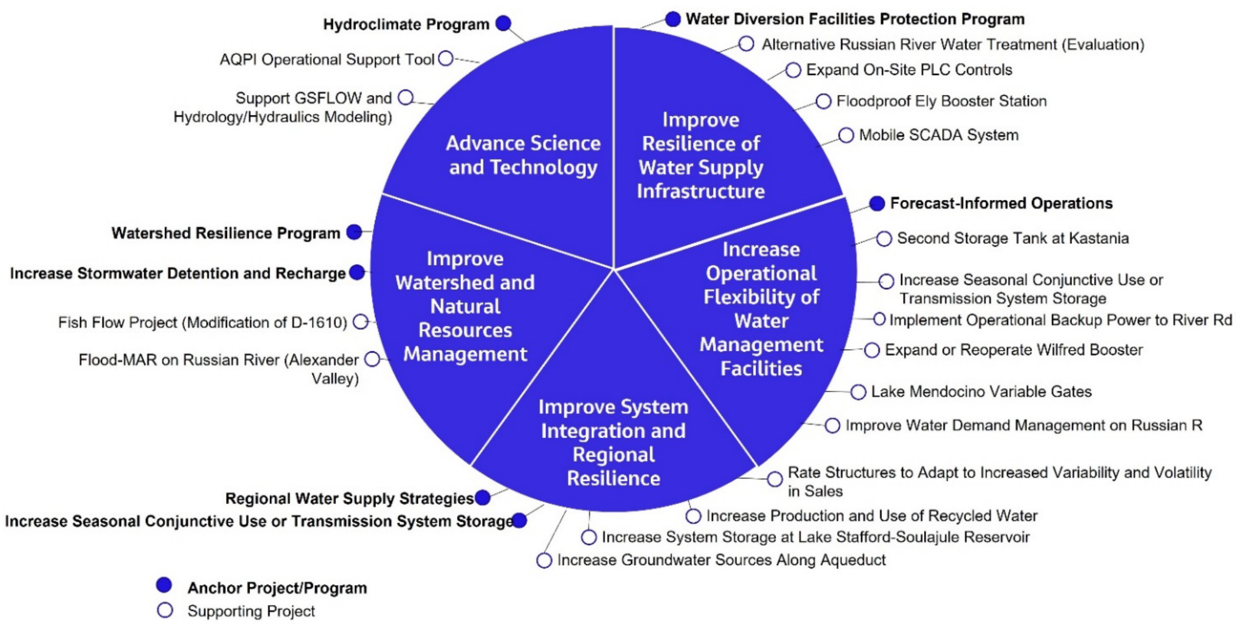
3. **Improve System Integration and Regional Resilience** – The anchor project for this action is the development of *Regional Water Supply Strategies* that continues investments such as the Regional Water Supply Resiliency Study and the Water Supply Action Plan that facilitate diversification of supplies and demands during changed conditions and reduce regional water supply risks.

4. **Improve Watershed and Natural Resources Management** – Anchor projects for this action include the development of a *Watershed Resilience Program* that focuses on healthy headwaters, hydrologic and sediment management, land and vegetation management for flood attenuation, and water quality benefits during extreme hydrologic events post-

wildfire and *Increasing Stormwater Detention and Recharge* by enhancing detention, infiltration, and groundwater recharge.

5. **Advance Science and Technology** – The anchor project associated with this action is the initiation of a *Hydroclimate Program* that will Integrate multiple, related efforts of climate, weather, and hydrological measurement, data assimilation, prediction and modeling into a program to more effectively support Sonoma Water as a whole.

Figure ES-2. Recommended Water Supply Adaptation Portfolio



Flood Management Adaptation Strategy

The recommended flood management adaptation strategy consists of five major actions that are believed to best put Sonoma Water on a path for adapting to climate change (Figure ES-3):

1. **Develop and Implement Regional Flood Management** – Three anchor projects were identified for this action: development of a *Regional Flood Management Strategy* that seeks to address the current lack of an integrated regional flood management strategy; development of a *Sediment Source Study* to identify major sources of sediment within each watershed and quantify historical and future sediment loads using the modeling; and the *Central Sonoma Watershed Project Vulnerability Assessment* to better understand the vulnerabilities in the City of Santa Rosa and along Santa Rosa Creek, Mark West Creek, and the Laguna, and addressing flooding in Lower Sonoma Creek.

2. **Improve and Maintain Flood Management Infrastructure** – Two anchor projects for this action are *Improve Spillway at Matanzas* and *Improving Operational Control of Spring Lake Outflows*. Collectively, these projects could reduce facility and downstream flood risks.

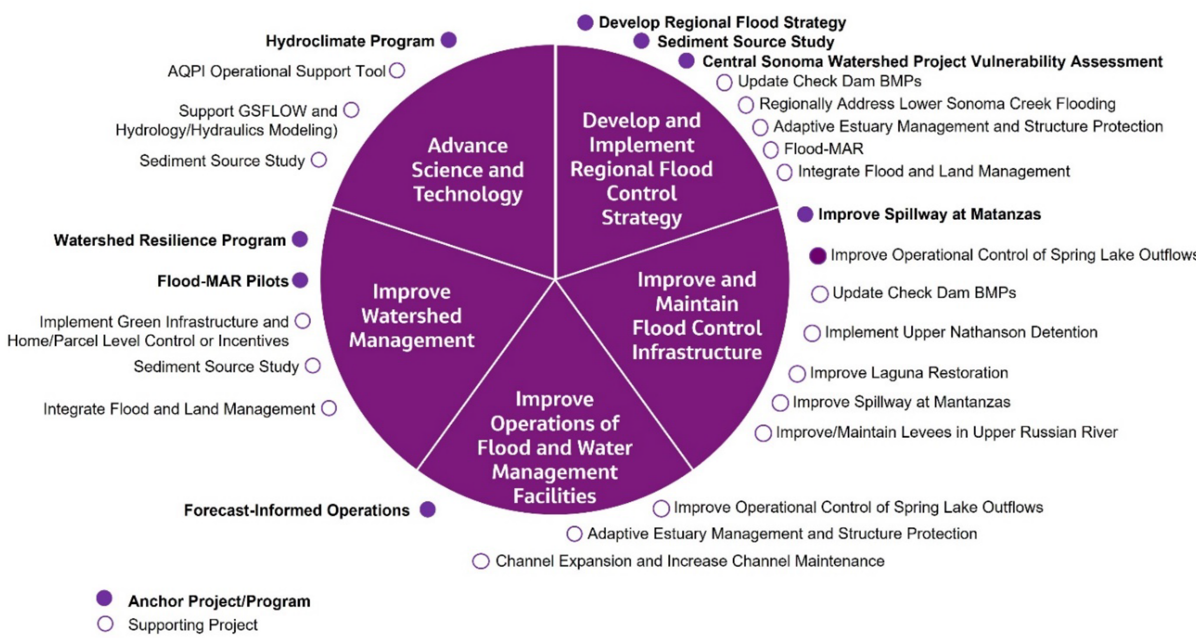
3. **Improve Operations of Flood and Water Management Facilities** – The principal project for this action is the development of *Forecast-Informed Reservoir Operations* that consolidates

FIRO efforts related to Lake Mendocino, Lake Sonoma, and Flood Control structures into a combined program.

4. **Improve Watershed Management** – The main anchor project for this action is the development of a *Watershed Resilience Program* that focuses on healthy headwaters, hydrologic and sediment management, land and vegetation management for flood attenuation, and water quality benefits during extreme hydrologic events post- wildfire.

5. **Advance Science and Technology** – The anchor project associated with this action is the initiation of a *Hydroclimate Program* that will Integrate multiple, related efforts of climate, weather, and hydrological measurement, data assimilation, prediction and modeling into a program to more effectively support Sonoma Water as a whole.

Figure ES-3. Recommended Flood Management Adaptation Portfolio



Sanitation System Adaptation Strategy

The recommended sanitation adaptation strategy consists of five major actions that are believed to best put Sonoma Water on a path for adapting to climate change (Figure ES-4):

1. **Improve Efficiency of Collection Systems** –The principal anchor project is the development of *Infiltration/Inflow (I/I) Monitoring and Reduction Program.* Many of the sanitation collection systems, but most acutely the Sonoma Valley and Russian River collection systems, suffer from high I/I during storm events which can also result in Sanitary sewer overflows (SSOs). In addition, projects such as *Revised Collection System Design Standards* will further reduce I/I through improved design/construction practices and consideration of higher frequency and magnitude of rainfall during storm events associated with climate change.

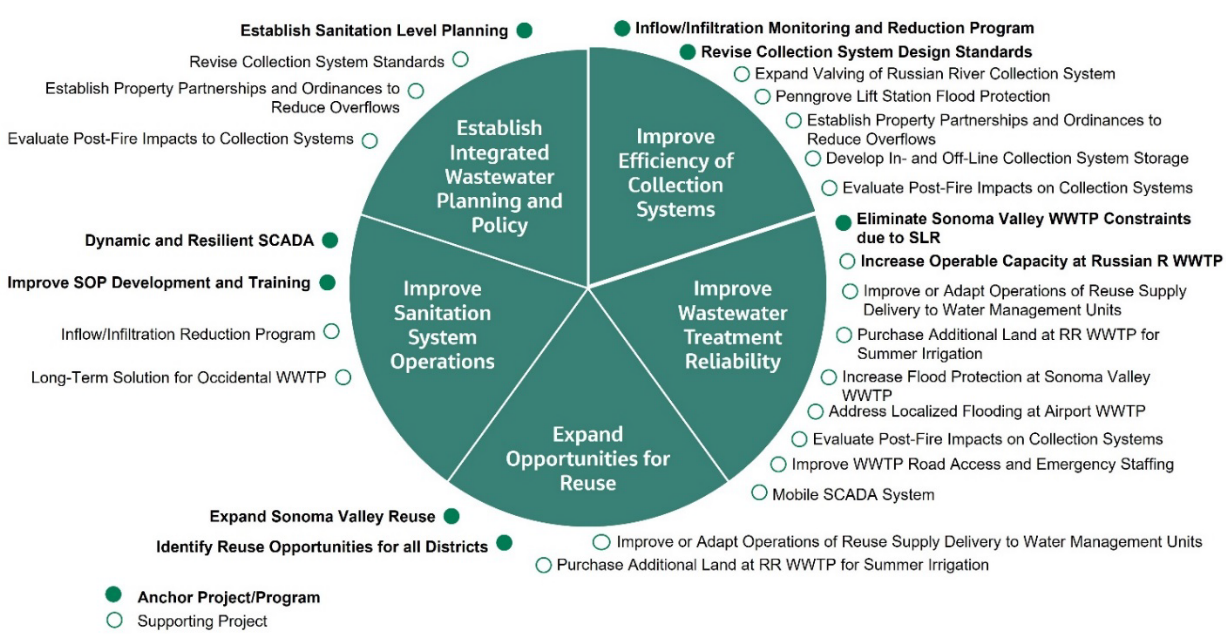
2. **Increase Wastewater Treatment Reliability** – The anchor project for this action is to *Eliminate Sonoma Valley WWTP Constraints due to Sea Level Rise.* During the wet season (November 1 to April 30), treated wastewater is discharged into Schell Slough, a tidally influenced waterbody downstream of Schell Creek. This project would increase the operational effluent pumping capacity and increase equalization storage capacity for sea level rise.

3. **Expand Opportunities for Reuse** – The anchor project for this action is to *Expand Sonoma Valley Reuse*. Sonoma Valley WWTP generates more treated wastewater in winter than it currently has demand. Future climate change will likely exacerbate water supply challenges and increase saltwater intrusion in the Sonoma Valley groundwater basin. This project includes the expansion of partnerships with wineries and other irrigators, groundwater management entities, and regional entities.

4. **Improve Sanitation System Operations** – The anchor project for this action is the development of *Dynamic and Resilient Supervisory Control and Data Acquisition System to further* implement automation pilots at Sonoma Valley and Russian River WWTPs, along with a mobile Supervisory Control and Data Acquisition (SCADA) system for continuity of operations during emergencies.

5. **Establish Integrated Wastewater Planning and Policy** – The principal anchor project for this action is to *Establish Sanitation Level Planning*. Many of the sanitation systems that are currently managed by Sonoma Water were conceived and built by other entities in isolation and no systemwide assessment of sanitation needs, assets, and strategies has been developed. This project would establish a Strategic Sanitation Systems Plan (or similar) that would compile the state of each sanitation system, identify risks and opportunities to these systems, and recommend local or regional solutions to address the challenges.

Figure ES-4. Recommended Sanitation Adaptation Portfolio



Integrated Strategies

Some common, integrated concepts have been identified that will likely provide the greatest improvements in climate resiliency across all core functions of Sonoma Water:

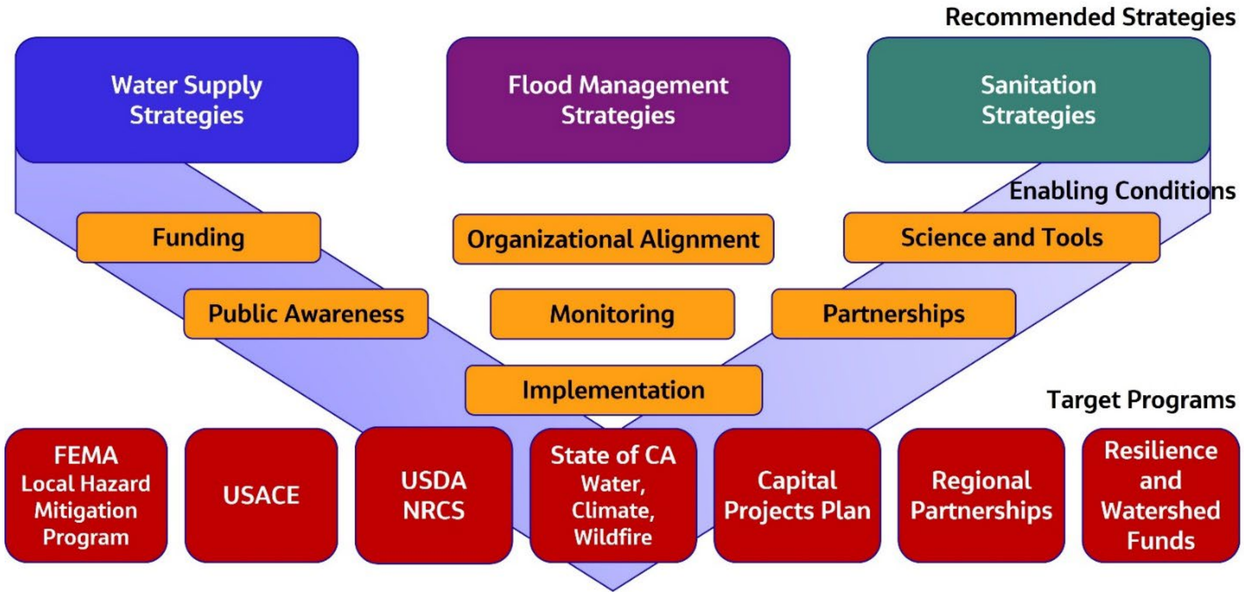
- Watershed Resilience Program
- Water Diversion Facilities Protection Program
- Regional Water Supply Strategies
- Forecast-Informed Operations
- Regional Flood Management Strategy
- Hydroclimate Program
- Dynamic and Resilient SCADA
- Integrated Sanitation Level Planning

Moving Toward Implementation

Adapting to climate change requires a systematic, but flexible approach to move from planning and strategy development to implementation and monitoring. As presented in the previous sections, climate change adaptation involves a range of adaptation approaches, including infrastructure development and improvements, operations, distributed actions throughout the watersheds, policies and ordinances, organizational changes, and planning. Thus, the implementation of adaptation strategies for Sonoma Water's systems must consider an equally diverse set of approaches.

An approach has been developed that links the climate change adaptation strategies to possible implementation programs. Figure ES-5 shows this approach, which considers the various enabling conditions that facilitate the successful and sustainable implementation of adaptation strategies. These enabling conditions include funding, science and tools, organizational alignment, partnerships, public awareness, project and program implementation, and monitoring.

Figure ES-5. Approach for Linking Adaptation Strategies, Enabling Conditions, and Potential Implementation Programs.



Next Steps

Sonoma Water's CAP represents a significant step forward for Sonoma Water to address climate risks to its water supply, flood management, and sanitation system infrastructure and operations. The CAP describes the approach and results of the vulnerability and risk assessments for each of these systems and identifies those with the greatest climate risk. The CAP outlines a range of potential adaptation measures to address these climate-related risks and provides a set of adaptation portfolio recommendations that integrate various concepts within and across the systems. To move toward implementation of adaptation strategies, several considerations and enabling conditions are necessary including funding, science and tools, organization alignment, partnerships and public awareness, and monitoring.

The suggested next steps are focused on ensuring Sonoma Water can deliver on the recommendations provided in the CAP. Specifically, the immediate next steps include:

- Obtain Board approval and support for recommendations in the CAP.
- Map the implementation pathway and prioritization for each project within the recommended portfolios, including target program and enabling conditions.
- Actively identify and pursue available funding sources, and explore innovative resilience funds.
- Organize Sonoma Water staff and build internal structure to mainstream climate resilience within the organization.
- Develop, build, and expand partnerships and outreach with federal, state, regional, local and county entities.
- Establish a robust monitoring plan and timeline for updating the CAP.

The urgency of climate change in the region is upon us. In the past five years, multiple wildfires have severely impacted the region, flooding has caused inundation in many areas, and power shutoffs due to fire risk have led to emergency operations. Now, severe drought is being experienced throughout the western United States and acutely in the Russian River watershed. Sonoma Water is on the right path for achieving climate resilience. Ensuring support for the recommendations in the plan and accelerating implementation of the most robust actions will provide significant benefit to Sonoma Water, its stakeholders, and the region as a whole.

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SECTION 1

Introduction

1.1 Introduction to Climate Adaptation Plan

Sonoma County Water Agency (Sonoma Water) is a regional leader in water resource management and strives to look forward, beyond today's issues, to anticipate ways to advance its mission. One of the most critical aspects of this mission is planning for, and ensuring, the long-term reliability and resilience of Sonoma Water's water supply, flood management, and sanitation systems. Climate variability and climate change are significant drivers influencing the future reliability of these systems. In response to current climate-related risks and projected future changes in climate, Sonoma Water has developed a forward-looking Climate Vulnerability Assessment and Adaptation Plan (Climate Adaptation Plan) to guide the Sonoma Water's assessment of climate vulnerabilities and risks, and to recommend adaptation strategies to increase the resilience of its water supply, flood management, and sanitation infrastructure and operations.

1.2 Purpose and Objectives

The water resources of Sonoma County are strongly influenced by climate, including climate variability and climatic extremes. In turn, Sonoma Water's water supply, flood management, and sanitation infrastructure and operations are also sensitive to changes in climate. The purpose of the Climate Adaptation Plan is to **guide Sonoma Water's assessment of climate risks to water supply, flood management, and sanitation infrastructure and operations**, and to **serve as a roadmap for developing, evaluating, and implementing adaptation strategies** to improve the resilience of the Sonoma Water systems.

The key objectives of the Climate Adaptation Plan are to:

- Improve understanding of the relationship between regional water supply, flood management, and sanitation systems and climate variability and change
- Document and describe the historical and projected climate and hydrologic threats to Sonoma Water's water supply, flood management, and sanitation infrastructure and operations
- Assess the vulnerability of Sonoma Water's water supply, flood management, and sanitation infrastructure and operations to past and future projected climate conditions
- Identify high-risk infrastructure and operations and identify inter-related risks between critical system components

- Identify, prioritize, and determine costs for adaptation measures to improve system resiliency
- Improve the resilience of Sonoma Water's infrastructure and operations and guide future operations and infrastructure investments
- Prioritize implementation strategies and actions to leverage funding.

1.3 Sonoma Water's Core Systems and Regional Interfaces

One of the key decisions to be made in scoping climate change assessments and adaptation planning is the scale and reach of the evaluations of system sensitivity, vulnerability, and risks. What is the "system" to be evaluated? Sonoma Water's core water supply, flood management, and sanitation infrastructure and operations are influenced by climate, watershed, and river conditions. However, there are also significant regional interfaces related to agricultural and municipal water demand, groundwater management, watershed protection, river and estuary restoration efforts, state and federal regulations, and other efforts that influence the reliability of the Sonoma Water core infrastructure and operations. Lack of these regional interfaces pose fundamental challenges in managing a system for public health and safety.

Sonoma Water's Climate Adaptation Plan consists of two levels of assessment. The first and primary level of assessment focuses on the climate impacts and adaptation related to water supply, flood management, and sanitation infrastructure for which Sonoma Water has *direct responsibility* for operation and management. These are termed "core systems" for this document. The secondary level of assessment evaluates climate impacts and adaptation for programs and projects that influence the Sonoma Water core systems, but for which Sonoma Water is a *collaborative partner or regional facilitator* as opposed to having direct responsibility. These are termed "regional interfaces" for this document.

Sonoma Water's core systems and regional interfaces related to water supply, flood management, and sanitation are listed in Table 1.

Table 1. Listing of Sonoma Water Core System Components and Regional Interfaces Considered in the Climate Adaptation Plan

Assessment Level	Water Supply	Flood Management	Sanitation
Sonoma Water Core System	**Russian River Project**: Lake Mendocino and Lake Sonoma Water Supply Releases, Maintaining Minimum Instream Russian River and Dry Creek Flows, Lake Sonoma hydropower operations, Biological Opinion	**Central Sonoma Watershed Project:** Flood control facilities on Santa Rosa Creek, Mantanzas Creek, Piner Creek, Brush Creek, and Spring Creek	**Wastewater Treatment**: Aeration, clarifiers, filtration, disinfection, solid s handling, equalization for six districts/zones

Assessment Level	Water Supply	Flood Management	Sanitation
	Russian River Diversion Facilities: Inflatable Dam, Fish Screens and Ladders, Infiltration Ponds, Collector Wells, Chlorination and pH Adjustment Facilities	**Engineered and Modified Flood Control Channels**: Flood control and natural channels	**Water Reclamation**: Water reclamation facilities
	Groundwater Wells: Mirabel Standby Wells, Santa Rosa Plain Wells	**Estuary Management**: Sandbar management at mouth of Russian River	**Discharge/Disposal**: Stream discharge or reuse delivery systems
	Transmission System: Aqueducts, Booster Pumps, Storage Tanks, Customer Delivery Connections	N/A	**Sanitary Sewer Systems**: Sanitary sewer systems in each of the eight districts/zones for which Sonoma Water has direct management authority (CSO and SSMPs)
Regional Interfaces	**Potter Valley Project**: Lake Pillsbury, Potter Valley Diversion (PG&E)	**Lake Mendocino and Lake Sonoma**: USACE flood control operation of Lake Mendocino and Lake Sonoma	**Recycled Water**: North Bay Water Reuse Authority
	Groundwater Management: Santa Rosa Plain, Sonoma Valley, Petaluma Valley	**Stormwater**: Municipal stormwater collection systems	**Sanitary Sewer Systems**: Non-Sonoma Water sanitary sewer systems in each of the districts/zones that provide flow to wastewater treatment facilities
	Municipal and Industrial Demand: Municipal and industrial demand within contractor service areas (e.g. Sonoma-Marin Saving Water Partnership)	**Watershed**: Stormwater-groundwater recharge programs, watershed protection	N/A
	Recycled Water: North Bay Water Reuse Authority	N/A	N/A
	Water Use Efficiency: Urban and agricultural water use efficiency planning	N/A	N/A

Assessment Level	Water Supply	Flood Management	Sanitation
	Agricultural Demand: Agricultural demand and use with Russian River	N/A	N/A
	Wildfire Risk Reduction: Programs such as FireSmart Lake Sonoma Watershed	N/A	N/A

1.4 Overview of Sonoma Water's Regional Climate Science

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 over the past 15 years 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 USGS, SIO, and National Oceanic and Atmospheric Administration (NOAA). These efforts have resulted in improved understanding of the regional climate threats and have put the Sonoma Water on the cutting edge of climate planning. The following is a list of examples of some of the Sonoma Water-supported programs and studies related to regional climate science, collaborations, and studies.

- Sonoma County Regional Climate Protection Authority (RCPA) – *ten local governments with emphasis on improving coordination on climate change activities and establishing a clearinghouse for efforts to reduce greenhouse gas emissions*
- North Bay Climate Adaptation Initiative (NBCAI) – *coalition of natural resource managers, policy makers and scientists committed to working together to create positive solutions to the problem of climate adaptation for the ecosystems and watersheds*
- U.S. Geological Survey (USGS) Climate Science and Watershed Hydrology Modeling – *collaborations with USGS on regional climate projections, downscaling, and hydrologic modeling*
- USGS/Scripps Research on Atmospheric Rivers – *supported research with Scripps Institution of Oceanography (SIO) and USGS on regional assessments and forecasts of atmospheric river events*
- USACE Activities Related to Real-Time Flood Control Operations – *collaborations with USACE on addressing more suitable hydrologic indices and dynamic operation of Lake Mendocino*
- NOAA Hydrometeorology Testbed – *collaboration with NOAA and DWR to improve precipitation forecasting tools to support efforts in managing water resources, flood control, and climate change adaptation*
- NOAA Habitat Blueprint – *program developed by NOAA to integrate habitat conservation throughout regions where NOAA's efforts are present. Sonoma Water was awarded multiple grants to develop a strategy for habitat conservation in the Russian River watershed via the Habitat Blueprint framework*

- Integrated Water Resources Science and Services (IWRSS) – *partnership with IWRSS to address stakeholder issues with lack of organization in forecasting, hydrologic modeling, data management, data collection and monitoring*
- Advanced Quantitative Precipitation Information (AQPI) –*partnership with NOAA and Bay Area agencies to implement X- and C-band radar technology coupled with state-of-the-art forecast models and decision support tools for water resource and utility managers*
- 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
- Fire Camera Alert System (AlertWildfire) –*partnership with PG&E, CalFire, SIO, University of Nevada, University of Oregon, and Sonoma State University to expand the regional network of fire cameras for early fire detection, situational awareness and logistical support for fire response activities*

In addition to the supported programs, collaborations, and studies, Sonoma Water is engaged in a range of planning activities that have or will be incorporating climate change into future efforts. These plans include Stormwater Resources Resource Plans, Watershed Plans, Regional Plans, Stormwater Management Plan guidelines, Groundwater Sustainability Plans, Baylands Strategies, and various county plans.

1.5 Stakeholder Engagement

Sonoma Water realizes that climate adaptation planning in the region cannot be performed in isolation. As part of the Climate Adaptation Plan efforts, Sonoma Water has held multiple meetings to engage with other related efforts by County, State, Federal, and research organizations in the region (Figure 1). The Climate Adaptation Plan also acknowledges that additional future discussions and collaborations are necessary to further plan and implement regional strategies to increase resilience in the face of a changing climate. Networks of entities leading in the regional climate adaptation space could provide for greater collaboration and efficiency of developing regional solutions.

