Considering Climate Change Impacts

I.1 Legislative Language on Considering Climate Change in IRWM

Water Code Sections. California Water code *stipulates that climate change is to be considered within IRWM planning (Water Code 79740 et seq.). It does not specify the technical nor general methods for how to consider climate change within IRWM. It does emphasize that the purpose is to improve regional water self-reliance security, adapt to the effects of climate change on water supply, and to help water infrastructure systems adapt to climate change, including, but not limited to, sea level rise. The water code also aims to provide incentives for planning at the watershed scale with priority being given to projects in plans that cover a greater portion of the watershed.*

This guidance is not prescriptive but is written recognizing that some groups seek guidance on how to consider climate change in their IRWM planning. As such, this guidance describes common approaches to incorporate climate change in planning and management, pulling from the California Department of Water Resources' (DWR's) experiences, as well as experiences of water suppliers, local, state, and national governments, non-governmental organizations, and research scientists. The fields and practice of climate change science and climate adaptation have grown tremendously in the last decade, offering experiences and perspectives from which regional planners can use.

Climate change descriptions in the 2022 IRWM Guidelines can be found in Section II.C. and in the Project Solicitation Proposal in Section II.C, Exhibit A.

Planning at the Watershed Scale

Watersheds delineate natural hydrologic areas and functions that encourage systems thinking across water resources sectors, including water supply, water quality, drainage, stormwater, runoff, and groundwater. Watersheds comprehensively characterize the natural systems needed to understand trends and cumulative impacts and discover new adaption opportunities and are the appropriate and effective landscape units for assessing climate vulnerability and evaluating adaptation strategies. Watersheds are an appropriate organizing landscape unit for collaboration on integrated water management as they encompass the actions, policies, and processes that affect the system as a whole:

- Watersheds describe a natural system more comprehensively and accurately than jurisdictional boundaries.
- Conditions and trends can be understood across the entire system.
- Cumulative impacts of water management activities can be accounted for at the watershed scale.
- Multi-objective, systemwide planning is facilitated by using a whole-system context.

I.2 Background: Climate Change & Integrated Regional Water Management Planning

The State of California recognizes the threat of climate change impacts to our communities, infrastructure, and economy, and as such introduced IRWM climate change planning requirements in 2011 with Proposition 84, and with strengthened language in 2016 under Proposition 1. In addition, under Assembly Bill 2800, the state is mandated to account for climate change in all planning, infrastructure, and investments, including grant making. Investments made under IRWM need to be effective under the climate of the future. Climate models and observations have shown us the climate is no longer static and planning based on the hydrology of the past is no longer adequate. Projections of climate change in California indicate a further intensification of wet and dry extremes and shifting temperatures that can lead to more frequent flooding and droughts and impacts to both water demand and supply. Extreme and higher temperatures can lead to increases in water use and evapotranspiration. A declining snowpack and earlier runoff patterns could result in changes to stream flow patterns and reservoir operations. Projections of more frequent, severe, and prolonged droughts could lead to not only less surface water available, but also exacerbate ongoing stressors in groundwater basins across the state. Without implementing preparedness and resilience strategies to adapt to or mitigate these impacts, the changing climate can jeopardize water supply reliability, ecosystem health, and increase flood risk.

How a water manager can best prepare for climate change differs according to several conditions including planning capacity, planning goals and objectives, existing water infrastructure, water rights, sources, and demands, as well as across the variety of tools available to assess the impacts of climate change on water supply reliability.

I.3 Guidance for Selecting a Climate Change Analysis Approach

This guidance provides a two-step decision-making process useful in determining which tools and approaches will work best for regional climate change analysis. The process is sensitive to the planners needs and capacity, which range widely by geography, water sources, human and ecological demands, and infrastructural and organizational arrangements.

Step 1 involves completing a vulnerability checklist. The Step 1 exercise assists the planner in self-identifying areas where their water supply reliability may be at risk to the impacts of climate change. Information gathered in Step 1 guides selection of an analysis approach in Step 2.

Climate change studies, analysis and planning for your region may have already been completed by the regional Groundwater Sustainability Agency (GSA), or within Agricultural Water Management Planning, Urban Water Management Planning or another local general planning or hazard mitigation document. DWR encourages water managers to participate in these planning efforts. Noting that the best available science should always be used and that it is not always feasible or appropriate to reuse studies.

Agricultural water management planning, groundwater sustainability planning, and urban water management planning all have a similar planning horizon which can foster regional plan alignment. The guidance offered here for climate change analysis is based on DWR's *Climate Action Plan: Phase 2* (DWR 2018) and the *Climate Change Handbook for Regional Water Management* (DWR 2011) to promote alignment with DWR approaches.

Regional climate change studies may use different scenarios and approaches to analyze the impacts of climate change and could obtain varying results. Analysis options vary greatly with respect to complexity and sophistication. The various methods described here are intended to give a representative overview of the most common options. It is not possible to include every method, as climate change science is frequently advancing.

I.4 Common Steps to Considering Climate Change

DWR recommends three main steps to conduct a climate change analysis.

First, a screening process determines what assets and other aspects of the system may be exposed and sensitive to climate change. These may include water supply source, demand and/or use projections, infrastructure, operations of the infrastructure, timing and volumes of supplies, customers and other users, existing adaptation capacity for extreme conditions and events, among others. The second step involves selecting and conducting an analysis on those assets and other system aspects at risk, which tends to require more staff time and technical capacity. The third step involves developing strategies and actions to mitigate the impacts of climate change on the water uses, supplies, and reliability.

