Sonoma County Water Agency Climate Vulnerability Assessment and Adaptation Work Plan

Work Plan

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A Stakeholder Engagement Plan

Acronyms and Abbreviations

AR	Atmospheric River
ARO	Atmospheric River Observatory
BAP	Basin Advisory Panel
BCM	Basin Characterization Model
CDFW	California Department of Fish and Wildlife
CMIP3	Coupled Model Intercomparison Project 3
CMIP5	Coupled Model Intercomparison Project 5
CNAP	California-Nevada Applications Program
CoSMoS	Coastal Storm Modeling System
CSO	Combined sewer overflow
CVFPP	Central Valley Flood Protection Plan
CW3E	Center for Western Weather and Water Extremes
DWR	California Department of Water Resources
FIRO	Forecast informed reservoir operations
GHG	Greenhouse gas
GCM	General Circulation Model or Global Climate Model
HMT	Hydrometeorology Testbed
IPCC	Intergovernmental Panel on Climate Change
IWRSS	Integrated Water Resources Science and Services
MOA	Memorandum of agreement
NBCAI	North Bay Climate Adaptation Initiative
NGO	Non-governmental organization
NIDIS	National Integrated Drought Information System
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
PG&E	Pacific Gas and Electric
QPI	Quantitative Precipitation Information
RCPA	Sonoma County Regional Climate Protection Authority
RRWPC	Russian River Watershed Protection Committee
RWQCB	Regional Water Quality Control Board

SARP	Sectoral Applications Research Program
SCWA	Sonoma County Water Agency
SIO	Scripps Institution of Oceanography
SSMP	Sanitary sewer management plan
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VIC	Variable Infiltration Model
WSSAP	Water Supply Strategies Action Plan

Work Plan

1.0 Introduction

The Sonoma County Water Agency (SCWA) is a regional leader in water resources management. SCWA 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 SCWA's water supply, sanitation, and flood control systems. Climate variability and climate change are significant drivers influencing the future reliability of these systems. SCWA is developing a forward-looking climate adaptation plan to serve as a roadmap for the agency's assessment of climate risks and potential adaptation strategies related to its water supply, sanitation, and flood control infrastructure and operations.

As part of these efforts, CH2M has developed a draft work plan (Work Plan) for the development of the SCWA Climate Vulnerability Assessment and Adaptation Plan (Climate Adaptation Plan). The adaptation plan will serve to guide SCWA in terms of prioritizing and allocating resources towards practices and projects that will improve resiliency of its operations and facilities to climate variability and change. The Work Plan is intended to outline the overall approach for completion of the vulnerability assessment and to guide the development of the adaptation plan. The recommended approach for developing the Climate Adaptation Plan is outlined in this Work Plan and is intended to help organize and prioritize work elements. The Work Plan includes the following sections:

- **Section 1 – Introduction**

  Introduction to the Work Plan.

- **Section 2 – Climate Adaptation Planning Framework**

  Brief section that outlines the general approach to the vulnerability assessment and adaptation planning. Introduces the major steps: (1) scoping, (2) climate science and system understanding, (3) vulnerability and risk assessment, (4) adaptation options and strategy development, and (5) implementation and monitoring.

- **Section 3 - Vision and Objectives**

  Describes vision and strategy for the development and desired outcomes for the climate vulnerability assessment and adaptation plan.

- **Section 4 - SCWA Climate Science and Adaptation Efforts**

  This section highlights SCWA and SCWA-supported climate science and adaptation efforts. A summary of major climate activities that SCWA has been engaged in to date is included.

- **Section 5 - Climate and Hydrologic Science**

  This section includes a synthesis of climate and hydrologic science for the region. Global to regional aspects of climate change are discussed along with current projected changes in key climate variables (threats).

- **Section 6 – Potential Climate Impacts to SCWA Infrastructure**

This section provides a high level description of potential impacts to SCWA water supply, flood control, and sanitation infrastructure and operations.

- **Section 7 - Vulnerability and Risk Assessment**

  This section outlines the approach and examples for conducting the vulnerability and risk assessment, describes vulnerability and risk matrices, ratings, and how the assessment will be developed.

- **Section 8 - Adaptation Options and Strategies**

  Section 8 outlines the approach for identifying, developing, and evaluating adaptation options. The section also outlines the approach for integrating options into adaptation strategies.

- **Section 9 – Stakeholder Engagement**

  This section summarizes the stakeholder engagement plan for this project. The full stakeholder engagement plan is included as Appendix A.

- **Section 10 - References**

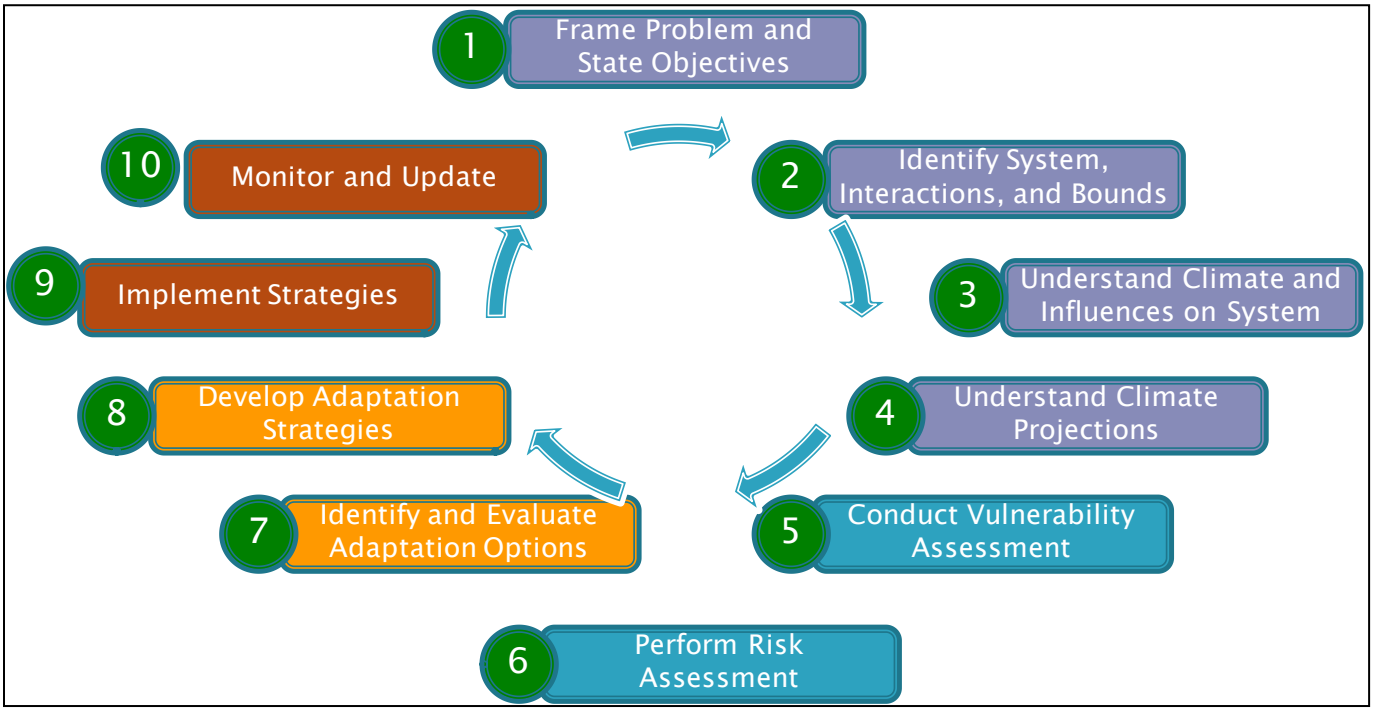
  References cited in this Work Plan.

- ***Appendix A – Stakeholder Engagement Plan***

2.0 Climate Adaptation Planning Framework

Planning for climate change and adaptation requires a structured framework to ensure that scope and objectives are established early in the planning effort, that climate related vulnerabilities and risks are understood, that adaptation strategies are focused on improving resilience, and that communication of the value of climate adaptation and future investments is facilitated to technical and non-technical audiences. The general climate adaptation planning framework outlined in this work plan is shown graphically in Figure 1 (CH2M HILL 2013). The framework consists of a 10-step process consisting of five main activities: scoping (steps 1-2), climate science and system understanding (steps 3-4), vulnerability and risk assessments (steps 5-6), adaptation options and strategy development (steps 7-8), and implementation and monitoring (steps 9-10).

Figure 1. General Framework for Climate Risk and Resilience Planning (CH2M HILL 2013).



The key steps in overall framework are the following:

1. **Frame the Problem and State Objectives (Scoping)**

   Frame the questions to be addressed and desired outcomes from both a technical and policy perspective. *See section 3 of this Work Plan.*

2. **Identify System, Components, Interactions, and Bounds of Study (Scoping)**

   Identify system to be analyzed, the individual components, interactions between the components, and the bounds of the system to be addressed in the study. *See section 3 of this Work Plan.*

3. **Understand Climate and Climate Influences of System (Understanding)**

   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. *See section 4 and 5 of this Work Plan.*

4. **Understand Climate Projections (Understanding)**

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. *See section 4 and 5 of this Work Plan.*

5. **Conduct Vulnerability Assessment (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. *See section 6 and 7 of this Work Plan.*

6. **Perform Risk Assessment (Assessment)**

   Takes the vulnerability assessment one step further and relates it to the consequence and likelihood of specific climate changes. 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. *See section 6 and 7 of this Work Plan.*

7. **Identify and Evaluate Adaptation Options (Adaptation)**

   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. *See section 8 of this Work Plan.*

8. **Develop Adaptation Strategies (Adaptation)**

   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. *See section 8 of this Work Plan.*

9. **Implement Strategies (Implementation)**

   Implement selected strategies and ensure that physical, operational, and policy elements are consistently aligned with risk reduction strategies.

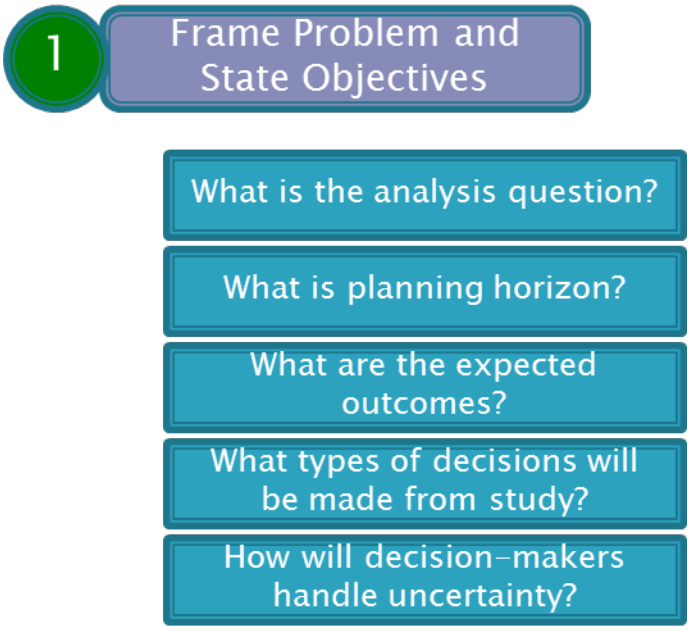
10. **Monitor Effectiveness (Implementation)**

    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.

The Work Plan includes activities needed to address scoping, climate science and system understanding, vulnerability and risk assessments, and adaptation options and strategy development (steps 1-8), as well as a robust stakeholder engagement process for each major phase of work. The implementation and monitoring steps (steps 9-10) are not included in the Work Plan, but these steps are expected to be developed once specific adaptation strategies are selected and the bundling of measures for implementation is completed.

3.0 Vision and Objectives

Critical to establishing a robust climate adaptation planning process are framing discussions with key decision-makers to develop a common vision of the questions to be answered and desired outcomes of the adaptation plan. Based on input from the SCWA climate adaptation planning team at initial chartering meetings and several meetings with stakeholders and related climate program teams, this section has been prepared to articulate the vision and objectives, and serve as the guiding set of principles for the Climate Adaptation Plan.



3.1 Vision

SCWA is a regional leader in water resources management. SCWA 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 SCWA's water supply, sanitation, and flood control systems. Climate variability and climate change are significant drivers influencing the future reliability of these systems. SCWA has developed a Water Supply Strategies Actions Plan (WSSAP) that help guide future investments and management of the agency's resources. Continuing with this regional leadership, SCWA is developing a forward-looking climate adaptation plan to serve as a roadmap for the agency's assessment of climate risks and potential adaptation strategies related to its water supply, sanitation, and flood control infrastructure and operations.

3.2 Purpose

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

3.3 Key Objectives

The key objectives of the development of the Climate Adaptation Plan are to:

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

5. Identify, prioritize, and cost adaptation measures to improve the system reliability
6. Develop a strategy for improving the resilience of SCWA's infrastructure and operations and to assist in guiding future infrastructure investments and operational changes

The recommended approach for achieving each of these objectives is outlined in this Work Plan and will help organize and prioritize work elements.

3.4 Desired Outcomes and Potential Decisions to be Supported

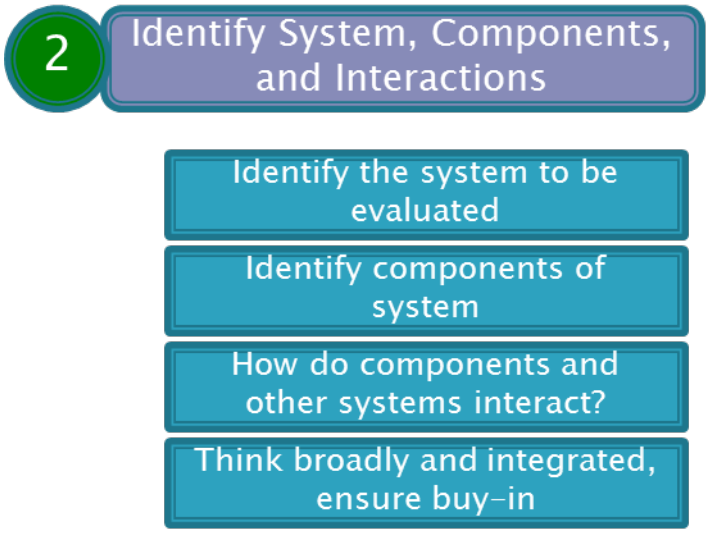
While the purpose of the Work Plan is to serve as a roadmap for developing, evaluating, and implementing adaptation strategies, it is useful to envision the long-term desired outcomes of the Climate Adaptation Plan and the types of decisions that the plan may support. Foremost, the Climate Adaptation Plan should help guide SCWA activities and investments to improve the resiliency of SCWA's water supply, flood control, and sanitation infrastructure to future changes in climate. The Climate Adaptation Plan could also support the following specific activities:

- Assist in developing long-range agency strategies for water supply, flood control, and sanitation
- Support the development of prioritized projects and programs for inclusion in the Capital Projects Plans
- Support the identification and leveraging of state and federal funding sources for implementation of specific adaptation measures
- Provide support for policy direction and agency engagement in climate adaptation and resiliency efforts
- Provide specific, measurable indicators of climate change that relate to SCWA system risk to improve confidence in making climate-related investment decisions
- Provide supporting metrics for monitoring climate adaptation measure implementation and resiliency improvements over time
- Provide a framework to inform engagement and coordination with related regional climate adaptation efforts

It is envisioned that several other types of SCWA-related decisions can be supported from the final Climate Adaptation Plan. These may evolve over time, and may be yet unknown, but the current process will be developed using these listed supported decisions as guides for the eventual use of the information in the Climate Adaptation Plan.

3.5 SCWA'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? Quite obviously, SCWA's core water supply, flood control, and sanitation infrastructure and operations are influenced by climate, watershed, and river conditions. However,



there are also significant regional interfaces related to agricultural water demand, groundwater management, watershed protection, river and estuary restoration efforts, state and federal regulations, and other efforts that influence the reliability of the SCWA core infrastructure and operations.

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

An initial listing of the SCWA core systems and regional interfaces related to water supply, flood control, and sanitation is included in Table 1.