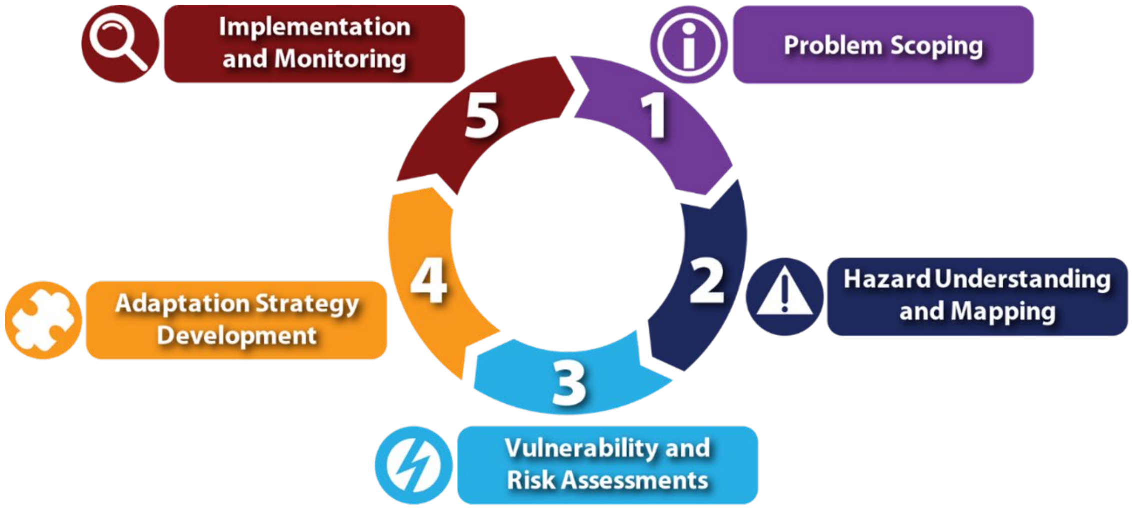
Appendix F – Stakeholder Engagement provides a summary of the stakeholder engagement included in this plan.

Figure 1. Climate Adaptation Plan recognizes the ongoing, collaborative climate adaptation planning activities in the region

1.6 Climate Adaptation Planning Framework

A robust five-step resiliency planning framework (Figure 2) has been applied to help organize and guide the planning process. This structured approach has been widely used in climate adaptation and resiliency planning efforts and ensures that the resulting plan addresses the major climate risks affecting Sonoma Water systems and provides an approach for implementing resilience through Sonoma Water activities and regional partnerships. The planning framework includes five distinct steps linked through a cycle, or adaptive planning process. As more information is gained on new science or monitoring, the process should be revisited and updated to address the changing understanding of risk.

Figure 2. Climate Adaptation Planning Framework used to guide planning process



The key steps in the overall framework are described in the following sections.

1.6.1 Problem Scoping

- **Identify Problems, Frame Questions, and State Objectives**

  Identify the problem, frame the questions to be addressed, and identify the desired outcomes from both a technical and policy perspective.

- **Identify System, Components, Interactions, and Bounds of Study**

  Identify system to be analyzed, the individual components, interactions between the components, and the bounds of the system to be addressed in the study.

1.6.2 Hazard Understanding

- **Understand Climate and Climate Influences of System**

  Ensure understanding of historical climate influences on system, range of historical climate variability, processes influencing climate and changes, and identifying the most important climate variables and scale for the analysis.

- **Understand Climate Projections**

  Understand future climate projections, scale, and uncertainty. Ensure proper understanding of the potential for climate changes and the uncertainty in quantifying the changes of critical interest at the local scale.

1.6.3 Vulnerability and Risk Assessments

- **Conduct Vulnerability Assessment**

  Assess the vulnerability of the system to changes in climate. Develop performance measures, metrics, and thresholds that can be used to measure system vulnerability. Develop system-relevant climate scenarios that are related to the primary climate drivers for system performance. Evaluate qualitatively and/or quantitatively the sensitivity, inherent adaptive capacity, and vulnerability of systems to climate changes.

- **Perform Risk Assessment**

  Take the vulnerability assessment one step further and relate it to the consequence and likelihood of specific climate changes to systems. Ratings of risk are developed from the combined assessment of consequence and likelihood. Priority risk areas result from this assessment and provide focus to areas in which adaptation measures should be considered.

1.6.4 Adaptation Strategy Development

- **Identify and Evaluate Adaptation Options**

  Based on an understanding of the baseline system vulnerability, a wide range of infrastructure, operational, and policy options should be identified. Evaluation criteria are developed and applied for each option to capture economic, environmental, and social attributes.

- **Develop Adaptation Strategies**

  Based on the information gained in the previous steps and working directly with the system experts and other related decision-makers, an adaptation strategy can be developed. The strategy should address improving climate resilience through an adaptive approach, identifying common or low-regret options, and identifying triggers for making other substantial investments in adaptation measures. Portfolios should be identified that implement a particular strategy.

1.6.5 Implementation and Monitoring

- **Implement Strategies**

  Implement selected strategies and ensure that physical, operational, and policy elements are consistently aligned with risk reduction strategies. Develop timeline or pathway for strategy implementation.

- **Monitor Effectiveness**

  Develop and implement a monitoring program that establishes parameters to measure over time to understand increasing or reducing risk, changes in climate, and critical indicators and thresholds that would trigger further investment or investigations.

SECTION 2

Sonoma Water System Description

2.1 General Description of Sonoma Water System

The Sonoma Water system has three core functions: water supply, flood management, and sanitation. The water supply system provides the sourcing, distribution, and storage of water throughout the transmission area. The flood management system contains nine flood zones and encompasses operation, management, and maintenance responsibilities for Sonoma Water within the surrounding area. This includes engineered components such as reservoirs and flood protection infrastructure, as well as flood maintenance easements for some natural channels. Finally, the sanitation system is divided into four sanitation zones and four county sanitation districts that are responsible for either treating influent, conveying wastewater to other treatment facilities, or discharging recycled water for a variety of uses. In total, more than 600,000 residents in Sonoma and Marin County are provided with drinking water, approximately 75 miles of creeks and managed and maintained for flood protection, and 22,000 households and business are serviced for sanitation purposes.

2.2 Water Supply System

Sonoma Water provides wholesale water, principally from the Russian River, to eight water contractors[1], other water transmission system customers[2], and to the Marin Municipal Water District (Marin Water)[3], collectively referred to as Sonoma Water's customers. Sonoma Water also supplies small quantities of water (when available) from its transmission system to surplus

[1] The water contractors include the Cities of Santa Rosa, Petaluma, Rohnert Park, Cotati, and Sonoma, the Town of Windsor, and the North Marin and Valley of the Moon Water Districts.

[2] The other water transmission system customers include the Forestville Water District, California-American Water Company (with respect to the Larkfield-Wikiup area), the Kenwood Village Water Company, Lawndale Mutual Water Company, and Penngrove Water Company, the County of Sonoma, the State of California, and Santa Rosa Junior College.

[3] Sonoma Water's deliveries to Marin Water are authorized by the Restructured Agreement for water supply (See Section 5.1.3) and are subject to the terms of a Supplemental Water Supply Agreement, dated July 1, 2015 between Sonoma Water and the Marin Water, which renewed two existing agreements (the "Offpeak Water Supply Agreement" and the "Agreement for the Sale of Water"). Deliveries to Marin Water under the Supplemental Water Supply Agreement are subject to a number of limitations, including sufficient transmission system capacity. The maximum monthly delivery limit for Marin Water is approximately 12.8 mgd during the months of May through October, which is a combination of the limits under the Agreement for the Sale of Water (9 mgd) and the Offpeak Water Supply Agreement (360 ac-ft/month).

water customers[4], and allows other entities known as Russian River customers[5] to divert water from the Russian River under Sonoma Water's water rights using their own facilities.

Sonoma Water makes water supply releases from Lake Mendocino and Lake Sonoma as necessary to comply with its water rights permits, which implement the provisions of the SWRCB's Decision 1610. Sonoma Water's permits authorize diversions to storage in Lake Mendocino and Lake Sonoma, re-diversions of water released from storage and direct diversions at points downstream. Collection of water into Lake Mendocino's water supply pool is authorized by Sonoma Water's water right Permit 12947A and collection of water into Lake Sonoma's water supply pool is authorized by the water right Permit 16596. Additionally, under these permits and with Permits 12949 and 12950, Sonoma Water and its customers may directly divert water from the Russian River with total direct diversions and re-diversions not exceeding 75,000 AFY.

Sonoma Water's water supply system sources most of its water using six Ranney-type collector wells to draw groundwater from the Russian River aquifer located in the Mirabel Park region. The aquifer is recharged by natural filtration directly from the Russian River through approximately 60 feet of sand and gravel. The average day peak month production by the six collector wells is about 92 gallons of water per day with inflatable dam in operation. Winter production varies (without inflatable dam) but is generally about 60 gallons of water per day. Ten smaller, conventional wells are also available to draw additional groundwater to supplement the main water supply. Seven of these wells are in close vicinity to the collector wells and withdraw Russian River water while the other three wells are located in the Santa Rosa Plain basin and pump groundwater from that basin. Seven of the ten conventional wells are not in use and are operated under emergency conditions only.

For additional water storage, two reservoir projects, Lake Mendocino and Lake Sonoma, store water in the conservation pool of these reservoirs. Lake Mendocino has a total current storage capacity of 116,500 acre-feet, which includes a water conservation pool of between 68,400 acre-feet and 111,000 acre-feet, depending on the time of year. Lake Sonoma has a total storage capacity of 381,000 acre-feet, which is comprised of a water conservation pool of 225,000 acre-feet, a flood control pool of 136,000 acre-feet, and an inactive pool of 20,000 acre-feet. Supplemental infrastructure components and facilities such as infiltration ponds, hydroelectric plants, and an inflatable dam on the Russian River complement and aid in the performance and operation of the water supply system. To convey water through Sonoma Water's service area, eight booster pump stations are used to supplement suitable head. A series of aqueducts convey water to 18 steel storage tanks located around the area that provide a combined storage capacity of approximately 129 million gallons. Figure 1 provides a general overview of the water supply system components.

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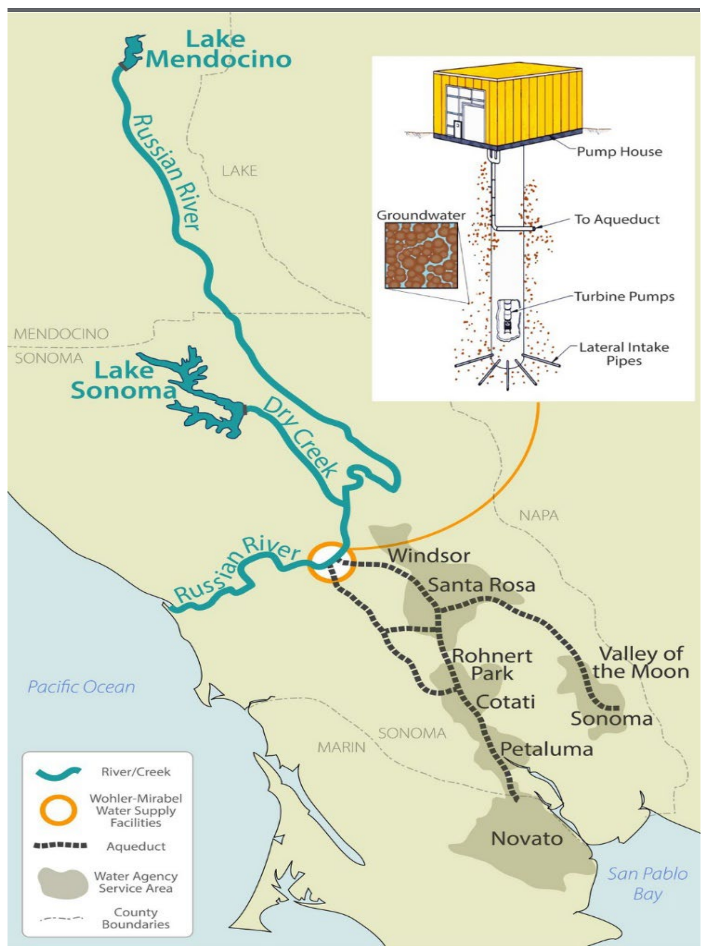
[4] Surplus Water is water that from time to time may be available for delivery from the Transmission System in excess of the amounts required to meet Sonoma Water's contractual obligations and the requirements of all Sonoma Water's regular customers. Surplus customers are subject to Sonoma Water's Water Service Rules.

[5] These "Russian River Customers" include: City of Healdsburg, Camp Meeker Recreation and Park District, and Occidental Community Services District. Russian River customers divert at least a portion of their water supply under Sonoma Water's water rights.

The key components of the water supply system (Figure 3) are as follows:

- Russian River System: There are two major reservoirs that affect flows in the Russian River watershed, Lake Mendocino and Lake Sonoma. Sonoma Water makes releases from Lake Mendocino, located in the upper watershed near Ukiah, into the Russian River to meet minimum instream flow requirements and downstream water demands for the upper Russian River, a 63-mile stretch of the Russian River to the confluence of Dry Creek. Sonoma Water makes releases from Lake Sonoma, located in the lower watershed, into Dry Creek to meet minimum instream flow requirements and downstream demands for a 14-mile stretch of Dry Creek to the confluence of the Russian River, as well for the 31-mile stretch of the Russian River from the confluence of Dry Creek to the Pacific Ocean near Jenner. The Russian River also receives trans-basin imports from the Eel River through the Porter Valley Project (PVP), a hydroelectric facility owned and operated by PG&E. Imports from the PVP are released into the upper reach of the East Fork Russian River approximately 12 miles upstream of Lake Mendocino.
- Diversion facilities: Diversion facilities include the six Ranney-type collector wells that provide the main source of water; the ten conventional wells to supplement the primary collector wells; levee and diversion infrastructure in the Wohler-Mirabel area; an inflatable dam located on the Russian River; infiltration ponds to provide groundwater recharge; and infrastructure aimed at improving the performance and sustainability of the water supply system (i.e. intake screens and fish ladders). Sonoma Water diverts water from the Russian River at its Wohler and Mirabel diversion facilities located near the town of Forestville.
- Transmission Facilities: Transmission facilities include pipes, pumps, and storage facilities that aid in the distribution of water throughout Sonoma Water's transmission area. Aqueducts aid in the transport of water from diversion and pumping facilities to storage facilities. The aqueducts are designed to carry the average daily demand during maximum demand conditions that typically occur in the late summer. Storage facilities include the 18 steel storage tanks that provide a combined total of approximately 129 million

Figure 3. Sonoma Water Supply System Overview



Source: Sonoma Water

gallons of storage located around the transmission area. Seven booster pump stations provide the necessary hydraulic head for the conveyance of water throughout the transmission area.

- Treatment facilities: Chlorination and pH adjustments are made at three different treatment facilities as a precaution for any unexpected contaminants in the transmission system and a means to reduce the quantity of dissolved metal entering wastewater facilities.

2.3 Flood Management System

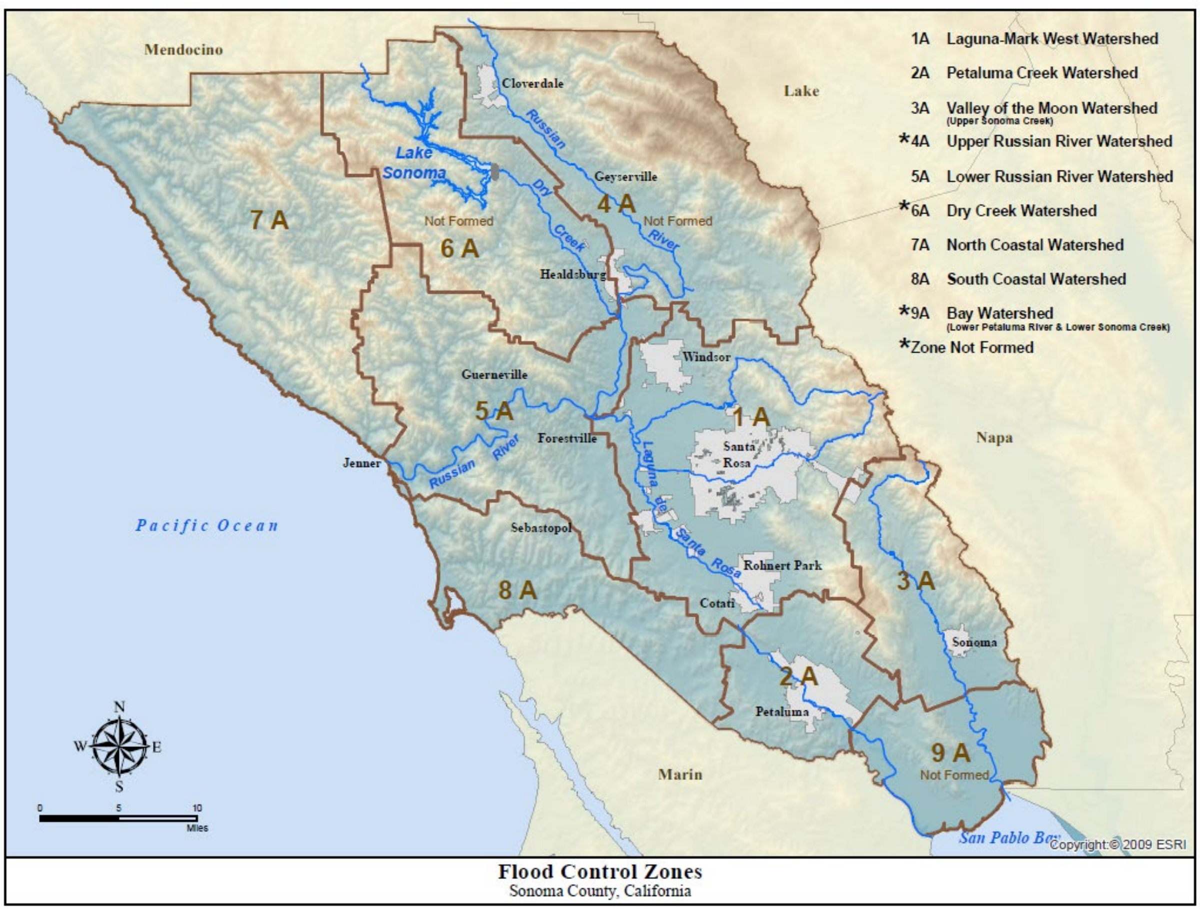
Sonoma Water works collaboratively with the United States Army Corps of Engineers (USACE) and the USDA Natural Resources Conservation Services (NRCS) to operate and maintain both federal and non-federal flood protection facilities in the Russian River watershed. There are two major reservoirs in the Russian River watershed, Lake Mendocino and Lake Sonoma. For both Coyote Valley Dam at Lake Mendocino and Warm Springs Dam at Lake Sonoma, Sonoma Water controls releases when the water level in the reservoirs is within water conservation pool while the USACE assumes control once the water level rises into the flood pool. The USACE determines the schedule and amounts of releases of water from Lake Mendocino and Lake Sonoma during flood control operations.

To provide a means of financing projects and prioritizing flood management improvements and maintenance, nine flood management zones were proposed to each encompass a major watershed in the region. Figure 4 provides a map of the nine flood protection zones. Six of the nine zones have been formed and are active, while the remaining three are still unformed (4A, 6A, and 9A). Zones 1A, 2A, and 3A each have their own distinct Advisory Committee who review, recommend, and prioritize improvements projects within these flood zones on a yearly basis. Likewise, Sonoma Water provides the maintenance services over the approximate 150 miles of channels within these three zones (1A, 2A and 3A). However, there are many other portions of streams within these zones that are not within Sonoma Water's maintenance responsibilities. The Flood Zone list generally describes the infrastructure projects within each flood zone that Sonoma Water is responsible for operating and maintaining:

- Flood Zone 1A – Laguna-Mark West Watershed: Covers both the Laguna de Santa Rosa Watershed and the Mark West Creek Watershed. As part of the Central Sonoma Watershed project (encompassing Santa Rosa Creek watershed), Sonoma Water is responsible for maintaining four detention reservoirs, two diversion structures, conduits, the downtown culverts, and engineered channels included in the Stream Maintenance Program.
- Flood Zone 2A – Petaluma Creek Watershed: Covers the Upper Petaluma Creek Watershed and contains several engineered channels as well as two conduits that Sonoma Water is responsible for managing.
- Flood Zone 3A – Valley of the Moon Watershed: Covers the Upper Valley of the Moon Watershed and is located to the east of Flood Zones 1A and 2A. Sonoma Water has limited flood protection infrastructure in this zone that consists primarily of the Kenwood Creek Bypass Conduit as well as engineered channel portions along Fryer Creek, Nathanson Creek, and Rodgers Creek.

- Flood Zone 4A – Upper Russian River Watershed: Sonoma Water has maintenance easements on certain levees along the Russian River as part of their cost share partnership in the Coyote Valley Dam Project as well as the Stream Management Program. However, the majority of the levees throughout the flood zone are not engineered levees, and Sonoma Water does not own or have maintenance responsibilities for these levees. There are a limited number of levees for which Sonoma Water has accepted maintenance responsibilities following USACE repairs made to levees due to historical flood events. Stream Maintenance Program activities are generally limited to Wood Creek and do not include levee management along the Russian River. This flood zone is not officially formed.
- Flood Zone 5A – Lower Russian River Watershed: As with Flood Zone 4A, Sonoma Water has maintenance easements on the lower Russian River and two tributaries, Fife Creek and Livereau Creek, are included within the Stream Maintenance Program.
- Other Flood Zones - 6A (Dry Creek Watershed), 7A (North Coastal Watershed), 8A (South Coastal Watershed), and 9A (Bay Watershed): Contain limited engineered and natural components managed by Sonoma Water. Fee titles and easements allow Sonoma Water to access these regions to perform flood management maintenance, however Sonoma Water is not obligated to engage in their upkeep. Zones 6A and 9A have not been officially formed.

Figure 4. Flood Control Zones Overview



Source: Sonoma Water

2.4 Sanitation System

The Sonoma Water sanitation system is divided into four sanitation zones and four county sanitation districts. Sonoma Water owns and operates the sanitation zones, but only operates the independent county sanitation districts. The county sanitation districts have their own separate Board of Directors and hold ownership over the respective assets within their district. Each provide varying levels of treatment and capacity depending on the facility characteristics and service area. The county sanitation districts and sanitation zones that comprise the Sonoma Water sanitation system are listed:

- Russian River County Sanitation District: The Russian River County Sanitation District services 3,821 Equivalent Single-Family Dwelling Units (ESDs) over a service area of 2,700 acres. The treatment plant provides tertiary treatment for an average intake of 200,000 gallons per day. Between October and mid-May, treated wastewater is discharged into the Russian River. Between mid-May and September, the recycled water is used to irrigate adjacent forest land as well as the Northwood Golf Course.
- Occidental County Sanitation District: Occidental County Sanitation District (OCSD) services 298 ESDs over a service area of 55 acres. The OCSD treatment plant was decommissioned in 2018. Currently, the OCSD lift station collects all wastewater from the District. The septic trucks extract wastewater from the lift station and haul the wastewater to Airport Larkfield Wikiup Sanitation Zone’s wastewater treatment plant. Alternate treatment and disposal options for OCSD are currently being explored.
- Sonoma Valley County Sanitation District: The Sonoma Valley County Sanitation District services 20,528 ESDs over a service area of 4,500 acres. The treatment facilities provide tertiary treatment for an average daily flow of 2,800,000 gallons of wastewater. Between May and October, the treated wastewater is used for both irrigation and wetland habitat purposes. Between November and April, the treated wastewater is discharged into either Schell Slough or Hudeman Slough.
- South Park County Sanitation District: South Park County Sanitation District services 4,032 ESDs over a service area of 1,460 acres. This county sanitation district does not own a treatment plant, and instead transfers collected wastewater through the Todd Road Lift Station to the Laguna Subregional system.
- Penngrove Sanitation Zone: The Penngrove Sanitation Zone services 562 ESDs over a service area of 475 acres. This sanitation zone lacks a treatment plant, and instead routes collected sewage from the service area through the Penngrove Lift Station to the City of Petaluma’s system for wastewater treatment procedures.
- Geyserville Sanitation Zone: The Geyserville Sanitation Zone services 405 ESD over a service area of 177 acres. The wastewater treatment plant provides secondary treatment for approximately 77,000 gallons per day. The discharged treated wastewater is disposed of through ponds used for percolation and by evaporation.
- Airport/Larkfield/Wikiup Sanitation Zone: The Airport/Larkfield/Wikiup Sanitation Zone services 3,847 ESDs over a service area of 2,100 acres. The wastewater treatment plant provides tertiary treatment for an average intake of 750,000 gallons per day. Treated wastewater from the plant is used entirely for irrigation.

- Sea Ranch Sanitation Zone: The Sea Ranch Sanitation Zone services 587 ESDs over a service area of 4,600 acres. The sanitation zone is divided into two sub-zones, each containing their own wastewater treatment plant: North and Central. The North treatment facility provides secondary treatment for 22,000 gallons per day. The treated wastewater is then transferred to the Gualala County Sanitation District for tertiary treatment to be used for irrigating the Sea Ranch Golf Links. The Central treatment facility provides secondary treatment for 2,000 gallons per day, and the treated wastewater is also used for irrigation purposes.

2.5 Administrative Facilities

While not involved in the direct treatment or movement of wastewater, administrative facilities including the Sonoma Water administrative office, the operations and maintenance center, and the operations and maintenance dispatch center are integral components that provide management and oversight for other facilities.

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SECTION 3

Climate and Hydrology Science

3.1 Climate and Hydrology Science

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 is 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. Additional detail is provided in Appendix A - Background of Sonoma Water Climate Resilience Efforts.

3.1.1 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), SIO, and 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.

3.1.1.1 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 270m spatial resolution.

Another study by the same authors (Flint and Flint, 2012b) 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 Hydrologic Engineering Center – Reservoir System Simulation (HEC-ResSim) model to evaluate potential risks to reservoir operations, Russian River flows, and regional water supply.

3.1.1.2 Atmospheric River Research for Flood Control and Drought Forecasting

Atmospheric Rivers (AR) are responsible for most, if not all, of Russian River extreme precipitation events. There is potential for AR, 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.

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 AR and its relationship to improved water supply and reservoir operations. The NOAA/SIO's West Coast Atmospheric River Program is conducting research on AR to help understand their processes to support water resource and flood risk planning. ARs are classified as narrow (400 to 600 km 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.

3.1.1.3 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 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.

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.

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 which 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.

3.1.1.4 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 (MOA) 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 (QPI) 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 the California Department of Water Resources (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.

3.1.1.5 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.

3.1.1.6 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 the 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.

3.1.1.7 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.

3.1.1.8 Integrated Water Resources Science and Services

The USACE (U.S Army Corps of Engineers), USGS (U.S Geological Survey), and the 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.

3.1.1.9 North Bay Climate Ready

Working in partnership with the Sonoma County RCPA, the 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.

3.2 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.

