Appendix I.

Considering Climate Change Impacts

I.1 Legislative Language on Considering Climate Change in UWMPs

There are several sections in the revised California Water Code (Water Code) relevant to urban water management plans (UWMPs) that refer to climate change, many of which are new since the 2015 UWMP Guidebook. The Water Code does not specify the technical nor general methods for how to consider climate change in the UWMPs, but it does emphasize in several sections that climate change is appropriate to consider, including the projected future uses, water supply characterization projections, and reliability of supplies. The flexibility within the Water Code to conduct the analysis appropriately allows water suppliers (suppliers) to incorporate climate change as is relevant for their sources and water uses.

This guidance is not prescriptive but is written recognizing that some suppliers seek guidance on how to consider climate change in their UWMPs. As such, this appendix describes common approaches to incorporate climate change in planning and management, pulling from the California Department of Water Resources' (DWR's) experience, 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 suppliers can use.

For quick reference the climate change sections of the UWMP-relevant Water Code are listed below:

> ***Water Code Section 10608***
>
> *The Legislature finds and declares all of the following: [...]*
>
> *(b) Growing population, climate change, and the need to protect and grow California's economy while protecting and restoring our fish and wildlife habitats make it essential that the state manage its water resources as efficiently as possible.*

Water Code Section 10609

(a) (c) It is the intent of the Legislature that the following principles apply to the development and implementation of long-term standards and urban water use objectives: …

> *(2) Long-term standards and urban water use objectives should advance the state's goals to mitigate and adapt to climate change.*

Water Code Section 10610.2

(a) The Legislature finds and declares all of the following: […]

> *(3) A long-term, reliable supply of water is essential to protect the productivity of California's businesses and economic climate, and increasing long-term water conservation among Californians, improving water use efficiency within the state's communities and agricultural production, and strengthening local and regional drought planning are critical to California's resilience to drought and climate change.*

Water Code Section 10630

It is the intention of the Legislature, in enacting this part, to permit levels of water management planning commensurate with the numbers of customers served and the volume of water supplied, while accounting for impacts from climate change.

Water Code Section 10631

A plan shall be adopted in accordance with this chapter that shall do all of the following […]

(b) Identify and quantify, to the extent practicable, the existing and planned sources of water available to the supplier over the same five-year increments described in subdivision (a) providing supporting and related information, including all of the following:

(1) A detailed discussion of anticipated supply availability under a normal water year, single dry year, and droughts lasting at least five years, as well as more frequent and severe periods of drought, as described in the drought risk assessment. For each source of water supply, consider any information pertinent to the reliability analysis conducted pursuant to Section 10635, including changes in supply due to climate change.

Water Code Section 10635

(a) Every urban water supplier shall include, as part of its urban water management plan, an assessment of the reliability of its water service to its customers during normal, dry, and multiple dry water years. This water supply and demand assessment shall compare the total water supply sources available to the water supplier with the long-term total projected water use over the next 20 years, in five-year increments, for a normal water year, a single dry water year, and a drought lasting five consecutive water years. The water service reliability assessment shall be based upon the information compiled pursuant to Section 10631, including available data from state, regional, or local agency population projections within the service area of the urban water supplier.

(b) Every urban water supplier shall include, as part of its urban water management plan, a drought risk assessment for its water service to its customers as part of information considered in developing the demand management measures and water supply projects and programs to be included in the urban water management plan. The urban water supplier may conduct an interim update or updates to this drought risk assessment within the five-year cycle of its urban water management plan update. The drought risk assessment shall include each of the following: […]

(4) Considerations of the historical drought hydrology, plausible changes on projected supplies and demands under climate change conditions, anticipated regulatory changes, and other locally applicable criteria.

I.2 Background: Climate Change & Urban Water Management Planning

Water resource management in California has historically managed and planned for substantial climatic and seasonal variability. Projections of climate change in California indicate a further intensification of wet and dry extremes and shifting temperatures that can have affect both water uses and supplies. Extreme and higher temperatures can lead to increases in water use. A declining snowpack and earlier runoff patterns could result in changes in stream flows and reservoir operations. Projections of more frequent, severe, and prolonged droughts could lead to not only less surface water available, but also exacerbating ongoing stressors in groundwater basins across the state. Without implementing preparedness and other strategies to adapt to or mitigate these impacts, the changing climate jeopardize a supplier’s reliability over near-term and long-term.

