RECLAMATION
Managing Water in the West

Technical Guidance for Incorporating Climate Change Information into Water Resources Planning Studies

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
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MISSION STATEMENTS

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

DISCLAIMER

Information presented in this guidance document is provided as recommendations and not a mandatory requirement for water resources planning studies. Study teams have the option of adapting these instructions or using other approaches that better suits their study goals and objectives to address the climate change requirement in the Feasibility Study Directives and Standards, CMP 09-02.

ACRONYMS AND ABBREVIATIONS

°F	Fahrenheit
AR4	Fourth Assessment Report IPCC 2007
AR5	IPCC Fifth Assessment Report
BCCA	bias corrected constructed analogue
BCSD	bias corrected and spatially disaggregated
CMIP	Coupled Model Inter- comparison Project
CMIP3	CMIP Phase 3
CMIP5	CMIP Phase 5
D&S	Directives and Standards
DOI	Department of Interior
ESA	Endangered Species Act of 1973
GCM	Global Climate Models
GHG	greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
km	kilometers
LCC	Landscape Conservation Cooperatives
M&I	municipal and industrial
NARCCAP	North American Regional Climate Change Assessment Program
NEPA	National Environmental Policy Act
NRC	National Research Council
P&G	Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies
RCP	Representative Concentration Pathways
Reclamation	Bureau of Reclamation
RMJOC	River Management Joint Operating Committee
S&T	Science and Technology Program
SRES	Special Report on Emission Scenarios
USGCRP	U.S. Global Change Research Program
VIC	Variable Infiltration Capacity
WWCRA	West-Wide Climate Risk Assessments
WaterSMART	Sustain and Manage America's Resources for Tomorrow Program
WCRP	World Climate Research Programme
W/m^2	Watt per square meter

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EXECUTIVE SUMMARY

The impacts of climate change are being felt across the Western United States. Warming is affecting water supplies by changing the overall annual volume of precipitation and altering the balance of rain versus snowfall. Communities are facing increasing problems with water availability and drought, flooding, and increased risk of forest fires. The requirements established by Secretarial Order 3289, Departmental Manual 523 DM 1, Executive Order 13653, and Reclamation's Directives and Standards CMP 09-02 for feasibility studies reinforces the need for Reclamation's on-going programs to be more resilient to the impacts of climate change and for continued efforts to incorporate climate change information into aspects of our mission where it has not been fully considered in the past such as in decisions regarding ecosystem restoration, reservoir operations, infrastructure investments and planning capacity.

This document is an important step to reinforcing Reclamation's planning capacity by providing guidance to help study teams navigate the range of planning and technical methods available to account for climate change impacts in feasibility studies. The effects of climate change have altered and will continue to alter the basic assumptions underlying Reclamation's water resources planning. Effective water management and planning rely on an understanding of climate change impacts on water supply, demand, and criteria that govern or guide water management. The guidance in this document may also be applied to environmental compliance studies since they are typically conducted concurrently with feasibility studies. The guidance is organized around the planning and technical framework for conducting a feasibility study as detailed in CMP 09-02, and which occurs in two phases: the scoping phase and the alternative formulation and evaluation phase.

Study teams determine the level of climate change analysis needed for the study and appropriate methods to characterize climate conditions. Prior to CMP 09-02, feasibility studies were allowed to assume historical climate conditions would continue into the future when developing the without-plan future condition and alternatives and complement that evaluation with sensitivity analysis addressing climate change uncertainty. Since the release of CMP 09-02 in 2012, studies are now required to assume some amount of climate change when developing without-plan future condition and alternatives.

Understanding that climate change information ranges from more to less certain and that without-plan future assumptions directly frame decision-support, CMP 09-02 forces study teams to determine which portions of climate change information are:

1) Certain and relevant enough to be included in without –plan future condition

2) Highly uncertain but still relevant and therefore worthy of exploring through sensitivity analysis

3) Irrelevant or too uncertain and therefore excluded from the study

This guidance helps study teams make this determination by addressing a series of scoping questions about decision relevance, information reliability, and analysis practicalities. Responses to the scoping questions will help study teams determine what climate change information to include in the without-plan future condition and potentially what to include in complementary sensitivity analysis and a quantitative method of analysis to accomplish this body of analysis.

The guidance is designed to be used in existing decision making processes within Reclamation that allow for some level of flexibility to address both net economic benefits and protection of environmental resources. In the future, this document will be expanded and include a decision making framework which incorporates climate change.

1. INTRODUCTION

In 2009, the Department of Interior (DOI) issued Secretarial Order (S.O.) 3289, "Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources". The S.O. states that "*each bureau and office of the Department must consider and analyze potential climate change impacts when undertaking long-range planning exercises, setting priorities for scientific research and investigations, developing multi-year management plans, and making major decisions regarding the potential use of resources under the Department's purview*." The requirements established in the S.O. are consistent with Reclamation's efforts to implement a climate change program to evaluate the risks and impacts of climate change across major Reclamation river basins.

In 2012, DOI built on those requirements through the establishment of a broad new policy on climate change adaptation for all bureaus within DOI to adapt to the challenges posed by climate change to our mission, programs, operations, and personnel (Departmental Manual 523 DM 1).

> *"The Department will use the best available science to increase understanding of climate change impacts, inform decision making, and coordinate an appropriate response to impacts on land, water, wildlife, cultural and tribal resources, and other assets. The Department will integrate climate change adaptation strategies into its policies, planning, programs, and operations, including, but not limited to, park, refuge, and public land management; habitat restoration; conservation of species and ecosystems; services and support for tribes and Alaska Natives; protection and restoration of cultural, archeological and tribal resources; water management; scientific research and data collection; land acquisition; management of employees and volunteers; visitor services; construction; use authorizations; and facilities maintenance."*

Further direction for a climate change adaptation program comes from Executive Order (EO) 13653, which lays out new policy directives for Federal agencies to ". . . *prepare the Nation for the impacts of climate change by undertaking actions to enhance climate preparedness and resilience*. . ." The EO includes direction for agencies to modernize Federal programs to support climate resilient investments and manage land and water resources for climate preparedness and resilience.

In addition to the implementation of DOI Policy 523 DM 1, the Bureau of Reclamation (Reclamation) updated its Reclamation Manual Directives and Standards (D&S) for Water and Related Resources Feasibility Studies (CMP 09-

02)[1] on September 30, 2012. CMP 09-02 outlines the process by which Reclamation conducts feasibility studies. Specifically, CMP 09-02 requires that "potential impacts of climate change will be considered when developing projections of environmental conditions, water supply and demand, and operational conditions at existing facilities as part of the **without-plan future condition**," [2] (CMP 09-02 section 7.H.2.f). CMP 09-02 also directs climate change impacts to be further analyzed if "there is a reasonable likelihood of significant variation in hydro-climatic conditions over the planning horizon, between alternatives, or both; and regional models have been down-scaled to a resolution adequate for the study area, or can be produced within a reasonable time and cost constraints" (CMP 09-02 section 7.H.2.f (i) and (ii)).

The guidance presented below is intended to support Reclamation's planning process that are subject to the requirements of CMP 09-02 and therefore may or may not be beneficial for incorporating climate change into other Reclamation studies and activities. Dam safety and reservoir operations studies are being addressed in separate processes that will result in guidance documents specific to those activities.

1.1. Reclamation Activities to Address the Effects of Climate Change

Reclamation is already taking actions to address the impacts of climate change by working with our partners in river basins across the West to optimize available water supplies for competing water uses. Reclamation's Science and Technology Program is taking a leading role to develop the data and tools necessary to support climate change adaptation within Reclamation and by customers and stakeholders. Since 2007, Reclamation has led a partnership of eight Federal, academic, and Non-Governmental Organizations to provide future projections of temperature, precipitation, and streamflow throughout the continental United States to support locally relevant decision making.[3]

The Basin Study Program, part of DOI's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program, is a key component of Reclamation's implementation of a climate change adaptation program through a tiered approach which includes:

[1] http://www.usbr.gov/recman/cmp/cmp09-02.pdf

[2] The without-plan future condition is also termed the "Forecast Future Condition" and is defined in CMP 09-02 as, "Characterizing future conditions without the proposed Reclamation action, including actions that may be expected or anticipated by others."

[3] http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/

- **West-Wide Climate Risk Assessments (WWCRA)**. Through a variety of WWCRA activities, Reclamation develops baseline information regarding the risks and impacts of climate change to water supplies and demands, and conducts Impact Assessments to evaluate impacts to Reclamation's operations and activities.

- **Basin Studies.** The Basin Studies are in-depth water supply and demand analyses that are cost shared between local stakeholders and Reclamation and are selected through a competitive proposal process. Through the Basin Studies, Reclamation works collaboratively with stakeholders to evaluate the ability to meet future water demands in a particular basin and to identify mitigation and adaptation strategies to address potential climate change impacts.

- **Landscape Conservation Cooperatives (LCC).** LCCs are partnerships of governmental (Federal, State, Tribal and local) and non-governmental entities and are an important part of DOI's efforts to coordinate climate change science efforts and resource management strategies. Reclamation participates in LCCs encompassing the Western 17 states and is co-leading the Desert and Southern Rockies LCCs with the U.S. Fish and Wildlife Service to identify, build capacity for, and implement shared applied science activities to support resource management at the landscape scale. The Desert and Southern Rockies LCCs span the upper and lower Colorado River Basin and, together, include portions of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Texas.

These activities are complementary and represent a multi-faceted approach to assess climate change risks to water supplies and impacts to activities in Reclamation's mission, as well as the identification of adaptation strategies to meet future water supply and demands.

To meet the needs for affordable water and power in the West, protect the water-related environment, and meet trust obligations to tribes, Reclamation must become more resilient to the impacts of climate change and extremes. This requires a continued emphasis on successful, ongoing efforts, as well as considering climate change information in aspects of our mission where it has not been fully considered in the past such as in decisions regarding ecosystem restoration, reservoir operations, and infrastructure investments and planning capacity.

1.2. Purpose and Organization of this Document

This guidance document addresses requirements in CMP 09-02 section 7.H.2.f to incorporate climate change information into feasibility studies. The guidance has been developed to help study teams navigate the range of planning and technical methodological choices available to account for climate change impacts. Typically environmental compliance studies (e.g., under the National Environmental Policy Act [NEPA] and Endangered Species Act of 1973 [ESA]) are conducted concurrently and released with the final feasibility report. The guidance provided within this document may also be applied to these environmental compliance studies. The guidance within this document will assist study teams in:

1) Determining an appropriate level of climate change analysis

2) Identifying a specific climate change method to use in evaluating both the without- plan future condition and the action alternatives being considered in the study

The guidance is designed to be used in existing decision making processes within Reclamation that allow for some level of flexibility to address both net economic benefits and protection of environmental resources. In the future, as policy continues to be developed such as the release of the Principles and Requirements for Federal Investments in Water Resources,[4] there may be more information to draw upon, to expand this document to develop a decision making framework that incorporates climate change which is consistent at the Federal level.

This document is organized around the planning and technical framework for conducting a feasibility study as detailed in CMP 09-02 and is structured as follows:

- ***Section 2*** provides an overview of the process Reclamation uses to conduct planning (appraisal and feasibility) and environmental compliance studies. In general, planning studies occur in two phases, which include the Scoping Phase and the Alternative Formulation and Evaluation Phase.

- ***Sections 3 through 6*** address the Scoping Phase to ensure that climate change analysis is performed consistently relative to the accuracy or certainty of the rest of the study and provides the necessary results to support making decisions needed from the study.

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[4] These Principles and Requirements were released in March 2013 but will not take effect until the corresponding Guidelines are released by the White House Council on Environmental Quality.

- ***Section 3*** introduces some of the plausible climate change impacts that could pose challenges to water resources planning as these impacts are considered through the feasibility study and environmental compliance processes.

- ***Section 4*** presents a structured way to establish the appropriate level of climate change analysis to be used during the Alternative Formulation and Evaluation Phase. The levels are presented as "options" that range from No Analysis to a Quantitative Effects Analysis.

- ***Sections 5 and 6*** expand on the Quantitative Effects Analysis. Methods that are appropriate for the study scope, key study decisions, time frame for the study, and budget for conducting the study are presented.

    - ***Section 5*** introduces a series of questions to help study teams determine appropriate methods to characterize climate conditions that fits study needs and requirements. Key considerations will include the relevance of climate change projections to the study questions being posed, reliability of available climate projections, and practical limitations at the proposed level of analysis.

    - ***Section 6*** presents four specific quantitative climate change analysis methods that study teams can choose from based on the answers developed using ***Section 5.***

- ***Section 7*** addresses the Alternative Formulation and Evaluation Phase of the feasibility study process described in ***Section 2.2.*** This section describes how study teams can use the selected climate change method to evaluate the without-plan future condition and compare results to the action alternatives.

2. Overview of Reclamation's Planning and Environmental Compliance Study Process

This section provides a brief overview of the processes and requirements associated with conducting water resources planning studies in which climate change data may be incorporated. Reclamation conducts two principal types of planning studies:

- **Appraisal studies**, which are investigations performed to determine water and related resource problems and needs, formulate and assess alternatives and recommend subsequent actions

- **Feasibility studies**, which build from appraisal studies to evaluate the technical, economic, and financial feasibility of a proposed project

Reclamation conducts other types of planning studies, but generally equates these to either appraisal or feasibility level. For example, WaterSMART Basin Studies are considered somewhat similar to appraisal studies in terms of the level of effort and detail the study is conducted at, despite having slightly different programmatic requirements.

While this guidance is written for feasibility and associated environmental compliance studies, appraisal studies are briefly discussed in ***Section 2.1*** to provide some assistance to Reclamation staff involved with appraisal studies that have plans to progress to a feasibility study. Given the climate change requirement in CMP 09-02, study teams can take steps during the appraisal study to address climate change that may help reduce costs at the feasibility stage when trying to meet the requirements in CMP 09-02.

2.1. Appraisal Studies

An appraisal study is a preliminary investigation of limited scope used to:

- Investigate water resource problems, needs, and opportunities in a study area

- Formulate and assess a wide range of potential solutions

- Determine if a subsequent study is warranted to investigate the feasibility of implementing any of the potential solutions identified

2.1.1. Incorporating Climate Change Information into Appraisal Studies

If study teams performing an appraisal study are considering incorporating climate change data into their study, they can rely primarily on available existing information to answer two fundamental questions relative to climate change:

1) *Is there a Federal interest in the problem being investigated that climate change may affect?*
   In many cases, the particular nature of a water resource issue will establish Federal interest, with or without incorporating climate change information into the analysis. However, an examination of the potential impacts of climate change may further substantiate the Federal interest. In some cases, it may reveal a Federal interest that would not be readily apparent using traditional methods.

2) *Are there viable solutions that should be studied in greater detail through a feasibility study that may be affected by climate change?*
   A key test of viability will be the capacity of a proposed system to withstand the range of potential stresses caused by both climate variability and long-term climate change. In addition to project viability, as study team formulate and evaluate alternatives, teams should incorporate climate information into the without-plan future alternative, as well as understand the effects of the designed system on the climate (e.g., greenhouse gas emissions [GHG]).

2.1.2. Using this Guidance to Support Appraisal Studies

The analysis of climate change for an appraisal study will be similar to the work described in ***Section 2.2*** for the Scoping Phase of a feasibility study. However, with the exception of WaterSMART Basin Studies, the analysis will be limited to fit the purposes of determining Federal interest and project viability. Using existing information, including relevant data that may have been generated to conduct a West-Wide Climate Risk Assessment and/or Basin Study, appraisal study teams can begin answering the questions in ***Section 4*** of this guidance to select the appropriate climate change analysis option (see the flow chart in Figure 2).

Teams conducting an appraisal study outside of the Basin Study Program should, at a minimum, begin with a literature review[5] (Option B in Figure 2) to determine

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[5] On October 31, 2013, Reclamation released its third edition of the Literature Synthesis on Climate Change Implications for Water and Environmental Resources. The report offers a summary of recent literature on the current and projected effects of climate change on hydrology and water resources covering the western 17 States. http://www.usbr.gov/climate/docs/ClimateChangeLiteratureSynthesis3.pdf

the relevancy of climate change to the problem definition and alternative formulation. The literature review will also enable the evaluation of the planning horizon within the context of climate change effects.

2.2. Feasibility Studies

A feasibility study is a detailed investigation involving systematic planning, engineering, environmental, and economic and social analyses to formulate and evaluate a range of reasonable alternative solutions. Feasibility studies also require an assessment of the impact of the alternatives on the environment in compliance with NEPA and other applicable environmental laws (CMP 09-02 section 6.B). As described in CMP 09-02, feasibility studies are conducted in accordance with the iterative planning process described in the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) and generally consist of two phases:

1) **Scoping Phase.** In this phase, study teams identify specific problems, opportunities, and constraints, while also establishing planning objectives. In addition, study teams gain a better understanding of the conditions on the ground for key resource areas or affected environments, while also projecting future conditions for those same resource areas.

2) **Alternative Formulation and Evaluation Phase.** This phase involves all of the steps necessary to further refine and evaluate alternative solutions using detailed analysis. This phase is expected to occur in an iterative process involving formulation of new alternatives or refinement of existing alternatives based on results of the analysis and leading towards a final set of alternatives that meet the planning objectives and reasonably protect environmental resources. More details of the two phases of the feasibility study process are provided in CMP 09-02 section 7.G and 7.H.

2.3. Environmental Compliance

There is a tight integration between a feasibility study and associated environmental compliance study; therefore, the guidance provided below is intended to support the needs and requirements of both study processes. Instructions in this document refer to "**study teams**" and steps of the **"study process**" to convey to the reader that the instructions can be used by both feasibility study teams and the environmental compliance teams as is appropriate for each respective study.