3.2.1 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 (Erkstrom and Moser 2012). 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 (RCMs) forced with specific global greenhouse gas (GHG) emission scenarios. GCMs have relatively coarse resolution (~100-km 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, twenty individual downscaled GCM projections were selected from ten different GCMs and two different representative concentration pathways, RCP4.5 and RCP8.5. These ten 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 twenty climate projections were downscaled using a statistical downscaling method called LOCA (localized constructed analogs) at 1/16th degree (~6 km) (~3.75 miles) spatial resolution by SIO (Pierce et al., 2014; Pierce et al., 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 will be 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 to 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 2 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 2 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 2. 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)
	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)
	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	Magnitude and direction are uncertain, although latest models suggest wetter conditions	Maurer et al (2007); Brekke et al. (2013); Pierce et al. (2018)
	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)
	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 feet (0.40 to 1.99 feet) [+28 cm (12.3 to 60.8 cm)] 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 1991-2009 mean. By 2100, median probability of SLR is projected to be 1.6 foot (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 mean between years 1991 to 2009. 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 1991-2009 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)
	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
	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)

3.2.2 Projected Changes in Temperature

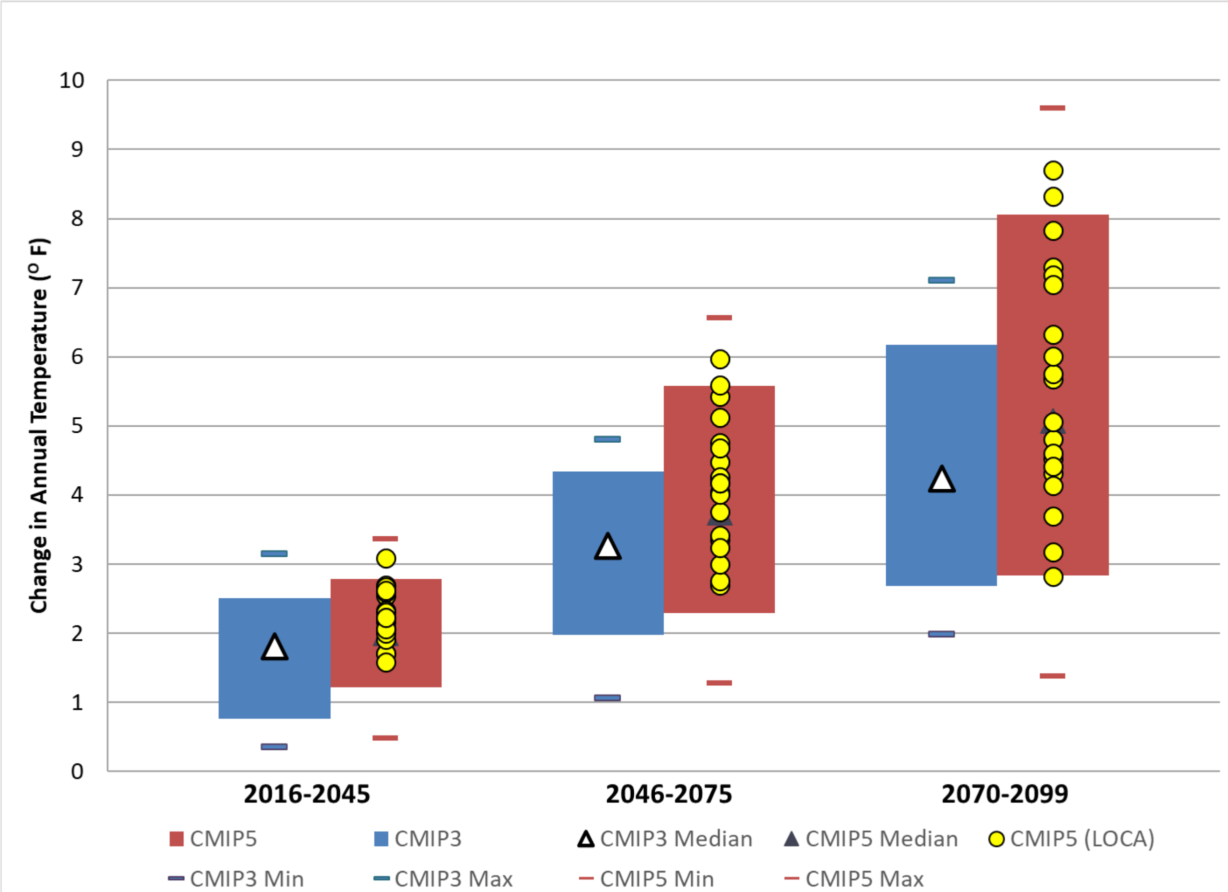
Under all available future climate scenarios, air temperatures are projected to increase in California. All projections are consistent in the direction of the temperature change (increase) but vary in terms of climate sensitivity (magnitude) (Cayan et al. 2009; Cayan et al. 2008a, 2008b, and 2008c). 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 5). 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.

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 mid-century (2040 to 2069). By late century (2070-2099), 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. The number of days that exceed 95 °F (35 °C) and 100 °F (37.77 °C) temperatures are projected to increase under future climate conditions.

Figure 5. Projected Changes in Mean Annual Temperatures for the Sonoma County Region based on CMIP3 and CMIP5 Projections



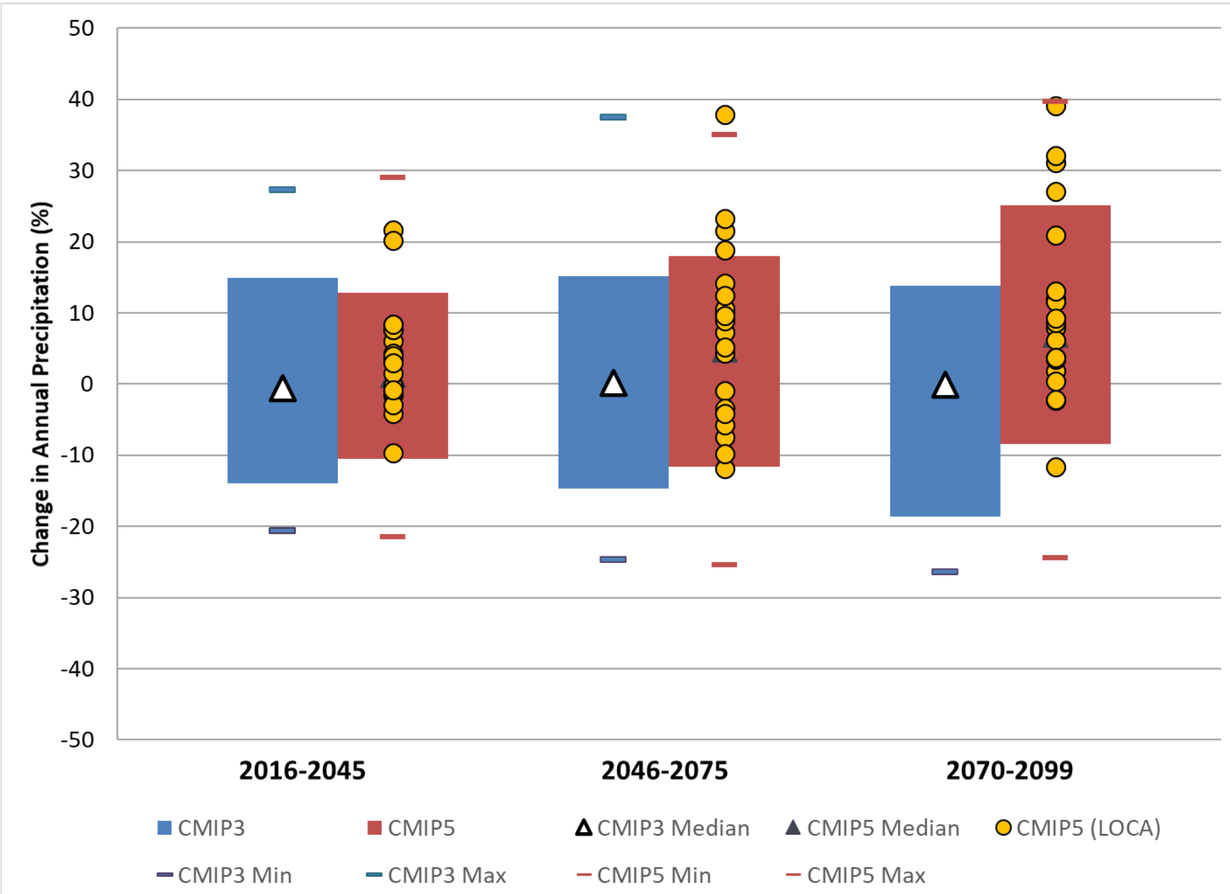
Note: The projected changes for CMIP3 and CMIP5 are computed using 112 and 178 downscaled climate model projections, simulated under SRES emission scenarios A2, A1B, and B1 for CMIP3 and simulated under Representative Concentration Pathways RCP8.5, RCP6.0, and RCP4.5 for CMIP5, used in the IPCC's AR4 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 (~12 km) (~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 localized constructed analogs (LOCA) daily statistical downscaling method at 1/16th degree (~6 km) (~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.

3.2.3 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 6). 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).

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

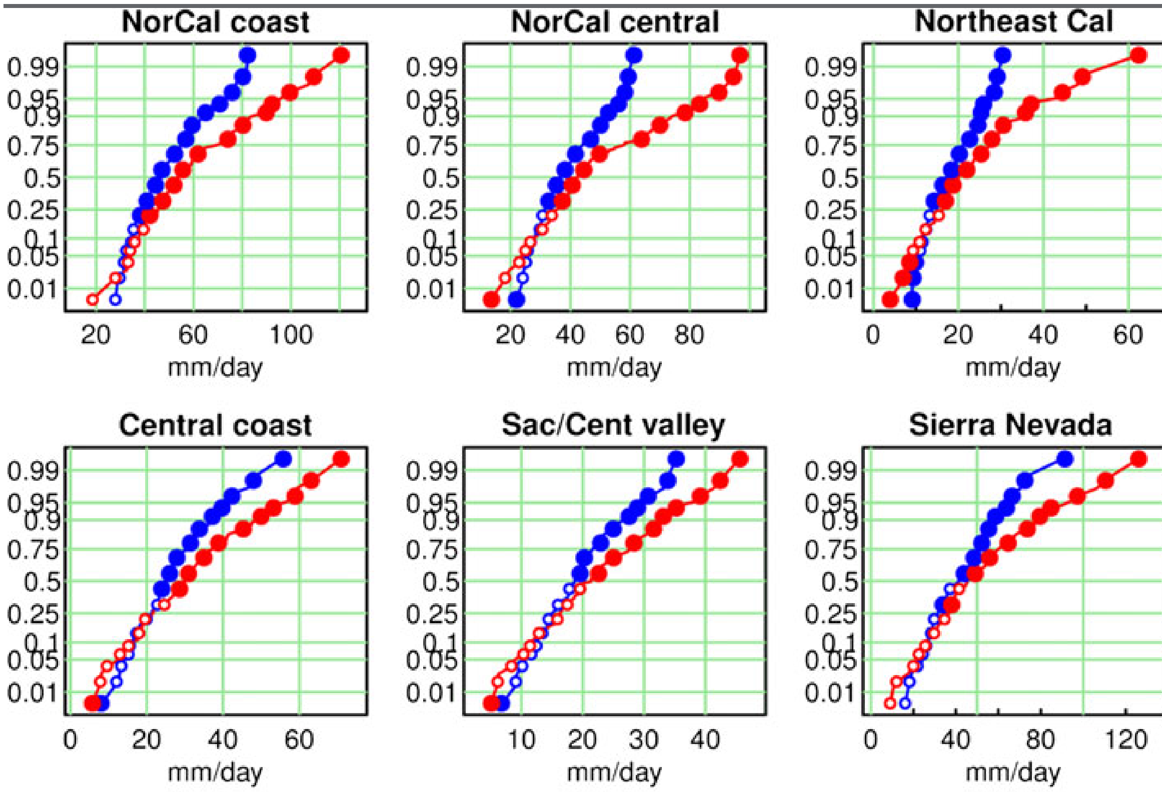


Note: The projected changes for CMIP3 and CMIP5 are computed using 112 and 178 downscaled climate model projections, simulated under SRES emission scenarios A2, A1B, and B1 for CMIP3 and simulated under Representative Concentration Pathways RCP8.5, RCP6.0, and RCP4.5 for CMIP5, used in the IPCC's AR4 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 (~12 km) (~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 (~6 km) (~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 is 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 nine 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 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 century (Figure 7). 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 (OAR) 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. 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; Gershunov et al., 2019).

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



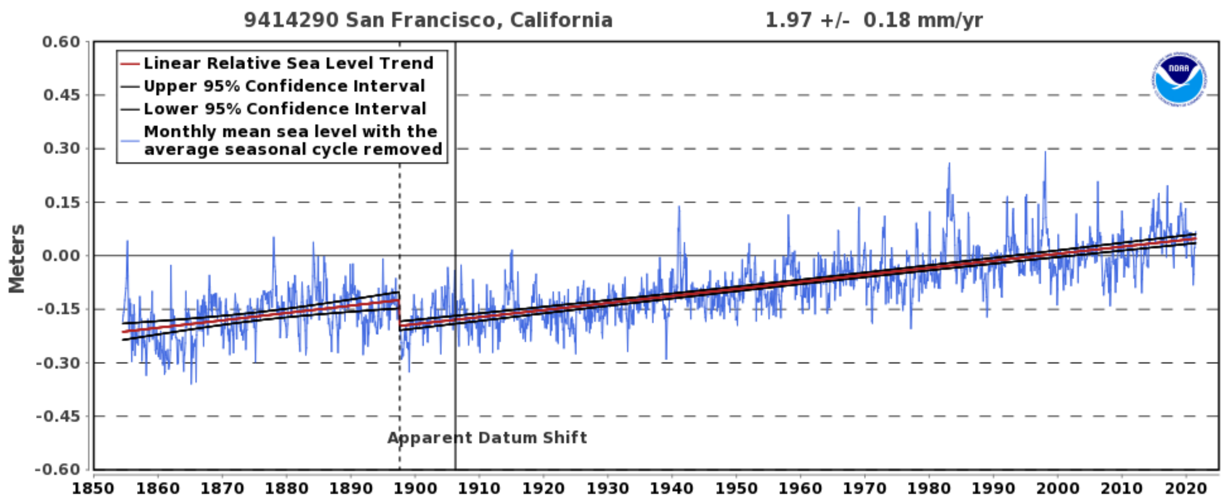
Note: Regions are plotted roughly geographically. Y axis is probability (0–1) of experiencing the indicated average 3-day precipitation rate (mm/day), or lower. Large solid dots show where the two curves are different at the 95 % significance level, evaluated using a bootstrap technique. Open circles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

3.2.4 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 feet to–0.66 feet (17 to 20 centimeters) (cm) per century (Cayan et al 2009). There is considerable variability among tide gauges along the Pacific Coast, primarily reflecting local differences in vertical movement of the land and length of gauge record. Figure 8 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 feet (19.8 cm) in 100 years.

Figure 8. Monthly Mean Sea Level and Trend at San Francisco Tide Gauge (NOAA Gauge Number 9414290)



Source: NOAA (September 25, 2021) *https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9414290*

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). Table 3 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. 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 3. 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	0.3 and 0.5	0.6	0.8	1
	2040	0.6	0.5 and 0.8	1	1.3	1.8
	2050	0.9	0.6 and 1.1	1.4	1.9	2.7
Low	2060	1	0.6 and 1.3	1.6	2.4	3.9
High	2060	1.1	0.8 and 1.5	1.8	2.6	
Low	2070	1.1	0.8 and 1.5	1.9	3.1	5.2
High	2070	1.4	1 and 1.9	2.4	3.5	
Low	2080	1.3	0.9 and 1.8	2.3	3.9	6.6
High	2080	1.7	1.2 and 2.4	3	4.5	
Low	2090	1.4	1 and 2.1	2.8	4.7	8.3
High	2090	2.1	1.4 and 2.9	3.6	5.6	
Low	2100	1.6	1 and 2.4	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

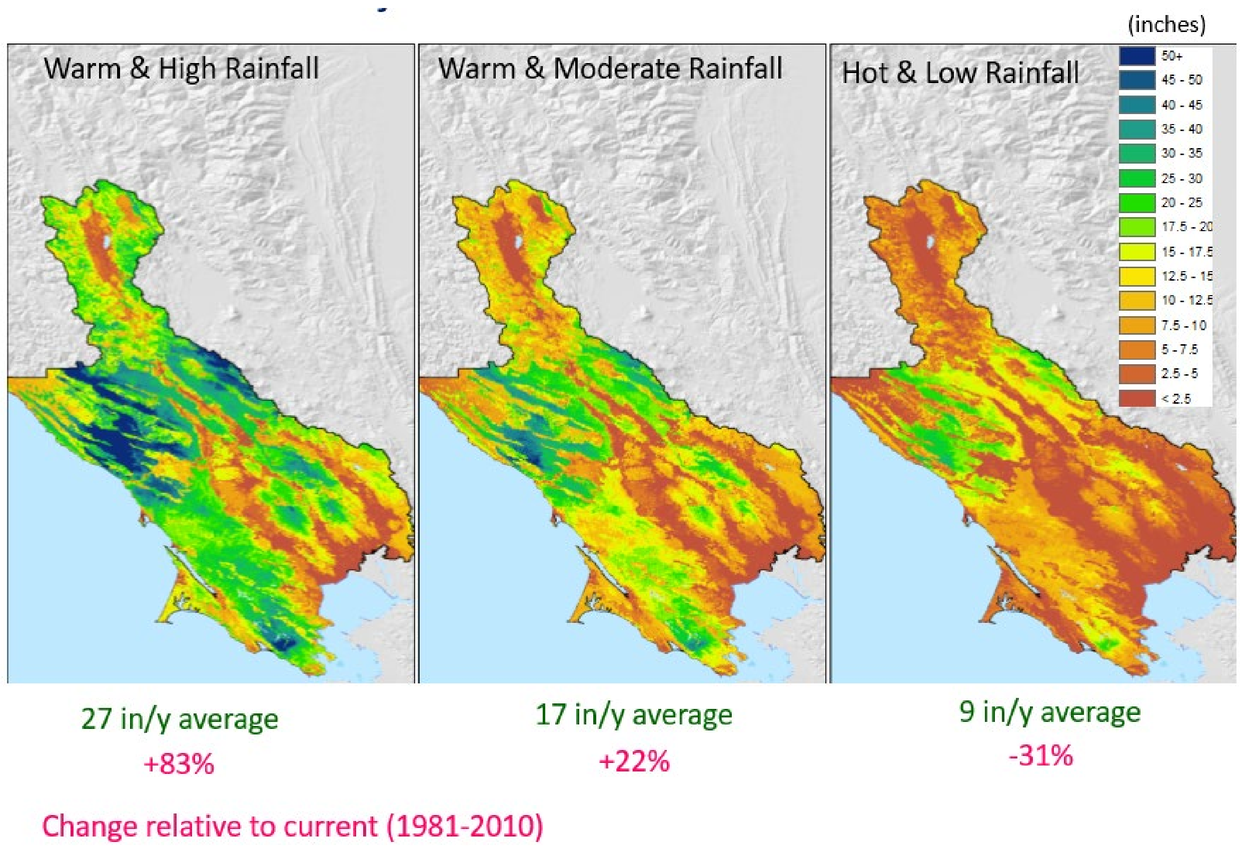
Sonoma Water has supported modeling of the sea level rise and storm surge impacts to the North Bay through the Coastal Storm Modeling System (CoSMoS). The CoSMoS study was part of the NOAA Russian River Blueprint Habitat and included an assessment of the effects of sea level rise and the impacts of winter 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.

3.2.5 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 9 translates projected changes in precipitation to runoff through a water balance in the BCM simulation at 270m resolution in Sonoma County. Increases in runoff are expected to be seen in warm & high rainfall and warm & moderate rainfall scenarios, however, increases in runoff are not expected hot & low rainfall scenarios. The projected average rainfall is 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 to 2010 runoff levels.

Figure 9. Projected Runoff in Sonoma County Under Three Climate Scenarios Over the Future Period 2070 to 2099



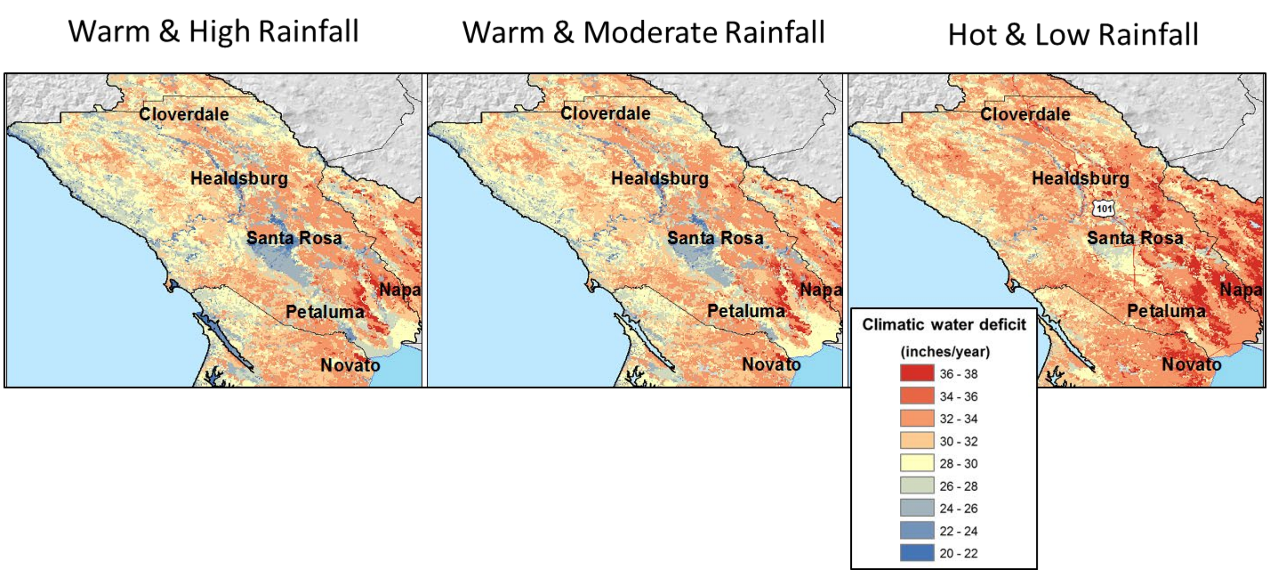
Source: NBCAI, 2016

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 10 (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 10. Projected Climatic Water Deficit 2040 to 2069 Under Different Climate Change Scenarios



Source: NBCAI 2016

3.2.6 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 7 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.

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.

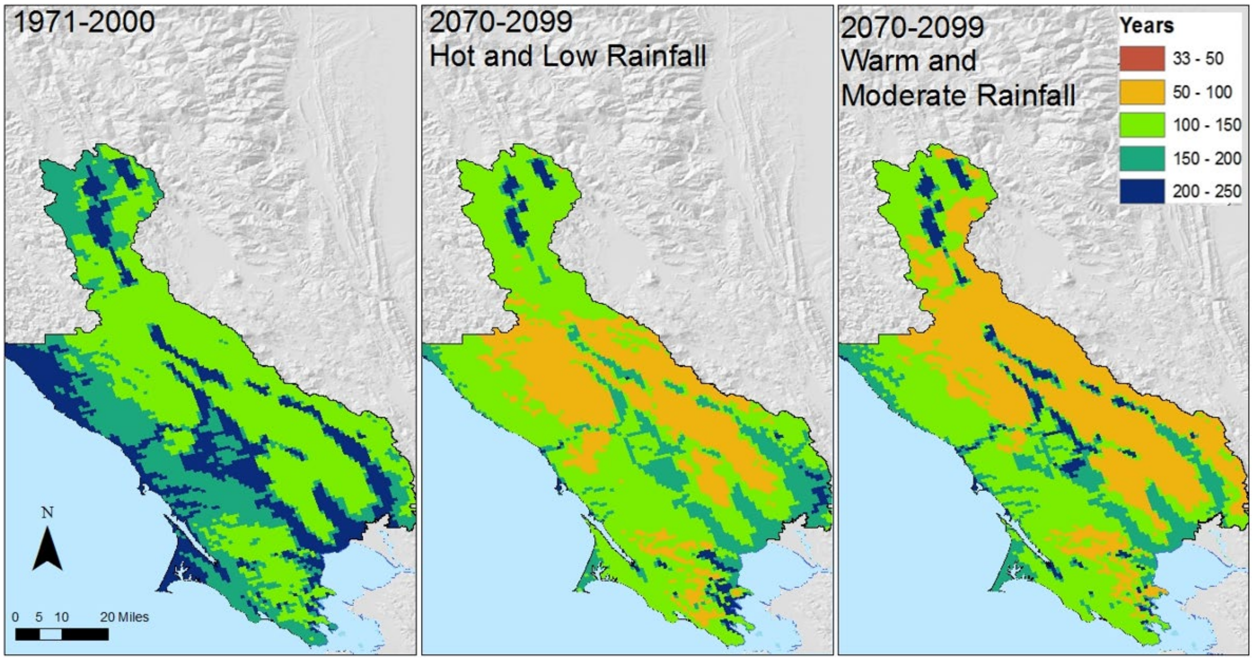
Work performed by Jacobs for the DWR, evaluated flood risks for all major watersheds in the Central Valley associated with projected changes in extreme precipitation and warming (DWR, 2017). Hydrologic modeling simulated changes in flood volumes associated with projected changes in extreme precipitation 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.

3.2.7 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 included the Tubbs, Nuns, Pocket, and Atlas fires substantially impacted Sonoma County in October 2017. More recently the Walbridge Fire impacted communities and a portion of the lower Russian River watershed (http://sonomavegmap.org/firestory/index.html). Climate change is generally expected to increase the wildfire risk in the Sonoma County 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). 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.

Figure 11 shows projected reduction in fire return intervals in Sonoma by approximately 25% by late century.

Figure 11. Change in Projected Fire Return Interval Under Different Climate Change Scenarios



Source: NBCAI,2016

SECTION 4

Vulnerability Assessment

4.1 Introduction

The vulnerability assessment evaluated the degree to which each of Sonoma Water's systems is susceptible to, and unable to cope with, the adverse effects of climate and climate change. The vulnerability assessment was performed for current and historical conditions in order to establish the current vulnerabilities as well as for future conditions incorporating climate change to estimate future vulnerabilities.

This section describes the approach used to assess vulnerability, includes a summary of each system's vulnerability assessment, and summarizes the overall vulnerability assessment findings.

4.2 Vulnerability Assessment Approach

The vulnerability assessment was conducted using a combination of field visits, interviews with Sonoma Water operations, maintenance, engineering, and environmental staff, review of historical vulnerabilities, and mapping of historical and future conditions. The vulnerability assessment was performed using both qualitative and quantitative information. The qualitative assessment helped to improve understanding of local climate and variables of interest, engaged those who manage, operate, and maintain the system, and identified the areas that required further investment of resources to improve the assessment. The quantitative assessment focused on areas of the most critical need and for which system models or other quantitative tools that could refine estimates of vulnerability and risk.

The qualitative vulnerability assessment began with an in-depth review of Sonoma Water's Facility Guide and a tour of each system led by facility operators and managers. Existing reports, hazard mapping, photos, critical elevations, and climate projections were reviewed to arrive at preliminary vulnerability findings. Workshops were then conducted with Sonoma Water staff to confirm and modify findings of vulnerability at each of the major system components or facilities, to help in determining the thresholds for performance, to identify the system component's sensitivity to climate and climate changes, and qualitatively address the adaptive capacity inherent in the certain system components. Sonoma Water personnel including members of the management team as well as water supply, flood control, and sanitation system operations and maintenance staff participated in the workshops.