Table 1. Preliminary listing of SCWA core system components and regional interfaces to be considered in the climate adaptation plan

Water Supply	Flood Control	Sanitation
SCWA Core System		
Russian River Project: Lake Mendocino, Lake Sonoma, Maintaining In-stream Russian River and Dry Creek Flows, 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, solids handling, equalization for six districts/zones
Russian River Diversion Facilities: Inflatable Dam, Fish Screens and Ladders, Infiltration Ponds, Collector Wells, Chlorination and pH Adjustment Facilities	**Spring Lake**: Reservoir and flood control facilities	**Water Reclamation**: Water reclamation facilities
Groundwater Wells: Mirabel Standby Wells, Santa Rosa Plain Wells	**Stream Maintenance Program**: Flood control and natural channels	**Discharge/Disposal**: Stream discharge or reuse delivery systems
Transmission System: Aqueduct, Booster Pumps, Storage Tanks, Customer Delivery Connections		**Sanitary Sewer Systems**: Sanitary sewer systems in each of the eight districts/zones for which SCWA 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-SCWA 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	
Recycled Water: North Bay Water Reuse Authority		
Water Conservation: Urban and agricultural water conservation planning		
Agricultural Demand: Agricultural demand and use with Russian River		

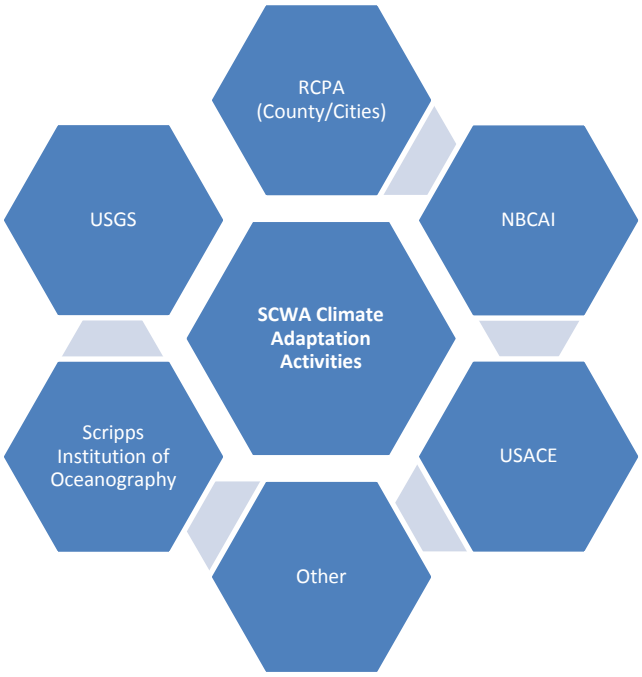
In addition to the regional interfaces related to SCWA's physical, operational, and management systems, there are number of on-going and related climate adaptation activities in Sonoma County for which technical and coordination interfaces will need to be recognized in the Climate Adaptation Plan. Important regional climate adaptation activities that will need to be recognized include:

- 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 (e.g. Climate Action 2020)*
- 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*

- National Oceanic and Atmospheric Administration (NOAA) Hydrometeorology Testbed – *collaboration with NOAA 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. SCWA was recently awarded a grant to develop a strategy for habitat conservation in the Russian River watershed via the Habitat Blueprint framework.*
- Integrated Water Resources Science and Services (IWRSS) - *SCWA is partnering with IWRSS to address stakeholder issues with lack of organization in forecasting, hydrologic modeling, data management, data collection and monitoring.*

SCWA is already engaged in, or leading, many of the climate activities identified above. The Climate Adaptation Plan will benefit from recognizing the on-going activities, the relationship to SCWA's climate adaptation needs, and identifying opportunities to further leverage these activities to support the vulnerability and risk assessments and adaptation planning.

Figure 2. Climate adaptation plan will need to recognize the on-going, collaborative climate adaptation planning activities in the region



3.6 Planning Horizons

Planning horizons for climate adaptation plans typically span 50 to 100 years. This long-term view has traditionally been taken due to the time-scales for realizing changes in the climate system that can be attributed to climate change, rather than natural climate variability. In addition, many climate adaptation plans have been developed to support long-term policy or strategy statements, rather than specific actionable adaptation measures.

For the SCWA Climate Adaptation Plan, it is proposed to view the future trajectory of climate in terms of three periods: 25-, 50-, and 75-years from the present. The near-term period will permit evaluation of vulnerabilities and measures to support Urban Water Management Plans and early start actions in Capital Projects Plans. The two longer-term periods will allow a better assessment of the change signal versus the natural variability noise, and will allow improved confidence that near-term projections are robust in the long-term. These three time periods will also allow assessments of approximate timing of climate change impacts, the confidence in the assessment of impacts, and phasing of adaptation measures.

3.7 Uncertainty

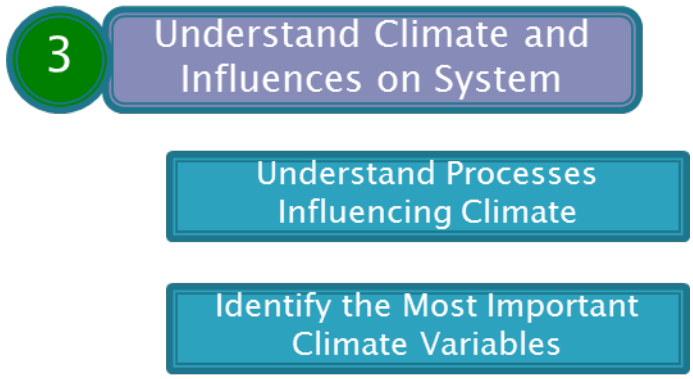
Projecting the future is always fraught with uncertainty. Climate model projections, given the uncertainty in the ability to simulate the global and regional climate systems, global emission pathways, and spatial downscaling, present a unique challenge when attempting to translate climate information into actionable decisions. Exploring multiple time horizons (as discussed previously) and multiple model projections is important to be able to assess the robustness of certain aspects of future climate projections. At least five alternative projections, selected or derived from the ensemble of available projections, are recommended for use in SCWA's Climate Adaptation Planning. These projections should represent the range of available projections and include at least one hybrid approach that utilizes historical natural variability combined with climate change projections to gauge the signal versus noise aspects of climate models.

3.8 Focusing on Resiliency

Management of water supply, flood control, and sanitation systems in Sonoma County is a highly complex endeavor. The water supply and flood control systems have already been found to be highly sensitive to recent historical extremes related to floods and droughts. Future growth will increase demands and require more integrated measures to more effectively provide these services. Climate variability and change will further exacerbate the risks to these systems. While significant uncertainty exists in assigning magnitudes of change for certain climate variables, the Climate Adaptation Plan can provide measures that will improve the resiliency of these systems. Getting the "correct" projection is not possible, nor necessary. Rather the recommended focus is on exploring the vulnerability of SCWA's systems to potential changes in climate, and identifying measures that are robust across the spectrum of future changes. The Work Plan will ensure that the guidance keeps a focus on systems and resiliency.

4.0 SCWA Climate Science and Adaptation Efforts

SCWA is a regional and national leader in climate science and adaptation planning and has supported a number of efforts in both the science and planning areas. This section provides a summary of the climate-related activities that SCWA has been engaged in to date.



4.1 SCWA-Supported Climate Science Studies

Recognizing the sensitivity of the region to climate extremes and the potential for changes in climate in the future, SCWA has made considerable investments in climate science to improve understanding of, and planning for, climate changes in the region. SCWA is supporting several climate science efforts in collaboration with various research agencies, such as the USGS, SIO, and NOAA. These efforts have resulted in improved understanding of the regional climate threats and have put the SCWA on the cutting edge of climate planning. The following is a brief review of SCWA-supported programs and studies related to regional climate science.

4.1.1 USGS Climate Science and Watershed Hydrologic Modeling

SCWA has been collaborating with the USGS on regional climate downscaling and hydrologic modeling for the Russian River watershed. The 2012a Flint and Flint study (2012a, Ecological Processes) was conducted to refine climate change impacts on hydrology and ecology from a global scale to a smaller scale. A methodology was spatially developed using a gradient-inverse-distance-squared approach for hydrologic modeling applications. The methodology is intended to reduce inaccuracies in climate data, and new results were produced for the US at 4km, the southwest US at 270m, and California at 90m.

Another study by the same authors (2012b, USGS Scientific Investigations Report 2012–5132) was conducted to investigate how climate change affects water resources and habitats in the San Francisco Bay area, specifically areas in the Russian River Valley and Santa Cruz Mountains. The Basin Characterization Model (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.

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

4.1.2 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 atmospheric rivers, 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. SIO/USGS are 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 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.

SCWA has been an early and leading partner with NOAA/SIO supporting improved research on atmospheric river characterization and forecasting. The NOAA/SIO's West Coast Atmospheric River Program is conducting research on atmospheric rivers to help understand their processes to support water resource and flood risk planning. ARs are classified as narrow (400-600 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 30-50% of annual precipitation on the west coast take place during just a few AR events and are significant features in the global water cycle.

4.1.2.1 *NOAA Hydrometeorology Testbed (HMT)*

ARs previously have only been identified by measuring atmospheric moisture level content with satellite imagery. However, the issue with only using satellite imagery for detecting ARs 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 SCWA, for testing new ideas, technologies, and developing predictive models for weather forecasting. A memorandum of agreement (MOA) between SCWA 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 cases 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. Four AROs are to be installed by 2014 along the California coast in Goleta, Point Sur, Eureka and Bodega Bay, costing roughly $11 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.

4.1.2.2 *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 SCWA 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 will produce a climate change adaptation/drought readiness report that will assist water resource planners in identifying drought indicators and linked response measures to reduce drought impacts.

4.1.2.3 *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 SCWA 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 SCWA 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.

4.1.2.4 *Center for Western Weather and Water Extremes (CW3E)*

A formal agreement was recently made between SCWA and the CW3E, a new center at SIO, which was initiated with three projects (http://woodland.ucsd.edu/?p=2007). The first project includes the study of atmospheric rivers role in filling Lake Mendocino and forecasting to aid in retaining water without increasing flood risk. The second project is a NOAA-funded climate program aiming to study how atmospheric rivers aid in ending droughts in the Russian River, including climate change effects, drought scenarios and drought readiness assessments. The third project is a feasibility assessment in cooperation with the USACE for the possibility of forecast-informed reservoir operations (FIRO) for Lake Mendocino.

4.1.3 NOAA Habitat Blueprint Sea Level Rise Project

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. SCWA 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 will be employed. The focus for the strategy in this region will be to:

1. Rebuild endangered coho and threatened Chinook and steelhead stocks to sustainable levels through habitat protection and restoration.
2. Improve frost, rainfall, and river forecasts in the Russian River watershed through improved data collection and modeling.
3. Increase community and ecosystem resiliency to flooding and drought through improved planning and water management strategies.

The SCWA will also be collaborating with the Gold Ridge Resource Conservation District, University of California Davis Bodega Marine Laboratory, SIO, University of California Cooperative Extension, Environmental Science Associates, USGSy, and NOAA's Office of Atmospheric Research. The collaboration team will be implementing six projects to support the habitat conservation effort. Project 3, the Russian River Estuary: Climate Change Sea Level Rise project, will involve climate modeling that will help inform resource managers on the impacts of climate change to the salmon and steelhead habitat. The model will also inform fishery managers on priority actions for climate change adaptation.

4.1.4 Integrated Water Resources Science and Services (IWRSS)

The USACE (U.S. Department of the Army), USGS (U.S. Department of the Interior), and the NOAA (U.S. Department of Commerce) 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 will also provide 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. Currently, the IWRSS is partnering with SCWA to address stakeholder issues with lack of organization in forecasting, hydrologic modeling, data management, data collection and monitoring. Pilot projects proposed for this program include improved forecasting technology to benefit water management in Lake Mendocino, development of a hydrologic model inventory to identify gaps in modeling efforts, identify locations to optimize stream gauge monitoring, and develop a common data access repository.

4.1.5 Climate Ready Sonoma County and North Bay Climate Ready

In December 2014, the RCPA released the draft 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 the SCWA, 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.

4.2 Summary of Current Climate Adaptation Planning Efforts, Partnerships, and Projects

SCWA is engaged in several climate science and adaptation planning efforts in the Sonoma and North Bay regions. The SCWA-supported climate science related efforts have been summarized previously. The following section includes a brief review of the known activities and relevant related studies or efforts, and can be used to help understand and plan future climate adaptation activities. The activities are separated into three sections: planning efforts, partnerships, and projects.

4.2.1 Planning Efforts

4.2.1.1 *Water Supply Strategies Action Plan*

The 2013 SCWA Water Supply Strategies Action Plan (WSSAP) developed nine strategies to improve water and biological resource management efforts within Sonoma County. Many immediate, near term and long term actions were identified. Immediate actions included increased water conservation, water reuse, water fixture retrofits, leak detection, and enhanced weather forecasting for frost protection and irrigation by agriculture. Water resource management and reliability immediate actions include a groundwater banking feasibility study, forming a science panel to evaluate existing data and develop a conceptual model to describe the hydrologic system upstream of the Dry Creek and Russian River junction, supporting the SCWA and USACE efforts in enhancing operations at Lake Mendocino to increase water levels, and conducting water supply and reliability analysis of the upper Russian River. Biological conservation immediate actions involve ResSim modeling for the Fish Flow Project EIR, developing a new hydrologic index, as well as modifying the Russian River estuary program for steelhead rearing habitat. Other projects identified within the WSSAP include flood control planning, groundwater and stormwater management, and improvements in treatment and transmission systems.

Strategy Three of the WSSAP focuses on incorporating climate change forecasts into water supply and flood protection planning. The first immediate action involves conducting a climate change model for the Russian River and Sonoma Valley watersheds. The goal of the model is to take large scale climate forecasts and downscale them to the local watershed scale. The output data from the model will then be used as inputs into the aforementioned ResSim model, as well as the Sonoma Valley and Santa Rosa Plain groundwater models. The second immediate action will support federal partners in the development of the Russian River HMT that will improve temperature forecasting in Alexander Valley, as well as enhance precipitation monitoring and forecasting throughout the valley. The last immediate actions will develop adaptation measures after the information gathering from federal, state and local agencies and NGOs has been conducted, as well as the modeling efforts. The long term action in Strategy Three will be determined based on advances in scientific understanding of climate processes and forecast modeling.

4.2.1.2 *Santa Rosa Plain Groundwater Study/Management Plan*

A comprehensive study was conducted by USGS over seven years as part of a program for SCWA to characterize the surface and groundwater resources of the Santa Rosa Plain Watershed. The study found pumping is the largest discharge from the basin, the largest groundwater users are agriculture and rural residents. On average, approximately 3,300 acre-feet (4%) more water is pumped out every year than is recharged back into the basin. However, one groundwater pumping depression in the southern Plain region formed in the 1980's and 1990's is almost fully recovered on account of the change to importing surface water from the Russian River to replace groundwater pumping over the past decade. The groundwater quality varies greatly throughout the basin, with natural contamination problems as well as an increase in chloride and specific conductance. For the second phase of the study, USGS developed a coupled surface and groundwater model to characterize the water budget for the study area. In addition, SCWA is the lead agency for a groundwater management plan for the Santa Rosa Plain. The management program is comprised of several stakeholder groups representing groundwater interests that form a Basin Advisory Panel. (BAP) The BAP and SCWA are using information from the USGS study and model to support management activities and implement a monitoring program for the groundwater and surface water resources. The groundwater model has been used to simulate the impacts of different climate futures on surface and groundwater conditions. The AB 3030/SB 1938 compliant groundwater management plan was approved by the Basin Advisory Panel in August 2014 and SCWA's board in October 2014.

4.2.1.3 *Sonoma Valley Groundwater Management Program*

The USGS also completed a groundwater study and model of the Sonoma Valley for SCWA in 2006. A Groundwater Management Plan was developed by a group of twenty stakeholders called the Basin Advisory Panel (BAP), representatives from local agriculture, dairy, government, water purveyors, business and environmental interests in 2007. The BAP developed the Groundwater Management Plan, which was adopted by the SCWA, City of Sonoma, and Valley of the Moon Water District in 2007, with SCWA serving as the lead agency for the management program. The plan assesses water management actions that will sustain resources for future generations such as groundwater recharge, monitoring, water conservation and recycled water use. Currently the program is focusing on advancing model approaches for conceptualizing groundwater recharge/rainwater harvesting, data collection and analysis, and monitoring groundwater elevation and quality throughout the basin. The BAP plans to incorporate the information gathered from these efforts to streamline the planning process for sustaining the quantity and quality of groundwater in Sonoma Valley (Sonoma Valley Groundwater Management Program, 2012. Basin Advisory Panel/Technical Advisory Committee Work Plan). The BAP produced a five year update in January 2014 that summarized the trends in Sonoma Valley's precipitation, groundwater elevations, a groundwater supply and demand assessment, and more. The groundwater elevations and precipitation monitoring showed a drying trend for the last ten years and declines in groundwater elevations of up to several feet per year in two specific areas. The supply and demand assessment totaled in an estimated, annual demand of 17,900 acre-feet of water, while 10,500 acre-feet (59%) of the supply came from groundwater. The update also noted that the groundwater demands in 2012 were monitored to be 52% agriculture, 29% rural domestic, 7% irrigation of golf courses and parks, and 3-5% municipal, small commercial, and mutual/private systems, the greatest areas being El Verano/Fowler Creek subareas.

4.2.1.4 *Sustainable Groundwater Management Act of 2014*

The newly enacted Sustainable Groundwater Management Act of 2014 (SGMA or Act) provides a framework for long-term sustainable groundwater management by local authorities. It requires the formation of new groundwater sustainability agencies (GSAs) tasked with assessing the conditions in their local basins and adopting locally-based sustainable groundwater management plans. If a GSA is not formed or fails to create a groundwater sustainability plan by 2020 and implement a plan that will result in groundwater sustainability within 20 years, the Act provides for limited state intervention to protect groundwater resources.

GSAs are empowered to utilize a number of new management tools to achieve the sustainability goal. For example, GSAs may conduct investigations, require registration of groundwater wells, determine the sustainable yield of a basin, measure and limit extractions, assess fees for groundwater management, and enforce the terms of a groundwater sustainability plan. GSAs also may request a revision of a groundwater basin boundary, including the establishment new sub-basins.

There may be multiple GSAs and plans for a basin but in such cases the Act requires a coordination agreement that covers the entire basin. Communities with high and medium priority groundwater basins, as designated by the California Department of Water Resources (DWR), must identify or form a GSA by June 30, 2017. In Sonoma County, the Sonoma Valley subbasin, Santa Rosa Plain subbasin, and Petaluma Valley basin are currently designated as medium priority basins by DWR. Medium priority basins must develop groundwater sustainability plans by January 2022.