Incorporating Climate Change Information

NEPA requires Federal agencies to analyze and disclose the environmental impacts of proposed Federal actions and reasonable alternatives before such actions are taken. Section 7(a)(2) of the ESA requires Federal agencies to determine whether proposed Federal actions may affect threatened or endangered species and/or designated critical habitat. As part of a feasibility study, CMP 09-02 requires that the environmental compliance of alternative plans be assessed in accordance with NEPA, ESA, and other applicable environmental laws.

Determining project outputs or environmental consequences often relies on historical hydrologic records and assumptions of future hydrology. Climate change must be considered as a possible issue that may affect the future projected hydrology. The level of climate change consideration in the environmental compliance analysis will depend on the results of the scoping process (discussed in ***Section 4***), other identifying issues relevant to the proposed action, the planning horizon, as well as individual project features, and available information for the study or proposed alternative. Instructions for study teams to address these issues and arrive at a decision are provided in ***Section 5***.

Typically, the environmental compliance process runs concurrent with the feasibility study. The completed results and findings of the environmental compliance are either integrated with the feasibility study report or attached as a separate document. As with a feasibility study, an environmental compliance process has parallel phases and steps that correspond with the feasibility study process, as shown in Appendix A of CMP 09-02.

3. CLIMATE CHANGE POSES CHALLENGES TO WATER RESOURCES PLANNING

The effects of climate change have altered and will continue to alter the basic assumptions underlying water resources planning that Reclamation conducts. Effective water management and planning rely on an understanding of climate change impacts on water supply, demand, and criteria that govern or guide water management. This section provides an overview of these potential impacts.

3.1. Potential Climate Change Impacts to Reclamation Operations

Climate change is occurring on global and regional scales, and the magnitude and rate of climate change is projected to increase above historical conditions during the 21st century. Impacts to water supply are currently being observed in the Western United States and will affect the total quantity of available water as well as the timing and volume of stream flow. Climate change is impacting the demand for water, the severity of floods, droughts, and environmental resources.

Climate change is projected to continue to warm the air and subsequently the oceans, lakes and rivers throughout the 21st century. This warming leads to increases in evapotranspiration, which includes evaporation from open water sources and moist soil, as well as transpiration by plants[6] including riparian vegetation communities. These changes can decrease water supplies that are available for human uses.

Many projections of future climate are available. Projections of temperature changes are considered relatively consistent whereas projections for precipitation are more varied. In many areas, little change is projected in the mean annual total precipitation. However, the timing of precipitation events may change, along with the proportion of the precipitation that falls as rain rather than snow and the frequency of rain-on-snow events. These changes can cause a decrease in the natural storage of water in mountain snowpack in some regions of the Western United States. For regions that do experience decreases, the loss of storage provided by mountain snowpack and the subsequent change in timing and quantity of runoff can affect the ability to capture and store runoff for water supply and for power generation, while maintaining adequate flood control. In addition, the projected temperature driven increases in the capacity of the atmosphere to store moisture may likely heighten the intensity of storm events. In

[6] It should be noted that while warming in general may lead to an increase in plant transpiration, other factors such as increasing CO^2 may have the opposite effect.

turn, higher intensity storms would increase the potential for flooding, even in areas where water supplies are projected to decrease.

The combined effect of changes in evapotranspiration, the timing and form of precipitation, and snowpack conditions is leading to changes in the timing of river flows, generally characterized by increases in water supplies in the winter and decreases in the summer. This decrease in supply coincides with an increase in the growing season for crops, which will likely lead to changes in crop water demands. The projected hydrologic changes are also leading to changes in human demands. These changes may alter municipal and industrial (M&I) demands because of higher demand for summer cooling (including evaporative coolers in arid areas). Increased needs for water supply for irrigation of urban landscapes are also expected.

In river basins where imbalances between water supply and demand could be exacerbated by the impacts of climate change, there is an increased risk of water shortages in the future. Such water shortages may manifest in an environment of significant constraints, such as the limits on consumptive use of water imposed by interstate river compacts to equitably distribute the right to water among affected states. The projected changes may also affect water temperature, water quantity and quality, and other environmental factors which influence the health of aquatic species. Furthermore, it is expected that groundwater pumping will be on the rise to balance surface water supply shortages, leading to lower groundwater levels, land subsidence and saltwater intrusion in coastal aquifers. In summary, the impacts from climate change may affect all aspects of water management (Brekke et al. 2009) and thus planning for water resources projects must include climate change when making and evaluating alternatives.

3.2. Challenges to Water Resources Planning Assumptions Resulting From Climate Change

The requirement in CMP 09-02 to include climate change in the without-plan future condition now requires study teams to decide how to develop assumptions for the baseline future without-plan future condition that appropriately characterizes future climate conditions and which are relevant to the decisions that must be made in the study.

More information and instructions on dealing with the challenges are provided in ***Section 4 and 5***. A series of questions and figures are introduced in these questions to help study teams better understand what specific steps to work through when needing to consider climate change. This includes determining the climate change factors and methods for analyzing climate change that are relevant to the study questions posed, identifying climate projections among the different sources available to choose from that provide reliable information relative to study questions, and determining the practical limitations of the level of analysis in a study (funding, staffing resources, etc.). Additionally, ***Appendix 1 - Supplemental Information*** introduces a selection of information resources available to planners and technical specialists for scoping and conducting climate change analyses. Technical synthesis reports described in Appendix 1 Supplemental Information include climate change planning and adaptation guidelines developed by other agencies, along with reports that provide information to help planners assess information relevance and reliability. ***Appendix 1 - Supplemental Information*** will be updated as new information becomes available

3.1.1. Study Framework

Figure 1 provides a graphical representation of a water resources study framework (Brekke et al. 2009) of a process that study teams could use to include climate change information in water resources planning studies. In Figure 1, the top panel (I) of the graphic illustrates different information and data sources study teams can use to characterize climate conditions (e.g., temperature and precipitation). Traditionally, instrumental records of observed or historical data have been used for this purpose because the prevailing assumption has been that past climate is representative of future climate (stationarity).

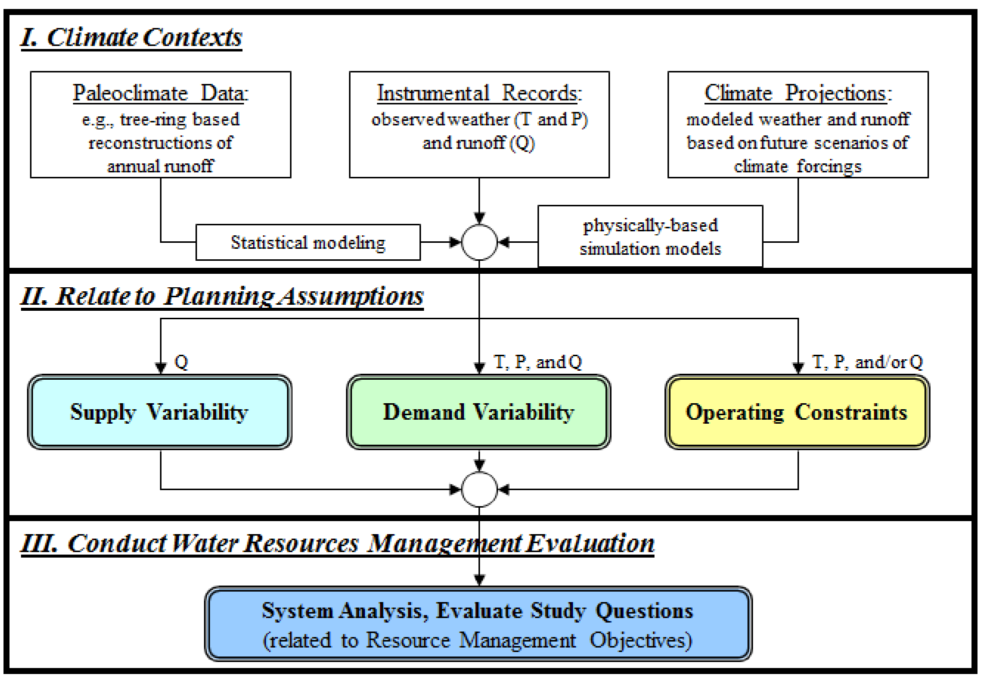

Figure 1. Water Resources and Environmental Planning Framework. Adapted from: Reclamation/USACE 2011.[7]

[7] Available at http://ccawwg.us/index.php/activities/addressing-climate-change-in-long-term-water-resources-planning-and-management.

3.1.2. Planning Assumptions and Evaluations

After study teams select a source for climate data to define the climate context for the study, study teams then establish planning assumptions for supply and demand variability as well as future conditions, as shown in the second panel (II) in Figure 1. This might include determining trends in:

- Available water supply
- Timing variability (e.g., floods and droughts)
- Demand variability (e.g., agricultural, M&I, urban, and environmental demands)
- Operational constraints (e.g., required reservoir flood storage allotments; reservoir release constraints designed to serve hydropower generation objectives or to serve instream flow requirements linked to environmental and navigation objectives, etc.)

The planning assumptions related to water supply, demand, and operational constraints are influenced by climate conditions and, in turn, will affect analysis of future performance of the proposed alternative or study conclusions.

The bottom panel of Figure 1 (III) brings together the information from the previous two panels to evaluate and compare the without-plan future conditions in conjunction with alternatives formulated through the study process. Observations from the historical instrument record will remain an information source used for the without-plan future assumptions, but these historical observations will no longer be the only source of information. Therefore, a key challenge to using climate change projections along with historical observations is deciding upon the scale and resolution of climate change data that is relevant for the study objectives.

As will be discussed in ***Section 6***, climate change data are available in a variety of spatial and temporal resolutions, not all of which may be appropriate for use in a study that is guiding decision making. So, study teams must consider the study goals and decisions that will be made as part of the study to know how best to select appropriate climate projection data that can be integrated with historical observations. The instructions and scoping questions posed in ***Sections 4 and 5*** are intended to assist study teams to address this challenge and to know how best to incorporate climate change projections and analysis information into the without-plan future conditions.

3.1.3. Uncertainty

While Reclamation has experience conducting feasibility studies and estimating future socio-economic conditions for planning purposes, climate change adds new considerations of complexity and uncertainty. The reason for this uncertainty is that traditionally the without-plan future condition has been based on the assumption that the future climate will be the same as the historical climate, otherwise referred to as stationarity. Within a stationarity paradigm, the accepted practice is to use one historically observed climate scenario such as the record drought as the basis for establishing a without-plan future condition. Using multiple potential future conditions to frame the without-plan future condition in a non-stationary paradigm is a relatively new consideration within water resources planning and management.

3.1.4. Modeling Needs

Another challenge of characterizing future system conditions under a changing climate is the potential need for additional modeling in the study that could involve modeling physical processes for hydrologic, environmental or operations simulation models. These types of models might not be needed if climate change were not included in the study. Therefore, including climate change may result in the need for more time to complete a study and in turn requiring more funding. For example, characterizing future water supplies based on projected climate change requires using hydrologic models. Hydrologic models generate stream flow at defined locations relevant to the study based on changes in the temperature and precipitation over the same study area. Estimating crop irrigation requirements under future climate conditions may also warrant the use of a crop consumptive use model that portrays biological and physical connections between crop growth, evapotranspiration and climate conditions. Such models would replace the use of information of historical water consumption as the only proxy for agricultural water demand.

4. DETERMINING THE LEVEL OF CLIMATE CHANGE ANALYSIS NEEDED FOR THE STUDY

Reclamation and DOI policies require considering the potential effects of climate change on all planning and operations. However, the level of climate change analysis will vary according to the purpose and scope of the implementation action. This section assists planners to determine the appropriate level of climate change analysis for their actions.

To support investment and operations decisions, feasibility and associated environmental compliance studies must produce accurate and relevant information for decision-makers, stakeholders, and the public. Often, this requires analyzing how well the proposed alternatives will meet the intended purposes under projected future conditions and the relative costs amongst alternatives. The projected future conditions are generally described by several components which include:

1) Water supply projections

2) Water demand projections

3) Reclamation facility capabilities

4) The planning time horizon being considered for the study

Water supply projections typically encompass hydrologic runoff quantities and the related climatic conditions that produce the runoff. Water demand projections provide information on the shifts in demands due to changes in population, land use, M&I, agricultural water demands, and environmental needs. The capabilities of Reclamation facilities includes the energy generation capacity at power plants, water conveyance and storage capacities, dam safety concerns, recreation, environmental benefits and other authorized uses that exist or could become a concern in the future. For each of these components, the projected changes would need to be considered in cost/benefit analyses associated with resources and services provided by the proposed alternatives.

This section takes study teams through the steps of considering how the factors mentioned above can be used to inform determination of the level of climate change analysis needed for the study. The determination should be arrived at early in the overall scoping process through discussions with technical staff, stakeholders and climate scientists to ensure that the relevant and important factors influencing cost and schedule are understood upfront. The information presented in this section is encapsulated in Figure 2,

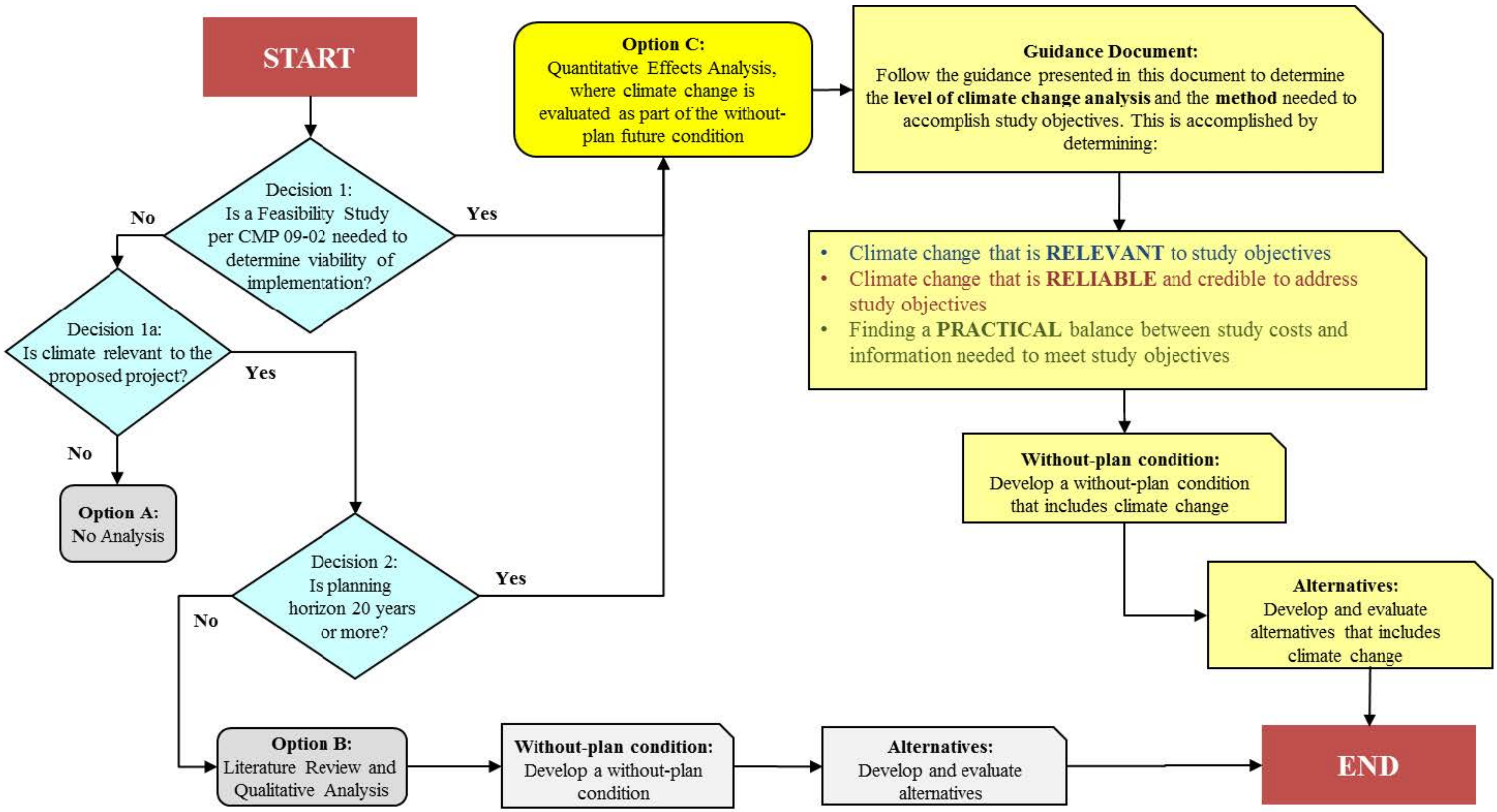

Figure 2. Decision-Tree Diagram: Level of Climate Change Analysis Options: This chart illustrates general guidance for considering whether and how to incorporate climate change information into project-specific planning.

Study teams can follow this flowchart to identify a level of climate change analysis that best characterizes the potential impacts of climate change on proposed actions and alternatives, including the without-plan future condition.

Scoping discussions, early in the planning process, on the level of climate change analysis are intended to focus study teams on specific details that need to be considered in the context of climate change in conjunction with the larger socio-economic and environmental issues that may be driving the study. ***Appendix 2 – Climate Change 101*** provides an introductory primer on climate change science. Detailed descriptions of the options, including advantages and disadvantages for each, are provided in the subsections below.

4.1. Option A - No Analysis

This option would be chosen for studies where potential climate change impacts are not relevant to the study or will not affect decisions based on the study. Study teams should document the justification for determining that climate is not relevant and the reasons why climate change analysis was not conducted. This option would apply only to a very small set of Reclamation's studies. Study teams should give careful consideration before selecting this option.

Advantages:

- No additional analysis needed, so the study can proceed using traditional study methods.

Disadvantages:

- Expectations of the interested or affected parties may not be met.
- Allows others outside of the study team to frame climate change discussion and analysis.
- Environmental compliance documents may require the study team to justify the decision not to address or analyze climate change.

