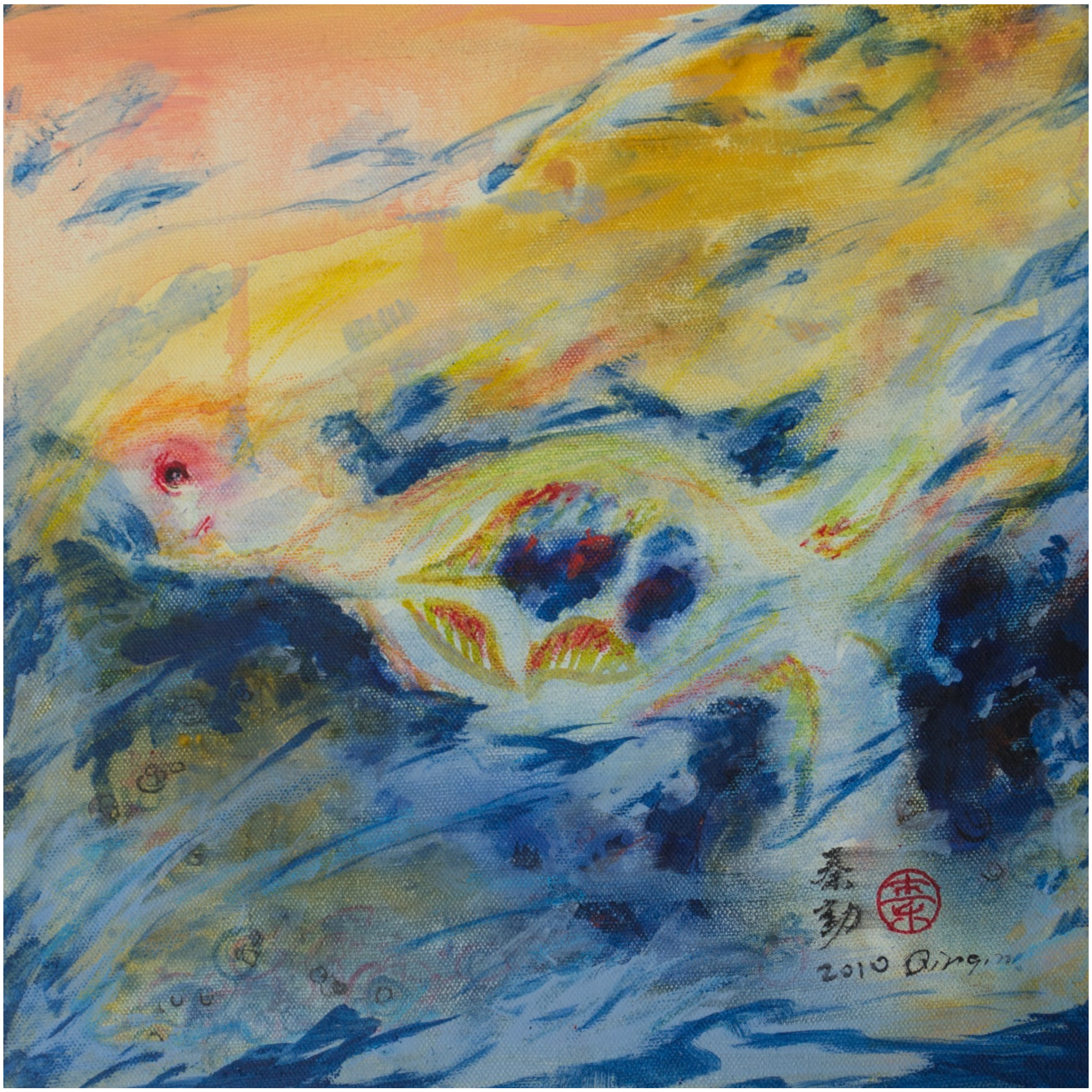
California Department of Water Resources



"Fish and Water Imagination," Dr. Qinqin Liu, DWR Climate Change Program (2010)

Climate Action Plan

Phase 2: Climate Change Analysis

Guidance September 2018

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Executive Direction

California's climate is changing. Despite local, statewide, national, and global efforts to curb greenhouse gas (GHG) emissions, past and current activities have committed California and the rest of the world to some amount of future climate change. Relying on only historical observations of climate as the basis for future planning and development is no longer adequate. The California Department of Water Resources (DWR) has an important role to play in ensuring that California's water planning, management, and investments are made in a way that will not only withstand, but thrive in changing climate conditions.

California's climate policy focuses on reducing GHG emissions, preparing for climate change impacts, and supporting climate-related research to inform policy responses and decision-making processes. Executive Order B-30-15, signed by Governor Edmund G. Brown Jr. in April 2015 and later codified by Assembly Bill (AB) 1482 and AB 2800, directed all State agencies to consider climate change in all planning and investment decisions, including infrastructure investment decisions. Building resilience into State planning, management, and investments is a key element of the State's strategy for adapting to climate change. The DWR Climate Change Program has provided a strategic path forward and the Climate Action Plan addresses mitigation, provides consistency in the analysis of climate change, and identifies adaptation approaches.

Key benefits of the Climate Action Plan include:

- Better planning outcomes, including awareness of long-term risks to projects and the ability to account for those risks in the most economical manner.
- Reduced "surprises" that affect the performance of a plan or investment.
- Development of a more systematic approach to planning and investment efforts, including increased inter-agency and inter-sector coordination.

Climate change is not a far-off future risk. The extreme hydro-climatic conditions of the last six years — both dry and wet — are exactly the types of conditions scientists have been identifying as the hallmark of what climate change will look like. Today's planning, management, and investment efforts must factor in resiliency and adaptability to climate conditions outside the scope of our historical experience.

Karla A. Nemeth
Director of Water Resources
September 10, 2018

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Section I. Objective, Needs, and Background

The objective of this *Climate Change Analysis Guidance* is to guide the California Department of Water Resources (DWR) in its decision-making and assist DWR managers as they incorporate climate change analyses into their planning for DWR activities [1], such as strategic planning documents, investment decisions, risk assessments, and infrastructure development.

This guidance document is Phase II of DWR's Climate Action Plan. The Climate Action Plan is divided into three phases to address mitigation, consistency in the analysis of climate change, and adaptation. Additional information can be found here: https://www.water.ca.gov/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan.

- **Phase I:** *Greenhouse Gas Emissions Reduction Plan* (GGERP) — This plan lays out DWR's greenhouse gas (GHG) emissions reduction goals and strategies for both the near term (present to 2020) and long term (2050).
- **Phase II:** *Climate Change Analysis Guide* — This phase of planning develops a framework and guidance for consistent incorporation and alignment of analyses for climate change impacts on DWR's project and program planning activities.

  Phase III: Climate Change Vulnerability Assessment and Adaptation Plan (VA/AP) — The VA will describe, evaluate, and quantify the vulnerabilities of DWR's assets and business to potential climate change impacts. The AP will prioritize and address the vulnerabilities to DWR owned and operated facilities and activities throughout the state and establish comprehensive DWR policies and procedures to guide climate change adaptation.

This guidance document is intended to provide the following benefits to DWR:

- Assist DWR managers in conducting required climate change analyses.
- Improve the consistency and scientific rigor of DWR's approaches for analyzing climate change and its potential impacts on DWR projects and operations, while preserving both flexibility and efficiency.
- Improve compatibility and comparison of data from different studies.
- Promote use of the best available science.
- Eliminate duplication of efforts.
- Improve clarity and consistency of messaging across DWR documents.
- Streamline decision-making and document review.

[1] Throughout this document, "activity" is used broadly to describe any action proposed or undertaken by DWR and could include anything from programmatic and planning activities to specific construction projects to continuation of ongoing activities.

The *Climate Change Analysis Guidance* establishes a process and framework that enable managers to evaluate the potential for observed and projected changes in climate to affect their activities.

Section I introduces this guide and provides background information.

Section II outlines a two-step process that DWR managers shall follow to determine the appropriate level of climate analysis for their activity or project. Step 1 includes completion and submission of the online *DWR Climate Change Screening Analysis Form* and *Climate Change Vulnerability Checklist for DWR Activities*[2] forms to screen a project's level of exposure and sensitivity to climate changes. Step 2 is intended for DWR managers that have determined the project has some level of risk based on Step 1 and now require a deeper analysis of those risks. Step 2 provides a list of considerations that managers should evaluate to understand the different types of analyses that are appropriate, potential tools and data that would be necessary, and constraints on analytical approaches or data that may apply to their projects.

Appendix A catalogues existing datasets and tools used in recent DWR climate change analyses and a summary of how these datasets and tools may be useful for future DWR climate change analyses.

Appendix B catalogues State and federal climate change pronouncements and guidance documents.

Appendix C summarizes the two basic approaches that have been used to simulate climate change in water resource modeling by DWR: transient analysis and climate period analysis.