How an urban water supplier can best account and prepare for projected climate change differs across several variables including arrangements of infrastructure, water rights, water sources, demands, and a variety of tools are available to assist urban water planners assessing the potential impacts of climate change on their water supplies and reliability.

This appendix provides a discussion of the decision-making process helpful in determining which tools and analytical approach will work best for a given water supplier’s particular needs. This process is determined by each supplier’s needs and capacity, which range widely by geography, water sources, human and ecological demands, and infrastructural and organizational arrangements. This section lays out the factors that are appropriate for an urban water supplier to consider when selecting an analytical approach and tools. In Step 1, the planner can walk through a vulnerability checklist for each water supply source identified. The Step 1 exercise is set up to assist the planner self-identify areas where their water supply reliability may be at risk to the impacts of climate change. Planners can use the information gathering in Step 1 to an approach to analysis in Step 2.

Climate change studies, analysis and planning for your water supply sources may have already been completed by the regional groundwater sustainability agency (GSA), integrated regional water management (IRWM) group, or within agricultural water management planning or other local general planning or hazard mitigation documents. DWR encourages urban water managers to participate in these planning efforts and use existing resources whenever feasible and appropriate. Urban water management planning, groundwater sustainability planning, agricultural water management planning all have a similar planning horizon around 2040, which can help maintain regional planning alignment. DWR's *Climate Action Plan: Phase 2* (DWR 2018) and the *Climate Change Handbook for Regional Water Management* (DWR 2011) offer the framework presented here for climate change analysis in a way that maintains alignment within DWR programs. Note that regional climate change studies may have used 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. But, it is not possible to include every method, as climate change science is frequently advancing.

I.3 Common Steps to Considering Climate Change

DWR recommends three main steps to conduct a climate change analysis, which is a common approach for adaptation. First is a screening process to determine what assets and other aspects of the supplier's system may be at risk to climate change. Assets and other aspects of the system to evaluate 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 preparations for extreme conditions and events and capacity to activate those more frequently, among others. The second step involves selecting and conducting the full 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 overall water supply reliability of the supplier.

There are several places in the UWMP that are appropriate for consideration of climate change.

Several places of the UWMP warrant climate change analysis, including:

- System description (Chapter 3)
- Water use characterization (Chapter 4)
- Water supply characterization (Chapter 6)
- Water reliability evaluations (Chapter 7)

I.3.1 Step 1: Climate Change Risk Determination Screening

The first step in conducting a climate change analysis is assessing the supplier's risk to the 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 supplier is to climate change impacts and how vulnerable that supplier is to being exposed. Exposure refers to the degree to which the water system (including its demand) may be influenced by changes in climate. Vulnerability of a supplier 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 necessarily will be exposed to significant impacts of climate change. Even if risk is low, understanding the risk faced by each water supply source can contribute to better planning and reliability outcomes. Completing the "Climate Change Vulnerability Screening Form for Urban Water Management Planning" (see the Resources and References section at the end of this appendix) can help a supplier to gauge aspects of their water supply source that may be vulnerable to climate change impacts which can help guide the climate change analysis in Step 2.

In addition to this screening form exercise, a supplier may choose to conduct a stand-alone climate risk assessment. This can vary widely in terms of how in-depth the supplier pursues. In-depth assessments with scientific rigor can have multiple benefits for a supplier. The assessment provides information from which to increase understanding among policy makers for the supplier, other decision-makers, operators and customers. Updates of critical infrastructure or personnel training budgets over the long-term can then also include to mitigate some of the high impact climate risks. A rigorous assessment can also be valuable for justification to their Board or customers of expensive or otherwise controversial adaptation strategies. The Water Research Foundation (2020) offers several guidance materials on how to incorporate climate change information into the business functions. Materials include a web-based tool and several written case studies and step-by-step guidance.

I.3.2 Step 2: Selecting the Climate Change Analysis Approach

Extending from the screening risk assessment, the next common step in building resilience to climate change involves a more in-depth analysis on the assets and other supplier aspects of concern. Determining what is of concern may be a political process and should involve decision-makers and other stakeholders that hold an interest in the supplier’s long-term reliability and viability. There have been several cases demonstrating the inclusion of decision-makers and other stakeholders are part of the process (Moser and Ekstrom 2011; Brugger et al. 2015; Vogel et al. 2019) that should determine what existing climate change analysis may have already been completed on the water source in question, and if a new analysis needs to be completed, what are the most appropriate methods and tools to use in projecting the potential changes in supply and demand. The following information is provided only as a guide to assist in selecting a climate change analysis approach and does not make any prescriptive recommendations or requirements.