4.2. Option B - Literature Review and Qualitative Analysis

Under this option, study teams summarize available climate change information for the study area, conduct a qualitative analysis for the action alternatives, and discuss how climate change could impact water supply, demand, and the environment. Study documentation should state that evaluation of the potential impacts of climate change was performed through a qualitative analysis and the justification for why a qualitative analysis was sufficient to meet study objectives.

Advantages:

- Allows the study team to frame climate change discussion/analysis.
- Qualitative analysis is relatively simple and cost-effective.
- If the proposed study lacks definitive or quantitative information on specific climate change impacts a qualitative analysis can still make use of the best available information for the proposed alternatives.

Disadvantages:

- May invite criticism from interested or potentially impacted parties for not doing a quantitative analysis.
- Uncertain threshold for if, or when, a quantitative analysis may be warranted over a qualitative analysis.

4.3. Option C - Quantitative Effects Analyses

Under this option, study teams incorporate climate change information quantitatively into the analytical framework, including hydrology and planning inputs that are consistent with a projected climate change scenario. Within Option C, study teams quantify effects of proposed alternatives with some degree of climate change embedded in the planning and analysis assumptions. The decisions resulting from this analysis would be based on the assumption that there would be future climate change.

Advantages:

- Allows the study team to frame climate change discussion/analysis.
- This option allows for the disclosure of potential climate change impacts on alternatives.
- Proactive effort to address climate change in a planning and environmental compliance context.

Disadvantages:

- Taking this approach for climate change analysis could affect studies in-progress.

- This option may pose the most decision-making risk of any option, because impacts and mitigation needs are based on an assumed future climate scenario. A more highly scrutinized process for establishing future climate assumptions is also expected if those assumptions are applied to disclosure of the effects of a proposed alternative rather than conducting a sensitivity analysis only.

- Planning and environmental documents could be complicated by the need to consider future climate assumptions as part of the effects analysis and impacts determination.

- More likely to disclose results that water users may consider to be unjustified conjectures, overly speculative, and/or counter to stakeholders' interests.

As shown in Figure 2, feasibility studies conducted per CMP 09-02 require Option C, Quantitative Effects Analysis. This level of analysis quantifies the effects of climate change on the proposed alternatives. In other words, climate change is embedded in the without-plan future and carried through into the formulation and evaluation of alternatives. Climate change effects on proposed alternatives are informed by projections of future climate conditions and/or paleoclimate records, rather than relying solely on consideration of historical climate conditions.

5. Establish a Foundation for Selecting a Climate Change Analysis Method and Scoping the Level of Quantitative Effects Analysis

Study teams must determine appropriate methods to characterize climate conditions for their study. Prior to CMP 09-02, studies were allowed to assume a historical climate in the without–plan future condition and alternatives analysis, and to complement that assumption with sensitivity analysis addressing climate change uncertainty. Since the release of CMP 09-02 in 2012, studies are now required to assume some amount of climate change in the without-plan future condition. Understanding that climate change information ranges from more to less certain and that the without-plan future assumptions directly frame decision-support, CMP 09-02 compels study teams to determine which portions of climate change information are:

1) Certain and relevant enough to be included in the without-plan future condition

2) Highly uncertain but still relevant and therefore worthy of exploring through sensitivity analysis

3) Irrelevant or too uncertain and therefore excluded from the study

This chapter helps study teams make that determination by addressing a series of scoping questions about decision relevance, information reliability, and analysis practicalities. Consistent use of these scoping questions across Reclamation will facilitate development of community approaches and facilitate review of final reports.

The rest of this guidance document provides detailed instructions for **Option C, Quantitative Effects Analysis.** The instructions are intended for all members of a study team to encourage team discussion about how uncertainty and the management of risks should be addressed as part of the study. The team should recognize that climate change is one source of uncertainty among the various sources that will need to be addressed within the study. When making choices regarding climate change analysis for a study it is important that all members of the study team including, planners, engineers, and environmental specialists have an understanding of the opportunities and constraints climate change presents to the study.

Incorporating Climate Change Information

This section helps study teams to select a **climate change method** for the study. A climate change method is the procedure used to characterize and evaluate future climate and hydrology conditions. There are typically two categories of methods for characterizing future climate and hydrology conditions that have been used in past studies:

- **Period-change methods** feature developing climate change scenarios that reflect what the impact of climate change would be between a historical reference time period and a future time period. This is accomplished by shifting the historical dataset to create a new dataset of the same length as the historical dataset. This new dataset reflects how the particular record (temperature and precipitation) would have appeared under future climate conditions. These climate change scenarios are used to generate new hydrology information and new system change scenarios using system operations models.[8]

- **Transient methods** do not use climate change scenarios using historical data. Instead, they are used to develop climate, hydrology, and system projections that use the future projections generated from global climate models (GCM), which are a continuous dataset from present-day out through the study's planning time horizon. Transient projections represent evolving climate conditions through time from present-day conditions through the 21st century. To capture an appropriate range of future climate uncertainty, transient method studies tend to feature a large number of transient projections to adequately characterize the possible range of future hydrology and system conditions at any stage in time during a planning horizon.

Under **Option C, Quantitative Effects Analysis**, study teams can use a wide range of methods for evaluating climate change impacts. Guidance in this document is focused on the above two methods since they are commonly used in climate change studies. Given the fast pace of advances in climate science, it may not be possible to keep this document up-to-date with the best practices available for each study type and objective. If other methods are known to the study team and are better suited to study objectives, the study team is encouraged to consider those methods and apply the questions presented in this section to analysis choices for in those methods as well.

This section of the guidance leads study teams through a series of questions to select one of the two climate change methods for carrying out the **Quantitative Effects Analysis.**

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[8] Stated differently, the climate change and hydrology change scenarios are correlated and extrapolated to the historical records to produce future scenarios that feature trusted information from the past historical climate variability together with a comparison of information from climate projections judged to be reliable.

Additionally, the questions will help study teams determine whether to use existing hydrologic data or develop new hydrologic data. ***Section 6*** goes into more detail on the different climate change methods and guides study teams on selecting one of the methods based on answering questions posed in this section (***Section 5***).

When selecting a method, consider three questions:

1) **What's relevant?** Understand how climate change uncertainties can affect an alternative, what metrics relevant to the alternative are of interest from a climate change perspective, and how climate could affect these metrics. This is considered "information relevance (***Section 5.1***)."

2) **What's reliable?** Understand what climate and hydrology datasets (hydro- climate) are available, which ones are good for a particular study area and objectives, and what future hydro-climate assumptions should be based on historical data rather than climate change projections. This is considered "information reliability (***Section 5.***2)."

3) **What's practical?** Decide on the practicality of investing the funds, time and resources needed for modeling and analysis of the metrics from the answers to the above questions balanced against the relative value provided back to the study to address study objectives. This consideration is called "study practicalities (***Section 5.3***)."

For each primary consideration, three additional questions were developed as shown in Figure 3, for a total of nine questions for study teams to address and document. Study teams are encouraged to document their answers to the question. Documenting answers will also benefit the study process by explaining the rationale behind choices and decisions made by the study team when responses to these questions are used to select a climate change method in ***Section 6.***

By addressing these questions, study teams can develop a scope of work for the study that represents approaches being used elsewhere in water resources planning studies, but gives the study team flexibility in meeting the needs of non-Federal partners. To accomplish this, the questions have been framed to encourage study teams to reach out to experts within Reclamation and other Federal agencies, as well as experts from state, local, and academic institutions that can provide assistance and input when preparing responses to questions. The questions also provide a basis from which study teams can approach the evaluation of alternatives. Using relevant climate change information, the strengths and weaknesses of each alternative can be appropriately measured relative to the without-plan future condition.

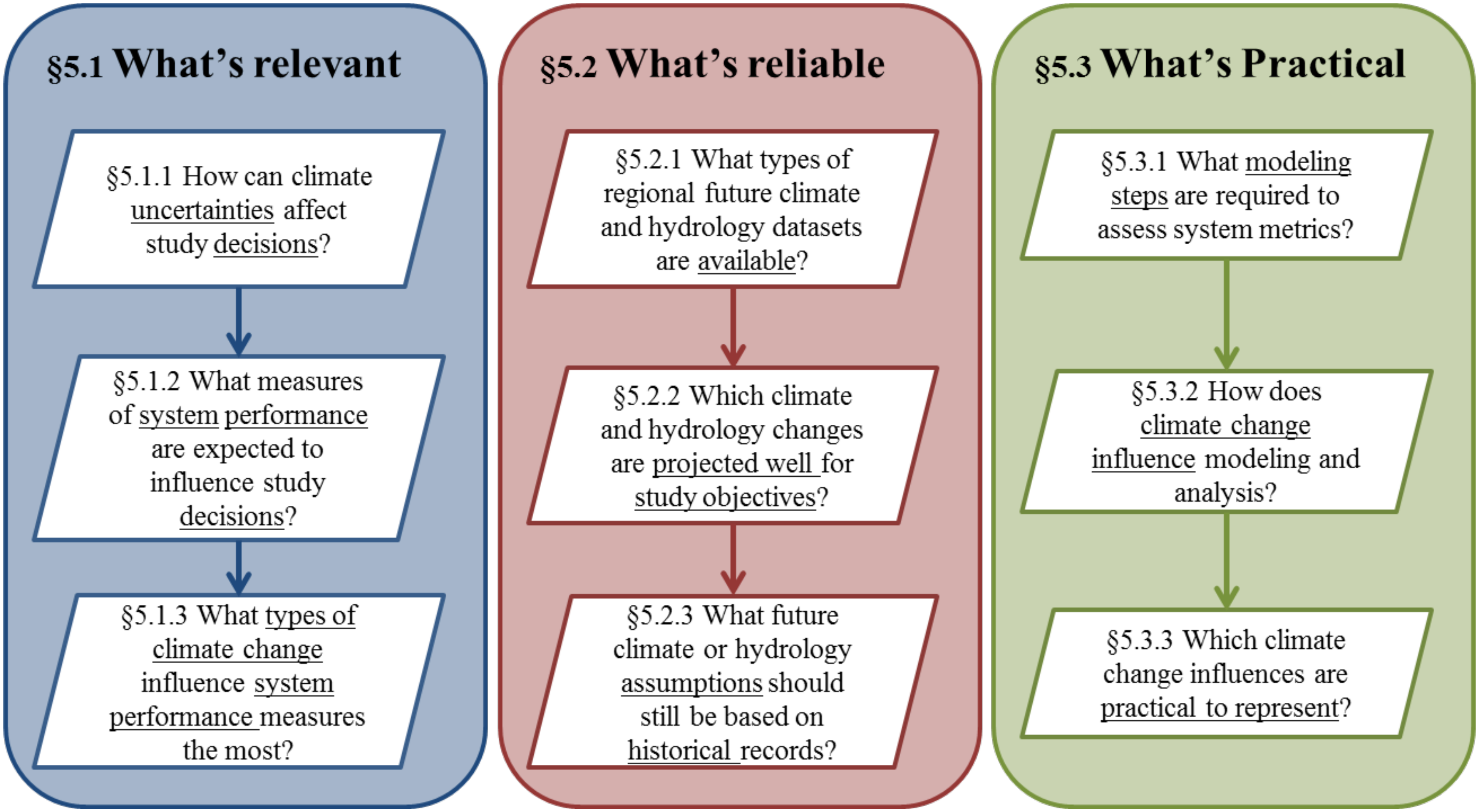

Figure 3. Questions to address during the scoping process.

5.1. Determine What's Relevant

The climate change factors that have significant impact and are most relevant to study objectives and associated decisions will determine which methods discussed in ***Section 6*** for analyzing climate change are suitable for the study. Climate change factors include both the causes and effects of climate change, including greenhouse gas emissions, increased temperature, changes in precipitation patterns, decreased snowpack accumulation, and altered stream flow. To determine the relevance of these climate change factors, models must incorporate the associated spatial resolution and time intervals of available data. For example, is the study more sensitive to coarse types of climate change (e.g., regional change in mean-annual climate) or is the study more sensitive to assumptions at finer resolution of space and time (e.g., changes in seasonal, monthly or daily climate variability over small watersheds)?

Climate change factors include both the causes and effects of climate change. Consider:

- **Greenhouse gas emissions**
- **Increased temperature**
- **Changes in precipitation patterns**
- **Decreased snowpack accumulation**
- **Altered stream flows**

The focus on this consideration should not be on whether the future climate information is credible or reliable. Rather, the focus should be on determining how climate change will be relevant to the study results. To answer questions from this section, study teams may benefit from referencing information generated in vulnerability assessments, such as WWCRA Impact Assessments, Basin Studies, the National Climate Assessment, or other studies previously conducted by States or irrigation districts in the study area. Specific questions to address are:

- How can climate uncertainties affect study decisions? ***Section 5.1.1***
- What measures of system performance (system metrics)[9] are expected to influence study decisions? ***Section 5.1.2***.
- What types of climate change impacts influence these system metrics the most? ***Section 5.1.3***

[9] A system metric is generally the combination of a physical or environmental condition (e.g., streamflow) within the study domain and a statistic describing that condition (e.g., average monthly flow) or a relevant threshold that is important to a decision.

5.1.1. How Can Climate Uncertainties Affect Decisions Targeted by the Study?

The influence of climate change on local weather and hydrology is assumed to increase over time, resulting in a range of conditions not seen in the historical record. Consequently, study teams must develop an understanding of how climate relates to the problems, needs, and opportunities surrounding the decisions targeted by the study.

It is important to consider how climate change might influence investment decisions.[10] The nature of the investment will vary for each study. Therefore, when responding to this question, study teams should focus on the problems, needs, and opportunities the study intends to address.

Examples of the types of investments affected by climate change include: proposed construction of new water storage or conveyance facilities, adoption of new long-term reservoir operating criteria, and/or development of system features that support long-term river restoration and species recovery efforts.

This section of the guidance assumes that the study is addressing long-term investment decisions (i.e., the proposed project will typically have a service life of 20 years or more) and that climate change factors such as change in temperature, precipitation, snowpack, streamflow, evapotranspiration, and soil moisture will be relevant.

Responses to the question, "How can climate uncertainties affect decisions about the problems, needs, and opportunities to be addressed in the study?" should describe:

- The expected period of significant impact resulting from climate change on proposed alternatives. The period of significant impact will be determined by how far into the future the study team expects this action to affect water management. The team should also consider opportunities to make adjustments for adaptation to potential climate change impacts.

- Geography (e.g., where is this investment located? What are the influential or affected watersheds and other natural systems? What are the influential or potentially impacted systems?)

[10] Investments include any activity that uses federally appropriated funding including federally owned but independently operated facilities.

To assist in answering these questions, study teams may want to consider key climate-related uncertainties that need to be considered and quantified. Climate uncertainties can stem from factors (e.g., the choice of future emission scenarios used to produce climate projections) and analytical methods (e.g., the choice of downscaling method or hydrologic model used to generate climate change projections or streamflows, respectively). This part of the response to the questions should be developed with thought toward how study teams will approach answering questions in ***Section 5.3***, which addresses study practicalities, analyses tailored to specific resource areas of interest, and how climate change information affects those analyses.

5.1.2. What Measures of System Performance Are Expected to Influence Study Decisions?

Decisions made as part of a study will be based on evaluations and comparisons of how well the action alternatives meet management objectives for the system, using a menu of analyzed performance measures. Before connecting climate change to the study, study teams need to define relationships between the targeted decision, performance measures that relate to that decision, and climate conditions that relate to those performance measures.

Many potential metrics can be used to assess the impacts of climate change; therefore, selection of appropriate metrics is an important part of the overall study process when climate change is considered. Study teams should focus on the natural or social system metrics that are expected to drive analysis and assessments in the study and be most important when characterizing the problems and opportunities for the study area. A metric is generally the combination of a physical or environmental condition within the study area and a statistic describing that condition.

Useful metrics will be able to indicate when a system is likely to fail (i.e., when the desired performance of a system has crossed a threshold to an undesirable state). A list of useful system metrics may not be obvious at the beginning of the study. In particular, useful metrics will need to be carefully considered in studies where climate change information generates new data which differ from what users are familiar with from historical observations. This change could be seen in various parameters covering climate data such as temperature and precipitation, streamflow extremes, or changes to physical processes such as shifts in timing of runoff, and warmer water temperatures. If a study team realizes that climate change may result in such changes to what has become familiar, new metrics that have not previously been used in a previous study may need to be established.

For example, in a feasibility study, the economic analyses might be informed by various river system conditions such as water delivery reliability or frequency of meeting environmental flow targets. Relevant metrics from a climate change perspective could include statistical conditions such as long-term mean annual or mean-monthly conditions. Reporting climate change impacts in environmental compliance analyses might focus on the condition of various resources such as habitat, water quality, or cultural resources, along with the associated statistics and thresholds.

5.1.3. What Types of Climate Change Impact System Performance Measures the Most?

Study teams will need to cross-walk system performance measures relevant to the decision (***Section 5.1.2***) with climate conditions that might affect the proposed investment (***Section 5.1.1***), and judge what types of climate changes would seem to impact system performance the most.

Study teams will need to develop an understanding for how climate interacts with key metrics, identified in ***Section 5.1.2.*** For example, if a relevant metric quantifies the mean-annual regional water supply, then a reasonable assumption is that this metric depends on estimates of the mean-annual to mean-monthly climate and hydrology occurring over the large basin or regional area where the water supply originates. Another metric might involve the mean-monthly riparian habitat conditions during spring for a given river reach (e.g., the floodplain area of inundated by snowmelt runoff during a critical period). In this case, estimates of the mean monthly climate and hydrology over the small basin tributaries to the river reach would likely provide data that are more representative of actual conditions than estimates based on climate conditions for the entire river basin.