Step 1: Climate Change Risk Determination Screening

The first step in conducting a climate change analysis is to assess exposure and sensitivity to changing climatic conditions. In the absence of quantifiable likelihoods and impacts (an absence of which is common in assessing a range of future conditions), risk is evaluated by combining how exposed a region is to climate change, and the sensitivity of the supply system to those exposures. Exposure refers to the degree to which the water system (including its demand) may be influenced by changes in climate. Sensitivity to exposure commonly involves an assessment of its system, considering tolerance changes to factors such as temperature, precipitation, and other key processes. Not all water sources will be exposed to impacts of climate change. Even if risk to changing climate conditions is low, understanding the risks of each water supply source can contribute to better planning and reliability outcomes. Completing the "Climate Change Vulnerability Screening Form for Integrated Regional Water Management Planning" (see the Resources and References section at the end of this document) can help gauge if aspects of the water supply may be vulnerable to climate change impacts which can guide the climate change analysis in Step 2.

In addition to this screening form exercise, a planner may choose to conduct a stand-alone in-depth climate risk assessment. In-depth assessments with scientific rigor can have multiple benefits. The assessment can help provide information to policy and decision-makers, operators, and customers. Updates of critical infrastructure or personnel training budgets over the long-term can be targeted to mitigate high impact climate risks. A rigorous assessment can be valuable for justification of costly or otherwise controversial adaptation strategies.

Step 2: Selecting the Climate Change Analysis Approach

After completing the screening risk assessment, the next step involves a thorough analysis of assets identified in Step 1 as exposed, sensitive, and therefore at higher risk to climate change. This is a delicate process and should involve decision-makers and other stakeholders that hold an interest in the region's long-term reliability and viability. Including stakeholders and other decision-makers in this process can help identify climate change analyses that may have been completed by others and are relevant and applicable, as well as the most appropriate methods and tools to use if a new analysis needs to be completed, and with an approach needing to be tailored toward the understanding and interest of decision-makers. The following information is provided as a guide to assist in selecting a climate change analysis approach. It does not establish prescriptive recommendations or requirements.

Existing Climate Change Analysis

Modelling how climate change is projected to impact a region's water reliability can be a resource intensive exercise. For planners who are unable to pursue such an analysis, it is prudent to explore if an existing climate change analysis of their region may have already been conducted by other entities. Using climate change analyses conducted by another governmental agency, research institution, wholesaler, raw water supplier, or consulting firm could save time and resources and can help ensure planning with a consistent set of climate change projections.

Conducting a New Climate Change Analysis

There are multiple approaches for analyzing the impact of climate change, such as bottom-up (starting with system characteristics and capabilities), top-down (starting with characterizations of future climate), sensitivity analysis, and stress tests. Whatever approach is selected, it should adhere to the best available scientific guidance on climate change analysis.

Determining what type of climate change analysis is appropriate depends on several considerations. Some of which are listed below:

- Data Sources: The following factors are considered in assessing future climate change in a region: historical changes, changes projected by global climate models (GCMs) and their downscaled products, and climatic process-based changes such as intensification of atmospheric rivers or increases in the climatic water deficit. This means that the climate change analysis should incorporate information from historical observations, GCMs, downscaled GCM projections, and other relevant information about historical and projected changes.

- Purpose and Uncertainty: Climate change impact assessments are made for multiple reasons and employ different methodological approaches. Depending on the purpose, some impact studies explore the variations in models and in what is referred to as the "uncertainty space," more thoroughly than others. Some studies may legitimately reach a specific conclusion by using a single global climate model or downscaled product. For policy-relevant impact studies, it is desirable to sample the uncertainty space by evaluating global and regional climate model ensembles and downscaling techniques.
- Other Forcings: It should be recognized that additional forcings and feedbacks, which may not be fully represented in global models, may be important for regional climate change (e.g., land use change, heat island effect, or the influence of atmospheric pollutants). Climate forcings refer to those physical factors outside the climate itself that affect the Earth's climate. These include human-induced changes in greenhouse gas emissions, surface reflectivity, and atmospheric aerosols.
- Qualitative Information: When quantitative information is limited or missing, assessments may provide narratives of climate projections (storylines, quantitative or qualitative descriptions of possible realizations of climate change) in addition to, or as an alternative to, maps, averages, ranges, scatter plots, or formal statistical frameworks for the representation of uncertainty.
- Communicate Uncertainties: Limits to the information content of climate model outputs for regional projections need to be communicated clearly. The relative importance of uncertainties typically increases for small scales and affects relevant quantities due to limitations in model resolution, local feedbacks and forcings, low signal-to-noise ratio of observed trends, and possibly other confounding factors relevant for local effects.
- Model Selection: For regional applications, some climate models may not be considered because of their poor performance for some regional metric or relevant process. That said, there are no simple rules or criteria to define this distinction. Whether a set of models should be considered is a different research-specific question in every case. Selection criteria for model assessment should be

based, among other factors, on availability of specific parameters and the spatial and temporal resolution within the model.

- Downscaling: The usefulness and applicability of downscaling methods strongly depend on the purpose of the assessment (e.g., for the analysis of extreme events or assessments in complex terrain). If only a subsample of the uncertainty space of the available global climate model is used for the downscaling, this should be noted explicitly.
- Time Horizon and Emissions Scenarios: Many impact studies are affected by the relative similarity between different greenhouse gas emission scenarios in the near term. The length of the time period considered in the assessment studies can significantly affect results.

The following analytical considerations can assist in determining the most appropriate approach that planners can use to structure their decisional process for choosing an approach for the climate change analysis:

1. Climate sensitive parameters.
2. Spatial scale/watershed area.
3. Infrastructure/systems and operational activities.
4. Legal and institutional issues.
5. Continuity with previous work/studies.

