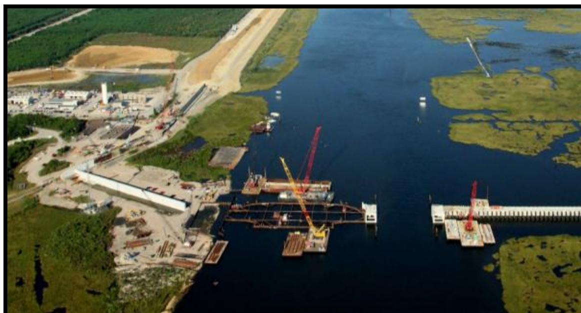
Addressing Climate Change in Long-Term Water Resources Planning and Management

User Needs for Improving Tools and Information



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Technical climate change information may be incorporated into longer-term water resources planning using various methods. In this report, eight technical steps representative of these various methods are used to categorize tools and information needs (i.e., gaps): 1. Summarize Relevant Literature; 2. Obtain Climate Change Information; 3. Make Decisions About How To Use the Climate Change Information; 4. Assess Natural Systems Response; 5. Assess Socioeconomic and Institutional Response; 6. Assess System Risks and Evaluate Alternatives; 7. Assess and Characterize Uncertainties; and 8. Communicating Results and Uncertainties to Decisionmakers.

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Addressing Climate Change in Long-Term Water Resources Planning and Management

User Needs for Improving Tools and Information

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US Army Corps of Engineers®

January 2011

Abstract

This document describes the water management community's needs for climate change information and tools to support long-term planning. Reclamation and the U.S. Army Corps of Engineers (USACE) technical specialists and program managers have worked with their planners, water operators, and environmental compliance managers to identify the information and tools most relevant to their programs. Reclamation and USACE also have engaged and consulted with other Federal, State, and local agencies and stakeholder groups that have a role in water and water-related resource management to identify complementary priorities and individual perspectives. This document is meant to help focus research and technology efforts to address information and tools gaps relevant to the water management user community.

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A Joint Message from the Commissioner, Bureau of Reclamation, and the Director of Civil Works, U.S. Army Corps of Engineers:

Water resources underpin our quality of life and our national economy. Climate change impacts to water and water-dependent resources present new and complex challenges to the water resources management community. Meeting these challenges will require close collaboration between the water resources management community and the science community to develop and apply new and improved scientific information and technical tools.

With this publication, the Bureau of Reclamation and the U.S. Army Corps of Engineers, as part of the Climate Change and Water Working Group, offer our joint agency perspectives on user needs we have identified to help us meet this challenge for long-term water resources planning. We also recognize the other Federal and non-Federal water resource organizations and interest groups that have contributed their perspectives to this document. We have published these contributed perspectives along with our own, and offer a synthesis of the collective messages heard.

We hope this document takes a step toward communicating a collective expression of needs from the water resources community of practice to the science community and fosters closer collaboration and expedited application of research results. As a next step, we encourage other water and natural resource user and coordination groups, such as the U.S. Department of the Interior (DOI) Landscape Conservation Cooperatives, to assist as new capabilities and new knowledge are applied and new perspectives and insights are gained.

We also encourage the science community to rally behind these needs with collaborative research and development (R&D) efforts to build the capabilities that we have identified. We look forward to effective, collaborative R&D across this community, including organizations such as the DOI Climate Science Centers, National Oceanic and Atmospheric Administration Regional Integrated Science and Assessment Centers, National Science Foundation and other Federal and non-Federal science organizations, as well as our own science capabilities. As water resource management agencies, we stand ready to work with the science community.

Michael L. Connor
Commissioner,
Bureau of Reclamation

Steven L. Stockton, P.E.
Director of Civil Works
U.S. Army Corps of Engineers

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Non-Federal organizations:

American Society of Civil Engineers
American Water Works Association
Association of Metropolitan Water Agencies
California Department of Water Resources
California Water and Environmental Modeling Forum
Family Farm Alliance
Seattle City Light
Water Utility Climate Alliance
Western States Water Council

Other Federal water and water-related management organizations:

Federal Emergency Management Agency
Federal Energy Regulatory Commission
NOAA National Ocean Service - Coastal Services Center
Power Marketing Administration – Western Area Power Administration
USEPA – Office of Research and Development
USEPA – Office of Water
USEPA – Region 8

Executive Summary

The Bureau of Reclamation (Reclamation) and the United States Army Corps of Engineers (USACE) recognize that there is a critical need to begin incorporating climate change science into the design, construction, and operations of our water resources management infrastructure. These two agencies, together with the United States Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA), formed an interagency working group called the Climate Change and Water Working Group (CCAWWG) in 2007 to provide scientific collaborations in support of water management as climate changes. In February 2009, the four agencies produced an interagency report, USGS Circular 1331, *Climate Change and Water Resources Management: A Federal Perspective*, which provides a foundation to guide future policies, methods, and technologies.

Building on the foundation established by USGS Circular 1331, CCAWWG is pursuing a collaborative process to better define the critical capability gaps that face the water management community and to define a sound science strategy for filling the information gaps and providing critical tools. The effort builds on chapter 6, table 2 of USGS Circular 1331 and is guided by the following objectives:

- *Consolidate the Needs of the Water Management Community* - Identify the common needs of the Federal and non-Federal water management community for information and tools required to support adaptation as climate changes.

- *Inform the Scientific Community* - Guide and foster Federal and non-Federal research and technology investments toward meeting these “user-defined” needs.

- *Teamwork* - Generate collaborative efforts across the water management and scientific communities to develop, test, and apply new methods, tools, and capabilities

- *Flexible and Inclusive* - Issue periodic updates as new information and additional perspectives are obtained. It is unrealistic to assume that all relevant perspectives can be represented in the initial release of a user-needs document. The intent is to seed the initial release with a representative cross section of the other Federal and non-Federal water management perspectives and then use online networking technologies to accommodate input and perspectives across the water management community of practice.

To accomplish this aim, CCAWWG is developing four related documents describing water managers' needs for climate change information to support both short-term and long-term water resources planning and the complementary science strategy to address those needs. The four documents are as shown below, with the current document highlighted.

	Water Resources Planning Time Scale	
	< 5 years	>5 years
User Needs	Short-Term Needs	Long-Term Needs
Science Strategy	Short-Term Science Strategy	Long-Term Science Strategy

This document, the Long-Term Needs document, describes the water management community's needs for climate change information and tools to support long-term planning. As two of the primary Federal representatives of the water management community, Reclamation and USACE technical specialists and program managers have worked with their planners, water operators, and environmental compliance managers to identify the information and tools most relevant to their programs. Reclamation and USACE also have engaged and consulted with other Federal, State, and local agencies and stakeholder groups that have a role in water and water-related resource management to identify complementary priorities and individual perspectives (see chapter 3 and appendix B).

At the same time, Reclamation and the USACE have begun work on the Short-Term Needs document, describing water managers' needs for information to better manage water resources under short-term climate variability and change. Climate variability involves fluctuations in climate conditions on time scales of months, years, and decades. Improved ability to forecast and use climate variability information would greatly enhance the ability of water managers and water users to plan their short-term-operations and water delivery schedules. The influence of climate change on short-term climate variability is an additional factor that is now central to this area of concern.

In response to these user-needs documents, the USGS and NOAA will jointly prepare two documents describing respectively a science strategy for meeting short-term and long-term needs for information and tools. Development of those documents also will incorporate perspectives from other Federal and non-Federal representatives of the scientific community.

> **Note:** This report refers to ***planning*** as the analyses conducted to inform decisions about water system development and management. In contrast, USACE defines ***Planning*** as a six-step process in accordance with *Economic and Environmental Principles and Guidelines for Water and Related Resources Implementation Studies* (Water Resources Council 1983) and as authorized by the Water Resources Development Act of 1986 (Public Law 99-662) (see Orth and Yoe 1997). The ***Planning*** process includes decisionmaking under uncertainty, based on information from these analyses. Although decisionmaking is not explicitly addressed in the ***planning*** definition of this report, many gaps in this report address how supporting analyses are affected by knowledge limits and uncertainties. Research to address such gaps, thus, should benefit decisionmaking in ***Planning*** processes.

Audience: This document is meant to help focus research and technology efforts to address information and tools gaps relevant to the water management user community. As such, the primary audience for this document is the research and technology community in position to address these gaps. Such community members include CCAWWG science agencies (NOAA, USGS), other Federal research entities and programs (e.g., National Science Foundation, National Aeronautics and Space Administration, U.S. Environmental Protection Agency, U.S. Department of Agriculture, U.S. Forest Service, Department of Energy), State and local science centers, academic institutions, and the members of the practitioner community that support climate and water resources research.

Summary of Gap Categories: Technical climate change information may be incorporated into longer-term water resources planning using various methods. For this report, eight technical steps representative of these various methods are used to categorize tools and information needs (i.e., gaps). These steps are:

1. *Summarize Relevant Literature:* For a given planning study, this step involves identifying, synthesizing, and summarizing previous research on global to regional climate change and what it means for the region's water resources.

2. *Obtain Climate Change Information*: This step involves obtaining contemporary climate projections and associated uncertainties that may have been spatially downscaled to finer resolution desired for water resources planning at the regional to local scale. This step also involves consideration of paleoclimate proxies that may imply climate conditions different from those of the observed record.

3. *Make Decisions About How To Use the Climate Change Information*: From the body of climate projections surveyed, decisions must be made on which projections to use and which aspects of these projections to relate to planning assumptions on water supplies, water demands, and operating constraints.

4. *Assess Natural Systems Response*: Based on the preceding step's decisions, this step involves assessing the natural systems response under projected climate conditions. Results from these analyses will be used to set assumptions about future water supplies, water demands, and operating constraints. Types of natural systems responses include watershed hydrology, ecosystems, land cover, water quality, consumptive use requirements of irrigated lands, sedimentation and river hydraulics, and sea level rise.

5. *Assess Socioeconomic and Institutional Response*: This step involves assessing social, economic, and institutional responses to climate change that could influence planning assumptions concerning water demands and

operating constraints (e.g., constraints that determine source of supply preference and/or expected level of operating performance relative to objectives such as flood risk reduction, environmental management, water quality management, water allocation for agricultural and municipal use, energy production, recreation, and navigation).

6. *Assess System Risks and Evaluate Alternatives:* This step involves assessing system risks based on future planning assumptions (informed by Steps 4 and 5); and, as necessary, evaluating long-term management alternatives to address climate change risks. For example, many water resources management studies focus on operations risk and assumptions about future water supplies, demands, and operating constraints. In contrast, infrastructure safety or flood risk reduction studies focus on human safety and economic and environmental damages under assumptions about future extreme hydrologic event probabilities; and water quality studies focus on the interaction between the human activities, landscape hydrology, and aquatic systems.

7. *Assess and Characterize Uncertainties*: This step involves assessing and characterizing uncertainties accumulated during preceding steps (e.g., uncertainties of projecting future factors forcing climate, simulating climate, downscaling climate, assessing natural and social system responses, etc.).

8. *Communicating Results and Uncertainties to Decisionmakers:* This step involves aggregating information from previous steps and then communicating this distilled information to decisionmakers to support planning decisions.

Table ES-1 provides an initial list of gaps in tools and information associated with these steps. Given the geographic areas served by Reclamation and USACE, these gaps may be thought of as being nationally relevant. While this document presents gaps that are particularly relevant for management of Reclamation and USACE water supply and river regulation systems, it was envisioned that these gaps may be generally applicable for long-term management of any type of water infrastructure. To gauge this possibility, feedback on the gaps in table ES-1 was gathered from non-Federal organizations and other Federal agencies. The most-frequent relative priority (i.e., low, medium, high) assigned by Reclamation and USACE for each gap is shown next to the most frequent relative priority received from all Federal (including Reclamation and USACE) and non-Federal respondents combined. In the event of a tie, the lower priority was assigned. For example, if one gap had an equal number of medium priority responses as high responses, then the gap was assigned a medium priority. An examination of table ES-1 shows the priority rankings assigned by Reclamation/USACE compare favorably with those assigned by all respondents combined with only minor differences (e.g., low versus medium or medium versus high) on 12 of the 39 gaps listed.

Table ES-1. Summary of gaps and relation to other needs assessments

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1]		Other Assessments Having Related Discussion
	Reclamation/ USACE	All Respondents	
Step 1 – Summarize Relevant Literature			
1.01 Access to a clearinghouse of climate change literature relevant to water management or access to a bibliography of recommended literature to represent in literature syntheses.	Low	Low	CCAWWG 2008
1.02 Region-specific literature summaries, regularly maintained and peer-reviewed.	Medium	Medium	CCAWWG 2008
Step 2 – Obtaining Climate Change Information			
2.01 Improved skill in simulating long-term global to regional climate.	High	High	Reclamation 2007, Western States Water Council (WSWC) 2007
2.02 Downscaled data at finer space and time resolutions and for different variables.	High	High	CCAWWG 2008, WSWC 2007
2.03 Information on the strengths and weaknesses of downscaled data and the downscaling methodologies used to develop these data (including both statistical and dynamical methods and associated approaches for climate model bias-correction).	High	High	WSWC 2007
2.04 Indication of conditions of where and when the stationarity assumption of statistical downscaling may not hold (defined above) and should motivate use of dynamical downscaling techniques rather than statistical.	Medium	Medium	CCAWWG 2008, WSWC 2007
2.05 Synthesis of sea level projection information and guidance on consistent use in planning for all Reclamation and USACE coastal areas.	Low	Low	

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Table ES-1. Summary of gaps and relation to other needs assessments (continued)

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1]		Other Assessments Having Related Discussion
	Reclamation/ USACE	All Respondents	
Step 3 – Make Decisions About How To Use the Climate Change Information			
3.01 Understanding on observed climate variability from daily to multidecadal time scales, which underpins interpretation of future variability in climate projections and its relation to planning assumptions.	High	High	Reclamation 2007, WSWC 2007
3.02 Understanding how to interpret future variability in climate projections and relevance to operating constraints on shorter- to longer-term time scales (from daily to multidecadal).	High	High	Reclamation 2007
3.03 Basis for culling or weighting climate projections (if at all) when deciding which projections to use in planning.	Medium	Medium	CCAWWG 2008
3.04 Guidance on how to appropriately relate planning assumptions to either *Period-Change* or *Time-Developing* aspects of climate projections when deciding how to use projections in planning.	Low	Medium	
3.05 Guidance on how to jointly utilize the longer-term climate variability from observed records, paleoclimate, and projected climate information when portraying drought and surplus possibilities in planning.	Medium	High	Reclamation 2007, CCAWWG 2008
3.06 Method and basis for estimating extreme meteorological event possibilities, deterministically or probabilistically, in a changing climate.	High	High	CCAWWG 2008
Step 4 – Assess Natural Systems Response – Watershed Hydrology (WH), Ecosystems (E), Land Cover (LC), Water Quality (WQ), Consumptive Use on Irrigated Lands (CU), and Sedimentation and River Hydraulics (SRH)			
4.01 (*WH*) Guidance on strengths and weaknesses of watershed hydrologic models/methods to support scoping decisions in planning.	Low	Low	CCAWWG 2008
4.02 (*WH*) Understanding how climate change should impact potential evapotranspiration and how it is represented in watershed hydrologic models.	High	High	Reclamation 2007

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Table ES-1. Summary of gaps and relation to other needs assessments (continued)

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1]		Other Assessments Having Related Discussion
	Reclamation/ USACE	All Respondents	
Step 4 – Assess Natural Systems Response – Watershed Hydrology (WH), Ecosystems (E), Land Cover (LC), Water Quality (WQ), Consumptive Use on Irrigated Lands (CU), and Sedimentation and River Hydraulics (SRH) (continued)			
4.03 (*WH*) Method and basis for estimating extreme hydrologic event possibilities, deterministically or probabilistically, in a changing climate. *(Similar to Gap 3.06 but focused here on hydrology rather than meteorological variables)*	High	High	CCAWWG 2008
4.04 (*WH*) Guidance on strengths and weaknesses of available versions of spatially distributed hydrologic weather data that may be used for both watershed hydrologic model development (Step 4) and in climate model bias-correction (Step 2).	Medium	Medium	
4.05 (*WH*) Understanding how climate change should impact groundwater recharge and groundwater interaction with surface water supplies.	Medium	Medium	Reclamation 2007, CCAWWG 2008
4.06 (*E*) Understanding how climate change should impact inland and coastal anadromous fisheries.	Medium	Low	CCAWWG 2008
4.07 (*E*) Understanding how climate change may impact riparian ecosystems and vegetation that affect both longer-term water budgets and ecological resources.	High	Medium	CCAWWG 2008
4.08 (*E*) Understanding translated into model frameworks for assessing climate change responses for fisheries, nonnative riparian vegetation, and other species or habitat conditions.	High	Medium	CCAWWG 2008
4.09 (*LC*) Understanding how climate and/or carbon dioxide changes should impact land cover communities that control natural evapotranspiration and soil erosion potential.	Medium	Low	Reclamation 2007, CCAWWG 2008
4.10 (*WQ*) Understanding how water quality characteristics depend on climatic variables and how dependencies may evolve in a changing climate.	High	High	
4.11 (*CU*) Understanding how climate and carbon dioxide changes should impact plant physiology, how impacts vary with crop type, and how impacts affect irrigation demand.	Medium	Medium	CCAWWG 2008

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Table ES-1. Summary of gaps and relation to other needs assessments (continued)

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1] Reclamation/ USACE	All Respondents	Other Assessments Having Related Discussion
Step 4 – Assess Natural Systems Response – Watershed Hydrology (WH), Ecosystems (E), Land Cover (LC), Water Quality (WQ), Consumptive Use on Irrigated Lands (CU), and Sedimentation and River Hydraulics (SRH) (continued)			
4.12 (*SRH*) Understanding how climate and/or land cover changes will change watershed sediment yield, changes in sediment constituency, and the resulting impacts on water resources.	Medium	Medium	
4.13 (*SRH*) Understanding how climate, land cover, and/or sedimentation changes will affect river and reservoir ice-event potential.	Medium	Low	
Step 5 – Assess Socioeconomic and Institutional Response			
5.01 Understanding how socioeconomic factors may affect flood risk reduction and reservoir regulation objectives in a changing climate (e.g., flood protection values, land management).	Medium	High	CCAWWG 2008
5.02 Understanding how socioeconomic factors may affect water and power delivery reliability, water allocations, as well as decisions on source of supply under a changing climate (e.g., groundwater pumping versus surface water diversion).	High	High	CCAWWG 2008
5.03 Understanding how institutional realities currently control socioeconomic responses to climate variability and could control socioeconomic responses under a changing climate.	Medium	Low	
Step 6 – Assess System Risks and Evaluate Alternatives			
6.01 Guidance on how to conduct an adaptation evaluation that efficiently explores and ranks strategy options, potentially using optimization techniques.	High	High	CCAWWG 2008
6.02 Guidance on how to portray realistic operator "learning" in evaluations supporting planning for climate change adaptation.	Low	Low	CCAWWG 2008
6.03 Guidance on how to assess the effect of planning proposals on climate.	Low	Medium	CCAWWG 2008

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Table ES-1. Summary of gaps and relation to other needs assessments (continued)

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1]		Other Assessments Having Related Discussion
	Reclamation/ USACE	All Respondents	
Step 7 – Assess and Characterize Uncertainties			
7.01 Uncertainty information on global climate projections data, including uncertainties about climate system science, portrayal in climate models, emissions scenario development, and simulation methods.	High	High	CCAWWG 2008
7.02 Uncertainty information on regional climate projections data, including uncertainties from choice of bias-correction and spatial downscaling methods.	High	High	CCAWWG 2008
7.03 Uncertainty in planning results stemming from method choices on how to use transient characteristics of climate projections in planning scenarios.	Medium	Medium	CCAWWG 2008
7.04 For each response analysis on a natural system, uncertainty information on system science and associated ways of portraying this science in a system model and the observations used to customize a model for a specific system.	Medium	High	CCAWWG 2008
7.05 For each response analysis on a socio-economic system, uncertainty information on system science and associated ways of portraying this science in a system model and the observations used to customize a model for a specific system.	High	Medium	CCAWWG 2008
Step 8 – Communicating Results and Uncertainties to Decisionmakers			
8.01 Guidance on strengths and weaknesses of various methods for communicating results and uncertainties affected by using climate projection information.	High	High	CCAWWG 2008
8.02 Guidance on how to make decisions given the uncertainties introduced by considering climate projection information.	High	High	

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Gaps are more fully discussed in section 2.4, and the priority ratings received during the perspective gathering process is discussed in section 3.0 (e.g., inviting prioritization of research to address gaps, inviting general comments, and inviting suggestions on missing gaps). A complete record of perspectives received, including relative priority assignments, are included in appendices B-D.

The relative priority ratings assigned to each of the gaps listed in tableES-1 were also averaged across the gaps associated with each Technical Step (also known as Gap Category) to derive a relative priority that could be associated for each Technical Step. These results are shown in table ES-2

Table ES-2. Prioritization of research to support each gap category

Technical Step	Gap Category (Technical Step)	Average Priority Rankings[1]	
		USACE/ Reclamation	All Respondents Combined
1	Summarize Relevant Literature	1.5	1.5
2	Obtaining Climate Change Information	2.5	2.4
3	Make Decisions About How To Use the Climate Change Information	3.0	2.7
4	Assess Natural Systems Response	3.0	1.9
5	Assess Socioeconomic and Institutional Response	2.5	2.3
6	Assess System Risks and Evaluate Alternatives	1.5	2.0
7	Assess and Characterize Uncertainties	2.0	2.6
8	Communicating Results and Uncertainties to Decisionmakers	3.0	3.0

[1] Low=1, Medium=2, High=3.

In terms of summary messages heard, Reclamation and the USACE indicate relatively greater concern for the following three Technical Steps:

- Step 3: Make Decisions About How to Use the Climate Change Information
- Step 4: Assess Natural System Responses
- Step 8: Communicating Results and Uncertainties to Decision-makers

This compares favorably to the perspectives of water managers from all respondents combined with agreement that both Steps 3 and Step 8 deserve the greatest concern. However, all respondents combined indicate a greater concern for Step 7: Assess and Characterize Uncertainties.

The remaining steps received relatively lower priority. Review of gap-specific summaries (section 3.3) suggests that much of this lower prioritization stems from perception that a relatively greater understanding currently exists in these step areas compared to those that were given higher priority and does not necessarily indicate they are not as important as those assigned a high priority.

Lastly, a number of commenting entities provided letter responses, some of which highlighted themes that were largely absent in the draft version of this report. Those letter responses are provided in appendix D. Two notable themes were:

- **Monitoring and Data Collection**: Need for supporting current data collection networks and understanding their adequacy to support water management in a changing climate.
- **Making Decisions Under Uncertainty**: Need for understanding the relative merits of various tools/concepts (e.g., adaptive management, robustness, resilience, flexibility) to support water management and development under a changing climate, and also understanding the compatibility of these tools/concepts with current influences on management (e.g., legislation, appropriations, policy).

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Figures and Tables

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List of Acronyms

°C	degrees Celsius
°F	degrees Fahrenheit
AMWA	Association of Metropolitan Water Agencies
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
BCSD	Bias-Correction Spatial Disaggregation
CA DWR	California Department of Water Resources
CCAWWG	Climate Change and Water Working Group
CCSD	Climate Change Science Program
cfs	cubic feet per second
CIRES	Cooperative Institute for Research in Environmental Science
CMIP3	Coupled Model Intercomparison Project, phase 3
CO_2	carbon dioxide
DCP	downscaled climate projections
DOD	Department of Defense
DOI	United States Department of the Interior
DOT	Department of Transportation
EIS	environmental impact statement
ESRL	Earth System Research Laboratory
ERDC	Engineer Research and Development Center
ET	evapotranspiration
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
GCM	general circulation model (i.e., a type of global climate model)
GHG	greenhouse gas

GSSHA	Gridded Surface Subsurface Hydrologic Analysis
GW	groundwater
HEC-HMS	Hydrologic Engineering Center hydrological modeling system
IACWD	Interagency Committee on Water Data
I&E	Installations and Environment
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
LLNL	Lawrence Livermore National Laboratory
NASA	National Aeronautics and Space Administration
NARCCAP	North American Regional Climate Change Assessment Program
NED	National Economic Development
NER	National Ecosystem Restoration
NOAA	National Oceanic and Atmospheric Administration
NOAA Fisheries	National Oceanic and Atmospheric Administration National Marine Fisheries Service
NRC	National Research Council
NSTC-CENR	National Science and Technology Council - Committee on Environment and Natural Resources
NWS	National Weather Service
OSD	Office of the Secretary of Defense
OSE	Other Social Effects
P	Precipitation
P&G	*Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies*
PMA	Power Marketing Administration
Q	Runoff (or streamflow)
R&D	Research and Development
Reclamation	Bureau of Reclamation

RED	Regional Economic Development
RFC	River Forecast Centers
RISA	Regional Integrated Science and Assessment
SECURE	Science and Engineering to Comprehensively Understand and Responsibly Enhance Water Act
SERDP	Strategic Environmental Research and Development Program
SRES	IPCC Special Report on Emissions Scenarios
SW	surface water
SWE	snow water equivalent
SWP	State Water Project
T	temperature
TAF	thousand acre-feet
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WCRP	World Climate Research Programme
WestFAST	Western Federal Agency Support Team
WRC	Water Resources Council
WSWC	Western States Water Council
WUCA	Water Utility Climate Alliance

1 Introduction

1.1 Background

The Bureau of Reclamation (Reclamation) (figure 1) was established more than 100 years ago with a mission centered on constructing irrigation projects in the Western United States, many of which are still functioning today. In the 107 years s7ince its creation, Reclamation's mission has evolved to include hydroelectric generation, municipal and industrial water supply projects, water reuse, ecosystem restoration, dam safety, and the protection and management of water supplies. As part of this evolution, Reclamation is looking for ways to better address environmental impacts, changing water uses, and periodic drought in the West. The effects of climate change on water resources pose new challenges that Reclamation must also address in fulfilling its mission.