4.2.1.5 *Potential Impacts of Climate Change on CA's Fish and Fisheries*

Potential Impacts of Climate Change on CA's Fish and Fisheries is an assessment of possible impacts from climate change on fisheries in California (Sydeman and Thompson, 2013). The assessment was led by the Ocean Protection Council Science Advisory Team (OPC-SAT) member

Dr. Bill Sydeman from the Farallon Institute. It includes a study on the current science of risks on California's marine ecosystems and fisheries inflicted by climate change. The study was funded by the California Ocean Science Trust and SCWA. The aim of the report was to provide a synopsis of potential effects of ongoing and future climate change on the fish populations of management concern.

4.2.1.6 *California DWR Central Valley Flood Protection Plan*

While not specifically addressing the Russian River watershed, work conducted for the California DWR Central Valley Flood Protection Plan (CVFPP) may show relevance. Potential climate change impacts to all the major watersheds in the Central Valley were assessed as part of this plan. The results suggest there could be an increase in future 100-year 3-day floods on the order of 20% in rainfall dominated watersheds in Sacramento River Basin. Flooding in these watersheds, similar to the Russian River watershed, is dominated by ARs.

Multiple future climate change scenarios were considered in the CVFPP for the early phase of this study. For each of the future climate scenarios, regional hydrologic modeling was performed for the entire Central Valley using the Variable Infiltration Capacity (VIC) hydrology model (Liang et al. 1994; Maurer et al. 2002). When considering the combined effect of temperature changes and precipitation changes, every major watershed demonstrates a response with greater flood flows. Even in the southernmost watersheds where annual reductions in precipitation are projected, the extreme precipitation is projected to increase and flood flows are correspondingly increased. Sacramento River Basin watersheds are projected to exhibit increased flood flows on the order of 20% to 40% due precipitation and temperature changes. San Joaquin River Basin watersheds demonstrate an even larger response due to the combine effect of temperature and precipitation changes and low frequency floods are projected to be on the order of 60% to 80% larger than the historical reference.

4.2.2 Partnerships

4.2.2.1 *Sonoma County Regional Climate Protection Authority (RCPA)*

The RCPA is an organization consisting of ten local governments with an emphasis on improving coordination on climate change activities and establishing a clearinghouse for efforts to reduce greenhouse gas emissions. The emphasis of the RCPA has largely been related to GHG emission monitoring, reductions, and coordination, with recent efforts beginning to consider climate impacts and adaptation. The Climate Action 2020 Plan includes a summary of current activities in Sonoma County focused on improving resilience in the face of future climate changes.

4.2.2.2 *North Bay Climate Adaptation Initiative (NBCAI)*

The North Bay Climate Adaptation Initiative (http://www.northbayclimate.org) is a group of natural resource managers, policy makers and scientists working to solve problems associated with climate change in the San Francisco North Bay region. The initiative includes three working groups: Habitat Conservation and Stewardship Working Group, Science, Technology and Land Management Nexus Working Group, and the Public Policy Working Group. The initiative functions to facilitate a networking structure for sharing resources, arrange activities for collaboration between the working groups, and provide support for state and federal adaptation strategies. Its goal is to strengthen coordination between scientists, government officials and engaged community members in climate change adaptation efforts. The group has also established a goal to create a model to supplement the countywide Biodiversity Action Plan that will assist local conservation organizations in maximizing their impact. Current efforts by the NBCAI, as part of Climate Ready North Bay, is beginning to conduct a high level vulnerability assessment for the region using climate information developed by the USGS.

4.2.3 Projects

4.2.3.1 *Lake Mendocino Forecast Informed Reservoir Operations (FIRO) Project*

Lake Mendocino experiences a highly variable hydroclimate, creating a challenge for managing water levels in the reservoir. The 2014 drought has brought the reservoir water level down as low as 34 percent capacity. Contrarily, operators are also balancing water levels for flood protection, ecological, recreational, fishing, and water supply purposes. "Forecast-Informed Reservoir Operations" or FIRO is a collaborative project between SCWA, CW3E, NOAA, USGS, U.S. Bureau of Reclamation, DWR, and USACE. The goal of the FIRO project is to assist Lake Mendocino operators in making better informed decisions for maintaining appropriate, climate-dependent water levels in the reservoir.

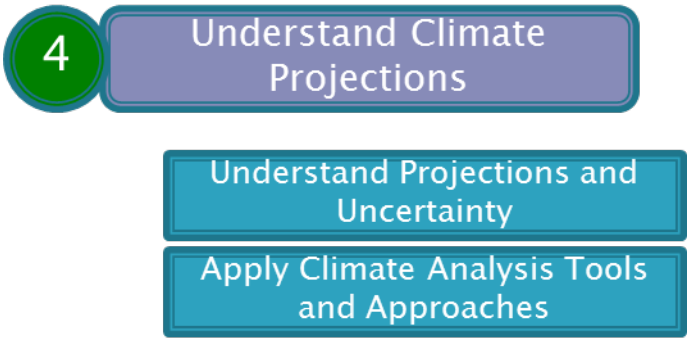
Advancing research on atmospheric rivers is helping to improve weather forecasting along the coast of California and is nearing the capability of forecasting the hydroclimate of the watershed surrounding Lake Mendocino. Data produced from this research can help reservoir operators understand the climate for weeks ahead and manage water levels accordingly, helping to prevent difficulties that currently ensue during droughts and floods. A workshop was held at the SIO in August 2014 to develop a draft work plan for a feasibility project to develop and demonstrate FIRO and its associated benefits. Participants from NOAA, USGS, USACE, Bureau of Reclamation, DWR, CW3E, and SCWA collaborated on the inter-agency draft work plan and hope that the project will prove to be feasible for many other reservoirs facing the same climate-related challenges. The FIRO steering committee meets approximately every three months to continue to develop the FIRO project.

4.2.3.2 *Enhanced Frost and Heat Forecast Information System: Improving Russian River Vineyard and Water Management*

During frost and heat events, Sonoma County vineyards pump extra water to protect their crops and greatly alter the amount of water drawn from the Russian River. NOAA, in partnership with SCWA and the HMT, is developing the Enhanced Frost/Heat Forecast Information System to improve temperature forecasting to help farmers reduce pumping costs and impacts on the Russian River. The automated digital forecasting system provides dynamic and statistical forecast models run by NOAA, high-resolution digital terrain information, and real-time vineyard surface observations from over 50-vineyeards in the Russian River area. These combined variables eliminate the bias found in typical statistical forecast models for this particular region and microclimate. NOAA, through its Habitat Blueprint program is also partnering with UC Cooperative Extension to determine when and where fans may be a more viable alternative than sprinklers to protect the crops from overheating/frost.

5.0 Climate and Hydrologic Science

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, and provides a high-level description of potential impacts to SCWA's infrastructure and operations.



5.1 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 the Work Plan relies upon available climate projections using the models and emissions scenarios included in either the Coupled Model Intercomparison Project 3 (CMIP3) or 5 (CMIP5). These include over 200 individual downscaled climate projections that were included in the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 4 (AR4) and 5 (AR5) (Taylor et al. 2012). Additional scientific literature was reviewed to augment the information from the available projections. Where possible, specific climate projections selected for the North Bay Climate Ready project are included and presented along with the full ensemble of projections. North Bay Climate Ready selected six future climate projections simulated by five different GCMs; three climate projections from CMIP3 and the remaining three climate projections from CMIP5 (North Bay Climate Ready Natural Resource Managers User Group Meeting, 2014). As this Work Plan presents a synthesis of available information, no additional processing of regional climate information was performed for this effort. However, this work could be performed based on the climate projections selected by North Bay Climate Ready and is recommended for the actual implementation of the climate vulnerability assessment.

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 as well as the six downscaled projections included in the North Bay Climate Ready effort. More detailed information related to the projections of each of these variables, and important hydrologic variables, is included in the subsequent sections.

Table 2. Synthesis of Projected Climate and Hydrologic Changes for the Russian River Watershed Region

Climate Variables	Projected Changes and Range	Likelihood	Reference
Temperature Changes			
Annual Mean Temperature	+1.8°C (1.1 to 2.4°C) by mid-century from CMIP3 models +2.1°C (1.3 to 3.1°C) by mid-century from CMIP5 models +2.1°C (1.2 to 2.9°C) by mid-century from six climate projections selected by North Bay Climate Ready effort	High degree of confidence in future warming; magnitude is uncertain within reported range	Maurer et al (2007); Brekke et al (2013); North Bay Climate Ready (2014)
Seasonal Mean Temperature	+1.6°C in Winter by mid-century +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 +2°C by mid-century across the distribution; increase in frequency of 3-day maximum temperatures above 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); North Bay Climate Ready (2014)
Precipitation Changes			
Annual Mean Precipitation	+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 -2.7% (-16 to +14.8%) by mid-century from six climate projections selected by North Bay Climate Ready effort	Magnitude and direction are uncertain, although latest models suggest wetter conditions	Maurer et al (2007); Brekke et al (2013); North Bay Climate Ready (2014)
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)

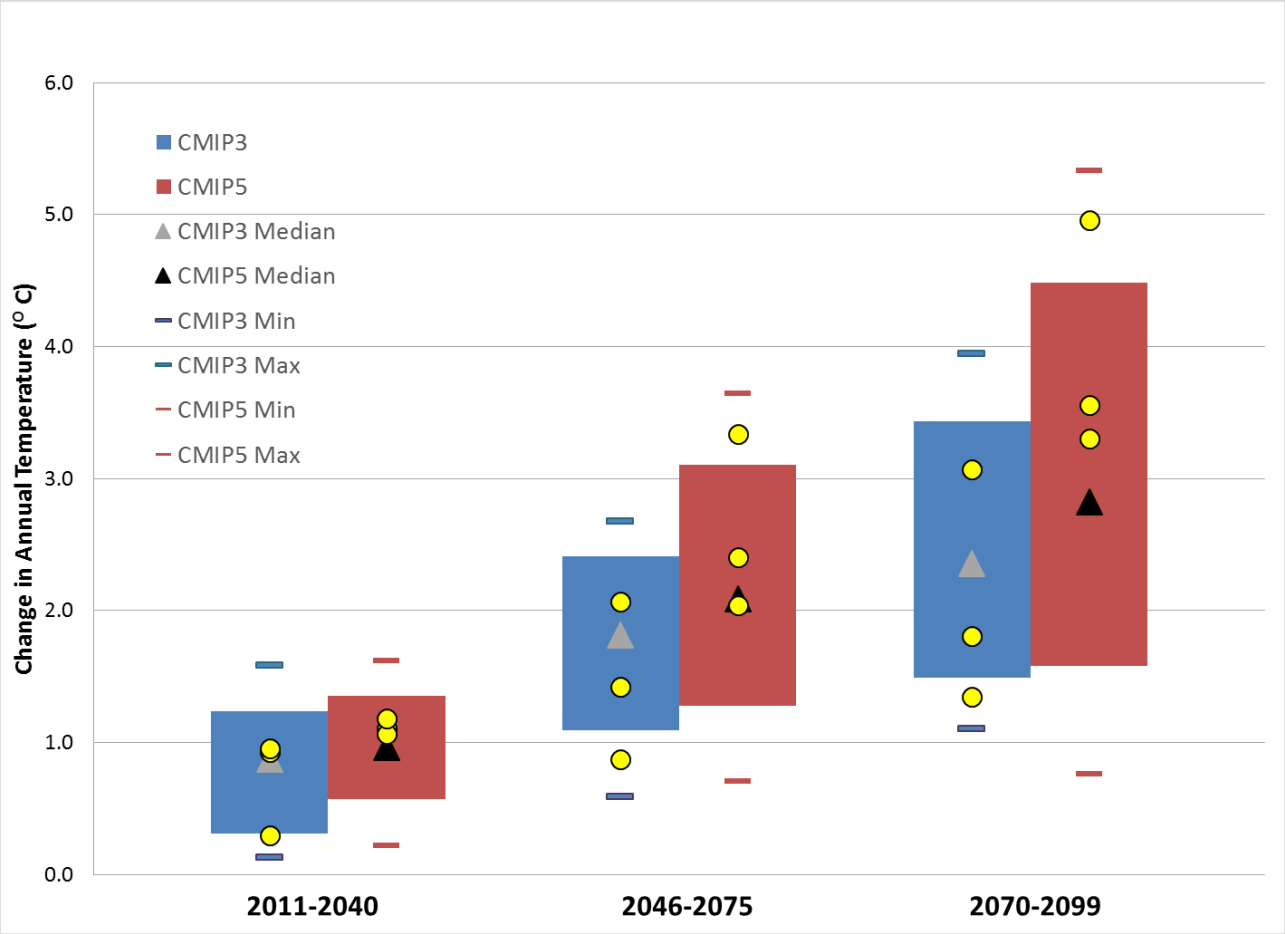
Climate Variables	Projected Changes and Range	Likelihood	Reference
Annual 3-day Extreme Precipitation	Maximum 3-day accumulations are expected to increase. In many instances maximum 3-day accumulations are projected far outside the historical distribution	Medium degree of confidence in increase of future extreme precipitation, magnitude is uncertain	Pierce et al (2012)
Sea Level Changes			
Mean sea level	+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.	High degree of confidence of future sea level rise; magnitude is uncertain within reported range	National Research Council (2012)
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)
River Flooding	Potential increase for atmospheric rivers (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 10-20% higher relative to historical period	Medium degree of confidence in increase of future extreme precipitation which drive flooding risk	Dettinger (2011); DWR (2014)
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 increases by 15-33%.	High degree of confidence due to warming and extended dry season length variability	Westerling et al (2011); Bryant and Westerling (2012); Ekstrom and Moser (2012); Kwawchuck and Moritz (2012)

5.1.1 Projected Changes in Temperature

Under all available future climate scenarios, air temperatures are projected to increase in California. All projections are consistent in the direction of the temperature change (increase), but vary in terms of climate sensitivity (magnitude) (Cayan et al. 2009; Cayan et al. 2008a, 2008b, and 2008c). The median of the available climate model projections suggests up to 2 °C to 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 1.6 °C to 4.5 °C by end of century (Figure 1). Climate projections selected for the North Bay Climate Ready effort span the range of the broader ensemble; from nearly 1 °C to more than 3 °C by mid-century.

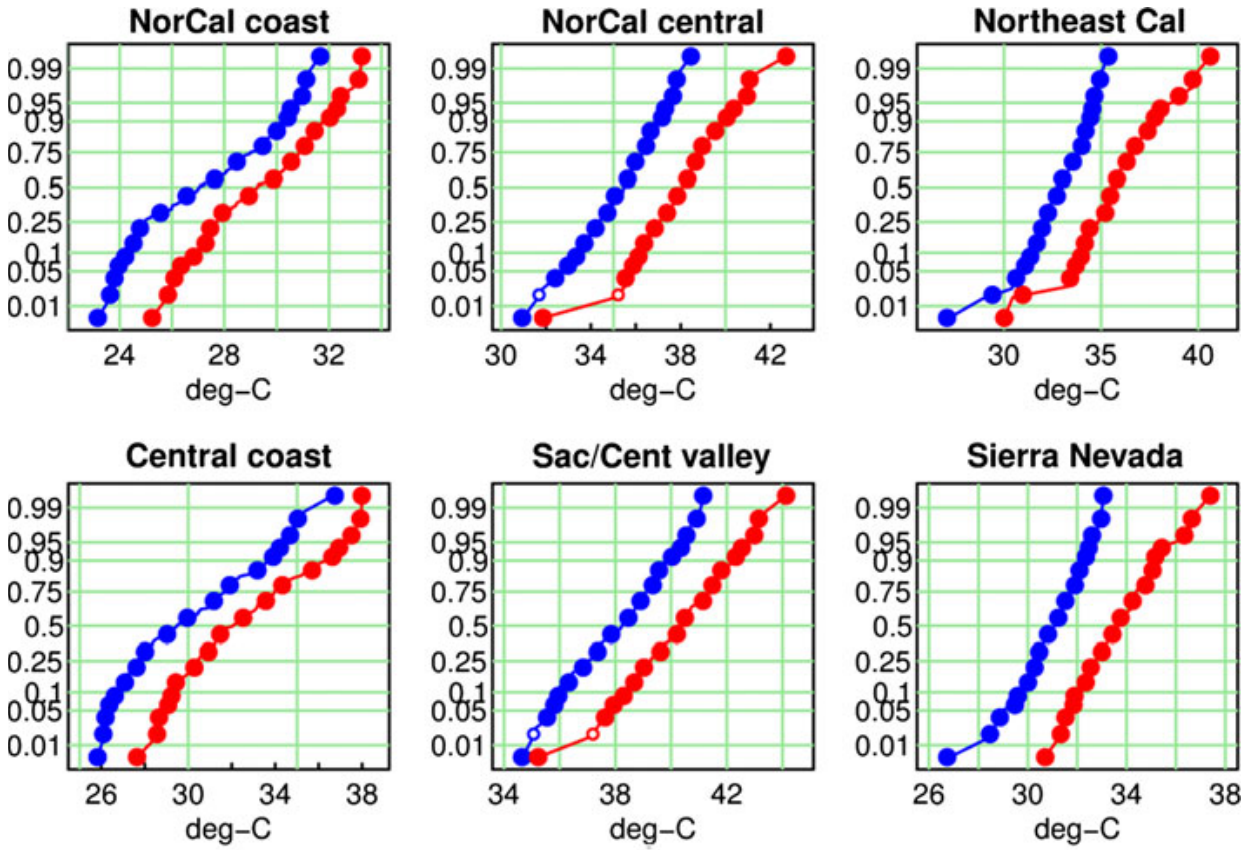
Summer temperatures are projected to increase more than those in winter. Pierce et al (2012) analyzed seasonal changes in the projected warming and reported that winter warming was projected to increase by 1.6 °C, while summer warming was projected to increase by 2.1 °C. In addition, the frequency of 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 2 °C are projected for the warmest 3-day periods in the future (Figure 2). Figure 3 shows a map of projected changes in summer maximum air temperature for the North Bay using one of the climate projections selected by North Bay Climate Ready effort. While increased warming is projected for the entire region, inland valley and mountain ridges are projected to exhibit a larger increase in maximum temperatures.