The workshops covered the following items:

- Brief presentation of the regional/local climate and projected changes for the region, including maps that showed key climate variables and system assets

- Overview of the vulnerability and/or risk assessment process
- Overview of vulnerability-risk assessment table that was used to collect participant feedback and qualitative assessments
- Pictures and descriptions of historical climate events that proved challenging to the system
- Review of the consultant's initial findings following the facility tours and discussion of the vulnerability ratings in the vulnerability-risk table

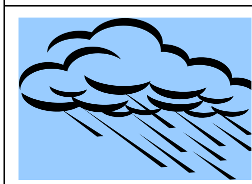
Following the workshops, the findings were summarized in facility summaries. The facility summaries are included in Appendix B – Vulnerability Assessment.

Quantitative information was introduced for flood elevation mapping at critical facilities and specific modeling and technical analyses were developed to investigate some climate vulnerabilities and risks further. Areas with large uncertainty, or where additional technical information would be valuable, were identified as the focus for the more detailed quantitative assessment.

4.2.1 Climate Scenarios for Vulnerability Assessment

For the vulnerability assessment, a range of climate scenarios were utilized to support the assessment. These scenarios include changes in temperature, sea level rise, changes in precipitation, changes in drought, changes in wildfire, and changes in river flooding. Table 4 shows the range of climate changes considered in the vulnerability assessment.

Table 4. Summary of the Range of Climate Change Considered in Vulnerability Assessment

Hydroclimate Variables		Projected Trends
	Temperature	• Increases up to 1.3 to 3.1°C by mid-century • Increased frequency of temperature extremes (days hotter than 30°C or 86°F)
	Sea Level Rise	• MSL increases by 0.1 to 0.6 meter (0.3 to 2 feet) by mid-century • Storm surge will cause additional increases
	Precipitation	• Extreme precipitation increases (ARs) by 15% • Increased winter, decreased summer precipitation (more variability)
	Drought	• Increasing intensity of drought conditions • Increasing frequency and duration of dry weather conditions

Hydroclimate Variables		Projected Trends
	Wildfire	• More frequent and intense wildfires due to warmer temperatures and drier conditions • Increase in probability of wildfires by 15 to 33%
	River Flooding	• Potential increase in AR-driven floods on Russian River • 100-year flood magnitudes could increase by 10 to 20%

4.2.2 Vulnerability Matrix and Rating Scale

For this assessment, vulnerability is a function of an asset's or system's sensitivity (how susceptible the system or asset is to changing climate conditions) and adaptive capacity (ability of a system or asset to respond to changing climate conditions). Sensitivity and adaptive capacity are combined in a vulnerability rating.

		Sensitivity				
		Low = 1	Moderate/Low = 2	Moderate = 3	Moderate/High = 4	High = 5
Adaptive Capacity	Low = 1	L	M/L	H	H	H
	Moderate/Low = 2	L	M	M/H	H	H
	Moderate = 3	L	L	M	M	H
	Moderate/High = 4	L	L	L	M	M
	High = 5	L	L	L	L	M

A five-point rating scaled was used in vulnerability and risk assessments (H=high, M=moderate, L=low)

The *sensitivity* of the system to current climate and climate changes is assessed through a standard five-point rating scale ranging from low to high. The sensitivity rating is based on the responsiveness of the system to changes in climate without consideration of the ability to adapt. The current *adaptive capacity* is then assessed based on the ability of the system, operations, or management to adapt with little or no changes in the current system function or operational/management structure. As with the sensitivity rating, a standard five-point rating scale is also used for adaptive capacity. The combined rating of sensitivity and adaptive capacity results in a qualitative assessment of *vulnerability*. A system component that is highly sensitive (high) to climate changes and has little adaptive capacity (low) represents a high vulnerability. However, not all system components that show high sensitivity to climate are considered highly vulnerable. If substantial operational flexibility exists to adapt to such changes, then the component may be considered to have only low to moderate vulnerability. Table 5 and Table 6 define the vulnerability rating scales for sensitivity and adaptive capacity, respectively.

Table 5. Sensitivity Rating Scale

Level	Descriptor	Description
1	Low	Low sensitivity: Climate and climate changes have little to no influence on asset or operations.
2	Low to Moderate	Intermediate between Low and Moderate sensitivity
3	Moderate	Moderate sensitivity: Climate and climate changes have influence on asset or operations.
4	Moderate to High	Intermediate between Moderate and High sensitivity
5	High	High sensitivity: Climate and climate changes have a high influence on asset or operations.

Table 6. Adaptive Capacity Rating Scale

Level	Descriptor	Description
1	Low	System component has little inherent capacity to adapt to climate-induced changes.
2	Low to Moderate	Intermediate between Low and Moderate
3	Moderate	System component has some inherent capacity to adapt to climate-induced changes.
4	Moderate to High	Intermediate between Moderate and High
5	High	System component has substantial inherent capacity to adapt to climate-induced changes.

4.3 Vulnerability Assessment Summary

The combined rating of sensitivity and adaptive capacity results in an assessment of vulnerability. A system component that is highly sensitive (high) to climate changes and has little adaptive capacity (low) represents a high vulnerability. However, not all system components that show high sensitivity to climate are considered highly vulnerable. If substantial operational flexibility exists to adapt to such changes, then the component may be considered to have only low to moderate vulnerability. Table 7 provides a summary of the vulnerabilities identified in the various systems evaluated for this study. Note for sanitation systems, the ownership, assets, and operation of the Sea Ranch Sanitation Zone and the South Park County Sanitation District are expected to be transferred to other entities within a few years. No detailed vulnerability assessments were performed on these sanitation systems. However, some of the broad adaptation strategies developed for the other sanitation systems could be applied to Sea Ranch Sanitation Zone and the South Park County Sanitation District.

Table 7. Vulnerability Assessment Summary

System	Planning Area	System Component (Asset)	Vulnerability Rating (Low, Moderate, High)
Water Supply System	Potter Valley Project	Lake Pillsbury/Scott Dam	Moderate/High
	Coyote Valley Dam Project	Lake Mendocino/Coyote Valley Dam	High
	Russian River Project	Lake Sonoma/Warm Springs Dam	Moderate
		Dry Creek	Moderate
	Russian River Diversion Facilities	Wohler Ranney Collector - Collector Number 1	Moderate/High
		Mirabel Ranney Collector - Collector Number 3	Moderate/High
	Russian River Water Treatment	River Road Chlorination and Control Facility	Moderate
		Mirabel Chlorination Facility	Low/Moderate
	Russian River Water Treatment	Wohler Chlorination and Corrosion Control Facility	Moderate/High
	Transmission System	Booster Pump Station - Ely Booster	High
		Booster Pump Station - Kawana Booster	Moderate
Flood Management System	Zone 4A	Russian River Engineered Levees (Cloverdale)	Moderate
	Russian River Project (Zone 5A)	Lower Russian River	Moderate

System	Planning Area	System Component (Asset)	Vulnerability Rating (Low, Moderate, High)
	Central Flood Management System - Sonoma Watershed Project (Zone 1A)	Detention Basins (Santa Rosa Creek Reservoir / Spring Lake, Matanzas Creek Reservoir, Piner Creek Reservoir, Brush Creek Reservoir, Spring Creek Reservoir)	High
	Engineered Flood Control Channels in Zone 1A	Engineered Flood Control Channels in Zone 1A	High
	Sonoma Creek (Zone 3A)	Sonoma Creek Main Channel	Moderate/High
	Petaluma River (Zone 2A)	Petaluma River Main Channel and Flood Control Project components	High
Sanitation System	Airport/Larkfield/Wikiup Sanitation Zone	Wastewater Treatment Plant	Moderate
		Collection system	Moderate
	Geyserville Sanitation Zone	Wastewater Treatment Plant	Moderate
		Collections System	Moderate
	Occidental County Sanitation Zone	Wastewater Treatment Plant	Moderate/High
		Collections System	Moderate/High
	Penngrove Sanitation Zone	Collections System	High
	Russian River County Sanitation District	Wastewater Treatment Plant	High
		Collections System	High
	Sonoma Valley County Sanitation District	Wastewater Treatment Plant	Moderate/High
		Collections System	High

System	Planning Area	System Component (Asset)	Vulnerability Rating (Low, Moderate, High)
		Recycled Water	High
Administration Building	SCWA Service Area	Administrative Offices	Low/Moderate

A summary of the vulnerability assessment results for the water supply system are shown in Table 8.

- Russian River water supply is projected to be impacted by increasing climate variability and severity of drought. While not well simulated in GCMs, some projections suggest future droughts through mid-century up to 20% more severe than historical droughts. All GCMs analyzed suggest future increases in wildfire intensity and frequency which could contribute to high sediment and organic carbon loading in the Russian River.
- Wohler and Mirabel diversion facilities have risk due to flooding and wildfire/post-fire threats. Projected future floods under climate change will exceed historical 100-year floods with river stage exceeding critical elevations of caissons, roads, ponds, and wells.
- Post-wildfire storm runoff carrying burn-area sediment and dissolved organic carbon (DOC) to Wohler and Mirabel diversion facilities was identified as a risk. Projections under future climate change indicate growing wildfire risks in terms of both severity and frequency of occurrence. Large increases in DOC in the Russian River may impact riverbank infiltration water quality and severely limit the ability to chlorinate without generating higher levels of disinfection byproducts.
- Both River Road Chlorination Facility and Wohler Chlorination and Corrosion Control Facility will experience increased risk due to extreme precipitation, river flooding, and wildfires. Both facilities are likely to experience flooding impacts under future climate change and may be impacted with changing water quality conditions post-wildfire. Loss of power during extreme events is a risk and limited backup power exists, particularly at River Road.
- Ely Booster Pump Station is at high risk due to extreme precipitation and localized flooding. Historical flooding has already presented risk at this facility and future climate change will increase the flood stage.
- Kawana Booster Station is susceptible to localized flooding from the adjacent creek and Highway 12. Projected increased precipitation extremes will exacerbate the current periodic flooding/drainage issues.

Table 8. Vulnerability Assessment Summary for the Water Supply System

System Component	Temperature	Sea Level Rise	Extreme Precipitation	River Flooding	Drought	Wildfire
Upper Russian River Supply (Watershed and Lake Mendocino)	Moderate	N/A	N/A	N/A	High	Moderate
Lake Sonoma	Moderate	N/A	N/A	N/A	Moderate	Moderate
Mirabel Diversion Facilities	N/A	N/A	N/A	High	Moderate	High
Wohler Diversion Facilities	N/A	N/A	N/A	High	Moderate	High
Wohler Chlorination and Corrosion Control	N/A	N/A	Moderate/ High	Moderate/ High	N/A	Moderate/ High
Mirabel Chlorination and Corrosion Control	N/A	N/A	Low	Low	N/A	Low
River Road Chlorination	N/A	N/A	Moderate/ High	High	N/A	N/A
Ely Booster	N/A	N/A	High	N/A	N/A	N/A
Kawana Booster	N/A	N/A	Moderate	N/A	N/A	N/A

A summary of the vulnerability assessment results for the flood management system are shown in Table 9.

- Highest risk is related to flood management facilities for which Sonoma Water has responsibility is in Central Sonoma Watershed (Zone 1A). These facilities are currently unable to adequately manage flood flows greater than historical 25-year flood on Santa Rosa Creek and Matanzas Creek. Future extreme precipitation is projected to increase by 10 to 30% and will exacerbate the detention basins, culvert, and channel capacity to manage high flows. Increasing runoff and wildfire potential will lead to higher sediment loading to these facilities and may exceed sediment removal resources.
- Flood-related vulnerabilities in the upper Russian River near Cloverdale are related to increased peak discharges and potential levee overtopping or risks due to more extreme precipitation events. In addition, increased sediment loading near Big Sulphur Creek is projected to further exacerbate flooding due to loss of flood conveyance capacity.
- On the lower Russian River, increased flood flows and sea level rise will exacerbate river flooding and challenge the management of the Russian River Estuary. Rising sea levels will change the depositional environment and tidal influence (upstream) at the estuary and will alter the stability and location of the natural berm, frequency and duration of closure events, and timing of breach.

- Flood conveyance channels in the Petaluma River and tributaries (Zone 2A) are highly sensitive to climate change due to increases in extreme precipitation and sea level rise. Increased runoff volumes associated with increased precipitation rates and intensities could exceed channel conveyance capacity in the Petaluma River and its tributaries.
- Moderate vulnerability is assessed for Sonoma Creek due to increased flood flows and sea level rise. Flooding vulnerability for tributaries Nathanson Creek and Fowler Creek is high. Sea level rise is anticipated to cause more extensive flooding in lower Sonoma Creek impacting marshes near San Pablo Bay and along highways 37 and 121, but is not likely to cause increased flood levels near the upstream urban areas.

Table 9. Vulnerability Assessment Summary for the Flood Management System

System Component	Temperature	Sea Level Rise	Extreme Precipitation	River Flooding	Drought	Wildfire
Central Sonoma Watershed Project (Zone 1A) – Detention Basins	N/A	N/A	High	High	N/A	Moderate
Central Sonoma Watershed Project (Zone 1A) – Triple Box Culvert	N/A	N/A	High	High	N/A	Moderate
Central Sonoma Watershed Project (Zone 1A) – Channels	N/A	N/A	High	High	N/A	Moderate
Petaluma River (Zone 2A)	N/A	High	High	High	N/A	N/A
Sonoma Creek (Zone 3A)	N/A	Moderate	Moderate	Moderate	N/A	N/A
Upper Russian River (Zone 4A)	N/A	N/A	N/A	Moderate	N/A	N/A
Lower Russian River (Zone 5A)	N/A	Moderate	N/A	Moderate	N/A	N/A

A summary of the vulnerability assessment results for the sanitation system are shown in Table 10.

- Russian River WWTP and collection system already experience substantial flooding risk due to high river stage, low lying developments, high infiltration and inflow (I/I), road access, and power outages. Climate change will exacerbate all of these risks due to increased river flooding and extreme precipitation events and will substantially challenge the operability during flood events.
- Sonoma Valley WWTP, collection system, and recycled water system have moderate to high vulnerability to climate change. The collection system suffers from aging sewer lines and

insufficient capacity in some areas which contribute to vulnerability to increased I/I and SSOs during high precipitation events. The WWTP is moderately vulnerable to increasing sea level which will impact the discharge capacity during high tide events and over time at Schell Slough. Similarly, the recycled water system is vulnerable to increased river flooding and sea level rise including tide gate operations in Hudeman Slough and roads and levees adjacent to the wetland management units.

- In the Penngrove Sanitation Zone, the Penngrove Lift Station is highly vulnerable to creek flooding. The lift station is located within the current 100-year floodplain and electrical equipment is near ground floor. Climate change will further increase the extent and frequency of flooding, damage equipment, and limit lift station operation during these events.
- Geyserville WWTP and lift station are located within the Russian River 100-year floodplain and are moderately vulnerable to climate change. Increased river flooding will inundate access roads, causing increased flooding at the lift station, and limit the percolation capacity of the WWTP ponds.
- Moderate vulnerability is assessed for Occidental collection system due to projected increase I/I during flood events causing additional SSO incidences.
- At the Airport Sanitation Zone, moderate climate vulnerability is assessed due to increased creek flooding that inundates the road to North Pond (effluent storage pond), limiting access to the pond and to several valves, as well as the access road to Oceanview Reservoir (an off-site storage pond). In addition, portions of the collection system and the lift station are vulnerable to increasing wildfires associated with climate change.

Table 10. Vulnerability Assessment Summary for the Sanitation System

System Component	Temperature	Sea Level Rise	Extreme Precipitation	River Flooding	Drought	Wildfire
Russian River CSD - WWTP	N/A	N/A	High	High	N/A	Moderate
Russian River CSD - Collection	N/A	N/A	High	High	N/A	Moderate
Sonoma Valley CSD - WWTP	N/A	Moderate/ High	Moderate	Moderate	N/A	Moderate/ Low
Sonoma Valley CSD – Collection	N/A	N/A	High	High	N/A	Moderate
Penngrove SZ – Collection	N/A	Low	High	High	N/A	Moderate/ Low
Occidental County SZ – WWTP & Collection	N/A	N/A	Moderate	N/A	N/A	Moderate
Geyserville SZ - WWTP	N/A	N/A	Moderate	Moderate	N/A	N/A

System Component	Temperature	Sea Level Rise	Extreme Precipitation	River Flooding	Drought	Wildfire
Geyserville SZ – Collection	N/A	N/A	**High**	**High**	N/A	N/A
Airport SZ – WWTP	N/A	N/A	**Moderate**	**Moderate**	N/A	N/A
Airport SZ - Collection	N/A	N/A	**Low**	N/A	N/A	**Moderate**

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SECTION 5

Risk Assessment

5.1 Introduction

The vulnerability assessment considers the relative degree to which each of Sonoma Water's systems is susceptible to, and unable to cope with, the adverse effects of climate and climate change. Following a vulnerability assessment, a risk assessment is often developed to combine the likelihood and consequence of specific climate changes, to assess risk, and to provide focus to the areas in which adaptation measures should be prioritized.

This section describes the approach used to assess risk, specific quantitative analyses that were performed, and summary of the overall risk assessment findings for each of the three Sonoma Water systems.

5.2 Risk Assessment Approach

The risk assessment involves characterizing both the *likelihood* of specific climate changes and the *consequence* of those changes on Sonoma Water's systems. Thus, the risk equation can be described as Risk = Consequence x Likelihood. Following the completion of the draft vulnerability assessment, the Sonoma Water team provided review of the approach for conducting the risk assessment through a series of workshops. This review included the definition and use of risk categories, application of climate and sea level change scenarios, and the extent to which quantitative information could be developed to support the assessment.

For the purposes of the Climate Adaptation Plan, risk was assessed across four categories: (1) system function, (2) financial, (3) social, and (4) governance in order to consider the broad impacts of climate change on Sonoma Water. The risk assessment relied primarily on qualitative information based on Sonoma Water reports, mapping, and system knowledge, but was supplemented with some new quantitative information in a few areas.

5.2.1 Risk Matrix and Rating Scale

> Risk is defined as the likelihood of an event occurring and the potential consequence of the event.

Risks were assessed based on rating the likelihood of occurrence and the potential consequence should it actually occur. Those with a high likelihood of occurrence and high consequence represent a higher priority for adaptative strategies. The likelihood rating was assessed based on an estimation of the likelihood of the relevant climate conditions determined from an ensemble of global climate model projections. While climate model projections are not suitable for translating into specific probabilities, we apply similar definitions of likelihood as used in the

IPCC reports (Mastrandrea et al. 2010, IPCC 2016) when describing likelihood of future climate changes. A standard five-point rating scale, ranging from very unlikely to very likely, was used.

Similarly, a five-point rating scale from negligible to severe was used to evaluate consequences in the four risk categories. The combined rating of likelihood and consequence resulted in a qualitative assessment of risk. Future climate change outcomes that are assessed to be likely to occur and have high consequence on the system received the highest risk ratings.

Table 11 shows the likelihood scale and Table 12 shows the consequence scales used in the risk assessment.

Table 11. Likelihood Rating Scale

Level	Descriptor	Description
1	Very Unlikely	Event is not expected to occur, but occurrence cannot be excluded. Less than 10% of climate projections indicate this occurrence.
2	Unlikely	This event could occur but is not projected to occur in the majority of climate projections. Less than 33% of projections indicate this occurrence.
3	Moderate	Moderate likelihood. More than 50% of climate projections indicate this occurrence.
4	Likely	Likely to occur. Greater than 66% of climate projections indicate this occurrence.
5	Very Likely	Almost certain to occur. Greater than 90% of climate projections indicate this occurrence.

Table 12. Consequence Rating Scales

Level	Descriptor	System Function	Financial	Social	Governance
1	Negligible	No impact to infrastructure or system function.	Financial impact less than $2M.	No adverse human health effects or complaints.	No changes to management required.
2	Minor	Localized impact to infrastructure or system function. No permanent damage. Minor changes or upgrades to facilities may be needed to improve adaptive capacity.	Additional operational costs. Financial impact $2M to $10M.	Short-term disruption to employees, customers, or neighbors. Slight adverse human health effects or general amenity issues. Negative reports in local media.	General concern raised by regulators require response action. Capacity of Sonoma Water to respond on its own.
3	Moderate	Widespread impacts resulting in short-term loss of service and/or damage to infrastructure. Damage recoverable by maintenance and minor repair. Partial loss of local infrastructure.	Financial impact $10M to $25M.	Frequent disruptions to employees, customers, or neighbors. Adverse human health effects. Negative reports in state media.	Investigation by regulators. Changes to management actions required. Capacity to respond requires partnerships, which are in place.
4	Major	Extensive infrastructure impacts or widespread loss of service. Loss of service is not immediately recoverable. Permanent damage to regional infrastructure services.	Major financial impact $25M to $50M.	Permanent physical injury and loss of life may occur from an individual event. Negative reports in national media. Public debate about infrastructure performance. Disproportionate impacts to disadvantaged communities.	Notices issued by regulators for corrective actions. Changes required in management. Capacity to respond requires partnerships which are not yet in place.
5	Severe	Permanent, systemwide damage to infrastructure or failure of system to provide service. Significant changes to major infrastructure required to respond.	Severe financial impact of greater than $50M.	Severe adverse human health effects. Potential for significant loss of life. Emergency response required. Negative reports in international media. Disproportionate impacts to disadvantaged communities.	Major policy shifts. Change to legislative requirements. Full change of management control. Capacity to respond requires substantive action by non-Sonoma Water partners.

5.2.2 Climate and Sea Level Change Scenarios

In order to consider the range of available CMIP5 climate projections, a total of 20 individual daily downscaled climate projections were analyzed for the quantitative aspects of the risk analysis. These climate projections were statistically downscaled using the LOCA statistical daily downscaling method (Pierce et al., 2014) from 10 GCMs at approximately 6 km spatial resolution by the researchers at SIO (Pierce et al., 2014). A list of the GCMs utilized in this study is included in Table 13. The climate projections reflect the use of these GCMs and two representative concentration pathways (RCPs) (i.e., RCP 4.5 and RCP 8.5) in the IPCC's CMIP5 model data set (Taylor et al., 2012), and are recommended for use by the California DWR Climate Change Technical Advisory Group (DWR CCTAG, 2015). LOCA downscaled climate model projections were collected from the SIO.

Table 13. GCMs Downscaled by LOCA

Model Number	Model Name	Model Institution	Model Resolution
1	ACCESS-1.0	Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology	192 x 145 (165 km)
2	CCSM4	National Center for Atmospheric Research	288 x 192 (110 km)
3	CESM1-BGC	National Science Foundation, Department of Energy, National Center for Atmospheric Research	288 x 192 (110 km)
4	CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	192 x 96 (165 km)
5	CNRM-CM5	Centre National de Recherches Météorologiques, Centre Européen de Recherche et Formation Avancées en Calcul Scientifique	256 x 128 (123 km)
6	CanESM2	Canadian Centre for Climate Modeling and Analysis	128 x 64 (247 km)
7	GFDL-CM3	Geophysical Fluid Dynamics Laboratory	144 x 90 (219km)
8	HadGEM2-CC	Met Office Hadley Centre	192 x 145 (165 km)
9	HadGEM2-ES	Met Office Hadley Centre; additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais	192 x 145 (165 km)
10	MIROC5	Atmosphere and Ocean Research Institute at the University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	256 x 128 (123km)

Notes: km = kilometers; models are listed alphabetically; and size of the model's atmospheric grid (number of longitudes by number of latitudes)

Based on these projections, specific climate change scenarios were developed to support water supply, flood management, and sanitation system assessments. When quantitative analyses permitted, all 20 climate projections were utilized. However, for many assessments, such as flood modeling, specific scenarios derived from the projections were used to represent the range of projections.

Specific scenarios were developed for flood modeling analyses, depicting increases in precipitation based on downscaled results from the set of 20 global climate model simulations. Climate model simulated 24-hour precipitation total was processed to develop a scaling factor relative to a baseline period for 19 different watersheds presented in the Russian River Basin HEC-HMS model for three future time periods over early (2016 to 2045), mid (2046 to 2075), and late (2070 to 2099) century. Similar scaling factors were also developed for the watersheds presented in the Santa Rosa Creek HEC-HMS model. These factors were developed for a range of return interval events ranging from about 1-year through 100-years using the L-moments method, which is consistent with NOAA Atlas 14.

Sea level rise scenarios were developed based on Kopp et al (2014) and are consistent with those included in the State of California's Ocean Protection Council (OPC) sea level rise guidance (OPC 2018). Polynomial regressions were developed for the RCP 8.5 and RCP 4.5 scenarios using the Kopp et al (2014) published percentile data for San Francisco centered on 2030, 2060, and 2085 future periods.

Table 14. shows the projected changes in temperature, precipitation, and mean sea level based on likelihood for the mid-century and end-of-century periods.

Table 14. Projected Climate Change Parameters by Likelihood of Exceedance for 2046 to 2075 Period Compared to the 1981 to 2010 Period

Future Period	Change in Parameter	Likelihood of Change Exceeding Specific Value				
		Very Likely (90% Of Projections Exceed)	Likely (66% Of Projections Exceed)	Moderate (50% Of Projections Exceed)	Unlikely (33% Of Projections Exceed)	Very Unlikely (10% Of Projections Exceed)
Mid-Century	Annual Average Temperature (degrees C)	1.4	2.0	2.1	2.3	3.1
	Annual Average Precipitation (%)	-6.0%	-1.3%	5.7%	10.1%	30.8%

Future Period	Change in Parameter	Likelihood of Change Exceeding Specific Value				
		Very Likely (90% Of Projections Exceed)	Likely (66% Of Projections Exceed)	Moderate (50% Of Projections Exceed)	Unlikely (33% Of Projections Exceed)	Very Unlikely (10% Of Projections Exceed)
	100-year 24-hour Precipitation Total (%)	-4.1%	0.1%	4.3%	9.6%	20.3%
	Mean Sea Level (cm) – 2060	22.2	29.3	33.2	36.7	44.8
Late Century	Annual Average Temperature (degrees C)	1.7	2.4	2.9	3.2	4.6
	Annual Average Precipitation (%)	-3.0%	2.1%	7.9%	12.6%	34.2%
	100-year 24-hour Precipitation Total (%)	0.1%	5.6%	10.5%	26.1%	33.0%
	Mean Sea Level (cm) – 2085	34.6	46.6	53.1	60.1	75.5

5.3 Quantitative Analysis to Support Risk Assessment

Following the vulnerability assessment findings and workshops with the CAP team, several areas of uncertainty with respect the magnitude of risk were identified. Specific modeling and technical analyses were developed to gain further insight into the climate vulnerabilities and risks for these areas. Five areas were identified as needing further information to support the quantitative assessment. These included the climate impacts for the following:

1. Russian River hydrologic impacts on water supply management and operations
2. Fire risk and water quality impacts to the water supply system
3. Russian River flooding impacts
4. Santa Rosa Creek flooding impacts
5. Sediment loading impacts on flood system operations

The quantitative analyses that were conducted for each of these areas are briefly summarized in the subsequent sections. Detailed descriptions of these assessments are available in Appendix C – Risk Assessment Special Studies.

5.3.1 Russian River Water Supply Modeling

The goal of this analysis was to conduct water supply modeling of the PVP and Russian River System to quantify impacts of climate change on this integrated water system. Hydrological information based on the 20 downscaled climate projections were selected from available USGS BCM hydrological model results. These climate and hydrologic projections were used to adjust inflow time series and to adjust water demands in the PVP Fortran Model ER2.5 and Russian River HEC-ResSim model. The models used in this assessment are identical to those used by Sonoma Water in the Fish Flow Project Draft Environmental Impact Report (SCWA, 2016).