Identifying how climate and hydrology conditions relates to a system metric may be challenging enough by itself, but when combined with the fact that climate and hydrology data are available in different spatial and temporal resolutions, the challenge is greater. For instance, coarse estimates of the regional mean-annual or mean-monthly variables might be suitable for large geographic extents, but not for smaller areas where finer resolution data are necessary to describe sub- monthly conditions.

Where possible, study teams should consider results from climate sensitivity studies to make such judgments.[11] Sensitivity studies evaluate system metrics under different types of climate change to improve understanding of the variables and scales that are most significant. Sensitivity studies may not be present in every region or watershed, so study teams are encouraged to reach out to climate science experts, academic institutions or other resources provided in ***Appendix 1 - Supplemental Information*** to determine if this information is already available or if there is a need to include this work in the scope of the study. If new metrics are

[11] ***Appendix 1 - Supplemental Information*** provides references and sources of information study teams can use to locate sensitivity studies that may have been conducted in their region/study area.

developed, study teams may need to develop new hydrologic projections so that the hydrologic modeling properly captures physical processes needed to evaluate whether the new metrics are crossing key thresholds and in turn may inform decision-making processes.

5.2. Determine What's Reliable

Many sources of climate change information can inform feasibility studies. It is important that study teams use due diligence in surveying available information and make judgments about what information source is reliable in supporting the without-plan future condition. Study teams will benefit by narrowing the range of possible climate change information sources based on relevant climate change projections using responses to questions in ***Section 5.1*** and information provided in ***Appendix 1 - Supplemental Information.***

Use due diligence in surveying available information and make judgments about what information source is reliable.

Specific questions to address under this topic are:

- What types of regional future climate and hydrologic datasets are currently available? ***Section 5.2.1***
- Which climate and hydrologic changes are projected well and are considered reliable? ***Section 5.2.2***
- What future climate and hydrologic assumptions should remain based on historical observations? ***Section 5.2.3***

The reliability of available data and models will determine whether the projected information of climate and hydrology is developed using:

1) Climate models
2) Historical information
3) A mixture of both as appropriate

Addressing and documenting this step will demonstrate due diligence needed to indicate a full survey of available information was completed.

5.2.1 What Types of Regional Future Climate and Hydrology Datasets Are Available?

Study teams must first access and understand available information resources containing climate and hydrologic projections to support subsequent evaluation on the reliability of this information for their study. In this step, the study team should limit focus to most relevant types of climate changes (***Section 5.1.3***) and assess strengths and weaknesses of each information resource.

There are generally two categories of available climate projection resources:

1) **Only projected climate,** which includes projections of temperature, precipitation, and other climate variables for use in a study. Projected climate datasets are generally in the form of grids of various sizes across the United States. If the study team selects datasets that only have climate projections, then those climate projections will have to be input into a hydrologic model to generate stream flow at locations of interest. This additional step involves additional resources (e.g., time in a project, staffing, and funding) but permits hydrologic analyses tailored to the study. The benefit of this approach is that streamflow can be generated at specific locations in a basin relevant to a particular study.

2) **Both projected climate and hydrology**, which adds surface water flow at specific locations in a basin to the available climate variables for use in a study. Study teams select not only climate projections but also streamflow projections that have already been generated meaning no additional hydrologic modeling is necessary. The drawback may be that the streamflows might not be at locations of interest relevant to the study, but study teams consider the data sufficient for the analysis. Figure 4 illustrates the basic steps involved in using both climate and hydrology projections to support water resources planning studies.

Projected climate and hydrology information originates from global climate projections that are managed by the World Climate Research Programme (WCRP) through the Coupled Model Inter- comparison Project (CMIP) at the grid resolution (e.g., around 200 kilometers) of the Global Climate Models (GCM). The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (IPCC 2007) used CMIP Phase 3 (CMIP3) projection datasets. Many vulnerability assessments, including several conducted through Reclamation's WaterSMART Basin Study Program, were completed using the CMIP3 datasets.

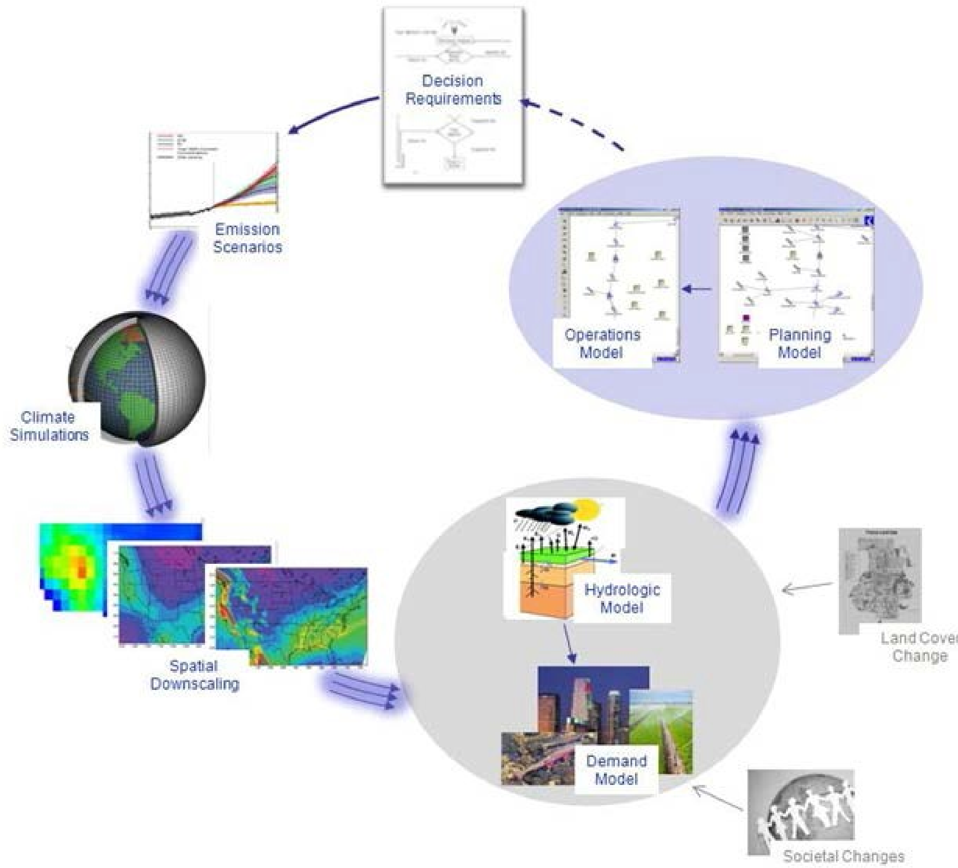

Figure 4. Modeling and analytical steps involved in the development of local hydrologic projections for use in water resources planning studies.

After the release of the IPCC Fourth Assessment, WCRP initiated CMIP Phase 5 (CMIP5), this time numbered "5" to coincide with the IPCC Fifth Assessment Report (AR5). WCRP has now released CMIP5 data sets to the public and the data are being used by the communities of researchers addressing climate change impacts, adaptations, and vulnerabilities. Study teams should consider using climate projections from both, phases of CMIP projection datasets after the projections have been bias-corrected and downscaled to a finer grid resolution over the study area of interest.

Guidance on projection selection is currently being developed by the WWCRA Implementation Team and Science and Technology Program (S&T) funded research projects. Further discussion in ***Appendix 2 – Climate Change 101*** explains differences between the two phases of CMIP projections.

The Reclamation and Collaborators' Archive for Non-Dynamically Downscaled Climate and Hydrology Projections

The Bias Corrected and Downscaled WCRP CMIP3/CMIP5 Projections archive can be accessed at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html. Reclamation has worked with others to support this archive since 2007.

Other candidate resources are listed in ***Appendix 1 - Supplemental Information.***

Study teams may need to analyze hydrologic processes that are not well-represented in the results of readily available hydrologic models. For example, in the Reclamation and Collaborators' archive, a surface water hydrology model, the Variable Infiltration Capacity (VIC) model, was used to develop hydrologic projections. This model has been widely used by researchers to characterize impacts to water supply and has done a fairly good job in basins that are primarily surface water dominant. For basins where groundwater or groundwater interactions with surface water are important to characterize impacts to water supply, other hydrologic models may do a better job of projecting climate change impacts. Study teams might also consider whether the hydrologic model is designed to provide more reliable streamflow projections at locations on the mainstem of large river systems such as the Columbia or Colorado Rivers and thus may generate less reliable flow projections on smaller tributaries to those systems which may be the focus of the proposed alternatives.

Further, climate projections are generated using different assumptions, approximation methods, spatial and temporal scales, and modeling techniques. Different choices of emissions scenarios, models of ocean and atmospheric circulation, and downscaling methods are a few of the factors that bring about a wide range of available climate projections. Ideally, study teams should strive to represent the breadth of available climate projections.

Study teams are encouraged to consider whether access to future climate and hydrology datasets featured in other peer-reviewed information for the study area is available. For example, there may be recently conducted vulnerability assessments for the study area where future climate projections have been translated into future hydrology datasets. If so, then study teams may wish to consider using the same future climate and hydrology datasets, or at least consider using these completed datasets as starting points for a new study. As study teams explore the variety of available climate information, they should consider:

> **One method of downscaling is not inherently more reliable than the other.**

- **Whether the resource features downscaled climate projections developed using non- dynamical or dynamical downscaling techniques?**

    - **Non-dynamical downscaling methods** (e.g., statistical), means that the statistical patterns of climate variables are determined at the large global spatial and temporal scales and are assumed to be the same at the smaller scales. This approach was used in the Reclamation and Collaborators' Archive to estimate future surface temperature and precipitation conditions only.

      Non-dynamical techniques permit building datasets with large numbers of projections representing a wide range of variability because such techniques are computationally less expensive than dynamical downscaling. However, non-dynamical downscaling assumptions simplify statistical relationships between atmospheric conditions over a large area and local surface climate. The primary limitation of non-dynamically downscaled projections is the underlying assumption of stationarity between the large and small scales.

    - **Dynamical downscaling** involves simulating a three-dimensional and multivariate atmospheric response to global climate change. In other words, a regional climate model is nested inside the larger, global climate model so that the results are more applicable at a local planning scale. This type of downscaling is very computationally intensive and is not very wide-spread yet.

      Dynamical downscaling techniques do not make assumptions about stationarity. Rather, they use a physical based atmospheric model, not unlike a global climate model, but running at finer spatial resolution (e.g., 12 to 50 kilometer [km] grids), to connect large-scale atmospheric conditions to local weather. However, the computational requirements are quite extensive. As a result, not many datasets are available to study teams from existing sources. Costs would be quite high for study teams to generate their own dynamically downscaled data. To assess reliability of either downscaling method or others that the climate science community may develop in the future, study teams are encouraged to work with climate science experts either within Reclamation or at other institutions to better understand which method supports study objectives and key metrics identified in ***Section 5.1.2***. Study objectives and key metrics provide important reference points from which to evaluate the reliability of downscaling methods for the particular study.

- ***How many downscaled WCRP CMIP3 and CMIP5 global climate projections underpin the information for each resource?*** The Reclamation and Collaborator's archive includes 112 CMIP3 projections and more than 200 CMIP5 projections developed using a non-dynamical downscaling approach. Alternatively, the dynamically downscaled North American Regional Climate Change Assessment Program (NARCCAP) resource consists of four high resolution Regional Climate Models based on CMIP3 projections.

- ***What future period is covered by the resource?*** Study teams should consider the future periods that are relevant to the study and assess whether the available information covers periods of interest. For example, if a Biological Assessment has a future period of interest through 2035, the climate projections that are relevant to that time frame can be selected. The Reclamation and Collaborators' archive features CMIP3 and CMIP5 climate simulations that are continuous from 1950 to the end of the 21st century. The NARCCAP archive features CMIP3 projections that are developed for two periods: 1971 through 2000 and 2041 through 2070 which allows for a relative change analysis between two time periods.

- ***Does the resource report all relevant climate variables?*** Many resources are available for studies that are driven by future assumptions of precipitation, air temperature, and runoff. However, some studies may require other projected atmospheric conditions such as humidity and carbon dioxide concentrations relevant to crop water use, or meteorological conditions affecting plant growth and water use. In these cases, study teams should survey information resources that directly report these variables of interest or consider how these variables might be estimated from more conventional resources featuring only precipitation and temperature. For example, the NARCCAP archive and other dynamically downscaled information resources report on more atmospheric variables than the Reclamation and Collaborators' archive.

- ***Which set of projections best suits this project?*** The Reclamation and Collaborators' archive permits exploration of a suite of climate projections (CMIP3 and CMIP5), and the degree to which future projections over the study area will differ when driven by CMIP3 or CMIP5. The research community has not issued guidance on whether CMIP5 should be used in place of CMIP3, or whether both should be blended. Therefore, at the time of this writing, study teams must evaluate and select the CMIP version(s) most appropriate for the study requirements. Study teams should work with stakeholders to decide whether to use CMIP3, CMIP5, or a blend of information from both, based on study-specific requirements. A rationale for using CMIP3 is that CMIP5 global climate projections and the corresponding downscaled counterpart portray differences from CMIP3 information; and, these differences have not been fully evaluated as of early 2014.

Rationales for using CMIP5 may stem from:

1) CMIP5 is informed by a new composition of climate models reflecting recent climate science advancements since CMIP3

2) CMIP5 climate projections are forced by updated future emissions and climate forcing scenarios (i.e., Representative Concentration Pathways (RCP)[12] that replace the Special Report on Emission Scenarios or SRES[13] pathways used as inputs to GCMs that in turn generated the CMIP3 projections)

5.2.2. Which Climate and Hydrology Changes are Considered Reliable for Study Objectives?

Study teams must determine what projection information from ***Section 5.2.1*** is:

- Good enough to be included in the without-plan future condition or

- Highly uncertain but still relevant enough to be considered in complementary sensitivity analysis

This determination should be made in collaboration with climate and hydrology scientists, planning partners, technical team members, and potentially interested stakeholders.

Study teams will be challenged with questions of how well the climate projections reproduce observed records of temperature and precipitation. To address this

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[12] **Representative Concentration Pathways** (RCP): RCPs are sets of emission projections of only radiative forcing and are used as input to GCMs. They are not complete packages of socio-economic, emissions, and technologic advances as the SRESs are. Assumptions about these other advances are incorporated into GCM modeling separately, which allows for more interaction among the variables that could affect future climate (http://www.wmo.int/pages/themes/climate/emission_scenarios.php).

[13] **Special Report on Emission Scenarios** (SRES): SRESs are “storylines” of assumed volumes of future greenhouse gas emission rates along with assumptions about future socio-economic and technological advances in our society. These emission forcings were developed in 2000 and have been replaced by RCPs in the AR5 (http://www.wmo.int/pages/themes/climate/emission_scenarios.php).

question, study teams should work with internal and external climate science experts to evaluate the climate conditions that GCMs and downscaling techniques represent well, and the conditions that the GCMs do not represent well. This amounts to a judgment of the reliability and credibility of the projected information when applied to the study area of interest.

In the context of this guidance, use of the term “well” poses a challenge to study teams as no current standard in the climate science community defines how well climate change conditions represent potential future scenarios. Determining what is well-represented is typically based on comparing the climate models’ historical simulation results with observations. Study teams should reconcile their judgment of the representativeness of available climate models to the study area with evaluations conducted by researchers in the past to assess model reliability. Most past evaluations were intended to identify a set of climate models that could better inform future assumptions of climate uncertainty at a given spatial and temporal scale. Climate scientists deemed climate models that did a better job of reproducing historical climate conditions to be more reliable. Regardless of whether study teams choose to use a subset of “best” climate models or consider information from all climate models available, ultimately, study teams must judge which model outputs are sufficient to represent future assumptions in support of key study decisions and meet peer review requirements.

Climate science experts may offer diverse views on the issue of model reliability. Study teams are encouraged to document any diverse views encountered, presenting a preferred consensus judgment on which climate aspects are reliable and sufficient in the support of future without- plan future assumptions. Climate science experts supporting study teams will weigh the significance of any bias-correction that was applied to the climate simulations prior to comparisons, or any bias-correction that could be applied after comparisons.

5.2.3. What Future Climate or Hydrology Assumptions Should Still Be Based on Historical Records?

Future climate and hydrology assumptions will be based on a combination of future projections and historical information. This section asks the corollary to ***Section 5.2.2*** – what portion of future climate and hydrology projection variability is too uncertain to be included in the without-plan future condition and therefore should be informed by historical information, including observations and potentially paleoclimate proxies (e.g., tree ring analyses)?

Incorporating climate information into a study may not always require using GCM based climate projections to characterize future climate or hydrology assumptions. Using historical data, either through observed instrumental records or through paleoclimate proxies (e.g., tree ring analyses) for climate change, may be required in order to support the study. Climate projections that are based on climate models may not provide the necessary reliability at all of the spatial and temporal scales needed for a study. For example, a study team may determine that climate models sufficient reproduce changes in monthly variability of precipitation and temperature, but not changes in sub-monthly time-steps (e.g., hours to days). In such a case, the study team may determine that a variety of time-steps is necessary for definition of the future climate conditions. As a result, the study team may select climate data from a blend of historical and projected climate resources for assurance that an adequate evaluation of climate change impacts across all needed time intervals is substantiated.

Historical climate information may originate from observations during the period of instrument records (e.g., weather and streamgage stations and snow course records) or from proxies of climate conditions prior to instrument records (i.e., paleoclimate approximations). See ***Appendix 1 - Supplemental Information*** for information on paleoclimate proxy resources and the blending of instrument records and paleoclimate proxies.

5.3. Determine What's Practical

The state of available data and models will shape the approach study teams use to integrate climate change information into the study.