Figure 3. Projected Changes in Mean Annual Temperatures for the Sonoma County Region based on CMIP3 and CMIP5 Projections



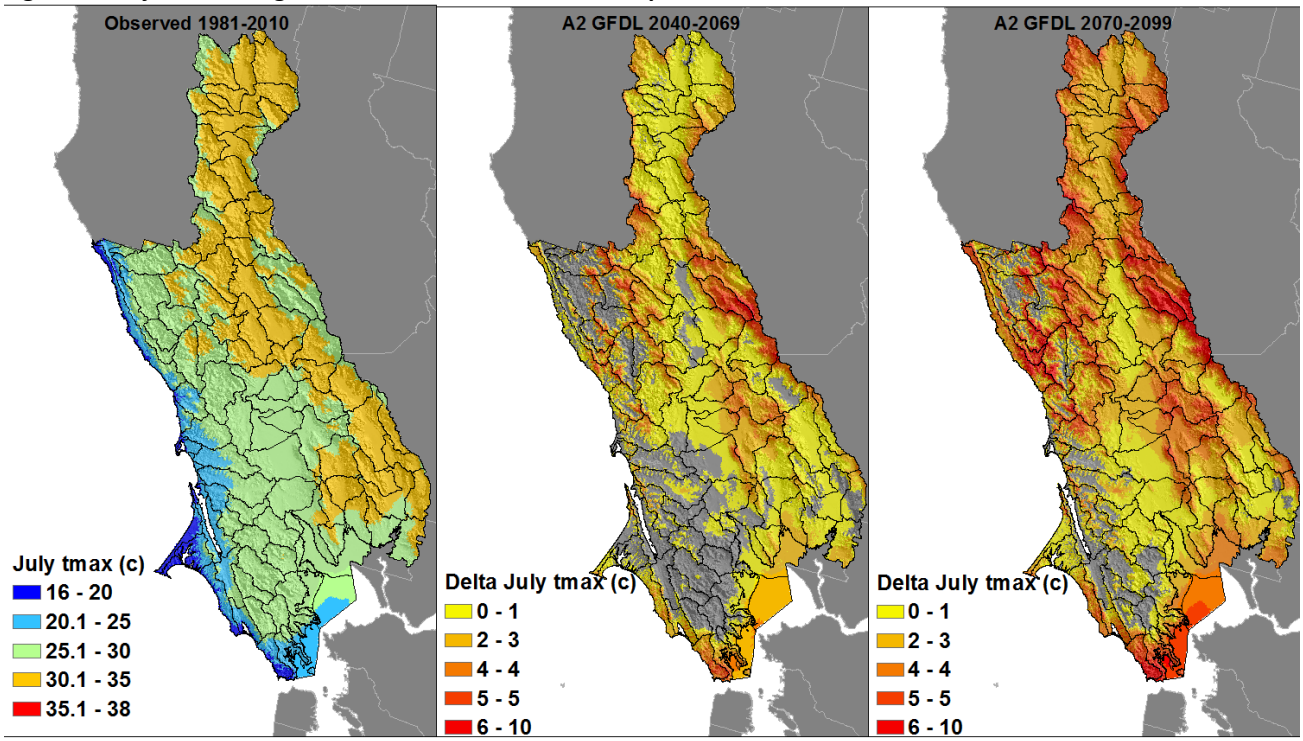
Note: The projected changes for CMIP3 and CMIP5 are computed using more than 100 and 200 downscaled climate model projections used in the IPCC's AR4 and AR5, respectively. CMIP3 and CMIP5 climate model projections have been bias-corrected and spatially downscaled (Maurer et al. 2007; Brekke et al. 2013). Bars represent the range between the 10th and 90th percentiles. Circles represent the 6 climate projections selected for the North Bay Climate Ready project.

Figure 4. Historical (blue) and Projected (red) 3-Day Extreme Temperature Frequency for Central and Northern California Regions (Source: Pierce et al 2012)



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

Figure 5. Projected Changes in Summer Maximum Air Temperature



Source: North Bay Climate Ready Natural Resource Managers User Group Meeting, August 26, 2014

Note: The projected changes are computed using one of the climate projections, GFDL SRESA2, selected by North Bay Climate Adaptation Initiative

5.1.2 Projected Changes in Precipitation

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

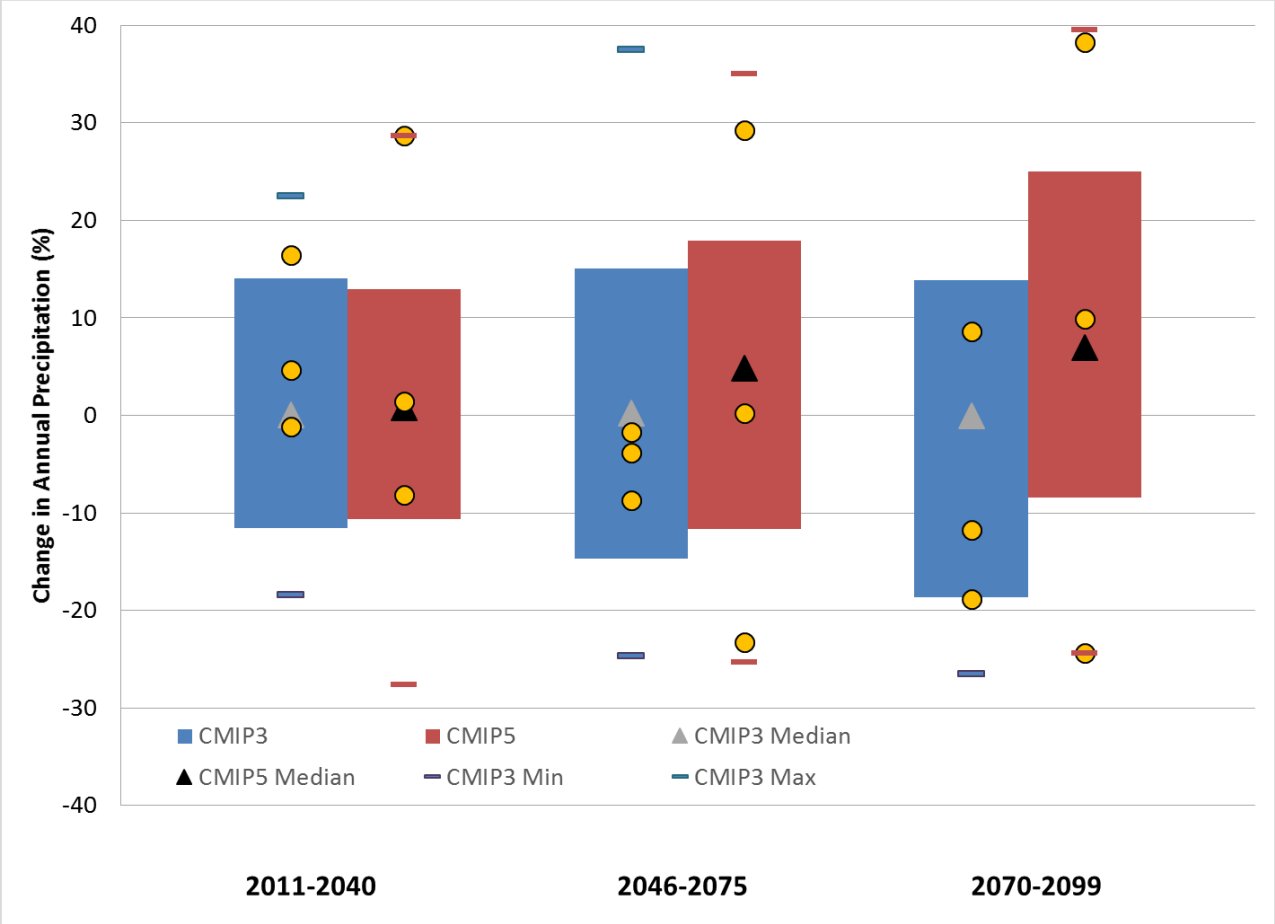
Projections of future precipitation are much more uncertain than those for temperature. While it is difficult to discern strong trends from the full range of climate projections, the median of the projections suggest neutral to wetter futures. While the median of the future climate projections included in CMIP3 ensemble, suggests a slight increase or no change in annual precipitation, the median of the projections in CMIP5 ensemble suggest an increase by about 5% by mid-century and about 8% by end of century (Brekke et al. 2013) (Figure 4). Climate projections selected for the North Bay Climate Ready effort span the range of the broader ensemble; from a decrease in annual precipitation of approximately 25% to an increase of approximately 35%.

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) found significant increases in the frequency of the most extreme precipitation events for all regions of California (Figure 5).

Sonoma County Water Agency and CW3E are currently partnering to improve the assessment of future changes in atmospheric river conditions. Atmospheric Rivers are responsible for most if not all of Sonoma County extreme precipitation events. Figure 6 shows the projected changes in AR intensities for different annual exceedance probability (AEP) events, as computed using data from seven global climate model simulations under SRES A2 emission scenario. For example, for the 1 percent AEP event, simulations suggest a range of average AR intensities from 94 percent to 125

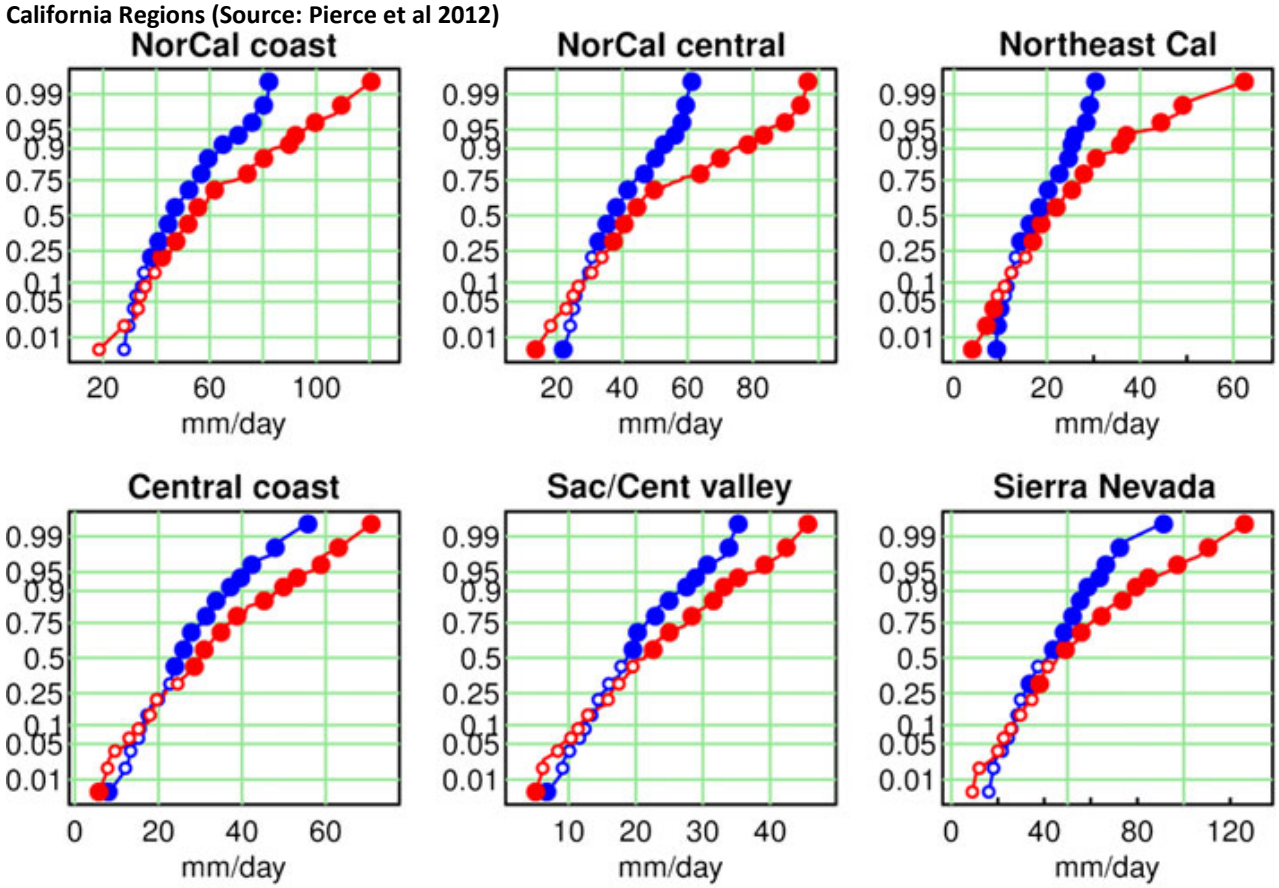
percent of historical events using the 2046 through 2065 period relative to a baseline from 1961 through 2000.

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



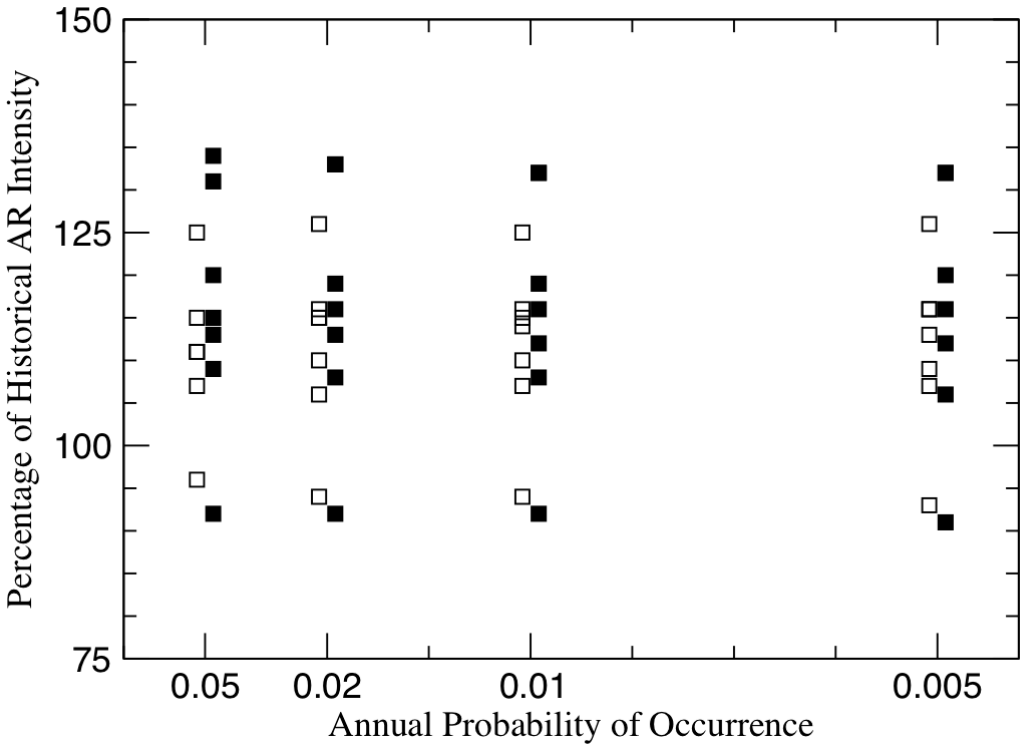
Note: The projected changes for CMIP3 and CMIP5 are computed using more than 100 and 200 downscaled climate model projections used in the IPCC's AR4 and AR5, respectively. CMIP3 and CMIP5 climate model projections have been bias-corrected and spatially downscaled (Maurer et al. 2007; Brekke et al. 2013). Bars represent the range between the 10th and 90th percentiles. Circles represent the 6 climate projections selected for the North Bay Climate Ready project.