I.3.2.1 Existing Climate Change Analysis

Modelling how climate change is projected to impact a supplier’s water reliability can be a time- and resource-intensive exercise. For those supplier’s unable to pursue such an analysis, it is prudent to explore if an existing climate change analysis of their water supply sources has already been conducted. Using a climate change analysis conducted by the wholesaler, raw water supplier or research institution or consulting firm could save time and resources and, in cases where a supplier receives water from a wholesaler, using the wholesaler’s analysis can help ensure the supplier is planning under a consistent set of climate change projections.

I.3.2.2 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. The sensitivity analysis and stress tests can both be good options for utilities with less financial or technical capacity. 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 for a supplier depends on a number of considerations (Knutti et al. 2010). Many of these are listed below:

- Data Sources: The following factors should be considered in assessing the likely future climate change in a region: historical change, process change, global climate change projected by global climate models (GCMs), and downscaled projected change. This means that for any given region, 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, the two latter of which can impact regional climate.
- 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 because of 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 time period considered in the assessment studies can significantly affect results.

Building upon the preceding scientific principles, this guide translates these principles into analytical considerations that planners can use to structure their decisional process for choosing an approach for the climate change analysis. The following analytical considerations can assist in determining the most appropriate approach:

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 the 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 key climate-sensitive parameters that effect 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 key 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 supply?
- Do extreme events (floods, droughts, heat waves, wildfires) significantly impact the performance of the water source or the water use?
- How skillfully do downscaled global climate models simulate historical 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 within the context of UWMP focuses 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 water supply source before deciding on an approach.

2. Spatial Scale/Watershed Area

In selecting the climate change analysis approach, suppliers 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 water source?

- Is the analysis, whether localized or statewide, consistent with other previously used datasets and analysis?
- 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? For example, if the local water supply is fed by local streams, groundwater, and other inter-basin water, can all those sources be analyzed in a consistent manner?

Some analysis 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 run 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). DWR provided applicants with all the tools, data, and guidance needed to facilitate successful completion of the analysis. 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.

I.3.3 Step 3: Developing Adaptation Strategies, Planning and Implementation

The purpose of analyzing how a changing climate could impact the supplier's water reliability is to help reveal what needs to be mitigated for and otherwise planned or implemented to decrease the increasing risks. Often times the supplier's vulnerabilities to climate change impacts are also its vulnerabilities to existing extreme conditions. Climate change can create an added risk that raises some existing challenges to become higher priority. For example, if a supplier relies on groundwater in a basin that is already periodically affected by saltwater intrusion, it will likely need to take further actions to mitigate additional intrusion as sea level rises or seek new water sources.

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 supplier. They may include adding an additional water source as a back-up in case the existing sources are projected to decrease under climate change. This would involve both engineered infrastructure changes and also legal changes to account for necessary water rights. A supplier that identifies sea level rise as a threat to its coastal aquifer may decide to increase groundwater recharge in that area as a barrier to saltwater intrusion. In a case that a supplier identifies late summer increased risks of shortage, the supplier may also pursue behavior changes in its customers to reduce water usage in peak periods. How a supplier adapts to climate change varies widely and will depend on what types of projected impacts the supplier's supplies and uses are exposed to, as well as its existing capacity to cope or otherwise mitigate those impacts. The sociopolitical context also influences how a supplier adapts to climate change and what is considered successful adaptation.

Several cases of urban water suppliers in the United States planning for climate change are summarized by the Water Research Foundation (2020).

I.4 Resources

The list below includes a limited catalogue of existing resources and their potential uses for climate change analyses. This information is not meant to recommend any particular tool over another or represent an exhaustive list of available resources, but intends to offer a glimpse of the scope of what is available in California.

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.

- 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: Water evaluation and planning (WEAP).
- 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 2020: 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, but these scenarios cannot be run directly through CalSim-II. Additional preprocessing steps must be taken to prepare these climate projections for input into CalSim-II. 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.

- 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, 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 the "Water Budget" heading.

Status as of 2020: The WSIP/SGMA scenarios are based on the latest climate models and downscaling techniques. 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.

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 Scenarios

Developed throughout 2015, 2016, and 2017, these climate change scenarios were established specifically for the Central Valley Flood Protection Plan (CVFPP) 2017 Update. They cover the Central Valley and develop 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.