DWR Climate Analysis Needs

DWR performs and participates in a wide array of planning and operational activities that are sensitive to the impacts of climate change. In 2010, DWR conducted a survey of studies that had incorporated climate change considerations, revealing that 13 different planning studies had been done by that time (Khan and Schwarz 2010). Since 2010, several additional approaches have been developed by various groups within DWR. Climate change is being considered in a wider array of analysis types while also addressing a broader range of issues. Table 1 provides an overview of the six major types of applications in which DWR incorporates potential future climate changes into its analysis and decision-making.

Beyond DWR's own planning and operations activities, DWR supports, contributes to, and/or administers several programs throughout the state that consider climate change at both the local and regional scales (Table 2). For these programs, DWR provides recommendations, climate data, analysis frameworks, and methodologies to water agencies throughout the state.

[2] The *DWR Climate Change Screening Analysis Form* and *Climate Change Vulnerability Checklist for DWR Activities* are available on Climate Change's internal SharePoint site: https://current.water.ca.gov/programs/icc/SitePages/ClimateActionPlan.aspx.

Table 1. DWR Planning and Operational Analysis Activities

Study Type	*Level of Detail*	*Time Horizon*	*Spatial Coverage*	*Notes*	*Example*
General Planning Studies	Policy Level/General.	30–100 years.	Typically, large (statewide/Central Valley water systems).	Not specific to climate change, ability to explore multiple future projections may vary. High level and broad analysis, usually not directly connected to specific decision-making. Designed to inform the legislature, public, or local/regional water planning and management agencies.	California Water Plan.
Climate Change Specific General Planning Studies	Policy Level/General.	30–100 years.	Typically, large (statewide/Central Valley water systems).	Specifically designed to explore, estimate, and disclose climate change impacts, has a broad ability to explore multiple future projections. High level and broad analysis, usually not directly connected to specific decision-making. Designed to inform the legislature, public, or local/regional water planning and management agencies.	2006 and 2009 State Water Project (SWP) and Central Valley Project (CVP) Climate Change Impact Reports.
Specific Operations Reports	Very specific to operations.	20–40 years.	Systemwide (typically SWP).	Specifically designed to estimate and disclose performance of SWP and project future reliability. Ability to explore multiple climate future projections has historically been limited. Planning level often used by local and regional water users for their decision-making.	State Water Project Delivery Reliability Reports.
Operations Investigation Reports	Investigative.	20–80 years.	Systemwide (typically SWP).	Specifically designed to test future vulnerabilities and potential strategies to improve future reliability. Ability to explore multiple future climate projections may vary. Planning level, used by the California Department of Water Resources (DWR), legislature, and Governor's Office to evaluate efficacy of various potential approaches to water management challenges.	Status Report on Preliminary Operations Simulations.
Specific Project Analysis	Highly detailed.	20–60 years.	Highly localized to very large.	Directly related to project-level decision-making. Ability to explore multiple future climate projections is very limited. Climate change is one of many areas of very specific analysis. Implementation level, used by DWR to explore and disclose potential impacts and benefits of specific proposed projects.	Bay Delta Conservation Plan California Environmental Quality Act/National Environmental Policy Act (CEQA/NEPA) Environmental Impact Analysis.
Water Resources Research and Analysis	Specific to State Water Project watersheds.	Varies.	Varies.	These studies typically explore specific aspects of climate impacts on the hydrology of the SWP watersheds or other impacts that affect DWR managed resources.	"Isolated and integrated effects of sea level rise, seasonal runoff shifts, and annual runoff volume on California's largest water supply." Journal of Hydrology (May 2011).

Table 2. Programs Supported by DWR

Program	*Periodicity*	*Capability/Applicability of Conducting General Climate Change Impacts Analysis*	*Extreme Conditions Analysis Conducted to Date*	*Capability/Applicability of Conducting Extreme Conditions Analysis*	*Agency*
Central Valley Flood Protection Planning	5 years.	Limited applicability, flood protection vulnerabilities and impacts are predominantly driven by extreme events.	Pilot study of Threshold Analysis. Phase II analysis conducted as part of 2017 Central Valley Flood Protection Plan (CVFPP) update.	Proceeding.	California Department of Water Resources (DWR) staff under auspices of CVFPB.
Urban Water Management Planning	5 years.	Limited, this type of analysis is not explicitly required of urban water management plans (UWMP).	Worst 3-year drought on record.	Varies by local water district.	Local water districts.
Agricultural Water Management Planning	5 years.	Required to "include an analysis, based upon available information, of the effect of climate change on future water supplies" (California Water Code §10826 (c)). Interpretation of this requirement is left to DWR and AWMP groups. Capacity to conduct analysis varies between AWMPs.	No requirement.	Varies by local water district.	Local agricultural water suppliers.
Integrated Regional Water Management Planning	Varies, depends on funding cycles.	Required to evaluate "the adaptability to climate change of water management systems in the region." Interpretation of this requirement is left to DWR and regional water management groups (RWMGs). Capacity to conduct analysis varies between RWMGs.	No requirement.	Varies by RWMG.	Regional water management groups.
Regional Flood Management Planning	No requirement.	Limited, this type of analysis is not a focus of the grant funding.	Rely on existing studies, no new analysis.	Limited, this type of analysis is not a focus of the grant funding.	Regional flood management groups.
Groundwater Management Planning Grants	No requirement.	Limited, this type of analysis is not required in legislation and not a focus of the grant funding.	No requirement.	Limited, this type of analysis is not a focus of the grant funding.	Local groundwater management groups.
Sustainable Groundwater Management Planning	5 years.	Regulations require analysis of projected future water budget conditions: "Projected water budgets shall be used to estimate future baseline conditions of supply, demand, and aquifer response to Plan implementation, and to identify the uncertainties of these projected water budget components." *Groundwater Sustainability Plan Emergency Regulations Guide* §354.18(c)(3).	Plans have not yet been submitted to DWR (due in January 2020 and 2022).	Currently evolving as best management practice resources are being developed by the program. Likely variable by groundwater sustainability agency (GSA). Drought conditions are likely an important stressor for groundwater sustainability conditions.	GSA, plans reviewed by DWR.
Water Storage Investment Program	No requirement.	"The without-project future conditions shall represent the change in climate and sea level conditions for California at the years 2030 and 2070." California Code of Regulations, title 23, §6004(a)(8)(A).	Application requires analysis of climate conditions at 2030 and 2070 that incorporate intensified extreme events that have occurred in the historical record. Applicants also required to evaluate project sensitivity to extreme climate change outcomes.	Analysis required in regulations necessitates analysis of all historical droughts under future climate changed conditions.	Local agencies applying for Water Storage Investment Program funding. Applications reviewed by DWR under auspices of the California Water Code.

The Need to Incorporate Climate Change Risk Management into Program and Project Planning

Risk management is an important part of the work that DWR managers perform. Risk management in the planning and development of programs and projects requires consideration of a wide variety of matters: engineering planning and design, program design, financing options, environmental impacts, staffing, schedule, operations, etc. Based on observational data, scientific research, and direction from Governor Edmund G. Brown Jr. and the Legislature, climate change risks must now be formally evaluated and managed in program and project planning.

State Mandates, Directives, and Policy Priorities

Consideration and analysis of changing climate conditions are expanding into a wider range of planning activities, as the understanding has grown that historical observations of climate and climate-driven variables are not stationary and thus are no longer adequate to characterize potential future conditions on their own. Consistent with this growing acknowledgement, State law requires DWR to consider climate change impacts, adaptation, and opportunities for mitigation in all its activities. California and the federal government have established legal and policy directives for addressing climate change, and it is anticipated that further directives will be forthcoming. A summary of the most important State pronouncements relevant to DWR's planning and decision-making processes are listed below. Additional State and federal pronouncements that provide important context, background, and guidance are provided in Appendix B.

State Pronouncements

Statutes

- Assembly Bill (AB) 1482 (Gordon, Chapter 603, Statutes of 2015) Climate Adaptation (https://leginfo.legislature.ca.gov/faces/billStatusClient.xhtml?bill_id=201520160AB1482). This statute, which became effective on January 1, 2016, establishes a framework to coordinate climate adaptation efforts across State agencies and departments. This law requires the California Natural Resources Agency (CNRA), by July 1, 2017, and every three years thereafter, to update the State's climate adaptation strategy. It also requires State agencies to promote the use of the climate adaptation strategy to inform planning decisions and to consider climate change impacts in State investments.

- AB 2800 (Quirk, Chapter 580, Statutes of 2016) Climate Change: Infrastructure Planning (http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800). This statute became effective on January 1, 2017. The Legislature recognized the impacts from climate change to California and declared its intent to incorporate anticipated changes stemming from climate change in planning for various infrastructure projects. It also recognized the need for a standardized approach to consider various scientific data and how to integrate such data into planning. This law requires State agencies, until July 1, 2020, to incorporate "current and future impacts from climate change when planning, designing, building, operating, maintaining, and investing in state infrastructure." The law requires the CNRA "to establish a

Climate-Safe Infrastructure Working Group for the purpose of examining how to integrate scientific data […] into state infrastructure engineering." This working group will consist of "registered professional engineers with specified relevant expertise from the Department of Transportation, the Department of Water Resources, the Department of General Services, and other relevant state agencies; scientists with specified expertise from the University of California, the California State University, and other institutions." This working group was required to provide recommendations to the Legislature by July 1, 2018.