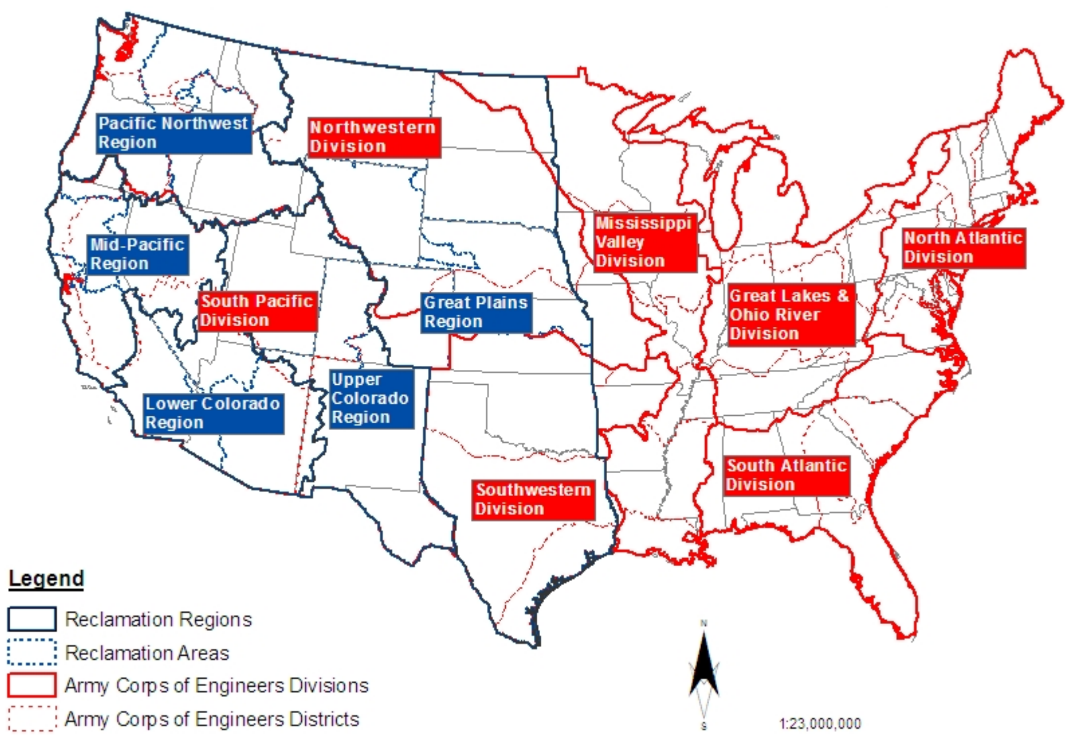

Figure 1. Reclamation and USACE geographical organization.

The U.S. Army Corps of Engineers (USACE) (figure 1) is the largest water resources operating agency in the United States. For more than 230 years, the USACE has supplied engineering solutions to water resources needs, including navigation, flood and coastal storm damage reduction, protection and restoration of aquatic ecosystems, hydropower, water supply, recreation, regulatory, and disaster preparedness and response. Each year, USACE implements new water resources development projects with non-Federal sponsors, adding to the approximately 12 million acres of land and water resources under USACE jurisdiction. The entire portfolio of USACE Civil Works water resources infrastructure and programs, existing and proposed, could be affected by climate change and adaptation to climate change, which in turn affect design and operational assumptions about resource supplies, system demands or performance requirements, and operational constraints. Both droughts and floods can affect the operations of these projects. Numerous regulatory decisions made by USACE will need to be informed by climate change impacts and adaptation considerations throughout the United States.

In February 2009, the National Oceanic and Atmospheric Administration (NOAA), USACE, Reclamation, and U.S. Geological Survey (USGS) released a report (USGS Circular 1331, *Climate Change and Water Resources Management: A Federal Perspective*) (Brekke et al. 2009a) on strategies to improve water management by tracking, anticipating, and responding to climate change. The report represents the views of two Federal water management agencies (USACE and Reclamation) and two Federal climate and water science agencies (USGS and NOAA) with respect to climate change impacts to water resources management. In addition to discussing climate impacts, the report also covered topics related to the use of available climate information in long-range planning, approaches for decisionmaking, and adaptation options. On the subject of anticipating and adapting to climate change impacts, the report offered the following key point:

> "Current expectations about future climate may indicate a need to supplement historical climate information. Planning assumptions might instead be related to projections of future temperature and precipitation. This can be accomplished using a multitude of approaches; a best approach has yet to be determined."

The point speaks to the growing need to incorporate climate projection information in planning. Planning in this document refers to planning in the general sense, encompassing studies that may involve proposed operations or physical changes to the water-related infrastructure that Reclamation and USACE manage. Other Federal, State, and local entities undertake similar types of planning and likely have similar needs.

Incorporating information means translating climate projection information into key planning assumptions (e.g., supplies, demands and constraints in the context of resource management studies, or hydrologic possibilities in flood risk and infrastructure safety evaluations). Although Reclamation and USACE have some understanding and capability of how to accomplish this, questions remain about how to interpret climate projection information and how to select appropriate methods for incorporating such information into planning evaluations, engineering design, construction, and operations. Circular 1331 highlights the importance of monitoring and research for addressing such limitations in understanding and planning capabilities.

> "Research and monitoring are both needed to fill knowledge gaps and set up advances in planning capabilities. Although neither will eliminate all uncertainties, they will provide significant improvements in understanding the effects of climate change on water resources, including quantity and quality, and in evaluating associated uncertainties and risks required for more informed decisionmaking."

Reclamation and USACE both recognize gaps between current and desired capabilities for incorporating climate change information into longer-term water resources planning, engineering design, construction, and operations. Some of these gaps are shared, given the mutual presence of these two Federal water management agencies in many Western United States (U.S.) systems. In contrast, some of these gaps are agency-specific, given the separate yet complementary missions of these two agencies.

1.2 Purpose

To build on the foundation established by USGS Circular 1331, the Climate Change and Water Working Group (CCAWWG) is pursuing a collaborative forum to better define the critical knowledge gaps that face the water management community. The effort builds on chapter 6, table 2 of USGS Circular 1331 and is guided by the following objectives:

- *Consolidate the Needs of the Water Management Community* - Identify the common needs of the Federal and non-Federal water management community for the information and tools they need to support adaptation as climate changes.

- *Inform the Scientific Community* - Guide and foster Federal and non-Federal research and technology investments toward meeting these "user-defined" needs.

- *Teamwork* - Generate collaborative efforts across members of the water management and scientific communities to develop, test, and apply new methods, tools, and capabilities

- *Flexible and Inclusive* - Issue periodic updates as new information and additional perspectives are obtained. It is unrealistic to assume that all relevant perspectives can be represented in the initial release of the document. The intent is to seed the initial release with a representative cross section of the other Federal and non-Federal water management perspectives and then utilize online networking technologies to accommodate input and perspectives across the water management community of practice.

The effort involves the two parts outlined below. **This document reports the results of Part I-A.**

Part I - Addressing Climate Change in Long-Term Water Resources Planning and Management: This effort involves communicating user needs and formulating science strategy to improve the tools and information that support resilient water management over multidecadal planning horizons.

- *Part I-A* is the preparation of a document outlining user needs by USACE and Reclamation that also contains the perspectives of the non-Federal and other Federal organizations that play a role in managing water resources.

- *Part I-B* is the preparation of a document by USGS and NOAA that provides the science strategy to meet the user needs indentified in Part I-A.

As the two primary Federal representatives of the water management community, Reclamation and USACE technical specialists and program managers have worked with their water and environmental compliance managers to identify the information and tools most relevant to their programs. Reclamation and USACE also have engaged and consulted with other Federal, State, and local agencies and stakeholder groups that have a role in water and water-related resource management to identify complementary priorities and individual perspectives (chapter 3). Part I-B will be led by NOAA and USGS and will also incorporate engagement and perspectives from other Federal and non-Federal representatives of the scientific community.

Part II – Addressing Climate Variability in Short-Term Water Resources Planning and Management: This effort involves communicating user needs and formulating science strategy to improve the tools and information that support water system management and operations scheduling over seasonal to annual planning horizons.

Climate variability is the fluctuation of climate around seasonal norms. The improved ability to forecast and utilize climate variability information would greatly enhance the ability of water managers and water user to plan their short-term operations and water delivery schedules. The influence of climate change on short-term climate variability is an additional factor now central to this area of concern.

Part II is being pursued in parallel to Part I. CCAWWG agencies will use a similar approach to ensure the perspectives of other Federal and non-Federal representatives are incorporated.

Lastly, it is noted that this document speaks to the technical issues when conducting “top-down” vulnerability assessments rather than “bottom-up” assessments. In a “top-down” assessment, climate projection information is obtained and explicitly translated into inputs for system vulnerability analyses (e.g., translating climate projection information into associated weather inputs for a hydrologic modeling exercise, which produces results that then are used to adjust water supply inputs for a reservoir systems analysis). In this sense, the “top-down” assessment is an exercise in information generation for decisionmaking. A “bottom-up” approach also generates such information, but in a simplified manner where stressing scenarios are defined without going through the explicit steps of a “top-down" assessment. "Bottom-up" assessments might be thought of as providing screening-level information on system vulnerabilities, which can be very useful in initiating discussion on adaptation needs and options (i.e., How would we operate our reservoir system if we experienced a 20 percent [%] reduction in water supply?). To be useful, "bottom-up" assessments must feature stressing scenarios that are plausible in the context of information that might be generated using a more rigorous top-down approach. Further, as the discussion on adaptation needs and options proceeds to decisions on capital improvement investments, it is expected that a bottom-up approach will need to be complemented or possibly replaced by a top-down approach where contemporary climate projection information is more explicitly linked to characterization of adaptation needs and related investment decisions.

Note: This report refers to ***planning*** as the analyses conducted to inform decisions about water system development and management. In contrast, USACE defines ***Planning*** as a six-step process in accordance with *Economic and Environmental Principles and Guidelines for Water and Related Resources Implementation Studies* (Water Resources Council 1983) and as authorized by the Water Resources Development Act of 1986 (Public Law 99-662) (see Orth and Yoe 1997). The ***Planning*** process includes decisionmaking under uncertainty, based on information from these analyses. Although decisionmaking is not explicitly addressed in the ***planning*** definition of this report, many gaps in this report address how supporting analyses are affected by knowledge limits and uncertainties. Research to address such gaps, thus, should benefit decisionmaking in ***Planning*** processes.

1.3 Audience

This document is meant to motivate research efforts to address gaps in tools and information relevant to the water management user community. As such, the primary audience for this document is the research community in position to strategize research to address these gaps. Such community members include CCAWWG science agencies (NOAA, USGS), other Federal research agencies and programs (e.g., National

Science Foundation [NSF], National Aeronautics and Space Administration [NASA], U.S. Environmental Protection Agency [USEPA], U.S. Department of Agriculture [USDA], U.S. Forest Service [USFS], Department of Energy [DOE]), State and local science centers, academic institutions, and also members of the practitioner community that support climate and water resources research.

1.4 Document Organization

The remainder of this document is organized as follows:

2 Capabilities Assessment

This chapter is the primary contribution of this document. It outlines and discusses planning capability gaps as they related to the planning frameworks broadly used by Reclamation and USACE to evaluate proposed resource management strategies and infrastructure safety/reliability issues. It builds on the foundation laid in USGS Circular 1331 and the effort discussed in chapter 2.0.

3 Perspectives from Other Water Management Organizations

This section summarizes views and reactions to gaps from section 2.0, offered by internal management at Reclamation and USACE, other Federal agencies, and non-Federal organizations. The common attribute of entities providing perspectives is that they all manage, or play a role in, managing water and water-related resources. This section provides a summary of views and perspectives offered, including opinions on how research to address gaps in section 2.0 might be relatively prioritized.

Appendix A: Preliminary Activities

This appendix summarizes findings from a technology and research scoping workshop in Denver, Colorado, during February 20–21, 2008, which included initial discussions between Reclamation, USACE, NOAA, USGS, USEPA, the Federal Emergency Management Agency (FEMA), and other agencies regarding capability gaps.

Appendix B: Survey Results on Gap Prioritization

This appendix is a table of surveyed priority ratings by gap statement from section 2.0, which is also summarized in section 3.

Appendix C: Record of Perspectives Contributed by Other Organizations – Table Comments (Electronic Supplement)

This appendix contains unedited feedback provided by organizations receiving the initial release of this document, as explained in section 3.0. The appendix is available at: www.usbr.gov/climate/userneeds.

Appendix D: Record of Perspectives Contributed by Other Organizations – Letter Comments (Electronic Supplement)

This appendix contains unedited feedback provided by organizations receiving the initial release of this document, as explained in section 3.0. The appendix is available at: www.usbr.gov/climate/userneeds.

2 Capabilities Assessment

This chapter describes contemporary (2009) perspectives of Reclamation and USACE on their technical capabilities status for incorporating climate change information into longer-term water resources planning, as described in the "Introduction." This chapter outlines and discusses planning capability gaps as they relate to the planning frameworks broadly used by Reclamation and USACE to evaluate proposed resource management strategies and infrastructure safety/reliability issues. The gap statements in this outline build on discussions from a workshop convened by CCAWWG in 2008 (appendix A) and include gap statements discussed during that workshop and later reported in USGS Circular 1331.

This chapter is organized as follows:

- Section 2.1: Summary of longer-term water resources planning evaluations regularly carried out by Reclamation and USACE.
- Section 2.2: Role of climate information in making planning assumptions for two types of studies: (1) water resource management studies and (2) infrastructure safety and flood risk reduction evaluations.
- Section 2.3: Approaches for considering climate change (or climate projection) information in longer-term planning, with approaches varying from qualitative to quantitative.
- Section 2.4: Capability assessment on implementing quantitative approaches:
    - *Desired Capabilities* in carrying out the planning analysis steps involved with translating climate change information into study assumptions for both types of studies listed above.
    - *Current Capabilities* in conducting those planning analysis steps.
    - *Capability Gaps* where current capabilities fall short of those desired.

- Section 2.5: Tabular summary of capability gaps from section 2.4, and cross-reference with other needs assessment conducted prior to 2009:

Note: Reclamation and USACE plan to periodically update this capabilities assessment.

2.1 Longer-Term Water Systems Planning in Reclamation and USACE

Reclamation and USACE are two of the principle Federal water management agencies, but each provide separate and complementary roles within their participation in the broader water management community of practice. Reclamation is primarily a water supply agency, and the USACE is primarily a flood control and waterway navigation agency. Both agencies have complementary responsibilities involving hydropower generation, aquatic ecosystem stewardship and restoration, operating and maintaining water infrastructure, and administering water-related recreation. USACE also has roles in regulatory and emergency response that are not addressed specifically in this document.

Both Reclamation and USACE regularly carry out studies that may lead to long-term investments in water infrastructure or long-term changes in facility operations. Two broad categories of planning are introduced in this section:

1. Planning for water resources management

2. Planning for infrastructure safety and flood risk reduction

These studies are conducted in accordance with the *Economic and Environmental Principles and Guidelines* (P&G) *for Water and Related Land Resources Implementation Studies* (WRC), 1983]. While the P&G contain no explicit discussion of climate change, the process is flexible enough to account for climate change (Frederick et al. 1997). Efforts are currently underway to review and update the P&G.

2.1.1 Planning for Water Resources Management

These studies examine options for providing new water-related services. These services include agricultural, municipal and industrial water supply, managed river flows, enhanced river transport, hydropower generation, and lake recreation. Study options may focus on the development of infrastructure to support these services, or possibly long-term changes in the operation of existing facilities.

The challenges of climate change now are being recognized as an important focus of water planning studies. The Federal Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act, signed as part of the Omnibus Land Management Act of 2009, authorizes a Climate Change Adaptation Program and requires the Secretary of the Interior to report to Congress on the effect of global climate change on each major Reclamation river basin. Monitoring and reporting increments are detailed in this section, and much of it is focused on the potential effects of climate change on Reclamation projects and developing mitigation strategies.

The USACE similarly has proposed the Adaptations to Climate Change Program scheduled for fiscal year (FY) 2010–2014. This program's goal is to develop and begin implementing practical, nationally consistent, and cost-effective approaches and policies to reduce potential vulnerabilities to the Nation's water infrastructure resulting from climate change and variability, in partnership with other Federal science and water management agencies and other stakeholders

2.1.2 Planning for Infrastructure Safety and Flood Risk Reduction

A second set of studies, aimed at reducing flood risk, might be further separated into two subsets: one focusing on ensuring the safety of existing infrastructure and another focusing on societal flood protection through developing flood control rules that constrain reservoir operations and river regulation.

Focusing on infrastructure safety evaluations, all Reclamation and USACE dams are subjected to periodic review of safety and risks, including risks associated with extreme flood events. For Reclamation, base reviews (comprehensive facility reviews) occur approximately every 6 years. For USACE, a national screening level has occurred and initial comprehensive reviews are underway, with implementation of a cycle of regular review expected thereafter. If the base process reveals significant risk, subsequent Issue Evaluations may occur. These evaluations may lead to decisions to modify operations or facility structures to reduce risk. For the latter types of modifications, an evaluation of longer-term service is required in accordance with the P&Gs for Water Resources Projects. USACE also is in the process of developing and implementing a similar process for levees.

Focusing on studies to develop flood control rules, USACE leads such studies for facilities with Flood Control Act of 1944, Section 7 requirements. Reclamation participates in these evaluations, along with other system stakeholders. These evaluations lead to USACE specifying "flood control rules" that govern USACE reservoir regulation and constrain Reclamation's (and other's) reservoir operations. Such rules reflect calendar periods when historical information suggests relatively greater and lesser flood risk, manifesting into respective periods when Reclamation must either operate reservoirs to reserve more or less storage space for flood risk reduction objectives. These rules typically are described in water control manuals specific to a given reservoir system and periodically are supposed to be revisited (approximately [~]10–15 years). However, funding constraints have limited the occurrence and frequency of reviews. Reclamation also evaluates flood potentials at facilities that are authorized for nonflood control objections.

2.2 Role of Climate in Longer-Term Planning Assumptions

This section explores how climate is represented in the two types of Reclamation and USACE planning studies discussed above. Discussion focuses on how climate information influences planning assumptions for each type of study.

2.2.1 Planning for Water Resources Management

Climate information influences longer-term evaluations of resource management strategies through assumptions about possible air temperature (T), precipitation (P) and runoff (Q) conditions, among other weather variables. These physical variables are translated into assumed variability in future water supplies, demands, and/or operational constraints (figure 2, adapted from Brekke et al. 2009a). Water supply assumptions are developed to portray the expected envelope of supply variability suitable for the given planning horizon. This includes assumptions about future surface water and groundwater supplies and associated statistics (e.g., mean, variance, possibilities for drought and surplus spells, and accumulations), including the potential for hydrologic extremes that create flood risk. All projections must reflect expected climate during the study's planning period.

Demand assumptions are characterized for each of the various system uses, including agricultural, municipal, environmental, hydropower generation, etc. For many studies, it is only necessary to establish "limits of demands" (upper or lower) and then assess system performance subject to the assumed demand limits, supplies, and system constraints. For other studies, the demands themselves may be the central question (e.g., establishment of long-term service contracts) and are evaluated subject to available supplies, constraints, and expected levels of delivery reliability. Demands are often characterized at a local level (e.g., municipality, irrigation district). Demands also depend on physical factors like temperature and precipitation, available nonsystem water supplies, atmospheric composition affecting plant evapotranspiration (carbon dioxide [CO_2]) and a variety of socioeconomic factors such as economic drivers of cropping choices, municipal use, and hydropower generation; institutional/legal capacity for water markets or transfer schemes affecting the timing of various system demands; technology development affecting water use efficiency; environmental trends affecting timing and amount of reservoir releases to support aquatic and riparian habitats.

Operating constraint assumptions are similar to demand assumptions in that both physical and nonphysical factors determine these assumptions. For example, flood control rules governing operation of surface water reservoirs depend on hydrologic event probabilities that, in turn, represent the present or assumed future climate conditions. Such rules also reflect other factors that determine USACE's ability to regulate reservoir systems to meet flood risk reduction objectives (e.g., channel conveyance capacity below flood control reservoirs, flood plain management affecting vulnerability and risk). System operations are also guided by, and constrained by, environmental objectives, social values (e.g., recreation), and the maintenance of important ecosystems and species habitat. Accomplishment of these objectives also must occur within projected climatic conditions.

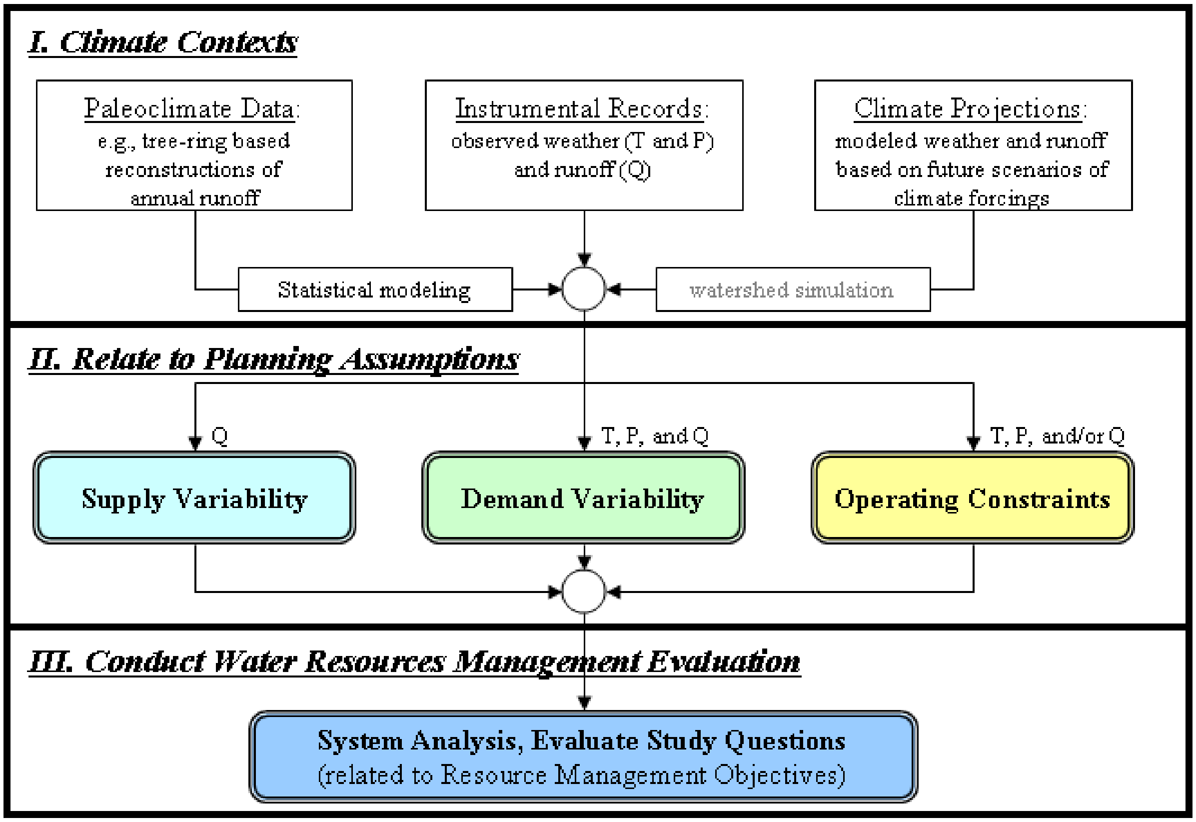

Figure 2. Types of planning assumptions in resource management studies affected by climate information.

2.2.2 Planning for Infrastructure Safety and Flood Risk Reduction

Climate information influences longer-term evaluations of hydrologic hazard possibilities and flood risk reduction primarily through assumptions about possible hydrologic events (figure 3). Extreme hydrologic events are related to possible air temperature (T) and precipitation (P) conditions that control the occurrence of acute runoff events (e.g., storm-related) or seasonally developing runoff events (e.g., related to rate of snowmelt, or snowpack development for recruitment during rain-on-snow events).