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 9 runs with daily data was used to make the figure (adapted from Pierce et al. 2012)

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

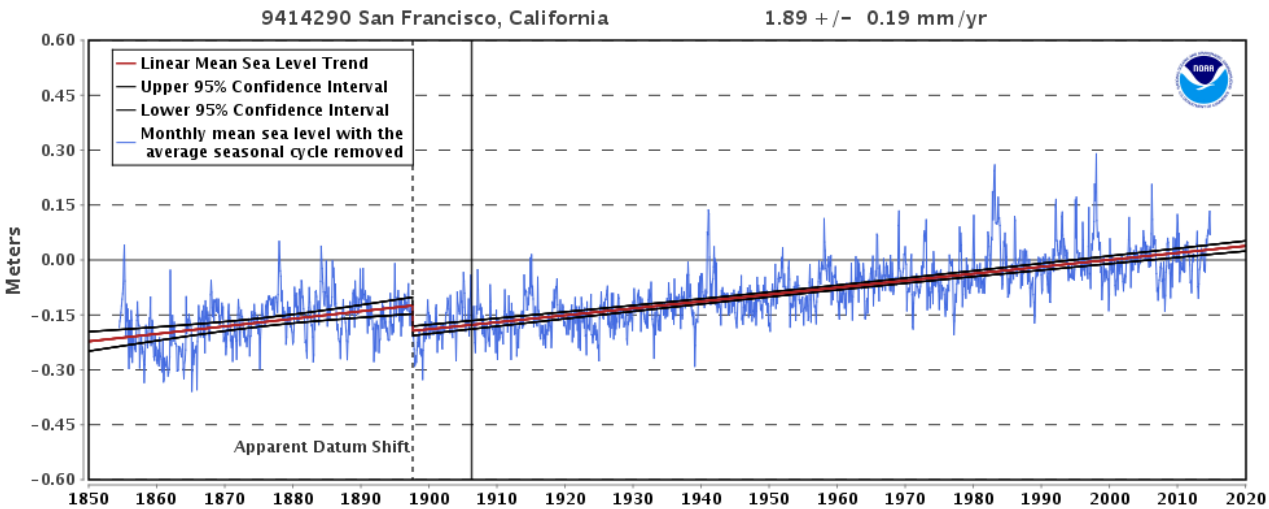


Note
Solid: Changes in AR Intensities, 2081–2100 vs 1961–2000
Open: Changes in AR Intensities, 2046–2065 vs 1961–2000

5.1.3 Projected Changes in Sea Level

Global and regional sea levels have been increasing over the past century and are expected to continue to increase throughout this century. Over the past several decades, sea level measured at tide gages along the California coast has risen at rate of about 17 - 20 centimeters (cm) per century (Cayan et al 2009). There is considerable variability amongst tide gages along the Pacific Coast, primarily reflecting local differences in vertical movement of the land and length of gage record. Figure 7 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 1.89 mm/year with a 95% confidence interval of +/- 0.19 mm/year based on monthly mean sea level data from 1897 to 2013 which is equivalent to a change of 18.9 cm in 100 years.

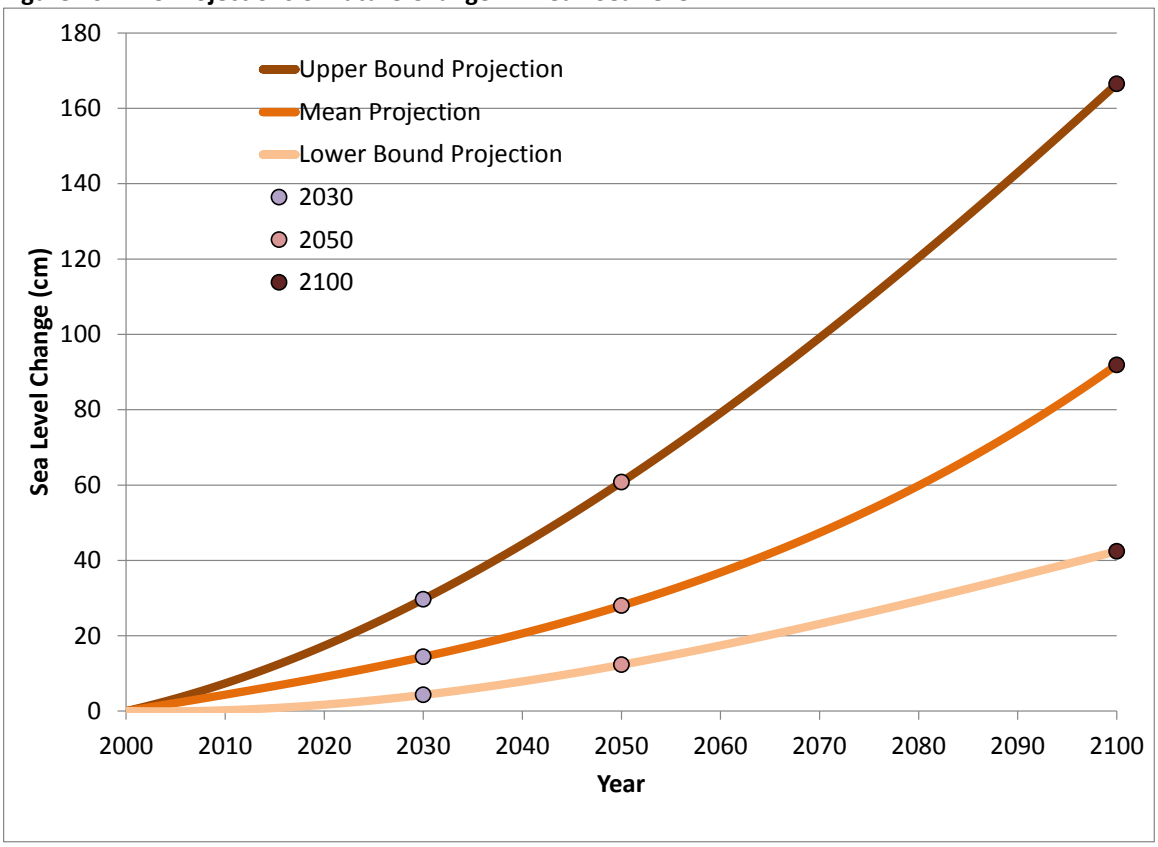
Figure 9. Monthly Mean Sea Level and Trend at San Francisco Tide Gauge (NOAA Gauge No. 9414290)



Source: NOAA (January 13, 2015)

A recent National Research Council (NRC) study suggests a future increase in sea level in the range of 42 to 166 cm by 2100 relative to 2000 at San Francisco Bay (NRC 2012) (Figure 8). The NRC study on West Coast sea level rise relies on estimates of the individual components that contribute to sea level rise and then sums those to produce the future mean sea level projections. These projections have been adopted by the Coastal and Ocean Working Group of the California Climate Action Team as guidance for incorporating sea level rise projections into planning and decision making for projects in California. In addition to increases in mean sea level, there is a high likelihood of increases in storm surge and greater coastal inundation associated with tidal energy.

Figure 10. NRC Projections of Future Change in Mean Sea Level



Note: The NRC study on west coast sea level rise relies on estimates of the individual components that contribute to sea level rise and then sums those to produce the projections The report suggested sea level rise projections at three future times relative to 2000 (2030, 2050, and 2100), along with upper- and lower-bound projections for San Francisco. These projections were fit to polynomial equations to obtain transient annual sea level rise projections over the period 2000 through 2100. The NRC sea level rise projections for California have wider ranges, but the upper limits are not as high as those from Vermeer and Rahmstorf's (2009) global projections. The National Academy of Sciences' reported projections have been adopted by the Coastal and Ocean Working Group of the CAT as guidance for incorporating sea level rise projections into planning and decision making for projects in California.

SCWA is supporting refined modeling of the sea level rise and storm surge impacts to the North Bay through the Coastal Storm Modeling System (CoSMoS). The CoSMoS study is part of the NOAA Russian River Blueprint Habitat and includes 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 application for the North Bay is expected to be completed by summer or fall of 2015.

5.1.4 Projected Changes in Droughts

Droughts are often characterized by prolonged periods of below average precipitation and above average temperatures, resulting in prolonged periods of water deficits. 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 SCWA water supply system vulnerabilities, but could be expressed as both climatic indicators (precipitation minus potential evapotranspiration) and hydrologic indicators.

5.1.5 Projected Changes in Floods

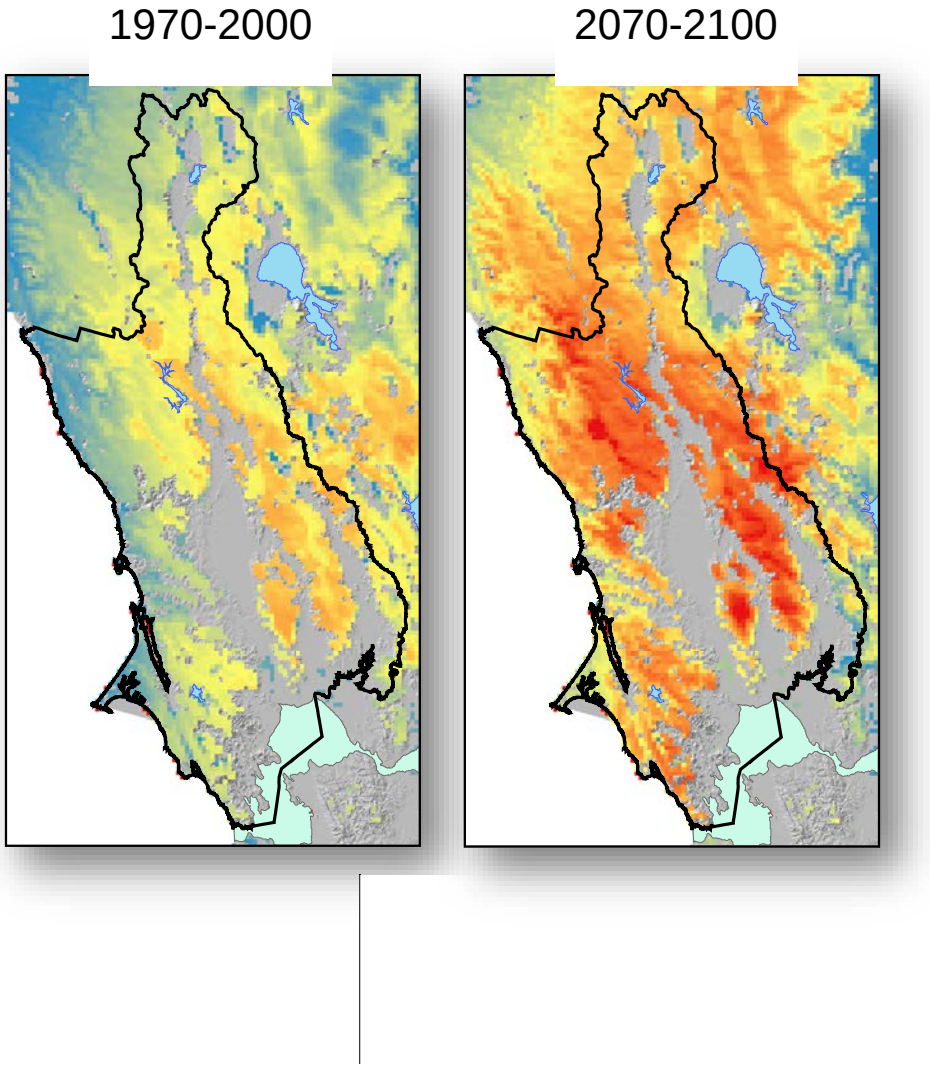
Most significant flooding events on the Russian River are associated with AR events. Dettinger (2014) has suggested that about 87% of Russian River floods since the 1950's are associated with AR events. As discussed under extreme precipitation, the frequency and/or magnitude of AR storms are projected 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. SCWA and SIO are currently partnering to improve the assessment of future changes in atmospheric river conditions. This remains an area of active research.

Recent work performed by CH2M for the DWR, evaluated flood risks for all major watersheds in the Central Valley associated with projected changes in extreme precipitation and warming. 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, one hundred year flood volumes increased from 10% to 20%. Changes were substantially larger for high elevation watersheds with significant historical snow accumulations.

5.1.6 Projected Changes in Wildfires

Wildfires are a common occurrence in many parts of California and Sonoma and Napa Counties have had much higher historical wildfire risk than other North Bay counties (Krawchuk and Moritz 2012). Climate change is generally expected to increase the wildfire risk in the Sonoma region, through increased incidence of dry conditions (drought) and higher temperatures over a longer and longer fire season. However, significant other factors that contribute to wildfire risk included 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 in many other areas is strongly dependent on the land use and development conditions. Under low growth scenarios with little or no increase in the interface between wildland and urban areas, little increase in wildfire risk was projected under future climate scenarios. However, 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). Figure 9 depicts spatial distribution of probability of burning two or more times in the projected future. As shown in the figure, the projections suggest a substantial increase in the probability of wildfires in the region.

Figure 11. Probability of Burning Two or More Times



Source: North Bay Climate Ready Natural Resource Managers User Group Meeting, August 26, 2014)

Note: The results are based on one of the climate projections, GFDL SRESA2, selected by North Bay Climate Adaptation Initiative Urban, agricultural, and water are masked in grey

6.0 Potential Climate Impacts to SCWA Infrastructure and Operations

Each of the projected changes in climate and hydrologic conditions discussed in the previous section has the potential to impact SCWA's water supply, flood control, and sanitation infrastructure and operations. The eventual climate vulnerability assessment will explore the threat of these changes to specific SCWA system infrastructure and operations with consistent climate scenarios and time frames. However, the climate and hydrologic threats that are currently understood are described in the following sections.

6.1.1 Water Supply System

Climate change is projected to impact the SCWA's water supply system through changes in future hydrology and water supply availability, changes in water demands, changes in operations of water-related facilities by SCWA or by other parties, and direct risks to water supply infrastructure or operations. The SCWA water supply system consists of an interconnected system utilizing both surface water and groundwater resources, surface and groundwater diversion facilities, reservoir storage, disinfection, pH control, transmission, and integration of recycled water to reliably deliver water to customers. Table 3 below provides a summary of the potential climate impacts to the main water supply system components.

Table 3. Potential Climate Impacts to SCWA's Water Supply System

Water Supply System Component	Potential Climate Impacts
SCWA Core System	
Russian River Project: Lake Mendocino, Lake Sonoma, Dry Creek, Instream Flows, Hydropower Operations, Biological Opinion	Changes in hydrology may impact Lake Mendocino and Lake Sonoma storage operations for water supply and flood control. Increased variability in dry season compliance flows due to more variable reservoir storage levels. Increases in flood risk may cause changes to flood control operations in Lake Mendocino, further exacerbating the current flood operation impacts on SCWA water supply. Increased dry season reservoir releases due to increases in agricultural diversion from the Russian River and Dry Creek associated with increased summer temperatures.
Russian River Diversion Facilities: Inflatable Dam, Fish Screens and Ladders, Infiltration Ponds, Collector Wells, Chlorination and pH Adjustment Facilities	Increased flooding potential may cause an increase in direct risk to Russian River collector system infrastructure due to inundation risk (Mirabel and Wohler). Changes in river flows and water temperatures may require further protection of flows for instream purposes or limit the operation of inflatable dam and infiltration ponds. Increases in summer demands on the Russian River associated with warming may further reduce river flows. Water quality issues may arise due to increased wildfire in the contributing watershed; riverbank filtration has been shown to be sensitive to increases in dissolved organic carbon/natural organic matter in the river water.
Groundwater Wells: Mirabel Standby Wells, San Rosa Plain Wells	Potential for increased inundation risk at Mirabel wells and pumping facilities. Groundwater level and water quality issues associated with increased groundwater pumping.
Transmission System: Aqueduct, Booster Pumps, Storage Tanks, Customer Delivery Connections	Increased variability in supply and likely increases in demand due to climate change may stress existing conveyance, pumping, and storage systems. Pipeline crossings and pump stations may be at increased risk due to flooding. Changes in river water quality may require altered disinfection.
Operations and Maintenance	Reduced access to certain facilities due to increased flooding. Increased number of days where worker safety precautions will need to be managed due to extreme heat. Power outage risks for facilities with no backup.

Regional Interfaces	
Potter Valley Project: Lake Pillsbury, Potter Valley Diversion	More variable hydrology may lead to reduced water availability and changed timing of Upper Eel River flows in some years. PG&E operations and Potter Valley diversions may change in response to changes in energy demand, resulting in reduced water available in Lake Mendocino. In addition, warmer temperatures and increased agricultural demand may require increased releases from Lake Mendocino to maintain instream flows.
Groundwater Management: Santa Rosa Plain, Sonoma Valley, Petaluma Valley	Groundwater resources may be increasingly stressed during drought periods with higher demands, (likely) increased groundwater pumping in these aquifers, and changes in recharge. There may be saline water intrusion in Sonoma Valley and Petaluma Valley due to sea level rise.
Recycled Water	Unknown. Likely increase in demand for recycled water as an alternative supply.
Agricultural and Municipal and Industrial Demand	Increases in agricultural and M&I demand and timing, due to warming and other weather-based indicators such as frost and heat thresholds, with resulting impacts on river flows and operations.

6.1.2 Flood Control System

Climate change is projected to impact the SCWA's flood control system principally through the potential for more extreme precipitation than in the past. The SCWA flood control system consists of dams and reservoirs, flood control and natural channels, municipal storm sewers, and watershed management to provide flood protection in the region. Table 4 below provides a summary of the potential climate impacts to the main flood control system components.