Six climate change scenarios, each scenario over a 96-year period, are included.

- Warming Only Scenarios (no precipitation changes):
    - Near-Term Warming: Projected warming of approximately +1 o C (+1.8 o F).
    - Mid Century Warming: Projected warming of approximately +2 o C (+3.6 o F).
    - Late Century Warming: Projected warming of approximately +3 o C (+5.4 o F).
- Combined Warming and Precipitation Change Scenarios based on CMIP5 Climate Model Simulations:
    - Near-Term: Projected precipitation and temperature changes.
    - Mid Century: Projected precipitation and temperature changes.
    - 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 2020: The CVFPP climate change approach used climate model simulation data from the CMIP5, which was the basis of the most recently released Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). Projected changes to historical unregulated flow volumes were 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. Although not applied to 2017 CVFPP Update flood risk analyses, additional analysis was undertaken to assess changes in the characteristics of future simulated hydrographs using 20 individual downscaled climate projections via the LOCA downscaling method.

Recommended Uses: These scenarios have applicability for flood planning studies. 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: California Climate Risk: Evaluation of Climate Risks for California Department of Water Resources.

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 2020: 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.

1.5 References and Other Resources

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 urban water planners.

Climate Change Planning for Water Suppliers

Abraham S, Diringer S, Cooley H. 2020. An Assessment of Urban Water Demand Forecasts in California. Pacific Institute Report, Oakland, California. Available at: https://pacinst.org/publication/urban-water-demand-forecasts-california/

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

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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

Christian-Smith J, Heberger M, Allen, L. 2012. Urban Water Demand in California to 2100: Incorporating Climate Change. Pacific Institute Report. Available at: https://pacinst.org/publication/urban-water-demand-to-2100/

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. (The Handbook is being formatted for accessibility compliance and will be available soon.)

Kimbrough D. 2019. Impact of local climate change on drinking water quality in a distribution system. *Water Quality Research Journal* 54 (3): 179–192. https://doi.org/10.2166/wqrj.2019.054

Water Utility Climate Alliance. 2020. Website. Offers examples of how different urban 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. This resource offers several summary case studies of urban water suppliers and how they incorporated climate change into their decision-making.

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State Water Project-Related Projections and Operations

California Natural Resources Agency. 2018. The Final State Water Project Delivery Capability Report 2017. Please note that a 2019/2020 updated version is forthcoming and should be used for planning purposes. https://water.ca.gov/Library/Modeling-and-Analysis/Central-Valley-models-and-tools/CalSim-2/DCR2017

Khan A, Schwarz A. 2010. Climate Change Characterization and Analysis in California Water Resources Planning Studies. California Department of Water Resources. https://www.water.ca.gov/LegacyFiles/climatechange/docs/DWR_CCCStudy_FinalReport_Dec23.pdf

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, Barnard PL, Hoover DJ, Finzi Hart JA, Voss CI, 2020. Increasing threat of coastal groundwater hazards from sea level rise in California. Nature Climate Change, 16 pp., Available at: https://doi.org/10.1038/s41558-020-0874-1.

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 Natural Resources Agency. 2016. California Water Action Plan 2016 Update. Available at: http://resources.ca.gov/docs/california_water_action_plan/Final_California_Water_Action_Plan.pdf

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Brugger J, Crimmins M. 2015. Designing institutions to support local-level climate change adaptation: Insights from a case study of the U.S. Cooperative Extension System. Weather, Climate, and Society. 7(1): 18-38. Available at: https://journals.ametsoc.org/wcas/article/7/1/18/924

Knutti R, Abramowitz G, Collins M, Eyring V, Gleckler PJ, Hewitson B, Mearns L. 2010: Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections. In: Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Assessing and Combining Multi Model Climate Projections [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, and P.M. Midgley (eds.)]. IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland. Available at: http://www.ipcc-wg2.awi.de/guidancepaper/IPCC_EM_MME_GoodPracticeGuidancePaper.pdf

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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/

1.6 Climate Change Vulnerability Screening Form for Urban Water Management Planning

This screening exercise is intended to guide urban water management planners in identifying climate change vulnerabilities in their water supply source. The information gathered here can help guide the climate change analysis.

I. Water Supply and Demand

Are the water supply diversions sensitive to climate change?