Infrastructure safety and flood risk reduction evaluations consider different types of hydrologic events. Infrastructure safety evaluations focus on rare events that could possibly cause facility failure and consequences that may include loss of life. Reclamation and USACE estimate such events using either deterministic methods to estimate of Probable Maximum Precipitation and Probable Maximum Flood (Brekke et al. 2009a) or methods that involve estimating event probabilities as

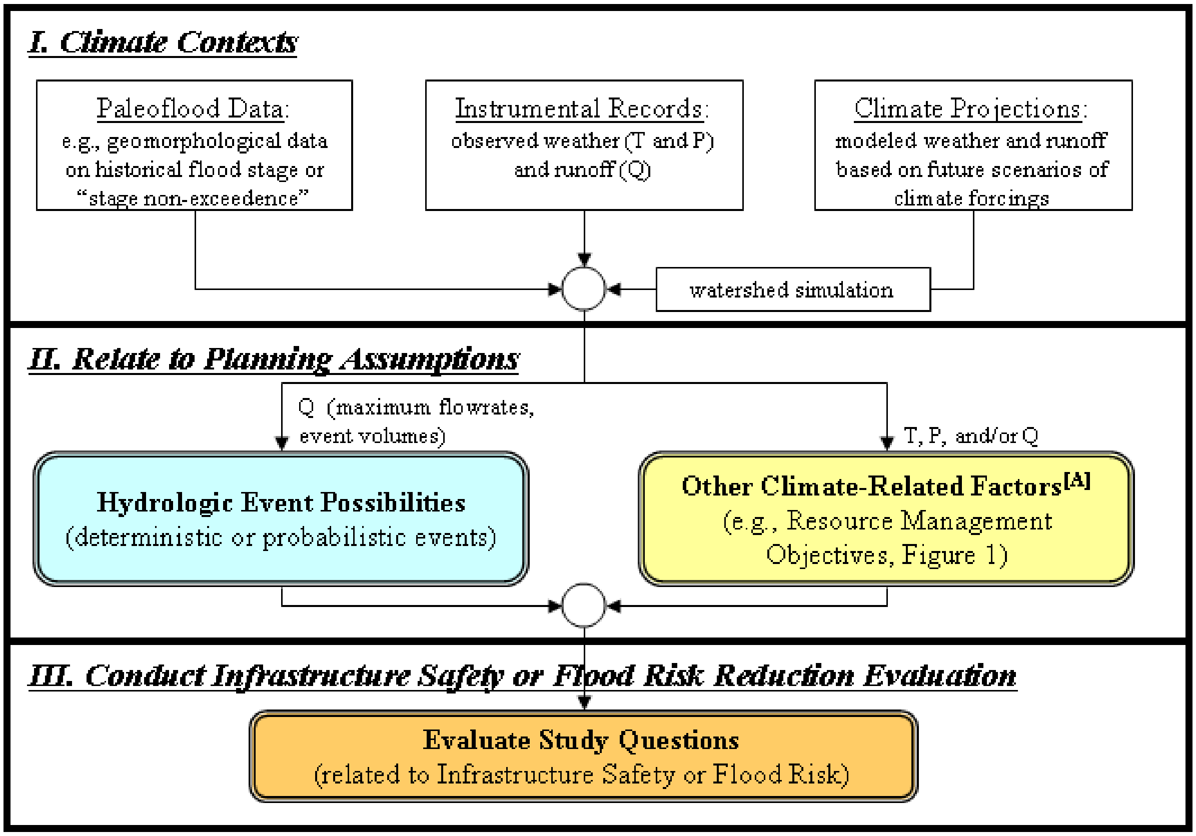

Figure 3. Types of planning assumptions in hydrologic hazards and flood risk evaluations affected by climate information. [A] – Often considered in evaluations of flood risk, but not in evaluations of infrastructure safety.

parametric extrapolations from historical flood frequency information (Interagency Committee on Water Data [IACWD] 1982). In contrast, evaluations of flood risk reduction through reservoir regulation consider a range of hydrologic events that have relatively higher probability of occurrence and would cause flooding and associated damages without such regulation (termed the "without project" case). The spectrum of relevant events for flood risk reduction evaluations is arguably broader than that associated with infrastructure safety and includes events that feature relatively less runoff rates or event volumes and occur more frequently.

Other climate-related considerations may factor into evaluations on flood risk reduction, as indicated on figure 3. For example, while the assessment of flood risk obviously depends on the hydrologic possibilities, it also depends on the contemporary paradigm of how the reservoir system is being managed to balance a variety of competing objectives. The assessment also depends on how downstream infrastructure may be used in combination with reservoir regulation to control runoff events, the potential for failure of flood risk reduction infrastructure, and the ability to evacuate the flood plain when runoff events cannot be fully controlled. Any proposed change to reservoir regulation policy may need to consider effects on other system management objectives, including the resource management objectives (figure 2). For evaluations about infrastructure safety, there may not be consideration for these other climate-related factors, and the sole climate-related assumption may be focused on hydrologic event possibilities.

Traditionally, Reclamation and USACE have based planning assumptions about hydrologic event possibilities on climate information from the period of instrumental records and, sometimes, on paleoflood evidence of flood stage or "stage nonexceedence." Recently, Reclamation and USACE have begun to look at climate projection implications for characterizing hydrologic event possibilities. Reclamation and USACE are currently collaborating on a study that explores the veracity of traditional probabilistic procedures for hydrologic hazard assessment in dam safety evaluations, but in the context of time-developing climate projections (Raff et al. in review). Reclamation and USACE also teamed on an earlier study that explored how hydrologic impacts information under climate change might be used to rationalize adjustments to seasonal flood control constraints (Brekke et al. 2009b). The motive of that study was to understand how assessments of reservoir operations risk under climate change may be sensitive to assumptions about flood control constraints on reservoir operations.

2.3 Approaches for Considering Climate Change in Planning

The previous section describes how climate change is relevant to longer-term water planning. Focus now shifts to how climate change information might be used.

The potential relevance of projected climate information varies by study, particularly with respect to the planning period. For example, proposed changes in resource management might apply through 2030 and invite questions about climate possibilities through the ~2030s. A proposed infrastructure addition would provide service well into the 21st century, perhaps inviting questions about longer-term climate. Depending on the relevance of climate change to the issues being studied, the planning period (or planning horizon), and other study-specific factors, the treatment of projected climate information might range from no analysis and a literature review to analytical treatments that proceed qualitatively or quantitatively. The flowchart in figure 4 represents such decisions.

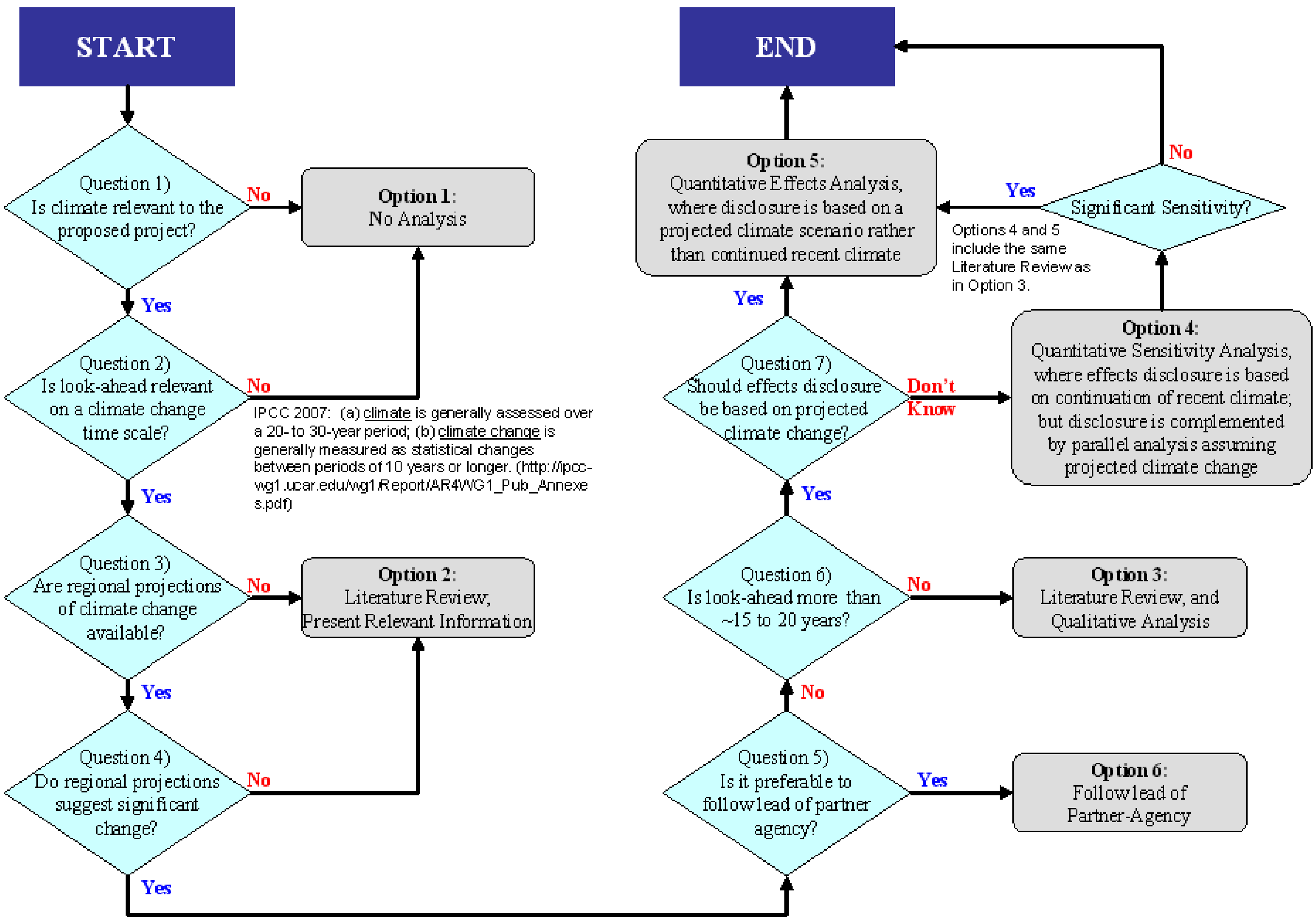

Figure 4. Decision tree for guiding level of analysis on incorporating projected climate information into longer-term project planning. Adapted from U.S. Department of the Interior (DOI) 2008, chart shows potential scoping questions, and answers leading to recommended options for considering whether and how to incorporate projected climate information into project-specific planning. Options 4 through 6 also include the literature review from Options 2 and 3.

Recent examples of *qualitative* analysis in longer-term planning studies include:

> Lower Colorado and Upper Colorado Regions, final environmental impact statement (EIS), for the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell*

and Lake Mead,[1] (Reclamation 2007). A separate report to the final EIS, Appendix U, *Review of Science and Methods for Incorporating Climate Change Information into Reclamation's Colorado River Basin Planning Studies* was developed to provide supporting information for the qualitative analysis and was co-edited by a team of Federal, academic, and private-sector researchers.

- Pacific Northwest Region, Final Planning Report/EIS, for the *Yakima River Basin Water Storage Feasibility Study*[2] (Reclamation 2008b).

Recent examples of *quantitative* sensitivity analysis in longer-term planning studies include:

- Mid-Pacific Region, biological assessment on the *Continued Long-term Operations of the Central Valley Project and the State Water Project*[3] (Reclamation 2008a). The analysis featured selection of climate and sea level scenarios, adjustments to assumptions on supplies and constraints related to sea level conditions. Evaluations were conducted on water system conditions (i.e., storage, river flows, and water deliveries) and dependent resources (i.e., water temperatures in reservoirs and rivers, channel flows and velocities in the Sacramento/San Joaquin Delta). Methods and results were documented in Appendix R, "Sensitivity of Future Central Valley Project and State Water Project Operations to Potential Climate Change and Associated Sea Level Rise."

- Pacific Northwest Region, general planning study, *The Effects of Climate Change on the Operation of Boise River Reservoirs, Initial Assessment Report*[4] (Reclamation 2008c). The analysis featured a selection of climate scenarios and adjustment to water supply assumptions (runoff). Evaluations were conducted on water system conditions, with focus placed on impacts to both water supply and flood control operations.

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[11] http://www.usbr.gov/lc/region/programs/strategies/FEIS/index.html, section 4.2.5.

[2] http://www.usbr.gov/pn/programs/storage_study/, section 4.2.2.6.

[3] http://www.usbr.gov/mp/cvo/ocap_page.html.

[4] http://www.usbr.gov/pn/programs/srao_misc/climatestudy/boiseclimatestudy.pdf.

- *Lake Ontario–St Lawrence River Study* used climate projection information and stochastic modeling to guide hydrologic variability assumptions in water control planning for the Lake Ontario–St. Lawrence River System[1] (International Joint Commission [IJC] 2006).

2.4 Step-by-Step Capabilities in Quantitative Approach

When incorporating projected climate information into longer-term planning, the broadest range of necessary planning capabilities occurs when a quantitative approach is implemented (i.e., either Options 4 or 5, figure 4). For that reason, this section focuses on planning capability gaps associated with implementing a quantitative approach to serve either water resources management or infrastructure safety and flood risk reduction studies.

For any quantitative approach, climate change information may be technically incorporated into longer-term planning using a variety of methods. For this report, eight technical planning steps representative of these various methods are used to categorize tools and information needs (i.e., gaps). These steps are:

1. *Summarize Relevant Literature:* For the region of a given planning study, this step involves identifying, synthesizing, and summarizing previous research on global to regional climate change and what it means for the region's water resources.

2. *Obtaining Climate Change Information*: This step involves obtaining contemporary climate projections data and associated uncertainties that have been spatially downscaled to finer resolution desired for water resources planning at the regional to local scale. This step also involves consideration of paleoclimate proxies that may imply climate conditions different from those of the observed record.

3. *Make Decisions About How to Relate Climate Projections Data to Planning*: From the body of climate projections surveyed, decisions must be made on which projections to use and which aspects of these projections to relate to planning assumptions on water supplies, water demands, and operating constraints.

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[1] http://www.ijc.org/en/activities/losl/losl_study.php.

4. *Assess Natural Systems Response*: Pending the preceding step's decisions, this step involves assessing natural systems responses under projected climate conditions. Results from these analyses will be used to set assumptions about future water supplies, water demands, and operating constraints. Types of natural systems responses include watershed hydrology, ecosystems, land cover, water quality, consumptive use requirements of irrigated lands, sedimentation and river hydraulics, and sea level rise.

5. *Assess Socioeconomic and Institutional Response*: Similar to the preceding step, this step involves assessing social, economic, and institutional responses to climate change that could influence planning assumptions concerning water demands and operating constraints (e.g., constraints that determine source of supply preference and/or expected level of operating performance relative to objectives such as flood risk reduction, environmental management, water quality management, water allocation for agricultural and municipal use, energy production, recreation, navigation).

6. *Assess Systems Risks and Evaluate Alternatives:* This step involves assessing system risks based on future planning assumptions (informed by Steps 4 and 5) and, as necessary, evaluating long-term management alternatives to address climate change risks. For example, in many water resources management studies, the focus is on operations risk and assumptions about future water supplies, demands, and operating constraints. In contrast, infrastructure safety or flood risk reduction studies focus on human safety and economic and environmental damages under assumptions about future extreme hydrologic event probabilities; and water quality studies focus on the interaction between the human activities, landscape hydrology, and aquatic systems.

7. *Assess and Characterize Uncertainties*: This step involves assessing and characterizing uncertainties accumulated during preceding steps (e.g., uncertainties of projecting future factors forcing climate, simulating climate, downscaling climate, assessing natural and social system responses, etc.).

8. *Communicating Results and Uncertainties to Decisionmakers:* This step involves aggregating information from previous steps and then communicating this distilled information to decisionmakers to support planning decisions.

Figure 5 illustrates the occurrence of each step within the context of resource management evaluations. Figure 6 shows the occurrence of each step during infrastructure safety or flood risk reduction evaluations.

Following the outline of these eight steps, the remainder of this section provides Reclamation and USACE perspectives on desired planning capabilities for each step, current capabilities, and capability gaps pointing to tool and information needs. When reading these discussions, two considerations should be recognized:

- The capability inventories in the following sections may not be exhaustive. However, Reclamation and USACE view these inventories as representative of the range of capabilities relevant to both agencies and, also, the range of shared capability gaps.

- This is a living document. Future updates are anticipated, based on research progress that addresses capability gaps as well as input from interested government, private sector, and stakeholder parties.

2.4.1 Step 1 – Summarize Relevant Literature

For longer-term planning processes, it is necessary to explain the role and impacts of climate change in the given study. Context is provided by a narrative representing available peer-reviewed literature and synthesis reports, summarizing:

- The state of climate change science (e.g., What are key indicators that climate is changing globally or regionally? What is our ability to project future changes in regional climate?).

- Historical and projected effects of climate change on water resources featured in the planning study.

- Contemporary climate projections characterized over the study region, focusing on climate variables and look-ahead period relevant to given planning evaluation.

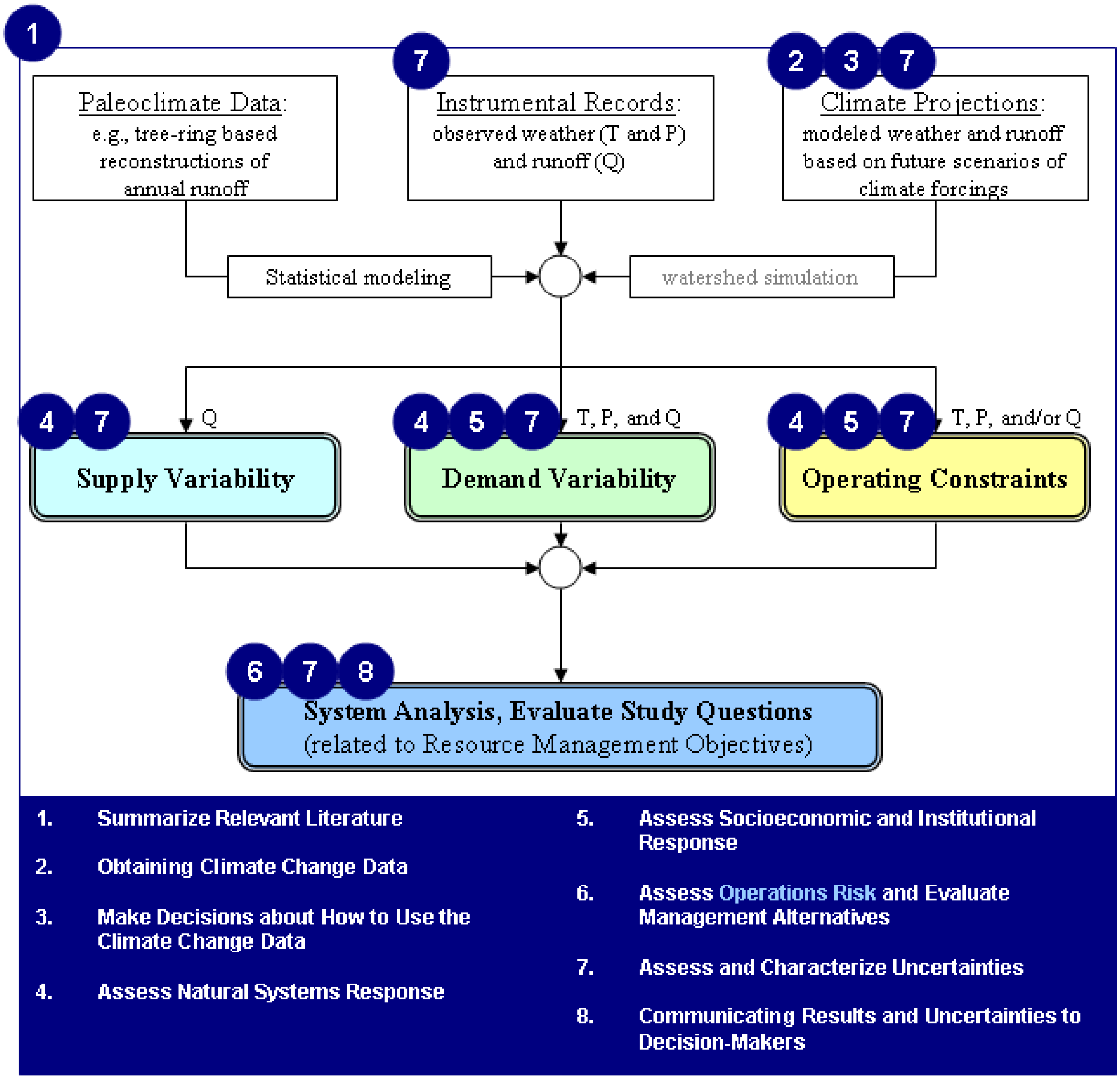

Figure 5. Analytical steps involved with translating climate projection information into planning assumptions for resource management evaluations.

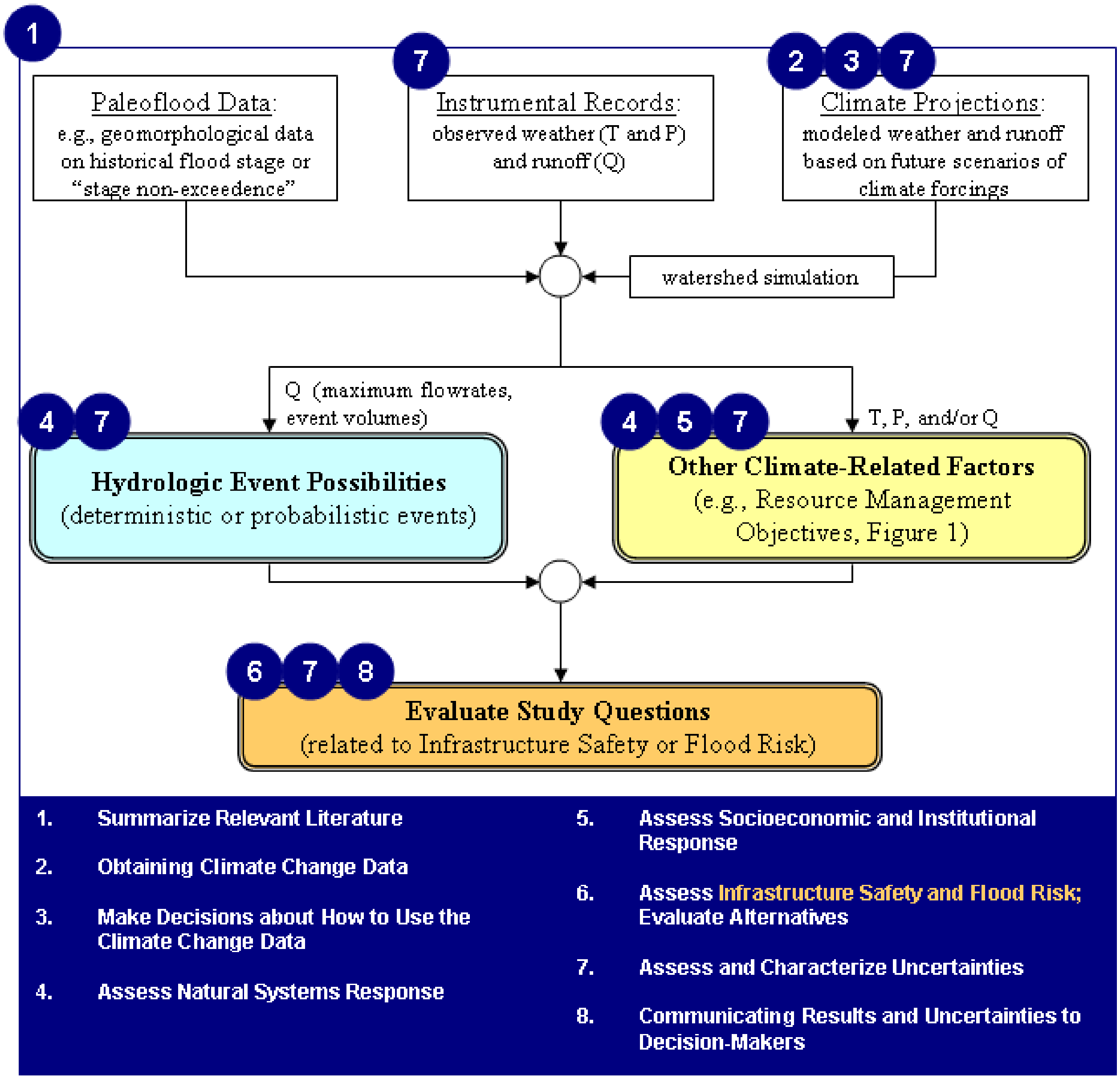

Figure 6. Analytical steps involved with translating climate projection information into planning assumptions for infrastructure safety and flood risk reduction evaluations.

For example, consider a study that involves evaluating new water service contracts for the next 30 years. The study might introduce the role of climate change by summarizing historical and projected climate patterns and impacts on water supplies and summarizing projections for temperature and precipitation through the ~2030s. Such background would provide a context for subsequent analysis of what these climate projections imply for planning assumptions about supplies, demands, and constraints.

Desired Capabilities

In the 2008 Research and Development (R&D) Scoping Workshop (appendix A), two desired capabilities were discussed. To be able to generate suitable literature summaries for environmental compliance and other longer-term planning documents, water resources study managers should:

- Have access to a clearinghouse for climate change literature.
- Have a means to consistently discuss climate change knowledge and implications for Reclamation and USACE systems on a regional basis. As shown on figure 1, Reclamation regions and areas have some border similarities with USACE districts and divisions, with borders largely following hydrological boundaries relevant to each agencies projects or systems of projects. Key differences are that USACE divisions and districts span the entire United States (lower 48 States shown on figure 1) while Reclamation regions and areas span only the 17 Western States.

Current Capabilities

Reclamation and USACE planning, engineering, and R&D groups are capable of initiating literature review and preparing a synthesis to address the points listed above. However, there are logistical limitations. Climate change research is dynamic. It is difficult to start from no background and be able to efficiently conduct a comprehensive literature review. Also, there are multiple potential ways to interpret the significance of literature research findings and/or current climate projection information. Given these realities, potential exists for syntheses to be inconsistent if prepared separately by each planning group. Doing so is also not cost effective, especially considering that both Reclamation and USACE conduct multiple longer-term planning processes in their geographic jurisdictions at any given time.

The need to efficiently and consistently prepare literature syntheses in all Reclamation regions was discussed at the 2008 R&D Scoping Workshop (Appendix A). Prior to that workshop, Reclamation had generated two “example” narratives for environmental compliance documents (appendix U of Reclamation 2007, and draft section 4.2.2.6 of Reclamation 2008b). The first narrative was relatively longer in form.