Table 4. Potential Climate Impacts to SCWA's Flood Management System

Flood Control System Component	Potential Climate Impacts
SCWA Core System	
Central Sonoma Watershed Project: Flood control facilities on Santa Rosa Creek, Mantanzas Creek, Piner Creek, Brush Creek, and Spring Creek	Increases in extreme precipitation (associated with ARs) likely translate into increased flood risk on all creeks. Flood control facilities may be insufficient to provide the same level of protection for a 10% to 20% increase in the 100-yr 3-day rainfall. Flood control challenges may be observed at Spring Lake and Matanzas reservoirs and city of Santa Rosa downtown box culverts. Flooding has also historically occurred in Rohnert Park, Petaluma, and Sonoma Valley.
Stream Maintenance Program: Flood control and natural channels	Increased sediment loads associated with increased precipitation intensity and flashier flows (especially following wildfire) may require more frequent stream maintenance and sediment removal. Warming may increase growth of riparian vegetation.
Operations and Maintenance	Reduced access to certain facilities due to increased flooding. Increased number of days where worker safety precautions will need to be managed due to extreme heat. Power outage risks for facilities with no backup.
Regional Interfaces	
Lake Mendocino and Lake Sonoma: USACE flood control operation of Lake Mendocino and Lake Sonoma	Increases in extreme precipitation (associated with ARs) could translate into increased flood risk. Operations at Lake Mendocino and Lake Sonoma could be modified in the future.
Stormwater: Municipal storm sewer systems	Many municipal storm sewers in the U.S. are designed based on older precipitation frequency analysis and recent updates have revealed insufficient storm sewer sizing for the stated return periods. Considerations of future climate changes further demonstrates insufficient system performance. Increased potential for sewer overflows, regulatory compliance, and risk of urban flooding.
Watershed: Stormwater-groundwater recharge programs	Increases in extreme precipitation will likely challenge existing stormwater-storage-recharge efforts, but increases in more frequent events could increase the opportunity for groundwater recharge.

Petaluma, Cotati and Rohnert Park Flood Control Channels	Increased flooding in areas along the Petaluma River and Willowbrook Creek in the Petaluma River Watershed. Increased flooding in the Southern Laguna De Santa Rosa Watershed.

6.1.3 Sanitation System

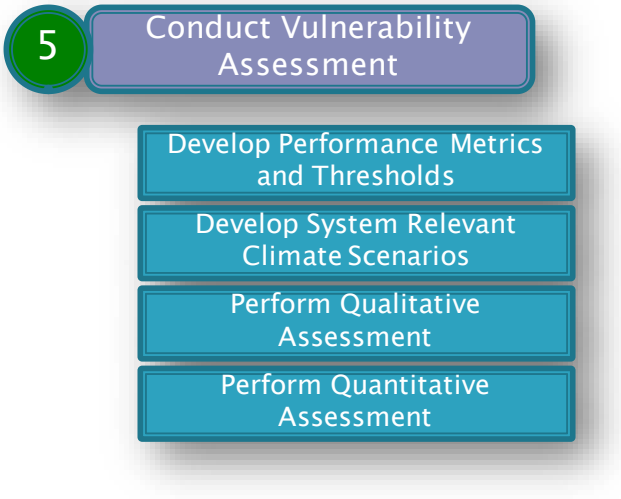
Climate change is projected to impact the sanitation systems owned or managed by SCWA through changes in ambient temperatures for both wastewater treatment processes and discharge, changes in flows into the wastewater system, and through increased flooding risks to low-lying or insufficiently sized sanitation infrastructure. The sanitation systems consist of wastewater treatment facilities, water reclamation facilities, discharge and disposal facilities, and sanitary sewer facilities which provide reliable sanitation service to the eight districts and zones. Table 5 below provides a summary of the potential climate impacts to the main sanitation system components.

Table 5. Potential Climate Impacts to SCWA's Sanitation System

Sanitation System Component	Potential Climate Impacts
SCWA Core System	
Wastewater Treatment: Aeration, clarifiers, filtration, disinfection, solids handling, equalization for 6 districts/zones	Increased summer temperatures may impact biological and chemical process (positively and negatively), altering the operations of treatment plants. Increased extreme precipitation may translate into increased flood risk to low-lying wastewater infrastructure and increased peak flows and infiltration entering wastewater treatment plants during storm events.
Sanitary Sewer Systems: Sanitary sewer systems in each of the 8 districts/zones for which SCWA has direct management authority (CSO and SSMPs)	During increased precipitation events, sewers may have infiltration of stormwater that exceeds the capacity of the sanitary sewer systems. Increased potential for CSOs and regulatory compliance impacts. Pump systems may be undersized.
Water Reclamation: Water reclamation facilities	Similar to those for wastewater treatment. Likely increase in demand for reuse of reclaimed water during spring and summer.
Discharge/Disposal: Stream discharge or reuse delivery systems	Increased warming may reduce assimilative capacity for stream discharge during warm, low flow periods. During increased flood periods, hydraulic limitations may exist that reduce the ability to discharge without pumping, or require additional duration of pumping.
Operations and Maintenance	Reduced access to certain facilities due to increased flooding. Increased number of days where worker safety precautions will need to be managed due to extreme heat. Power outage risks for facilities with no backup.

7.0 Vulnerability and Risk Assessment

A vulnerability assessment is one of the most important steps in assessing the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate and climate change. Vulnerability generally relates to the frequency or extent of conditions that indicate that the system is severely affected by some change. While the focus of climate change vulnerability assessments is obviously on "climate", other future potential changes are commonly integrated through scenarios to make the assessment more robust and to better understand interactions between climate and other possible changes.



The vulnerability assessment generally includes the following steps:

1. Develop or refine performance metrics and vulnerability thresholds
2. Assess current vulnerabilities
3. Develop future scenarios
4. Assess future vulnerabilities

The vulnerability assessment is performed for current or historical conditions in order to establish the current vulnerabilities and for future conditions incorporating climate to estimate future vulnerabilities. In addition, the vulnerability assessment will be conducted for both the existing system and for the system with potential adaptation strategies. In this fashion, the effectiveness of various adaptation options can be assessed by the reduction in future vulnerabilities.

7.1 Performance Metrics and Thresholds

The water supply, flood control, and sanitation systems function for specific purposes (e.g. provide safe and reliable water delivery, provide flood protection, provide reliable wastewater treatment, provide habitat refugia for critical species, etc) and more and more systems are being asked to support a larger number of purposes. Performance measures are used to measure how well the system functions in providing these services under current conditions as well as under future conditions considering climate change. Performance measures will need to be identified for the SCWA Climate Adaptation Plan. The performance measures should describe the function and the reliability (or level of service) goal. Specific performance metrics then describe the method in which the measure will be evaluated quantitatively. Several performance metrics may be used to capture different aspects of the measure. Finally, thresholds for each metric are developed that indicate the vulnerability associated with the particular system function. The thresholds may be based on factors such as system operator experience, inundation risk, regulatory limits, or biological limits. Table 6 provides some examples of performance measures used in recent climate risk and resilience efforts.

Table 6. Example Performance Measures, Metrics, and Thresholds

Performance Measure	Performance Metrics	Threshold	Basis for Threshold
Delivery Reliability	Annual water system delivery shortage	Greater than 20,000 acre-feet in any year	Shortages less than 20,000 acre-feet per year may be managed by use of internal system storage and member agency flexibility

Conveyance Reliability	Conveyance usage exceeding 95% of capacity	Greater than 45 days during peak season	Reduces opportunity for outages and increases risk of conveyance-related reliability concerns
Energy Generation	Monthly hydropower generation for Western Area Power Administration grid	Less than minimum monthly targets required for the grid	Contracts stipulate minimum generation that must be supplied by reservoir hydropower to the regional grid
Fish Survival	River water temperatures during spawning season	Days greater than 56°F during July-September	Successful spawning is severely threatened above these temperatures

Note that none of the metrics are directly associated with a climate variable, but rather all are dependent on the system response to climate variables (reduced supply, increasing demand, loss of operational storage, or water temperatures). These performance measures and associated metrics and thresholds will be specific to each system. They should be developed in direct coordination with system managers, operators, and other experts to ensure that they are defensible measures that can be withstand technical review and public scrutiny.

7.2 System-Relevant Climate Scenarios

Climate change has the potential to impact each system in a different manner. Climate scenarios for use in the vulnerability assessment should be selected to test the system performance for the range of future climate outcomes that are most relevant to the system being evaluated. This requires a tailored set of scenarios for SCWA's climate vulnerability and adaptation planning efforts.

Climate scenarios should consider the following factors:

- *Planning horizon*. Climate projections need to be consistent with the time horizon of the planning question. For example, 25-, 50-, and 75-year future periods.
- *Key climate drivers*. Ensure the climate variables selected are the actual drivers of vulnerability for the system. For example, daily minimum temperature for frost protection or 3-day maximum precipitation for flooding.
- *Spatial resolution*. Align climate scenarios with the spatial resolution of need for the system. If the system is influenced by the upstream watershed, ensure that regional climate projections are included along with more localized projections.
- *Temporal resolution*. Align the climate scenarios with the temporal resolution needed to address vulnerability. For example, for flood risk assessments, scenarios of changes in intensity-duration-frequency on the order of 5% (20-year flood) to 1% (100-yr flood) or more extreme are required. For water supply assessments, it is important to capture potential regional changes and low-frequency events such as droughts.

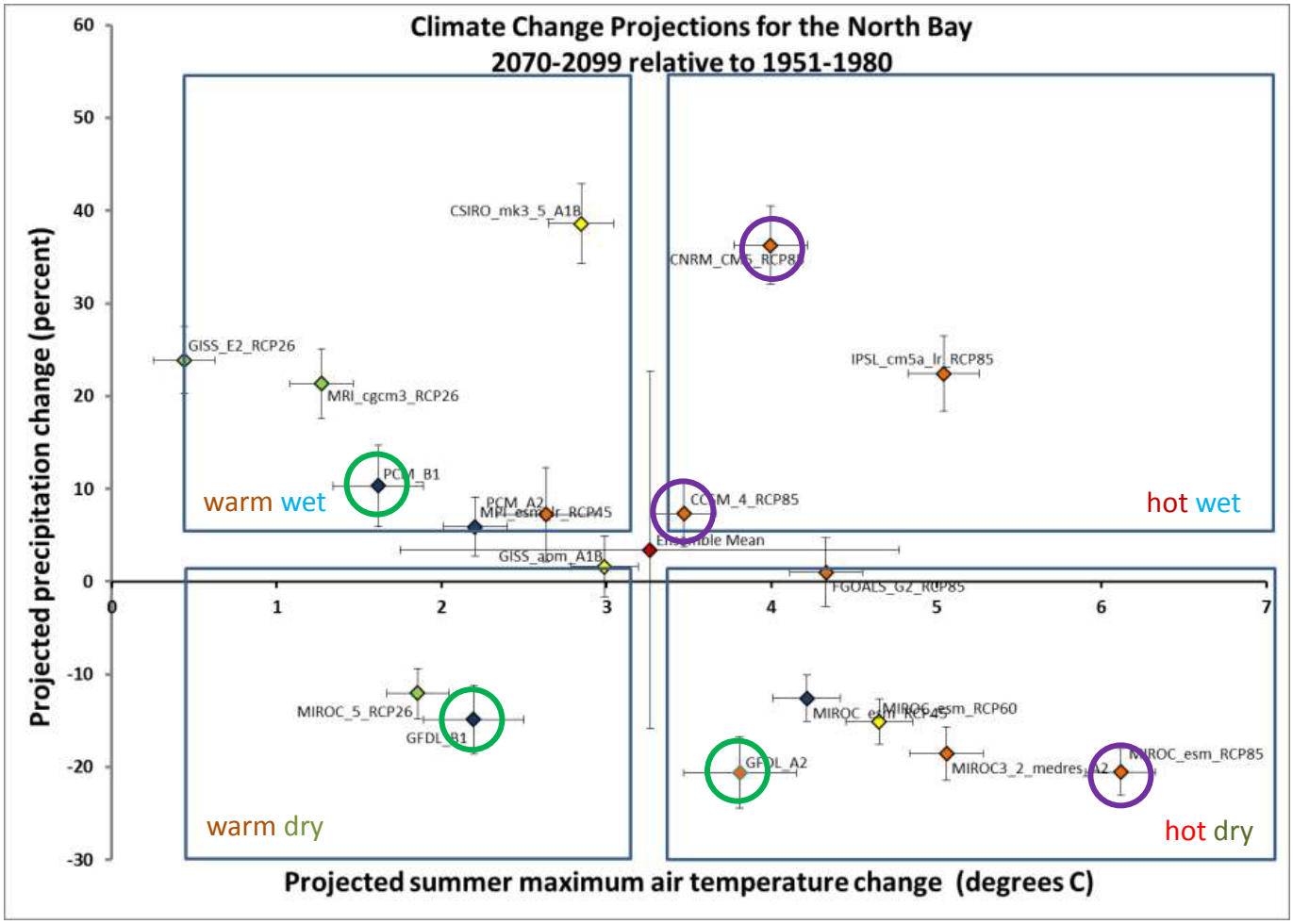
Consideration of climate changes and improving system resilience encourages the embracement of uncertainty. There are three main sources of uncertainty in climate projections. These are: (1) uncertainty in future greenhouse gas (GHG) emissions, (2) uncertainty in climate model projections and how well the models capture the climate system including the natural variability in climate and feedbacks between oceans, atmosphere, and the cryosphere (ice sheet dynamics), and (3) uncertainty in the methods and continuity of physics in the processes used to downscale climate projections from GCM scales to the spatial and temporal scales of interest. Consequently, a specific climate model may yield a range of

results that are dependent on future emission scenarios, differing initial conditions, and climate model start date.

To capture the range of uncertainty inherent in “projecting the future”, at least three climate scenarios should be considered in vulnerability assessments. These scenarios should be developed from low, medium, and high emission scenarios (and/or representation concentration pathways) and should also consider multiple GCMs and simulations. A large portion of the projection uncertainty through mid-century is associated with the GCMs themselves. Therefore, multiple GCMs or sub-ensembles of GCM projections such as those surrounding the 10th and 90th percentile of projections can be used to capture the uncertainty.

Six climate projections have been selected by North Bay Climate Adaptation Initiative (NBCAI) to represent potential future changes in the North Bay region. Initial comparisons of the annual temperature and precipitation changes from these projections and the nearly 200-member ensemble included in CMIP5, suggest that the range of future climate uncertainty is reasonable well-captured in the six selected projections. The six climate projections include results from five different GCMs and include three projections from each of the CMIP3 and CMIP5 archives (NBCAI, 2014; Cornwall et al. 2014). Figure 12 shows the annual temperature and precipitation changes for the six North Bay climate projections. It is recommended that further comparisons be conducted for climate variables (e.g. Tmin and Tmax) and timescales (e.g. seasonal and 3-day) that are most relevant to the system vulnerability prior to final selection of climate scenarios for use in SCWA’s climate vulnerability assessment.

Figure 12. Selected Future Climate Projections for North Bay Region Regional Vulnerability Assessment



Source: North Bay Climate Ready Natural Resource Managers User Group Meeting, August 26, 2014)

7.3 Vulnerability Assessment

The vulnerability assessment is commonly performed using both qualitative and quantitative information. The qualitative assessment helps to improve understanding of local climate and variables of interest, to engage those who actually manage and operate the system, and identify the areas that will require further investment of resources to improve the assessment of vulnerability. The quantitative assessment focuses on areas of the most critical need and for which system models or other quantitative tools can refine estimates of vulnerability.

7.3.1 Qualitative Assessment

The vulnerability assessment should begin with a qualitative approach in order to improve understanding of local climate and variables of interest, to engage those who actually manage the system, and to identify the areas that will require further investment of resources to improve the assessment of vulnerability. This early, qualitative vulnerability assessment is usually conducted in the form of a facilitated workshop with those most knowledgeable of the system, climate, and agency decision-making. The initial workshop is focused on confirming the system and its components, determining the performance metrics and thresholds, identifying the system component's sensitivity to climate and climate changes, and qualitatively addressing the adaptive capacity inherent in the certain system components. The first workshop should include the following participants:

- Project team members from SCWA and consultants,
- Representatives from SCWA management team,
- Representatives from SCWA's water supply, flood control, and sanitation system managers and operators,
- Expert stakeholders or local climate researchers identified by SCWA,
- At least one representative from policy staff who may present the results to the general manager or board of directors (may be same member as the SCWA management team).

Due to the large number of individuals and diverse areas of expertise needed at this initial workshop, it is important to adequately prepare and facilitate the discussion. The vulnerability workshop should cover the following items:

- Brief presentation of the regional/local climate and projected changes for the region
- Overview of the vulnerability and/or risk assessment process
- Case studies of similar and related climate vulnerability assessments
- Overview of vulnerability-risk assessment table that will be used to collect participant feedback and qualitative assessments
- Pictures and descriptions of historical climate events that proved challenging to the system
- Facilitated table-top exercise to establish the qualitative vulnerability-risk information table
- Summary of findings from the qualitative vulnerability-risk assessment table

The workshop is best conducted as two half-day events, but this is not always possible given the depth of engagement of resources that is required. Prior to the workshop, information related to historical climate and projected changes, and the structure and examples of the vulnerability/risk tables should be prepared in order to facilitate this workshop in the most efficient manner.

The vulnerability-risk table is the primary tool for capturing the participant's discussion and expert opinion related to system vulnerability and risk. Table 7 provides an example of the vulnerability portion of one such table. The major system components and corresponding performance measures and vulnerability thresholds are described. Then the most important climate variables that influence the performance of the system components are defined along with a description of the projected changes in these variables over the planning period.

The *sensitivity* of the system to current climate and climate changes is assessed through a standard 5-point rating scale ranging from low to high. The sensitivity rating should be 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. A standard 5-point rating scale is also used. 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.