1. Climate-sensitive Parameters

Assessing the climate sensitivity of the water supply and water use can assist in determining the type and scope of climate change analysis to use. Climate-sensitive parameters should indicate if the water supply or use type is sensitive to climactic events, how sensitive, and in what ways. Analytical considerations may include climate-sensitive parameters, climate-driven parameters, and how definite the assessment of these parameters can be. Analytical considerations include:

- What are the climate-sensitive parameters that affect performance of the supply or water use (e.g., average precipitation, summer high daily temperatures, extended heat waves, atmospheric river driven precipitation)?
- What are the climate-driven parameters that affect vulnerability of the supply (e.g., average annual streamflow; September streamflow; 3-,

5-, 7-day streamflow; stream temperatures; minimum flows; wildfire; sea level rise)?

- Does adequate data exist to explore how climate change could affect the water supply?
- Do extreme events (floods, droughts, heat waves, wildfires) significantly impact the performance of the water sources, infrastructure, or water use?
- How skillfully do downscaled global climate models simulate historically observed climate parameters of interest? How will the observed historical record of climate parameters of interest be used? How will (downscaled) global climate model data for climate parameters of interest be used? Is low-frequency variability in the climate parameters of interest an important consideration?
- What is the optimal temporal scale to adequately analyze the climate conditions (e.g., hourly, 6-hourly, daily, weekly, monthly, annually, multi-year averages)?

Common climate-sensitive parameters include:

- Average monthly temperature and precipitation.
- Average monthly streamflow.
- Inter-annual and low frequency hydrologic variability in terms of how it could affect recurrence, length, and severity of droughts and wet periods.

GCMs and their downscaled results may not adequately simulate the variance and cyclical nature of California's observed hydrological variability. Because of this, hydrologic modeling of future conditions has often, though not always, used the historical precipitation or streamflow record as the basis for future conditions modeling, with the climate change trend data mapped onto that historical record in a way that allows comparisons of historical experience with potential future conditions. This type of analysis has strengths and weaknesses that planners should critically evaluate before deciding on an approach.

Flood-protection analyses focus on flooding that could possibly disrupt the water supply, most likely through damage to infrastructure. When analyzing potential flood impacts daily and, in some cases, hourly temperature and precipitation will be the key climate-sensitive parameters of interest, while 1-, 3-, 5-, and 7-day peak streamflow and antecedent watershed conditions (such as snowpack and soil moisture) will be key climate-driven parameters of interest. GCMs are not designed to provide climate information at these temporal scales and do not have the spatial resolution to adequately simulate orographic precipitation patterns and other acute spatial characteristics. Downscaling approaches have been used in the past to address these issues, but concerns remain about the ability of downscaling methods to adequately translate important large-scale phenomena to smaller scale impacts. Again, planners should evaluate past efforts and the unique characteristics of the region before deciding on an approach.

2. Spatial Scale/Watershed Area

In selecting the climate change analysis approach, planners will want to assess analytical considerations relevant to the spatial scale/watershed area. These issues may include the following:

- Is the analysis being conducted for a small, localized water source or broad statewide/regional scale?
- Is the analysis, whether localized or statewide, consistent with other previously used datasets and analyses?
- Is the analysis consistent with other plans or analyses conducted over the same, similar, or overlapping areas?
- Does the analysis require simulation of multiple systems in a consistent manner?

Some analyses can be done at localized scales and are not influenced by conditions outside of the watershed in question; but, in many cases, conditions outside of the watershed will have important ramifications for the analysis.

3. Infrastructure, Systems and Operational Activities

Infrastructure, systems, and operational considerations include the following:

- Does the analysis consider multiple infrastructure or system changes? Or is the existing system (without changes) being analyzed under modified climate conditions?
- Is there an existing operations model (e.g., flood protection or water supply) that can be run with different climate conditions to simulate performance under differing climate conditions?
- What are the climate-sensitive inputs to the existing system model?

What is the time step of the existing system model? Do these system model characteristics align with available climate datasets?

- Does the system model allow all important conditions to vary over time (land use, population, sea level, water demand, etc.)?

Often the models used to evaluate climate impacts, such as a water system operations model, are configured so that certain conditions remain fixed throughout the simulation. This constraint may have important ramifications for how the simulation is configured and the type of climate dataset and tools used. For example, California Water Resources Simulation Model (CalSim) is designed to run with land use, sea level, and water demand characteristics that remain static throughout the simulation. This configuration means that CalSim-II is often run in a "climate period" analysis mode, as opposed to a transient analysis mode.

Additionally, CalSim-II simulations historically have been ran using the historical sequence of wet and dry years, and these simulations are then perturbed with monthly and annual climate change trends from climate change studies. This configuration has limited ability to simulate certain types of changes in climate and hydrology (e.g., changes in inter-annual variability, longer and more frequent droughts, etc.) that may be important for some impact evaluations.

4. Legal and Institutional Issues

Analytical considerations relevant to identifying the legal and institutional issues and constraints include the following:

- Is there a statute, regulation, or policy that requires a specific approach or the use of specific tools or datasets?
- Are there partnership agreements for the water supply that require or constrain the selection of approaches, tools, or data for climate change analysis?
- Who will be performing the analysis?