Workshop discussions suggested that centrally coordinated development of these syntheses was needed. Reclamation R&D scoping ensued, and a project was initiated to develop region-specific short-form literature syntheses more analogous to the shorter form (Reclamation 2008b) for use in Reclamation's environmental compliance and other longer-term planning reports. The first release of these literature syntheses was released in September 2009 (Reclamation 2009a[1]) and is scoped to support longer-term planning processes for Reclamation's five administered regions in the 17 Western States (figure 1). The document reflects peer-review by climate scientists from the five NOAA Regional Integrated Sciences and Assessment (RISA) centers focused on climate and hydrology in Reclamation regions.

Capability Gaps

While the initial release of Reclamation 2009a supports Reclamation planning on the near-term, it is understood that this document will need to be a living document, with literature review and synthesis narratives updated annually to take advantage of ongoing research developments. Drivers of this document maintenance include the facts that climate change science is dynamic and new research will need to be reported; also, the initial release is strong in some water resource areas and weak in others (Reclamation 2009a). It also is recognized that, while these syntheses are of value to USACE studies within the Reclamation region, USACE would be need to develop similar syntheses to support its additional missions within the 17 Western States and to support its missions in divisions and districts outside the 17 Western States.

Gap 1.01: Access to a clearinghouse of climate change literature relevant to water management or access to a bibliography of recommended literature to represent in literature syntheses.

Gap 1.02: Region-specific literature summaries, regularly maintained and peer-reviewed.

[1] Available at: http://www.usbr.gov/research/docs/climatechangelitsynthesis.pdf .

Current efforts have begun to build capability on distributing and utilizing region-specific literature syntheses in planning evaluations. More work remains to be done on completing, implementing, and refining the framework, and potentially broadening the scope of resource areas surveyed. Potential future efforts may focus on targeting these syntheses to discipline-specific audiences (e.g., hydrologists, ecologists) rather than solely to geographic audiences.

The matter of Reclamation and USACE having joint access to a clearinghouse for climate change literature remains unaddressed. Assuming that such a clearinghouse could be assembled within copyright limitations, its existence would benefit the preparation and maintenance of region-specific literature syntheses. Short of assembling such a clearinghouse, it would be helpful to at least have access to a recommended bibliography (possibly with abstracts) of relevant region- and resource-specific literature. Input from CCAWWG science agencies would help shape such a bibliography.

2.4.2 Step 2 – Obtain Climate Change Information

This step involves obtaining contemporary climate projection information over the study region. For water resources management evaluations, these data would be related to assumptions on future supplies, demands, and operating constraints during the planning period. For infrastructure safety and flood risk reduction evaluations, these data would be related to assumptions about hydrologic event probabilities.

Desired Capabilities

At a minimum, this step requires gathering projected temperature and precipitation data over the study region. Such regional projection data would presumably stem from available global climate projections that have been simulated by general circulation models (GCM, sometimes referred to as "global climate models") under various greenhouse gas (GHG) emissions scenarios and from different initial estimates of distributed ocean and atmospheric conditions.[1]

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[1] Represented in the World Climate Research Programme's Coupled Model Intercomparison Project – Phase 3 (WCRP CMIP3) multimodel dataset maintained by the Lawrence Livermore National Laboratory Program for Coupled Model Diagnosis and Intercomparison, http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php.

Planners also require information on the quality of GCMs being used to develop these climate projections.[1]

For "climate change" assessment, planners must have access to historical temperature and precipitation data to define a climate reference for two purposes: climate model bias-correction and climate projection spatial downscaling.

- The need for climate model bias-correction starts with recognition that the GCMs have been used to simulate historical conditions as well as future conditions. Comparing historical simulations to historical observations provides a sense of how that particular model's projections may be biased, given that the model may simulate historical climate that is too wet, dry, warm, and cool, etc. Each model has its own unique biases, and decisions must be made on whether and how to account for these climate model tendencies in planning (i.e., bias-correction).

- The need for climate projection downscaling stems from how spatial hydrologic processes at the study region-scale are coarsely resolved in GCM at the atmospheric circulation model region-scale. This raises questions about how to translate climate projections data to resolutions that are relevant to the planning process. Spatially, the data need to be translated from the coarse spatial resolution of GCMs to a finer "basin-relevant" resolution necessary for impacts analysis on natural and social systems (e.g., hydrologic, ecosystem, social). This process typically is called spatial downscaling and can be conducted statistically or dynamically (e.g., appendix B of Brekke et al. 2009a). Temporally, GCM generate climate projections at subhourly time steps. The value of raw, subhourly GCM information is questionable, given the spatially coarse nature of the output (e.g., subhourly output over Western U.S. mountainous topography that is necessarily smoothed for

[1] In 2009, the Water Utility Climate Alliance (http://www.wucaonline.org/html/) has commissioned the report (WUCA 2009) that is concerned with how investments in climate modeling can best be directed to help improve the quality of science so that it may be more useful to water utilities and other possible users in adapting to climate change. The main focus of the report is the identification of investments in the science of climate change that, in the opinion of the report's authors, can best improve the science to support adaptation.

GCM-simulation purposes). As it is, much of these GCM output datasets have been temporally aggregated from subhourly to monthly for data sharing purposes.[1] For some of the impacts assessments that follow, assumptions have to be introduced to disaggregate this available monthly projection information into submonthly time-steps (e.g., daily, hourly) at the spatially downscaled resolution desired to meet the study purposes.

Participants at the 2008 R&D Scoping Workshop discussed various issues on access to downscaling and regional climate projection information. Several needs were expressed:

- Projections of temperature, precipitation, and other climate variables (e.g., humidity, daily minimum and maximum temperature) at spatial and temporal resolutions that vary with type of impact being analyzed. For example, for resource management evaluations in a given reservoir system, suitable spatial and temporal scales may be tributary subbasin and monthly to daily. For flood risk evaluation in that same system, the temporal scale may need to be daily or finer. For ecosystem habitat or water quality evaluations, there may be added emphasis on diurnal temperature range as a determinant of habitat conditions, with the resulting need for daily minimum and maximum temperature information.

- Understanding the relative strengths and weaknesses of the various downscaling methodologies.

- Understanding the significance of the stationarity assumption[1] featured in nondynamical techniques.

In addition to having access to regional climate projection information, planning in coastal areas requires sea level projection information consistent with global climate projections. Global drivers of sea level change include ocean thermal expansion due to warming and ocean volume change due to melting of global ice (Mote et al. 2009). Local drivers include regional atmospheric circulation and vertical tectonic movements (e.g., subsidence or isostatic rebound). Sea level projection

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[1] In the context of downscaling, “stationarity” means that the relationship between regional atmospheric circulation and local surface weather will remain constant while global and regional climate changes.

information affects Reclamation and USACE planning in a variety of U.S. coastal areas (e.g., Reclamation's Mid-Pacific Region Central Valley Project, where water supplies are conveyed through the Sacramento-San Joaquin Delta). USACE has developed guidance on sea level change based on three scenarios (USACE 2009), which are: 1) a continuation of the local mean relative sea level trend, 2) an "intermediate" rate of local mean sea level change using the modified Curve I provided in the guidance from the National Research Council's (NRC) report *Responding to Changes in Sea Level: Engineering Implications* (NRC 1987), and 3) a "high" rate of local sea level change using the modified NRC Curve III provided in the guidance.

Current Capabilities

Reclamation and USACE have access to a large collection of current global climate projections.[1] It is recognized that the GCMs used to generate these projections have strengths and weaknesses in simulating regional climate conditions. Summaries of these weaknesses have been well-documented (Christensen et al. 2007, CCSP 2008).

Reclamation and USACE also have access[1] to numerous types of downscaling techniques that might be applied to translate global climate projections from GCM-resolution to basin-relevant resolution over their study areas. Information is also available on the relative strengths and weaknesses of these available techniques (Fowler et al. 2007, CWCB 2008, Maurer and Hidalgo 2008, Brekke et al. 2009a, Water Utility Climate Alliance [WUCA] 2009).

Reclamation and USACE have access to downscaled climate projections data over the lower 48 States, produced using two different techniques, dynamical and statistical downscaling:

- *Dynamically Downscaled Data.* The North American Regional Climate Change Assessment Program (NARCCAP[2]) is a dynamical downscaling effort funded by Nationals Science Foundation, Department of Energy, NOAA, the Canadian consortium OURANOS

[1] From this point forward, it is understood that members of the broader water management community share the same access as Reclamation and USACE, except in instances where noted.

[2] http://www.narccap.ucar.edu/.

and the U.S. Environmental Protection Agency (USEPA). The main goals of NARCAAP are: (1) exploration of multiple uncertainties in regional model and global climate model regional projections, and (2) development of multiple high resolution regional climate scenarios for use in impacts assessments. The approach involves using multiple regional climate models (RCMs) laterally forced by output from a GCM, where the latter output originates from a chosen GCM and its simulation of historical climate (1961-1990) and future climate (2041–2070 based on SRES A2). The NARCCAP dataset is being completed in 2009 and will contain downscaled output from four global climate projections. While the dataset is sparse in number of global climate projections represented, it is variable rich and provides downscaled conditions for not only surface conditions but also atmospheric conditions. It is also informed by multiple RCMs, which supports some investigation of RCM-specific uncertainties associated with dynamical downscaling.

- *Statistically Downscaled Data*. The "Statistically Downscaled WCRP CMIP3 Climate Projections" comprises an archive of downscaled projections of *monthly* precipitation and temperature from 1950-2099, downscaled to 1/8° spatial resolution (~12 km^2), over the contiguous United States (downscaled climate projections [DCP] archive). Relative to the NARCCAP archive, the DCP archive is variable-poor but projection-rich as it represents a large collection of currently available global climate projections. The archive was developed through collaboration by Reclamation, Santa Clara University and Lawrence Livermore National Laboratory (LLNL). It is accessible through a public Web service.[1] Downscaling was conducted using a statistical technique known as Bias Corrected Spatial Downscaling (BCSD) that uses fine-scale climate observations to (1) adjust future climate projections based upon errors in simulations of historical climate and (2) add spatial detail to the coarse-resolution results (Wood et al. 2002, Wood et al. 2004). The technique has been applied to numerous hydrologic impacts studies (e.g., Payne et al. 2004, Maurer 2007, Christensen and Lettenmaier 2007, Brekke et al. 2009b). Reclamation, Santa Clara University, and LLNL maintain the Web service, which supports custom and region-specific data

[1] *Statistically Downscaled WCRP CMIP3 Climate Projections* at http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/.

requests by archive users. The archive has been used to support various Reclamation planning studies (e.g., Reclamation 2008a) and research activities (e.g., Brekke et al. 2009b, Raff et al., in review).[1]

USACE has joined the development group of the DCP archive. Some of their effort will focus on daily time-step downscaling to compliment monthly data already contained in the archive. Daily data may be generated using Constructed Analogs (Hidalgo et al. 2007) coupled with bias-correction, which is a relatively new statistical downscaling technique.

For planning in coastal areas, Reclamation and USACE have access to sea level projection information directly produced by GCM and also sea level rise information derived using alternative, temperature-based methods (e.g., Rahmstorf 2007). The latter has been referenced in recent impacts assessments given limitations of interpreting sea level projections directly produced by global climate models (e.g., California Department of Water Resources [CA DWR] 2009 and Mote et al. 2008 addressing coastal impacts in California and Washington, respectively). This latter information was featured in a recent resource management evaluation conducted by Mid-Pacific Region (e.g., Reclamation 2008a). USACE projects in the planning, engineering, construction, and operation phases are in the process of complying with the recent sea level guidance (USACE 2009).

Capability Gaps:

Gap 2.01: Improved skill in simulating long-term global to regional climate.

Gap 2.02: Downscaled data at finer space and time resolutions and for more than just temperature and precipitation.

[1] Since being launched in 2007, the archive has served 488 users, collectively submitting over 3,500 data requests (as of July 9, 2009).

Gap 2.03: Information on the strengths and weaknesses of downscaled data and the downscaling methodologies used to develop these data (including both statistical and dynamical methods, and associated approaches for climate model bias-correction).

Gap 2.04: Indication of conditions of where and when the stationarity assumption of statistical downscaling may not hold (defined above) and should motivate use of dynamical downscaling techniques rather than statistical.

Gap 2.05: Synthesis of sea level projection information and guidance on consistent use in planning for all Reclamation and USACE coastal areas.

On the matter of obtaining climate projections data, perhaps the most apparent capability gap stems from perceptions held by water resource planning managers that global to regional climate projections currently have limited applicability in supporting water resources investigations (Reclamation 2007, WSWC 2007, perspectives offered at the 2008 R&D Scoping Workshop (appendix A), WUCA 2009). Improving global and regional climate prediction capabilities would improve the planners' inclination to incorporate such projection information into water resources investigations. Planners would also benefit if capabilities in downscaling were advanced. Relative to the archive of monthly data described above, some planning processes require temperature and precipitation information at finer resolution in space and time. For example, flood risk reduction evaluations require information at the daily or subdaily time scale, and information is needed on the quality of GCM outputs at these time scales for flood risk evaluation purposes. Other planning processes require information for climate variables other than the archive's temperature and precipitation (e.g., as noted, ecological studies requiring information about diurnal temperature range).

On the downscaling technique used to develop the archive data (BCSD) or the proposed new technique that will be applied with USACE support (BCCA), there is limited understanding about whether the underlying stationarity assumption is significant (geographically, by season, etc.). For example, it is questionable how climate change might trigger changes in land-atmosphere feedbacks that determine local microclimates, giving rise to questions about the "stationarity" of statistical relationships between local surface climate conditions and larger-scale atmospheric circulation (appendix B in Brekke et al. 2009a). Such questions might be addressed though comparison of NARCCAP data (dynamical downscaling, not encumbered by the stationarity assumption) and the BCSD- or BCCA-derived data for common underlying projections.

On sea level projection information, Reclamation and USACE have access to regionally oriented sea level projection assessments (e.g., Mote et al. 2008, CA DWR 2009). The Climate Change Science Program (CCSP) Synthesis and Assessment Product 4.1 (SAP 4.1), *Coastal Sensitivity to Sea Level Rise: A Focus on the Mid-Atlantic Region*, details both how sea level change affects coastal environments and what needs to be addressed to protect the environment and sustain economic growth (USEPA 2009). Reclamation and USACE still require guidance on how to synthesize coastal and inland regional assessments into information that consistently serves planning in all of their coastal areas.

2.4.3 Step 3 – Make Decisions About How To Use the Climate Change Information

After obtaining climate projections information, decisions must be made on: (a) which portion of this projection information to use in the planning study and (b) how the retained portion will be related to planning scenarios.

Desired Capabilities

To appropriately relate the body of projection information to a given planning study, practitioners need to be able to address several questions regarding choice and use of projections:

- How do we use our understanding of shorter-term historical climate variability (from daily to monthly time scales) to aid interpretation of the storm and synoptic weather possibilities portrayed in climate projections? Or, how do we use our understanding of longer-term historical climate variability (from annual to multidecadal time scales) to aid interpretation of climatological pattern possibilities portrayed in climate projections?

- For hydrologic event portrayal in infrastructure safety and flood risk reduction evaluations, how should historical observations affect or constrain consideration of shorter-term variability in climate projections?

- For drought and surplus portrayal in resource management evaluations, how should historical observations and paleoclimate proxies affect or constrain consideration of longer-term variability in climate projections?

- Should some of the projection information be culled from consideration? If yes, then what is an appropriate rationale for culling projections? Considering the retained projections after culling, should these projections be regarded as equally plausible or weighted in some unequal fashion? If the latter, what is an appropriate rationale for weighting retained projections?

- Which *aspects* of projected climate variability should be related to planning? For example, one approach would be to sample projections for period-statistics in mean climate and assess changes in those period-means from historical to future. Another approach would be to relate a more complete envelope of projected variability to planning assumptions, possibly considering the projection's portrayal of how temperature and precipitation conditions will unfold over time (e.g., mean and variability possible at any point in time, including frequency characteristics that govern reoccurrence potential for storms and droughts).

Much discussion was spent during the 2008 R&D Scoping Workshop (appendix A) on how to regard regional aspects projected climate variability and particularly that of precipitation projections. It was recognized that Intergovernmental Panel on Climate Change (IPCC) 2007 offered guidance on how to interpret global to continental projections, but offered less guidance for interpreting local to regional projections. There was particular interest in understanding projected low-frequency variability in precipitation (i.e., interannual to interdecadal spells of surplus or drought) as well as projected extreme event possibilities (e.g., probable maximum precipitation, storm possibilities relevant to flood control, heat wave possibilities). It was questioned how low-frequency variability should be regarded relative to such variability in historical observations and paleoclimate proxies (e.g., tree ring records).

On relating hydrologic event portrayal in infrastructure safety and flood risk reduction evaluations to shorter-term variability in climate projections, Reclamation and USACE are interested in how such information interfaces with either deterministic event portrayal (e.g., probable maximum precipitation estimation) or probabilistic portrayal (e.g., characterizing precipitation intensity-duration-frequency estimates in an historically or projected changing climate). The matter of probabilistic portrayal requires guidance on how much retrospective history should inform a point-in-time estimate of precipitation intensity-duration-frequency. This raises questions on how to interpret historical climate variability and, specifically, the time-changing nature of period statistics in that climate history (i.e., climate nonstationarity). Nonstationarity issues are also a matter of interpretation when using historical and projected climate information to inform drought and surplus portrayal in resource management evaluations.

On the drought and surplus portrayal in resource management evaluations, Reclamation and USACE are interested in how paleoclimate and projected climate variability information might be jointly utilized to support assumptions about water supplies. Paleoclimate data is of interest because it features a longer period of historical evidence for droughts and surpluses that have occurred. However, it is recognized that this evidence is more reliable for characterizing historical hydrologic year-type rather than actual runoff (Reclamation 2007). In contrast, climate projections can infer both runoff magnitudes and variability. However, projected variability generated by climate models is questionable given their limitations in simulating historical climate variability (Christensen et al. 2007, CCSP 2008). This has led to suggestions that water supply assumptions in resource management evaluations might be based on a blend of paleoclimate and projected climate information, where drought and surplus reoccurrence is linked to paleoclimate evidence, and intensity is linked to climate and runoff conditions climate projections (Reclamation 2007).

On the matter of deciding which projections to use, there was interest among managers at the 2008 R&D Scoping Workshop on whether climate projections might be culled or weighted. While managers wish to represent the breadth of climate projection information in planning assumptions, there is also a desire to minimize computational burdens in planning analyses and, therefore, limit the set of projections that would be related to planning assumptions to regard those assumptions as representative of available climate projections. Further, there was interest in being able to assert that planning assumptions were rooted in a body of "more credible" climate projection information, if that claim can be supported. To that end, there was workshop discussion on how climate projections might be culled or weighted based on regard for the relative likelihood of greenhouse gas emissions scenarios in the 21st century and/or regard for relative climate model skill at simulating historical climate conditions.

The question of deciding which aspects of climate projections to use in planning hints at the two paradigm options, listed below, for system portrayal in climate change planning:

1. *Period-Change*: system response to a period-change in climate conditions

2. *Time-Developing*: system response to a time-developing climate projection (Brekke et al. 2009a).[1]

The contrasting nature of these two paradigms is relevant to planning because they can portray significantly different climate change possibilities and associated impacts on water management. This is illustrated in the following example for the Trinity River basin. For this illustration, the *Period-Change* application is discussed first, then the *Time-Developing* application, followed by a comparison of the two.

Period-Change Application

To understand this paradigm, it helps to review a traditional planning approach, focusing on resource management evaluations. In the traditional approach (prior to considering changes in period climate), planning assumptions on water supply, demands, and operations constraint possibilities are based on observed historical data. Collectively, these planning assumptions represent an envelope of historical climate variability that is also assumed to be plausible and appropriate for the

[1] Brekke et al. 2009a used labels "Stationary System" and "System Projection," respectively.

planning future. In the *Period-Change* paradigm, parallel analyses are conducted, building from the traditional approach. One analysis is conducted with the traditional assumption representing the envelope of historical climate variability. The other analysis is conducted where traditional assumptions are incrementally adjusted to reflect an incremental change in climate. An increment of interest might be change in period-mean temperature conditions from historical to future periods sampled from a given climate projection.[1]

A conceptual illustration of water supply variability assumptions in a hypothetical *Period-Change* application is shown on figure 7 (water demand and operational constraint assumptions are not considered in this illustration). In this example, water supply variability is represented by reservoir inflow variability over time. Variability is defined by both period statistical and sequencing aspects. Figure 7 shows two reservoir inflow time series, each exhibiting an envelope of variability and having sequencing characteristics consistent with historical. The series differ in their full-period statistics. The first series (blue) reflects historical statistics from the period of instrumental record. The second series (red) reflects a uniform 10% reduction in historical. This 10% presumably is based on a related hydrologic impacts assessment where hydrology is simulated under historical weather and under adjusted weather reflecting a given increment of climate change (e.g., change in 30-year climate from a given climate projection; 1971–2000 to 2031–2060 in this example). Carrying forward these results in the planning process, the two reservoir inflow series are meant to reflect water supply variability under two climates: "historical" and "future." Two operations analyses then follow, and comparison of the two studies results reveals a resource management response (e.g., Miller et al. 2003, Anderson et al. 2008, Reclamation 2008a, CH2M-Hill 2008, and Vano et al. 2009).

[1] Many *Period-Change* studies have featured "change in monthly mean" as the climate change increment (Miller et al. 2003 for runoff impacts, or Anderson et al. 2008 and Vano et al. 2009 for water system management impacts). Recent *Period-Change* studies have featured "change in period distribution of conditions" (e.g., CH2M-Hill 2008).

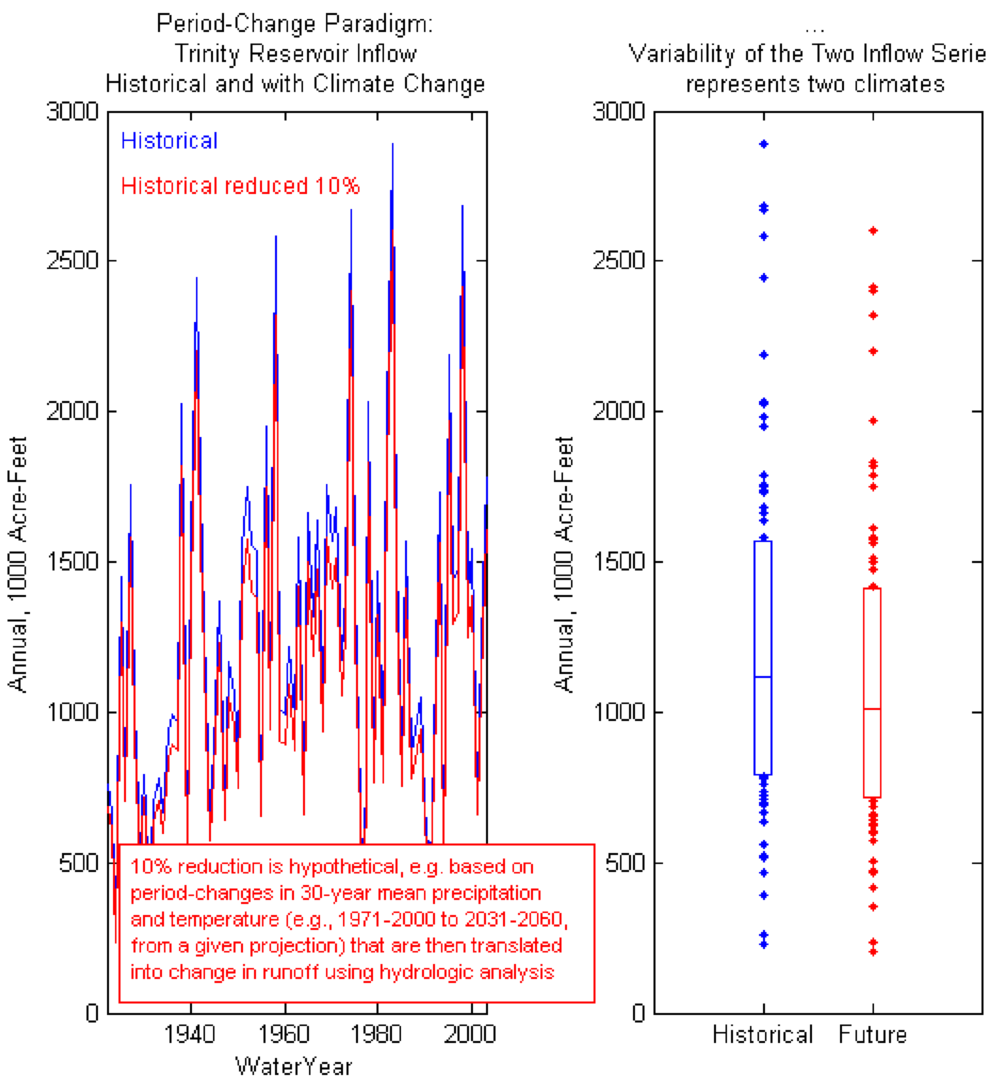

Figure 7. Period-change paradigm example – two water supply variability assumptions. Hypothetical study location is Trinity Reservoir, California.

The *Period-Change* paradigm is useful if the focus is primarily to illustrate how operations performance is *sensitive* to change in climate (e.g., wetter to drier, cooler to warmer). A shortcoming of this approach is that interpretation of incremental changes in period-climate statistics within climate projections is not straight-forward (Brekke et al. 2009a). Being able to identify incremental "climate change" in projections requires being able to define future and historical "climates," which are periods of hydroclimate variability having unique statistical and/or frequency (sequencing) characteristics. This draws on understanding of observed historical climate variability from daily to multidecadal time scales. For some variables, such as air temperature, it may be clear that conditions are evolving in a fashion where trends in period-statistics through time are significant relative to the natural variability that overlies these trends. For other variables, such as precipitation, this may not be so clear.