Study practicalities often limit the level of analysis that can be performed. Such practicalities include:

- The types of analyses that must be applied to specific resource and study areas[14]
- How climate change information interfaces with each analysis
- The utility and applicability of simulation models used to assess the resource or study area
- The choice of software suited to making the interface between the data and modeling platforms

Climate data and models will be used in conjunction with other resource models and sources of data to assess the impact of climate change on resource conditions. Consequently, the state of available data and models will shape the approach study teams use to integrate climate change information into the study. Three questions will help study teams determine what climate information should be integrated based on practicality:

[14] For example, the various resource areas evaluated in an Environmental Impact Statement under NEPA.

- What modeling steps are required to assess system metrics? ***Section 5.3.1***
- How does climate change influence modeling and analysis? ***Section 5.3.2***
- Which climate change influences are practical to represent? ***Section 5.3.3***

5.3.1. What Modeling Steps Are Required to Assess System Metrics?

Focusing on the relevant system performance measures (***Section 5.1.3***), study teams should identify the analytical methods (e.g., analysis steps, models, and datasets) and project resources (e.g., team expertise, costs, and schedules) that are necessary to support evaluations of the without-plan future condition and action alternatives. Study teams should consider the system metrics that are relevant to key study decisions and found to be potentially sensitive to climate change (as discussed in ***Sections 5.1.2 and 5.1.3***).

Study teams should compile an inventory of analyses specific to resources of interest in the study that are necessary to assess conditions using appropriate system metrics. For example:

- For a proposed water storage investigation, the chain of analyses affected by future climate might involve watershed hydrology, consumptive uses, reservoir operations, and various societal and natural resource conditions affected by reservoir operations
- For reservoir operations, climate might affect operational constraints such as the storage reserved for flood control and risk reduction or the reservoir release targets supporting minimum instream flow objectives

By considering the modeling and analysis requirements for the study, an evaluation of how climate change analysis will impact the level of effort for the study which in turn will impact cost and schedule can be incorporated in the study. Based on this evaluation, study teams can determine if the limitations of study practicalities require additional constraints or alternative steps are required to meet study objectives.

5.3.2. How Does Climate Change Influence Modeling and Analysis?

Study teams should next compare responses to ***Section 5.2.2***—the projected climate changes that were deemed relevant and reliable enough to include in the without-plan future condition and the projected changes that were deemed relevant but highly uncertain and therefore worthy of evaluation through sensitivity analysis. Consider the level of effort required to integrate climate change into the analytical methods (e.g., adjusting modeling inputs to account for climate change or switching to different models that are more compatible for changing climate conditions), and the study team's ability to implement that integration to produce meaningful decision-support information.

Study teams should consider direct climate connections that may occur at any step in the modeling and analysis process when responding to this question. Consider each resource-specific analysis from ***Section 5.3.1*** and identify inputs influenced by climate assumptions (e.g., changes in precipitation, temperature, runoff). Climate change information may directly connect with several "front-end" analyses such as watershed hydrology and water demands, which affect subsequent analyses. Using the reservoir example introduced in ***Section 5.3.1***, the supply and demand assumptions used to create future without plan scenarios and then applied to reservoir operations shape the analysis of resources that are affected by the reservoir operations. Steps in the middle of the overall modeling and analysis process (e.g., river and reservoir temperature analyses driven by storage and release conditions as well as air and inflow temperatures) may also include inputs influenced by climate change.

5.3.3. Which Climate Change Influences Are Practical to Represent?

Available project resources (e.g., staff expertise, budget, and schedule) and ability to accommodate climate change considerations within those resource constraints should be considered when choosing an analytical approach and associated quantitative method (***Section 6***).

In responding to this question, study teams should explain the model and tool requirements and limitations that influence a chosen approach for using climate change information. Study teams might describe how the number of future climate scenarios considered will affect the level of effort required to adequately analyze the resource areas of interest.

Discussion might draw attention to resource areas where representing climate change is most critical or a strategy for using a few future climate scenarios to represent a range of possibilities. If decisions are made to focus on a few resource areas, then the discussion should identify potential limitations and uncertainties introduced by not integrating the climate change information in the analysis of other resource areas. Best available models for evaluating resources may have limited compatibility with climate change inputs, or there may not be consensus within the study team on the “best available method” for using climate change information in a particular resource analysis. In either case, study teams must decide how to apply project resources to developing compatible models or an acceptable procedure for incorporating climate change information, including opportunities to leverage tools, data, and results from other studies.

6. Selecting a Quantitative Effects Analysis Method

Responses to scoping questions in ***Section 5*** will help study teams determine what climate change information to include in the without-plan future condition and potentially what to include in complementary sensitivity analysis. A quantitative approach will be required to accomplish these analyses. This section describes several suitable techniques, collectively representing approaches that have been used in various types of Reclamation planning studies since 2008.

As study teams decide on what climate change information is relevant and reliable to be featured in the without-plan future assumptions (and implicitly what other climate change information is too uncertain for that use, but still relevant enough to be featured in sensitivity analysis) they will also need to identify a quantitative method that will support climate change analysis in both the without-plan future condition and in the sensitivity analyses (if the latter are included). Selecting a quantitative method can be affected by any of the responses in ***Section 5***. In addition, it can be affected by two other dimensions of consideration: whether study teams:

1) Wish to portray analyses under “stationary climate” (present-day or future) versus gradually changing climate (from present-day to future)

2) Feel compelled to conduct watershed hydrology modeling tailored for their study needs versus leveraging pre-existing hydrologic modeling under climate change that is applicable to their study needs

Several quantitative approaches have been featured in Reclamation planning studies. This chapter provides information about quantitative methods that might be used to address these two dimensions, with the goal to help study teams decide on an appropriate quantitative method for their study.

On dimension (1) above, two types of methods have been used in Reclamation: **period-change methods** that support “stationary” studies, and **transient methods** that support gradual-change studies. Selecting a method may be informed by scoping discussions surrounding decision relevance (***Section 5.1***) and analysis practicalities (***Section 5.3***).

- **What’s relevant?** Study teams might ask whether the study is intended to inform decisions about adaptive management strategies which will result in future investments that may occur in increments over the planning horizon. If yes, this would invite choosing a transient approach. Or is the study intended to inform system evaluations (e.g., the results from an ESA biological assessment or effects disclosure from a NEPA environmental impact statement) during a target future period relative to a reference historical period, but not for the years between the historical and future periods? If yes, then this may invite choosing a period-change approach (although a transient approach may be used and support such period-to-period evaluation of results).

- **What's practical?** Study teams might ask whether one method is more compatible with the way study participants and audiences are accustomed to viewing future system conditions as portrayed. If yes, then the simplest method may be to adopt the more compatible method. For example, in the Colorado River basin, long-term planning has involved developing system projections that evolved from initial conditions dominated by reservoir storage in Lake Mead and Lake Powell. The transient method is particularly compatible with this situation. In other basins, long-term planning is commonly based on the "stationary system" paradigm (Milly et al. 2008) where the past is considered representative of the future; therefore, historical climate and hydrology records are viewed as providing a sufficient basis for assumed future climate and hydrology conditions. In these cases, the period-change method requires relatively smaller adjustments to the mechanics of developing study information and therefore may be preferable over the transient method.

On dimension (2) above, study teams may have access to information describing hydrologic conditions under climate change, which are important for analyzing future water supplies and may be relevant for making future assumptions on water demands and other water management criteria. Alternatively, study teams may be concerned about the approach and assumptions that underpin those information resources (e.g., perhaps the resources do a good job describing surface water conditions but poorly describe groundwater conditions that are relevant to the study). Preference between leveraging an available information resource versus developing a new one may be informed by scoping discussions surrounding information reliability (***Section 5.2***) and analysis practicalities (***Section 5.3***).

- **On reliability,** teams can identify hydrologic projection information that's available (e.g., projections of future runoff, evaporation, evapotranspiration) and work with scoping team members to determine its efficacy, limitations, and resultant suitability for their study purposes.

- **On practicality,** teams can consider the level of effort required to generate a new hydrologic information resource under climate change, the marginal information quality they expect to gain from that effort, and ultimately decide whether that effort is worthwhile for the study.

This combination of the above considerations leads to four possible method categories:

1) Period Change Climate, Develop Hydrology

2) Period Change Climate, Use Available Hydrology

3) Transient Climate, Develop Hydrology

4) Transient Climate, Use Available Hydrology

These methods are labeled (C.1) through (C.4) in Figure 5 (the letter C before a method corresponds to Option C from Figure 2). This chart summarizes additional questions and how information relevance, information reliability, and study practicalities influence method selection. Details on each of the four methods follow. The next subsections explain these methods in more detail, with a summarizing table of the advantages and disadvantages of each method in one comprehensive view.

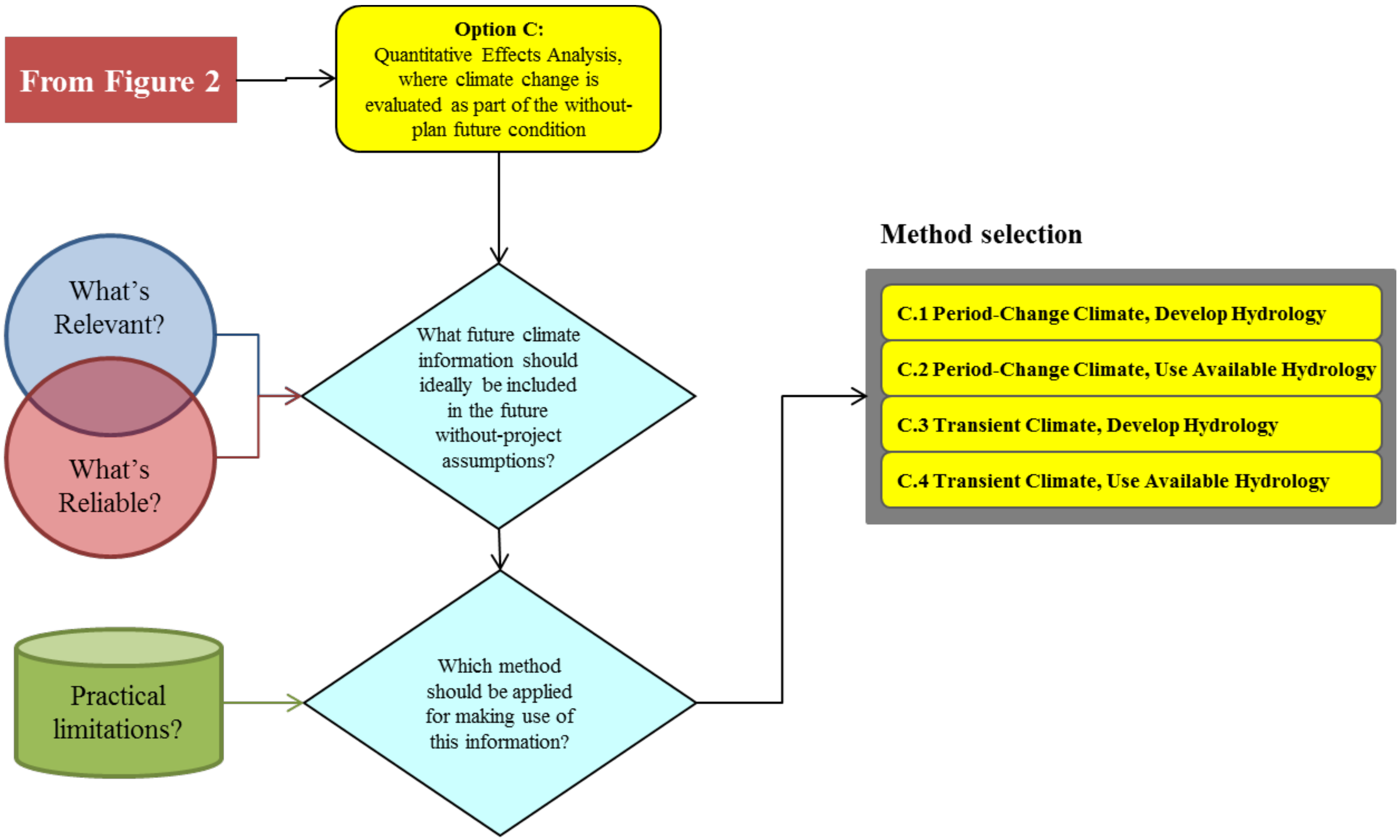

Figure 5. Integrating Answers to Scoping Questions to inform Method Selection for an Option C Level of Analysis.

6.1. Period-Change Climate, Develop Hydrology

In a period-change analysis, historically observed hydrology, water use, and system conditions are retained as reference data. Climate change scenarios are then defined by adjusting the historical water supply and demand sequences to reflect the projected climate change between a historical reference period and a selected future period. Several approaches are available for implementing the period-change approach based on how climate change on resource conditions are measured and the number of climate projections needed to describe a scenario. The details of various period-change approaches are not discussed in this document, but can be found in Reclamation 2011.

The first step in any period-change analysis is to identify an appropriate historical reference period, and subsequently identify a future period that will be compared to the historical reference period selected. The future period is typically 30 years in duration and centered on the future year of interest that is relevant to study questions. For example, if the future year of interest is 2040, the future period used as comparison would assume a window of 15 years on either side of the year 2040—the years 2025 to 2054. Note that the length of the historical reference period and the future period need not be identical. The length of the historical period might be 50 years (1950 to 1999), for example, even though the length of the future period is 30 years.

Climate change scenarios are commonly defined in terms of precipitation and temperature changes between the reference period and future period. There may be one to several projections informing a single climate change scenario. The benefit of using several projections to inform a single scenario is that the resultant scenario will have been developed from multiple climate projections and will not overly emphasize the natural climate variations from any single projection. Future climate change uncertainty is addressed by defining multiple climate change scenarios that collectively reflect a range of precipitation and temperature changes in the future.

Reclamation has used several climate change scenarios in past studies to assess future hydrologic and subsequent system operation impacts. For examples of the use of this method in Reclamation studies, see the Oklahoma Yield Study (Reclamation 2010a) and the St. Mary-Milk Rivers Basin Study (Reclamation 2010b). Studies using this method typically adopt a central change scenario followed by four bounding scenarios using the maximum and minimum changes in mean temperature and precipitation. On a graph depicting change in temperature and precipitation on each respective axis, this process will generate a rectangle with a point at the center and represents change uncertainty from relatively lesser, to greater, warming and relatively lesser, to greater, precipitation changes that often span drier, to wetter, conditions in the future. Figure 6 shows an example of a central change and four bounding scenarios for wetter or dryer and hotter or cooler conditions.

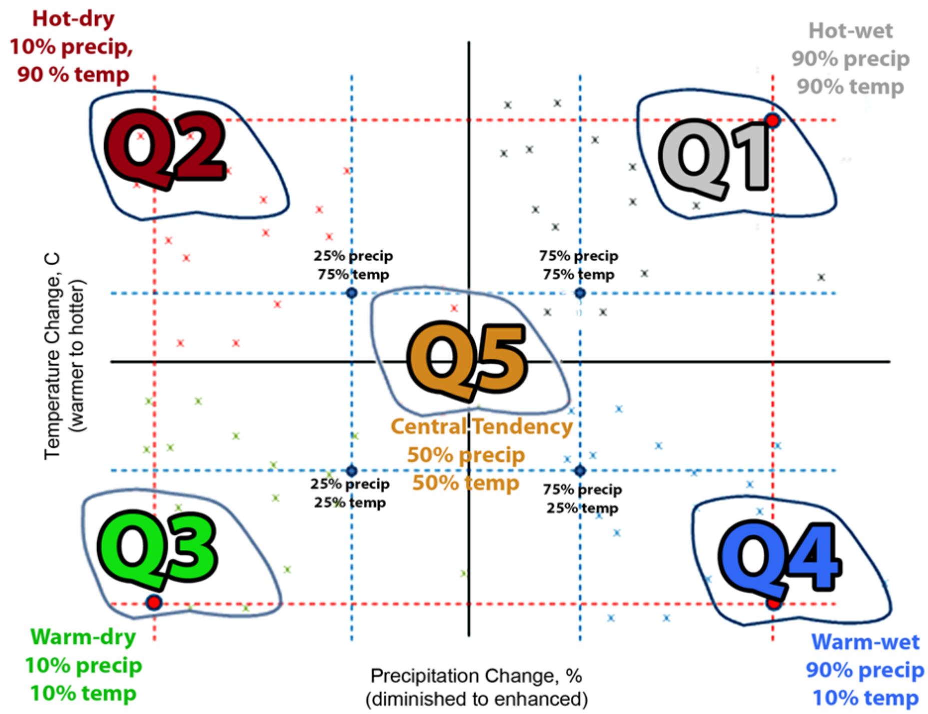

Figure 6. Example of bounding scenarios and central change.

As guidance for the period-change method, study teams are advised to develop the central change scenario and apply it to the without-plan future conditions. Study teams are also advised to develop at least two bounding scenarios that collectively reflect climate change uncertainty surrounding the central change scenario.

Climate change scenarios are translated into runoff and demand change scenarios using hydrology and consumptive use modeling, respectively. Runoff and demand change scenarios are coupled with climate scenarios discussed in the previous paragraph to transform the historical supply and demand conditions that are inputs to system operations models, resulting in a characterization of system conditions under future climate conditions.

This method is used when developing future hydrology is preferred over using existing future hydrology projections. Reasons for needing to develop hydrology simulations may include lack of access to hydrologic projections or a judgment that existing hydrologic projections are not suitable for study purposes. If the underlying hydrology model does not represent relevant physical processes, or the model is not developed at the required spatial or temporal resolution, then new simulations will need to be developed.

The following are some advantages and disadvantages for selecting this method. Advantages and disadvantages marked with (*) are shared with ***Method C.2 Period Change, Available Hydrology***.