Developing new tools and datasets or deploying existing tools and datasets to be used for planning often involves additional considerations because of the range of technical capacities and data needs at local levels. For example, in 2016, DWR developed tools and data for climate change analysis to be used for the Water Storage Investment Program (WSIP), which were updated for the Sustainable Groundwater Management Act. An important consideration in WSIP was that the datasets and tools had to cover the entire state (because projects under the program could be located anywhere in the state) and provide temporally and spatially consistent information for temperature, precipitation, runoff, and State Water Project/Central Valley Project (SWP/CVP) water deliveries. Because of these considerations, a novel approach had to be developed specifically for the program. Some water supply sources may be similar in the sense that they have not yet been analyzed for impacts from climate change, and they are complicated by their source, topography, legal obligations, infrastructure, or stakeholder goals and objectives, as well as other challenges.

5. Continuity with Previous Work/Studies

The following considerations are useful to ensure continuity with previous analyses to the greatest ability possible:

- Does the analysis/plan need to be consistent with previously performed work? Does this analysis fit within an existing framework or larger/programmatic plan that was already analyzed using a specific approach and dataset?
- Does the analysis build upon or update previously completed analysis or planning work?
- Has a similar analysis been completed previously?

When a new analysis connected to previous work is being performed, additional considerations are useful to maintain alignment with the previous work. In these situations, it is important to maintain coherence and alignment between previous work and new work while also addressing the need to evolve and incorporate scientific, analytical, and management improvements. This stresses the importance of beginning this process with a thorough examination of existing climate change analysis at the local/regional level up to the watershed and statewide levels.

Step 3: Developing Adaptation Strategies, Planning, and Implementation

Analyzing how a changing climate can impact water reliability helps reveal what needs to be mitigated, planned for, or otherwise implemented to decrease risks. Often the vulnerabilities to climate change are also vulnerabilities to existing extreme conditions. Climate change can create an added risk that raises some existing challenges to become higher priority.

The actions, infrastructure, and social processes of developing ways to mitigate climate change impacts is referred to as "climate adaptation." Adaptation strategies range widely depending on the needs of the region. They may include adding an additional water source as a back-up in case the existing sources decrease under climate change. This may involve both engineered infrastructure and legal actions to secure water rights. A region that identifies sea level rise as a threat to its coastal aquifer may decide to increase groundwater recharge to act as a barrier to saltwater intrusion. In the case where a region identifies increased risks of shortage in late summer months, the planner might promote customer behavioral changes to reduce water usage during peak periods. How a region adapts to climate change varies widely and will depend on the types of projected impacts supplies and uses are exposed to as well as existing capacity to cope or otherwise mitigate those impacts. More information on developing climate change adaptation strategies can be found at https://resilientca.org/apg.

I.5 Resources

The list below includes a catalogue of existing DWR-produced climate change datasets and resources. This information is not meant to recommend any tool or dataset over another; rather, the description of each resource clarifies its purpose and contents which may or may not align with the region's chosen approach to climate change analysis.

Cal-Adapt and the Climate Change Technical Advisory Group (CCTAG) — California Climate Change Projections

This document was developed in 2015 by a formal committee of outside experts working with DWR staff. The projections are drawn from the Coupled Model Intercomparison Project Phase 5 (CMIP5) archive and use a three-step culling procedure with a variety of metrics pertinent to water management in California to select the 10 global climate models that have the greatest ability in simulating California climate conditions. This information is now stored on the Cal-Adapt platform.

- Total of 20 transient projections running from 1950–2099.
- Ten global climate models and two representative concentration pathways (4.5 and 8.5).
- Uses localized constructed analogs (LOCA) downscaling (6 kilometer [km] x 6 km grid spacing).
- Provides daily maximum and minimum temperature and precipitation.

- Hydrology model: Variable infiltration capacity (VIC).
- Water management model: WEAP.
- Operations model: CalSim-II.

Reference: Perspectives and Guidance for Climate Change Analysis.

Data Availability: LOCA downscaled projections data are available for exploration and download from the CalAdapt website and API.

Status as of 2022: The CCTAG scenarios are based on the newest available climate models and downscaling techniques. These scenarios provide a suite of future climate projections that generally cover the range of uncertainty expected in potential future climate conditions. The California Fourth Climate Change Assessment has recommended this suite of scenarios for all studies done for the upcoming assessment report. The Fourth Assessment team has also provided additional guidance on which of the 20 scenarios to use when using the full 20-model ensemble is infeasible.

Recommended Uses: These scenarios have wide applicability for many types of studies. The WSIP scenarios (below) provide an example of how those additional preprocessing steps have been performed by DWR for the Water Storage Investment Program.

SGMA/WSIP Scenarios

Developed in 2016 and 2017, these climate change scenarios were developed specifically for the WSIP and are being provided to groundwater sustainability agencies pursuant to the SGMA. They cover California in its entirety and provide a set of data products covering climate, hydrology, and water supply variables. The scenarios provide a suite of future climate projections that provide consensus projections at two future time periods as well as “bounding scenarios” at 2070 conditions that provide users with extreme climate outcomes that help explore the range of uncertainty expected in potential future climate conditions

- Total of four climate period projections.
    - One 96-year scenario run at 2030 conditions representing the consensus of the CCTAG ensemble of projections
    - Three 96-year scenarios run at 2070 conditions representing the consensus of the CCTAG ensemble of projections plus a dry-extreme warming scenario and a wet-moderate warming

scenario.

- Uses LOCA downscaling (6 km x 6 km grid spacing).
- Quantile mapping methodology used to perturb historical observed record of temperature and precipitation with climate trends.
- Provides monthly maximum and minimum temperature, precipitation, potential evapotranspiration (two vegetation coverages), surface runoff, baseflow, soil moisture, Central Valley streamflows, SWP/CVP operations, and SWP/CVP water deliveries.
- Hydrology model: VIC
- Operations Model: CalSim-II.

Reference: Guidance for Climate Change Data Use During Sustainability Plan Development.