Detecting changes in "30-year precipitation climatology" is difficult given the occurrence of multidecadal natural variability in both regional observations and regional climate simulations. For example, the Pacific Decadal Oscillation and its historical effects on the Western United States hydroclimate have been well documented. Focusing first on observations, consider our case study area over the Trinity Reservoir basin in California. Historical annual precipitation in the overlying NOAA Climate Division is shown in figure 8. Let "climate change" be defined as change in 30-year mean precipitation between consecutive 30-year periods. As the figure indicates, if we compute all of the change possibilities in this record, the range of "climate change" is -6% to +19%. This illustrates the presence of multidecadal variability in the historical record at this location raises questions about a 30-year-period duration being sufficiently long when sampling change in 30-year mean precipitation and then calling it "climate change."

Current climate projections also exhibit multidecadal variability, although to different degrees (discussed later). Figure 9 shows sampled "period-climate changes" from an ensemble of 112 projections of annual precipitation over the Trinity River basin from 1950–2099.[1] For each projection, five periods were considered: 1951–1980,[2] 1981–2040, 2041–2070, and 2070–2099, and period-mean precipitation was computed for each period (figure 9, top panel). Change in 30-year mean precipitation (P) was then computed in each projection for the four latter periods relative to the first period, 1951–1980 (figure 9, middle panel as incremental change, bottom panel as percentage change). Projections were then color-classified for whether the sign of period-change from the first period stayed consistent through the four future periods (gray) or was

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[1] *Statistically Downscaled WCRP CMIP3 Climate Projections* at http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/.

[2] Historical period results on figure 9 are "simulated historical" and not observed historical. Simulated historical climate varies with climate model choice and initial conditions. These simulated historical results also reflect adjustment to be statistically consistent with observed period-statistics during 1950–1999 (see footnote 1 and review how downscaled data were developed); but within this 50-year period, subperiod statistics can still vary as shown.

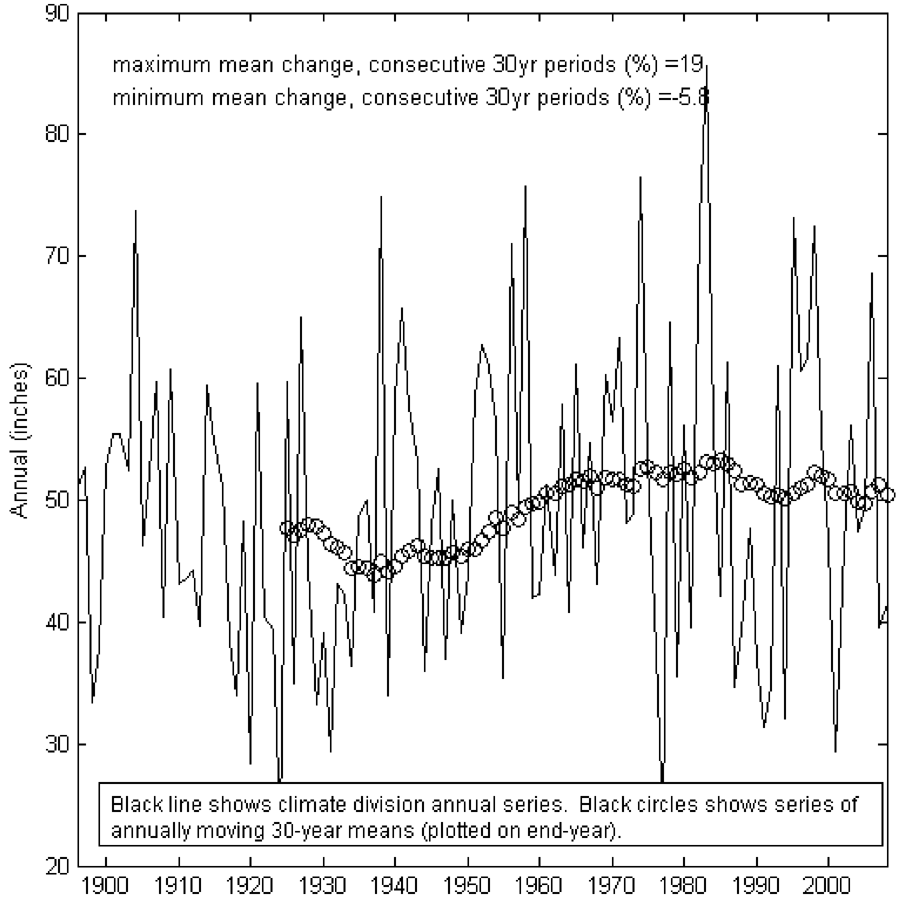

Figure 8. Historical precipitation, NOAA Climate Division #1, Trinity Reservoir basin, California

inconsistent (green). Roughly 50% of the projections evaluated had inconsistent signs of change through the four future periods. Four of these projections are red-highlighted on the bottom panel. These results highlight that, as with reality, climate projections over a given region may exhibit multidecadal variability signatures. This suggests that multidecadal variability should be accounted for when trying to diagnose and define "climate change" in climate projections.

Time-Developing Application

To avoid the uncertainties of climate change diagnosis associated with using the *Period-Change* paradigm, it may be clearer and more appropriate (albeit at the cost of complexity) to adopt a *Time-Developing* paradigm for the planning evaluation. The *Time-Developing* paradigm does not require sampling climate projections for period-statistical

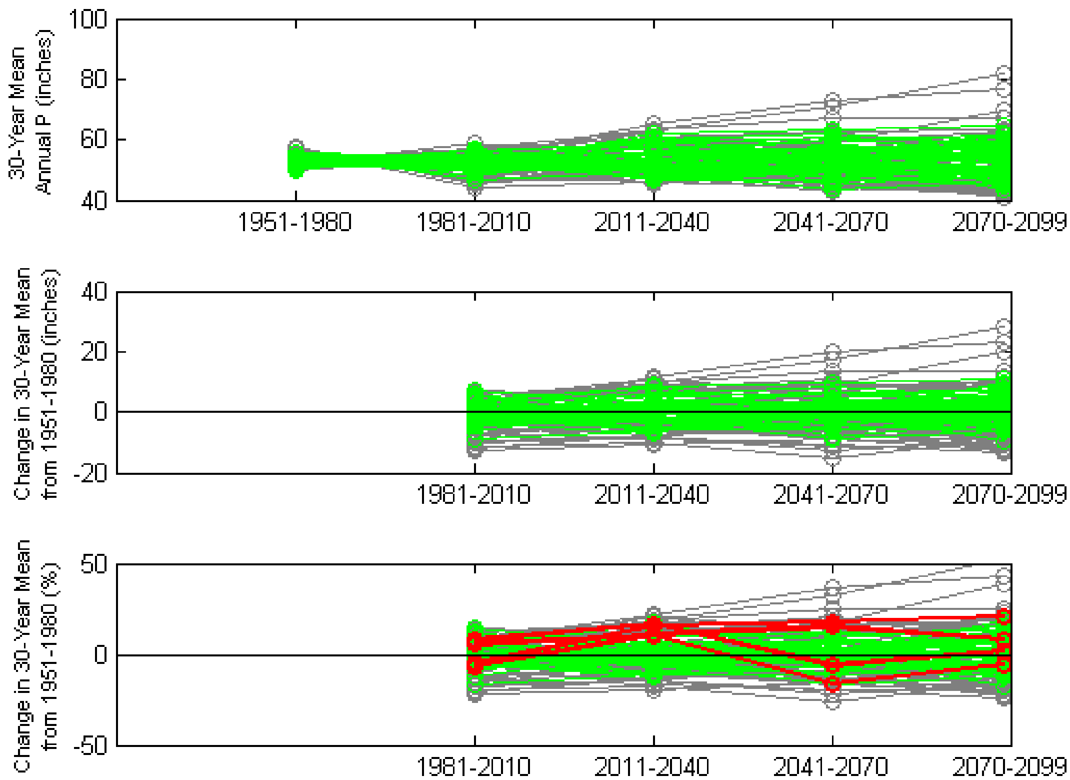

Figure 9. Period-change paradigm issue: stability of projected change through time.

conditions nor assessing change in period-statistics and casting such changes as "climate change" for planning purposes. Instead, planning assumptions are developed to be temporally consistent with time-series temperature and precipitation information in climate projections (Brekke et al. 2009a).

To illustrate, consider an application of the *Time-Developing* paradigm also to the Trinity Reservoir basin—this time, for the purpose of developing runoff projections that would serve as water supply projection possibilities in planning. The ensemble of climate projections from figure 9 are translated into runoff projections following the procedures in Maurer 2007 (and others) and using a hydrologic model for the Trinity Reservoir basin, as calibrated by the NOAA National Weather Service California-Nevada River Forecast Center. Time-developing characteristics of these climate projections (i.e., monthly temperature and precipitation projections, shown in aggregated form as annual series on the top row of figure 10) are translated into similarly time-developing hydrologic projections (e.g., shown in aggregated form as annual and April–July runoff projections on bottom row of figure 10).

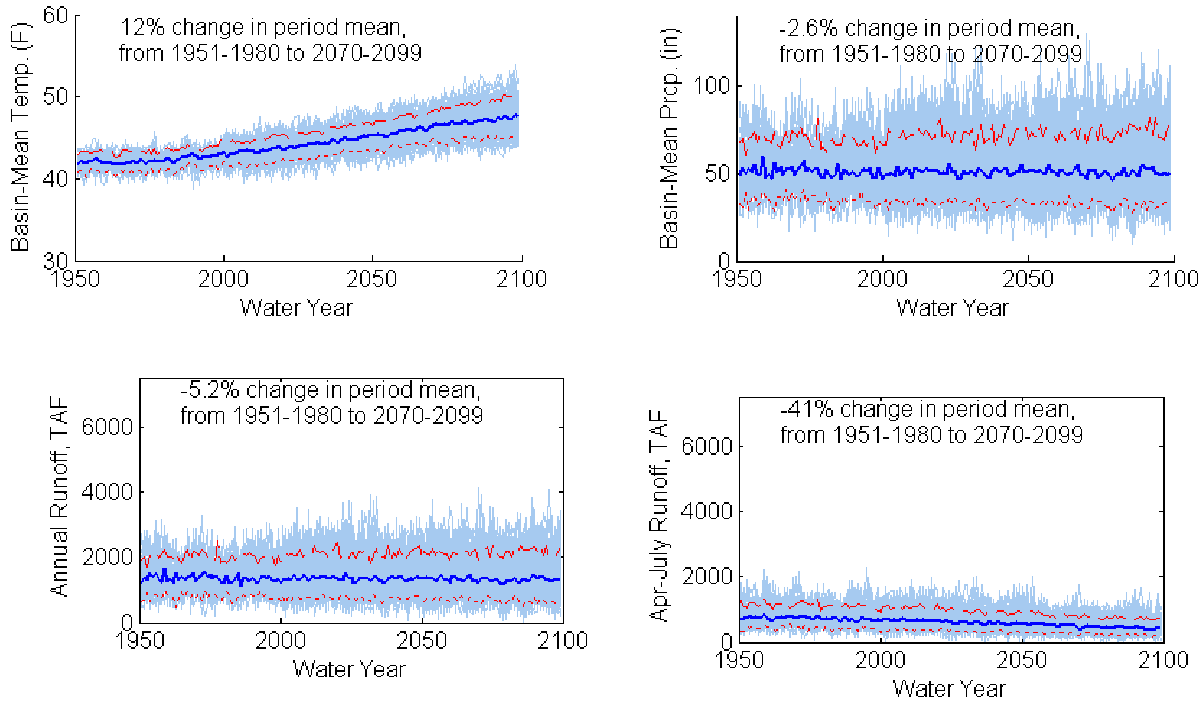

Figure 10. Time-developing paradigm example – Trinity Reservoir, California.

The point of this example is not to focus on details of the hydrologic analysis but to, instead, draw attention to how the *Time-Developing* paradigm invites an ensemble projection analysis that produces results that portray how climate and hydrologic statistics evolve through time. Specifically, the tracking of ensemble-median and ensemble-distribution of any variable in figure 10 might be interpreting as time-developing expectation for that variable's condition in any given projection year. This view, created by the *Time-Developing* paradigm, can set up a considerably different view than the *Period-Change* paradigm on what type of climate change might be expected.

Comparison of Period-Change and Time-Developing Applications:

As stated at the beginning of this illustration, the two paradigms can lead to a significantly different portrayal of climate change possibilities and implications for water management. For example, figure 9 suggests that change in 30-year mean annual precipitation from 1951–1980 could range from at least -20% to +20% progressing into the 21st century. In contrast, figure 10 suggests that 30-year mean annual precipitation (indicated by ensemble-median annual conditions during a given period) would be expected to change very little through the 21st century. In fact, the 30-year average ensemble-median condition in 2070–2099 is only –3% from the same condition during 1951–1980.

Use of the *Time-Developing* paradigm is not without its own interpretation challenges. Contrasting from use of the *Period-Change* paradigm, use of the *Time-Developing* paradigm requires:

- The view that *variability* aspects in climate projections are reasonable for planning purposes, understanding that different planning processes will have different criteria for credibility (e.g., flood risk evaluations may be more concerned about the credibility of projected daily precipitation possibilities compared to resource management evaluations more concerned about seasonal to multidecadal precipitation variability).

- The view that *frequency* aspects in climate projections are reasonable for planning purposes (e.g., reoccurrence and intensity of drought and surplus spells, reoccurrence of storm patterns relevant to flood risk evaluation) and acknowledgment that the *sequencing* of events (e.g., reoccurrence of storms and droughts) will not align with historically experienced events (unlike the *Period-Change* paradigm).

- The view that planning evaluations must be conducted for an ensemble of climate projections to adequately characterize the envelope of climatic possibility evolving through time (contrasting from the *Period-Change* paradigm that invites a view that a relatively smaller, "bracketing" set of climate projections can be selected to represent the breadth of projected incremental change possibilities).

These views aside, a *Time-Developing* paradigm may permit more efficient development of longer-term climate change adaptation strategies (where "adaptation" in the climate change context is not to be confused with "adaptive management" featured in Reclamation and USACE ecosystem management activities). While a *Period-Change* paradigm would indicate resource management response specific to a specific future period or period center-year (e.g., 2050), a *Time-Developing* paradigm would include analysis of resource management during intervening years, from historical to future and reveal the onset and development of management vulnerability. Likewise, while a *Period-*

Change paradigm could indicate the level of adaptive intervention necessary for that given future year, a *Time-Developing* paradigm could provide a time-evolving context within which multiple adaptive interventions may be strategized and scheduled, fostering climate change preparedness through time.

Current Capabilities

On the matter of interpreting historical climate variability for the purpose of interpreting projected climate variability, Reclamation and USACE have access to synthesis understanding on climate variability reported by IPCC (Meehl et al. 2007, Christensen et al. 2007) and the U.S. Climate Change Science Program (CCSP 2008). However, given the complexity of information included in these synthesis reports, Reclamation and USACE also pursue assistance from Government science partners (e.g., NOAA, USGS), regional science centers (e.g., NOAA RISA centers), and academic partners to help interpret the relevance of report findings in the context of Reclamation and USACE planning evaluations.

On the matter of culling or weighting projections based on regard for *greenhouse gas emissions scenarios*, Reclamation and USACE do not have a basis for doing so. On the matter of culling or weighting projections based on regard for *climate model skill*, Reclamation and USACE have access to several methods (e.g., Tebaldi et al.2005; Brekke et al. 2008). Reclamation recently collaborated with USGS, Santa Clara University, and the California Department of Water Resources to develop and apply a rationale to cull or weight climate models based on skill when assessing climate projection uncertainty (Brekke et al. 2008).[1] The rationale was applied in a study over northern California, where climate model skill was assessed and used to cull the model-ensemble to a "better half" of models. Climate projection ensembles were then evaluated for both the full and "better half" model-ensembles. Results showed that projection uncertainty depicted by the "better half" model-ensemble was not substantially different from the complete ensemble, suggesting that substantial projection uncertainty was introduced by emissions pathway and optional initial conditions for the climate projections (Brekke et al. 2008). Findings from this study supported a decision

[1] This work occurred in a broader study involving these collaborators and additional support from USACE and focusing on applying risk analysis principles to exploring climate change implications for reservoir operations (Brekke et al. 2009b).

by Reclamation to not cull climate models and their projections in a subsequent planning application (Reclamation 2008a)

On the choice of framing planning evaluations based on the *Period-Change* or *Time-Developing* paradigms discussed above, Reclamation has previous discussed the paradigm options in the resource management evaluations (e.g., appendix U of Reclamation 2007, where terms "Period Composite" and "Transient" were used rather than *Period-Change* and *Time-Developing*). Reclamation and USACE have access to both methodologies but does not have guidance on best paradigm choice and for various planning situations. Reclamation has experience applying the *Period-Change* paradigm resource management evaluations (Reclamation 2008a, Brekke et al. 2009b). Reclamation also has experience applying the *Time-Developing* paradigm to hydrologic impacts investigations (Raff et al. in review, Reclamation 2009b).

On relating hydrologic event portrayal in infrastructure safety and flood risk reduction evaluations to shorter-term variability in climate projections, Reclamation and USACE are exploring the veracity of traditional procedures for assessing hydrologic hazard potential in the context of time-changing climate (i.e., "nonstationary" climate). Using the *Time-Developing* paradigm above, the effort involves developing hydrologic projections consistent with climate projections and conducting hydrologic hazard assessments, updating through time (Raff et al. in review). This activity represents an initial effort to explore scoping guidance for this issue of hydrologic event portrayal in a changing climate. Reclamation and USACE also are seeking input from Federal science partners on how to develop such guidance (e.g., NOAA, USGS).

Reclamation is leading an interagency effort to develop a methodology for relating drought and surplus portrayal in resource management evaluations to a blend of paleoclimate and projected climate information. An additional objective is to explore how water supply variability portrayal differs when based on a blend of paleoclimate and projected climate information versus either paleoclimate or projected climate information individually (Reclamation 2009b).

Capability Gaps

Comparison of the preceding discussions on desired and current capabilities leads to the following list of gaps in understanding, guidance and methods.

Gap 3.01: Understanding on observed climate variability from daily to multidecadal time scales, which underpins interpretation of future variability in climate projections and it's relation to planning assumptions.

Gap 3.02: Understanding on how to interpret climate projections' simulated climate variability on *longer-term scales* (from annual to multidecadal scales).

Gap 3.03: Basis for culling or weighting climate projections (if at all) when deciding which projections to use in planning.

Gap 3.04: Guidance on how to appropriately relate planning assumptions to either *Period-Change* or *Time-Developing* aspects of climate projections, when deciding how to use projections in planning.

Gap 3.05: Guidance on how to jointly utilize the longer-term climate variability from observed records, paleoclimate, and projected climate information when portraying drought and surplus possibilities in planning.

Gap 3.06: Method and basis for estimating extreme meteoro-ogical event possibilities, deterministically or probabilistically, in a changing climate.

2.3.4 Step 4 – Assess Natural Systems Response

After obtaining climate projection data (Step 2) and making decisions on how to translate these data into climate scenarios for planning (Step 3, e.g., *Period-Change* or *Time-Developing* scenarios), work proceeds on the analyses necessary to map these data to planning assumptions. For resource management evaluations, this means analyses to develop water supply, demand, and operating constraint assumptions, given the availability of methods and tools to do so (figure 2). Likewise, for infrastructure safety and flood risk reduction evaluations, this means characterizing hydrologic events possibilities (figure 3).

Two categories of analyses occur to establish planning assumptions: response of natural systems to climate scenarios (Step 4) and response of socioeconomic conditions (Step 5). This section focuses on Step 4 analyses, which includes a broad range of natural systems. Discussion in this section is divided for several types of natural systems or conditions: watershed hydrology, ecosystems, land cover, water quality, consumptive use of irrigated areas (physical drivers only), and sedimentation.

Desired Capabilities

For the types of natural systems and conditions discussed in this section, planning managers need to be able to defend method and tool choices as best available for their evaluations, particularly for environmental compliance evaluations. It is recognized that a variety of system models might be considered for use in these evaluations. Models may have differing levels of complexity. Choice among these models will vary depending on the study question being addressed.

Watershed Hydrology: For characterizing water supply assumptions or a hydrologic event potential consistent with climate scenarios, planning teams must be able to simulate surface water hydrologic response to these climate scenarios using process-based hydrologic models. Modeled weather inputs and land cover assumptions (which control evapotranspiration) need to be cast consistently with climate scenarios. Simulations must adequately portray all aspects of the surface water balance, including basin water storage (i.e., soil moisture and in mountain regions, snowpack), groundwater recharge, and evapotranspiration (from natural land cover and riparian vegetation).

One necessary method decision when developing a hydrologic model for a given basin is how to specify spatially distributed historical weather over the basin. Proper specification of historical weather affects the process of model development, where model parameters are set so that hydrologic simulation reproduces historical runoff when forced by historical weather. Different methods have been proposed for specifying distributed historical weather (e.g., Daly et al. 1994, Maurer et al. 2002, Hamlet and

Lettenmaier 2005), each leading to versions having different characteristics. Differences arise from how a particular method establishes weather station eligibility for informing the dataset and how selected station data are mapped to the distributed dataset. It is possible for a hydrologic model to similarly reproduce runoff characteristics when using any of these historical weather versions. This is because there is considerable flexibility on setting model parameters during calibration (i.e., lack of field evidence or physical understanding to constrain what parameter values could be). Nevertheless, it is necessary for hydrologic modeling teams to be able to rationalize how this distributed weather should be specified. Further, to avoid challenges in interpreting differences between historical climate simulations (Step 2) and hydrologic simulations (Step 4), it would be desirable to use a common distributed historical weather dataset to serve bias-correction of both climate projections (Step 2) and to hydrologic model calibration (Step 4).

Ecosystems: A variety of ecological resources and related conditions affect reservoir operations and regulation. Notable resources include coastal anadromous fisheries, inland freshwater fisheries in reservoirs and rivers, riparian ecosystems, wetlands, and coastal ecosystems. For the purposes of characterizing ecosystem-related constraints on operations that are consistent with climate scenarios, planning teams must understand how to simulate response of associated ecosystems (or ecosystem habitat) to a given climate scenario. For systems where operations are constrained by management objectives related to anadromous fisheries, planning teams may require understanding on how climate change could alter the factors that affect these fisheries, including hydrology (e.g., flow frequency, duration, and magnitude during various life stages), habitat (during various life stages, implying interest in both freshwater and ocean habitat), human harvest, and hatchery production. For systems where riparian ecosystems and vegetation control operations, teams also may require understanding on how carbon dioxide conditions associated with that scenario affect ecosystem function.

Land Cover: It is necessary for planning teams to understand how watershed and riparian vegetation communities will respond to climate and carbon dioxide change. Vegetation change would affect natural evapotranspiration in tributary watersheds (watershed hydrology, discussed above) as well as soil erosion-related river sedimentation (discussed below). The response of vegetation communities also affects potential for wildfires and associated land cover disturbances that would further alter watershed evapotranspiration and the potential for soil erosion. In addition, the interaction of climate change and land use (such as extent of impervious cover) also affects stream flow and water quality.

Water Quality: For many resource management evaluations (certainly for evaluation of pollution control, water treatment systems, and sometimes for evaluation of water supply system featuring dams and reservoirs, it is necessary to consider water quality response to climate and hydrologic change. Examples of water supply system evaluation might be assessing changes in salinity controls on water management in the Colorado River Basin and the San Joaquin River basin or water temperature controls on reservoir water releases in the Upper Sacramento River basin. Analysis first involves assessing surface water hydrology response to climate scenario information and then overlaying water quality simulation and source water quality information to simulate system water quality response.

Consumptive Use in Irrigated Areas: For characterizing water demands in resource management evaluations, planners must be able to assess changes in plant water use efficiency (agricultural or urban landscape) to given changes in climate (temperature, precipitation, growing season length) and atmospheric composition (carbon dioxide). Further, as the energy sector changes to new forms of energy and fuel production, patterns of water demand are likely to change.

Sedimentation and River Hydraulics: Reclamation and USACE both require understanding of how sedimentation budgets in reservoirs and river systems may respond under a given climate scenario and hydrologic regime. Reservoir sedimentation budgets affect reservoir storage capacity through time, which affects ability to operate or regulate reservoirs to satisfy a variety of objectives (e.g., water supply, hydropower, flood control, ecosystem, navigation, recreation). On river hydraulics, cold-season hydrology also may be of interest in regulated river systems affected by “ice events.” Assessing the response of ice-event potential to climate scenario information first requires hydrologic analysis, followed by river hydraulics and potentially sedimentation analysis.

Current Capabilities

Reclamation and USACE both have invested considerably in the development of tools and capabilities to analyze these natural systems and conditions. Capabilities are relatively more evolved on the analysis of watershed hydrology, river hydraulics and sedimentation, consumptive use in irrigated areas (climate controls only), and water quality. This investment will continue so long as there are issues with physical understanding limiting the development and application of model concepts or issues with monitoring affecting the application of these concepts to particular systems. Specific to this section, the discussion on current capabilities is focused on specific aspects in physical understanding, tool selection, and tool application that are confounded when considering climate change.