Both streamflows and water demands are likely to be affected by climate change. Any water supply source that involves long-term water diversions may be subject to conditions that differ from current or historical conditions. As average temperatures increase, water demands from agriculture, industrial, and municipal users may increase resulting in changes to water availability. Droughts are also expected to become more frequent and more severe in the future potentially leading to increased restrictions on water diversions.

Is the water supply source affected by urban or agricultural water demand that might be climate sensitive?

Would shifts in daily heat patterns, such as how long heat lingers before night-time cooling, potentially change cropping patterns, landscaping, or water demand in other ways?

Is groundwater a major supply source?

Climate change may affect natural recharge to aquifers. Droughts are expected to become more frequent and more severe in the future. In times of drought, California water users tend to rely more heavily on groundwater. These changing conditions would likely affect future groundwater conditions.

Does the water supply source rely on or could it be affected by snowmelt?

As climate warming occurs a greater percentage of precipitation falls as rain instead of snow resulting in smaller snowpack. Also, higher temperatures result in remaining snowpack melting earlier. (All water diverted from the Sacramento River, San Joaquin River, Colorado River, or the Delta would be affected by changes in snowmelt.)

Does the water supply source come from or could it be affected by coastal aquifers? Has saltwater intrusion been a problem in the past?

Coastal aquifers are susceptible to saltwater intrusion as sea levels rise and many have already observed salt intrusion as a result of groundwater overdraft.

Does the water supply source rely on or could it be affected by changes in stored water supplies?

Changes in hydrology and water demand are likely to have significant effects on the amount of water stored in reservoirs, particularly water storage for carryover from one year to the next. Droughts are expected to become more frequent and more severe in the future potentially leading to changes in stored water supplies.

II. Extreme Heat

Could extreme heat impact operations of the water supply project or diversions?

Climate change is altering seasonal patterns in California, making hot days hotter, and increasing the duration of heat waves. This change could drive up customer usage and evaporative-related water losses.

Does the supply source rely on equipment or infrastructure that could be impacted by extreme or prolonged heat?

Infrastructure impacts from extreme or prolonged heat can include things such as increased corrosion, wear from heat expansion, and difficulties operating cooling systems.

III. Water Quality

Could water quality issues, such as low dissolved oxygen, algal blooms, disinfectant biproducts affect the water supply source?

Warming temperatures result in lower dissolved oxygen levels in water bodies, which are conducive to algal blooms and eutrophication. Changes in streamflows may also alter pollutant concentrations in water bodies.

Could reduction in assimilative capacity of a receiving water body affect the water supply source?

In the future, low flow conditions are projected to be more extreme and last longer. This may result in higher pollutant concentrations where loadings increase or remain constant, including potentially in groundwater as observed in the 2012–2016 Drought. Disinfectant biproducts also can build up in reservoirs or distribution systems as supplier’s implement conservation measures (reducing movement of supplies through the system) (Kimbrough 2019).

Could the water supply source be affected by water quality shifts during rainfall/runoff events?

Although it is unclear how average precipitation will change with temperature changes, it is generally agreed that storm severity likely will increase. Areas that already observe water quality responses to rainstorm intensity may be especially vulnerable.

IV. Sea Level Rise

Is any of the water supply source infrastructure located in area that could be exposed to rising tides?

While sea level rise of 10 feet would be a very extreme outcome by the end of the 21st century, more modest levels of sea level rise combined with higher storm surge, and coinciding with high tide could pose risks to areas below 10 feet.

IV. Flooding

Is the water supply source or any of its associated infrastructure located within the 200-year floodplain? Does the water supply source rely on flood protection infrastructure such as levees or dams?

DWR’s best available floodplain maps are available for download.

Although it is unclear how average precipitation will change, it is generally agreed that storm severity will increase. More intense, severe storms may lead to higher peak flows and more severe floods.

V. Wildfire

Is the water supply source located in an area that is expected to experience an increase in wildfire activity or severity? Would a wildfire result in damage to the water supply source infrastructure or interruption of its ability to perform as designed? Could the water supply source be affected by an increase in wildfire activity or severity in an upstream watershed or other adjacent area?

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. Sea Level Rise

Could coastal erosion affect the water supply source?

Higher sea levels and more severe storms in the future are expected to result in higher rates of coastal erosion.

Is the water supply source dependent on coastal structures, such as levees or breakwaters, for protection from flooding?

Coastal structures designed for a specific mean sea level may be impacted by sea level rise.