Data Availability: Model products and data are available for download on the SGMA Data Viewer web mapping application under "Water Budget".

Status as of 2022: The WSIP/SGMA scenarios are based on the best available climate models and downscaling techniques. They are consistent with the 20 scenarios presented in CalAdapt and CCTAG efforts.

Recommended Uses: These scenarios have wide applicability for many types of studies. They are specifically designed to work within a CalSim-II modeling environment (and CalSim-II outputs are already available). Accordingly, these scenarios are likely the most readily usable for studies involving project operations, Delta conditions, or those that require simulation of future SWP or CVP water deliveries. These scenarios are DWR's only currently available dataset that provides a complete and consistent set of statewide temperature, precipitation, evapotranspiration, runoff, and SWP/CVP operations and deliveries. As such, the WSIP scenarios are generally the most useful tool for planning that involve areas within and outside of the Central Valley, especially in cases where SWP and CVP water deliveries are an important consideration in the study.

CVFPP Scenario

Developed in 2017, this climate change scenario was established specifically for the Central Valley Flood Protection Plan (CVFPP) 2017 Update. This scenario covers the Central Valley and develops changes in flood volumes at various return periods to modify Central Valley Hydrology Study (CVHS) unregulated volume-frequency curves to incorporate future climate change for the flood risk analysis.

One climate change scenario over a 96-year period, is included.

- Combined Warming and Precipitation Change Scenario based on CMIP5 Climate Model Simulations:
    - Late Century: Projected precipitation and temperature changes.
- Uses downscaled climate model data based on bias-correction spatial disaggregation downscaling method.
- Quantile mapping methodology used to perturb historical observed record of temperature and precipitation with climate trends.
- Hydrology model: VIC at 1/16-degree spatial resolution (6 km x 6 km grid spacing).
- Flood Frequency Analysis: Bulletin 17B method in the United States Geological Survey's PeakFQ software.
- Uses end-of-century climate change scenario considering combined changes in precipitation and temperature for CVFPP complete risk analysis.

Reference: 2017 CVFPP Update — Climate Change Analysis Technical Memorandum.

Data Availability: Data products can be requested via email.

Status as of 2022: The 2022 CVFPP Update will soon release three climate change scenarios following the procedure established in the 2017 CVFPP Update. These new scenarios used climate model simulation data from the CMIP5, which was the basis of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). The three scenarios represent three future conditions centered at 2072. 1) A drier – less warming condition, 2) A median condition similar to the scenario developed under the 2017 CVFPP Update, and 3) a wetter – more warming condition. Projected changes to historical unregulated flow volumes are derived through hydrologic modeling of the Central Valley watersheds. Unregulated flow volumes were estimated by applying climate scenarios (i.e., temperature and precipitation projections derived from CMIP5) to the historical variability in climate and simulating the hydrologic responses of the Central Valley watersheds using the VIC model.

Recommended Uses: This scenario has applicability for flood planning studies in the Central Valley. The CVFPP 2017 climate change scenarios were used to develop changes in flood volumes at various return periods for more than 150 locations throughout the Central Valley. The changes in flood volumes developed to support the CVFPP 2017 Update can be useful for other planning studies but require extra caution to use them for designing a flood project.

Decision Scaling Platform

Decision scaling is a platform for climate change analysis rather than a specific set of scenarios to be used for analysis. Decision scaling integrates vulnerability-based analysis with traditional risk-based assessment methods, allowing for the assessment of climate vulnerability across a wide range of potential future climate conditions and estimation of the probability of specific outcomes. This bottom-up approach enables planning for future changes that is informed by the best available science on climate change while not dependent on precise prediction of future values (i.e., does not rely on specific climate scenarios). Since 2016, DWR has collaborated with the University of Massachusetts Hydrosystems Research Group on the development of the decision scaling platform for the Central Valley watershed.

- Analysis platform evaluates system impacts and potential adaptation strategies across precipitation changes of +/- 30 percent and temperature changes of 0–4 degrees Celsius.
- Fifty-four hydrological sequences explore variations in inter-annual hydrologic variability observed in the 1,100-year reconstructed paleo record of streamflows in the Sacramento-San Joaquin watershed.
- Provides ability to explore hydrologic or system performance metrics across a range of climate changes.
- Hydrology model: Sacramento Soil Moisture Accounting hydrologic model (SAC-SMADS).
- Operations Model: CalLite 3.0.

Reference: Decision Scaling Evaluation of Climate Change Driven Hydrologic Risk to the State Water Project Final Report

Data Availability: Guidance on incorporating the decision scaling platform and related data products can be requested via email from the DWR Climate Change Program.

Status as of 2022: The decision scaling platform draws on cutting edge climate analysis research and techniques that have evolved out of a field known as "decision-making under deep uncertainty." This platform allows DWR to analyze the Central Valley water system and potential changes to it across a wide range of climate changes and to assign conditional probability estimates to each outcome so that decision-makers have probabilistic information about expected outcomes as well as less likely outcomes.

Recommended Uses: This platform is recommended for higher-level strategic planning applications and has not yet been used for specific project-level evaluations. Additional future work will focus on integrating decision scaling and detailed project level analysis.

Cal-Adapt.org

Cal-Adapt provides a view of how climate change might affect California, including changes in temperature, precipitation, snowpack, sea level rise, and wildfire. It contains tools, data, and resources to conduct research, develop adaptation plans, and build applications. Data products currently available on Cal-Adapt include:

- LOCA downscaled projections.
- Historical observed daily temperature and precipitation gridded data.
- Sea level rise scenarios.
- Snowpack forced by LOCA and gridded observed data.
- Wildfire scenarios.
- Long drought scenarios (LOCA).
- Streamflow (routed and bias corrected by LOCA).
- Additional climate variables generated through use of the VIC model forced by LOCA, downscaled projections, and gridded observed data.