Watershed Hydrology: For assessments of surface water hydrologic response to climate change and establishing water supply assumptions for resource management evaluations, Reclamation and USACE have access to multiple hydrologic model types and methods of application (e.g., see appendix U in Reclamation 2007). USACE has extensive experience with their Hydrologic Engineering Center hydrological modeling system (HEC-HMS) (USACE 2008a and b), both in terms of software development and application to address basin-specific studies. The USACE Engineer Research and Development Center (ERDC) and Environmental Modeling Systems Inc. are collaborating to develop the Gridded Surface Subsurface Hydrologic Analysis (GSSHA). GSSHA capabilities include simulation of overland flow, streamflow, infiltration, groundwater flow, and coupling between the groundwater, vadose zone, streams, and overland flow. Reclamation has not sponsored internal development of hydrologic modeling software. However, Reclamation has become experienced applying two types of surface water models in the context of climate change studies[1] and is working to developing capability with other types of models.

Reclamation and USACE do not have guidance on which surface water model types may be structurally more appropriate for climate change evaluations, although this is a subject of ongoing collaborative research by

[1] Models provided by the NOAA National Weather Service River Forecast Center (Sacramento Soil Moisture Accounting model) and the University of Washington (Variable Infiltration Capacity model).

Reclamation, USGS, and the NWS Colorado Basin River Forecast Center.[1] It has been shown that runoff projections can vary greatly depending on model type and method choice (e.g., see discussions about Colorado River runoff uncertainty in appendix U of Reclamation 2007 and WWA 2008). Results also can vary greatly relative to process representation (e.g., representing potential evapotranspiration using a simple temperature-based method versus a more variable-intensive but possibly more appropriate method like Penman-Monteith).

For characterizing hydrologic event potential, Reclamation and USACE have access to deterministic (e.g., probable maximum flood) and probabilistic techniques, as outlined in *Guidelines for Determining Flood Flow Frequency* (IACWD 1982). However, an assumption underlying these techniques is that the historical period of hydrologic and climate data is statistically representative of the evaluation's planning future. In other words, an assumption of "stationarity"[2] is applied such that historical flood frequency possibilities are adopted for the planning future. However, in a changing climate, it is recognized that local hydrologic and climate statistics may not be stationary (Milly et al. 2008). Properly evaluating future flood risk within a changing, or "nonstationary," climate remains a goal for water-management decisionmakers (Brekke et al. 2009a).

For the matter of developing a hydrologic model for a given basin and doing the necessary preliminary step of specifying historical distributed weather over the basin, Reclamation and USACE have access to multiple methods. Such methods have been applied to develop similar but unequal versions of historical weather (e.g., Maurer et al. 2002, Hamlet and Lettenmaier 2005, NWS River Forecast Centers' (RFC) datasets used to calibrate hydrologic simulation models and force them during operational forecasting, plus numerous others). Among these available versions, only the RFC operationally maintains a data management system designed to track and gather station meteorological data to serve as inputs for

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[1] *Assessing Preference among Surface Water Hydrologic Models for studies involving Climate Change*, https://www.usbr.gov/research/Propcweb/reviewer/print_research_question.cfm?fy=2009&proposalid=2404.

[2] This use of "stationarity" to describe the consistency of local hydrologic and climate statistics through time is not to be confused with the use of "stationarity" in downscaling discussions (Step 2) ,which relates to the consistency of spatially distributed land-atmospheric interactions through time.

hydrologic simulations models (also developed and operationally maintained by the RFC). In comparison, the datasets from Maurer et al. (2002) and Hamlet and Lettenmaier (2005) include meteorological variables necessary to simulate both surface water and energy balances—for example, using the Variable Infiltration Capacity model (Liang et al. 1994) rather than only surface water balance (e.g., using the Sacramento Soil Moisture Accounting and Snow17 models [Burnash et al. 1973, Anderson et al. 1973] used by the RFC). Further, there is currently a lack of guidance on the strengths and weaknesses of these available methods and versions for the task of supporting (a) climate projection bias-correction and (b) hydrologic model calibration. There is also a lack of understanding on whether an altogether different version needs to be developed to support these latter objectives, recognizing that different applications and purposes motivated the development of existing methods and versions.

For assessments of coupled surface water (SW) and groundwater (GW) response to climate change, Reclamation is less familiar with available tools and application methods. During the 2008 R&D Scoping Workshop, there was discussion about the USGS' new model type for coupled SW-GW simulation (GSFlow) and its potential use in climate change studies (see further discussion in chapter 4). Reclamation's Mid-Pacific Region has access to other two types of models for coupled surface water and groundwater systems: Integrated Water Flow Model (developed by the California Department of Water Resources[1] and applied to the California Central Valley) and HydroGeoSphere (developed by the University of Waterloo, HydroGeoLogic Inc., and Mid-Pacific Region and being applied to the California Central Valley). Currently, no authoritative peer assessment provides guidance on which coupled SW-GW model types and application methods are most appropriate for climate change evaluations.

Ecosystems: Depending on the species considered, Reclamation and USACE have varying capability in being able to characterize how climate change may affect fisheries population and health as well as the health of important ecosystems such as wetlands. Capabilities depend on Reclamation and USACE understanding the primary factors that control fisheries population and how climate will affect those factors. For anadromous fisheries, Reclamation and USACE have some

[1] http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/.

understanding on two key factors: surface water hydrology and aquatic temperatures. Capabilities are more limited in other factor areas due to lack of understanding on both the relationship between fisheries population and those factors and how climate change could affect those factors (e.g., ocean habitat, riparian and wetland ecosystem function, and vegetation that control freshwater habitat).

Land Cover: Reclamation and USACE do not have methods for assessing land cover response to climate and carbon dioxide changes, nor do they have methods for integrating such land cover response into hydrologic impacts assessment. However, Reclamation has begun to build research partnerships in this area. One ongoing effort[1] involves collaboration with Texas Water Development Board and Oklahoma Water Resources Board to investigate the role of joint land cover and climate changes in the Upper Canadian and North Fork Red River basins. The second year of the effort involves assessing hydrologic response to joint projections of climate and land cover, with the latter information being provided by collaborators from the U.S. Forest Service Pacific Northwest Research Station and USGS Earth Systems Observation and Science Data Center. Still, this research represents an initial effort, and questions remain about frameworks for studying land cover response to climate change, including species- or community-specific aspects.

Water Quality: Reclamation and USACE have methods and models for studying the fate and transport of water quality constituents in river and reservoir systems. Different model types are available for use, with complexity depending on the specificity of study objectives. As stated, the analysis first involves assessing hydrologic conditions relative to climate scenario information, and then overlaying water quality simulation and source water quality data to simulate system water quality conditions. Uncertainties and questions about characterizing hydrologic conditions were discussed above. Water quality simulation frameworks generally are well established, given available field evidence on source water quality to apply a given framework to a given system. Questions may be more prevalent on how given water quality parameters have source characteristics that depend on climate variability (e.g., air temperature and/or precipitation regimes). Reclamation and USACE continue to rely

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[1] "Methodology to Evaluate the Influence of Joint Changes in Climate and Land Cover on Water Availability." https://www.usbr.gov/research/Propcweb/reviewer/print_research_question.cfm?fy=2009&proposalid=2768.

on input from other agencies (e.g., USEPA Office of Water) for guidance on evaluating these dependencies and how they may be affected by changing climate conditions.

Consumptive Use in Irrigated Areas: On assessing physical drivers of irrigation water demand (agricultural and urban), Reclamation has methods that can translate input climate scenarios into consumptive use requirements, predicated on a static plant physiological relationship and availability of meteorological data. Methods differ in how they simulate potential evapotranspiration over irrigated lands, by crop type, and range from U.S. Department of Agriculture Soil Conservation Service modified Blaney-Criddle (which might be applied when data on key meteorological variables are limited) to more sophisticated methods featuring Penman-Monteith. Effects of growth stage and growing season are accounted for empirically in these methodologies. Reclamation currently does not have guidance on how to modify consumptive use models to account for changes in plant physiological relationships with joint changes in climate and carbon dioxide. Nor does Reclamation factor in long-term changes in agricultural crops, such as from shifting to biomass to produce energy and fuel. Reclamation will continue to look to guidance from other agencies (e.g., USDA Agricultural Research Service) for guidance on how to advance capabilities in this area.

Sedimentation and River Hydraulics: USACE and Reclamation field an extremely competent array of sedimentation tools. The inherent complexity of sedimentation, whether it is due to watershed, river, or reservoir processes, limits sediment modeling to a heuristic exercise. In this sense, the existing models are competent for detecting changes in sediment yield, transport, and fate under climate change scenarios that are mainly manifested in changes in hydrology. Relative, not absolute, changes in sedimentation rates should correlate directly with changes in hydrology, and indirectly with changes in land cover due to climate change.

Capability Gaps

Comparison of the preceding discussions on desired and current capabilities leads to the following list of gaps in understanding, guidance, and methods.

Watershed Hydrology

Gap 4.01: Guidance on strengths and weaknesses of watershed hydrologic models/methods to support scoping decisions in planning.

Gap 4.02: Understanding on how climate change should impact potential evapotranspiration and how it is represented in watershed hydrologic models.

Gap 4.03: Method and basis for estimating extreme meteorological event possibilities, deterministically or probabilistically, in a changing climate. (Similar to Gap 3.4, but focused here on hydrology rather than meteorological variables).

Gap 4.04: Guidance on strengths and weaknesses of available versions of spatially distributed hydrologic weather data that may be used for both watershed hydrologic model development (Step 4) and in climate model bias-correction (Step 2).

Gap 4.05: Understanding on how climate change should impact groundwater recharge and groundwater interaction with surface water supplies.

Ecosystems

Gap 4.06: Understanding on how climate change should impact inland and coastal anadromous fisheries.

Gap 4.07: Understanding on how climate change may impact riparian ecosystems and vegetation that affect both longer-term water budgets and ecological resources.

Gap 4.08: Understanding translated into model frameworks for assessing climate change responses for fisheries, nonnative riparian vegetation, and other species or habitat conditions.

Land Cover

Gap 4.09: Understanding on how climate and/or carbon dioxide changes should impact land cover communities that control natural evapotranspiration and soil erosion potential.

Water Quality

Gap 4.10: Understanding on how water quality characteristics depend on climatic variables and how dependencies may evolve in a changing climate.

Consumptive Use in Irrigated Areas

Gap 4.11: Understanding on how climate and carbon dioxide changes should impact plant physiology, how impacts vary with crop type, and how impacts affect irrigation demand.

Sedimentation and River Hydraulics

Gap 4.12: Understanding how climate and/or land cover changes will change watershed sediment yield, changes in sediment constituency, and the resulting impacts on water resources.

Gap 4.13: Understanding how climate, land cover, and/or sedimentation changes will affect river and reservoir ice-event potential.

2.4.5 Step 5 – Assess Socioeconomic and Institutional Response

As previewed for Step 4, work in Step 5 continues to focus on mapping climate scenario data to planning assumptions. Here, the focus is on social and economic systems that are influenced in some fashion by climate factors, estimating responses in those systems to climate scenario data, and translating those responses into adjusted planning assumptions on water demands, source of supply preferences, and operational constraints.

Social and economic systems generate the water demands, source of supply preferences, and values that shape various operational constraints.

These factors interact to affect how water managers make and implement water allocation decisions. These system dynamics may alter under changed climatic conditions. For example, under some climate change scenarios the volume and spatial distribution of water supply and demand in the U.S. West may be expected to change. The way society values water and the environment, and what constraints this puts on the ways water is used, may also change. Furthermore, the relation between society and climate is reciprocal; social and economic dynamics can also impact how climate change unfolds.

Without climate change as a new driver, the relations between these social and economic system dynamics and water management are traditionally complex, poorly understood, and underemphasized in water management. The National Research Council concludes that *"research leading to the development of improved water management institutions should receive much more attention in the research agenda of the 21st century than it did in the past*" (NRC 2001). In this context, an "institution" can be thought of as any assemblage of rules, legal or otherwise, which governs how water users make use of their resource and how water managers facilitate that use. Underlying any institution are sets of social, political, cultural, and economic variables, which interact to determine what is acceptable, profitable, or otherwise valued by society.

Economic, political, and social variables are dynamic with time, particularly under pressure from significant forcers like climate change. As Heclo (2008) states, "*… to be enduring, institutions also have to be adaptive and change in time-factored ways*." Water managers will need relevant, concise, and timely information on potential shifts that may occur in environmental values, water demand, and other social, political, and economic variables if they are to adapt to climate change efficiently and effectively

In exploring institutional dynamics, it is fully understood that decisions on water management are most often made at the State and local level. The objective of improving capability in Step 5 is to generate and provide information that is useful to decisionmakers at all levels, not to influence decisionmaking responsibilities in any way. Toward this objective, it is vital that work in this area is done in consultation and coordination with State and local water managers, so that their knowledge and experience is included in identifying current and desired capabilities.

As members of the water community of practice, Reclamation and USACE studies and decisions are also guided by social and economic factors. The current P&G are used to guide the formulation and evaluation of water resource alternatives and investments by the Federal water resources agencies. USACE policy requires that any planning study evaluate National Economic Development (NED), National Ecosystem Restoration (NER), Regional Economic Development (RED), and Other Social Effects (OSE) benefits (the latter encompassing life safety). Given the focus on NED in the current P&G and in USACE policy, developing new methods for economic evaluation embracing NER, OSE, and RED under the influence of climate change considerations is anticipated. The P&G are currently undergoing revision under the leadership of the President's Council on Environmental Quality. The USACE has already begun an internal process to suggest and review potential new methods. In the fiscal year 2010 budget hearing before the U.S. Senate Subcommittee on Energy and Water Development, Reclamation Commissioner Michael L. Connor announced that Reclamation will work with State and local partners to initiate comprehensive water supply and demand studies in the West, with each study including state-of-the-art projections of future water supply and demand on a basin-wide scale.

Desired Capabilities

For longer-term water resources evaluations, Reclamation and USACE seek capability in being able to relate climate scenario data to the social and economic factors that govern assumptions on water demands, source of supply preference, and a variety of constraints affecting reservoir operations or regulation. For water demand assumptions, this means understanding social and economic influences of demand from the field- to district-management level, where a mix of social, economic, and natural factors determine aggregate demand. For constraint assumptions, this means understanding the interaction of climate, social, and economic factors in a variety of areas:

- Flood protection expectations and risk reduction objectives
- Water and hydropower delivery reliability objectives
- Environmental preservation, restoration, and management objectives
- Reservoir and river recreation objectives
- River navigation objectives

Current Capabilities

Assuming historical social and economic trends will continue in a linear fashion are generally accepted assumptions when conducting water and water-related resource planning studies, unless changes in social drivers are assumed as part of the longer-term system change being evaluated.

From the perspective of a more dynamic, climate-sensitive view of social and economic factors, there are isolated researchers and research programs within and outside of the Federal Government examining this issue. The interdisciplinary and "second-thought" nature of these issues within the water research community are typically a barrier to more mainstream collaboration on the development and integration of these capabilities across the water management community of practice.

Similarly, some members of the water community of practice have a keen awareness of the issues, but the awareness is not uniform or widespread. Finally, while there is a relatively large body of research scattered across different disciplines and journals, there are few general synthesis publications and even fewer relevant to water management. Consequently, there remains little capacity in the realm of gathering, filtering, synthesizing, and packaging this kind of information in ways that are relevant to and supportive of the mission of water managers.

On matters of relating climate scenario data to the social and economic drivers, Reclamation and USACE have limited capability. For example, while flood risk reduction evaluations are clearly informed by natural hydrologic response (Step 4), the assessment of flood risk also depends on social, political, and economic drivers of flood plain management and community expectations on flood protection. Reclamation and USACE currently do not have guidance on how to assess these drivers in a changing climate.

On environmental preservation and restoration efforts, strategy evaluations under a changing climate will not only depend on physical drivers from that climate scenario, but also assumed socioeconomic responses that translate into paradigms for ecosystem management and valuation of ecosystem services. For example, if the restoration is focused on a species that will experience habitat reduction as climate warms, the paradigm for preservation and/or restoration management comes into question. Reclamation and USACE continue to look to natural resource and wildlife management agencies for guidance on exploring these questions (e.g., U.S. Fish and Wildlife Service, NOAA National Marie Fisheries Service [NOAA Fisheries], USEPA). The question of valuing ecosystem services is a perennial and controversial issue in the water resources planning community. Despite a strong statement by the NRC in 2004 that "*the economic values of the ecosystem goods and services must be known so that they can be compared with the economic values of activities that may compromise them and so that improvements to one ecosystem can be compared to those in another,*" there remains no single approach to consider ecosystem services—an issue that is more critical in the face of climate change.

Expected levels of water and hydropower delivery reliability depend on the robustness of hydrosystems and source of supply options for system users. The latter depends on whether system users are economically inclined to enter into water transfer arrangements or participate in water markets. Physical drivers of a climate scenario feedback to affect the economics of source of supply decisions and, thus, the tendencies of system users to enter into transfer agreements and water markets. Reclamation and USACE have ability to conduct such analyses when the underlying social and economic drivers on the system can be characterized. Reclamation and USACE continue to look for guidance from others on characterizing these drivers or supporting research for these purposes (e.g., USGS, USDA Economic Research Service, USDA Cooperative State Research, Education, and Extension Service; National Science Foundation, and Federal hydropower authorities).

It is recognized that prediction of future social, economic, and institutional conditions are already quite challenging without considering the interactions of these conditions with climate change. Given the complexity of this problem, capability advancements may be slow to develop, even with targeted efforts in research. For the interim, water management agencies may look to applications of scenario planning, where potential social, economic, and institutional pathways might be conceptualized and used to bound assumption uncertainties on how climate change may affect social, economic, and institutional systems. Frameworks are available for conducting scenario planning (Schwartz 1996). Such an approach would be generally consistent with the approach taken by IPCC to characterize future climate system drivers associated with anthropogenic emissions of greenhouse gases (IPCC 2000), where scenario assumptions on global demographic, economic, technology and energy usage pathways are characterized and translated into atmospheric composition scenarios (e.g., scenarios labeled A2, A1b, B1). Scenario planning may also be coupled to robust-decision support methods (e.g., Lempert et al. 2003) where management approaches are explored for robustness relative to the space of uncertain planning assumptions and associated scenarios for each assumption.

Capability Gaps

Comparison of the preceding discussions on desired and current capabilities leads to the following list of gaps in understanding.

Gap 5.01: Understanding on how socioeconomic factors may affect flood risk reduction and reservoir regulation objectives in a changing climate (e.g., flood protection values, land management).

Gap 5.02: Understanding on how socioeconomic factors may affect water and power delivery reliability, water allocations, as well as decisions on source of supply under a changing climate (e.g., groundwater pumping versus surface water diversion).

Gap 5.03: Understanding on how institutional realities currently control socioeconomic responses to climate variability and could control socioeconomic responses under a changing climate.

These gap statements are rather general in nature. A more precise and more informed characterization of these gaps (and current capabilities) can only be achieved through follow-on consultation and collaboration across the water community of practice.

2.4.6 Step 6 – Assess Systems Risks and Evaluate Alternatives

In this step, the results from Steps 4 and 5 are now integrated into planning assumptions for either the resource management evaluation (i.e., supplies, demands, and operating constraint assumptions framing reservoir operations analysis) or infrastructure safety and flood risk-reduction assessments (i.e., hydrologic hazard and socioeconomic assumptions framing these assessments). Analyses then follow, where results are used to inform the driving study questions about resource management, infrastructure safety or flood risk.

Desired Capabilities

Reclamation and USACE require analytical tools and methods that can relate planning assumptions to plan evaluation outcomes of interest. For example, resource management evaluations may be focused on the reliability of satisfying water and power delivery objectives, downstream river flow targets, reservoir water levels, etc. Flood risk-reduction evaluations may be concerned about the combined outcomes of storage space encroachment and downstream flow rates during hydrologic events of interest. Infrastructure evaluations may be concerned about facility integrity under assumed hydrologic loads. Reclamation and USACE must apply tools and methods with thought given to regulatory, institutional, and social contexts.

It is expected that Reclamation and USACE will be increasingly asked to evaluate planning proposals or strategies that serve climate change adaptation efforts. When considering multiple strategy options for system developments, there is a need to be able to efficiently assess and rank strategies (e.g., resource management evaluations concerned with supply side, demand side, or constraint-change strategies, or some mix of all three).

For reservoir operations and regulation simulations, decisions are made (often implicitly) on how to portray operator knowledge as climate changes. There may be a need to be able to portray realistic operator "learning" as climate change develops. Doing so leads to a more realistic portrayal of the onset and degree of impacts. It also leads to a more realistic portrayal of adaptive capacity (something that may otherwise be overestimated in perfect-foresight "strategy evaluation" studies), which could influence decisions on when and which adaptation strategies to implement.

All of the discussion thus far on Steps 2 through 6 has focused on how climate change is expected to affect operations. *Conversely, there may be questions in a planning evaluation about how the planning proposal (operational or infrastructure) may affect climate (i.e., climate change mitigation).* For example, several Western States now have objectives for reducing greenhouse gas emissions on a future timeline (e.g., California).

In those States, it is becoming increasingly necessary for environmental compliance documents on proposed system changes to disclose how the proposed action affects regional emission strategies.

Current Capabilities

Reclamation and USACE have much collective experience conducting resource management, infrastructure safety, and flood risk-reduction evaluations. These evaluations are supported by a "toolbox" of system-specific models that have gained acceptance by managers, stakeholders, and planning practitioners in the given study region.

Reclamation and USACE have yet to establish a common understanding on how climate change should be incorporated in flood risk and dam safety evaluations, although collaborative efforts and research are being conducted in this area. Questions remain about how risk depends on characterization of storm and hydrologic event possibilities under a changing climate (Steps 3 and 4) and on how socioeconomic drivers in these assessments may change (Step 5).

Reclamation and USACE have limited recent experience in basin development planning that involves multiproject strategy and phased implementation over time. Such planning may be of interest in demonstrating preparedness for climate change adaptation. On assessing and ranking strategies that promote climate change adaptation, Reclamation and USACE have access to a variety of "master planning" techniques, some of which involve economically driven optimization (e.g., Tanaka et al. 2006). However, neither agency has guidance on appropriate frameworks for conducting such evaluations. Reclamation and USACE will continue to look for collaborative opportunities with local and regional water management entities that have more recent experience applying and developing approaches for multiproject "master planning" evaluations (e.g., AWWA, Water Utilities Climate Alliance, State water agencies coordinating multibasin water development efforts). On the portrayal of operator learning in adaptation evaluations, Reclamation does not have an established method.[1]

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[1] This is not to say that Reclamation does not have access to software that can simulate operations under user-define rules that may change with time, reflecting operator learning as climate changes. It is only saying that a rationale for specifying

On the issue of estimating the effects of operational changes on climate, Reclamation and USACE have access to online "calculators" of greenhouse gas emissions changes. However, there is lack of guidance on appropriate tools and methods of application. Reclamation and USACE will continue to look to other agencies for assistance on developing such guidance (e.g., USEPA).

Capability Gaps

Comparison of the preceding discussions on desired and current capabilities leads to the following list of gaps in guidance.

Gap 6.01: Guidance on how to conduct an adaptation evaluation that efficiently explores and rank strategy options, potentially using optimization techniques.

Gap 6.02: Guidance on how to portray realistic operator learning in evaluations supporting planning for climate change adaptation.[1]

Gap 6.03: Guidance on how to assess the effect of planning proposals *on* climate.

Note that the list of gaps does not include two other areas potentially requiring guidance:

- How to assess flood control requirements in a changing climate
- How to assess infrastructure safety in a changing climate

In the context of this document, these gaps seem to require programmatic reactions rather than a research or technology response. However, success in developing such programmatic responses will be affected by the success

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such rule changes over time (and specifying operator learning as climate changes) remains to be developed.

[1] In this context, "climate change adaptation" has a longer-term context, contrasting from concerns of shorter-term "adaptive management" featured in a number of Reclamation and USACE ecosystem management efforts.

of implementing research to address a number of associated gaps (e.g., Gaps 2.01–2.03, 3.01–3.06, 4.01–4.13, 5.01 and 5.03).

2.4.7 Step 7 – Assess and Characterize Uncertainties

This step involves assembling the various uncertainties that were individually introduced, assessed, and characterized during the course of the planning evaluation in Steps 2 through 6 (as possible). This element also involves assessing the interactions between these uncertainties (as far as is possible).

Desired Capabilities

Such assessment would ideally consider uncertainties arising from model structures, model development data, and methods of application. Reclamation requires an understanding on how to assess these various types of uncertainties, some of which are highlighted below:

- Step 2 (Obtain Climate Projections Data)
    - Data uncertainties affecting the regard for climate projections and their use (e.g., global socioeconomic and technological development translating into future greenhouse gas emissions; subsequent fate and transport of these emissions through the global ocean-atmosphere-land system, ultimately affecting climate; ability to model the climate system).
    - Method uncertainties involving bias-correction of climate projections.
    - Method uncertainties involving spatial downscaling of climate projections (e.g., statistically or dynamically).
- Step 3 (Decisions on Which Projections to Use and How to Use in Planning Scenarios)
    - Method uncertainties for culling or weighting climate projections.
    - Method uncertainties for blending climate information from the instrumental record, paleoclimate, and climate projections in planning assumptions.

  - Method uncertainties for assessing regional precipitation characteristics in climate projections, on time scales from days to decades.

  - Method uncertainties for incorporating *Period-Change* or *Time-Developing* projection or prediction information into planning assumptions.

- Step 4 (Assess Natural Systems Response)

  - Data uncertainties affecting the development and calibration of natural systems models (hydrologic, ecosystem).

  - Method and model development uncertainties associated with natural system models and how they are applied to the given study area.

- Step 5 and 6 (Assess Socioeconomics Response and Evaluate Study Questions)

  - Similar data and method uncertainties as Step 4, but for the various social system, operations, and dependent-resource analyses considered.