Advantages

- Provides an opportunity to develop hydrology using study-tailored and scope-specific hydrology models.
- (*) Retains familiar historical variability, such as the occurrence of droughts and floods, which is useful for communicating results to decisionmakers and stakeholders.
- (*) Provides a simple framework for exploring system response to a climate change scenario.
- (*) Permits "cautious" sampling of climate projection aspects in the definition of climate change scenarios. Scenario definition can be simple, such as the change in the annual mean climate over a basin.
- (*) Helps to focus planning in the context of a defined future period.
- (*) Communication ease—provides a preview of hydrologic conditions for a defined future period. Provides an opportunity to develop hydrology using study relevant and scope specific hydrology model.

Disadvantages

- Requires added time and expense for generating new hydrology compared to using available data.
- (*) Goals for climate adaptation planning may be to schedule multiple adaptation alternatives. If so, the timing of change matters and a study would need to feature multiple future periods and associated scenarios.
- (*) Distinguishing climate change from natural climate variability within climate projections can be challenging, especially for precipitation projections.
- (*) Requires time up front educate technical practitioners on the mechanics, and time after the analysis to educate decision-makers and stakeholders on how climate change describes the multiple views of future conditions.

- (*) The future period needs to be selected before developing hydrologic projections, and the future period is difficult to change in a later phase of the study.

- (*) Analysis needs to be completed for multiple future periods to span the full planning horizon.

6.2. Period-Change Climate, Use Available Hydrology

In this method, the approach to identifying climate change scenarios is the same as that described in ***Method C.1 Period-Change, Develop Hydrology*** except that study teams would proceed by evaluating and selecting existing hydrology projections to inform runoff change scenarios rather than developing new hydrology projections.

Some study teams may have access to climate change scenarios that have already have been translated into runoff change scenarios using hydrologic modeling (River Management Joint Operating Committee [RMJOC] 2010). In this case, even more time is saved as hydrologic modeling and development of runoff change scenarios is not required. In either case, the study team must evaluate the hydrologic analysis, assumptions, calibration data, and methods that underpin the hydrologic projections used to develop the runoff change scenarios and determine whether it suitably serves study purposes. Once the runoff change scenarios are identified, they are used to transform historical water supply conditions similar to ***Method C.1 Period-Change, Develop Hydrology***.

The following are some advantages and disadvantages for selecting this method. Advantages and disadvantages marked with (*) are shared with ***Method C.1 Period-Change, Develop Hydrology.***

Advantages

- Using readily available information reduces amount of time and expense that would otherwise be required for data-development.

- (*) Retains familiar historical variability, such as the occurrence of droughts and floods, which is useful for communicating results to decision-makers and stakeholders.

- (*) Provides a simple framework for exploring system response to a change scenario.

- (*) Permits "cautious" sampling of climate projection aspects in the definition of climate change scenarios. Scenario definitions can be simple, such as the change in the annual mean climate over a basin.

- (*) Assists in focusing planning efforts in the context of a defined future period.

- (*) Communication ease—provides a preview of hydrologic conditions for a defined future period.

Disadvantages

- Relies on use of hydrology models that may not be well-tailored for the study area relative to a model that might have been used to develop data.

- (*) For climate adaptation planning, the goal may be to schedule multiple adaptation alternatives or projects. The timing of change matters and a study would need to feature multiple future periods and associated scenarios.

- (*) Distinguishing climate change from natural climate variability within climate projections can be challenging, especially for precipitation projections.

- (*) Requires time to educate technical practitioners on the mechanics, and subsequently time to educate decision-makers and stakeholders on this new view of future conditions.

- (*) Portrays a step change in climate information, i.e., the future period needs to be selected prior to the development of hydrologic projections, and is difficult to change in a later phase of the study.

- (*) Analysis needs to be completed for multiple future periods to span the full planning horizon.

6.3. Transient Climate, Develop Hydrology

In a transient approach, portions of the historical sequence of climate variability are selectively used to develop the climate change scenario. The intent is to develop future sequences of climate variability that evolve or change over time from present-day into the future. These sequences combine downscaled climate projection information and reliable climate features from historical information, discarding aspects of the historical sequence that do not represent climate change conditions. For example, the monthly to annual time series information may come from climate projections and sub-monthly information may come from historical information such the historical pattern of daily precipitation scaled to match monthly statistics from climate projections.

The ensemble of transient sequences represents an evolving envelope of climate possibility from present day into the future. The envelope is developed so that present day conditions are similar to recent historical climate variability. Projections of the final system conditions are evaluated at future years of interest to answer study questions. Using many transient sequences in a study has the added benefit of serving as the approach for characterizing future climate uncertainty in the study with a higher degree of robustness. In contrast, using period-change sequences would use multiple scenarios to characterize centrally expected change and a less robust characterization of uncertainty.

This method uses downscaled climate projections to drive the hydrology model. The downscaled climate projections may be available on a monthly or daily timescale, and the choice of appropriate timescale for the hydrologic modeling depends on the study objectives. If the downscaled climate projection data are only available at the monthly timescale and daily timescale projections are needed to drive the selected hydrology model, then daily weather forcing data can be developed using a combination of projected climate data and daily weather data from the reference historical period. Once these daily weather projections have been developed, each of the weather projections can be used to run a daily timescale hydrology model.

The following are some advantages and disadvantages for selecting this method. Advantages and disadvantages marked with (*) are shared with ***Method C.4 Transient Climate, Use Available Hydrology.***

Advantages

- Provides an opportunity to develop hydrology using alternative tailored and scope-specific hydrology models.

- (*) Well tailored for study situations in which present-day system states influence future watershed or basin system conditions (e.g., reservoir systems with large amounts of storage capacity like the Colorado River Storage System).

- (*) Supports "master planning" for climate change adaptation by portraying time- evolving system conditions from present-day conditions and revealing when adaptation interventions would be triggered.

- (*) Avoids challenges of abstracting period-changes from climate projections and interpreting whether they are indeed "climate changes" or facets of climate variability.

Disadvantages

- Requires added time and expense for data development.

- (*) Future supply and demand projections feature sequences that differ from historical experience and instead reflect sequences from climate projections.

- (*) Requires greater reliance on the sampling of time-related information from climate projections. "Period-change" methods permit cautious sampling of changes in period-mean conditions based on many projections; whereas "transient" methods require using time-series information from fewer climate projections, which involves accepting the projections' expression of drought and surplus sequences.

- (*) Requires time up front to educate technical practitioners on the mechanics, and time after the analysis to educate decision-makers and stakeholders on the projection of a new view of future conditions.

- (*) Using transient hydrologic projections involves working with a larger data volume, which can be viewed as impractical for some modeling sub-teams.

6.4. Transient Climate, Use Available Hydrology

In this method, the approach to identifying transient climate, hydrology, demand, and system projections is the same as that described in ***Method C.3 Transient Climate, Develop Hydrology***. The difference is that this method assumes that transient hydrology projections have already been developed in association with transient climate projections selected for the study area. For example, tandem climate and hydrology projections are available in the Bias-Corrected and Downscaled WCRP CMIP3 Climate and Hydrology Projections archive (Reclamation 2011). However, as with ***Method C.2 Period-Change Climate, Use Available Hydrology,*** it is important to evaluate whether the hydrologic analysis underpinning these hydrologic projections are suitable for the study before using hydrologic information from these types of archives.

The following are some advantages and disadvantages for selecting this method. Advantages and disadvantages marked with (*) are shared with ***Method C.3 Transient Climate, Develop Hydrology.***

Advantages

- Using readily available information reduces amount of time and expense that would otherwise be required for data-development (i.e., ***Method C.3 Transient Climate, Develop Hydrology***).

- (*) Well tailored for study situations in which present-day system states influence future system conditions (e.g., reservoir systems with large amounts of storage capacity like the Colorado River System).

- (*) Avoids challenges of abstracting period-changes from climate projections and interpreting whether they are indeed “climate changes” or facets of climate variability.

- (*) Supports “master planning” for climate change adaptation by portraying time-evolving system conditions from present-day conditions and revealing when adaptation interventions would be triggered.

Disadvantages

- Relies on use of hydrology models that may not be as well-tailored for the study relative to a model that might have been used to develop data, if being considered. (e.g., ***Method C.3 Transient Climate, Develop Hydrology***)

- (*) Future supply and demand projections feature sequences that differ from historical experience, and instead reflect sequences from climate projections.

- (*) Requires greater reliance on the sampling of time-related information from climate projections. “Period-change” methods permit cautious sampling of changes in period- mean conditions based on many projections. On the other hand, “transient” methods require using time-series information from fewer climate projections, which involves accepting the projections’ expression of drought and in the projection surplus sequences).

- (*) Requires time up front to educate technical practitioners on the mechanics, and time after the analyses to educate decision-makers and stakeholders on the changes and this new view of future conditions.

- (*) Using transient hydrologic projections involves working with a larger data volume, which can be viewed as impractical for some modeling sub-teams.

Table 1 provides a summary of the advantages and disadvantages or each of the quantitative effects analysis methods.

Table 1. Advantages and Disadvantages of Quantitative Effects Analysis Methods.

Method	Advantages	Disadvantages
Method C.1 Period-Change, Develop Hydrology	• Develops hydrology using study-tailored & scope-specific models. • Retains familiar historical variability which facilitates communicating results to decision-makers & stakeholders. • Provides a simple framework for exploring system response. • Permits “cautious” sampling of climate projection aspects in the definition of climate change scenarios. • Focuses planning in the context of a defined future period. • Communication ease—develops hydrology using study relevant and scope specific hydrology models.	• Added time and expense for generating new hydrology. • If planning objectives require multiple alternatives implemented over time then a study must feature multiple future periods & scenarios. • Distinguishing climate change from natural climate variability can be challenging, especially for precipitation projections. • Requires time to educate technical practitioners, decision-makers, and stakeholders on how climate change describes multiple views of future conditions. • The future period must be selected before development of hydrologic projections, and is difficult to change in a later phase of the study. • Analysis for multiple future periods to span the full planning horizon.
Method C.2 Period-Change Climate, Use Available Hydrology	• Reduces amount of time & expense for data-development. • Retains familiar historical variability, which facilitates communicating results to decision-makers & stakeholders. • Provides a simple framework for exploring system response to changes. • Permits “cautious” sampling of climate projection aspects in the definition of climate change scenarios. • Focuses planning in the context of a defined future period. • Communication ease—provides a preview of hydrologic conditions for a defined future period.	• Relies on hydrology models that may not be well-tailored for the study area. • If planning objectives require multiple alternatives implemented over time then a study must feature multiple future periods & scenarios. • Distinguishing climate change from natural climate variability can be challenging, especially for precipitation projections. • Requires time to educate technical practitioners, decision-makers and stakeholders on this new view of future conditions. • The future period must be selected before developing hydrologic projections, and is difficult to change in a later phase of the study. • Analysis for multiple future periods to span the full planning horizon.

Method	Advantages	Disadvantages
Method C.3 Transient Climate, Develop Hydrology	• Develops hydrology using alternative tailored & scope-specific models. • Well-tailored for studies in which present-day system states influence future watershed or basin system conditions. • Plans for climate change adaptation using time-evolving system conditions from present-day conditions to reveal trigger points for adaptation interventions. • Avoids challenges of interpreting whether period change projections are indeed "climate changes" or facets of climate variability.	• Added time and expense for data-development. • Future supply & demand projections differ from historical experience, reflecting sequences from climate projections. • Requires greater reliance on the sampling of time-evolving information from climate projections. • Requires time to educate technical practitioners, decision-makers and stakeholders on the projection of a new view of future conditions. • Involves working with a larger data volume, which can be viewed as impractical for some modeling sub-teams.
Method C.4 Transient Climate, Use Available Hydrology	• Reduces amount of time & expense for data-development. • Well-tailored for study situations in which present-day system states influence future system conditions • Avoids challenges of interpreting whether period-change projections are indeed impacts from climate changes or facets of climate variability. • Plan for climate change adaptation using time-evolving system conditions from present-day conditions to reveal trigger points for adaptation interventions	• Relies on hydrology models that may not be well-tailored for the study area. • Future supply & demand projections differ from historical experience, reflecting sequences from climate projections. • Requires greater reliance on the sampling of time-related information from climate projections. • Requires time to educate technical practitioners, decision-makers, and stakeholders on the changes and this new view of future conditions. • Involves working with more data, which can be viewed as impractical for some modeling sub-teams

7. ALTERNATIVE FORMULATION AND EVALUATION PHASE

The climate change projections and analysis methodology selected by study teams in the early stages of the planning process will influence the choices, conclusions, and recommendations made throughout the study. The climate change methods described in this guidance document were developed to help study teams incorporate climate change analysis throughout the planning process. The instructions in ***Sections 4 through 6*** are intended to guide study teams in selecting a climate change methodology and the climate projections best suited to the purpose of the study. This section discusses using the climate change analysis to develop and evaluate alternatives and comparing them to the without-plan future condition. In this way, alternatives can be analyzed and risks characterized and compared to the without-plan future condition, with climate change in mind.

As noted earlier, Reclamation feasibility studies are conducted in a two-phase process. During the scoping phase, study teams will choose a climate change method as part of the identification of planning objectives, opportunities, and constraints as well as to define purpose and need for NEPA compliance. Study teams will select relevant, reliable, and practical climate change information to include in the without-plan future condition (***Section 5***), supplemented by additional potentially less certain climate change assumptions that will be explored through a sensitivity analysis. The selected quantitative method of analysis (***Section 6***) supports both the characterization of the without-plan future conditions and the sensitivity tests. As study teams proceed with analyzing future system conditions under the proposed project, and developing and comparing action alternatives, climate change analysis can be integrated into the planning process by following these steps:

1) Analyze without-plan future conditions using selected climate information (***Section 7.1***)

2) Identify a reasonable range of future conditions that alternatives are intended to alleviate or attenuate, and the baseline thresholds for comparison of alternatives (***Section 7.2***)

3) Compare alternatives using selected climate projections (***Section 7.3***)

4) Compare results between action alternatives and the without-plan future condition to identify the alternative that best meets the needs, challenges and opportunities that includes the effects of projected climate change (***Section 7.4***).

7.1. Analyze Without-Plan Future Condition Using Selected Climate Projections (Baseline)

The first step in the climate analysis supports the forecast of future conditions and the definition of the without-plan future conditions. The goal of this first step is to establish baseline levels of performance and thresholds of risk for comparison to action alternatives. The climate methods and associated data selected from ***Section 6*** will be used to analyze the without-plan future condition. One of the challenges of applying this methodology is the potential for generating an amount of data that can quickly overwhelm the study teams. This will result in the necessity to use the results to convey a story of how climate change will impact the issues of concern to stakeholders in the alternative, and by extension, the choice of metrics for evaluating alternatives. Therefore, a key early objective for study teams will be to determine which of the many possible future conditions are likely to impact the development of alternatives, as these will be most important to establishing a baseline condition. As a result, the without-plan future condition will consist of at least one potential future scenario that the action alternatives will be compared against.

If a small subset of climate projections was selected using steps described in ***Section 6***, each climate projection could produce a unique without-plan future condition, resulting in a corresponding number of separate climate projection baselines. For instance, three without-plan future conditions may be developed to show responses to low, medium, and high climate change projections, resulting in three future outcomes that characterize how climate change might shape the without-plan future condition. Most likely, one of the three outcomes will be selected to represent the without-plan future condition because it is based on the most relevant and reliable information. The other two outcomes would then serve as the basis for a sensitivity analysis.

If an ensemble or collection of many climate projections is developed, the study team will need to decide how to establish the without-plan future condition, and how to bracket the remaining conditions for the sensitivity analysis, from the ensemble of climate projections.

7.2. Identify the Range of Future Conditions

During the second phase of a feasibility study, study teams formulate and evaluate a reasonable range of alternatives, as required by both the P&Gs and NEPA. The key to this step of the feasibility study is to connect the results back to the underlying assumptions and objectives. To effectively develop a reasonable range of alternatives, the selection of climate projections and the metrics chosen for the analysis must support the decision making process established at the start.

Climate change, represented in the without-plan future condition, will typically be one of many sources of uncertainties, such as changing demographics, socioeconomic conditions, and future land use decisions. In some cases, one or more factors other than climate change may ultimately determine the future condition(s) that alternatives are developed for. However, at this point the team is focused on understanding which of the potential future climate conditions affect key decisions made by the team as they define the problems to be addressed and then develop implementation alternatives.

This step should be conducted in iterations to ensure that key elements of the study process, including metrics, choice of climate change method and projections, and choice of models and analytical tools, are adequately characterizing the decision parameters when applied to the without-plan future condition. This will ensure that the base conditions have been properly specified when evaluating the action alternatives.

7.3. Compare Alternatives Using Selected Climate Projections

To evaluate the effects of the plans under consideration, study teams will apply the climate change methods and metrics that have been refined in the previous step to the assessment of the action alternatives. The value of knowledge gained through the iterative process of establishing the baseline is realized as action alternatives are developed and analyzed to determine their effectiveness at addressing the impacts of climate change. Results from this step will form the basis of evaluating the performance of a given alternative in the next step when the performances of action alternatives are compared against the without-plan future condition and baseline performance thresholds established earlier.

Study teams may find that certain action alternatives are not sensitive to changes in climate projections. As action alternatives are refined and the range of alternatives is narrowed, study teams may choose to focus on a particular set of governing conditions. Study teams will also need to consider other sources of risk and uncertainty and decide which of those sources drive the development and selection of alternatives. During this process, study teams may find that climate change is not a primary driver in the selection of an alternative.

7.4. Compare Results and Identify a Climate Robust Alternative

Finally, climate analysis is incorporated into the comparison of alternative plans using the data generated in the preceding steps. The effects of the action alternatives are compared to the without-plan future condition to determine which of the alternatives performs the best across the range of climate conditions the study teams have determined is important to stakeholders and decision makers.