Hydrological adjustments to reflect future climate change consisted of routed streamflows for 10 locations that are required as input to the Russian River Basin HEC-ResSim model and two locations in the Eel River Basin that are used for the PVP operations model. Due to inherent limitations in the downscaling methods, meteorological inputs, and BCM model, the resulting streamflows were adjusted to remove historical bias before being applied for future simulations in the models.

Adjustment factors were also applied to historical consumptive use estimates to reflect future changes in potential evapotranspiration and open water surface evaporation. Existing Variable Infiltration Model (VIC) model results for potential evapotranspiration (using short grass as a reference crop) and open water surface evaporation were used to develop these demand and evaporation adjustment factors. In addition, due to the significance of frost days on water depletions on Russian River, a method was developed to translate projected changes in frost days to increases in river demand.

PVP Fortran Model ER2.5 and Russian River HEC-ResSim model simulations were developed for a historical baseline and for future climate change conditions. PVP and Russian River HEC-ResSim model simulations were evaluated and summarized for the historical simulations and climate change conditions, and results of model simulations under historical and climate change conditions across the key locations over the Russian River were documented.

Modeling results were evaluated for changes in future streamflow, reservoir storage, and water delivery as compared to a no climate change condition. Based on these modeling results the following findings are relevant:

- Annual and 3-year streamflow on the Russian River downstream of the Dry Creek confluence is projected to become even more variable in the future with climate change. The results indicate the potential for both lower streamflows during the drier years (lower percentiles) and higher streamflows during wetter years (higher percentiles). While most projections indicate potential increases in streamflow, several projections suggest conditions drier than historical record for the lowest 10 percent of years. It should be noted that multi-year drought prediction in GCMs is still not a robust feature.

- Most future projections project decreases in Lake Sonoma end-of-September storage across all exceedance values due to projected increases in water demand in the basin and by Sonoma Water contractors. However, changes in the lowest 30 to 40% of years are largely driven by climate change and some projections suggest lower storage conditions than that under historical hydrology. All projections indicate an incidence of Lake Sonoma end-of-September storage less than 150,000 AF and five projections indicate storage lower than 100,000 AF.
- Sonoma Water diversion under both baseline and future conditions appears relatively robust in the face of changing climate and hydrology. Due to increases in water demand, the Sonoma Water diversion is increased in all simulations. However, simulations indicate similar delivery capability (meeting contractor demand). The Sonoma Water system appears to be able to adapt to the climate and hydrologic changes projected in the scenarios.

5.3.2 Fire Risk and Water Quality Modeling

The role of increasing fire risk and its impacts on river and intake water quality was identified as a need for the improved quantitative information. An innovative analysis was developed to better understand the probability, location, and extent of fire risk; and to assess impacts on intake water quality. This analysis integrates fire risk modeling, hydrologic modeling, and water quality estimates (primarily organic carbon) to assess impacts to water supply operations. The BCM hydrology model and landscape-scale fire modeling has been used to assess to fire risk and water quality risk.

Daily runoff volumes in each of the 19 study area watersheds were simulated by HEC-HMS under baseline and early, mid, and late future climate conditions. Potential future fires of low, medium, and high severity in each climate scenario were represented by the fraction of watershed area burned. Geographic specification of future fire severity by watershed was accomplished using change in area burned in wildfire scenario projections from Cal Adapt (Cal Adapt Wildfire Tool, 2018). Percent difference in area burned between historical and future periods for eight climate projections for nine HUC-10 watersheds that covered the study area were used to develop change factors to apply to baseline burn severities to include the effect of climate change. For each future time period, climate change factors were considered to be uniform for low, medium, and high burn severities. Pre-fire flows in each watershed were translated to post-fire flows using severity of the potential future fires based on the USGS Regression Methodology (Foltz, Robichaud, and Rhee, 2009).

The sediment and organic carbon (DOC and TOC) relationship with hydrology and watershed changes post-fire was characterized. The hydrologic and sediment/carbon response to climate/land disturbance conditions were also developed. The organic carbon loading at the Russian River water supply intakes was estimated under historical and future conditions. The carbon loading (TOC and DOC) in each watershed was calculated from streamflow and concentration relationships developed based on observed data, and then summed to create systemwide loading at the Russian River Diversion. Russian River organic carbon was related to caisson organic carbon with appropriate attenuation and filtration based on historical relationships. Results of potential changes in fire frequency, hydrologic conditions, and organic carbon at water supply intakes were documented, and the potential for significant water supply impacts due to water quality were estimated.

While this modeling analysis should be considered only approximate at this point in the development, it did suggest important findings that should be considered in both current and future climate risks. The following observations are drawn from this quantitative analysis:

- Wildfire risks are found to be increasing throughout the contributing watersheds to the Russian River. Both the extent and severity of wildfire burn is expected to increase under future climate change associated with earlier drying of the watershed, extended dry season length, and substantial combustible fuel in the predominantly privately owned lands.
- Post-wildfire extreme precipitation events (flood-after-fire) have the ability to substantially increase sediment and carbon runoff from the disturbed watershed lands. Total and DOC in the Russian River post-fire may increase by more than 10 times the concentration under an undisturbed (non-fire) condition.
- The alluvial aquifer underlying the Russian River transmits water to the Mirabel and Wohler collectors and substantially reduces the organic carbon in the water supply. Following the 2020 Walbridge Fire, Sonoma Water conducted a robust water quality monitoring program. Some changes were noted in surface water quality, but no impacts were detected in the collector well water. However, water year 2020 was dry and no significant runoff events followed. The analysis included here suggests that under more severe hydrologic conditions water quality could be challenged. This analysis suggests that DOC at the collectors may increase by up to five times during large post-fire runoff events. Several simulated post-fire runoff events produced estimated DOC concentrations greater than the disinfection byproducts threshold which is 2 mg/L for chlorination. While this condition has not yet been experienced after recent wildfires, this analysis suggests that the flood-after-fire risk is high depending on the location and timing of coincident wildfire and extreme precipitation.

5.3.3 Russian River Flood Modeling

Modeling was conducted to support a more refined assessment of Russian River flood impacts under future climate change. The primary objectives were to assess potential changes in Russian River flood frequencies at the Wohler and Mirabel water supply facilities and within the Russian River County Sanitation District facilities.

Historical and future climate change hydrologic time series were developed for the existing Russian River HEC-RAS models for the lower Russian River. HEC-HMS and HEC-RAS models were used from the Analyzing Flood Risk for FIRO in the Russian River watershed using HEC-WAT. The downstream coastal boundary of the Russian River HEC-RAS was modified to reflect increases in mean sea level at the estuary. Changes in flood flow and stage frequencies were determined and impacts were then evaluated at the Mirabel and Wohler facilities. Additionally, changes were also evaluated for flood (flow and stage) frequencies and impacts at the Russian River Sanitation Zone.

The change in elevation characterized by a future 1986-magnitude flood event under three future climate scenarios was examined along each river mile for the Russian River beginning with the mouth and ending with the East Fork of the Russian River. Key findings from this analysis are summarized:

- Under mid-century scenarios, changes in peak flood elevations greater than 3 feet occur in the lower Russian River, with the largest increases shown in the reach between the confluence with Mark West Creek and Austin Creek. Under the late-century scenarios, changes in peak flood elevation increase dramatically, with the largest magnitude of changes exceeding 6 feet. Across all scenarios, river miles between Geyserville and Big Sulphur Creek and between river mile 82 and the East Fork of the Russian River show the smallest magnitude of changes.
- Most infrastructure at the Wohler and Mirabel diversion facilities (e.g., collectors, access roads) will be experience substantial inundation under future climate change extreme events. All collector critical elevations will be exceeded under future extreme events and flooding may cause structural damage to facilities and will very likely flood the collectors through the access doors.
- The Russian River near Cloverdale is expected to exceed its channel capacity during the 100-year event. FEMA mapping of the 100-year and 500-year floodplains indicate that expected inundation extends over fields on the eastern bank and over light industrial areas, including the All-Coast property, and fields on the western bank. Sediment loading from Big Sulphur Creek is expected to increase and impact the riverbed significantly.
- Hazards to flood conveyance in Zone 5A include increased precipitation intensity and associated runoff, bank erosion and bank failure with higher runoff, and increased sediment transport in the Russian River and tributaries. Most populated areas in the lower Russian River are located in the 100-year floodplain, including communities of Guerneville, Monte Rio, Villa Grande, and Duncan Mills.
- Management of the freshwater lagoon in the estuary can be affected by changes in the timing and amount of runoff as well as sea level rise. Projected sea level rise and increased wave action will lead to changes in the beach profile and the effectiveness of the natural sand berm that currently closes the estuary on an annual cycle. Changes in flood stage in the lower river associated with sea level rise is most pronounced up to river mile 4 but decreases to nearly no change by river mile 10.

5.3.4 Santa Rosa Creek Flood Modeling

Flood management operations on Santa Rosa Creek were assessed to be highly vulnerable to climate change. To better understand climate-flood-related vulnerabilities along the Santa Rosa Creek flood management system, a modeling study was performed covering the extent of the watershed, detention facilities, hydraulic control facilities, culverts, and flood channels.

The flood modeling analysis on Santa Rosa Creek made use of existing HEC-HMS and HEC-RAS models. Precipitation time series for 69 HEC-HMS watersheds was developed to reflect future climate change. The climate and hydrologic projections were translated into modified design storms to reflect projected changes in extreme precipitation. HEC-HMS modeling using these modified design storms was also performed to investigate detention basin operations and vulnerability. Finally, two-dimensional HEC-RAS modeling, using the existing model developed by ESA, was employed to investigate flood flows and inundation throughout Santa Rosa Creek (SCWA, 2017).

Modeling results for simulations under historical and climate change conditions were evaluated at key locations in order to inform the risk assessment. The flood risk was found to be high in several areas of the watershed. The key findings are summarized:

- Flood conveyance channels along Santa Rosa Creek and its tributaries provide flood protection for downtown Santa Rosa. The triple box culverts along Santa Rosa Creek and Matanzas Creek, which route these two creeks through downtown Santa Rosa, are of particular concern. The primary hazard for these culverts is their inability to convey flood flows much larger than a 10-year event. High resolution hydraulic modeling conducted by ESA as part of the Santa Rosa Creek Hydrology and Hydraulics Study (SCWA, 2017) indicate the inability of these culverts to pass flood flows above a certain return interval event between 10 and 25 years. These results are in stark contrast to assumptions made by FEMA in the development of local Flood Insurance Rate Maps.
- Analysis of inundation depth results suggest substantial inundation throughout downtown Santa Rosa. Overbank flow is simulated from Santa Rosa Creek between the Triple Box Culverts and Brush Creek, and from Matanzas Creek between the triple box culvert and Spring Creek for each return period simulated. Overbank flow exceeding 1,000 cubic feet per second (cfs) is predicted for the 25-year event, nearly 4,000 cfs for the 50-year event, and over 6,000 cfs for the 100-year event.
- Peak flow in Santa Rosa Creek below Brush Creek is projected to increase by about 40% under mid-century climate changes and over 60% by end-of-century changes. By late century, the current 25-year event will be closer to a 5-year event, and the 100-year event will be best represented as a 10-year event.
- The nonlinear nature between flood flow and sediment transport could exacerbate future flood control channel maintenance, as expected increases in precipitation intensity drive increases in runoff and increases in sediment transport.
- Detention basins in the upper reaches of Santa Rosa Creek and tributaries will be substantially impacted by greater flow volumes associated with climate change. These reservoirs serve a vital role in reducing flood risk for the City of Santa Rosa by attenuating flows on the largest watersheds draining through Santa Rosa. The basins were designed for a 100-year event and are designed for passive operation. Increases in runoff events, sediment, and debris will reduce the effectiveness of these basins to attenuate peak flows

and could lead to overtopping of the dam. Matanzas Creek Reservoir is the most at risk due to its earthen embankment that serves as the emergency spillway.

- Sedimentation is expected to increase under all future climate scenarios. The diversion structure on Santa Rosa Creek, the vortex drain structure under Montgomery Drive, and the diversion structure on Spring Creek and box culvert are all susceptible to sedimentation and/or woody debris reducing hydraulic performance.

5.3.5 Sediment Loading Estimates

One of the major responsibilities of Sonoma Water's Stream Maintenance Program is associated with sediment management in Zone 1A. The goal of this analysis was to improve understanding of the distribution of sediment load, and potential changes in sediment loading in this zone.

Historical sediment transport was correlated to historical hydrology based on maintenance records and local stream gauges. A GIS analysis was also conducted to relate gauged to ungagged streams. To estimate future sediment transport volumes for normalized and future hydrology, HEC-RAS modeling results from analyses for Santa Rosa Creek were used. Flow return periods of 2 years and 10 years, as well as Early, Mid, and Late Future climate scenarios were developed for this model.

To estimate sediment loading, the Bedload Assessment in Gravel-bedded Streams (BAGS) program was used from the U.S. Forest Service and STREAM System Technology Center. BAGS employs bedload transport equations based on channel geometry, reach-average slope, and bed material grain size (Pitlick et al., 2009). The BAGS data was used to develop bedload transport estimates within the Santa Rose Creek based on the HEC-RAS model output. The Parker (1990) and Wilcock and Crowe (2003) methods were applied within BAGS. The percent change in bedload sediment transport was estimated at three stations (cross-sections) within the Santa Rosa Creek for the future climate scenarios compared to the baseline historic climate scenario. Stations 11342 and 13677 are on Santa Rosa Creek downstream of Patterson Creek, and station 52535 is on Santa Rosa Creek just downstream of Brush Creek.

Several key observations derived from this analysis are summarized:

- Results vary based on the method and grain size considered. However, bedload transport increases in across all methods used.
- Station on the Santa Rosa Creek downstream of Brush Creek (52535) generally shows the largest percent changes from baseline conditions. Station 11342 and 13677 are estimated to have less than half the loading of station 52535.
- Under the mid-century scenarios, bedload transport at station 52535 is projected to increase by up to 25 to 55% for the 2-year event and 41 to 76% for the 10-year event. Bedload transport could increase by more than 150% for the late-century 10-year event.

- Planning for substantial increases in sediment removal or management is necessary for sediment management maintenance activities within the Sonoma Water Stream Maintenance Program.

5.4 Risk Assessment Summary

While some elements of the risk assessment were evaluated quantitatively, much of the assessment was performed qualitatively. The risk assessment involved characterizing both the *likelihood* of specific climate changes and the *consequence* of those changes on Sonoma Water's systems. The likelihood of occurrence was assessed based on the rating scale. The consequence, and subsequently risk, was assessed separately across each of the four categories (system function, financial, social, and governance).

Figure 12 provides a summary of the risk assessment for each of the major components of the water supply, flood management, and sanitation systems. In this figure, individual risk scores for each of the four categories are shown as a stacked, or total, risk score. In many cases, it was found that the scores across categories were highly correlated. For example, a high risk in system function often correlated to a high financial and governance risk. While this was not universally the case, there was a strong correlation or risk ratings for many of the facility components evaluated. Further refinement to the risk ratings may provide more distinction between risk categories but is not expected to change the overall risk picture.

System components that have high risk across multiple categories are shown as a longer length bar in Figure 12. Conversely, those system components with lower risk scores are shown as shorter length bars. The areas of high to moderate risk ratings have been summarized in Table 15.

Figure 12. Risk Assessment Summary Considering Four Risk Categories (5=high risk, 1=low risk)

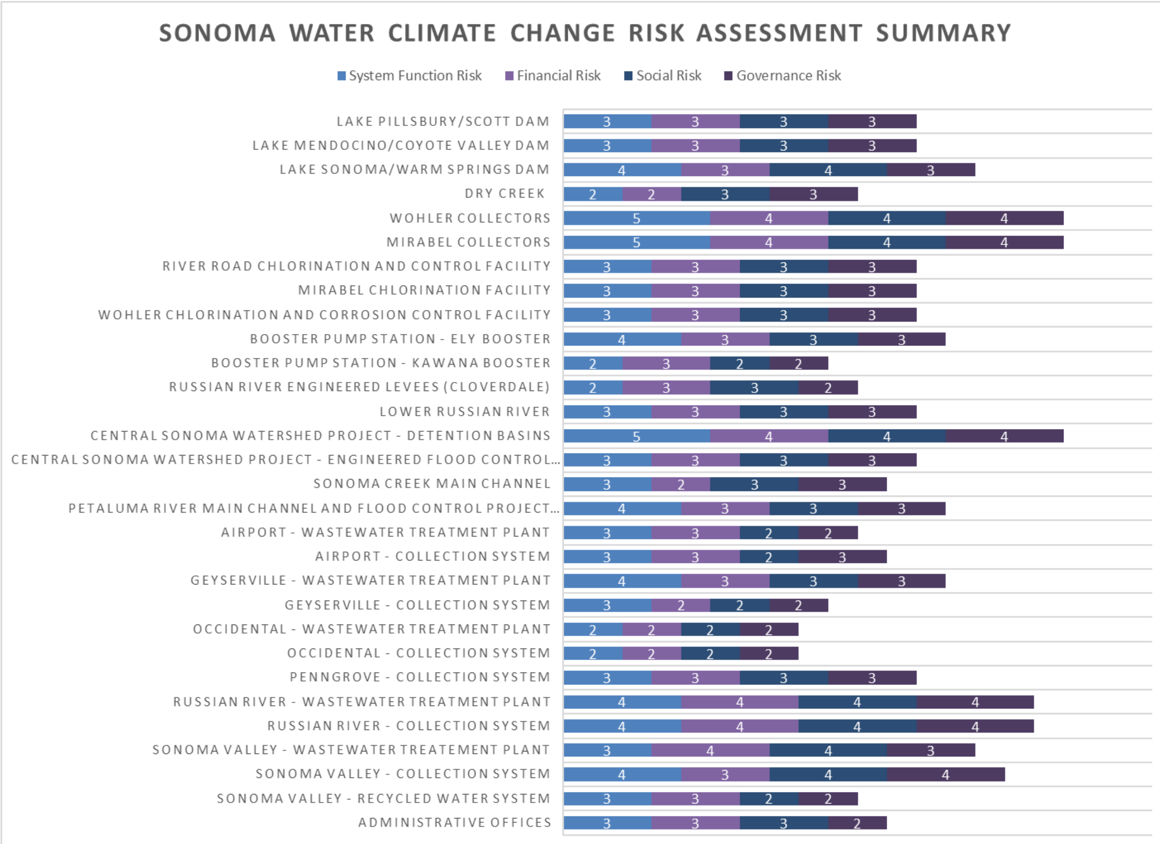

Table 15. Risk Assessment Summary

System	Risk Overview
Water Supply System	PVP and Lake Mendocino were considered moderate risk due to their sensitivity to modest changes in hydrology and importance in providing flows for the upper Russian River for instream flows, flood control, and buffering impacts to Lake Sonoma. Lake Sonoma was assessed to have moderate/high risk primarily due to the drought and wildfire risks. The importance of the facility for providing water supply, hydropower, and ecosystem benefits led to high consequences should the operation be restricted. Wohler and Mirabel diversion facilities have high risk across all categories. These facilities and operations are susceptible to flooding, and wildfire/post-fire threats. The dependence on natural watershed processes (regulated flow, natural filtration, etc.) is a strength of the water supply system, but any failure of these systems or risk to the facilities themselves pose high risks. Financial, social, and governance risks would be considered high if these facilities were to be operated at limited capacity. River Road Chlorination Facility, Wohler Chlorination and Corrosion Control Facility, and Mirabel Chlorination Facility are assessed with moderate risk. While they may suffer temporary impacts due to climate change, redundancy of operations between facilities may reduce overall risk. Ely Booster Pump Station is considered high risk with respect to system function.

System	Risk Overview
Flood Management System	Highest risk is related to flood management facilities in Central Sonoma Watershed (Zone 1A). The existing facilities and operations are inadequate to manage flood risks for City of Santa Rosa under historical hydrology and will be further challenged under future climate change. Impact to the largest city in the county and population centers presents a social and governance risk. Associated financial risks are also high. Petaluma River and tributaries (Zone 2A) and Sonoma Creek (Zone 3A) are assessed with moderate risk due to increased flooding potential with extreme precipitation and sea level rise. The lower Russian River is assessed as moderate risk due to the high likelihood of increased community flooding and impacts to the management of the Russian River Estuary under future sea levels.
Sanitation Systems	Russian River WWTP and collection system represent a high risk under both current and future climate conditions. Future increases in flooding and inability to effectively treat wastewater under high I/I condition represent risks in system function, social, and governance categories. Sonoma Valley WWTP and collection system are assessed as moderate risk to climate change. The climate impacts of increased I/I and sea level rise will have moderate impacts on Sonoma Valley, but the importance of the system for the region implies higher consequences in financial, social, and governance categories. Penngrove Lift Station is assessed with moderate risk due to creek flooding. Geyserville WWTP and lift station are also assessed with moderate risk. These facilities and their operation will be impacted due to increased river flooding and may be unable to adequately treat and dispose wastewater inflows.

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SECTION 6

Adaptation Strategy Development

6.1 Introduction

After completion of the vulnerability and risk assessments, the CAP team had gained an improved understanding of the projected climate changes, impacts to Sonoma Water's systems, and the areas of greatest risk. In order to reduce or manage these future risks, Sonoma Water staff considered a range of adaptation concepts and strategies including infrastructure, operational, and policy measures. A broad range of concepts were considered across all three systems and were evaluated based on specific criteria to capture economic, environmental, and social attributes.

This section describes the approach used to develop the adaptation concepts, the evaluation criteria used to characterize the concepts, and provides a summary of the results of the evaluation.

6.2 Approach for Adaptation Concept Development and Evaluation

The Sonoma Water CAP team conducted two, multiple-day workshops with Sonoma Water staff to focus on collecting ideas on how to best address various vulnerabilities and risks. Separate workshops were held to address the water supply, flood management, and sanitation system risks. Participants included Sonoma Water management, finance, engineering, operations, maintenance, and environmental staff, along with subject matter experts from the Jacobs consulting team. Several individuals participated in all workshops to ensure that cross-cutting ideas were captured.

The workshops consisted of two main steps:

1. Ensure that the participants understood the moderate and high vulnerable/risk areas.

2. Collect a wide range of ideas based on the participant's expertise and understanding of the system.

Participants were asked to think uninhibitedly and to not limit ideas due to potential implementation complexities. Ideas were generated during the workshops and compiled throughout subsequent sessions. During the course of the adaptation strategy workshops, over 250 initial ideas or concepts were documented. After review of the ideas and removal of redundancies, the CAP team performed a synthesis which resulted in nearly 80 individual project concepts. Each project concept was specifically aligned to address one or more vulnerabilities.

After compiling the list of project concepts, an evaluation was performed on each in order to provide a characterization with respect to criteria such as cost, feasibility, implementation timing and complexity, permitting, legal, environmental, and jurisdiction. The complete list of evaluation criteria is shown in Table 16. For each criterion, a rating scale of “A” through “E” or 1 to 5 was used to characterize the project concept related to the specific measure. The CAP team provided project concept review and evaluation. The characterization of project concepts in this fashion allowed the CAP team to distinguish between concepts and ascertain where some rated better than others in a specific criterion.

Table 16. Evaluation Criteria Used to Characterize Adaptation Concepts

Criteria	Description	A (1)	B (2)	C (3)	D (4)	E (5)
Cost	Estimate of capital and annual costs.	< $1M	< $4M	< $10M	< $25M	> $25M
Timing	Estimate of time required before project could be implemented considering planning, design, permitting, and implementation.	< 2 years	< 5 years	< 10 years	< 15 years	> 20 years
Environmental	Anticipated positive or negative impacts on the natural environment.	Significantly positive impacts are likely to exist, and negative impacts are not readily apparent	Moderately positive impacts are anticipated at some locations while other locations may or may not have negative impacts of a lesser degree	Option does not have an impact or impacts are expected to be neutral	Moderately negative impacts are anticipated at some locations while other locations may or may not have positive impacts of a lesser degree	Significant negative impacts are likely to exist, and positive impacts are not readily apparent
Feasibility	Maturity of the concept and technical ability to implement.	Regularly implemented in USA at scale proposed	Occasionally implemented somewhere in the world at similar scale	Regularly implemented but at smaller scales	Occasionally implemented somewhere in the world or has not been done, but peer review articles indicate promise	Has not been done and no peer review articles exist or they indicate challenges

Criteria	Description	A (1)	B (2)	C (3)	D (4)	E (5)
Energy	Estimated change in energy required to implement and operate.	Requires no additional energy, or results in net positive generation	Minor increases in energy use (less than 5%)	Modest increases in energy use (less than 15%)	Large increases in energy use (less than 30%)	Major changes in energy use (greater than 30%)
Permitting/ Legal	List of permits required and status if option has begun permitting process.	Does not require an EIR or other major permits	Requires an EIR or other major permits, but similar projects of this scale have been approved in the past 20 years	Requires an EIR or other major permits, but similar projects of smaller scale have been approved in the past 20 years	Requires an EIR and no precedent exists for the option	Requires an EIR and similar options have been declined during the permit process
Social	Description of positive or negative socioeconomic effects.	Significantly positive impacts are likely to exist, and negative impacts are not readily apparent	Moderately positive impacts are anticipated at some locations while other locations may or may not have negative impacts of a lesser degree	Option does not have an impact or impacts are expected to be neutral	Moderately negative impacts are anticipated at some locations while other locations may or may not have positive impacts of a lesser degree	Significant negative impacts are likely to exist, and positive impacts are not readily apparent
Jurisdiction	Primary jurisdiction for implementation.	Primarily involves Sonoma Water facilities and control	Requires Sonoma Water and other County department actions	Requires Sonoma Water Contractor actions	Requires utility or state agency/ federal actions	Requires private citizens and landholder actions

6.3 Adaptation Concepts

The synthesis of adaptation concepts resulted in nearly 80 individual project concepts. These comprise of 32 concepts to address water supply risks, 25 concepts to help address flood management risks, and 20 concepts for sanitation risks due climate change. Within each of Sonoma Water's systems, adaptation concepts were organized into four or five categories related to the concept approach to facilitate review. The types and listing of project concepts for each of Sonoma Water's systems is included in the next sections. Project concept descriptions and evaluation details are provided in Appendix D – Adaptation Concepts.

6.3.1 Water Supply System

The complete list of adaptation concepts for the water supply system synthesized from the workshop ideas is shown in Table 17. Water supply system adaptation concepts include various types of responses and mechanisms to address the risks, ranging from major infrastructure improvements to the advancement of science and data collection. The water supply adaptation concepts can be grouped into five adaptation strategies that reflect a unique approach toward addressing the climate vulnerabilities and risks. A brief description of the water supply system adaptation strategies and representative concepts is included.

- **Improve Resilience of Water Supply Infrastructure**

  These concepts focus on either protection or adapting existing infrastructure or developing new water infrastructure. Project concept examples include floodproofing of Ely Booster Station and evaluating an alternative Russian River water treatment facility.