I.6 Other Resources and References

Several additional reports, studies, and other resources provide more guidance and information on conducting climate change analyses in California and beyond and may be helpful for agricultural water planners.

Climate Change Planning for Water Suppliers

Association of Metropolitan Water Agencies (AMWA). 2019. Insurance, Bond Ratings and Climate Risk: A Primer for Water Utilities. A Report of the AMWA. Available at: https://www.amwa.net/assets/Insurance-BondRatings-ClimateRisk-Paper.pdf

California Department of Water Resources. 2018. Climate Action Plan: Phase 2. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan/Files/CAPII-Climate-Change-Analysis-Guidance.pdf

United States Environmental Protection Agency, California Department of Water Resources. 2011. *Climate Change Handbook for Regional Water Planning*. November 2011. This document provides a framework for considering climate change in water management planning. Key decision considerations, resources, tools, and decision options are presented that will guide resource managers and planners as they develop means of adapting their programs to a changing climate. Available at: http://climate.calcommons.org/sites/default/files/basic/climate_change_handbook_regional_water_planning.pdf

Water Utility Climate Alliance. 2020. Website. Offers examples of how different water suppliers are planning for climate change. Available at: https://www.wucaonline.org

Water Research Foundation. 2020. Mapping Climate Exposure and Climate Information Needs to Water Utility Business Functions; Appendix E: Water Utility Business Risk and Opportunity Profiles. Prepared by Cadmus and University of Arizona. Available at: https://www.wucaonline.org/assets/pdf/project-4729A-appendix-e.pdf.

Vogel J, McNie E, Behar D. 2016. Co-producing actionable science for water utilities. Climate Services 2-3:30-40. Available at: https://www.sciencedirect.com/science/article/pii/S240588071630007 3

State Water Project-Related Projections and Operations

California Natural Resources Agency. 2020. The Final State Water Project Delivery Capability Report 2019. https://data.cnra.ca.gov/dataset/state-water-project-delivery-capability-report-dcr-2019/resource/119da5c5-1c47-4142-8896-334628ca61cd

Drought-Related Science for Informing Management

Woodhouse C, Meko D, Bigio E, Frederick S. Using Tree Ring Records for Understanding Droughts in a Long-Term Context: A Guidebook. https://data.cnra.ca.gov/dataset/paleo-dendrochronology-tree-ring-hyrdo-climatic-reconstructions/resource/c1622256-912d-4384-a363-a0a3e4755487

Sea-Level-Rise Guidance for California Local Planning

Befus KM, Hoover DJ, Barnard PL, Erikson LH, 2020. Projected responses of the coastal water table for California using present-day and future sea-level-rise scenarios: U.S. Geological Survey data release. Available at: https://doi.org/10.5066/P9H5PBXP.

California Ocean Protection Council (OPC): Updated Sea Level Rise Guidance, March 2018. Available at: http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf.
This guidance builds on previous sea-level-rise guidance from OPC and includes probabilistic sea-level-rise projections for 2030, 2050, 2070, and 2100 that should be used by State agencies as well as non-State entities implementing projects or programs funded by the state or on State property.

California Governor's Office of Emergency Services. 2020. California Adaptation Planning Guide 2020 Update. State of California. Available at: https://www.caloes.ca.gov/cal-oes-divisions/hazard-mitigation/hazard-mitigation-planning/california-climate-adaptation

Selection of California USBR Basin Studies

Los Angeles Basin Study

The Los Angeles Basin Study was released on Nov. 17, 2016. It looks at the changing demographics, climate change and competing interests for available water supplies and identifies options to meet the water needs of the Los

Angeles area into the future. The study found that there is a potential water supply deficit for the region of approximately 160,000 acre-feet-per year by 2035 and 440,000 acre-feet-per-year or 25-percent less water than the region is projected to need in 2095.

- Los Angeles Basin Study Summary Report
- Los Angeles Basin Study Website

Sacramento and San Joaquin Rivers Basin Study

This study, collaboratively developed by Reclamation, the State of California Department of Water Resources, El Dorado County Water Agency, Stockton East Water District, California Partnership for the San Joaquin Valley and Madera County Resource Management Agency, examines climate change impacts and adaptation actions for the Sacramento River Basin, San Joaquin River Basin and the Tulare Lake Basin.

- Sacramento and San Joaquin Rivers Basin Study Report and Executive Summary
- Sacramento and San Joaquin Rivers Basin Study Technical Report
- Sacramento and San Joaquin Rivers Basin Study Appendices

Santa Ana Watershed Basin Study

The Santa Ana River Watershed Basin Study addresses water supply and demand projections for the next 50 years and identifies potential climate change impacts to Southern California's Santa Ana River Watershed. This study is a first of its kind for the predominantly urban basin. It encompasses approximately 2,600 square miles in Orange, Riverside and San Bernardino counties and is home to more than 6 million residents.

- Summary Report
- Tech Memo 1 - Climate Change Analysis for the Santa Ana River Watershed
- Tech Memo 2 - Greenhouse Gas Emissions Calculator for the Water Sector: User's Manual
- Tech Memo 3 - Inland Empire Interceptor Appraisal Analysis
- Overview of Disadvantaged Communities and Native American Tribes in the Santa Ana River Watershed

Southeast California Regional Basin Study

The Southeast California Regional Basin Study, developed by the Bureau of Reclamation and the Borrego Water District, with input from the Coachella Valley Water District and the Imperial Irrigation District, was released in September 2015. The Study addressed current and future supply and demand imbalances in the Coachella, Borrego, and Imperial Valleys, finding that supply has and will likely remain static while demand is projected to grow. The Study identified a range of structural and non-structural strategies to address these imbalances, focusing on collaborative, stakeholder-driven strategies.