Current Capabilities

Reclamation and USACE are capable of performing uncertainty analyses on each analytical step, given available uncertainty information on model structures, model development data, and method of use. For example, tools like "@Risk" (Palisade Corporation, http://www.palisade.com/) and custom-built tools may be used to conduct studies on how system model outputs vary in relation to the possible values for model input data and/or model parameters.

On the analysis of how uncertainties interact across analytical elements, Reclamation and USACE have methods and tools for conducting such studies. However, the scope of such studies would be limited by understanding of how model inputs and structures should be free to vary. For example, in Step 2, Reclamation and USACE receive climate projections data from external groups.[1] These data reflect a series of analyses linking global economic and technological developments to future climate. Uncertainties stemming from these analyses are not readily accessible to the water planning community. Likewise, in Step 3, there are a number of uncertainties on how to best use *Period-Change* or *Time-Developing* characteristics of the climate projections in planning scenarios. There is also limited understanding on how these uncertainties affect analysis results and subsequent decisions. Generally speaking, it could be said that each of the step and gaps previously discussed have associated questions about how to characterize data, models, and methods uncertainties.

Capability Gaps

Comparison of the preceding discussions on desired and current capabilities leads to the following list of gaps in uncertainty information.

Gap 7.01: Uncertainty information on global climate projections data, including uncertainties about climate system science, portrayal in climate models, emissions scenario development, and simulation methods.

Gap 7.02: Uncertainty information on regional climate projections data, including uncertainties from choice of bias-correction and spatial downscaling methods.

Gap 7.03: Uncertainty in planning results stemming from method choices on how to use transient characteristics of climate projections in planning scenarios.

Gap 7.04: For each response analysis on a *natural system*, uncertainty information on system science and associated ways of portraying this science in a system model and the observations used to customize a model for a specific system.

[1] http://www.narccap.ucar.edu/. *Statistically Downscaled WCRP CMIP3 Climate Projections* at http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/.

Gap 7.05: For each response analysis on a *socioeconomic system*, uncertainty information on system science and associated ways of portraying this science in a system model and the observations used to customize a model for a specific system.

2.4.8 Step 8 – Communicate Results and Uncertainties to Decisionmakers

After completing the analytical tasks of the planning evaluation, results are summarized and presented for the consideration of decisionmakers and interested parties, along with characterized uncertainties.

Desired Capabilities

To support decisionmaking, the salient results of planning evaluations must be communicated effectively. Uncertainties in the evaluation's results must be disclosed and related to interpretation of results.

Current Capabilities

Reclamation and USACE have considerable experience in communicating planning results and uncertainties to decisionmakers and stakeholder groups. Such communication is a common feature of environmental compliance and other longer-term planning documentation. However, climate change is a relatively new feature in these studies and raises new communication questions. Further, much of this communication experience is rooted in the system portrayal paradigm that is more amenable to the *Period-Change* paradigm discussed under Step 3 (section 2.4.3). Switching to a *Time-Developing* paradigm would necessitate a view of a time-changing system with evolving probabilities of system conditions through time, which differs from the comparative "stationary systems" view featured under the *Period-Change* paradigm.

Reclamation's Mid-Pacific and Pacific Northwest Regions have experience communicating climate change implications for environmental compliance processes using the *Period-Change* paradigm (Reclamation 2008a, Reclamation 2008c). Reclamation's Upper Colorado and Lower Colorado Regions have experience communicating in a *Time-Developing* paradigm (e.g., Reclamation 2007). USACE adopted a risk-based analysis policy for water resource projects in 1996. However, much of that analysis is based on a static hydrologic characterization for expected project life, typically 50 years. Incorporating either a *Period-Change* or a *Time-Developing* paradigm is beyond the current capabilities of USACE analytical tools. USACE does not have standards for evaluating potential futures under either paradigm.

Capability Gaps

Reclamation has recently implemented different approaches to communicating climate change and variability information in planning (Reclamation 2007 and 2008a) but continues to be in a learning phase on best approaches for doing so. USACE is developing improved methods for risk communication and public involvement in risk management. They have yet to develop a framework for communicating risk related to climate but will be moving forward with Reclamation in this area.

Gap 8.01: Guidance on strengths and weaknesses of various methods for communicating results and uncertainties affected by the use of climate projection information.

Gap 8.02: Guidance on how to make decisions given the uncertainties introduced by consideration of climate projection information.

3 Perspectives from Other Water Management Organizations

The preceding section was prepared by the Bureau of Reclamation and the U.S. Army Corps of Engineers and is meant to be viewed as a joint agency perspective on improved tools and information our agencies need to better incorporate global climate change information into our management of water and water-related resources. Discussion now transitions to views and reactions to gaps from table 1, offered by internal management at Reclamation and USACE, other Federal agencies, and non-Federal organizations. The common attribute of entities providing perspectives is that they all manage, or play a role in managing water and water-related resources.

The purpose of this section is to provide a summary of views and perspectives offered, including opinions on how to relatively prioritize research to address gaps in table 1. This section proceeds in first describing the process for gathering feedback on gap statements, followed by key themes among gathered perspectives, and then a gap-specific summary of comments and perspectives.

3.1 Process for Gathering Perspectives

A draft version of this document, completed through section 2.0, was distributed to a list of internal Reclamation and USACE offices, non-Federal organizations, and other Federal organizations. These entities also received a summary table of gaps statements that included columns where the respondent could indicate priority-level rating for research to address the given gap (i.e., low, medium, and high rating choices), and/or offer comments on the given gap. The list of entities receiving distribution materials includes:

- Reclamation's regional offices, who then distributed materials to various area offices
- USACE division offices, who then distributed materials to various district offices

- Non-Federal organizations
  - American Water Works Association (AWWA)
  - American Society of Civil Engineers (ASCE) - Environmental and Water Resources Institute
  - ASCE Task Committee on Sustainable Design
  - Association of Fish and Wildlife Agencies
  - Association of Metropolitan Water Agencies (AMWA)
  - Association of State and Interstate Water Pollution Control Authorities
  - Association of State Dam Safety Officers
  - Association of State Drinking Water Administrators
  - Association of State Flood Plain Managers
  - Association of State Wetland Managers
  - California Department of Water Resources
  - California Energy Commission
  - California Farm Water Coalition
  - California Water and Environmental Modeling Forum
  - Central Arizona Project
  - Family Farm Alliance
  - Interstate Council on Water Policy
  - National Association of Flood and Stormwater Management Agencies
  - National Water Resources Association
  - National Waterways Conference
  - Salt River Project
  - Seattle City Light
  - Northern Colorado Water Conservancy District
  - The Nature Conservancy
  - Trout Unlimited

- Water Utility Climate Alliance
- Waterways Council, Inc.
- Western Colorado Water Conservation District
- Western States Water Council

- Other Federal Water and Water Related Management Organizations
  - Department of Health and Human Services (DHHS) – Centers for Disease Control and Prevention
  - DHHS – Coast Guard
  - DHHS – Federal Emergency Management Agency
  - U.S. Department of Defense (DOD) – Installation and Environment
  - DOD – Navy
  - DOD – Office of the Secretary of Defense (OSD) Installations and Environment (I&E)
  - DOD – OSD Strategic Environmental Research and Development Program (SERDP)
  - U.S. Department of Interior – Bureau of Indian Affairs
  - DOI – Bureau of Land Management
  - DOI – National Park Service
  - DOI – U.S. Fish and Wildlife Service
  - Department of Transportation (DOT) – Federal Highway Administration
  - Federal Energy Regulatory Commission (FERC)
  - Inland Waterways Users Board
  - International Joint Commission
  - NOAA Fisheries
  - NOAA National Ocean Service - Coastal Services Center
  - Nuclear Regulatory Commission
  - Power Marketing Administration (PMA) – Bonneville Power Administration
  - PMA – Western Area Power Administration

  - PMA – Tennessee Valley Authority
  - U.S. Environmental Protection Agency
  - U.S. Department of Agriculture – Forest Service
  - USDA – Natural Resource Conservation Service
- Potential Facilitators of Engagement
  - Council on Environmental Quality
  - National Science and Technology Council - Committee on Environment and Natural Resources (NSTC-CENR) Subcommittee on Water Availability and Quality
  - United States Global Change Research Program
  - Western Federal Agency Support Team (WestFAST)

The period for gathering perspectives occurred from March to June 2010. Entities providing feedback include:

- Reclamation
  - Great Plains Region – Eastern Colorado Area Office
  - Lower Colorado Region – Regional Office
  - Mid-Pacific Region – Central California Area Office
  - Mid-Pacific Region – Regional Office
  - Pacific Northwest Region – Regional Office
- USACE
  - Great Lakes and Ohio River Division
  - South Atlantic Division
  - South Atlantic Division – Jacksonville District
  - Northwestern Division – Portland District
  - Northwestern Division – Walla Walla District
- Non-Federal Organizations
  - American Society of Civil Engineers
  - American Water Works Association

  - Association of Metropolitan Water Agencies
  - California Department of Water Resources
  - California Water and Environmental Modeling Forum
  - Family Farm Alliance
  - Seattle City Light
  - Water Utility Climate Alliance
  - Western States Water Council
- Other Federal Water and Water Related Management Organizations
  - FEMA
  - FERC
  - NOAA National Ocean Service - Coastal Services Center
  - PMA – Western Area Power Administration
  - USEPA – Office Of Research and Development
  - USEPA – Office of Water
  - USEPA – Region 8

It is emphasized that Reclamation and USACE gathered perspectives while recognizing that it is unrealistic to assume that all relevant perspectives can be represented in the initial release of the document. The intent is to seed the initial release of this document with a representative cross-section of the other Federal, State, and local government water and ecosystem management perspectives as well as perspectives from nongovernment stakeholders. Subsequent to issuing this document, the intent is to utilize online networking to accommodate input and perspectives across the water management community of practice.

3.2 Key Themes Among Gathered Perspectives

Contributed perspectives were organized around the gap statements discussed in section 2.4 and summarized in table 1. The priority ratings were tallied to indicate priority regard for research to address the given gap. A complete record of perspectives received is included in appendices B–D. The last column of table 1 lists other needs assessments that contain discussions related to a given gap (i.e., Reclamation 2007, WSWC 2007, and CCAWWG 2008 [appendix A]).

Given the geographic areas served by Reclamation and USACE, these gaps may be thought of as being nationally relevant. While these gaps can be considered particularly relevant for management of Reclamation and USACE water supply and river regulation systems, it was envisioned that the gaps generally may be applicable for long-term management of any type of water infrastructure. Comparing the results of the relative priority rankings assigned by Reclamation/USACE, and those contributed from the perspective gathering process helps to identify where USACE/ Reclamation priorities are shared with the broader water management community. Appendix B contains a complete record of the priority rankings received and a comparison between those of USACE/ Reclamation and all respondents combined. These priorities and comparisons are also summarized in table 1 where the most-frequent relative priority (i.e., low, medium, high) assigned by Reclamation and USACE for each gap is shown next to the most frequent relative priority received from all Federal (including Reclamation and USACE) and non-Federal respondents combined. An examination of table 1 shows the priority rankings assigned by Reclamation/USACE compare favorably with those assigned by all respondents combined with only minor differences (e.g., low versus medium or medium versus high) on 12 of the 39 gaps listed.

Table 1. Summary of gaps and relation to other needs assessments

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1]		Other Assessments Having Related Discussion
	Reclamation/ USACE	All Respondents	
Step 1 – Summarize Relevant Literature			
1.01 Access to a clearinghouse of climate change literature relevant to water management or access to a bibliography of recommended literature to represent in literature syntheses.	Low	Low	CCAWWG 2008
1.02 Region-specific literature summaries, regularly maintained and peer-reviewed.	Medium	Medium	CCAWWG 2008
Step 2 – Obtaining Climate Change Information			
2.01 Improved skill in simulating long-term global to regional climate.	High	High	Reclamation 2007, Western States Water Council (WSWC) 2007
2.02 Downscaled data at finer space and time resolutions and for different variables.	High	High	CCAWWG 2008, WSWC 2007

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Table 1. Summary of gaps and relation to other needs assessments (continued)

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1]		Other Assessments Having Related Discussion
	Reclamation/ USACE	All Respondents	
Step 2 – Obtaining Climate Change Information (continued)			
2.03 Information on the strengths and weak-nesses of downscaled data and the down-scaling methodologies used to develop these data (including both statistical and dynamical methods and associated approaches for climate model bias-correction).	High	High	WSWC 2007
2.04 Indication of conditions of where and when the stationarity assumption of statistical downscaling may not hold (defined above) and should motivate use of dynamical downscaling techniques rather than statistical.	Medium	Medium	CCAWWG 2008, WSWC 2007
2.05 Synthesis of sea level projection information and guidance on consistent use in planning for all Reclamation and USACE coastal areas.	Low	Low	
Step 3 – Make Decisions About How To Use the Climate Change Information			
3.01 Understanding on observed climate variability from daily to multidecadal time scales, which underpins interpretation of future variability in climate projections and its relation to planning assumptions.	High	High	Reclamation 2007, WSWC 2007
3.02 Understanding how to interpret future variability in climate projections and relevance to operating constraints on shorter- to longer-term time scales (from daily to multidecadal).	High	High	Reclamation 2007
3.03 Basis for culling or weighting climate projections (if at all) when deciding which projections to use in planning.	Medium	Medium	CCAWWG 2008
3.04 Guidance on how to appropriately relate planning assumptions to either *Period-Change* or *Time-Developing* aspects of climate projections when deciding how to use projections in planning.	Low	Medium	
3.05 Guidance on how to jointly utilize the longer-term climate variability from observed records, paleoclimate, and projected climate information when portraying drought and surplus possibilities in planning.	Medium	High	Reclamation 2007, CCAWWG 2008
3.06 Method and basis for estimating extreme meteorological event possibilities, deterministically or probabilistically, in a changing climate.	High	High	CCAWWG 2008

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Table 1. Summary of gaps and relation to other needs assessments (continued)

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1]		Other Assessments Having Related Discussion
	Reclamation/ USACE	All Respondents	
Step 4 – Assess Natural Systems Response – Watershed Hydrology (WH), Ecosystems (E), Land Cover (LC), Water Quality (WQ), Consumptive Use on Irrigated Lands (CU), and Sedimentation and River Hydraulics (SRH)			
4.01 (*WH*) Guidance on strengths and weaknesses of watershed hydrologic models/methods to support scoping decisions in planning.	Low	Low	CCAWWG 2008
4.02 (*WH*) Understanding how climate change should impact potential evapotranspiration and how it is represented in watershed hydrologic models.	High	High	Reclamation 2007
4.03 (*WH*) Method and basis for estimating extreme hydrologic event possibilities, deterministically or probabilistically, in a changing climate. *(Similar to Gap 3.06 but focused here on hydrology rather than meteorological variables)*	High	High	CCAWWG 2008
4.04 (*WH*) Guidance on strengths and weaknesses of available versions of spatially distributed hydrologic weather data that may be used for both watershed hydrologic model development (Step 4) and in climate model bias-correction (Step 2).	Medium	Medium	
4.05 (*WH*) Understanding how climate change should impact groundwater recharge and groundwater interaction with surface water supplies.	Medium	Medium	Reclamation 2007, CCAWWG 2008
4.06 (E) Understanding how climate change should impact inland and coastal anadromous fisheries.	Medium	Low	CCAWWG 2008
4.07 (E) Understanding how climate change may impact riparian ecosystems and vegetation that affect both longer-term water budgets and ecological resources.	High	Medium	CCAWWG 2008
4.08 (E) Understanding translated into model frameworks for assessing climate change responses for fisheries, nonnative riparian vegetation, and other species or habitat conditions.	High	Medium	CCAWWG 2008
4.09 (LC) Understanding how climate and/or carbon dioxide changes should impact land cover communities that control natural evapotranspiration and soil erosion potential.	Medium	Low	Reclamation 2007, CCAWWG 2008
4.10 (WQ) Understanding how water quality characteristics depend on climatic variables and how dependencies may evolve in a changing climate.	High	High	

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Table 1. Summary of gaps and relation to other needs assessments (continued)

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1] Reclamation/ USACE	All Respondents	Other Assessments Having Related Discussion
Step 4 – Assess Natural Systems Response – Watershed Hydrology (WH), Ecosystems (E), Land Cover (LC), Water Quality (WQ), Consumptive Use on Irrigated Lands (CU), and Sedimentation and River Hydraulics (SRH) (continued)			
4.11 (*CU*) Understanding how climate and carbon dioxide changes should impact plant physiology, how impacts vary with crop type, and how impacts affect irrigation demand.	Medium	Medium	CCAWWG 2008
4.12 (*SRH*) Understanding how climate and/or land cover changes will change watershed sediment yield, changes in sediment constituency, and the resulting impacts on water resources.	Medium	Medium	
4.13 (*SRH*) Understanding how climate, land cover, and/or sedimentation changes will affect river and reservoir ice-event potential.	Medium	Low	
Step 5 – Assess Socioeconomic and Institutional Response			
5.01 Understanding how socioeconomic factors may affect flood risk reduction and reservoir regulation objectives in a changing climate (e.g., flood protection values, land management).	Medium	High	CCAWWG 2008
5.02 Understanding how socioeconomic factors may affect water and power delivery reliability, water allocations, as well as decisions on source of supply under a changing climate (e.g., ground-water pumping versus surface water diversion).	High	High	CCAWWG 2008
5.03 Understanding how institutional realities currently control socioeconomic responses to climate variability and could control socioeconomic responses under a changing climate.	Medium	Low	
Step 6 – Assess System Risks and Evaluate Alternatives			
6.01 Guidance on how to conduct an adaptation evaluation that efficiently explores and ranks strategy options, potentially using optimization techniques.	High	High	CCAWWG 2008
6.02 Guidance on how to portray realistic operator "learning" in evaluations supporting planning for climate change adaptation.	Low	Low	CCAWWG 2008
6.03 Guidance on how to assess the effect of planning proposals on climate.	Low	Medium	CCAWWG 2008

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

Table 1. Summary of gaps and relation to other needs assessments (continued)

Technical Planning Steps and Associated Gaps in Tools and Information	Priority Ranking[1]		Other Assessments Having Related Discussion
	Reclamation/ USACE	All Respondents	
Step 7 – Assess and Characterize Uncertainties			
7.01 Uncertainty information on global climate projections data, including uncertainties about climate system science, portrayal in climate models, emissions scenario development, and simulation methods.	High	High	CCAWWG 2008
7.02 Uncertainty information on regional climate projections data, including uncertainties from choice of bias-correction and spatial downscaling methods.	High	High	CCAWWG 2008
7.03 Uncertainty in planning results stemming from method choices on how to use transient characteristics of climate projections in planning scenarios.	Medium	Medium	CCAWWG 2008
7.04 For each response analysis on a natural system, uncertainty information on system science and associated ways of portraying this science in a system model and the observations used to customize a model for a specific system.	Medium	High	CCAWWG 2008
7.05 For each response analysis on a socioeconomic system, uncertainty information on system science and associated ways of portraying this science in a system model and the observations used to customize a model for a specific system.	High	Medium	CCAWWG 2008
Step 8 – Communicating Results and Uncertainties to Decisionmakers			
8.01 Guidance on strengths and weaknesses of various methods for communicating results and uncertainties affected by using climate projection information.	High	High	CCAWWG 2008
8.02 Guidance on how to make decisions given the uncertainties introduced by considering climate projection information.	High	High	

[1] Color shading indicates priority rating on research to address gaps: low (yellow), medium (light orange), and high (dark orange).

The relative priority ratings assigned to each of the gaps were also averaged across the gaps associated with each Technical Step (also known as Gap Category) to derive a relative priority that could be associated for each Technical Step. These results are shown in table 2.

Table 2. Prioritization of research to support each gap category

Technical Step	Gap Category (Technical Step)	Average Priority Rankings[1]	
		USACE/ Reclamation	All Respondents Combined
1	Summarize Relevant Literature	1.5	1.5
2	Obtaining Climate Change Information	2.5	2.4
3	Make Decisions About How To Use the Climate Change Information	3.0	2.7
4	Assess Natural Systems Response	3.0	1.9
5	Assess Socioeconomic and Institutional Response	2.5	2.3
6	Assess System Risks and Evaluate Alternatives	1.5	2.0
7	Assess and Characterize Uncertainties	2.0	2.6
8	Communicating Results and Uncertainties to Decisionmakers	3.0	3.0

[1] Low=1, Medium=2, High=3.

In terms of summary messages heard, Reclamation and the USACE indicate relatively greater concern for the following three Technical Steps:

- Step 3: Make Decisions About How to Use the Climate Change Information

- Step4: Assess Natural System Responses

- Step 8: Communicating Results and Uncertainties to Decisionmakers

This compares favorably to the perspectives of water managers from all respondents combined with agreement that both Steps 3 and Step 8 deserve the greatest concern. However, all respondents combined indicate a greater concern for Step 7: Assess and Characterize Uncertainties.

The remaining steps had medium priority ratings. Among these five remaining gaps, two received relatively greater priority regard:

- Step 2: Obtaining Climate Change Information

- Step 5: Assess Socioeconomic and Institutional Response.

The remaining steps received relatively lower priority. Review of gap-specific summaries (section 3.3) suggests that much of this lower prioritization stems from perception that a relatively greater understanding currently exists in these step areas compared to those that were given higher priority and does not necessarily indicate they are not as important as those assigned a high priority.

3.3 Perspectives Summaries for Each Gap Statement

This section provides gap-specific capsules that provide summary information on gathered feedback, including number of responses, most frequent priority rating for research to address the given gap, and comment highlights. A complete record of comments and feedback is provided in **appendix C,**[1] as an electronic supplement available at www.usbr.gov/climate/userneeds.

3.2.1 Step 1 – Summarize Relevant Literature

Gap 1.01: Access to a clearinghouse of climate change literature relevant to water management or access to a bibliography of recommended literature to represent in literature syntheses.

- Number of responses: 16
- Most frequent priority: Low (9)
- Some respondents suggested that providing such access should be viewed as a low priority, citing that many region-specific groups already monitor and gather relevant literature. Others suggested that providing such access ought to be high-priority, but only if it's done through an interagency effort that doesn't duplicate effort and complemented by an evaluation of documents included in the clearinghouse. There were also suggestions that any Reclamation and USACE investment in this area might involve partnering with entities that have begun to initiate such clearing houses (e.g., www.theclimatechangeclearinghouse.org).

[1] Several of the commenters cited the disclaimer that the perspectives they submitted are those of their own and do not necessarily represent the views of their respective agency/organization. This includes commenters from ASCE Geo-Institute, FEMA, Reclamation ECAO, Reclamation Mid-Pacific Region, USACE LRD, USACE NWP, USACE NWW, and Seattle City Light.

Gap 1.02: Region-specific literature summaries, regularly maintained and peer-reviewed.

- Number of responses: 16
- Most frequent priority: High (7)
- Several respondents suggested that this is a high priority activity, citing that such a review provides a place-based context for what's been studied. One respondent noted that most Federal water resources planning studies up to a feasibility level warrant only a literature review and that such a synthesis product would streamline reporting. Others suggested that any such review product be made easy to access by the water resources planning community (e.g., through a Share Point system). However, there were cautions that any synthesis would quickly become dated given the pace of climate change research and that there would need to be a continual effort to monitor, evaluate, and update such syntheses. Also, while summaries by administrated regions may be useful, suggestions also were made to consider organizing such summaries by natural watersheds, (which may or may not coincide with administrative boundaries)

3.2.2 Step 2 – Obtaining Climate Change Data

Gap 2.01: Improved skill in simulating long-term global to regional climate.

- Number of responses: 16
- Most frequent priority: High (9)
- A number of respondents suggested that activities to improve climate modeling skill should be highly prioritized. Some suggest that improvements in climate modeling would increase planners' inclination to incorporate climate projection information into investigations. Suggested targets for improvement ranged from global scale (e.g., processes in the equatorial Pacific related to ENSO, formation and tracking of hurricanes, low frequency climate variations like PDO and NAO) to the more regional and local scale where planning studies generally occur.

Gap 2.02: Downscaled data at finer space and time resolutions and for different variables.

- Number of responses: 17
- Most frequent priority: High (12)
- This gap received as many responses as any other gap and was also the most highly prioritized. Respondents generally recognized a need for downscaled climate projection information to translate global climate projection information at coarser spatial resolution to the finer spatial resolutions of assumptions that frame local water resources studies. Some respondents suggested consideration for supplying a suite of meteorological variables that support studies on vegetation water use in managed or natural areas (e.g., information on carbon dioxide, relative humidity and wind speed). Others suggested that downscaling be performed at time-resolutions consistent with a broad suite of watershed hydrologic analyses (e.g., monthly, daily, etc.).[1]

Gap 2.03: Information on the strengths and weaknesses of downscaled data and the downscaling methodologies used to develop these data (including both statistical and dynamical methods, and associated approaches for climate model bias-correction).

- Number of responses: 16
- Most frequent priority: High (9)
- A representative response was provided by FEMA:

> "It is extremely important for water managers to understand the limitations of the information they employ when making decisions. This could be addressed by educating engineers and other practitioners on the types of methods available for obtaining climate information, and the assumptions inherent in those methods. The question of scale is

[1] Many respondents gave comments that suggested they may not be familiar with Reclamation's current downscaled climate projection resources. This fall, there will be an update to include daily downscaled data products for three variables—the list of LTdoc respondents should be on the announcement list upon the release of this new dataset.

> extremely important. . . . Engineers have a tendency to rely on published datasets. If they don't understand how the values were estimated, they could be placing too much confidence in the results."