- **Increase Operational Flexibility of Water Management Facilities**

  These concepts focus on operationalizing reservoir operation changes, improving access to water management facilities, or optimizing transmission system storage. Project concept examples include operationalizing FIRO in Lake Mendocino and Lake Sonoma, installing operational backup power at River Road chlorination facility, and improving access to Wohler and Mirabel collectors.

- **Improve System Integration and Regional Resilience**

  Focus of these concepts is on integration of the regional systems (natural or developed) to take advantage of the interconnected responses, shared benefits, and common risks. Project concept examples include strategic engagement in PVP, increasing conjunctive use groundwater and surface water along the transmission system, and increasing system storage at Lake Stafford-Soulajule Reservoir.

- **Improve Watershed and Natural Resources Management**

  These adaptation concepts seek to address vulnerabilities through improvements in watershed and natural resources management. These concepts focus on changes in the management of water and land through natural processes. Project concept examples include increasing stormwater detention and recharge in the watershed, improving water and land management in water quality sensitive watersheds, and improving forest and wildland management.

- **Advance Science and Technology**

  These adaptation concepts seek to address vulnerabilities through the advancement and application of science and technology. These concepts focus on increasing the use of weather forecasting and climate prediction, developing and enhancing models, and improving data collection and monitoring. Project concept examples include operationalizing the AQPI support tool, furthering climate and weather modeling, and supporting groundwater and river hydraulic models.

Table 17. Water Supply Adaptation Concepts Synthesized from Workshops

System	Project Concept
Water	Protect Critical Infrastructure at Wohler and Mirabel Collectors
Water	Floodproof Ely Booster Station
Water	Evaluate Alternative Russian River Water Treatment
Water	Second Storage Tank at Kastania
Water	Bypass Ely Booster
Water	Operationalize Lake Mendocino FIRO
Water	Improve Access to Water Diversion Facilities (Collectors)
Water	Increase Seasonal Conjunctive Use or Transmission System Storage
Water	Install Operational Backup Power at River Road Chlorination Facility
Water	Improve Management in Water Quality Sensitive Watersheds
Water	Increase Groundwater Sources Located Along Aqueduct as Emergency Supply
Water	Increase System Storage at Lake Stafford-Soulajule Reservoir
Water	Increase Production and Use of Recycled Water
Water	Water Resiliency Study and Water Supply Action Strategy Implementation
Water	Increase Water Use Efficiency
Water	Rate Structures to Adapt to Increased Variability and Volatility in Sales
Water	Strategic Engagement in PVP Activities
Water	Increase Stormwater Detention and Recharge in Watershed
Water	AQPI Operational Support Tool

System	Project Concept
Water	Climate and Weather Modeling
Water	Support GSFLOW and Hydrology/Hydraulics Modeling
Water	Protect Kawana Booster Station
Water	Expand or Reoperate Wilfred Booster
Water	Raise Coyote Valley Dam
Water	Fish Flow Project (Modification of D-1610)
Water	Lake Sonoma FIRO
Water	Lake Mendocino Variable Gates
Water	Flood-Managed Aquifer Recharge on Russian River (Alexander Valley)
Water	Improve Water Demand Management on Russian River
Water	Protect Mirabel and Wohler Power Lines (relocate/undergrounding)
Water	Expand On-Site Controls to Address Centralized Control System Vulnerabilities
Water	Mobile Operational Control System

6.3.2 Flood Management System

The complete list of adaptation concepts for the flood management system synthesized from the workshop ideas is shown in Table 18. Flood management system adaptation concepts include various types of responses and mechanisms to address the risks, ranging from new or improved infrastructure to integrated flood forecasting and operations. The flood management adaptation concepts can be grouped into five adaptation strategies that reflect a unique approach toward addressing the climate vulnerabilities and risks. A brief description of the flood management system adaptation strategies and representative concepts is included.

- **Develop and Implement a Regional Flood Management Strategy**

  Adaptation concepts that seek to develop a regional approach to improving flood management. These concepts include those focused on increasing flood detention, improving flood conveyance, or increasing regional flood attenuation through emphasizing non-physical approaches (natural infrastructure). Project concept examples include the development of a regional flood management strategy, updating check dam best management practices (BMPs), modification of Spring Lake auxiliary spillway, and implementing home/parcel level incentives to promote green infrastructure development in targeted watersheds.

- **Improve and Maintain Flood Management Infrastructure**

  Adaptation concepts that seek to improve and maintain existing flood management infrastructure. These concepts could focus on improving the restoring natural channel alignments, improving sediment control and maintenance, and improving stream maintenance practices to capture sediment more efficiently. Project concept examples include supporting restoration of the natural flood detention capacity of the Laguna through upper and lower watershed actions, acquiring and using Middle Reach Hanson gravel ponds, and a sediment source study to identify "hot spots" and recommend source control measures.

- **Improve Operations of Flood and Water Management Facilities**

  Adaptation concepts that seek to improve the operations of flood and water management facilities. The focus of these concepts is on expanding and operationalizing forecast to inform operations and optimizing operations to adapt to extreme weather and hydrology. Project concept examples include operationalizing FIRO for Lake Mendocino and Lake Sonoma, the removal of the triple box culvert and widening of the channel on Santa Rosa Creek, and expanding operational control of facilities at Spring Lake and Matanzas Creek.

- **Improve Watershed Management**

  These adaptation concepts seek to address flood-related vulnerabilities through improvements in watershed management. These concepts focus on changes in the management of water and land through natural processes, improving watershed resilience to wildfire, attenuating watershed runoff, and integrating land and vegetation management. Project concept examples identification and management of lands at high risk to wildfire and flood-after-fire impacts, implementing flood-managed aquifer (Flood-MAR) projects to promote recharge, and engagement with landowners and land managers to positively influence management practices that increase flood detention/attenuation.

- **Advance Science and Technology**

  These adaptation concepts seek to address vulnerabilities through the advancement and application of science and technology. These concepts focus on increasing the use of weather forecasting and application, increasing system knowledge of flood risks, and developing and enhancing flood models. Project concept examples include operationalizing the AQPI support tool, furthering climate and weather modeling for extreme precipitation and wildfire assessment, and model development for flood hydrology/hydraulics and sediment transport.

Table 18. Water Supply Adaptation Concepts Synthesized from Workshops

System	Project Concept
Flood	Increase In-Channel and Off-Channel Flood Detention Basins (Zone 1A, 2A, 3A)
Flood	Update Check Dam BMPs for Upper Watershed (Zone 1A) and Petaluma River (Zone 2A)

System	Project Concept
Flood	Implement Upper Nathanson Detention (Zone 3A)
Flood	Channel Expansion and Increase Channel Maintenance (Zone 2A)
Flood	Channel Expansion and Increase Channel Maintenance (Zone 4A)
Flood	Adaptive Estuary Management and Flood Risk Management (Zone 5A)
Flood	Improve Operational Control of Outflows from Spring Lake
Flood	Implement Green Infrastructure and Home/Parcel Level Control or Incentives
Flood	Initiate Discussion of Regional Flood Management Strategy
Flood	Regionally Address Lower Sonoma Creek Flooding (Zone 3A)
Flood	Promote Flood and Brackish Tolerant Crop Growth (Zone 2A and Zone 3A)
Flood	Improve Laguna Restoration (Zone 5A)
Flood	Acquire and Use Middle Reach Hanson Gravel Ponds
Flood	Sediment Source Study for Improve Sediment Management
Flood	Raise Coyote Dam and Improve Sediment Management (Zone 4A)
Flood	Forecast-Informed Operations to Flood Control Structures & Sediment Basins
Flood	Widen Santa Rosa Creek and Remove/Daylight Triple Box Culvert
Flood	Improve Spillway at Matanzas
Flood	Implementation of Forecast-Informed Operations for Lake Mendocino
Flood	Increase Watershed Resilience to Wildfire
Flood	Flood-Managed Aquifer Recharge (Flood-MAR)
Flood	Integrate Flood Management and Land Management
Flood	AQPI Operational Support Tool
Flood	Climate and Weather Forecasting
Flood	Support and Develop Hydrology/Hydraulics and Sediment Modeling

6.3.3 Sanitation System

The complete list of adaptation concepts for the sanitation system synthesized from the workshop ideas is shown in Table 19. Sanitation system adaptation concepts include various types of responses and mechanisms to address the risks, ranging from major system efficiency improvements to planning and policy. The sanitation adaptation concepts can be grouped into five adaptation strategies that reflect a unique approach toward addressing the climate vulnerabilities and risks. A brief description of the sanitation system adaptation strategies and representative concepts is included.

- **Improve Efficiency of Collection Systems**

  Adaptation concepts that seek to improve the efficiency of collections systems. These concepts could either focus on reducing collection system infiltration and inflow or upgrading lift stations to improve hydraulic efficiency. Project concept examples include expanding valving on the Russian River collection system, implementing an infiltration/inflow monitoring and reduction program for Sonoma Valley and Russian River collection systems, protecting Penngrove Lift Station from flooding, and updating collection system design standards with specific consideration of climate change.

- **Improve Wastewater Treatment Reliability**

  Adaptation concepts that seek to improve the reliability of wastewater treatment under future climate change. These concepts could focus on reducing hydraulic constraints at wastewater treatment plants and upgrading plant capacities. Project concept examples include eliminating hydraulic constraints at Sonoma Valley WWTP due to sea level rise, developing inline or off-line collection system storage to reduce peak inflows to treatment plants, and flood protection of critical lift stations and management unit ponds on the reuse supply delivery system.

- **Expand Opportunities for Reuse**

  Adaptation concepts that seek to expand opportunities for reuse. The focus of these concepts is on expanding delivery of wastewater effluent to reduce the potential for discharge permit compliance and increase the resilience of the regional water supplies. Project concept examples include purchasing additional land at the Russian River WWTP for summer irrigation, expansion of partnerships to increase reuse delivery (irrigators, groundwater recharge, and North Bay Water Reuse Program – Phase 2 projects) and developing a long-term plan for the closure of Occidental WWTP and conveyance of wastewater to the Airport WWTP or to Graton WWTP.

- **Improve Sanitation System Operations**

  These adaptation concepts seek to address vulnerabilities through improved sanitation system operations of existing facilities. These concepts focus on improving operating procedures and improving real-time operational control. Project concept examples include improving access to and emergency staffing at the Geyserville and Russian River WWTPs during floods and implementing SCADA Master Plan pilots for better automation at Sonoma Valley and Russian River WWTPs.

- **Establish Integrated Wastewater Planning and Policy**

  These adaptation concepts seek to address vulnerabilities through wastewater planning and policy changes. Project concept examples include establishing sanitation level planning to develop a strategic plan and standards, evaluating post-fire impacts to sanitation systems, and establishing property partnerships and ordinances to reduce overflows.

Table 19. Water Supply Adaptation Concepts Synthesized from Workshops

System	Project Concept
Sanitation	Expand Valving of Russian River Collection System
Sanitation	Study Potential for Vacuum System for Russian River Collection
Sanitation	Implement Inflow/Infiltration Monitoring and Reduction Program
Sanitation	Eliminate Sonoma Valley WWTP Hydraulic Constraints due to Sea Level Rise
Sanitation	Improve or Adapt Operations of Reuse Supply Delivery to Management Units
Sanitation	Expand Opportunities for Sonoma Valley Reuse
Sanitation	Penngrove Lift Station Flood Protection
Sanitation	Revise Collection System Design Standards
Sanitation	Increase Operable Capacity at Russian River WWTP
Sanitation	Purchase Additional Land at Russian River WWTP for Summer Irrigation
Sanitation	Increase Flood Protection at Sonoma Valley WWTP
Sanitation	Establish Sanitation Level Planning
Sanitation	Implement SCADA Master Plan and Automation
Sanitation	Long-Term Solution for Occidental WWTP
Sanitation	Establish Property Partnerships and Ordinances to Reduce Overflows
Sanitation	Develop Inline or Off-Line Collection System Storage
Sanitation	Improve SOP Development and Training
Sanitation	Address Localized Flooding at Airport WWTP
Sanitation	Evaluate Post-Fire Impacts on Collection Systems
Sanitation	Improve WWTP Road Access and Emergency Staffing

6.3.4 Cross-system Adaptation Concepts

During the course of synthesizing various concepts from the water supply, flood management, and sanitation system workshops, several concepts were identified that applied to all systems or generally pertained to the Sonoma Water organization as a whole. These cross-system concepts relate to funding, policy, partnerships, education and outreach, operational control, and data and monitoring. Integration of these concepts is vital to effective system management in adapting to a changing climate and fundamental to Sonoma Water's core mission. A brief description of the cross-system adaptation concepts is included.

- **Identify and Access State, Federal, and Other Funding Sources**

  Recognizing that adapting Sonoma Water's systems to climate change risks will require a significant investment, the CAP team identified the need to identify and access state, federal, and other funding sources in order to leverage local sources. Sonoma Water has been successful in leveraging external funding for related programs. Potential funding sources to support climate resilience planning and implementation have been summarized in Appendix E.

- **Support Management and Policy to Facilitate Resilient Systems**

  Some responses to climate change impacts to Sonoma Water's systems require substantial management and policy alignment to facilitate resilient systems. Developing regional responses to climate changes risks, for example, will require policy setting to engage with federal, state, and regional entities on resilience planning principles, approaches for incentivizing improved land and wildfire management practices, and coordinated policies and ordinances with other county departments.

- **Increase Regional Partnerships to Support Climate Resilience**

  While many adaptations to climate change risks to Sonoma Water's systems can be developed largely under the jurisdiction of Sonoma Water, others require regional partnerships to implement. Some of the more impactful concepts and strategies to respond to growing drought, wildfire, and flooding risks need comprehensive regional responses by many regional actors. These actors include water supply retail customers, private landowners, land trusts, counties, and federal/state agencies. Expansion of existing, and development of new, regional partnerships will promote and enable greater climate resilience for Sonoma Water.

- **Support Resilience Planning**

  Achieving climate resilience begins with robust planning that can evaluate systems, future risks, and integrative strategies. Recent drought, wildfire, and flood experiences in Sonoma, Marin, and Mendocino counties serve as a reminder that these risks are not outliers to a more "normal" condition. The CAP team suggested that Sonoma Water planning should continue to include plausible scenarios of these climate-related risks in strategic planning for future water supply, flood management, and sanitation, and seek to address these extreme impacts. Ensuring integration of resilience across Sonoma Water plans is essential.

- **Improve Data Collection and Monitoring**

  Common across all workshops, recommendations for improving data collection and monitoring were provided. Several major climate risks that would benefit from improved data collection and monitoring are: the extent and areas of high infiltration/inflow in many collection systems, the changes in post-fire runoff and sediment loading, the efficacy of the aquifer at the collectors mitigate for rapid changes in water quality, and improving estimates of creek and river flows with improved precipitation monitoring and forecasting. In many of these areas, data collection and monitoring would provide substantial benefit to the management of multiple systems.

- **Expand Education and Outreach**

  Since the actions need to respond to the risks of climate change require the participation of many stakeholders from individual citizens to regional government, education and outreach should be expanded. The outreach would serve the need to increase the understanding of climate risks in the region and would increase participation in implementing the actions needed to address the risks.

- **Increase Reliability of Operational Control**

  Many ideas were generated during the adaptation strategy workshops that included various measures to increase the reliability of operational control of the systems during critical events. These included ideas such as universal application of updated standard operating procedures, installation of redundant power, improving access to facilities, valving and backflow prevention for contamination prevention, replacing and improving control of tide gates, and improving the resilience of SCADA for redundant and remote control.

- **Integrate Climate Resilience with Emergency Response**

  Climate change adaptation and emergency response planning have traditionally been treated as related, but separate functions. Perhaps more than any other region of California, Sonoma County has experienced the impacts of climate change directly in recent emergencies. A more direct integration of the findings of climate change vulnerabilities and risks should be incorporated in emergency response planning. Similarly, emergency response measures should be considered in climate resilience planning. Improving the approaches and integration of each of these would support more resilient systems.

6.4 Adaptation Concept Evaluations

In order to better understand and compare adaptation concepts, an evaluation was performed based on the eight criteria described previously. Each project concept was evaluated for each of the criteria and assigned a rating of 1 through 5. A rating of 1 generally indicates that the concept is positive with respect to the specific criterion, while a rating of 5 indicates that the concept was unfavorable. However, for some criteria, such as “jurisdiction” the ratings simply indicate differing degrees of jurisdictional involvement.

The project concepts, descriptions, and ratings were integrated into a visualization tool to facilitate review and comparison. The characterization of project concepts in this fashion allowed the CAP team to distinguish between concepts and ascertain where some rated better than others in a specific criterion.

6.4.1 Water Supply System

A summary of the evaluation of adaptation concepts for the water supply system is shown in Figure 13.

Figure 13. Evaluation of Water Supply Adaptation Concepts for Specific Criteria

Project Concept Evaluation Criteria

Projec..	Project Name	Cost Rating	Timing Rating	Feasibility Rati..	Environmental ..	Permitting/Leg..	Energy Rating	Social Rating	Jurisdiction Ra..
CAP1	Protect Critical Infrastructure at Wohler and Mirabel Collect..	4	2	1	3	3	1	1	3
CAP2	Floodproof Ely Booster Station	3	2	1	2	1	1	1	1
CAP3	Alternative Russian River Water Treatment	5	4	1	3	3	3	1	3
CAP4	Second Storage Tank at Kastania	4	2	1	2	1	1	1	1
CAP5	Bypass Ely Booster	1	1	1	1	1	1	1	3
CAP6	Operationalize Lake Mendocino FIRO	1	1	1	1	2	1	1	4
CAP7	Improve Access to Water Diversion Facilities (Collectors)	2	2	1	3	1	1	1	1
CAP8	Increase Seasonal Source-Shifting or Transmission System S..	1	2	1	2	2	2	1	3
CAP9	Install Operational Backup Power at River Road Chlorination..	1	1	1	1	1	1	1	1
CAP10	Improve Management in Water Quality Sensitive Watersheds	2	2	1	1	2	1	1	5
CAP11	Increase Groundwater Sources Located Along Aqueduct as E..	3	3	1	3	3	2	1	4
CAP12	Increase System Storage at Lake Stafford-Soulajule Reservoir	3	3	1	2	3	3	1	4
CAP13	Increase Production and Use of Recycled Water	5	3	1	3	3	3	2	3
CAP14	Water Resiliency Study and Water Supply Action Strategy I..	1	1	1	1	1	1	1	3
CAP15	Increase Water Conservation	2	1	1	1	1	1	2	3
CAP16	Rate Structures to Adapt to Increased Variability and Volatil..	2	2	1	1	1	1	3	3
CAP17	Strategic Engagement in Potter Valley Project Activities	2	2	1	1	1	1	2	3
CAP18	Increase Stormwater Detention and Recharge in Watershed	3	3	1	3	4	1	2	5
CAP19	AQPI Operational Support Tool	2	2	1	1	1	1	1	2
CAP20	Climate and Weather Modeling	2	3	1	1	1	1	1	3
CAP21	Support GSFLOW and Hydrology/Hydraulics Modeling	2	2	1	1	1	1	1	1
CAP22	Protect Kawana Booster Station	2	2	1	1	1	1	1	1
CAP23	Expand or Reoperate Wilfred Booster	2	1	1	1	1	2	1	2
CAP24	Raise Coyote Valley Dam	5	5	2	5	5	1	3	5
CAP25	Fish Flow Project (Modification of D-1610)	2	2	1	1	2	1	1	2
CAP26	Lake Sonoma FIRO	1	2	1	1	2	1	1	4
CAP27	Lake Mendocino Variable Gates	5	5	2	5	5	2	3	5
CAP28	Flood-MAR on Russian River (Alexander Valley)	3	3	2	3	4	1	2	5
CAP29	Improve Water Demand Management on Russian River	2	2	1	1	2	1	1	3
CAP30	Protect Mirabel and Wohler Power Lines (relocate/undergro..	3	2	3	3	2	1	2	1
CAP31	Expand On-Site PLC Controls to Address SCADA Vulnerabiliti..	2	2	1	1	1	1	1	1
CAP32	Mobile SCADA System	1	2	1	1	1	1	1	1

The cost of various concepts ranges from less than $1M for studies and smaller asset-level improvements to potentially over $50M for dam improvements or alternative Russian River water treatment. Similarly, most of the concepts could be implemented in under 5 to 10 years except for the large infrastructure projects. In general, all project concepts were deemed to be technically feasible.

Project concepts with potentially large disturbances rated poorly across the environmental and permitting/legal criteria, while operational and watershed improvement concepts rated higher. Energy rating was only differentiated for projects that had expected increased operational energy requirements such as pumping and treatment, or hydropower generation changes. Social rating only differed for projects that could substantially impact rates or cause impacts at the community scale.

Some of the water supply project concepts indicated that Sonoma Water would have primary jurisdiction for implementation. These concepts tend to be associated with either monitoring, data and studies, and Sonoma Water asset-level improvements. However, the evaluation indicated that the majority of the water supply project concepts would require actions from other parties such as water supply contractors, federal or state agencies, or private citizens or landowners.

To focus the next phase of recommendations, it was found useful to screen out project concepts that were expected to perform the poorest across environmental, permitting, energy, and social criteria. Only projects that rated the poorest (5 rating) for any of these criteria were screened out for further consideration. This process resulted in the removal of the dam raise at Lake Mendocino.

6.4.2 Flood Management System

A summary of the evaluation of adaptation concepts for the flood management system is shown in Figure 14.

Figure 14. Evaluation of Flood Management Adaptation Concepts for Specific Criteria

Project Concept Evaluation Criteria

Projec..	Project Name	Cost Rating	Timing Rating	Feasibility Rati..	Environmental ..	Permitting/Leg..	Energy Rating	Social Rating	Jurisdiction Ra..
CAP53	Increase In-Channel and Off-Channel Flood Detention Basins ..	3	2	1	3	2	1	1	5
CAP54	Update Check Dam BMPs for Upper Watershed (Zone 1A) an..	1	2	2	1	1	1	1	2
CAP55	Implement Upper Nathanson Detention (Zone 3A)	3	3	1	1	2	1	1	5
CAP56	Channel Expansion and Increase Channel Maintenance (Zone..	2	2	1	3	2	2	1	4
CAP57	Channel Expansion and Increase Channel Maintenance (Zone..	1	1	1	3	3	1	1	4
CAP58	Adaptive Estuary Management and Structure Protection (Zo..	1	1	1	1	3	1	1	4
CAP59	Improve Operational Control of Outflows from Spring Lake	3	2	2	2	3	1	1	4
CAP60	Implement Green Infrastructure and Home/Parcel Level Con..	3	1	1	1	2	1	1	2
CAP61	Develop Regional Flood Strategy	2	2	1	1	2	1	1	2
CAP62	Regionally Address Lower Sonoma Creek Flooding (Zone 3A)	3	3	1	1	2	1	1	5
CAP63	Promote Flood and Brackish Tolerant Crop Growth (Zone 2A ..	1	3	1	1	2	1	1	5
CAP64	Improve Laguna Restoration (Zone 5A)	3	3	2	1	3	1	1	5
CAP65	Acquire and Use Middle Reach Hanson Gravel Ponds	5	3	2	1	3	1	1	4
CAP66	Sediment Source Study for Improve Sediment Management	1	1	1	1	1	1	1	2
CAP67	Raise Coyote Dam and Improve Sediment Management (Zon..	5	4	2	5	5	1	3	5
CAP68	Forecast-Informed Operations to Flood Control Structures &..	1	1	1	1	1	1	1	2
CAP69	Widen Santa Rosa Creek and Remove/Daylight Triple Box Cul..	5	2	1	1	3	1	2	4
CAP70	Improve Spillway at Matanzas	1	2	1	1	1	1	1	1
CAP71	Implementation of Forecast-Informed Operations for Lake M..	1	1	1	1	2	1	1	4
CAP72	Increase Watershed Resilience to Wildfire	2	2	1	1	2	1	1	5
CAP73	Flood-Managed Aquifer Recharge (Flood-MAR)	2	2	1	1	1	1	1	5
CAP74	Integrate Flood Management and Land Management	2	1	1	1	1	1	1	2
CAP75	AQPI Operational Support Tool	2	2	1	1	1	1	1	2
CAP76	Climate and Weather Forecasting	2	2	1	1	1	1	1	1
CAP77	Support and Develop Hydrology/Hydraulics and Sediment M..	2	2	1	1	1	1	1	4

The cost of various concepts ranges from less than $1M for studies and smaller maintenance related efforts to potentially over $50M for dam improvements or land acquisition. Similarly, most of the concepts could be implemented in under 5 to 10 years except for the large infrastructure projects. Similar to the water supply concepts, all project concepts were deemed to be technically feasible.

Project concepts with potentially large disturbances rated poorly across the environmental and permitting/legal criteria, while restoration and watershed improvement concepts rated higher. Energy rating was only differentiated for projects that had increased energy-related maintenance needs such as sediment removal. Social rating only differed for projects that could substantially cause impacts at the community scale.

The evaluation indicated that only a small number of flood management concepts fell under Sonoma Water's sole jurisdiction for implementation. These concepts were associated with forecasting, data, or studies. Nearly all flood management project concepts are expected to involve participation and collaboration with other county, state, or federal agencies or private citizens or landowners.

To focus the next phase of recommendations, it was found useful to screen out project concepts that were expected to perform the poorest across environmental, permitting, energy, and social criteria. Only projects that rated the poorest (5 rating) for any of these criteria were screened out for further consideration. This process resulted in the removal of the Lake Mendocino dam raise concept.

6.4.3 Sanitation System

A summary of the evaluation of adaptation concepts for the sanitation system is shown in Figure 15.

The cost of various concepts ranges from less than $1M for studies and smaller asset-level improvements to potentially up to $25M for large-scale infiltration/inflow reduction program, reuse delivery expansion, or capacity expansions at Russian River WWTP. All concepts could be implemented in under 10 years. In general, all project concepts were deemed to be technically feasible except for the vacuum system for Russian River collection system that would need to be investigated through study.

Sanitation system project concepts were generally scored favorably with respect to environmental and social criteria due to the anticipated reduced overflows and impacts to receiving water bodies. Energy rating was only differentiated for projects that had expected increased operational energy requirements such as pumping and treatment.

The evaluation indicates that many of the sanitation system project concepts could be implemented with Sonoma Water having primary jurisdiction. Although some project concepts that involve reuse or land acquisition would require substantial action by others for implementation.

No sanitation system project concepts were screened out based on poor ratings across environmental, permitting, energy, and social criteria.