Executive Orders

- Executive Order (EO) B-30-15 (https://www.gov.ca.gov/news.php?id=18938). Signed by Governor Brown on April 29, 2015, this executive order directs State government to incorporate climate change impacts into the State's Five-Year Infrastructure Plan, update the State climate adaptation strategy to identify how climate change will affect infrastructure, and identify the actions needed to reduce future risks. In addition, the EO states that "state agencies shall take climate change into account in their planning and investment decisions" and directs State agencies to use the following guiding principles when making planning and investment decisions:
    - Priority should be given to actions that both build climate preparedness and reduce greenhouse gas emissions;
    - Where possible, flexible and adaptive approaches should be taken to prepare for uncertain climate impacts;
    - Actions should protect the state's most vulnerable populations; and
    - Natural infrastructure solutions should be prioritized.

Plans, Guides, and Agreements

- Safeguarding California (http://resources.ca.gov/docs/climate/Final_Safeguarding_CA_Plan_July_31_2014.pdf). In January 2018, the Safeguarding California Plan update revised the 2014 Safeguarding California Plan, which in turn had updated the original 2009 California Climate Adaptation Strategy. The Safeguarding California Plan update provides "policy guidance for state decision makers" and "highlights climate risks in nine sectors including the water sector […] and makes realistic sector-specific recommendations." It identifies significant funding sources for investments in reducing climate risk and encourages collaboration between agencies and between State and federal entities. The CNRA also produced the Safeguarding California: Implementation Action Plans for the 10 sectors, which represent a blueprint for executing actions outlined in EO B-30-15 and requires the Safeguarding California Plan to be updated every three years.

- *Planning and Investing for a Resilient California: A Guidebook for State Agencies* (http://opr.ca.gov/docs/20180313-Building_a_Resilient_CA.pdf). This guidebook, developed by the Governor's Office of Planning and Research, with the help of a technical advisory group made up of local and regional governments, non-governmental and community organizations, State agencies, and the private sector, provides high-level guidance to State agencies for incorporating climate change analysis into their planning and investment decision-making (see Appendix B for additional information on this resource).

Building on High-Level Guidance from the Scientific Community to Provide Actionable Tools and Resources for DWR

In 2012, DWR formed a Climate Change Technical Advisory Group (CCTAG) to advise the department on the scientific aspects of climate change, its impacts on water resources, and the use and creation of planning approaches and analytical tools. This 15-member group included experts in atmospheric and climate science, hydrology, civil engineering, local/regional water management, land use, and social science. The group explored, in detail, DWR's needs and capacities for using available climate information, tools, and approaches for resource analysis. In 2015, the collaboration culminated in the publication of *Perspectives and Guidance for Climate Change Analysis* (Perspectives and Guidance) (California Department of Water Resources 2015). CCTAG provided overarching recommendations on several elements of climate change analysis, including:

- Global climate model sampling.
- GHG emissions scenarios.
- Downscaling approaches.
- Analyzing extreme conditions like floods and droughts.

Working with CCTAG and the information included in Perspectives and Guidance has proved to be instrumental in guiding DWR, and indeed many other California State agencies, toward improved analysis of climate change impacts. For example, California's Fourth Climate Change Assessment has built upon the work of CCTAG.

While Perspectives and Guidance provides generalized guidance on the use of global climate model projections, downscaling, and extreme event planning, it stopped short of providing the specificity needed by DWR project managers for deciding on the specific approach and data that should be used for the various types of analyses that DWR performs. Section II of this document builds on Perspectives and Guidance to provide a framework for climate change analysis decision-making at the program or project level.

Next Steps

While the guidance sets forth a process for evaluating DWR projects for climate change risks and provides a framework for determining the appropriate approach to climate change analysis, additional opportunities remain for integrating DWR's diverse analytical capacities and further aligning the ways in which DWR integrates, uses, and conveys climate change information to the public. Additional future work should:

- Consider the existing tools, datasets, and models DWR uses for climate change analysis and find ways to improve or modify those tools, datasets, and models, if necessary, to better align and integrate them across DWR programs and purposes.
- Establish a process for updating and replacing older methods and data when newer science or approaches justify replacement.
- Outline sensitivity and uncertainty best practices.
- Develop methods, tools, and procedures to comply with the AB 1755 Open and Transparent Water Data Act (https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1755) and better communicate and share datasets and results.

These additional future steps will require vigorous and sustained coordination across the entirety of DWR. Feedback on process improvement, alignment, and integration is welcomed by the Climate Change Program (climatechange@water.ca.gov).

Section II: Guidance on Conducting a Climate Change Analysis

Step 1. Climate Change Sensitivity Determination and Screening

This section describes a screening form and submission process that all DWR managers should use to evaluate which of their projects have little risk from climate changes and thus require only cursory or no detailed climate change analysis, and which projects may involve significant risks from climate changes and warrant a more detailed analysis of potential risks.

The first decision with respect to climate change analysis is to determine whether the project is exposed and sensitive to climate change. *Exposure* refers to extrinsic factors that affect a system, focusing on the character, magnitude, and rate of change the system is likely to experience. *Sensitivity* refers to the innate characteristics of a system, considering tolerance to changes in factors such as temperature, precipitation, fire regimes, or other key processes. *Risk* refers to the combined effects of exposure and sensitivity. Not all DWR activities will face significant risks from climate changes. Many activities are relatively insensitive to climate, such as routine maintenance activities or projects with relatively short, useful lives.

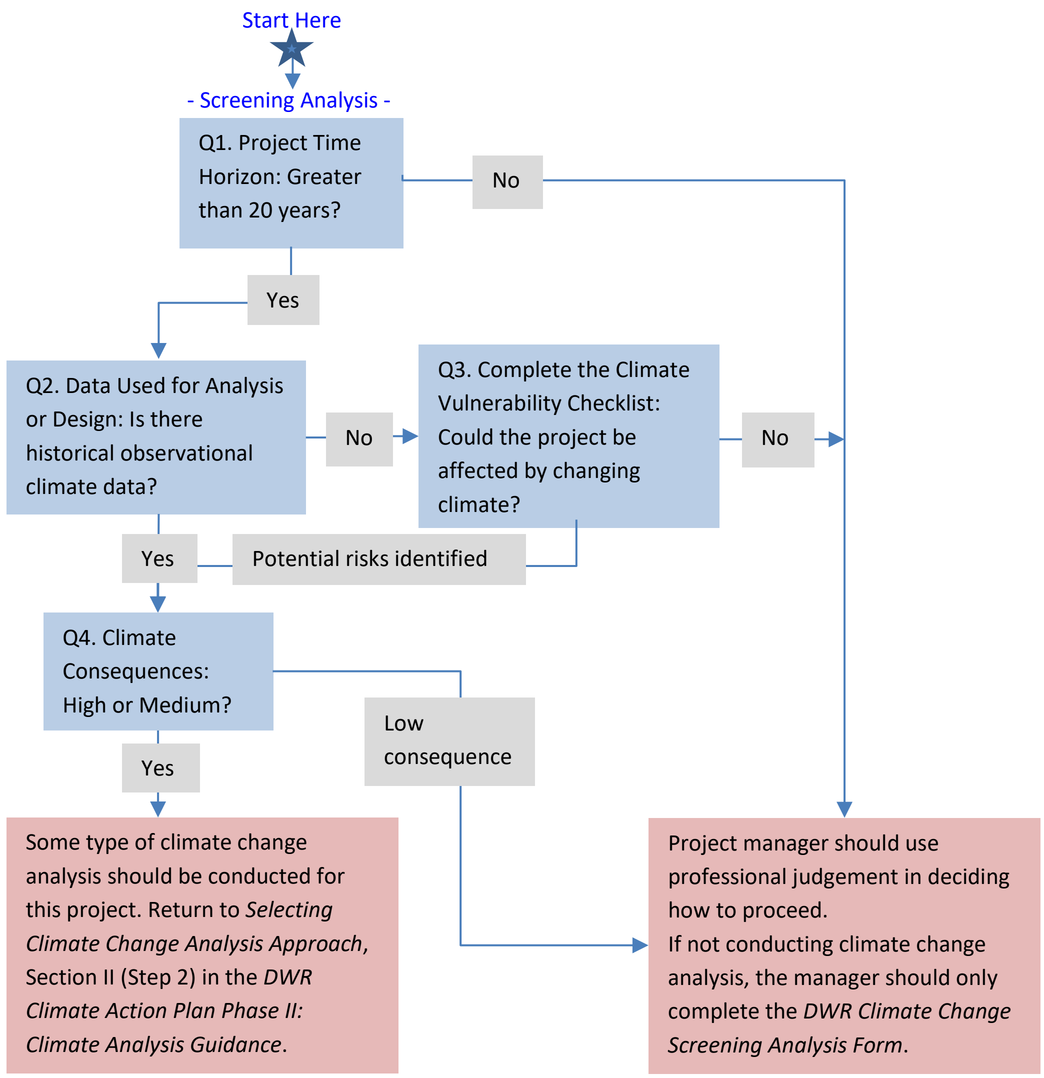
All projects will start with Step 1 to ensure that the effort expended to evaluate climate risks is proportional to the climate sensitivity of the project. Projects determined to have relatively low climate risks in Step 1 do not need to proceed to Step 2 and can continue with traditional risk management and decision-making approaches. Projects determined to have appreciable climate risks in Step 1 will move on to Step 2 to determine what specific approach best suits the needs of the project. Projects utilizing DWR's project management framework should incorporate climate change as part of the project documents. Black boxes, like the one below, highlight where the climate-change analysis decision process fits into specific project management steps.