During the workshop, it is important to have adequate discussion on the justification of such ratings and to allow for alternative views to be expressed by participants. A review of historical climate events and associated system responses are often useful to examine and test the ratings provided by the participants.

This dialog is considered healthy engagement and sheds light on differing perspectives of system tolerances and level of operational/management flexibility. If consensus cannot be achieved during the workshop process, it is reasonable to carry two alternative ratings forward.

After performing an initial assessment based on inputs with the participants, the findings will be summarized and workshop participants should review and suggest revisions to any ratings that are deemed necessary. A brief summary report of the qualitative vulnerability assessment will be prepared and provided to the workshop participants for comment. The areas of highest vulnerability will be summarized and areas of high uncertainty will also be identified. These areas of medium to high vulnerability will be identified as the focus for the more detailed quantitative assessment.

Table 7. Example Qualitative System Vulnerability Assessment Table

System and Peformance Measures				Climate Variables and Change		Vulnerability Assessment				
System	Performance Measure	Performance Metric	Threshold	Climate Variables	Projected Climate Change	Sensitivity	Rating	Adaptative Capacity	Rating	Vulnerability
Water Supply	Delivery Reliability	Reservoir Storage	Storage less than 100,000 acre-feet	Increased Temperature	Up to 3C increase by mid-century	Warming itself may increase ET losses in the watershed by 20%. Changes in seasonal runoff patterns will have pronounced impact on reservoir storage management. Decreases in precipitation will increase an already tenuous operation during drought years.	High	Little flexibility currently exists due to competing demands for flood and temperature management. Even under historical hydrologic conditions, the thresholds are projected to be exceeded for some years. Regulations and operational rules currently limit flexibility.	Low	High
				Change in Precipitation	Range of -20 to +20% in annual precip.					
				Decrease in Soil Moisture or Snowpack	Warming, combined with changes in precip will lead to decreased snowpack and reduction in late spring soil moisture.					
Flood Management	Manage the 1% Flood Event	Flood Level	Exceeding currently established 100-yr flood level	Increased Temperature	Up to 3C increase by mid-century	Analysis of historical storms suggests the flood system is already significantly challenged. Sea level rise by itself will increase coastal flooding and all projections/science suggest greater magnitude of extreme precip.	High	Little flexibility currently exists. Floodway and bypasses have been allowed to be encroached by urban development. Flood regulations have not been updated since the 1980s and are believed to be inadequate even for historical storms. Any future increases in intensity will significantly challenge system.	Low	High
				Increased Extreme Precipitation	Heaviest 1% of precipitation is projected to increase by 15% by mid-century					
				Increased Duration of Heavy Precipitation	Uncertain, but some projections show greater atmospheric river presence and possible increased "stalling" of storms					
				Increased Sea Level and Storm Surge	Mean sea levels projected to be 3ft higher by mid-century, and storm surge may increase by 5ft					
Stormwater Management	Combined Sewer Overflows	Overflow Frequency	Exceeding current EPA Standard	Increased Temperature	Up to 3C increase by mid-century	Current storm sewer drainage system has recently been upgraded in Region 1. Low lying Region 2 is 50 years old and requires suitable HGL for drainage to the tidally-influenced river. Combined increases in storm surge-urban runoff could cause this system to overflow directly to the river.	High	Pumps were recently installed to pump against the tide for short periods of time. These may mitigate for some of the potential increases in frequency, but may need to be used more frequently than designed.	Medium	Medium
				Increased Extreme Precipitation	Heaviest 1% of precipitation is projected to increase by 15% by mid-century					
				Increased Duration of Heavy Precipitation	Uncertain, but some projections show greater atmospheric river presence and possible increased "stalling" of storms					
				Increased Sea Level and Storm Surge	Mean sea levels projected to be 3ft higher by mid-century, and storm surge may increase by 5ft					
Power	Transmittion Integrity	Demand-Related Blackouts	Peak summer demand exceeding current transmission limits	Increased Extreme Temperature and Heatwaves	Increases in both extremes summer temperature and frequency of heatwaves are projected in all portions of the service area	Demand in this region is strongly correlated to peak temperatures as air conditioning and other cooling needs represent over 50% of the peak demand. A 1C increase corresponds to a 5% increase in peak demand.	High	Programs in place allow for rotating interruptible delivery to certain users that represents about 5% of the current limit.	Medium	Medium
Transportation	Roadway Integrity	Pavement Buckling on Asphalt Roads	Temperatures greater than 30 C	Increased Extreme Temperature	Frequency of events exceeding 30C are projected to increase by 20% by mid-century and 50% by end of century.	Buckling on asphalt roads is strongly correlated to peak temperatures. Occurs on some roadways currently.	High	Replacement of asphalt occurs on minor roads every 10 years. New mixes can accommodate higher temperature ranges.	Medium	Medium

7.3.2 Quantitative Assessment

After performing a qualitative vulnerability assessment through the facilitated workshop setting, a quantitative assessment should be conducted to explore those areas of moderate to high vulnerability in greater detail. The vulnerability should be evaluated first under current or historical climate, then again under projections of future climate. In this way, the results can be grounded with the current understanding of the system and can identify and quantify vulnerabilities that may already exist and those that arise due to a changing climate.

A system model is generally required to quantitatively translate climate and climate changes to system vulnerability. Hydrological models are often used to relate changes in climate to changes in variables such as runoff, streamflow, potential evapotranspiration, soil moisture, relative humidity, snow depth and snowpack/melt, and vegetation to more accurately describe the risk variables. As considerable work has already been conducted by SCWA and various research agencies (USGS, Scripps Institution of Oceanography, NOAA, and others) related to the climate science and initial threats to the agency's water system, it is recommended to utilize much of this available data and modeling tools. The data and tools needed to conduct a more detailed quantitative analysis, may include the following:

- SCWA facility database and facility descriptions,
- GIS mapping and analysis,
- watershed hydrological modeling using the USGS Basin Characteristic Model,
- groundwater modeling using the USGS GSFLOW groundwater model,
- river-reservoir system modeling using the HEC-ResSim model for the Russian River,
- river flood hydraulics and sediment transport using HEC-RAS models,
- coastal modeling using the CoSMoS modeling system,
- existing or updated system dynamic models for integrated risk assessment.

The facilities and systems will need to be described and mapped. Climate and sea level inputs for hydrologic models and coastal models will be adjusted for the selected scenarios of future change. The model inputs may also incorporate changes in other key parameters such as population, land use, efficiency trends, or infrastructure or management programs that are on-going. The modified inputs will translate into a changed system response based on the use of the quantitative tools. The quantitative information can provide substantially improved assessments of vulnerability.

Results from system analyses used in many water resource evaluations are often reported in terms of percent of time, or fraction of assets, or frequency that vulnerability thresholds were exceeded. The reporting in this manner can allow for a comparison of performance measures that are not commonly measured in like units. However, additional information relating to the extent of threshold exceedance can also be reported to shed light on risk attributes. For example, for a flooding vulnerability assessment, the reporting could demonstrate the frequency of flood levels <u>and</u> the magnitude of inundated acres under historical and future climate scenarios.

Table 8 provides an example of the vulnerability assessment results for an integrated water management system. In this case, the system was evaluated using both the historical observed climate and future climate projections. The vulnerability under each of these scenarios was evaluated as a proxy of potential future conditions and the impact of climate change. As shown by the results from the quantitative vulnerability assessment, the water delivery, electrical power, and ecological resources are particularly

vulnerable to projected future climate change. This quantitative information can provide more detailed support and justification for ratings provided in the vulnerability-risk table.

Table 8. Example Vulnerability Assessment Results without Adaptation Strategies (percent of time vulnerability threshold was exceeded by mid-century)

Resource	System Vulnerability	Historical Observed Climate	Projected Future Climate
Water Delivery	Lee Ferry Deficit (Upper Basin Reliability)	**0%**	**18%**
	Lake Mead pool elevation below 1,000 feet msl (Lower Basin Reliability)	**13%**	**50%**
Electrical Power	Upper Basin Generation (below 4,450 gigawatts per hour per year for 3 consecutive years)	**22%**	**46%**
	Lower Basin Generation (Lake Mead pool elevation below 1,050 feet msl)	**20%**	**50%**
Flood Control	Critical River Stage below Hoover Dam (greater than 28,000 cfs)	**25%**	**25%**
Water Quality	Salinity below Parker Dam (greater than numeric criteria)[1]	**0%**	**0%**
Ecological	Lake Mead to Lake Mohave Flow (annual flow change greater than 845 kaf)	**14%**	**47%**

7.4 Risk Assessment

A risk assessment provides information related to the consequence and likelihood of potential impacts to the system and enables a deeper understanding and prioritization of risk areas. A risk assessment involves the identification of the *hazard* (climate change), an assessment of the *consequence* of such changes, and an assessment of the probability or *likelihood* of the change. Similar to the vulnerability assessment, performance thresholds are used to identify the conditions for which performance is degraded or for which consequences will be evaluated.

Risk is the product of both the consequence (C) of the hazard and the likelihood (P) of the hazard occurring. These two terms are independent -- in assessing the consequence one must assume the event has occurred, and in assessing the likelihood one must not consider the consequence of the event. The consequence reflects the impact to the system in terms of system function, social, governance, or financial measures. The likelihood is related to the climate change factor (or factors) that drive the potential event. High risk areas are those with moderate to high consequences and moderate to high likelihood. The risk assessment can be used to identify a range of priority areas for which additional study can be focused or for which adaptation measures should be considered.

7.4.1 Consequence

As with the assessment of vulnerability, the experience of system managers and operators is especially important to translate the understanding into the consequence rating. Consequences are most commonly performed based on the system function. However, the consequences can be evaluated for other areas such as Social, Governance, or Financial if desired. An example consequence rating scale is shown in Table 6. The ratings include five levels ranging from "negligible" to "severe" reflecting the relative consequences that could occur for different system components.

Table 6. Example Consequence Rating Scales

Level	Descriptor	System Function	Social	Governance	Financial[1]
1	Negligible	No impact to infrastructure or system function.	No adverse human health effects or complaints.	No changes to management required.	Financial impact less than $2M.
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.	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.	Additional operational costs. Financial impact $2M - $10M.
3	Moderate	Widespread impacts resulting in loss of service and/or damage to infrastructure. Damage recoverable by maintenance and minor repair. Partial loss of local infrastructure.	Frequent disruptions to employees, customers, or neighbors. Adverse human health effects. Negative reports in state media.	Investigation by regulators. Changes to management actions required.	Financial impact $10M-$50M.
4	Major	Extensive infrastructure impacts or widespread loss of service. Loss of service is not immediately recoverable. Permanent damage to regional infrastructure services.	Permanent physical injury and loss of life may occur from an individual event. Negative reports in national media. Public debate about infrastructure performance.	Notices issued by regulators for corrective actions. Changes required in management. Senior management responsibility questionable.	Major financial impact $50M-$200M
5	Severe	Permanent, system-wide damage to infrastructure or failure of system to provide service. Significant changes to major infrastructure required to respond.	Severe adverse human health effects. Potential for significant loss of life. Emergency response required. Negative reports in international media.	Major policy shifts. Change to legislative requirements. Full change of management control.	Severe financial impact of greater than $200M

[1] Financial impact ranges ($M) will be dependent on the system size and budget.

7.4.2 Likelihood

The uncertainty in climate projections is related to several major areas of uncertainty such as future greenhouse gas emissions, general circulation model uncertainty, downscaling, and other factors. An assessment of "probability" is not possible and should not be attempted. Rather the likelihood should be assessed based on the range of projections that exceed the particular climate threshold. For example, if the consequence is evaluated for the condition in which daily summer temperatures exceed 30° C, then the

likelihood should be based on the percentage of projections that result in exceeding this temperature. The likelihood of the six North Bay climate scenarios can be assessed by comparing against the full climate projections publicly available (see Figure 3 and Figure 6).

An example of a standard likelihood rating scale is shown in Table 7. The ratings include five levels ranging from "very likely" to "very unlikely". The ratings are consistent to those used to describe the confidence in global change outcomes from the IPCC Fifth Assessment Report (Stocker et al. 2013).

Table 7. Example Likelihood Rating Scale

Level	Descriptor	Description
5	**Very Likely**	Almost certain to occur. Greater than 90% of climate projections indicate this occurrence.
4	**Likely**	Likely to occur. Greater than 66% of climate projections indicate this occurrence.
3	**Moderate (as likely as not)**	About as likely as not. More than 33% 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.
1	**Very Unlikely**	Event is not expected to occur, but occurrence cannot be excluded. Less than 10% of climate projections indicate this occurrence.

7.4.3 Risk Matrix

In order to translate the combined ratings of consequence and likelihood, a risk matrix as shown in Table 8 is used. Major to severe consequence events that are very likely to occur will constitute "high risk" areas. Slightly lower consequence or likelihood ratings will result in "moderate risk" areas. Finally, areas that reflect relatively low consequence or are unlikely to occur are generally considered "low risk" areas. It should be noted that these are general descriptions and it is common to review the ratings during the workshop setting to ensure that consistent evaluation approaches were used.

Table 8. Typical Risk Matrix

		Consequence				
		Negligible = 1	Minor = 2	Moderate = 3	Major = 4	Severe = 5
Likelihood	Very Likely = 5	L	M	H	H	H
	Likely = 4	L	M	M	H	H
	Moderate = 3	L	L	M	M	H
	Unlikely = 2	L	L	L	M	M
	Very Unlikely = 1	L	L	L	L	M

	Low Risk
	Special Case
	Moderate Risk
	High Risk

7.4.4 Black Swans and Other Special Cases

Two significant special cases to the risk matrix require additional consideration. These special cases involve the low likelihood but severe consequence events and the high likelihood but minor consequence events.

“Black Swans” is the term sometimes used to identify the seemingly unlikely or low probability events that, should they occur, could have transformative effects on systems, societies, and/or governance. Use of the traditional risk matrix would indicate that these have only “moderate risk” due the low “likelihood” of the occurrence (USGS ARkStorm Scenario or superstorm Sandy, for example). However, exploring these events further and questioning whether the likelihood ratings are due to rigorous science review or simply due to lack of model or science projection is important. In many cases, these “black swans” result in disaster response, loss of life and property, and extreme economic impacts. It is important to consider these events when prioritizing adaptation strategies and research related to more traditional “high risk” areas.

The other special case involves those events that are believed to be very likely but have only minor consequences. An accumulation of many of these cases may still constitute areas of priority investment, especially since the likelihood of the events is high. Upon completion of the risk tables, a review should be conducted as to whether a large number of similar areas fall within these cases. For example, changes in 24-hour precipitation may indicate that culverts will be unable to convey the design flow, but since the consequences of small localized flooding is relatively minor it may not draw significant consequence. However, if this same change in precipitation causes flooding throughout the SCWA service area, inhibits

use of backup power, or limits access to transportation, it may be considered quite significant due to the scale or cumulative effect. It is recommended to review these risk areas carefully to determine whether they should be considered separately.

7.4.5 Prioritized Risk Areas

Upon completion of the risk assessment, areas can be prioritized based on the relative risk ratings. Table 9 shows an example of a completed risk assessment table. Areas with ratings of “moderate” to “high” risk ratings should be identified and summarized. Spatial mapping of the system components and associated risk ratings is often useful for conveying the risk information. Often the end goal of some risk assessments is to identify the priority areas which should receive additional funding and effort for advancing science, developing adaptation strategies, and focused outreach to management or the public. A clear summary of these areas, the system components that are affected, and the climate changes that are the primary cause should be developed. It is also recommended to develop a concise set of findings statements that led to the selection of the priority areas.

Depending on the level of system component detail included in the risk assessment, it may be necessary to consolidate individual system component risks (e.g. high risk to pumping station No.15) to the major system function (e.g. collection system). The roll-up of the priority areas helps in communicating areas of risk and focus for seeking adaptation strategies.