Figure 15. Evaluation of Sanitation Adaptation Concepts for Specific Criteria

Project Concept Evaluation Criteria

Projec..	Project Name	Cost Rating	Timing Rating	Feasibility Rati..	Environmental ..	Permitting/Leg..	Energy Rating	Social Rating	Jurisdiction Ra..
CAP33	Expand Valving of Russian River Collection System	3	2	1	1	1	1	1	1
CAP34	Study Potential for Vacuum System for Russian River Collect..	1	2	3	1	3	2	1	2
CAP35	Implement Inflow/Infiltration Monitoring and Reduction Pro..	4	2	1	1	1	1	1	1
CAP36	Eliminate Sonoma Valley WWTP Hydraulic Constraints due t..	3	2	2	2	2	3	1	1
CAP37	Improve or Adapt Operations of Reuse Supply Delivery to M..	3	2	2	2	2	3	1	5
CAP38	Expand Opportunities for Sonoma Valley Reuse	4	3	1	2	2	3	1	5
CAP39	Penngrove Lift Station Flood Protection	3	2	1	2	1	1	1	1
CAP40	Revise Collection System Design Standards	1	2	2	1	1	1	1	2
CAP41	Increase Operable Capacity at Russian River WWTP	4	3	2	1	1	1	1	1
CAP42	Purchase Additional Land at Russian River WWTP for Summ..	2	3	1	1	1	2	1	5
CAP43	Increase Flood Protection at Sonoma Valley WWTP	2	2	1	1	1	1	1	1
CAP44	Establish Sanitation Level Planning	1	2	1	1	1	1	1	1
CAP45	Implement SCADA Master Plan and Automation	2	2	1	1	1	2	1	1
CAP46	Long-Term Solution for Occidential WWTP	1	1	1	1	1	1	1	1
CAP47	Establish Property Partnerships and Ordinances to Reduce ..	1	1	1	1	1	1	1	5
CAP48	Develop In-Line or Off-Line Collection System Storage	3	2	1	1	1	1	1	1
CAP49	Improve SOP Development and Training	1	2	1	1	1	1	1	1
CAP50	Address Localized Flooding at Airport WWTP	1	1	1	1	1	1	1	1
CAP51	Evaluate Post-Fire Impacts on Collection Systems	3	2	1	1	2	1	1	5
CAP52	Improve WWTP Road Access and Emergency Staffing	1	1	1	1	1	1	1	1

6.4.4 Cross-system Adaptation Concepts

Cross-system adaptation concepts, in most cases, enable or facilitate the system-specific adaptation concepts or are management and policy level activities. For these reasons, the cross-system adaptation concepts were not included in this evaluation but are incorporated into the adaptation strategy recommendations in the subsequent section.

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SECTION 7

Adaptation Strategy Recommendations

Based on the information gained in the vulnerability and risk assessments, the identification of adaptation strategies and project concepts, and the evaluation of project concepts, a set of recommended strategies are presented. This section describes the approach and results of considerable synthesis of adaptation strategy information to arrive at a suite of recommendations.

The development of climate adaptation responses in this CAP makes use of three levels of organization in an attempt to link the specific concepts that were developed in workshops with overarching strategies to address climate-related vulnerabilities. We have adopted similar terminology and organization as the Water Supply Strategies Action Plan (SCWA 2018) so as to increase the consistency and clarity of messaging within Sonoma Water.

The general organization consists of the following three levels:

- Strategy – An overarching goal and associated actions that can promote achievement of the goal
- Action – A specific action or set of actions that target one aspect of the strategy
- Project Concept – A specific project or project concept that links to the actions and can be evaluated for criteria such as cost, timing, and feasibility.

Portfolios, an intentional collection of project concepts, are introduced for each of Sonoma Water's systems as a tool to support the achievement of adaptation strategies. The most significant common, integrated strategies are also identified that reflect synergies that could be achieved by looking across systems. Finally, this section provides recommendations for moving the recommended strategies toward implementation with a focus on the common actions and needs.

7.1 Recommended Portfolios and Strategies

Adaptation to the impacts of climate change often involves the recognition that there is no single action that can address all the adaptation need or be robust enough alone to respond to the future conditions. Essentially there is no single silver bullet, even when considering only one system. The substantial and diverse set of climate risks to Sonoma Water's systems necessitated the development of an equally diverse set of potential adaptation responses.

Adaptation strategies reflect the overarching goal and associated actions that can promote achievement of the goal. Promising project concepts can be directly linked to the actions and subsequently the overall strategy. Portfolios can then be assembled to reflect the combination or collection of these concepts to achieve the strategy.

The CAP team developed a portfolio of adaptation project concepts to support the strategies for each of Sonoma Water's systems. Each major action associated with an adaptation strategy is represented with several promising concepts that if achieved would reduce risks due to climate change. *Anchor* project concepts were linked to each major action and reflect the hallmark concept(s) that could substantially "move the needle" on climate adaptation, could be substantially directed by Sonoma Water, and have targeted funding sources. These anchor project concepts are combined with several *supporting* concepts to help achieve the goals. The supporting project concepts should be synergistic with the anchor project(s), should be coordinated with other project concepts of a diversity in terms of robustness and timescales, and may also include concepts that are not primarily within the jurisdiction of Sonoma Water. Finally, several integrated concepts have been identified that will likely provide the largest improvements in climate resiliency for Sonoma Water across the water supply, flood management, and sanitation systems. These are described following the system-specific strategies.

7.1.1 Water Supply Adaptation Strategy

Evaluation of water supply project concepts led to discussions within the CAP team on the best ways to accomplish the adaptation strategy actions. This involved the identification of the most promising adaptation concepts and also the integration of similar concepts into a more cohesive project or program. The recommended water supply adaptation portfolio is presented in Table 20 and shown graphically in Figure 16.

The recommended water supply adaptation strategy consists of five major actions. These major actions and their associated anchor and supporting projects are believed to best put Sonoma Water on a path for adapting to climate change. These actions and anchor projects are listed and briefly described.

1. **Improve Resilience of Water Supply Infrastructure** – The anchor project for this action is the development of a *Water Diversion Facilities Protection Program* to protect Wohler and Mirabel diversion infrastructure and access during flood and wildfires. This program may include retrofitting collectors with submarine-type doors to seal from water entry during potential high flood events, elevating levee roads at Mirabel collectors, and elevating and strengthening collector number 6 to prioritize operation of this collector even under higher anticipated flood water levels. Supporting projects include an evaluation of alternative Russian River water treatment should post-fire water quality temporarily not allow existing chlorination methods to be used, improving and expanding remote operational control of the water infrastructure, and floodproofing Ely Booster Station.

2. **Increase Operational Flexibility of Water Management Facilities** – The anchor project for this action is an expanded *FIRO Program*. This program will consolidate Sonoma Water's FIRO efforts related to Lake Mendocino, Lake Sonoma, and Flood Control structures into a combined program. Incorporating into a program would allow the science, data, tools, and policies to have greater impact and operational capability. Supporting projects include new

transmission system storage at Kastania, a seasonal conjunctive use or groundwater banking program, and exploring variable gates at Lake Mendocino.

3. **Improve System Integration and Regional Resilience** – The anchor project for this action is the development of *Regional Water Supply Strategies* that continues investments such as the Regional Water Supply Resiliency Study and the Water Supply Action Plan that facilitate diversification of supplies and demands during changed conditions and reduce regional water supply risks. Recommend utilizing the Regional Water Supply Resiliency Study to identify and develop integrated water supply strategies such as a seasonal, annual, or interannual storage program (groundwater banking, source-shifting program, or transmission storage). Supporting project includes increasing groundwater pumping at existing or new well near the aqueducts, increasing use of recycled water, and increasing regional system storage.

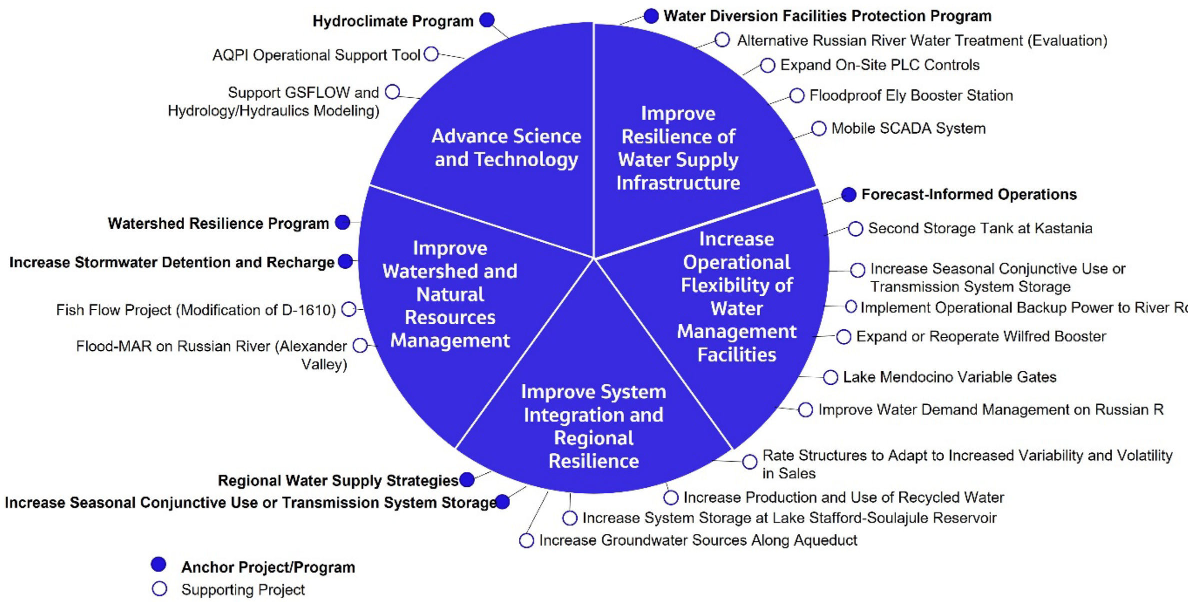
4. **Improve Watershed and Natural Resources Management** – One anchor project for this action is the development of a *Watershed Resilience Program* that focuses on healthy headwaters, hydrologic and sediment management, land and vegetation management for flood attenuation, and water quality benefits during extreme hydrologic events post-wildfire. This program would integrate strategic studies with specific watershed management activities under a program to promote and fund activities both within and outside of Sonoma Water's immediate jurisdiction. A second anchor project involves *Increasing Stormwater Detention and Recharge* by enhancing detention, infiltration, and groundwater recharge. This concept would fall into the broad domain of Flood-MAR projects being supported by DWR. Studies would identify areas of flooding and areas of higher recharge potential. Detention ponds or enhanced recharge areas would be constructed in strategic areas.

5. **Advance Science and Technology** – The anchor project associated with this action is the initiation of a *Hydroclimate Program* that will Integrate multiple, related efforts of climate, weather, and hydrological measurement, data assimilation, prediction and modeling into a program to support Sonoma Water more effectively as a whole. Supporting projects include the development of an AQPI support tool and continuing investments in groundwater, surface water hydrology, and river flood hydraulics model.

Table 20. Recommended Water Supply Adaptation Portfolio

Adaptation Strategy Action	Anchor Projects	Supporting Projects
Improve Resilience of Water Supply Infrastructure	Water Diversion Facilities Protection Program	Expand Decentralized Controls Floodproof Ely Booster Station Mobile Central Control System Evaluate Alternative Russian River Water Treatment
Increase Operational Flexibility of Water Management Facilities	Forecast-Informed Reservoir Operations	Second Storage Tank at Kastania Seasonal Conjunctive Use Program or Transmission System Storage Expand or Reoperate Wilfred Booster Lake Mendocino Variable Gates Improve Demand Management on Russian River
Improve System Integration and Regional Resilience	Regional Water Supply Strategies	Increase Groundwater Sources and Groundwater Bank Along Aqueduct Seasonal Conjunctive Use Program or Transmission System Storage Increase System Storage at Lake Stafford-Soulajule Reservoir Increase Production and Use of Recycled Water Rate Structures to Adapt to Increased Variability and Volatility in Sales
Improve Watershed and Natural Resources Management	Watershed Resilience Program Increase Stormwater Detention and Recharge	Fish Flow Project (Modification of D-1610) Flood-MAR on Russian River (Alexander Valley)
Advance Science and Technology	Hydroclimate Program	AQPI Operational Support Tool Support GSFLOW and Hydrology/Hydraulics Modeling

Figure 16. Graphical Depiction of Recommended Water Supply Adaptation Portfolio



7.1.2 Flood Management Adaptation Strategy

The evaluation of flood management concepts elucidated the integrated nature of many concepts with watershed management. The CAP team focused on best ways to accomplish the adaptation strategy actions. This involved the identification of the most promising adaptation concepts and also the integration of similar concepts into a more cohesive project or program. The recommended flood management adaptation portfolio is presented in Table 21 and shown graphically in Figure 17.

The recommended flood management adaptation strategy consists of five major actions. These major actions and their associated anchor and supporting projects are believed to best put Sonoma Water on a path for adapting to climate change. These actions and anchor projects are listed and briefly described.

1. **Develop and Implement Regional Flood Management** – Three anchor projects were identified for this action. The first is the development of a *Regional Flood Management Strategy* that seeks to address the current lack of an integrated regional flood management strategy that outlines specific goals and metrics for flood protection, common approaches for flood risk reduction, regional and local policies, and investment strategies. This effort would partner with other agencies that have flood risk reduction responsibilities and would integrate planning, modeling, and management approaches for the Central Sonoma, Russian River, Laguna, and Estuary into a common flood management plan. The second anchor project for this action is the development of a *Sediment Source Study* to identify major sources of sediment within each watershed and quantify historical and future sediment loads using the modeling. The study would identify sediment source "hot spots" and recommend strategies for source control. Finally, the *Central Sonoma Watershed Project Vulnerability Assessment* is recommended to better understand the vulnerabilities in

the City of Santa Rosa and along Santa Rosa Creek, Mark West Creek, and the Laguna, and addressing flooding in Lower Sonoma Creek.

2. **Improve and Maintain Flood Management Infrastructure** – Two anchor projects for this action are *Improve Spillway at Matanzas* and *Improving Operational Control of Spring Lake Outflows*. Collectively, these projects could reduce facility and downstream flood risks. Supporting projects include updates to check dam BMPs to incorporate climate change, implementing detention in Upper Nathanson Creek, and supporting improvements to upper Russian River levees.

3. **Improve Operations of Flood and Water Management Facilities** – The anchor project for this action is the development of *Forecast-Informed Reservoir Operations* that consolidates FIRO efforts related to Lake Mendocino, Lake Sonoma, and Flood Control structures into a combined program. Incorporating into a program would allow the science, data, tools, and policies to have greater impact and operational capability. Supporting projects include channel expansion in some areas and adapting Estuary management to rising sea levels and more severe floods.

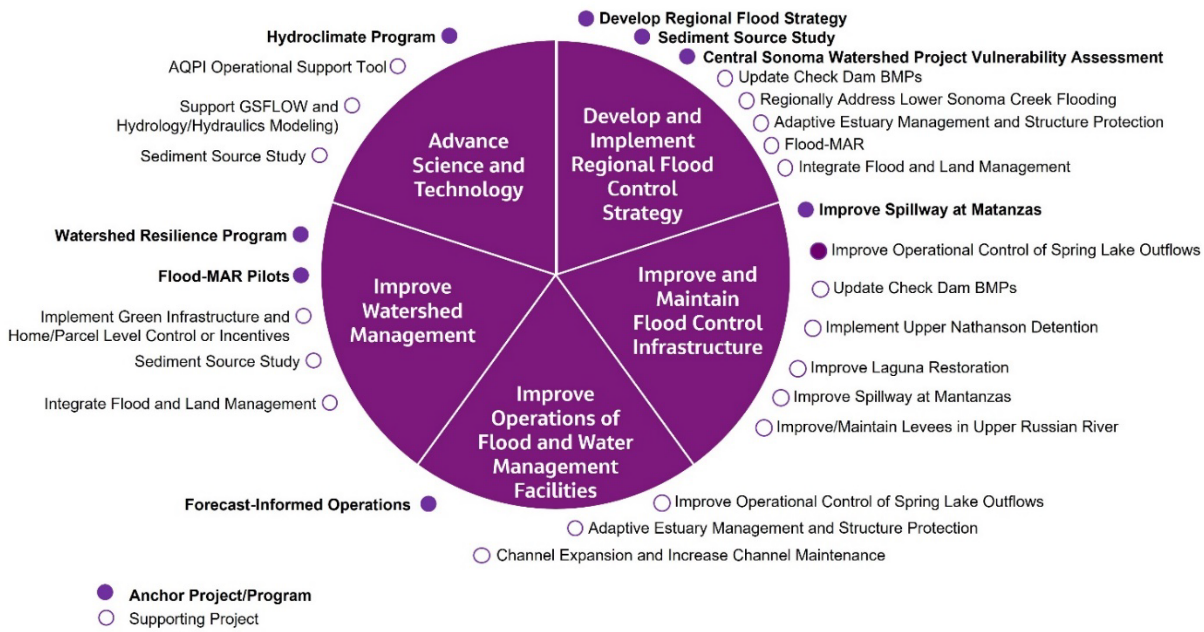
4. **Improve Watershed Management** – One anchor project for this action is the development of a *Watershed Resilience Program* that focuses on healthy headwaters, hydrologic and sediment management, land and vegetation management for flood attenuation, and water quality benefits during extreme hydrologic events post- wildfire. This program would integrate strategic studies with specific watershed management activities under a program to promote and fund activities both within and outside of Sonoma Water's immediate jurisdiction. A second anchor project involves the implementation of Flood-MAR type pilot projects in four flood zones: Laguna-Mark West watershed, the Alexander Valley watershed, the Sonoma Valley watershed and the Upper Petaluma River watershed. These pilot projects would implement strategies for recharging groundwater aquifers with excess flood waters, simultaneously lowering the risk of flooded communities while improving stressed groundwater resources. Supporting projects include implementing green infrastructure and parcel level hydrologic controls and integrating flood and land management.

5. **Advance Science and Technology** – The anchor project associated with this action is the initiation of a *Hydroclimate Program* that will Integrate multiple, related efforts of climate, weather, and hydrological measurement, data assimilation, prediction and modeling into a program to support Sonoma Water more effectively as a whole. Supporting projects include the development of an AQPI support tool and continuing investments in groundwater, surface water hydrology, and river flood hydraulics model.

Table 21. Recommended Flood Management Adaptation Portfolio

Adaptation Strategy Action	Anchor Projects	Supporting Projects
Develop and Implement a Regional Flood Management	Develop Regional Flood Management Strategy Sediment Source Study Central Sonoma Watershed Project Vulnerability Assessment	Update Check Dam BMPs Regional Approach to Lower Sonoma Creek Flooding
Improve and Maintain Flood Management Infrastructure	Improve Spillway at Matanzas Improve Operational Control of Spring Lake Outflows	Update Check Dam BMPs Implement Upper Nathanson Detention Improve Laguna Restoration Improve and Maintain Levees on upper Russian River
Improve Operations of Flood and Water Management Facilities	Forecast-Informed Reservoir Operations	Channel Expansion and Increase Channel Maintenance Adaptive Estuary Management and Flood Risk Reduction Improve Operational Control of Spring Lake Outflows
Improve Watershed Management	Watershed Resilience Program Flood-MAR Pilots	Implement Green Infrastructure and Home/Parcel Level Control and Incentives Sediment Source Study Integrate Flood and Land Management
Advance Science and Technology	Hydroclimate Program	AQPI Operational Support Tool Support GSFLOW and Hydrology/Hydraulics Modeling

Figure 17. Graphical Depiction of Recommended Flood Management Adaptation Portfolio



7.1.3 Sanitation Adaptation Strategy

Evaluation of sanitation project concepts led to discussions within the CAP team on best ways to accomplish the adaptation strategy actions. One challenge in developing sanitation systemwide actions is the relative isolated nature of the current sanitation districts and zones and their operations. However, the team found a number of common and impactful elements that will improve the resilience to climate change. Promising adaptation concepts and integrated concepts were identified. The recommended sanitation adaptation portfolio is presented in Table 22 and shown graphically in Figure 18.

The recommended sanitation adaptation strategy consists of five major actions. These major actions and their associated anchor and supporting projects are believed to best put Sonoma Water on a path for adapting to climate change. These actions and anchor projects are listed and briefly described.

1. **Improve Efficiency of Collection Systems** – Two anchor projects for this action have been identified. The first project is the development of *Infiltration/Inflow (I/I) Monitoring and Reduction Program* – Many of the sanitation collection systems, but most acutely the Sonoma Valley and Russian River collection systems, suffer from high I/I during storm events which can also result in SSOs. The relatively poor understanding of these flows and the likelihood that future climate change will increase I/I in these systems requires focused effort. This project concept would establish an I/I Monitoring and Reduction program that would seek to (1) better understand areas of systems that have large I/I contributions, (2) implement a monitoring system on critical collection system segments in Sonoma Valley and Russian River, and (3) implement asset management program to upgrade sewer capacity and strategically replace aging sewer lines. The second anchor project is to develop *Revised Collection System Design Standards* that will seek to further reduce I/I through

improved design/construction practices and consideration of higher frequency and magnitude of rainfall during storm events associated with climate change.

2. **Increase Wastewater Treatment Reliability** – The anchor project for this action is to *Eliminate Sonoma Valley WWTP Constraints due to Sea Level Rise.* During the wet season (November 1 to April 30), treated wastewater is discharged into Schell Slough, a tidally-influenced waterbody downstream of Schell Creek. During the dry season, tertiary treated effluent is used for irrigation or discharged to Wetland Management Units 1 and 3 to maintain freshwater marshlands and ponds for wetland habitat enhancement. Between May 1 and October 31, treated wastewater is also used for irrigation of dairy fodder crops and vineyards. Sea level rise will effectively reduce the hydraulic capacity of effluent discharge and recycled water delivery due to more frequent tide gate closure and increasing hydraulic constraint. This project would increase the operational effluent pumping capacity and increase equalization storage capacity for increased sea level. Supporting projects associated with this action include purchasing additional land at the Russian River WWTP for summer irrigation, improving emergency access to WWTPs, and implementing a mobile SCADA system.

3. **Expand Opportunities for Reuse** – The anchor project for this action to *Expand Sonoma Valley Reuse*. Sonoma Valley WWTP generates more treated wastewater in winter than it currently has demand. Future climate change will likely exacerbate water supply challenges and increase saltwater intrusion in the Sonoma Valley groundwater basin. This project includes the expansion of partnerships with wineries and other irrigators, groundwater management entities, and regional entities such as Bay Area Clean Water Agencies (BACWA) and Sonoma Land Trust to increase the service area for recycled water. Opportunities exist for increased delivery for seawater intrusion barrier, irrigation customers near the current delivery system, and connection additional customers and storage projects such as those in the North Bay Water Reuse Program - Phase 2 projects. While the emphasis should be appropriately placed on Sonoma Valley Reuse, opportunities exist for increased reuse opportunities in most sanitation entities.

4. **Improve Sanitation System Operations** – One anchor project for this action is the development of *Dynamic and Resilient SCADA System.* This project concept builds on Sonoma Water's Phase 1 SCADA Master Plan and implements automation pilots at Sonoma Valley and Russian River WWTPs based on the criticality of the systems and a priority list developed by operations staff. Most of the wastewater treatment plants have minimal automation and operations staff must manually make changes. Access to some of these facilities can be challenged during high flood events or fires which will be exacerbated by future climate change. Increased automation and redundant control capabilities are targeted. A second anchor project is to *Improve Standard Operating Procedure (SOP) Development and Training.* With projections of future climate change to indicating increased frequency and magnitude of extreme precipitation events, collection system I/I is expected to increase. This project seeks to reduce these flows through improved SOP development, training, and application. SOPs outline the procedures for ongoing operations, maintenance, and testing (e.g., lateral inspection and smoke testing) of the collection systems to reduce the potential for SSOs. SOPs would be revised, and training initiated for all sanitation operations staff.

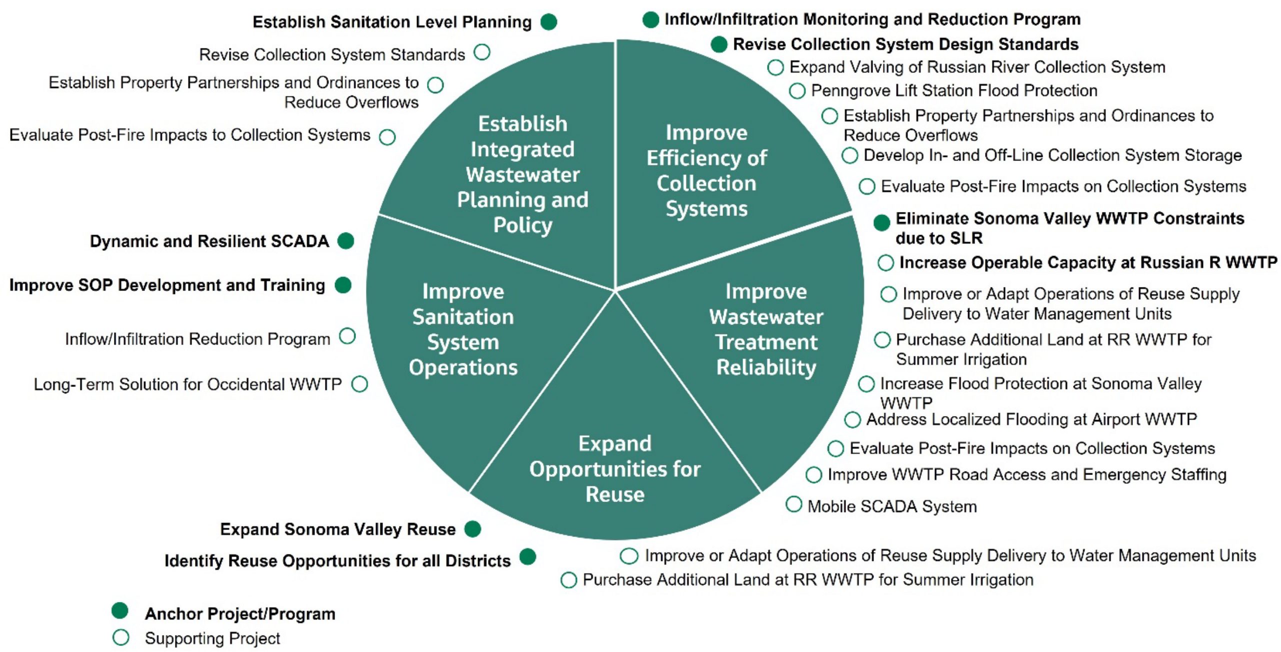
5. **Establish Integrated Wastewater Planning and Policy** – The anchor project for this action is the development of to *Establish Sanitation Level Planning*. Many of the sanitation systems that are currently managed by Sonoma Water were conceived and built by other entities in isolation. A regional and consistent systemwide assessment of sanitation needs, assets, and strategies has not been developed. No strategic planning level document such as the Water Supply Strategies Action Plan exists for the sanitation sector reflecting a differing approach. This project would establish a Strategic Sanitation Systems Plan (or similar) that would compile the state of each sanitation system, outline risks and opportunities to these systems, and perhaps identify regional solutions that could reduce risks, identify potential consolidation opportunities (e.g., Occidental and Airport or Graton). Supporting projects include establishing property partnerships and ordinances to reduce overflows and evaluating post-fire impacts to collection and treatment systems.