Project Management: Project managers/staff should complete Step 1 evaluation during early stages of the activity, which typically is the project chartering stage of project development. Climate change would be considered a "risk" and thus would be included in the "Risk Register" and in other appropriate project management documents. Project managers/staff should not wait until the environmental assessment phase of the project to consider climate change. If climate change analysis is required, it should be done in the earliest planning stages of the project so that it can factor into alternative screening decisions.

Project Screening

The objective of Step 1 is to quickly and efficiently assess projects and provide an "off ramp" or clearance for those projects that do not warrant further climate change analysis. Figure 1 shows a flow chart for screening projects. Each of the four questions (blue boxes) shown in Figure 1 provides a context for project managers to evaluate and make a determination for the project. The DWR manager should document their answers and reasoning in the *DWR Climate Change Screening Analysis Form* and *Climate Change Vulnerability Checklist for DWR Activities* forms made available on the Climate Change program's SharePoint site[3]. These forms should be provided to the Climate Change Program staff (climatechange@water.ca.gov) and kept in the project record.

Figure 1. Screening Process Flow Chart



[3] https://current.water.ca.gov/programs/icc/SitePages/ClimateActionPlan.aspx.

Step 2. Selecting Climate Change Analysis Approach

Once an activity has been determined to be exposed and sensitive to climate change via the Step 1 screening process, the manager will need to determine the most appropriate method and tools to use in evaluating the project's vulnerability to climate change. It is advised that this step be performed in collaboration with Climate Change Program staff, especially in identifying available studies/models and assessing their appropriateness for the analysis of climate change for the activity.

> **Project Management:** Project managers/staff should complete Step 2 during the project management plan development. Climate change analysis should be considered in all aspects of the project management plan.

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. These are all approaches that may be appropriate for different types of planning activities. In some cases, a simple qualitative assessment of potential impacts may be appropriate. Determining which approach to take should be done in a methodical and consistent manner to tailor the specific analysis to the project and to develop information that informs the decision-making process.

The selected approach should adhere to the best available scientific guidance on climate change analysis. The "IPCC Expert Meeting on Assessing and Combining Multi Model Climate Projections Meeting Report" (Knutti et al. 2010) provides one of the most comprehensive, consolidated synopses of this expansive research field. A few of the most pertinent principles from that report are summarized below. These principles are included here to introduce the theoretical underpinnings of the following section, which outlines specific considerations relevant to DWR's choice of climate change analysis methods and data.

- **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 sample the uncertainty space more thoroughly than others. Some process or sensitivity 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[4] and feedbacks, which may not be fully represented in global models, may be important for regional climate change (e.g., land use change and the influence of atmospheric pollutants).
- **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 output 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 sampled for the downscaling, this should be stated explicitly.
- **Time Horizon and Emissions Scenarios:** Many impact studies are affected by the relative similarity between different 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 DWR managers can use to structure their decisional process for choosing an approach for the climate change analysis. The following eight analytical considerations should be used to determine the most appropriate approach:

1. The purpose of the activity.
2. The decision resulting from the activity.
3. Climate sensitive parameters.
4. Spatial scale/watershed area.
5. Infrastructure/systems and operational activities.
6. Legal and institutional issues.
7. Stakeholders and their interests.
8. Continuity with previous work/studies

[4] Climate forcings are different factors that affect Earth's climate. These "forcings" drive or "force" the climate system to change, per the National Oceanic and Atmospheric Administration (NOAA). There are natural forcings (e.g., volcanic eruptions) and human-made forcings (e.g., air pollution).

Each of the above considerations are described in more detail below. In addition, Box 1 (page 25) contains guidance specific to analyses being conducted within a California Environmental Quality Act (CEQA) context. CEQA guidance is called out separately from other types of considerations because it is a specific legal and planning framework within which many projects will conduct their climate change analysis. Note that climate change analyses may be necessary regardless of the need for a CEQA analysis. The analytical considerations listed below will often apply whether analysis is being conducted within or outside of a CEQA context.

1. The Purpose of the Activity

DWR engages in many types of activities that may require climate change analyses, such as:

- Strategic planning.
- Investment decisions.
- CEQA.
- Feasibility studies.
- Competitive funding decisions.
- Regulatory planning.
- Research inquiries.

Analyses conducted for each of these objectives can be constrained and focused on different considerations. Strategic planning analysis, such as the analysis that has been conducted for California Water Plan updates, often compares current performance to future performance under a wide range of uncertain future conditions and potential management alternatives. Investment decision analyses may focus on retention of value over time. CEQA analyses often focus on a specific project alternative, typically comparing a future with the project to a future without the project. Competitive funding decisions (e.g., the Water Storage Investment Program [WSIP]) and regulatory planning (e.g., the Sustainable Groundwater Management Act [SGMA]) may require a consistent set of conditions that all projects can analyze — requiring datasets with large spatial ranges and providing data for an array of system responses.

Project managers must identify the reasons for their analyses and find helpful information for that type of analysis in Appendix A of this report, *Existing and Available Modeling Tools and Datasets*, which provides additional information on how currently available modeling tools and datasets have been used in the past for analyses with various types of objectives.

2. The Decision Resulting from the Activity

DWR activities may be related to a broad range of decisions. Focusing on the decision that must ultimately be made may help in determining the type of climate change analysis that should be conducted. Analytical considerations include: Is there a decision to be made (e.g., go/no go, sizing, location) or is the analysis illustrative?

- Over what time frame is the climate change analysis to be conducted? Is the project long-lived or short-lived? For long-lived projects, what time frame is most important for decision-making? At what point do future conditions and preferences become so uncertain that analysis of those conditions is meaningless?

- Are extreme/rare events (e.g. floods, droughts, heat waves) and performance during those extreme/rare events a significant driver for decision-making? Would information about low-frequency extreme conditions performance affect the decision on the project?
- If there is a decision, what are the consequences of the decision if assumptions about climate are wrong?
  - Investment in a project that may not provide expected value?
  - Infrastructure is overwhelmed and could fail?
  - Loss of life, property damage, damage to environmental resources, and/or economic disruption?
  - Who or what would be potentially harmed?

Scientific understanding of climate change and its impacts is constantly evolving. But DWR must continue planning and making decisions about the future by using imperfect information about what climate conditions will exist in the same way that it must determine what technology will be available, the future regulatory constraints placed on water management in California, what social preferences there will be, along with an array of other uncertain factors.

In cases where observations or scientific consensus indicate that conditions will change in the future, our assumptions should incorporate the best available information. For example, there is relative certainty that population in California will increase in the future. While we have some uncertainty about exactly what future population increases will be, we know that population in California has continuously increased since 1850, but the increases have tapered off in recent decades. In the case of making assumptions about future population, best practice is to take into consideration long-term and more recent trends as well as demographic information about population change.

Conversely, in cases where there is no observational record or scientific consensus to indicate how things will change in the future, a status quo assumption is often the least speculative. For example, there is relative certainty that Sacramento-San Joaquin Delta (Delta) water quality and flow regulations will change in the future because, since the 1980s, Delta requirements have changed several times. Yet, we do not know how those regulations will change in the future. In this case, any assumption about future regulations that is different from the status quo would be speculative.

With respect to climate change, there is relative certainty, based on the preponderance of the observational evidence and scientific research, that future climate will change. There is some scientific basis for how and when those changes are likely to occur, based on global climate model projections. Nonetheless, considerable uncertainty remains in these climate change projections. Global climate models project a range of potential change in temperature and precipitation. In this case, best practice is to incorporate as much of the scientific information about climate changes as possible and to explore the effects of a range of climate change projections.

In general, given the multiple dimensions of uncertainty that planners must deal with and the degree to which they may compound errors over time, analysis conducted by DWR for investment decision-making should focus on middle-term effects and decisions (i.e., 30 to 60 years into the future). Planning 5, 10, or 20 years into the future will likely not provide sufficient insight into potential future conditions and needs. Conversely, planning 80–100 years into the future is likely to be highly uncertain and of limited value in meeting the needs of decision-makers today. In some cases, evaluation of conditions 70 or more years into the future may still be important and provide important insights; however, those evaluations should explicitly consider the uncertainty and sensitivity of assumptions made about conditions that far into the future.