- Final Report

Truckee Basin Study

The Truckee Basin headwaters begin around Lake Tahoe. The basin includes the Truckee and Carson rivers and Pyramid Lake and encompasses the cities of Carson City, Reno and Sparks, as well as Reclamation's Newlands Project, all in Nevada.

- Truckee Basin Study Executive Summary
- Truckee Basin Study Full Report

Other References

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Ray P, Brown C. 2015. Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Design Tree Framework. International Bank for Reconstruction and Development/The World Bank. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/22544/9781464804779.pdf?sequence =1&isAllowed=y

U.S. Global Climate Research Program (USGCRP). 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018. Available at: http://climateassessment.ca.gov/

I.7 Climate Change Vulnerability Screening Form for Integrated Regional Water Management Planning

This screening exercise is intended to guide regional water managers in identifying climate change vulnerabilities. The information gathered here can help guide the climate change analysis.

I. Water Demand

- [ ] Are there major industries that require cooling/process water in your planning region?
    - As average temperatures increase, cooling water needs may also increase.
    - Identify major industrial water users in your region and assess their current and projected needs for cooling and process water.

- [ ] Does water use vary by more than 50% seasonally in parts of your region?
    - Seasonal water use, which is primarily outdoor water use, is expected to increase as average temperatures increase and droughts become more frequent.
    - Where water use records are available, look at total monthly water uses averaged over the last five years. If maximum and minimum monthly water uses vary by more than 25%, then the answer to this question is "yes".
    - Where no water use records exist, is crop irrigation responsible for a significant (say >50%) percentage of water demand in parts of your region?

- [ ] Are crops grown in your region climate-sensitive? Would shifts in daily heat patterns, such as how long heat lingers before night-time cooling, be prohibitive for some crops?
    - Fruit and nut crops are climate-sensitive and may require additional water as the climate warms.

- [ ] Do groundwater supplies in your region lack resiliency after drought events?
    - Droughts are expected to become more frequent and more severe in the future. Areas with a more hardened demand may be particularly vulnerable to droughts and may become more dependent on groundwater pumping.

- [ ] Are water use curtailment measures effective in your region?
    - Droughts are expected to become more frequent and more severe in the future. Areas with a more hardened demand may be

particularly vulnerable to droughts.
- Areas which experience increases in population may be vulnerable to increases in hardened demand.

- Are some instream flow requirements in your region either currently insufficient to support aquatic life, or occasionally unmet?
  - Changes in snowmelt patterns in the future may make it difficult to balance water demands. Vulnerabilities for ecosystems and municipal/agricultural water needs may be exacerbated by instream flow requirements that are:
    1. Not quantified,
    2. Not accurate for ecosystem needs under multiple environmental conditions including droughts, and
    3. Not met by regional water managers.

II. Water Supply

- Does a portion of the water supply in your region come from snowmelt?
  - Snowmelt is expected to decrease as the climate warms. Water systems supplied by snowmelt are therefore potentially vulnerable to climate change.
  - Where watershed planning documents are available, refer to these in identifying parts of your region that rely on surface water for supplies; if your region contains surface water supplies originating in watersheds where snowpack accumulates, the answer to this question is "Yes."
  - Where planning documents are not available, identify major rivers in your region with large users.
  - Identify whether the river's headwaters are fed by snowpack.

- Does part of your region rely on water diverted from the Delta, imported from the Colorado River, or imported from other climate-sensitive systems outside your region?
  - Some imported or transferred water supplies are sources from climate-sensitive watersheds, such as water imported from the Delta and the Colorado River.

- Does part of your region rely on coastal aquifers? Has salt intrusion been a problem in the past?
  - Coastal aquifers are susceptible to salt intrusion as sea levels rise, and many have already observed salt intrusion due to over-extraction, such as the West Coast Basin in southern California.

- Would your region have difficulty in storing carryover supply surpluses from year to year?
  - Droughts are expected to become more severe in the future.

Systems that can store more water may be more resilient to droughts.

- Has your region faced a drought in the past during which it failed to meet local water demands?
    - Droughts are expected to become more severe in the future. Systems that have already come close to their supply thresholds may be especially vulnerable to droughts in the future.

- Does your region have invasive species management issues at your facilities, along conveyance structures, or in habitat areas?
    - As invasive species are expected to become more prevalent with climate change, existing invasive species issues may indicate an ecological vulnerability to climate change.

III. Water Quality

- Are increased wildfires a threat in your region? If so, does your region include reservoirs with fire-susceptible vegetation nearby which could pose a water quality concern from increased erosion?
    - Some areas are expected to become more vulnerable to wildfires over time.

- Does part of your region rely on surface water bodies with current or recurrent water quality issues related to eutrophication, such as low dissolved oxygen or algal blooms? Are there other water quality constituents potentially exacerbated by climate change?
    - Warming temperatures will result in lower dissolved oxygen levels in water bodies, which are exacerbated by algal blooms and in turn enhance eutrophication. Changes in streamflows may alter pollutant concentrations in water bodies.

- Are seasonal low flows decreasing for some waterbodies in your region? If so, are the reduced low flows limiting the waterbodies' assimilative capacity?
    - In the future, low flow conditions are expected to be more extreme and last longer. This may result in higher pollutant concentrations where loadings increase or remain constant.