8. SUMMARY

The requirements established by Secretarial Order 3289, Departmental Manual 523 DM 1, Executive Order 13653, Reclamation Manual CMP P16, and Reclamation’s Directives and Standards CMP 09-02 for feasibility studies reinforces Reclamation's on-going programs to be more resilient to the impacts of climate change and continued efforts to incorporate climate change information into aspects of our mission where it has not been fully considered in the past such as in decisions regarding ecosystem restoration, reservoir operations, infrastructure investments and planning capacity. This document is an important step to reinforcing Reclamation’s planning capacity by providing guidance to help study teams navigate the range of planning and technical methods available to account for climate change impacts in feasibility studies.

Study teams determine the level of climate change analysis needed for the study and appropriate methods to characterize climate conditions. Understanding that climate change information ranges from more to less certain and that without-plan future assumptions directly frame decision-support, CMP 09-02 forces study teams to determine which portions of climate change information are:

4) Certain and relevant enough to be included in without –plan future condition

5) Highly uncertain but still relevant and therefore worthy of exploring through sensitivity analysis

6) Irrelevant or too uncertain and therefore excluded from the study

This guidance helps study teams make this determination by addressing a series of scoping questions about decision relevance, information reliability, and analysis practicalities. Responses to the scoping questions will help study teams determine what climate change information to include in the without-plan future condition and potentially what to include in complementary sensitivity analysis and a quantitative method of analysis to accomplish this body of analysis.

The guidance is designed to be used in existing decision making processes within Reclamation that allow for some level of flexibility to address both net economic benefits and protection of environmental resources. In the future, this document will be expanded and include a decision making framework which incorporates climate change.

DEFINITION OF TERMS

Appraisal Study An initial planning investigation performed to determine the nature of water and related resource problems and needs in a particular area, formulate and assess preliminary alternatives, determine Reclamation interests, and recommend subsequent actions. Appraisal studies are based primarily on available existing data.

Bias-Correction Simulations or forecasts of climate from dynamical models such as GCMs do not precisely correspond to reality (i.e., observations), thus, resulting in "bias." There are statistical methods to correct this, often referred to as "bias correction" methods. Typically, they involve fitting a statistical model between the dynamical model simulations and the observations over a period. The fitted statistical model is used to correct future model simulations.

Climate

i. Expected weather, including averages, variations, and extremes. More specifically, climate is the statistical description in terms of the mean and variability of relevant weather variables over a period of time that is subjectively chosen and may range from a period of months to thousands or millions of years.

ii. A standard period for defining climate is 30 years, as applied by the World Meteorological Organization.

iii. Relevant weather variables for describing climate include, but are not limited to, surface temperature, precipitation, and wind speed.

Climate Change A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or other statistical properties, measured over an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing's such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Note: The United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Climate Change Adaptation Actions and measures to reduce the climate change vulnerability of natural and human systems under present climate or expected future climate possibilities.

Climate Change Method A climate change method is the procedure used to characterize and evaluate future climate and hydrology conditions. There are typically two categories of methods for characterizing future climate and hydrology conditions that have been used in past studies: period-change and transient.

Climate Change Scenario A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate.

Climate Change Vulnerability The extent to which a water resource system with a Reclamation interest could be negatively affected as a result of climate change.

Climate Projection A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized (IPCC 2013a).

CMIP3 / 5 The World Climate Research Program (WCRP) develops global climate projections through its Coupled Model Inter- comparison Project (CMIP). CMIP results inform the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports. The projections from CMIP phase 3 (CMIP3) informed the IPCC Fourth Assessment, released in 2007. During 2012-2013, WCRP released projections from CMIP phase 5 (CMIP5), which will inform the IPCC Fifth Assessment, published in 2014.

Downscaling Downscaling is a method that derives local scale (grid size on the order of 10 kilometers [km]) information from larger-scale models (grid size on the order of 200 km) or data analyses. Two main methods exist: dynamical downscaling and non-dynamical downscaling. The dynamical method uses the output of regional climate models, global models with variable spatial resolution or high-resolution global models. The non-dynamical methods develop statistical relationships that link the large-scale atmospheric variables with local/regional climate variables. In all cases, the quality of the driving model remains an important limitation on the quality of the downscaled information.

Dynamical Downscaling Dynamical downscaling fits output from GCMs into regional meteorological models. Rather than using statistical analysis to downscale global climate projections down to a regional level, dynamical downscaling uses physically based meteorological models to reflect how global patterns affect local weather conditions.

Emission Scenario A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.

Feasibility A measure of the viability of a proposed plan or project based on an evaluation of:

i. How well the planning objectives are met
ii. The economic justification
iii. The validity of the scientific, technical, and design assumptions
iv. The ability to construct a project, implement a non-structural plan, or both

according to Reclamation standards and practices, within the estimated cost and schedule

v. The reliability of the estimated costs and benefits
vi. The reliability of the proposed construction schedule
vii. The capability and willingness of the project partner(s) to financially support the proposed alternatives

Feasibility Study An evaluation of the technical, economic, and financial feasibility of a proposed alternative based on detailed investigations requiring the acquisition of primary data, including an assessment of environmental impacts as required by NEPA. A feasibility study provides the basis for making recommendations to Congress about whether a proposed alternative should be authorized for construction.

Global Climate Model (GCM) Computer models designed to help understand and simulate global and regional climate, in particular the climatic response to changing concentrations of greenhouse gases. GCMs aim to include mathematical descriptions of important physical, chemical and biological processes governing climate, including the role of the atmosphere, land, oceans, and biological processes. The ability to simulate sub-regional climate is determined by the resolution of the model.

Hydro-climate data The datasets that result from modeling interactions between climatological and hydrologic processes, including the occurrence, motion, and changes of state of atmospheric water, and the land surface and subsurface phases of the hydrologic cycle. Hydro-climate data can be used to address questions regarding land use, the long-term effects of climate change on water resources, and regional precipitation.

Investment Any activity that uses federally appropriated funding, including federally owned but independently operated facilities.

Maladaptive Actions to avoid or reduce climate change vulnerability that negatively impact or increase the vulnerability of other systems, sectors, or social groups.

Metric A consistent measurement of a characteristic of an object or activity that is otherwise difficult to quantify. Within the context of the evaluation of climate models, this is a quantitative measure of agreement between a simulated and observed quantity which can be used to assess the performance of individual models.

Non-Dynamical Downscaling Using statistical methods to convert global climate projections to regional-scale conditions. Instead of maintaining a dynamic climate model at high resolution, this approach applies the information from GCMs to the region by using a series of statistical techniques to establish the relationship between large-scale variables, such as the driving factors derived from GCMs, to local level climate conditions. Once these relationships have been developed for existing conditions, they can be used to predict what might happen under the different conditions indicated by GCMs.

Paleoclimate Climate during periods prior to the development of measuring instruments, including historical and geologic time, for which only proxy climate records are available.

Period-Change Analysis Climate change scenarios that reflect what the impact of climate change would be between a historical reference time period and a future time period.

Planning

i. Studies which use Principles and Requirements for Federal Investments in Water Resources pursuant to the Water Resources Planning Act of 1965 (Public Law 89-8), as amended (42 U.S.C. 1962a-2) and consistent with Section 2031 of the Water Resources Development Act of 2007 (Public Law 110-114).

ii. Planning Investigations including Project Investigations, Special Investigations, Non-reimbursable Investigations, and Cost-Sharing on General Investigation Studies.

iii. Investigations which may result in the prioritization of major infrastructure investment.

Stationarity The assumption that the future climate will be the same as the historical climate.

Transient Analysis Climate, hydrology, and system projections that represent time evolving conditions through time from present-day conditions through the 21st century.

Without-plan future condition Characterizing future conditions without the proposed Reclamation action, including actions that may be expected or anticipated by others.

REFERENCES

Atcheson, Margaret E., et al. "Bioenergetic response by steelhead to variation in diet, thermal habitat, and climate in the North Pacific Ocean." Transactions of the American Fisheries Society, 141.4 (2012): 1081-1096.

Brekke, L.D., Kiang, J.E., Olsen, J.R., Pulwarty, R.S., Raff, D.A., Turnipseed, D.P., Webb, R.S., and White, K.D., 2009, Climate change and water resources management—A federal perspective: U.S. Geological Survey Circular 1331, 65 p. (Also available online at http://pubs.usgs.gov/circ/1331/.)

CBO 2009. Congressional Budget Office Cost Estimate of H.R. 2454, American Clean Energy and Security Act of 2009 (Washington DC: Congressional Budget Office)

Intergovernmental Panel on Climate Change (IPCC), 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States, 996 pp. Available at http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate

Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Milly, P.C.D., J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier, and R.J. Stouffer, 2008, "Stationarity is Dead: Whither Water Management?," Science, 319, 573-574.

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi: 10.7930/J0Z31WJ2.

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

Reclamation, 2010a. Climate Change and Hydrology Scenarios for Oklahoma Yield Studies. Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver Colorado. April 2010.

Reclamation, 2010b. Climate Change Analysis for the St. Mary and Milk River Systems in Montana. Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver Colorado. August 2010.

Reclamation, 2011. West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections, prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. March 2011.

Reclamation and U.S. Army Corps of Engineers (USACE), 2011. "Addressing Climate Change in Long-Term Water Resources Planning and Management: User Needs for Improving Tools and Information," U.S. Army Corps of Engineers Civil Works Technical Series CWTS-10-02, available at: http://www.ccawwg.us/docs/Long_Term_Addressing_Climate_Change.pdf.

River Management Joint Operating Committee (RMJOC), 2010, "Climate and Hydrology Datasets for Use in the RMJOC Agencies' Longer Term Planning Studies: Part I - Future Climate and Hydrology Datasets", prepared by Bureau of Reclamation, Bonneville Power Administration and U.S. Army Corps of Engineers, available at: http://www.usbr.gov/pn/programs/climatechange/reports/part1.pdf.

Vermeer and Rahmstorf, 2009. Global Sea Level Linked to Global Temperatures. http://www.pik-potsdam.de/~stefan/Publications/Journals/vermeer_rahmstorf_2009.pdf. Proceedings of the National Academy of Sciences of the United States of America.

APPENDIX 1 - SUPPLEMENTAL INFORMATION

As introduced in ***Section 3*** and discussed in ***Sections 5 and 6*** of this guidance, planners face three broad scoping questions when selecting a method for characterizing future climate and hydrology in a given study: information relevance; information reliability; and practical limitations. This appendix briefly describes selected information resources available to planners and technical specialists for scoping and conducting climate change analyses. Technical synthesis reports described below include climate change adaptation and planning guidelines developed by other agencies, along with reports that provide information to help planners assess information relevance and reliability; the data resources described below include climate and hydrology projection data that are currently available for use in climate change analyses.

Technical Synthesis Reports

U.S. Global Change Research Program (2014)

Climate Change Impacts in the United States: The Third National Climate Assessment.
http://nca2014.globalchange.gov
This report assesses the science of climate change and its impacts across the United States, now and throughout this century. It integrates findings of the U.S. Global Change Research Program (USGCRP) with the results of research and observations from across the U.S. and around the world, including reports from the U.S. National Research Council (NRC). This report documents climate change related impacts and responses for various sectors and regions, with the goal of better informing public and private decision-making at all levels.

Intergovernmental Panel on Climate Change (2014)

Working Group I - Climate Change 2013: The Physical Science Basis
http://www.climatechange2013.org
The Working Group I contribution to the IPCC Fifth Assessment Report (AR5) provides a comprehensive assessment of the physical science basis of climate change, drawing on the scientific literature accepted for publication up to 15 March 2013. The AR5 Summary for Policymakers was approved at the Twelfth Session of Working Group I, held in Stockholm, Sweden, from 23 to 26 September, 2013. The session also accepted the Technical Summary and underlying scientific assessment contained in 14 chapters and related annexes. The narrative of the Summary for Policymakers follows the structure of the full report and is supported by a series of overarching headline statements.

Bureau of Reclamation (2013)

Literature Synthesis on Climate Change Implications for Water and Environmental Resources
http://www.usbr.gov/climate/docs/ClimateChangeLiteratureSynthesis3.pdf
Reclamation developed this literature synthesis to provide region-specific summaries of historical climate and hydrology, projected climate change impacts on hydrology and water resources, and projected climate change impacts on environmental resources for each Reclamation region. Synthesis draws from peer-reviewed scientific literature as well as technical reports from federal, state, and international agencies.

State of California (2012)

California Climate Adaptation Planning Guide
http://resources.ca.gov/climate_adaptation/local_government/adaptation_policy_guide.html
Guide developed by California Emergency Management Agency and California National Resources Agency to provide information and guidance to local and regional planners. Guide provides information on understanding climate and climate change, defining local and regional impacts of climate change, and developing and implementing adaptation strategies.

Intergovernmental Panel on Climate Change (2007)

Contribution of Working Group I: The Physical Science Basis
http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html
This technical synthesis report describes current state of climate science, including projected climate and hydrologic changes, uncertainty of projected changes, and potential adaptation strategies. Report summarizes observations of changing climate and hydrologic conditions around the globe, climate models and their evaluation, and global and regional climate projections developed by researchers around the globe. Report represents current scientific understanding and consensus among the international science community.

Contribution of Working Group II: Impacts, Adaptation, and Vulnerability
http://www.ipcc.ch/publications_and_data/ar4/wg2/en/contents.html
Report summarizes projected impacts of climate change on natural resources and socioeconomic sectors, including water resources and water resources management. Report summarizes the range of assessment methods used to evaluate and characterize climate change impacts on specific sectors. Report represents current scientific understanding and consensus among the international science community.

Intergovernmental Panel on Climate Change (2008)

Climate Change and Water
http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf
A technical synthesis report describing projected changes in hydrology and water resources due to climate change. Report summarizes physical processes linking climate to surface water

and groundwater resources. Report includes regional summaries, as well as discussion of implications for water resources management by demand sector.

US Climate Change Science Program (2009)

Global Climate Change Impacts in the United States (Second Climate National Assessment)
http://www.globalchange.gov/what-we-do/assessment/previous-assessments/global-climate-change-impacts-in-the-us-2009
National assessment report containing synthesis of climate change projections at global, national, and regional scales, including assessment of climate change impacts by region and sector. Report draws from a number of synthesis and assessment products; relevant synthesis and assessment products include:

- 5.1: Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions

- 5.2: Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Climate Decision Making

Data Resources:

Bias Corrected and Downscaled WCRP CMIP3 Climate and Hydrology Projection Archive

http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/
Online archive developed by Reclamation in collaboration several other agencies, universities, and institutions. Archive contains bias corrected and spatially disaggregated (BCSD) monthly climate projections for the period 2000-2099; bias corrected constructed analogue (BCCA) daily climate projections for periods 1961-2000, 2046-2065, and 2081- 2100; and monthly hydrology projections developed by driving the Variable Infiltration Capacity (VIC) hydrology model with the BCSD climate projections. Online data portal allows users to extract climate projections over selected rectangular regions and hydrology projections over selected regions or watersheds (experimental).

North American Regional Climate Change Assessment Program (NARCCAP) Data Catalogue

http://www.narccap.ucar.edu/
Online archive developed by scientists and researchers from several agencies, universities, and institutions. Data catalogue provides access to 22 dynamically downscaled climate projections based on multiple regional climate models nested within multiple global climate models for 30-year current and future periods. Regional climate models share a common spatial and temporal resolution to facilitate inter-comparison.

Hydrologic Climate Change Scenarios for Pacific Northwest Columbia River and Coastal Drainages

http://warm.atmos.washington.edu/2860/

Online archive developed by the University of Washington Climate Impacts Group. Archive contains hydrologic projections for approximately 300 sites within the Columbia River Basin and coastal drainages along the western Cascade Mountains in the Pacific Northwest. Daily historical flows and a total of 76 daily streamflow projections are provided for each site based on three statistical downscaling methods (Delta, Hybrid Delta, and Transient) and two emissions scenarios (A1B, B1). Projections were developed by driving the Variable Infiltration Capacity hydrology model with downscaled climate projections. Climate and hydrology projections were developed at a spatial resolution of $^1/_{16}°$ latitude by $^1/_{16}°$ longitude; however, only streamflow projections at selected sites are available online.

Summary of Data Resources

Table A1: Summary of Data Resources

Dataset	Spatial Extent / Spatial Resolution	Period of Record / Temporal Resolution	Variables	Comments
BCSD Climate Projection Archive	Continental US $^1/_8°$ lat x $^1/_8°$ lon grid	1950-2099 / Monthly	Precipitation, Temperature	112 projections, statistically downscaled
BCCA Climate Projection Archive	Continental US $^1/_8°$ lat x $^1/_8°$ lon grid	1961-2000, 2046- 2065, 2081-2100 /Daily	Precipitation, Temperature	53 projections, statistically downscaled
BCSD Hydrology Projection Archive	Western US $^1/_8°$ lat x $^1/_8°$ lon grid	1950-2099 / Monthly	Precipitation, Max. Air Temp., Min. Air Temp., Wind Speed, Soil Moisture, Snow Water Eq., Total Runoff, Evap (Actual), Evap (Potential)	112 hydrology projections corresponding to BCSD downscaled climate projections
NARCCAP Climate Projection Data Catalog	North America / 50km x 50km grid	1969-2000; 2039-2070 3-hourly to daily (differs by variable)	Precipitation, Max. Air Temp., Min. Air Temp., Wind Speed (U,V), Air Pressure, Specific Humidity, Soil Moisture, Snow Water Eq., Total Runoff, Latent Heat Flux, Many others.	22 projections, dynamically downscaled, each projection from different GCM+RCM combination
CIG Hydrology Climate Change Scenarios	Columbia River Basin and Coastal Areas/Individual gage sites	1915-2005; multiple period-change and transient hydrology projections (85 years) / Daily	Total Runoff	76 projections at each of 300 sites; projections derived from period-change and transient methods applied to multiple climate projections

APPENDIX 2 – CLIMATE CHANGE 101

Climate is defined by the statistical characteristics of meteorological conditions including temperature, precipitation, solar radiation, wind, atmospheric pressure and humidity in a given region over a period of decades. In contrast, weather is characterized by the condition of these factors over periods of time extending from days to weeks. Although significant advancements in weather forecasting have occurred, the nonlinear nature of atmospheric processes makes skillful forecasting of even seasonal and annual weather extremely difficult. However, over most of human history, the non-linear dynamics that characterize weather systems have tended to average out with some consistency over a period of a few decades. Therefore, although we cannot predict weather conditions at any given time, we have an understanding of long-term average conditions, and could characterize the extremes likely to be encountered.