3. Climate-sensitive Parameters

Assessing the climate-sensitivity of the activity can assist in determining the type and scope of the climate change analysis to use. 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/sensitivity/vulnerability/risk of the project (e.g., average precipitation, summer high daily temperatures, atmospheric river driven precipitation)?
- What are the key *climate-driven* parameters that effect performance/sensitivity/vulnerability/risk of the project (e.g., average annual streamflow; September streamflow; 3, 5, 7-day streamflow; stream temperatures; minimum flows; wildfire; sea-level rise)?
- Do adequate data exist to explore how climate change will affect the project? (This consideration is particularly relevant to flood and environmental projects.)
- Is inter-annual variability a major driver of performance?
- Are extreme events (floods, droughts, heat waves, etc.) an important driver of project performance, effects, or economic value?
- 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)?
- Are there existing data/tools/frameworks that could be used “off-the-shelf” to meet the objectives of the analysis?
- Does something new have to be developed to appropriately evaluate the climate sensitivity of the activity?
- Can something in existence be adapted to appropriately evaluate the project?

Many climate-sensitive parameters are common to DWR analyses. For most water supply and environmental resource analyses that DWR performs, average monthly temperature and precipitation will be the key climate-sensitive parameters of interest, and average monthly streamflow will be the key climate-driven parameter of interest. Inter-annual and low frequency hydrologic variability will also typically be of significant concern, as these factors strongly influence 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 for DWR 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 which project managers should critically evaluate before deciding on an approach.

For most flood protection analyses that DWR performs, 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 (like 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, managers should critically evaluate past efforts and the needs of the current project before deciding on an approach.

Analyses performed for purposes other than water supply, environmental resource evaluation, or flood protection will likely have many of these and possibly other constraints and considerations that will need to be identified and carefully considered.

4. Spatial Scale/Watershed Area

In selecting the climate change analysis approach for their activity, managers will need to assess analytical considerations relevant to the spatial scale/watershed area. These issues may include, but are not limited to, the following:

- Is the analysis being conducted for a small localized area or broad statewide/regional coverage?
- 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, local water supply portfolios are often composed of water supplies from multiple sources, e.g., State Water Project, local streams, groundwater, other inter-basin water

projects. Each of these supplies may come from a different source area, but climate in those areas is likely highly correlated, thus necessitating that all areas be simulated in a consistent manner.

Some studies can be done at localized scales and are not influenced by conditions outside of the watershed in question; however, in many cases, conditions outside of the watershed in question will have important ramifications for the study. One example of this would be an analysis of a watershed in Southern California that gets some of its water from the State Water Project (SWP). To evaluate the impact of climate on water supplies to this southern California watershed, one would need to simulate impacts on both the local watersheds from which some water supplies originate and SWP watersheds from which other water supplies originate. Given that wet and dry conditions are correlated across the state, one would want to ensure that climate conditions were temporally and spatially consistent across the analyses of the two watershed areas.

5. Infrastructure, Systems and Operational Activities

Infrastructure, systems, and operational considerations include, but are not limited to, the following:

- Does the analysis require simulation of multiple systems in a consistent manner?
  For example, local water supply portfolios are often composed of water supplies from multiple sources, e.g., SWP, local streams, groundwater, other inter-basin water projects. Each of these supplies may come from a different source area, but climate in those areas is likely highly correlated, thus necessitating that all areas be simulated in a consistent manner.
- 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 (flood protection, water supply, etc.) 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 or fish mortality 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 II (CalSim-II) 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.[5] Appendix A, *Existing and Available Modeling Tools and Datasets*, highlights the different tools and datasets that are available and whether they would be used for transient climate analysis or climate period analysis.

Additionally, CalSim-II simulations have historically 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.

6. Legal and Institutional Issues

Analytical considerations relevant to identifying the legal and institutional issues and constraints include, but are not limited to, 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 project that require or constrain the selection of approaches, tools, or data for climate change analysis?
- Who will be performing the analysis?

In some cases, there will be clear constraints or advantages to using an existing approach or dataset. In other cases, DWR may be establishing the constraints or incentives for using an approach or dataset.

Developing new tools and datasets or deploying existing tools and datasets to be used by local or regional management agencies 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. DWR provided applicants with all of the tools, data, and guidance needed to facilitate successful completion of the analysis (see Appendix A, *Existing and Available Modeling Tools and Datasets*). 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.

7. Stakeholders and Their Interests

Analytical considerations relating to potential stakeholders and their interests may be relevant to choosing the appropriate climate change analysis for the activity. These could include the following:

- Who are the stakeholders? What are their interests?
- What information are stakeholders seeking?

[5] See Appendix C for more information about climate period and transient analyses.

- Are stakeholders asking for additional climate analysis?
- Is climate sensitivity a major issue for stakeholders?

In many cases, stakeholder groups have deep interests in and knowledge of the type of data and the analysis approach taken on projects. This may be particularly true when working with tribal communities and traditional ecological knowledge. These stakeholders may be beneficiaries of the project, local residents, local agencies, organizations concerned about the impacts of the project, or others. In some cases, concerns of stakeholders have resulted in additional climate change analysis being conducted on projects. In other cases, stakeholder concerns have overshadowed climate change issues, causing resources to be prioritized toward other analyses. Project managers should consider the interests and concerns of stakeholders and balance them with the interests and concerns of DWR in making decisions about the level of complexity and specific data and tools to be used for climate change analyses.

8. Continuity with Previous Work/Studies

The following considerations should be addressed to ensure continuity with previous work/studies:

- Does the analysis/plan need to be consistent with previously performed work? Does this project 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?
- Is the analysis part of a periodic update of information or reporting?

When a new analysis connected to previous work is being performed, additional considerations should be taken to maintain alignment with the previous work. Examples of such situations include:

- Tiering off a previously adopted CEQA document.
- Grant guideline or proposal solicitation package updates.
- Periodic updates to departmental plans or status documents (e.g., Water Plan updates, State Water Project Delivery Capability reports).

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 while maintaining consistency with other DWR efforts. In the case of periodic updates of the plans and/or the status documents, local and regional planners and managers often rely on these documents from DWR to complete their own planning. Thus, special attention should be given to coordinate with users to prepare them for changes and document differences between old and new information.

Aligning new studies with other DWR efforts, so that consistency across DWR's programs and divisions is maintained to the maximum extent feasible, should always be considered.

Box 1. CEQA Considerations

For projects that are going through the California Environmental Quality Act (CEQA)/Environmental Impact Report (EIR) process. The California Department of Water Resources (DWR) requires that additional information and analysis of climate change be completed and documented in the EIR.

Climate change is likely to have far-reaching consequences for buildings, infrastructure, and other types of projects for which DWR completes CEQA analyses. Impacts of climate change are likely to manifest themselves in three distinct ways:

1. Extreme climate phenomena such as floods and heat waves can impact project performance by overwhelming the design conditions for which a project was constructed.
2. Extreme climate phenomena and changing climate trends can alter the timing, nature, and magnitude of the environmental impacts of a project.
3. Climate changes can increase vulnerability or de-stabilize natural and human systems increasing sensitivity to project impacts.

Legal Background

CEQA requires lead agencies to determine whether a project may have a significant impact on the environment and to prepare an environmental impact report if such an impact is identified. (Public Resources Code § 21082.2.) CEQA defines "significant effect on the environment" as a substantial, or potentially substantial, adverse change in the environment. (Public Resources Code § 21068.) "Environment" means the physical conditions which exist within the area that will be affected by a proposed project, including land, air, water, minerals, flora, fauna, noise level, objects of historic or aesthetic significance. (Public Resources Code § 21060.5.) Therefore, CEQA analysis is concerned with a project's impact on the existing environment, rather than with the environment's impact on a project or project users. (*California Building Industry Association v. Bay Area Air Quality Management District ("CBIA")* (2015) 62 Cal.4th 369, 378.) But when a proposed project risks worsening existing environmental hazards or conditions, CEQA requires an agency to analyze the project's potentially significant exacerbating effects on existing environmental hazards, because such effects are viewed as impacts of the project on existing physical conditions rather than impacts of the environment on the project. (*CBIA*, 62 Cal.4th at 388-389.) For example, CEQA analysis would be required if a project threatens to disperse existing buried environmental contaminants that would otherwise remain undisturbed.

Pursuant to these statutory and judicial guidelines, CEQA does not require an agency to analyze potential impacts of climate change on the physical and/or operational elements of a proposed project, on project users, or on the surrounding environment. An analysis of how climate change might impact a project or its users would be required under CEQA only if the project could exacerbate certain climate change effects (see, e.g., *Ballona Wetlands Land Trust v. City of Los Angeles* (2011) 201 Cal.App.4th 455, 473-74, holding that an EIR was not required to address impacts relating to sea level rise resulting from global climate change on a proposed project where the project itself would not cause sea levels to rise).