- Are there beneficial uses designated for some water bodies in your region that cannot always be met due to water quality issues?
    - In the future, low flows are expected decrease, and to last longer. This may result in higher pollutant concentrations where loadings increase or remain constant.

- Does part of your region currently observe water quality shifts during rain events that impact treatment facility operation?
    - While it is unclear how average precipitation will change with temperature, it is generally agreed that storm severity will probably increase. More intense, severe storms may lead to increased erosion, which will increase turbidity in surface waters. Areas that already observe water quality responses to rainstorm intensity may be especially vulnerable.

IV. Sea Level Rise

- Has coastal erosion already been observed in your region?
    - Coastal erosion is expected to occur over the next century as sea levels rise.

- Are there coastal structures, such as levees or breakwaters, in your region?
    - Coastal structures designed for a specific mean sea level may be impacted by sea level rise.

- Is there significant coastal infrastructure, such as residences, recreation, water and wastewater treatment, tourism, and transportation, at less than six feet above mean sea level in your region?
    - Coastal flooding will become more common, and will impact a greater extent of property, as sea levels rise. Critical infrastructure in the coastal floodplain may be at risk.
    - Digital elevation maps should be compared with locations of coastal infrastructure.

- Are there climate-sensitive low-lying coastal habitats in your region?
    - Low-lying coastal habitats that are particularly vulnerable to climate change include estuaries and coastal wetlands that rely on a delicate balance of freshwater and salt water.

- Are there areas in your region that currently flood during extreme high tides or storm surges?
    - Areas that are already experiencing flooding during storm surges and very high tides, are more likely to experience increased flooding as sea levels rise.

- Is there land subsidence in the coastal areas of your region?
    - Land subsidence may compound the impacts of sea level rise.

- Do tidal gauges along the coastal parts of your region show an increase over the past several decades?

- Local sea level rise may be higher or lower than state, national, or continental projections.

V. Flooding

- [ ] Does critical infrastructure in your region lie within the 200-year floodplain?
  - While it is unclear how average precipitation will change with temperature, it is generally agreed that storm severity will probably increase. More intense, severe storms may lead to higher peak flows and more severe floods.
  - Refer to FEMA floodplain maps and any recent FEMA, US Army Corps of Engineers, or DWR studies that might help identify specific local vulnerabilities for your region. Other follow-up questions that might help answer this question:
    1. What public safety issues could be affected by increased flooding events or intensity? For example, evacuation routes, emergency personnel access, hospitals, water treatment and wastewater treatment plants, power generation plants and fire stations should be considered.
    2. Could key regional or economic functions be impacted from more frequent and/or intense flooding?

- [ ] Does part of your region lie within the Sacramento-San Joaquin Drainage District?
  - The SSJDD contains lands that are susceptible to overflows from the Sacramento and San Joaquin Rivers and are a key focus of the Central Valley Flood Protection Plan. https://water.ca.gov/Programs/Flood-Management/Flood-Planning-and-Studies/Central-Valley-Flood-Protection-Plan

- [ ] Does aging critical flood protection infrastructure exist in your region?
  - Levees and other flood protection facilities across the state of California are aging and in need of repair. Due to their overall lowered resiliency, these facilities may be particularly vulnerable to climate change impacts.

- [ ] Have flood control facilities (such as impoundment structures) been insufficient in the past?
  - Reservoirs and other facilities with impoundment capacity may be insufficient for severe storms in the future. Facilities that have been insufficient in the past may be particularly vulnerable.

- [ ] Are wildfires a concern in parts of your region?

  - Wildfires alter the landscape and soil conditions, increasing the risk of flooding within the burn and downstream areas. Some areas are expected to become more vulnerable to wildfires over time.

VI. Ecosystem and Habitat Vulnerability

- Does your region include inland or coastal aquatic habitats vulnerable to erosion and sedimentation issues?
  - Erosion is expected to increase with climate change, and sedimentation is expected to shift. Habitats sensitive to these events may be particularly vulnerable to climate change.

- Does your region include estuarine habitats which rely on seasonal freshwater flow patterns?
  - Seasonal high and low flows, especially those originating from snowmelt, are already shifting in many locations.

- Do climate-sensitive fauna or flora populations live in your region?
  - Some specific species are more sensitive to climate variations than others.

- Do endangered or threatened species exist in your region? Are changes in species distribution already being observed in parts of your region?
  - Species that are already threatened or endangered may have a lowered capacity to adapt to climate change.

- Does the region rely on aquatic or water-dependent habitats for recreation or other economic activities?
  - Economic values associated with natural habitat can influence prioritization.

- Are there rivers in your region with quantified environmental flow requirements or known water quality/quantity stressors to aquatic life?
  - Constrained water quality and quantity requirements may be difficult to meet in the future.

- Do estuaries, coastal dunes, wetlands, marshes, or exposed beaches exist in your region? If so, are coastal storms possible/frequent in your region?
  - Storm surges are expected to result in greater damage in the future due to sea level rise. This makes fragile coastal ecosystems vulnerable.

- Are there areas of fragmented estuarine, aquatic, or wetland wildlife habitat within your region? Are there movement corridors for species to

naturally migrate? Are there infrastructure projects planned that might preclude species movement?
   - These ecosystems are particularly vulnerable to climate change.

VII. Hydropower

- Is hydropower a source of electricity in your region?
   - As seasonal river flows shift, hydropower is expected to become less reliable in the future.

- Are energy needs in your region expected to increase in the future? If so, are there future plans for hydropower generation facilities or conditions for hydropower generation in your region?
   - Energy needs are expected to increase in many locations as the climate warms. This increase in electricity demand may compound decreases in hydropower production, increasing its priority for a region.