Table 22. Recommended Sanitation Adaptation Portfolio

Adaptation Strategy Action	Anchor Projects	Supporting Projects
Improve Efficiency of Collection Systems	Infiltration/Inflow Monitoring and Reduction Program Revise Collection System Design Standards	Expand Valving of Russian River Collection System Establish Property Partnerships and Ordinances to Reduce Overflows Develop Inline or Off-line Collection System Storage
Improve Wastewater Treatment Reliability	Eliminate Sonoma Valley WWTP Constraints due to Sea Level Rise	Improve or Adapt Operations of Reuse Supply Delivery to Water Management Units Purchase Additional Land at Russian River for Summer Irrigation Increase Flood Protection at Sonoma Valley WWTP Address Localized Flooding at Airport WWTP Evaluate Post-Fire Impacts on Collection Systems Improve WWTP Road Access and Emergency Staffing Mobile SCADA System
Expand Opportunities for Reuse	Expand Sonoma Valley Reuse Identify Reuse Opportunities for Sanitation Systems	Purchase Additional Land or Acquire Additional Right-Of-Way at Russian River WWTP for Summer Irrigation Improve or Adapt Operations of Reuse Supply Delivery to Water Management Units
Improve Sanitation System Operations	Dynamic and Resilient SCADA Improve SOP Development and Training	Infiltration/Inflow Reduction Program Long-Term Solution for Occidental WWTP

Adaptation Strategy Action	Anchor Projects	Supporting Projects
Establish Integrated Wastewater Planning and Policy	Establish Sanitation Level Planning	Revised Collection System Standards Establish Property Partnerships and Ordinances to Reduce Overflows Evaluate Post-Fire Impacts to Collection Systems

Figure 18. Graphical Depiction of Recommended Sanitation Adaptation Portfolio



7.2 Integrated Strategies

While portfolios were developed separately for the water supply, flood management, and sanitation systems, some important common, integrated concepts have been identified that will likely provide the largest improvements in climate resiliency for Sonoma Water. The most principal integrated strategies are listed, along with the expected benefits.

- **Watershed Resilience Program** –broad, multi-benefit, watershed resilience program benefits all Sonoma Water systems and will generate significant resiliency benefits to broader communities and region.
- **Water Diversion Facilities Protection Program** – focuses on water supply benefits but protects and improves the reliability of the major function of Sonoma Water and the backbone of the regional water system.
- **Regional Water Supply Strategies** – promotes regional partnerships throughout Sonoma, Marin, and Mendocino counties and achieves resilience through an integrated view of

water systems; springboard for many of the drought, wildfire, and flood resilience engagement and community and regional programs.

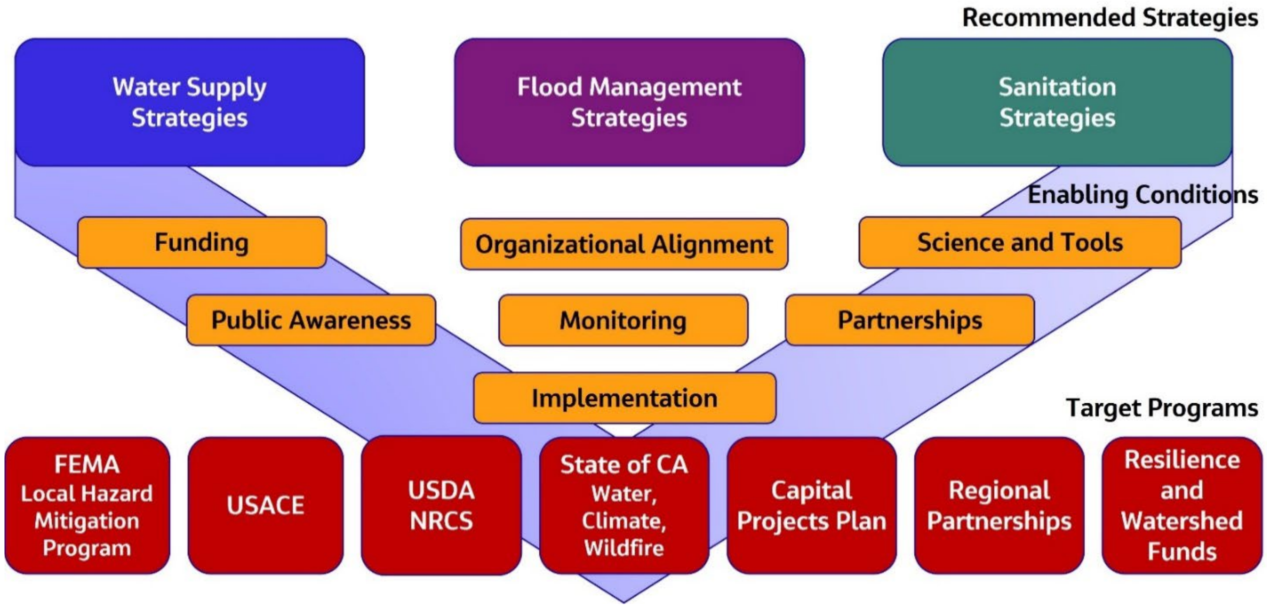
- **Forecast-Informed Reservoir Operations** – consolidates of related activities into combined program allowing for greater efficiencies in application, policy and regulatory alignment, and expanding impact to other forecast-dependent operations.
- **Regional Flood Management Strategy** – addresses a significant gap in resilience understanding and planning; promotes integrated system understanding and solutions, seeks to synchronize major regional stakeholders and siloed efforts together for improved effectiveness.
- **Hydroclimate Program** – integrates multiple, related efforts of climate, weather, and hydrological measurement, data assimilation, prediction and modeling into a program to support Sonoma Water more effectively as a whole; supports needs in all systems.
- **Dynamic and Resilient SCADA** – supports needs in the management and operation of all systems; ensures operational control under major climate-related risks; automation and redundant control capabilities are targeted.
- **Integrated Sanitation Level Planning** – focuses on the sanitation system but addresses a significant gap in Sonoma Water's planning capabilities; brings sanitation level planning to similar level as water supply and flood management (after regional flood management strategy is developed); and allows for synergies between system functions and actions to be identified.

7.3 Moving from Strategy to Implementation

Adapting to climate change requires a systematic, but flexible approach to move from planning and strategy development to implementation and monitoring. As presented in the previous sections, climate change adaptation involves a range of adaptation approaches including infrastructure development and improvements, operations, distributed actions throughout the watersheds, policies and ordinances, organizational changes, and planning. Thus, implementation of adaptation strategies for Sonoma Water's systems must consider an equally diverse set of approaches.

An approach linking the climate change adaptation strategies to possible implementation programs has been developed. This approach is shown graphically in Figure 19 and considers the various enabling conditions that facilitate successful and sustainable implementation of adaptation strategies. These enabling conditions include funding, science and tools, organizational alignment, partnerships, public awareness, program implementation, and monitoring. A brief description of the considerations for each of the enabling conditions is provided in the subsequent sections.

Figure 19. Conceptual Approach for Linking Adaptation Strategies, Enabling Conditions, and Potential Implementation Programs.



7.3.1 Funding

Most adaptation strategies require funding in order to support advanced planning, design, and implementation. Even non-infrastructure-based adaptation strategies require some level of funding to support incentives, policy and ordinance changes, partnerships, or changes in institutional approaches. Sonoma Water has been successful in the past in leveraging state and federal funding to support system improvements in response to impacts from local hazards and to advance science and policy changes, and should build upon this success to access available funding for climate adaptation strategy implementation. As Sonoma Water moves toward climate adaptation strategy implementation, each strategy should be mapped to potential local, state, and federal funding opportunities. Funding is dynamic and partnerships are critical to secure funding to be able to implement programs and projects.

Local funding opportunities include Sonoma Water's funds that are traditionally used to support Sonoma Water's Capital Projects Plan, including Water Transmission Fund, Water Supply Fund, Administration and General Fund, Internal Service Funds, Flood Control Funds, and sanitation enterprise specific funds. Some climate adaptation projects, especially those that are asset-level improvements, may be best funded using these local sources of funding due to the efficiency of delivery.

Under California's unexpected budget windfall in 2021, the Governor's budget for 2021 to 2022 has introduced substantial funding to support climate resilience. The current enacted budget includes $15 billion in investments to address and reduce the state's multi-faceted climate risks, ranging from water supplies, wildfires, heat, and sea level rise. This includes over $5.1 billion for immediate drought response and long-term resilience, $1.5 billion to address wildfire risks, and $3.7 billion for climate resilience. As part of these programs, climate adaptation and resilience planning grants will be made available for local governments and some funding will support the continuation and expansion of regional climate collaboratives. Sonoma Water should leverage this Climate Adaptation Plan and recommended strategies to access available funds starting in fall 2021.

In addition, state bonds may become available in 2022 for additional funding to support climate resilience. Assembly Bill-1500, “Safe Drinking Water, Wildfire Prevention, Drought Preparation, Flood Protection, Extreme Heat Mitigation, and Workforce Development Bond Act of 2022”, if approved by the voters, would authorize the issuance of bonds in the amount of nearly $7 billion to finance projects for safe drinking water, wildfire prevention, drought preparation, flood protection, extreme heat mitigation, and workforce development programs.

As with the state funding opportunities, several recent advancements have made significant federal funding opportunities available to support hazard mitigation, pre-disaster preparedness, and climate resilience. The Federal Emergency Management Agency (FEMA) has introduced novel grant programs such as the Building Resilient Infrastructure and Communities (BRIC), Flood Mitigation Assistance, and Hazard Mitigation Post-Fire. In addition, the recently passed $550 billion federal Infrastructure Bill includes $50 billion for Resilience and Western Water Infrastructure that should be available to support various climate adaptation projects.

Continued partnership and alliance with USDA NRCS and Resource Conservation Districts is important to solicit funds to implement flood management and integrated natural resource projects as Local Sponsor. Sonoma Water should continue its membership and partnership in regional and state climate adaptation programs and organizations. Participating in these integrated water management and climate adaptation entities is critical to advocating for funding, policy, and securing regional funding to implement climate adaptation strategies.

Finally, innovative funding approaches should also be considered to support implementation of some climate adaptation strategies. A growing trend is the development of basin funds, resilience funds, or forest funds to support a distributed set of actions across the natural landscapes. Funds such as “environmental impact bonds” or “forest health” funds leverage private capital through so-called “impact investing” funds to accelerate project implementation or to expand the scale of investment beyond a more traditional slow pace of government funding. Sonoma Water, with regional partners, should investigate the development of a “watershed resilience fund” to support implementation of watershed measures for natural flood attenuation, sediment management, pre- and post-wildfire risk reduction, and groundwater recharge benefits identified in the recommended watershed resilience program. In addition, water markets or credits for groundwater recharge and storage could be considered.

Appendix E – Potential Funding Sources summarizes the available funding opportunities that could be targeted to support climate adaptation.

7.3.2 Science and Tools

During the adaptation strategy development for this Climate Adaptation Plan, several adaptation concepts were identified to address vulnerabilities through the advancement and application of science and technology. A key component of sustaining climate adaptation is to ensure that the best science is available and used to translate climate changes to regional and local impacts. While many of the adaptation concepts focused on weather forecasting and climate prediction, hydrology and hydraulic modeling, and data collection and monitoring, it should be recognized that these types of supportive strategies require sustained investment.

Sonoma Water should ensure that the sustained investment in science and tools focuses on achieving the following outcomes:

- Continually improve and update the understanding of climate science (climate science, modeling, and downscaling)
- Continually improve and update the measurement of conditions in the region (observations of climate, hydrology, water quality, etc.)
- Continually improve the understanding and prediction of local, system-relevant impacts
- Operationalize updates to tools and monitoring to improve understanding of climate trajectory and rates of change

One example is Sonoma Water's leadership on Ensemble Forecast Operations (EFO) for implementing FIRO (Delaney et al. 2020). The EFO model is a key element of USACE's viability assessments for FIRO at several reservoirs. Successful implementation of a sustained science and tools program will facilitate better decisions and allow for an adaptive management approach to be taken for implementation. Sonoma Water has also developed a risk threshold analysis for flooding at California Nevada River Forecast Center's Russian River watershed forecast points by leveraging the Global Ensemble Forecast System developed by the National Weather Service. This information is provided to the Sonoma County Department of Emergency Management for emergency management and preparedness purposes.

7.3.3 Organizational Alignment

In the past, climate change studies and adaptation plans were generally used as "side" efforts to explore a new and evolving threat or to address or respond to concerns generated by the public. For the most part, these past studies improved understanding of climate science and impacts, but did not result in any substantial decisions made by agencies. However, recent trends toward "mainstreaming" climate resilience within organizations has been accelerating in parts of the U.S. and globally. This process involves gaining organizational alignment on climate resilience through existing or modified matrix management structures.

Sonoma Water recognizes the need for organizational alignment at both policy and management levels to address climate change. The organization alignment should focus on three main areas:

1. Common foundation of approaches, tools, and data throughout the organization,

2. Inter-disciplinary climate resilience teams made up of existing Sonoma Water resilience champions to ensure climate considerations are addressed in major Sonoma Water efforts, and

3. Board and County leadership through a thoughtful integration of climate and resilience programs with high-level strategic goals.

Focusing on these three areas would help Sonoma Water to both internalize climate resilience within Sonoma Water, but also amplify the message and increase adoption by others. In addition, Sonoma Water should continue to take steps to address the multiple risks, including seismic, power, cyber, and aging infrastructure, in addition to climate risks to achieve greater levels of resilience.

7.3.4 Partnerships and Public Awareness

Nearly all climate adaptation responses require partnerships of some form. These partnerships could include those between Sonoma Water water-flood-sanitation groups, with Sonoma County or cities, and with regional organizations or landholders. The engagement with the Sonoma Water Board, County departments, and other stakeholders, as part of this Climate Adaptation Plan offers a springboard to expand existing, or develop new, partnerships.

In addition, Sonoma Water will identify major Tribal, national, regional, utility, and organizational partners that share similar climate risks and strategies. Participation in regional climate collaboratives and the formation of regional alliances will assist in furthering adaptation strategy implementation.

Some of the important federal and state partners include:

- U.S. Army Corps of Engineers (USACE) including the San Francisco District, South Pacific Division, Engineering Research Development Center, and Hydrologic Engineering Center
- NOAA including the National Weather Service, Office Atmospheric Research and National Marine Fisheries Service
- U.S. Geological Survey (USGS)
- U.S. Department of Agriculture, NRCS
- Scripps Institution of Oceanography (SIO)
- U.S. Bureau of Reclamation (USBR)
- California Department of Water Resources (DWR)
- California Department of Fish and Wildlife (CDFW)
- State Water Resources Control Board (SWRCB)
- North Coast and San Francisco Bay Regional Water Quality Control Boards
- Lawrence Berkeley National Laboratory (LBNL)
- U.C. Cooperative Extension (UCCE)
- California Department of Forestry and Fire Prevention (CalFIRE)
- California Natural Resources Agency
- California Department of Conservation

Significant regional partners may include:

- Tribes and Federated Tribes
- Sonoma County RCPA
- North Coast Resource Partnership
- Bay Area Integrated Regional Water Management Program
- NBCAI
- The Climate Center – Sonoma County
- Sonoma County Agricultural Preservation & Open Space District
- Sonoma and Gold Ridge Resource Conservation Districts
- Sonoma Water Contractors
- Groundwater Sustainability Agencies for Sonoma Valley, Petaluma Valley and the Santa Rosa Plain
- Flood Zones Advisory Committees
- Local Fire Districts

Finally, the agricultural industry, Tribes, and the general public within Sonoma Water's service area are important stakeholders, and partners. It is possible that the implementation of the adaptation strategies may be associated with new costs and potentially rate increases. Ensuring property owners and the general public are aware of the risks and supportive of adaptation through community outreach and engagement will be important in building the support necessary to ultimately implement projects for effective public health and safety.

7.3.5 Monitoring

As indicated throughout this plan, climate change planning requires an adaptive management approach. Monitoring of both adaptation strategy implementation and observable regional changes in climate allows decisions to be made related to effectiveness of programs and timing of program need.

A monitoring program should be established that identifies parameters to measure over time to understand increasing or reducing risk, changes in climate, and critical indicators and thresholds that would trigger further investment or investigations. Monitoring could also support alignment of current plans with identified adaptation needs (disaster response plans, capital improvements plans, etc.) and lead to planned updates to the climate adaptation strategies.

7.4 Summary and Next Steps

Sonoma Water's Climate Adaptation Plan represents a significant step forward to address climate risks to its water, flood management, and sanitation system infrastructure and operations. The CAP describes the approach and results of the vulnerability and risk assessments for each of these systems and identifies those with highest climate risk. The CAP outlines a range of potential adaptation measures to address these climate-related risks and provides a set of adaptation portfolio recommendations that integrate various concepts within and across the systems. To move toward implementation of adaptation strategies, a number of considerations and enabling conditions are necessary including funding, science and tools, organization alignment, partnerships and public awareness, and monitoring.

The suggested next steps are focused on ensuring Sonoma Water can deliver on the recommendations provided in the CAP. Specifically, the immediate next steps include:

- Obtain Board approval and support for recommendations in the CAP.
- Map the implementation pathway and prioritization for each project within the recommended portfolios, including target program and enabling conditions.
- Actively identify and pursue available funding sources, and explore innovative resilience funds.
- Organize Sonoma Water staff and build internal structure to mainstream climate resilience within the organization.
- Develop, build, and expand partnerships and outreach with federal, state, regional, local and county entities.
- Establish a robust monitoring plan and timeline for updating the CAP.

The urgency of climate change in the region is upon us. In the past five years, multiple wildfires have severely impacted the region, flooding has caused inundation in many areas, and power shutoffs due to fire risk have led to emergency operations. Now, severe drought is being experienced throughout the western United States and acutely in the Russian River watershed. Sonoma Water is on the right path for achieving climate resilience. Ensuring support for the recommendations in the plan and accelerating implementation of the most robust actions will provide significant benefit to Sonoma Water, its stakeholders, and the region as a whole.

SECTION 8

References

Bedsworth, L., D. Cayan, G. Franco, L. Fisher, and S. Ziaja. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, and California Public Utilities Commission). 2019. California's Fourth Climate Change Assessment: Statewide Summary Report. Publication number: SUM-CCCA4-2018-013.

Brekke et al. 2013. Downscaled CMIP3 and CMIP5 Climate Projections Release of Downscaled CMIP5 Climate Projections, Comparison with Preceding Information, and Summary of User Needs

Bryant, B. P., and A. L. Westerling. 2012. Scenarios to Evaluate Long-Term Wildfire Risk in California: New Methods for Considering Links Between Changing Demography, Land Use and Climate. California Energy Commission. Publication number: CEC-500-2012-030.

California Department of Water Resources (DWR). 2017. Climate Change Analysis – Phase IIB Draft Technical Memorandum.

California Department of Water Resources Climate Change Technical Advisory Group (CCTAG). 2015. Perspectives and guidance for climate change analysis. California Department of Water Resources Technical Information Record. p. 142.

Cal Adapt Wildfire Tool. 2018. http://cal-adapt.org/tools/wildfire

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham and R. Flick. 2009. Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment. California Climate Change Center, Sacramento, CA. Publication #CEC-500-2009-014-F, 64 pages, August.

Cayan, D. R., A. L. Luers, G. Franco, M. Hanemann, B. Croes, and E. Vine. 2008a. Overview of the California climate change scenarios project. Climatic Change 87(Suppl 1): S1–S6, doi: 10.1007/s10584-007-9352-2.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree, and K. Hayhoe. 2008b. Climate Change Scenarios for the California Region. Climatic Change, published online January 26. doi: 10.1007/s10584-007-9377-6.

Cayan, D. R., P. D. Bromirski, K. Hayhoe, M. Tyree, M. D. Dettinger, and R. E. Flick. 2008c. Climate Change Projections of Sea Level Extremes Along the California Coast. Climatic Change 87(Suppl 1): S57–S73, doi: 10.1007/s10584-007-9376-7.

Corringham, T. W., Martin Ralph, F., Gershunov, A., Cayan, D. R., & Talbot, C. A. 2019. Atmospheric rivers drive flood damages in the western United States. Science Advances, 5(12). DOI:10.1126/sciadv.aax4631.

Delaney, C., Hartman, R., Mendoza, J, Dettinger, M., Monache, L. Jasperse, J., Ralph, F., Talbot, C., Brown, J., Reynolds, D., and Evett, S. 2020. Forecast Informed Reservoir Operations Using Ensemble Streamflow Predictions for a Multipurpose Reservoir in Northern California. Water Resources Research. Available online at https://doi.org/10.1029/2019WR026604

Dettinger M, Hidalgo H, Das T, Cayan D, Knowles N. 2009. Projections of potential flood regime changes in California. Public Interest Energy Research, California Energy Commission, Sacramento, CA. Available online at http://www.energy.ca.gov/2009publications/CEC-500-2009-050/CEC-500-2009-050-D.PDF

Dettinger, M. 2011. Climate Change, Atmospheric Rivers And Floods In California—A Multi-Model Analysis of Storm Frequency And Magnitude Changes. Journal of the American Water Resources Association. Volume 47, No. 3. June.

Ekstrom, Julia A., and Susanne C. Moser. 2012. Climate Change Impacts, Vulnerabilities, and Adaptation in the San Francisco Bay Area: A Synthesis of PIER Program Reports and Other Relevant Research. California Energy Commission. Publication number: CEC-500-2012-071.

FIRO Steering Committee. 2017., Preliminary Viability Assessment of Lake Mendocino Forecast Informed Reservoir Operations. (http://cw3e.ucsd.edu/firo-preliminary-viability-assessment-for-lake-mendocino/#TOP)

Foltz, R.B.; Robichaud, P.R.; Rhee, H. 2009. A synthesis of post-fire road treatments for BAER teams: methods, treatment effectiveness, and decision making tools for rehabilitation. Gen. Tech. Rep. RMRS-GTR-228. Fort Collins, CO. U.S.D.A., Forest Service, Rocky Mountain Research Station. 152 p.

Flint, L.E, and Flint, A.L. 2012a. Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis: Ecological Processes, v. 1, no. 1.

Flint, L.E., and Flint, A.L. 2012b. Simulation of climate change in San Francisco Bay Basins, California: Case studies in the Russian River Valley and Santa Cruz Mountains: U.S. Geological Survey Scientific Investigations Report 2012–5132, 55 p.

Flint et al. 2013. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. Ecological Processes, 2:25

Gershunov, A., Shulgina, T., Clemesha, R.E.S. et al. 2019. Precipitation regime change in Western North America: The role of Atmospheric Rivers. Sci Rep 9, 9944. DOI: 10.1038/s41598-019-46169-w.

Griggs, G, Árvai, J, Cayan, D, DeConto, R, Fox, J, Fricker, HA, Kopp, RE, Tebaldi, C, Whiteman, EA (California Ocean Protection Council Science Advisory Team Working Group). Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Science Trust, April 2017.

Huang, X., Swain, D.L., and Hall, A.D. (2020). "Future precipitation increase from very high resolution ensemble downscaling of extreme atmospheric river storms in California." Science Advances 6 (29). DOI: 10.1126/sciadv.aba1323.

Intergovernmental Panel on Climate Change (IPCC). 2007. AR4 Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change (IPCC). 2013. AR5 Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change (IPCC). 2021. AR6 Climate Change 2021: The Physical Science Basis. Contribution of Working Group 1 to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Jasperse, J., F. M. Ralph, M. Anderson, L. Brekke, N. Malasavage, M. D. Dettinger, J. Forbis, J. Fuller, C. Talbot, R. Webb, and A. Haynes. 2021. Lake Mendocino Forecast Informed Reservoir Operations Final Viability Assessment, UC San Diego.

Kopp, R. E., R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, and C. Tebaldi. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites, Earth's Future, 2, 383–406, doi:10.1002/2014EF000239

Krawchuk, M., and M. Moritz. 2012. Fire and Climate Change in California: Changes in the Distribution and Frequency of Fire in Climates of the Future and Recent Past (1911– 2099). California Energy Commission. Publication number: CEC-500-2012-026.

Mastrandrea et al. 2010. Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Retrieved from https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf

Maurer, E. P., L. Brekke, T. Pruitt, and P.B. Duffy. 2007. "Fine-Resolution Climate Projections Enhance Regional Climate Change Impact Studies." Eos, Transactions, American Geophysical Union. 88 (47), 504.

Micheli, Elisabeth, Flint, Lorraine, Veloz, Sam, Johnson, Kelley, Heller, Nicole. 2016. Climate Ready North Bay Vulnerability Assessment Data Products - Sonoma County Water Agency, Technical Memorandum.

National Research Council. 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. Committee on Sea Level Rise in California, Oregon, and Washington; Board on Earth Sciences and Resources; Ocean Studies Board; Division on Earth and Life Studies. The National Academies Press. Washington, D.C.

North Bay Climate Adaptation Initiative (NBCAI), 2016. Available at: http://www.northbayclimate.org/

North Bay Climate Ready Natural Resource Managers User Group Meeting, 2014

Ocean Protection Council. 2018. State of California Sea-Level Rise Guidance 2018 Update. Retrieved from http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf.

Parker, G. 1990. Surface-based bedload transport relation for gravel rivers. Journal of Hydraulic Research. 28: 417-436

Pierce D., Das T., Cayan D., Maurer E., Miller N., Bao Y., Kanamitsu M., Yoshimura K., Snyder M., Sloan L., Franco G., and Tyree M. March 30, 2012. Probabilistic estimates of future changes in California temperature and precipitation using statistical and dynamical downscaling. Climate Dynamics, doi: 10.1007/s00382-012-1337-9

Pierce, David W., Daniel R. Cayan, and Bridget L. Thrasher. 2014. "Statistical Downscaling Using Localized Constructed Analogs (LOCA)." J. Hydrometeor. 15, 2558–2585.

Pierce, D. W., J. F. Kalansky, and D. R. Cayan. 2018. Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CNRA-CEC-2018-006.

Pitlick, John, Cui, Yantao, Wilcock, Peter. 2009. Manual for computing bed load transport using BAGS (Bedload Assessment for Gravel-bed Streams) Software. Gen. Tech. Rep. RMRS-GTR-223. Fort Collins, CO: U.S. Department of

Agriculture, Forest Service, Rocky Mountain Research Station. 45 p.

Ralph, F. M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, D. R. Cayan, and A. B. White. 2006. Flooding on California's Russian River: Role of atmospheric rivers, Geophys. Res. Lett., 33, L13801, doi:10.1029/2006GL026689

Sonoma County Water Agency (SCWA). 2016. Russian River Hydrologic Modeling for the Fish Habitat Flows and Water Rights Project. August 2016.

Sonoma County Water Agency (SCWA). 2017. Santa Rosa Creek Hydrology and Hydraulics: Hydraulic Modeling Report. Prepared by ESA. D130851.00.

Taylor, Karl E., Ronald J. Stouffer, Gerald A. Meehl. 2012. An Overview of CMIP5 and the Experiment Design. Bull. Amer. Meteor. Soc., 93, 485–498.

U.S. Global Change Research Program (USGCRP). 2017. Climate Science Special Report: Four National Climate Assessment: Volume I. U.S. Global Change Research Program, Washington, DC.

Westerling A., Bryant B., Preisler H., Holmes T., Hidalgo H., Das T., and Shrestha S. 2011. Climate change and growth scenarios in California wildfire. Climatic Change, 109 (Suppl 1), S445-S463; doi: 10.1007/s10584-011-0329-9.

Westerling, Anthony Leroy. (University of California, Merced). 2018. Wildfire Simulations for California's Fourth Climate Change Assessment: Projecting Changes in Extreme Wildfire Events with a Warming Climate. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC-2018-014.

Wilcock, P.R., Crowe, J.C. 2003. Surface-based transport model for mixed-size sediment. Journal of Hydraulic Engineering. 129: 120-128.

Appendix A. Background of Sonoma Water Climate Resilience Efforts

Appendix B. Vulnerability Assessment

Appendix C. Risk Assessment Special Studies

Appendix D. Adaptation Concepts and Strategies

Appendix E. Potential Funding Sources

Appendix F. Stakeholder Engagement