Although CEQA does not require an agency to analyze how climate change will impact a project, such climate-related considerations may be incorporated into CEQA documents for informational purposes, including mitigation recommendations on reducing or avoiding climate change effects on project operations, where feasible.

With these considerations in mind, DWR has established a policy of including the following information in all EIRs in which DWR acts as the lead agency.

1. **Project Description —** If the project is being proposed in whole or in part as a climate change adaptation or resiliency project, the project description should include a summary of the range of future climate change

Box 1. CEQA Considerations (continued)

conditions that have been considered in the project selection and design process, the specific design elements that have been incorporated into the project to enhance adaptive capability and resilience, and the specific ways in which the project increases adaptive capacity or resilience.

2. **Purpose and Need —** If the proposed project is, in whole or in part, a climate change adaptation or resiliency project, the "Purpose and Need" section should indicate how observed trends and projected future conditions show the need for the proposed project and how climate change could influence the ability of the project to fulfill its intended purpose.

3. **Affected Environment and Resources —** The "Affected Environment and Resources" section should include a summary of the observed and projected future changes in climate and affected resources in the project area (including watershed areas or other areas outside of the immediate vicinity of the proposed project that would be likely to affect the proposed project). Data to support such summaries are available from an array of sources including: regional, State, and local climate change assessments and indicator reports (e.g., http://swccar.org/sites/all/themes/files/SW-NCA-color-FINALweb.pdf, http://climatechange.ca.gov/climate_action_team/reports/third_assessment/index.html, and https://oehha.ca.gov/climate-change/document/indicators-climate-change-california).

4. **Environmental Resource Impacts —** For impact evaluations, DWR projects should consider how expected changes in climate could exacerbate the environmental consequences of the project or generate new consequences that would not have otherwise occurred. This is typically done by comparing estimates of potential project impacts between a project alternative under existing climate conditions to the estimates of potential project impacts for a project alternative under expected future conditions 20–50 years into the future. This can also be done qualitatively in some circumstances.

5. **Resiliency and Adaptation Section —**This is a new section that should be added to DWR EIRs. This section can be a chapter, appendix, or can be included in a resource impact chapter covering climate change and greenhouse gasses (GHGs). This section should include information about how the proposed project will help meet the challenges posed by climate change and how the proposed project will make California more resilient or adaptable to climate changes.

   This section can be qualitative or quantitative. Qualitative information may include an explanation of how the proposed project supports or implements the climate adaptation strategies identified in the most recent update to the Safeguarding California Plan (http://resources.ca.gov/climate/safeguarding/), DWR's Climate Action Plan Phase III: Adaptation Plan (in process), or other local adaptation plans. This section should also include a description of how the proposed project would function to improve the project area's resiliency and/or ability to adapt to extreme climate events or shifts in climate.

The *DWR GHG Emissions Reduction Plan Consistency Determination Form* is to be used by DWR project managers to document a DWR CEQA project's consistency with the DWR Greenhouse Gas Emissions Reduction Plan. The form, as well as additional guidance for completing the form, can be found on the Climate Change Program's internal SharePoint site: https://current.water.ca.gov/programs/icc/SitePages/ClimateActionPlan.aspx.

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Appendix A. Existing and Available Modeling Tools and Datasets

The list below includes a catalogue of existing/available resources and their potential uses for DWR's climate change analyses. This information is provided to assist DWR managers in making choices about how to conduct a climate change analysis appropriate for the activity they are planning. Contact DWR's Climate Change Program at climatechange@water.ca.gov for additional guidance or assistance in handling the datasets listed below.

1. **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[6].
   - 10 global climate models and two Representative Concentration Pathways (4.5 and 8.5).
   - Uses Localized Constructed Analogs (LOCA) downscaling (6 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[7].

   Reference: *Perspectives and Guidance for Climate Change Analysis.* Available at: https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Files/Perspectives_Guidance_Climate_Change_Analysis.pdf.

   Data Availability: LOCA downscaled projections data are available for download from the Cal-Adapt website and API: http://cal-adapt.org/data/loca/. Model products are available on request from the DWR Climate Change Program (climatechange@water.ca.gov).

   Status as of 2018: 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

[6] Forty climate period analysis datasets have also been developed for research purposes only. These datasets map climate shifts onto the historical streamflow record using a three-step perturbation method and use CALSIM-III as the operations model.
[7] Additional preprocessing steps must be taken to prepare these climate projections for input into CalSim-II to simulate water system conditions and operations (see #2 under Appendix A for more information).

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 DWR studies and should be used in some way to inform the climate conditions under which a project is being analyzed. That being understood, 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 (#2 below) provide an example of how those additional preprocessing steps have been performed by DWR for the Water Storage Investment Program.

2. 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 the entire State of California 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 (DEW) scenario and a Wet-Moderate Warming (WMW) 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.* Available at: https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/Climate-Change-Guidance---SGMA.pdf.

Data Availability: Model products and data are available for download on the SGMA Data Viewer web mapping application under the "Water Budget" heading (left panel) located here: https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer.

Status as of 2018: 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 DWR 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 Central Valley Project (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. The WSIP scenarios are therefore generally the most useful tool for programs or projects 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.

3. 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.

- A total of six climate change scenarios — each scenario over a 96-year period.
    - Warming Only Scenarios (no precipitation changes):
        - Near-Term Warming: Projected warming of about +1 °C (+1.8 °F),
        - Mid Century Warming: Projected warming of about +2 °C (+3.6 °F), and
        - Late Century Warming: Projected warming of about +3 °C (+5.4 °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, and
        - Late Century: Projected precipitation and temperature changes.
- Uses downscaled climate model data based on Bias-Correction Spatial Disaggregation (BCSD) 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 (USGS'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.* Available at: https://www.water.ca.gov/LegacyFiles/cvfmp/docs/CC_DraftClimateChangeSummary_March2017.pdf.

Data Availability: Data products are available on request from the DWR Climate Change Program (climatechange@water.ca.gov).

Status as of 2018: 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 over 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.

4. 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% and temperature changes of 0–4 degrees Celsius.
- 54 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-SMA-DS).
- Operations Model: CalLite 3.0.

Reference: *California Climate Risk: Evaluation of Climate Risks for California Department of Water Resources*. Available at: https://www.water.ca.gov/-/media/DWR-Website/Web-

Pages/Programs/All-Programs/Climate-Change-Program/Files/California-Climate-Risk-Evaluation-of-Climate-Risks-for-California-Department-of-Water-Resources.pdf.

Data Availability: Guidance on incorporating the decision scaling platform and related data products is available on request from the DWR Climate Change Program (climatechange@water.ca.gov).

Status as of 2018: 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.

5. BDCP Climate Change Scenarios

The Bay-Delta Conservation Plan (BDCP) climate change scenarios were developed between 2009 and 2010 for future conditions analysis associated with the California WaterFix and the California WaterFix EIR/EIS. These scenarios are informed by 112 downscaled climate projections from the Coupled Model Intercomparison Project 3 (CMIP3) archive. Five climate period scenarios (four corners of wet/dry/hot/warm + a central tendency climate projection) are provided at 2025 (2011–2040) conditions and 2060 (2046–2075) conditions. The 2025 central tendency scenario was also used in the 2015 State Water Project Delivery Capability Report.

- Ten climate period projections.
- Five 82-year scenarios run at 2025 conditions and five 82-year scenarios run at 2060 conditions.
- BCSD Downscaling (12 km x 12 km grid spacing).
- Quantile mapping methodology used to perturb historical observed record of hydrology with climate trends.
- Hydrology model: VIC (CalSim watersheds only).
- Hydrology model: WEAP.
- Operations model: CalSim-II.
- Water management model: WEAP (for Q1 and Q3 only).

Reference: *BDCP/California WaterFix FEIR/FEIS Modeling Technical Appendix.* Available at: http://baydeltaconservationplan.com/Libraries/Dynamic_Document_Library/Final_EIR-EIS_Appendix_5A_-_BDCP-California_WaterFix_FEIR-FEIS_Modeling_Technical_Appendix_-_Section_A.sflb.ashx.

Data Availability: Data products are available on request from the DWR Climate Change Program (climatechange@water.ca.gov).

Status as of 2018: The BDCP climate change scenarios are based on the CMIP3 archive of global climate models, which is an older set of scenarios (2007); these scenarios use the BCSD method of downscaling, an older downscaling methodology (2002/2004) that has since been improved upon, and a quantile mapping approach that may result in unrealistically extreme outcomes because of a breakdown in spatial coherence. Nevertheless, the BDCP ensemble of scenarios still provides a wide range of potential outcomes that are adequately large enough to explore the uncertainty associated with mid- and late-century climate impacts.

Recommended Uses: CEQA projects that build upon the California WaterFix program and must show consistency with the original analysis done for the program may want to consider using this product in conjunction, as appropriate, with other, newer scenario information described above. For other uses, these scenarios should only be used in concert with other, newer scenario information described above.