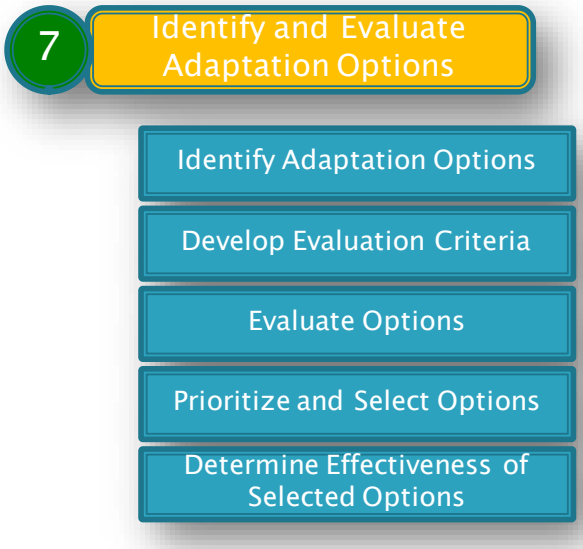
Table 9. Example Qualitative System Risk Assessment

Example Qualitative System Risk Assessment

System and Peformance Measures				Climate Variables and Change		Risk Assessment				
System	Performance Measure	Performance Metric	Threshold	Climate Variables	Projected Climate Change	Consequence	Rating	Likelihood	Rating	Risk
Water Supply	Delivery Reliability	Reservoir Storage	Storage less than 100,000 acre-feet	Increased Temperature	Up to 3C increase by mid-century	Failure to deliver firm supplies in dry periods. Failure to meet river flow and temperature obligations. Failure to meet hydropower minimum levels.	**Major**	Warming up to 2C is "very likely". Seasonal shifts runoff and reduction in snowpack are already observed and also considered "very likely".	**Very Likely**	**High**
				Change in Precipitation	Range of -20 to +20% in annual precip.					
				Decrease in Soil Moisture or Snowpack	Warming, combined with changes in precip will lead to decreased snowpack and reduction in late spring soil moisture.					
Flood Management	Manage the 1% Flood Event	Flood Level	Exceeding currently established 100-yr flood level	Increased Temperature	Up to 3C increase by mid-century	Inundation of over 20% of urban footprint and significant industrial and agricultural commerce. Loss of life is highly likely.	**Major**	Science of extremes is evolving and due to the rarity of these events the ability to track historical trends is difficult. However, more than 70% of all projections suggest increases in extreme precipitation events in this region. Magnitude ranges from 2% to 25%.	**Likely**	**High**
				Increased Extreme Precipitation	Heaviest 1% of precipitation is projected to increase by 15% by mid-century					
				Increased Duration of Heavy Precipitation	Uncertain, but some projections show greater atmospheric river presence and possible increased "stalling" of storms					
				Increased Sea Level and Storm Surge	Mean sea levels projected to be 3ft higher by mid-century, and storm surge may increase by 5ft					
Stormwater Management	Combined Sewer Overflows	Overflow Frequency	Exceeding current EPA Standard	Increased Temperature	Up to 3C increase by mid-century	Water quality effects on local water ways. Regulatory fines in the $MM for each increase in CSO event.	**Major**	Science of extremes is evolving and due to the rarity of these events the ability to track historical trends is difficult. However, the majority of projections suggest increases in extreme precipitation events in this region. Current operating plans are being updated for increased use of coastal pump stations.	**Moderate**	**Medium**
				Increased Extreme Precipitation	Heaviest 1% of precipitation is projected to increase by 15% by mid-century					
				Increased Duration of Heavy Precipitation	Uncertain, but some projections show greater atmospheric river presence and possible increased "stalling" of storms					
				Increased Sea Level and Storm Surge	Mean sea levels projected to be 3ft higher by mid-century, and storm surge may increase by 5ft					
Power	Transmittion Integrity	Demand-Related Blackouts	Peak summer demand exceeding current transmission limits	Increased Extreme Temperature and Heatwaves	Increases in both extremes summer temperature and frequency of heatwaves are projected in all portions of the service area	Potential implications for public health, business losses, and security. Linkage to critical elements of water and transportation systems suggest that the cumulative consequence will be high.	**Major**	Likelihood of exceeding peak summer temperatures by at least 1C, based on the range of climate projections, is "very likely",	**Very Likely**	**High**
Transportation	Roadway Integrity	Pavement Buckling on Asphalt Roads	Temperatures greater than 30 C	Increased Extreme Temperature	Frequency of events exceeding 30C are projected to increase by 20% by mid-century and 50% by end of century.	Potential implications for public safety, higher road maintenance costs, travel restrictions. Affects roughly 55% of the regions medium and high volume roadways.	**Moderate**	Warmer summer temperatures are already being observed and increases up to 3C are considered "very likely".	**Very Likely**	**High**

8.0 Adaptation Options and Strategies

At this stage, the climate change impacts analysis, vulnerability assessment, and risk assessment have been completed, and the risks areas have been prioritized. The focus of adaptation planning involves identifying and evaluating options and strategies that can reduce or manage risks, and improve the climate resiliency of the systems. Specifically, adaptation planning involves the identification of options, evaluating options based on specific criteria, prioritizing and selecting options, determining the effectiveness of selected options, and combining selected options into strategies. These elements are discussed in further detail below.



8.1 Identify Adaptation Options

A range of potential adaptation options will need to be identified through engagement of SCWA staff, stakeholders, and other participants. At this stage in the process, the identification of options should consider a wide range of options that include infrastructure measures, system re-operation, and management/policy measures. Experience on a range of climate adaptation projects suggests that it is best to essentially compile the "wish list" of adaptation options at this phase. However, adaptation options should be targeted toward addressing the high risk areas and the specific vulnerabilities. In addition, it is suggested to review the current planned actions for the system (such as those included in the current Capital Projects Plan) to identify actions that may have already been considered at depth.

It is sometimes useful to organize identified options into categories that describe a particular SCWA risk reduction approach. For example, a range of measures that target more efficient use of water or energy or reduce losses may be organized into an "increase efficiency" category. While this categorization is not required, it is highly recommended for studies that involve a large number of adaptation options as it helps to improve communication and frame the broad approaches toward adaptation.

8.2 Develop Evaluation Criteria

Adaptation options that may be considered could be quite broad – ranging from new infrastructure for supply/demand management to changes in management or regulatory mechanisms to specific natural infrastructure investments. Some of the options may have similar ability to reduce future risk, while some will outperform others but only with a very large investment. Others options may provide multiple benefits not limited to climate adaptation. Evaluation criteria are used to describe attributes of interest related to options. While these evaluation criteria will be specific to SCWA, criteria covering technical, environmental, economic, and social categories are commonly included. Each option is quantitatively or qualitatively evaluated for criteria within these categories. Table 10 shows

an example of these criteria used for a Colorado River Basin multi-resource evaluation (Reclamation, 2012).

Table 10. Example Evaluation Criteria and Categories for Adaptation Options for the Colorado River Basin Supply and Demand Study

Technical	Environmental
Technical Feasibility Implementation Risks Long-Term Viability Operational Flexibility	Permitting Energy Needs Energy Source Other Environmental Factors
Social	**Economic (and Other)**
Recreation Policy Legal Socioeconomics	Cost Timing Quantity of Yield Hydropower, Water Quality

Following the evaluation of an option's risk-reduction performance, preferences related to "least cost", "least energy use", "most technically feasible", and others may be used to determine which options, or portfolio of options, should be considered for inclusion in final adaptation strategies. The development of the evaluation criteria early in the process allows for different preferences to be explored following the vulnerability and risk assessment.

8.3 Evaluate Options Based on Criteria

Each option will need to be quantitatively or qualitatively evaluated for criteria. Numeric criteria are often defined for attributes such as cost, timing of implementation, yield, and others. Qualitative ratings are generally defined for the other criteria. Typically, letter ratings of "A" through "E" or numeric scales (1 through 5) are assigned based on the attributes of each option related to the specific qualitative criteria. Figure 13 shows an example of these qualitative criteria and results used for a river basin multi-resource evaluation.

Considerable effort may be involved in defining the attributes and developing the ratings for each of the options. However, the definition of options and evaluation is typically only performed at the appraisal level in this phase to limit premature investment of time and resources.

Figure 13. Example Results for Adaptation Option Evaluation Criteria

8.3.1 Prioritize and Select Adaptation Options

Based on the evaluation criteria, SCWA and stakeholder groups may express preferences or tolerances for specific ranges within these criteria. For example, options that rate high in "feasibility" and "permitting", or low in "energy needs" or "cost" may be prioritized by the adaptation team. The criteria and preferences can be used to prioritize and select adaptation options for further analysis. A facilitated workshop is often the best venue to explore these preferences along with the decision analysis tool. The goal of this step is to develop a subset of the identified options for which greater emphasis can be placed on evaluating option effectiveness.

8.3.2 Determine Effectiveness of Selected Options

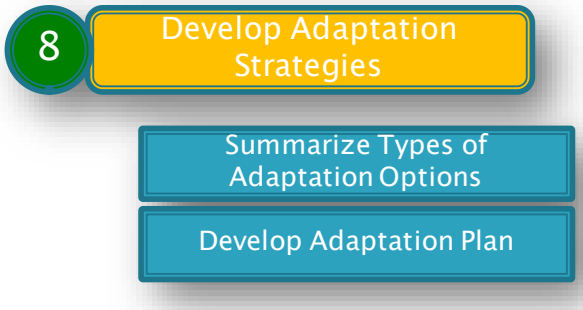
While the attributes and evaluation criteria describe the option related to a range of criteria, the effectiveness of the option at reducing the vulnerabilities or risks identified in previous steps is critical. Often, a general understanding of the risk reduction potential exists, but has not been quantified. Perception is often in greater supply than engineering analysis at this point. To better illuminate this assessment, an analysis of the system performance (e.g. hydrologic or hydraulic modeling) with implementation of the option is required to be able to quantify the relative performance of the selected options based on the identified system performance metrics. For example, increasing the capacity of a pump station may reduce flooding related vulnerabilities by 30%, while increasing regulatory storage or restoring tidal marshes/barriers may reduce vulnerabilities by 40%. The effectiveness of the options would not be known a priori. Systems analysis allows the effectiveness of the selected options to be studied further and quantified.

It is noted that the risk reduction effectiveness is only one (but important) measure of an adaptation option. The risk reduction effectiveness of the option(s) will be added to the

attributes and criteria discussed above (i.e. cost, feasibility, timing, legal, etc) to form part of the basis for eventual selection of adaptation strategies.

8.4 Develop Adaptation Strategies and Adaptation Plan

The final step emphasizes the development of adaptation ***strategies*** from the information that has been developed in the preceding steps. An adaptation strategy integrates the understanding of risk, uncertainty, adaptation option effectiveness and other attributes, timing, cost, resources, and other factors to develop a roadmap for actionable next steps (e.g., strategies implementation).



8.4.1 Summarize Types of Adaptation Options

In some cases, the adaptation strategy may emphasize accelerating investments in understanding the science and analysis tools. In other cases, it may lead to immediate investments to improve the resilience of infrastructure or operational methods. As an outcome of the analysis, three types of adaptation actions are typically identified:

1. ***Early, Low Regret Actions***. These actions are ones that can be implemented in the near-term (5-15 years) and will demonstrate value over a wide range of climate outcomes. Many of these actions may be needed for current risks in addition to future risks. These actions are generally robust in both the short-term and long-term, but are not likely sufficient by themselves to make a significant improvement in the resilience of the system.
2. ***Long Term, Robust Actions***. These actions generally require longer lead times (10+ years) for planning, design, and implementation and thus can only address mid- to long-term risks. However, through the analysis it is found that these actions will demonstrate value of a wide range of climate outcomes and thus represent robust actions.
3. ***Long Term, Contingent Actions***. Several long-term actions will only show significant risk reduction value under certain climate conditions. Often, these actions are effective at reducing risks due to the low likelihood events and can thus be considered "contingent" upon these outcomes. Since the science related to climate change and regional impacts is rapidly evolving, these actions may be considered if new science suggests that these contingent outcomes are now of greater likelihood.

The first two types of actions can and should be planned for in the near-term. Phased implementation can be considered for the long-term actions, if the potential exists. For example, levee sizing can consider establishing footprints for the ultimate build out (say, 100 years), but only include specific, on-the-ground infrastructure investments for the next 50 years. This phased approach can also be followed when considering a portfolio of options. In this case, some options in the overall portfolio can be considered in the near- to mid-term and, if conditions indicate a continuing need, the remainder of the portfolio can be

considered. Such adaptive strategies are necessary to balance the uncertainty of climate science and projections with the economic investments related to adaptation options.

After identification and selection of adaptation strategies, the vulnerability and risk of the system should be re-evaluated with the addition of these strategies. Reductions in vulnerabilities will necessarily translate into reduced risk and improved resilience. Table 9 below shows an example of the reductions in vulnerabilities with various adaptation strategies (portfolios).

Table 11. Example Reduction in Vulnerability with Adaptation Strategies (percent of time vulnerability threshold was exceeded)

Resource	System Vulnerability	Baseline	Portfolio A	Portfolio B	Portfolio C	Portfolio D
Water Delivery	Lee Ferry Deficit (Upper Basin Reliability)	**7%**	2%	2%	3%	3%
	Lake Mead pool elevation below 1,000 feet msl (Lower Basin Reliability)	**19%**	3%	3%	5%	6%
Electrical Power	Upper Basin Generation (below 4,450 gigawatts per hour per year for 3 consecutive years)	**18%**	9%	10%	10%	11%
	Lower Basin Generation (Lake Mead pool elevation below 1,050 feet msl)	**42%**	14%	14%	29%	20%
Flood Control	Critical River Stage below Hoover Dam (greater than 28,000 cfs)	**1%**	4%	4%	3%	34%
Water Quality	Salinity below Parker Dam (greater than numeric criteria)[1]	**0%**	0%	0%	0%	0%
Recreation	Colorado River Boating (days less than control run)	**30%**	14%	16%	17%	19%
	Powell Shoreline Facilities (pool elevation less than 3,560 feet msl)	**24%**	11%	11%	12%	13%
	Mead Shoreline Facilities (pool elevation less than 1,080 feet msl)	**57%**	31%	30%	37%	39%
Ecological	Colorado River Flow (less than reference value)	**38%**	40%	28%	28%	31%
	Lake Mead to Lake Mohave Flow (annual flow change greater than 845 kaf)	**12%**	4%	4%	7%	8%

This re-evaluation step is critically important for demonstrating the risk reduction value of the investments and for comparisons back to the “no action” alternative.

8.4.2 Developing the Adaptation Plan

The overall adaptation strategy will be documented in the adaptation plan report that integrates the findings of the study and develops the roadmap for moving forward. In general,

a climate vulnerability assessment and adaptation plan should include the following strategy elements:

- Science and System Analysis Tool Strategy
  - Improve understanding of climate science
  - Improve understanding and refine assessment of local, system-relevant impacts
  - Investment in upgrades to land surface and system analysis tools
- Adaptation Implementation Strategy
  - Implementation of early, low regret adaptation options
  - Implementation of early phases of longer-term adaptation options
  - Identification of triggers for longer-term adaptation options
- Monitoring and Update Strategy
  - Development of monitoring metrics and thresholds
  - Alignment of current plans with identified adaptation needs (disaster response plans, capital improvements plans)
  - Plan for updates to climate adaptation strategy
- Funding Strategy
  - Identify how actions will be funded through internal mechanisms (CIPs, rates, regional funds)
  - Identify state and national grant funding opportunities
  - Build regional partnerships to leverage limited funds
- Regional Partnership and Leadership Strategy
  - Identification of national or regional policies or programs that are related to goals
  - Identify partners in industry or utilities that have similar risks and strategies
  - Participate or form regional alliances to further causes
- Public Awareness and Outreach Strategy
  - Identify target stakeholders and general public
  - Identify key messages that align with adaptation strategy
  - Identify how stakeholders and public can engage
  - Explore whether incentives could be offered to change use behavior

The content and level of detail for each of these strategy elements will depend on SCWA management direction. The adaptation plan outline should be prepared early in the adaptation plan development process to ensure the appropriate level of information is compiled and that outreach is tailored for the needs of the final plan.

9.0 Stakeholder Engagement

As part of the Work Plan, an initial stakeholder outreach plan has been developed to guide the engagement of both internal and external stakeholders in first development and then implementation of the Work Plan. The stakeholder engagement plan suggests a list of internal and external stakeholders, a set of objectives for stakeholder engagement, and methods and timing of communication with various stakeholders. And to be successful, the stakeholder outreach plan must be flexible and respond to changing circumstances and the emerging concerns and level of interest of stakeholders.

This section provides a brief overview of the stakeholder engagement plan. The complete draft stakeholder engagement plan is included as Appendix A.

9.1 Defining Stakeholders and Interest in the Plan

For most projects there are naturally various "tiers" of stakeholders that have different types of investments in the outcome of a project and also varying levels of contribution to a project both in terms of specific content and overall direction. For the purposes of defining appropriate outreach strategies, stakeholders for this effort can be divided into several categories:

- Internal Stakeholders (SCWA)
- Contractors and other Agency Customers
- Close Partners
- State and Federal Agencies and Research Institutions
- General Public

Internal stakeholders include the core SCWA project team, key SCWA departments (water supply, flood control, sanitation, and community and government affairs), the SCWA Board of Directors, and Sanitation Districts and Zones. SCWA contractors include the cities and special districts for which water is provided. Close partners include the RCPA, NBCAI, Center for Climate Protection, Sonoma County Agricultural Preservation and Open Space District, Flood Zones and Advisory Committees, and other local governments and NGOs. State and federal agencies and research institutions include the USACE, RWQCB, CDFW, NOAA, USGS, and SIO. Finally, the general public would include ratepayers and residents within the SCWA service area.

9.2 Objectives for Stakeholder Outreach

As the Climate Adaptation Plan is developed and implemented there will be different objectives for the engagement of the different stakeholders. Suggested objectives for stakeholder engagement are the following:

- Solicit technical input and feedback into Work Plan/Vulnerability Assessment and Adaptation Plan
- Identify and respond to concerns
- Build and gain support for decisions/funding
- Education of community members

9.3 Methods and Timing of Communication

The timing of communication with the various stakeholders is linked to the various stages of project development when information is available to be shared and input and feedback is required. Four main stages of project where significant stakeholder engagement is required are:

1. Scoping/Work Plan Development

2. Vulnerability Assessment (Water, Flood, Sanitation)
3. Identify Adaptation Strategies
4. Climate Adaptation Plan Preparation

Methods of communication will vary depending on the stakeholder type and the stage of the project. The core project team will hold regularly scheduled in-person and conference call meetings. Other stakeholders may be engaged in facilitated workshops or periodic in-person meetings, while others may be engaged through web-based sharing methods or website updates.

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