Because of the past multi-decadal stability, climate has been characterized using the concept of stationarity, through which longer-term average weather conditions were used as a basis for water supply and infrastructure planning and engineering design. Paleoclimate based data from studies of tree rings, pollen, ice cores, ocean and lake sediments, stable and radioisotopes, and other long-term climatic records have been used to capture the natural variability of climate. This information has also been used with stochastic methods to characterize the uncertainties in climatic conditions. Climate change, however, imposes trends on both the magnitude and variability of climate parameters such as temperature and precipitation. Therefore, although much insight can be gained from the analysis of retrospective climate data, stationarity no longer characterizes average conditions. Water planning and engineering design in the future will need to rely also on new methods and information sources.

A. Climate Change Projections

The World Climate Research Program (WCRP) develops global climate projections through its Coupled Model Inter-comparison Project (CMIP) roughly every 5 to 7 years.

Projections of future climate changes are made through the use of global climate models referred to as General Circulation Models (GCM), which have been steadily increasing in sophistication and complexity over the past several decades. The CMIP3 climate projections are based on an assemblage of GCM simulations of coupled atmospheric and ocean conditions, with a variety of initial conditions of global ocean – atmosphere system and four distinct emission scenarios or “storylines” about how future demographics, technology and socioeconomic conditions might affect the emissions of greenhouse gases. The four families of emissions scenarios (A1, A2, B1 and B2) are described in the IPCC Special Report on Emissions Scenarios (SRES), which states that "the scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts." (IPCC 2007). Corresponding carbon dioxide (CO_2) emissions and atmospheric concentrations for some of the emissions scenarios are shown in Figure 1.

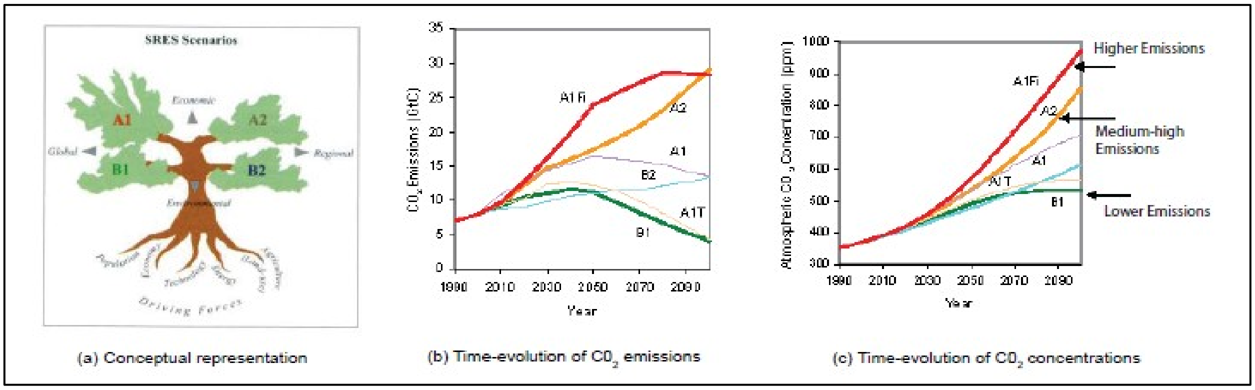

Figure 1. Carbon dioxide emissions and atmospheric concentrations for some emission scenarios.

The CMIP5 climate model simulations in support of AR5 use a different approach to account for increasing greenhouse gas concentrations than in the previous report. Instead of using the SRES scenarios, the GCM models perform simulations using four Representative Concentration Pathways (RCP): RCP2.6, RCP4.5, RCP6, and RCP8.5. Each RCP is representative of a particular amount of radiative forcing (2.6, 4.5, 6.0, and 8.5 W/m^2 [watts per square meter] respectively) occurring by the year 2100. As part of the preparation of the AR5 report, the WCRP has performed new GCM models simulations (CMIP5) using these RCPs. Figure 2 below shows the corresponding amounts of atmospheric greenhouse gases (GHG) associated with each of the RCPs.

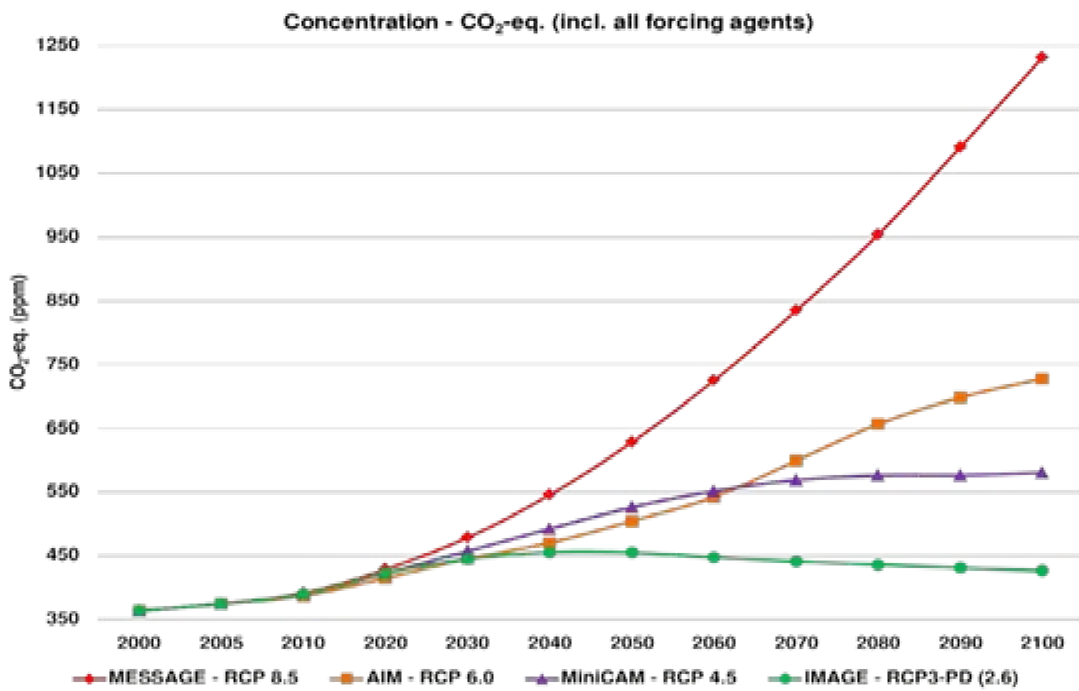

Figure 2. Atmospheric greenhouse gas concentrations associated with the AR5 Representative Concentration Pathways.

The spatial resolution of the global climate model (GCM) climate projections for both CMIP3 and CMIP5 is typically **on the order of one degree of latitude/longitude** (about 110 km x 110 km), which is too coarse for use in regional and project-scale planning. Additionally, local climates are likely to differ from the average climatic conditions across an entire degree of latitude or longitude, due to elevation differences and other local conditions. Therefore, projections of local conditions require a method of downscaling GCM projections to regional and local scales. These methods might be dynamical, using regional climate models (RCMs) that are bounded at the RCMs

CMIP3 vs. CMIP5

CMIP5 projections are a new opportunity to improve our understanding of climate science, which is evolving at a rapid pace. Even though CMIP5 is newer, it has not been determined to be a better or more reliable source of climate projections compared to CMIP3. CMIP5 projections should be considered an addition to (not a replacement of) CMIP3 projections unless the climate science community can offer an explanation as to why CMIP5 should be favored over CMIP3. Climate researchers are still studying the similarities and differences between the two sets of projections.

geographical extent by output from GCMs, or statistical, in which climate features are statistically related to finer-scale regional climate characteristics.

Dynamical downscaling using RCMs is computationally intensive and consequently fewer projections are available, although this is changing with advances in computing technologies. In contrast, statistical methods have been widely applied to produce spatially-continuous fields of temperature and precipitation at fine scales (< 10 miles) covering the entire United States. These statistical methods are typically coupled with bias corrections to regional and local conditions.

Reclamation and several partner organizations including Lawrence Livermore National Laboratory, Santa Clara University, Climate Central, U.S. Army Corps of Engineers, and the Institute for Climate Change and its Societal Impacts have created a data archive of statistically downscaled CMIP3 and CMIP5 climate and hydrologic projections that are available through the "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" website (DCHP website) at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/. For both CMIP3 and CMIP5 the archive features:

1) Monthly projections of precipitation and daily average temperature developed using Bias Correction and Spatial Disaggregation (BCSD)

2) Daily projections of precipitation, daily minimum temperature, and daily maximum temperature using Bias-Correction and Constructed Analogs (BCCA)

3) Downscaled CMIP5 monthly BCSD projections of mean daily minimum temperature and mean daily maximum temperature, as well as BCCA projections of daily average temperature

4) Hydrologic projections based on BCSD downscaling for both CMIP3 and CMIP5 projections at daily timesteps on a $^{1}/_{8}{}^{o}$ grid (12 km) for the period from 1950 to 2099.

B. Projected Impacts of Climate Change

Much of the Western United States has experienced warming during the 20th century. This warming averages roughly two degrees Fahrenheit (°F) in Reclamation's major Western river basins, and there is general consensus among the GCMs that this warming will continue during the 21st century. Using the central estimates from the GCMs these Western river basins are projected to increase another five to seven °F by the end of the 21st century. Warming will tend to be greater in the interior of the contiguous United States (CBO 2009).

There is less model consensus on the direction of precipitation change, as some climate models suggest decreases while others suggest increases. However, greater consensus does exist for some geographic locations:

- For the Northwestern United States and northern Great Plains (e.g., Columbia Basin and Missouri River basin), greater precipitation is consistently projected

- For the south-central and Southwestern United States (e.g., San Joaquin, Truckee, and Rio Grande River basins and the Middle to Lower Colorado River Basin), less precipitation is consistently projected.

- Areas in between these contrasts (e.g., Klamath and Sacramento basins and the Upper Colorado Basin) have roughly equal chances of increases in precipitation or decreases in precipitation.

1. Hydrologic Impacts

The historical and projected climate changes described above have implications for hydrology (Reclamation 2011). Warming trends appear to have led to a shift in cool season precipitation towards more rain and less snow, which has caused increased rainfall-runoff volume during the cool season accompanied by less snowpack accumulation in some Western United States locations. Hydrologic projections suggest that wintertime warming and associated loss of snowpack will persist over much of the Western United States through the 21st century.

However, there are some geographic contrasts. Snowpack losses are projected to be greatest where the baseline climate is closer to freezing thresholds (e.g., lower lying valley areas and lower altitude mountain ranges). In high altitude and high latitude areas (e.g., Columbia headwaters in Canada, Colorado headwaters in Wyoming), there is a chance that cool-season snowpack could increase during the 21st century, due to increases in precipitation that offset the snow-reduction effects of warming.

Geographic implications for future runoff are more complex than those for future snowpack, since runoff reflects the interplay between runoff and infiltration, and water supply and both natural and human water demand, and each of these factors is affected by climate change in a different way. However, some generalizations can be made:

- The Southwestern United States to Southern Rockies (e.g., Rio Grande River basins and the Colorado River Basin) are projected to experience gradual runoff declines during the 21st century

- The Northwest to north central United States (e.g., Columbia River Basin and Missouri River basin) are projected to experience little change through mid-21st century followed by increases in the late-21st century.

Warming is projected to affect snowpack conditions, as discussed above, as well as water demand, through changes in evaporation and evapotranspiration rates. Without precipitation change, warming alone would lead to increases in cool season rainfall-runoff and decreases in warm season snowmelt-runoff. Results show that the degree to which this plays out varies by location in the Western United States:

- Cool season runoff is projected to increase over the west coast basins from California to Washington and over the north-central United States (e.g., San Joaquin, Sacramento, Truckee, Klamath, and Missouri basins and the Columbia Basin) and to experience little change to slight decreases over the Southwestern United States to Southern Rockies (e.g., Colorado River Basin and Rio Grande River basin).

- Warm season runoff is projected to experience substantial decreases over a region spanning southern Oregon, the Southwestern United States, and Southern Rockies (e.g., Klamath, Sacramento, San Joaquin, Truckee, and Rio Grande River basins, and the Colorado River Basin). However, north of this region, warm season runoff is projected to experience little change to slight increases (e.g., Columbia River Basin and Missouri River basin).

- Projected increasing precipitation in the northern tier of the Western United States somewhat neutralizes warming-related decreases in warm season runoff, whereas projected decreasing precipitation in the southern tier of the Western United States serves to amplify such warming-related decreases in warm season runoff.

2. Sea Level Changes

Increasing global temperatures have already caused increases in sea level, and this trend is expected to continue as global temperatures rise further. These changes will affect coastal ecological resources both directly, through inundation of coastal and estuarine habitats, and indirectly through water quality (e. g., salinity, pH) changes. Climate change impacts on anadromous species such as salmonids may occur due to changes in oceanic habitat conditions caused by changes in ocean temperature, acidity, and upwelling of phytoplankton and other nutrients, as well as changes in copepod species composition due to changes in wind and ocean currents (Atcheson et. al. 2012).

The National Research Council (NRC) has estimated that global sea- levels have been rising at a rate of about 3.2 millimeters per year since 1990 (NRC 2012), primarily due to thermal expansion. In addition, the melting of the Greenland and Antarctic ice sheets are expected to contribute to sea- level rise through the addition of significant quantities of water to the oceans. The rate of sea-level rise due to ice- sheet melting is highly uncertain, and therefore was not included in the estimates of future sea-level rise presented in the IPCC AR4 (2007), therefore, the IPCC 2007 estimates are widely believed to be underestimates of the actual anticipated rate of rise. Regional variability in the rate of sea-level rise can also occur due to such factors as differences land subsidence, groundwater withdrawals and reservoir storage. Empirical methods (Vermeer and Rahmstorf, 2009) based the relationship between historically-observed global temperature and sea-level rise along with GCM temperature projections to estimate future sea-level rise. The NRC 2012 report estimates that global sea levels will rise between 8 and 23 centimeters (cm) by 2030 from 2000, by 18 to 48 cm by 2050, and by 50 to 140 cm by 2100. Estimates and ranges of sea-level rise along the west coast of the United States are presented in Figure 3.

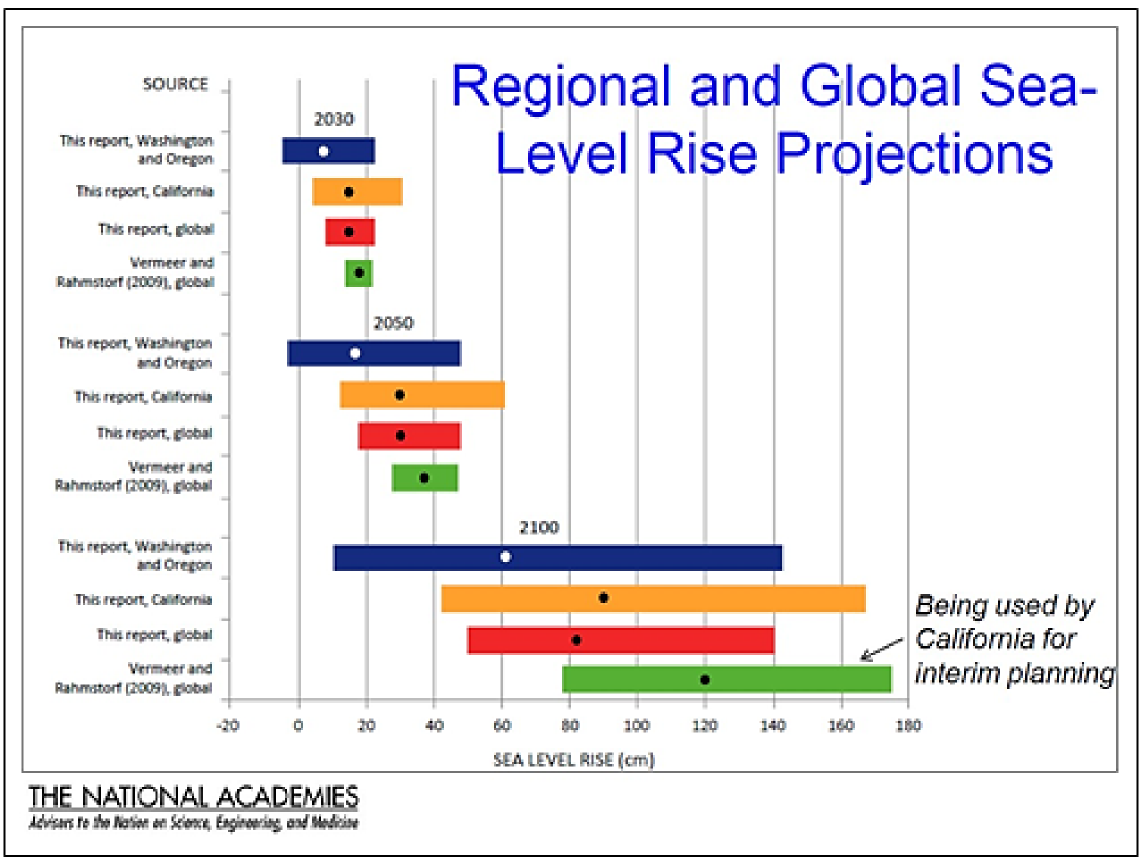

Figure 3: Regional and global sea level rise projections through the year 2100 from the NRC.