6. CAT 12 Climate Scenarios

CAT 12 climate scenarios were developed in 2009 for future conditions analysis related to the California Third Climate Change Assessment. Twelve transient climate scenarios were developed from six global climate models and two GHG emissions scenarios from the CMIP3 archive. The six GCMs were selected for their general ability to simulate important California climate processes and because of their finer temporal scales. These transient climate scenarios were subsequently used to create corresponding climate period projections of hydrology at mid-century (2036–2065) and end-of-century (2070–2099)

- Twelve transient climate projections running 1950–2099.
- Twenty-four climate period hydrology projections — 12 projections at 2050 conditions, 12 projections at 2085 conditions.
- Uses BCSD Downscaling (12 km x 12 km grid spacing).
- Three-step perturbation methodology to map climate trends on to historical observed hydrology.
- Hydrology model: VIC (CalSim watersheds only).
- Hydrology model: WEAP.
- Operations model: CalSim-II.
- Water management model: WEAP.

References:

Cayan, D., E. Maurer, M. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. Climatic Change, 87 (Suppl. 1): 21–42. DOI: 10.1007/s10584-007-9377-6.

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick. 2009. Climate Change Scenarios and Sea Level Rise Estimates for the California 2009

Climate Change Scenarios Assessment. California Energy Commission Report # CEC-500-2009-014-F. Available at: http://www.energy.ca.gov/2009publications/CEC-500-2009-014/CEC-500-2009-014-F.PDF.

Chung, F., J. Anderson, S. Arora, M. Ejeta, J. Galef, T. Kadir, K. Kao, A. Olson, C. Quan, E. Reyes, M. Roos, S. Seneviratne, J. Wang, H. Yin, and N. Blomquist. 2009. Using Future Climate Projections to Support Water Resources Decision Making in California. Draft Report: Prepared by the California Department of Water Resources. 66 p. May. Available at: https://www.water.ca.gov/LegacyFiles/pubs/climate/using_future_climate_projections_to_support_water_resources_decision_making_in_california/usingfutureclimateprojtosuppwater_jun09_web.pdf

Data Availability: Data products are available on request from the DWR Climate Change Program (climatechange@water.ca.gov).

Status as of 2018: CAT 12 climate scenarios are based on an older set of scenarios (2007), an older downscaling methodology (2002–2004), and a three-step perturbation methodology (2009) that may not adequately map the projected shifts in the extremes of climate (e.g., wet months getting wetter, dry months getting drier). These scenarios were used widely for California water resource and climate change impact assessments between 2009 and 2015.

Recommended Uses: These scenarios may still be useful for comparing newer studies with previous impact estimates. These scenarios still provide an important historical benchmark of impact assessment; however, these scenarios should only be used in concert with other, newer scenario information as described above.

7. Cal-Adapt.org

Cal-Adapt (http://cal-adapt.org/) 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.

8. Other Resources

In addition to the resources listed above, several additional resources provide more general guidance and information on conducting climate change analyses and may be helpful for DWR project managers.

- **Ocean Protection Council (OPC): Updated Sea Level Rise Guidance**, March 2018. 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, including lands granted by the Legislature. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/OPC_SeaLevelRise_Resolution_Adopted031111.pdf

- **Climate Change Handbook for Regional Water Planning. November 2011.** This document, developed collaboratively by DWR, the U.S. Environmental Protection Agency, Resources Legacy Fund, and the U.S. Army Corps of Engineers, 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 uses DWR's Integrated Regional Water Management (IRWM) planning framework as a model into which analysis of climate change impacts and planning for adaptation and mitigation can be integrated. https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Work-With-Us/Grants-And-Loans/IRWM-Grants/Files/Climate-Change-Handbook-for-Regional-Water-Planning.pdf.

- Ray P and Brown C. 2015. *Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework*. Washington, DC: World Band. Doi:10.1596/978-1-4648-0477-9.
  The Decision Tree Framework described in this book provides resource-limited project planners and program managers with a cost-effective and effort-efficient, scientifically defensible, repeatable, and clear method for demonstrating the robustness of a project to climate change. At the conclusion of this process, the project planner will be empowered to confidently communicate the method by which the vulnerabilities of the project have been assessed, and how the adjustments that were made (if any were necessary) improved the project's feasibility and profitability. The framework adopts a "bottom-up" approach to risk assessment that aims at a thorough understanding of a project's vulnerabilities to climate change in the context of other non-climate uncertainties (for example, economic, environmental, demographic, or political). It helps to identify projects that perform well across a wide range of potential future climate conditions, as opposed to seeking solutions that are optimal in expected conditions but fragile to conditions deviating from the expected.

http://documents.worldbank.org/curated/en/516801467986326382/pdf/99180-PUB-Box393189B-PUBLIC-PUBDATE-8-19-15-DOI-10-1596-978-1-4648-0477-9-EPI-210477.pdf.

- California Governor's Office of Planning and Research. 2018. *Planning and Investing for a Resilient California: A Guidebook for State Agencies*.
  This document is the product of the Technical Advisory Group (TAG) formed under EO B-30-15. The TAG was comprised of representatives from agencies, departments, offices and commissions of the governor's executive branch and members of the public, including local and regional governments, non-governmental organizations, and the private sector. This guidance document is designed to inform planning and investment processes to address the two primary elements of resilience — planning for future conditions and doing the actual planning differently. This document introduces a four-step process and a set of resilient decision-making principles for State agencies.

  1. Identify how climate change could affect a project or plan.
  2. Conduct an analysis of climate risks.
  3. Make a climate-informed decision.
  4. Track and monitor progress.

  This guidance is intended to be integrated into all planning and investment, but it does not require creating an entirely new process. The steps outlined in this document can (and should) be integrated into standard practices, which can streamline their application and reduce the need for additional analysis.
  http://opr.ca.gov/docs/20180313-Building_a_Resilient_CA.pdf.

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Appendix B. Additional State and Federal Climate Change Pronouncements

California Pronouncements

- AB 1471 Water Quality, Supply, and Infrastructure Improvement Act of 2014 (https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201320140AB1471). This bill, which became effective on August 13, 2014, reallocated $425 million of unissued bonds approved through various propositions passed between 1986 and 2006 and authorized $7.12 billion in general obligation bonds for State water supply infrastructure projects. In November 2014, voters approved Proposition 1, which enacted the bill. It funds a variety of projects that potentially improve the state's resilience relating to climate change, including environmental restoration projects and local water supply projects such as water recycling, stormwater capture, water conservation, etc.

- SB 246 Climate Change Adaptation (https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB246). This statute, which became effective on January 1, 2016, established the Integrated Climate Adaptation and Resiliency Program, administered by the Office of Planning and Research — to "coordinate regional and local efforts with state climate adaptation strategies to adapt to the impacts of climate change…" and requires "….within one year of an update to the Safeguarding California Plan, the Office of Emergency Services, in coordination with the Natural Resources Agency, the Office of Planning and Research, and relevant public and private entities, to review and update, as necessary, the Adaptation Planning Guide…"

- SB1755 The Open and Transparent Water Data Act (https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1755) This law, which became effective on January 1, 2017, requires DWR, in consultation with the California Water Quality Monitoring Council, the California State Water Resources Control Board, and the Department of Fish and Wildlife, to create, operate, and maintain a statewide integrated water data platform that integrates existing water and ecological data information from multiple databases and provides data on completed water transfers and exchanges.

- EO-S-13-08 (http://www.climatechange.ca.gov/state/executive_orders.html). Signed by Governor Schwarzenegger on November 14, 2008, this executive order directed the California Natural Resources Agency to, through various specific measures, investigate and address impacts to California's resources relating to sea level rise resulting from climate change. It also directed the agency to coordinate with various entities and develop the state's first Climate Adaptation Strategy, through the Climate Action Team, by June 30, 2009. In 2014, this strategy developed into what is now called "Safeguarding California: Reducing Climate Risk" or "Safeguarding California Plan." The agency then released, in 2016, "Safeguarding California: Implementation Action Plan."

- California Water Action Plan (http://resources.ca.gov/docs/california_water_action_plan/2014_California_Water_Action_Plan.pdf). The California Water Action Plan was released by Governor Brown in January 2014 and functions as a roadmap for the first five years of a commitment to sustainable water management, including conservation of ecological resources. Implementation reports are issued annually, and an update was produced in 2016.

- California Adaptation Planning Guide (APG) http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf). The California Adaptation Planning Guide was published in July 2012 and prepared by the California Emergency Management Agency and the California Natural Resources Agency. It consists of four complementary documents that provide guidance for local governments and regional collaboratives to address climate change impacts.

- Pacific Coast Collaborative (PCC) http://pacificcoastcollaborative.org/. Formed on July 1, 2008, the PCC is a partnership between the governments of Alaska, British Columbia, California, Oregon, and Washington, focusing on clean energy, regional transportation, research and development, and sustainable economy with respect to the environment.

Federal Pronouncements

Several policy and guidance documents on climate change analysis were issued at the federal level during the Obama administration. But many of these documents have been either rescinded (e.g., CEQ guidance for federal agencies on how to consider GHG emissions and the effects of climate change in NEPA reviews, released on August 1, 2016) or are currently under review by the Trump administration. Although some of the federal climate change guidance documents are no longer in effect, those documents contain valuable recommendations and approaches that have been considered in developing this guide.

- CEQ Guidelines (https://obamawhitehouse.archives.gov/the-press-office/2016/08/02/fact-sheet-white-house-council-environmental-quality-releases-final). In August 2016, the Obama administration's Council on Environmental Quality released final guidance for federal agencies on how to consider the impacts of their actions on climate change in their National Environmental Policy Act (NEPA) reviews. This guidance provided a framework for federal agencies to consider both the effects of a proposed action on climate change, as indicated by its estimated GHG emissions, and the effects of climate change on a proposed action. But, by an executive order issued on March 28, 2017, President Trump ordered the Council on Environmental Quality to rescind this NEPA guidance.

- National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate (https://www.epa.gov/sites/production/files/2016-12/documents/2011_national_action_plan_1.pdf). This document was released in October 2011 and is a product of the Interagency Climate Change Adaptation Task Force. It provides six priority recommendations, including recognizing the need to adapt water resources management, improve information for decision-making, strengthen the assessment of vulnerabilities, expand water use efficiency, support integrated water resources management, and increase outreach.
- U.S. Army Corps of Engineers (USACE) Engineering and Construction Bulletin 2016-25: Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects (http://www.iwr.usace.army.mil/Portals/70/docs/frmp/eo11988/ECB_2016_25.pdf). This bulletin, issued on September 16, 2016, provides guidance for incorporating climate change impacts in all hydrologic analyses supporting planning and engineering decisions. It is designed to fit within the USACE's climate change adaptation policy, which requires consideration of climate change in all current and future studies to reduce vulnerabilities and enhance resilience of water resources infrastructure.
- Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy (https://obamawhitehouse.archives.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf). This report, issued October 5, 2010, summarizes the progress of the task force, which was formed in 2009 and led by the CEQ, NOAA, and the Office of Science and Technology Policy, but was composed of more than 20 federal agencies and executive branch offices. This report provides guidance and recommendations for how federal agencies can better prepare the United States to respond to the impacts of climate change.

Building on State Level Guidance

The State's steering committee responsible for California's Fourth Climate Change Assessment has developed population, land use/land cover, and sea level rise projection recommendations for research projects contributing to the Fourth Assessment. These recommendations were not intended as guidance for policy or practitioners and do not replace State climate change guidance, but nonetheless may provide useful guidance and datasets for DWR projects. http://www.ccca4.org/index.html.

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Appendix C. Transient Climate Simulations versus Climate Period Simulations

There are two basic approaches that have been used to simulate climate change in water resource modeling by DWR: transient analysis and climate period analysis.

In a **transient analysis**, the climate change signal strengthens incrementally over time, like the way it has been occurring in recent decades. In general, years further into the future are warmer than years closer to the beginning of the simulation, and the most severe changes to climate tend to occur toward the later years of the simulation. Conversely, in a **climate period analysis**, climate change is modeled as a shift from a baseline condition (usually historical observed climate) where every year of the simulation is shifted in a way that represents the climate change signal at a future 30-year climate period.

Each approach has advantages and disadvantages and each may be appropriate depending on the application. For water resource modeling, particularly in California where inter-annual precipitation variability is extreme**, transient analysis** can be difficult to interpret. In a **transient analysis,** inter-annual variability can completely obscure the climate change signal — because each year of the simulation has both inter-annual variability and a climate change signal, making it difficult to determine which is causing shifts in precipitation. **Climate period analysis** provides advantages in this situation because it isolates the climate change signal independent of the inter-annual variability signal. In a **climate period analysis,** inter-annual variability is based on the reference period from which change is being measured, meaning that all differences between the future simulation and the reference period are the result of the climate change signal alone.

One drawback of a **climate period analysis** is that it provides information about climate impacts at only one future time period — usually a 30-year window. Therefore, multiple simulations need to be run to understand how climate changes will unfold over time. A **climate period analysis** might represent future conditions for 2036–2065 or more generally mid-century/2050 future conditions. Consequently, if one needed to evaluate future conditions throughout the 21st century, multiple simulations would have to be run to evaluate conditions at many climate periods between current conditions and the end of the century. Additionally, the **climate period analysis** that DWR has typically used relies on the perturbation of historical observed climatology (or hydrology) to represent potential future conditions. This approach preserves historical inter-annual variability but also limits the exploration of future changes in inter-annual variability.

In a **transient climate analysis**, multiple simulations are often necessary to tease out climate change signal information from inter-annual variability noise. Nevertheless, multiple transient simulations typically also provide important information about climate change uncertainties in a way that is more difficult to achieve with climate period simulation types.

Figure 2. Transient and Climate Period Simulations of Temperature and Precipitation

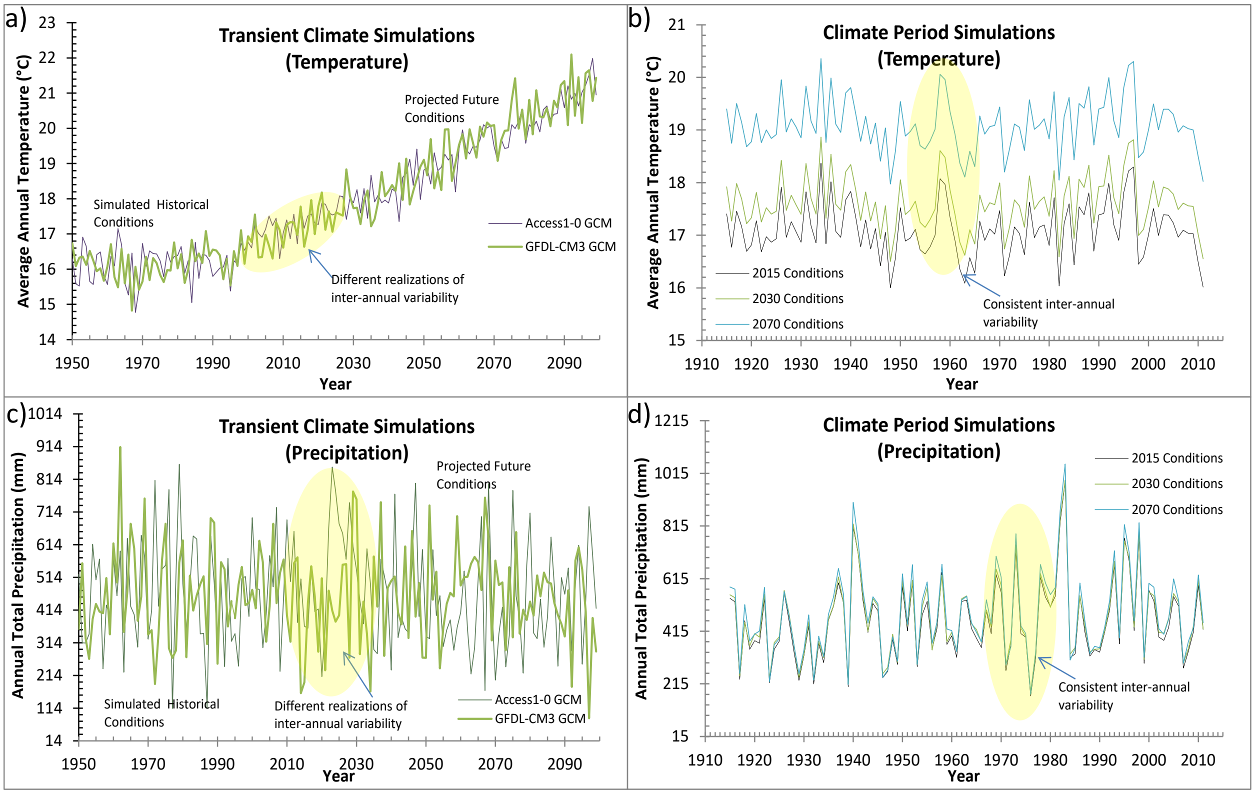

Figure 2 illustrates some of the differences in transient and climate period simulations for both temperature changes and precipitation changes. Figures 2a and 2b compare the difference in the ways that these two approaches represent changes in temperature. Figure 2a (**transient analysis**) shows the clear increasing trend in temperature over time. Figure 2b (**climate period analysis)** shows that a step change in temperature occurs between 2015 conditions and 2030 or 2070 conditions. Figure 2c (**transient analysis)** illustrates how noisy the precipitation data are for transient climate simulations but also how each run explores novel examples of inter-annual variability. Conversely, Figure 2d (**climate period analysis)** illustrates how a climate period simulation follows the historical pattern of inter-annual variability and the only differences come from the ways in which climate models project certain year-types will shift to wetter or drier conditions.

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