On the matter of bias-correction, concerns were expressed like the following offered by Reclamation Pacific Northwest Region:

> "Bias correction is a process which appears to use math tricks to create the illusion of good calibration. It is bothersome that a model, which is heavily dependent on bias correction, is used to predict flow into the future when there is no scientific reason behind the bias correction. More time should be spent on calibration. The problem is that time is usually short, and it is not known to me if you get the same solution with a good calibration with minor bias correction as compared to a poor calibration with major bias correction."

Another respondent directed attention to a useful white paper commissioned by the Water Utilities Climate Alliance describing the strengths and weaknesses of various downscaling methodologies and opportunities to improve such methods (www.wucaonline.org).

Gap 2.04: Indication of conditions of where and when the stationarity assumption of statistical downscaling may not hold (defined above) and should motivate use of dynamical downscaling techniques rather than statistical.

- Number of responses: 15
- Most frequent priority: Medium (9)
- One commenter pointed out the challenges of interpreting historical nonstationarity and to what degree historical hydroclimate information still applies for future planning. The same commenter suggests that

> "it would be great to have a national map, like the generalized skew coefficients map in Bulletin 17B, that shows how much to factor historic data to reflect the nonstationarity of hydrology for each part of the country."

On the choice of statistical versus dynamical techniques, one commenter suggested that, although statistical techniques are limited by the "flawed" stationarity assumption, it doesn't necessarily follow that dynamical downscaling will be more valuable. Instead, it depends on what we're trying to interpret from the downscaling results, relative to the strengths and weakness of the downscaling technique. Another reviewer suggested that research might be spent on developing downscaling methodologies that combine the strengths of both dynamical and statistical techniques, perhaps leading to an approach that still relies on data-driven statistical relationships, but honoring more physical cause-and-effect constraints.

Gap 2.05: Synthesis of sea level projection information and guidance on consistent use in planning for all Reclamation and USACE coastal areas.

- Number of responses: 16
- Most frequent priority: Low (6)
- This prioritization of this gap was almost evenly split between low, medium, and high. Some respondents commented that a lot of guidance is already available, including national guidance recently developed by USACE, guidance developed by the States of California, Oregon, and Washington, and guidance being developed by the National Research Council. Others recognized that development of syntheses and guidance would be a good activity, so long as the resultant guidance is appropriately tailored to a particular decision context and for use by any agency planning in coastal areas, not just Reclamation and USACE. Another commenter questioned how any synthesis development responding to this gap statement would be potentially incorporated into Federal P&Gs that are currently being revised.

3.2.3 Step 3 – Make Decisions About How To Relate Climate Projections Data to Planning

Gap 3.01: Understanding on observed climate variability from daily to multidecadal time scales, which underpins interpretation of future variability in climate projections and it's relation to planning assumptions.

- Number of responses: 16
- Most frequent priority: High (9)
- All priority ratings for this gap were at least medium or greater. Several commenters suggested that better historical climate understanding is needed to support future hydroclimate planning assumptions. One commenter pointed out that the climate varies on many different timescales and that it is difficult to interpret our relative position within sets of nested variability cycles. Another respondent suggested that more research is needed on being able to "*translate the observed variability from different, unknown historical mechanisms into a reasonable prediction of variability under new mechanisms.*" On the matter of needing to interpret historical climate variability simultaneously across multiple time scales, one commenter pointed out the challenge of doing this and how it could influence water resources planning, citing proposals to

  > "allow reservoirs to be more full in the future to mitigate for droughts brought on by climate change [which could conflict] with flood control requirements … designed for extreme events. It is currently very difficult to justify adjusting historic peak flows to simulate future flood events."

Gap 3.02: Understanding on how to interpret future variability in climate projections and relevance to operating constraints on shorter- to longer-term time scales (from daily to multidecadal).

- Number of responses: 15
- Most frequent priority: High (10)
- This gap statement received one of the more consensus priority ratings among all gap statements considered (high). Comments reflected how there is considerable debate and little guidance on how to interpret future climate variability in climate projections for the sake of influencing local water resources planning assumptions. For example, one commenter offered a planner's perspective "*we need to be confident that our adjustment for climate change is an improvement*" [relative to traditional planning assumptions] and concern that

planners not let any such adjustments cause planning miscalculations, especially in the short term. One respondent suggested that "*divergent viewpoints need to be aired and integrated*" in a way that would lead to "*guidance on best application of various downscaling methods/approaches relative to the use's temporal and spatial scales*." Another commenter offered the perception that, although climate models provide reasonable estimates of mean future conditions, they do not necessarily provide reasonable information about the extremes.

Gap 3.03: Basis for culling or weighting climate projections (if at all) when deciding which projections to use in planning.

- Number of responses: 14
- Most frequent priority: Medium (8)
- Most commenters recognized a need for more research to address this gap; however, some pointed out that considerable work in this area has already been completed. There was recognition that expert information on the use of individual projections or a projections ensemble is important given the wide array of projection information available. On the matter of using ensemble information, one commenter pointed out that doing so increased the analytical burden in planning analyses and that, in order to justify this burden, it's important to understand the merits of the ensemble view. Another commenter cautioned that, although an ensemble represents consensus information from many projections, it's possible that all projections could be relying on similar physical assumptions, right and wrong, leading to bias and pointing to the sensibility in understanding "*the methods associated with the projections to determine their biases, simplifications, and assumptions.*" The same commenter suggested that *"guidance on which projections (and methodologies) are most appropriate for specific management applications would be useful."*

Gap 3.04: Guidance on how to appropriately relate planning assumptions to either Period-Change or Time-Developing aspects of climate projections, when deciding how to use projections in planning.

- Number of responses: 16
- Most frequent priority: Medium (7)
- Although the majority of commenters suggested that this gap warranted a medium or greater priority, commenters had mixed feelings on whether the response to this gap involved research or subjective judgment and policy. One commenter conditioned their high priority rating on the chance that the statement might be edited to remove the word "guidance" and emphasized the research connotation. In terms of what type of information is sampled from the climate projections, a region-specific view was offered from the USACE Atlantic Coastal Region, suggesting that guidance is warranted on how to interpret climate projections for changes in future frequency and intensity of hurricanes.[1]

Gap 3.05: Guidance on how to jointly utilize the longer-term climate variability from observed records, paleoclimate, and projected climate information when portraying drought and surplus possibilities in planning.

- Number of responses: 16
- Most frequent priority: High (9)

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[1] Note from the authors: There were several comments suggesting that the review draft report's description of issues leading to this gap statement may have been unclear. For example, one commenter interpreted the gap to be about whether a collective of climate projections should inform planning, and not the subsequent matter of how the climate projections should be temporally sampled for information that would affect planning assumptions (i.e., Should a "*Time-Developing*" approach be used where time-developing climate is GCM simulated (historical to future) and mapped directly to time-developing planning assumptions? Or, should a "*Period-Change*" approach be used where more aspects of observed historical climate variability are preserved in planning assumptions, with the observed historical envelope adjusted to reflect period statistical changes in climate sampled from the climate projections?).

- Most commenters indicated a high-level of interest in this gap statement, with some pointing out that the research to address Gap 3.01 would likely be relevant to addressing 3.05. Some commenters suggested that paleoclimate information could be useful to help characterize hydrologic possibilities outside the range of instrumental observations, but that there was some uncertainty on how to best utilize such paleo-informed information.[1] Another commenter pointed out that it's clear that some water managers are making their own judgments on the utility of paleoclimate information for planning, noting examples where tree-ring studies have been used to characterize drought possibilities.

Gap 3.06: Method and basis for estimating extreme meteorological event possibilities, deterministically or probabilistically, in a changing climate.

- Number of responses: 15
- Most frequent priority: High (10)
- This gap received mostly high priority ratings among respondents. Several pointed out how this gap is relevant to characterizing the potential for rare flood events relevant to infrastructure safety and more common flood events relevant to flood control operating criteria in reservoir systems. It was recognized by several others that characterizing potential for rare flood events is already difficult based on historical climate information, without adding the complexity of interpreting potential changes in storm frequency within future climate projections or considering the uncertainties introduced by the chosen process of downscaling such information to local scales relevant to flood frequency estimation. One commenter focused on the apparent intractability of the problem, questioning whether significant research should be spent to address this gap, since it seems that this gap is relatively more difficult to address and that research outcomes seem *"highly uncertain."* Still another commenter offered more optimism about research success, suggesting that activities might be scoped "*to improve our understanding of the physical processes associated with extreme hydrologic events, to combine downscaling with an*

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[1] Several commenters suggested terminology change from "drought and surplus" to "drought and flood." However, the use of surplus was meant to contrast long, wet spells with long, dry spells and not necessarily conjure the notion of floods.

'upscaling' framework," progressing in scales from event to storm to weather patterns and finally to climate conditions, and "*to improve the statistical tools for nonstationary flood frequency analysis*."

3.2.4 Step 4 – Assess Natural Systems Response

Gap 4.01 (Watershed Hydrology): Guidance on strengths and weaknesses of watershed hydrologic models/methods to support scoping decisions in planning.

- Number of responses: 16
- Most frequent priority: Medium and Low (6 each)
- Some commenters felt that research in this gap area is critical to support planning efforts at the regional or basin watershed scale. However, there was a majority sentiment that much is already understood about the strengths and weaknesses of hydrologic models and that more research attention should be spent on how to best characterize climate change adjusted inputs to hydrologic models (e.g., weather, basin characteristics). One commenter shared the perception that the uncertainty of climate change overshadows the uncertainty of choosing among hydrologic models and that "*Institutions like their own models, so probably will not change them. Agencies without models will seek simplicity and 'good enough' answers rather than precision*." Still, other commenters showed interest in understanding how various model types (i.e., model structures and associated parameters) are more or less well-suited for assessing climate change implications for hydrology. One commenter suggested interagency collaboration on the matter, taking advantage of research and application developments by Federal, State, and nongovernmental entities.

Gap 4.02 (Watershed Hydrology): Understanding on how climate change should impact potential evapotranspiration and how it is represented in watershed hydrologic models.

- Number of responses: 15
- Most frequent priority: High (7)

- There were mixed perceptions about whether research to better understand climate change impacts on natural landscape evapotranspiration (ET) should be highly prioritized. The majority of commenters felt that it was a high-priority issue, with some suggesting that improved understanding in this area would lead to better characterization of future hydrologic processes and runoff. Other commenters wondered if we already understand a considerable amount in this area (e.g., "*How* [is this] *different from literature review question above?*"), or how relevant this issue area is to understanding hydrologic impacts in developed regions (e.g., "*This is important in undeveloped regions like the forests. Not so important in farm country. ET will change, but crops will change too.*").[1]

Gap 4.03 (Watershed Hydrology): Method and basis for estimating extreme hydrologic event possibilities, deterministically or probabilistically, in a changing climate. (Similar to Gap 3.06, but focused here on hydrology rather than meteorological variables).

- Number of responses: 16
- Most frequent priority: High (11)
- Most commenters shared the view that research in this area is a high priority and saw this as the hydrology follow-on to characterizing climatic and weather extremes in a changing climate (Gap 3.06). As with 3.06, several commenters found this gap to be relevant to a variety of water planning and management interests, including characterizing the potential for rare flood events relevant to infrastructure safety, characterizing more common flood events relevant to flood control, and characterizing long-term time scale events related to drought and wet periods.

[1] Note from the authors: The contrasting sentiments may reflect some contrast in geographic experience among commenters. For example, a low-priority view was contributed from Reclamation's Pacific Northwest Region, which experiences relatively more runoff-abundant conditions. In contrast, a high-priority view was contributed from Reclamation's Lower Colorado Region, which manages under relatively less abundant runoff and in a basin where ET is the dominant fate of precipitation.

Gap 4.04 (Watershed Hydrology): Guidance on strengths and weaknesses of available versions of spatially distributed hydrologic weather data that may be used for both watershed hydrologic model development (Step 4) and in climate model bias-correction (Step 2).

- Number of responses: 16
- Most frequent priority: Medium (9)
- The prevalent view among respondents was that research in this area was a medium priority; however, there was limited commentary offered to explain this level of prioritization. Two of the respondents that labeled this a high priority gap offered similar views on the need for research in this area, one commenting that research on:

  > ". . .the physical processes linking extreme flood events to mesoscale and synoptic weather patterns would be valuable. However, there are limitations on the datasets, including length of record and spatial distribution of [weather] stations."

  Another generically suggested that "Improving our understanding of existing tools, resources, models, datasets, etc. is important."

Gap 4.05 (Watershed Hydrology): Understanding on how climate change should impact groundwater recharge and groundwater interaction with surface water supplies.

- Number of responses: 16
- Most frequent priority: Medium (8)
- As with the preceding gap, the prevailing view was that the need for research in this gap area was a medium priority. However, as with 4.04, comments were primarily offered to explain high or low priority views. Low priority views were offered based on perception that we already have considerable amount of understanding about how to assess groundwater interactions with surface water. High priority view seemed to stem from several concerns, including questions about future water scarcity in regions where groundwater resources are already heavily utilized ("*Does not get much attention but is needed for*

many areas in Great Plains Region."), and questions about the adequacy of current hydrologic models for characterizing how ecologically relevant groundwater and surface water interactions might be affected by climate change (e.g., "*…this is particularly important for understanding effects on low-flow streamflow events and stream temperature which are very important/limiting for many ecosystem endpoints.*").

Gap 4.06 (Ecosystems) Understanding on how climate change should impact inland and coastal anadromous fisheries.

- Number of responses: 14
- Most frequent priority: Low (6)
- The prevailing view among respondents is that low priority should be assigned to address this gap, although priority views were fairly well mixed. Few respondents offered reasons for assigning low priority; one exception was a commenter expressing concern about the potential intractability of the issue ("*Too many variables (urban runoff, ocean harvest, management practices, etc.*"). Another commenter suggesting medium priority shared concern that perhaps there is already much understood on this subject, which should inform any additional research scoping.

Gap 4.07 (Ecosystems): Understanding on how climate change may impact riparian ecosystems and vegetation that affect both longer-term water budgets and ecological resources.

- Number of responses: 15
- Most frequent priority: Medium (7)
- All respondents except two either assigned medium or high priority level to research in this gap area. One commenter suggested that:

> ". . .there should be a focus on assessment of changes in ecosystem services provided by these habitats and what appropriate mitigative actions to preserve and/or restore these functions could be."

Another commented on how:

> “. . .vegetation health is intrinsically linked to aquatic life designated uses under the Clean Water Act, and water quality criteria protect vegetation and are based on the latest scientific information.”

Gap 4.08 (Ecosystems): Understanding translated into model frameworks for assessing climate change responses for fisheries, nonnative riparian vegetation, and other species or habitat.

- Number of responses: 15
- Most frequent priority: Medium (7)
- Similar to 4.07, most respondents assigned medium or high priority to research in this gap area, although one commenter, suggesting high priority ,did question the limited scope of the gap statement:

> “Unclear why there is specific focus on nonnative riparian vegetation unless for invasive species control. …the focus should be on assessment and quantification (if possible) of changes in ecosystem services provided by habitats.”

Another commenter placed their high priority rating in the context of others offered for 4.06 and 4.07, suggesting that research on the two former gaps should occur prior to research in this gap area.

Gap 4.09 (Land Cover): Understanding on how climate and/or carbon dioxide changes should impact land cover communities that control natural evapotranspiration and soil erosion potential.

- Number of responses: 14
- Most frequent priority: Low and High (5 each)
- There was a near even-split among the three possible priority levels surveyed. There also was limited commentary in association with priority ratings. One commenter, offering a high rating, cautioned

that research in this gap area may be “*sector-based, hard to prioritize*.” Another offering a low priority view commented that this gap seemed “*outside of scope*.”

Gap 4.10 (Water Quality): Understanding on how water quality characteristics depend on climatic variables and how dependencies may evolve in a changing climate.

- Number of responses: 16
- Most frequent priority: High (9)

Thirteen of the sixteen responses suggested a research priority-level of medium or greater in this area. For example, a commenter from USEPA offered the following view point (which was largely echoed in comments from AWWA and AMWA) in association with a high priority rating:

> “There is a lack of research regarding climate change impacts on water quality to protect designated uses (being management objectives in State, tribal, and territorial water quality standards for individual surface waters, e.g., aquatic life is a category of designated uses). This originates from the basic uncertainty in GCM precipitation projections and their compounded uncertainty when this information is used to drive hydrologic models. The focus of the output for these hydrologic models in most cases is water supply, but OW is interested in how this will impact water quality, not just quantity, and if current water quality standards under the Clean Water Act are sufficient to protect human health and the environment.”

Other commenters offered high priority ratings, but some views may have been motivated less by perceptions on limited understanding on how to conduct water quality assessments under climate change and more by the lack of built water quality model applications and lack of agency staff trained on how to use such models (e.g., “*There are few river/reservoir system water quality models. Water quality monitoring and modeling is in drastic need for upgrading. Staff needs experience and training with this.*”).

Gap 4.11 (Consumptive Use in Irrigated Areas): Understanding on how climate and carbon dioxide changes should impact plant physiology, how impacts vary with crop type, and how impacts affect irrigation demand.

- Number of responses: 15
- Most frequent priority: Medium (7)
- Respondent attitudes varied fairly evenly in how priority level was assigned to this gap area. One high priority rating came from the Family Farm Alliance, who also suggested that:

  > "The potential water impacts associated with use of alternative fuels must also be studied. Another growing demand that will be placed on Western water resources is driven by power requirements. The total water consumed by electric utilities accounts for 20 percent of all the nonfarm water consumed in the United States. By 2030, utilities could account for up to 60 percent of the nonfarm water, to meet the water needs required for cooling and pollutant scrubbing. This new demand will likely have the most serious impacts in fast-growing regions of the United States, such as the Southwest."

  Another commenter gave a high priority rating but cautioned that research in this area would be "*sector based, hard to prioritize,*" which perhaps suggests a research need that will be hard to prioritize on the grounds of multisector or broad geographic benefit. In this sense, the suggestion of another commenter may have merit, namely that Reclamation and USACE respond by scoping collaborative research activities with "*their fellow Federal agencies to develop solutions to these problems.*"

Gap 4.12 (Sedimentation and River Hydraulics): Understanding how climate and/or land cover changes will change watershed sediment yield, changes in sediment constituency, and the resulting impacts on water resources.

- Number of responses: 15
- Most frequent priority: Medium (9)

- A variety of priority levels and views were offered in reaction to this gap statement. One commenter focused on the water quality aspects of watershed sediment yield, suggesting that yield of other pollutants should also be studied. Several recognized that landscape vegetation response to climate change would affect watershed sediment yield and, perhaps, needs to be better characterized before addressing this issue.

Gap 4.13 (Sedimentation and River Hydraulics): Understanding how climate, land cover, and/or sedimentation changes will affect river and reservoir ice-event potential.

- Number of responses: 14
- Most frequent priority: Low and Medium (5 each)
- The response to this gap was nearly an even mix of low to high priority ratings. Comments were limited. One respondent was concerned about Pacific Northwest Region impacts, suggesting that "*streambed aggradation and increased sedimentation in reservoirs from loss of glaciers in North Cascades is a potential impact in our watersheds.*" Another questioned whether we need to have a better understanding of impacts from increased rainfall on soils that transition to being frozen for less time during the year.

3.2.5 Step 5 – Assess Socioeconomic Systems Response

Gap 5.01: Understanding on how socioeconomic factors may affect flood risk reduction and reservoir regulation objectives in a changing climate (e.g., flood protection values, land management).

- Number of responses: 15
- Most frequent priority: High (7)
- Most respondents viewed research on this gap to be of at least medium priority. One high priority view was offered with the comment that "*These socioeconomic research needs are highly ranked because we're simply lagging so much in integrating social sciences into climate change work.*" Another high priority view focused on the matter of estimating flood frequency and characterizing flood risk: "*Research activities which would provide improved projections of future flood*

risks under changing climate conditions for various regions of the nation would be extremely useful for local flood plain management efforts," suggesting that even though "*Flood Insurance Rate Maps (FIRMs) prepared for implementation of the National Flood Insurance Program use existing conditions, local communities can manage increased flood risks due to future conditions.*"

Gap 5.02: Understanding on how socioeconomic factors may affect water and power delivery reliability, water allocations, as well as decisions on source of supply under a changing climate (e.g., groundwater pumping versus surface water diversion).

- Number of responses: 14
- Most frequent priority: High (10)
- Respondents mostly gave this gap a high priority rating. One comment focused on how understanding on this aspect could become extremely important in water management as climate change leads to greater water scarcity in some areas. Another commenter from Reclamation suggested a broader scope to the gap statement, saying that better understanding is needed "*on how socioeconomic factors related to climate change may affect all resources (deliveries, hydropower, recreational, environmental, etc.)* [for which] *Reclamation operates.*"

Gap 5.03: Understanding on how institutional realities currently control socioeconomic responses to climate variability and could control socioeconomic responses under a changing climate.

- Number of responses: 14
- Most frequent priority: Low (6)
- Priority ratings varied fairly evenly for this gap, with a majority of responses suggesting low priority. One such low rating came with the comment that

> "Adaptation strategies will likely involve the reworking of institutional 'realities.' The ongoing efforts of the Council on

> Environmental Quality's Interagency Climate Change Adaptation Task Force should be useful in addressing this gap."

However, others felt this fell into the general category of understanding socioeconomic responses to climate change, which could, in turn, influence water and environmental resources management and warrants high priority research activity given that relatively little research has been spent to-date on the study of climate change impacts on socioeconomics relative to impacts on natural systems. Still other comments suggested that perhaps this gap statement doesn't easily invite research activities, as posed. To this effect, one commenter suggested the statement be edited to:

> ". . .understanding how socioeconomic responses to climate variability will impact established institutional structures and how rigidity of those structures may prevent adaptation to climate change."

3.2.6 Step 6 – Assess Socioeconomic Systems Response

Gap 6.01: Guidance on how to conduct an adaptation evaluation that efficiently explores and rank strategy options, potentially using optimization techniques.

- Number of responses: 17
- Most frequent priority: High (8)
- There was consensus among respondents that research in this area should be highly prioritized. More interestingly, most of the priority ratings were accompanied by a diverse set of perspectives. Several comments focused on how this gap relates to adaptation planning (e.g., "*Evaluation of adaptation alternatives and development of optimization strategies at the watershed or basin level is critical for future planning efforts.*"). Another suggested that this is an important research need and that non-optimization approaches should be explored. However, one comment, offered in association with a medium rating, suggested that although ranking strategies is important, "*optimization rarely ends up with a valuable product when dealing with water systems because institutional*

and legal constraints lead to non optimal solutions." On the scope of the gap statement, one comment suggested the scope might be broadened: "*Expand to include guidance on and an understanding of the strengths and weaknesses of decisionmaking approaches under climate change uncertainty*." This comment hints at a boundary of this report, namely that the document addresses user needs for the task of generating information to support decisions, and stops short of characterizing user needs for the task of making decisions under uncertainty (associated with potential climate change or uncertain study drivers). That said, several comments do speak to the need for research to address decisionmaking uncertainty—e.g., from USACE:

> "Adaptive management, robustness, resilience, and flexibility are some key tools for water managers to deal with climate change. This draft report barely dealt with the need for robustness, resilience, and adaptive management as tools for dealing with climate change. I feel this should be identified as a gap in tools in this draft report. A major impediment to robust and resilient design is focusing on the optimal solution.")

Gap 6.02: Guidance on how to portray realistic operator "learning" in evaluations supporting planning for climate change adaptation.

- Number of responses: 12
- Most frequent priority: Low (9)
- This gap statement received the lowest priority reaction among gaps considered. Based on a couple of comments received, it might be interpreted that this report doesn't clearly make a case on what is meant by operator "learning" in systems evaluations under a changing climate context and why portrayal of such learning is relevant or important to adaptation assessments.

Gap 6.03: Guidance on how to assess the effect of planning proposals on climate.

- Number of responses: 17
- Most frequent priority: Medium (9)
- Although this gap received a priority rating of medium, it is interesting to note that no respondent suggested that research in this area should be given a high priority. One comment was offered in association with medium priority rating:

  > "… we need this sort of information to complete our effects analysis in NEPA documents. One application for this information is in assessing the impacts of our operations (e.g., execution of long-term water contracts (40-years) on water supply. How are these actions affecting climate change?"

  Still another comment offered the contrasting view and low priority rating: "*Not too worried on Reclamation's impact on climate. More concerned with impact of climate on water supplies.*"

3.2.7 Step 7 – Assess Socioeconomic Systems Response

Gap 7.01: Uncertainty information on global climate projections data, including uncertainties about climate system science, portrayal in climate models, emissions scenario development, and simulation methods.

- Number of responses: 17
- Most frequent priority: High (8)
- The most prevalent reaction among respondents is that research should be highly prioritized in this area. One commenter suggested that it is extremely important for water managers to understand the limitations of the data they employ when making decisions and "*not just the uncertainty associated with individual steps, but the propagation of aggregated uncertainties throughout the process.*" Another commenter went beyond the scope of the gap statement,

suggesting that we need to understand how results from planning analyses are sensitive to such uncertainties. Still others held a more reserved view. One commenter suggested that uncertainty information would be useful but difficult to quantify. Another comment built on this thought, suggesting that any research to characterize uncertainties and their relevance will be decision-centric ("*Uncertainties are everywhere, and we need to understand them sure, but we need a decision context to help reveal which uncertainties are most important in a given problem.*"). Lastly, a suggestion was offered that research to address gaps under Technical Steps 2 through 6 should be scoped to also characterize associated uncertainties, rather than scope specific research to address Gaps 7.01–7.05.

Gap 7.02: Uncertainty information on regional climate projections data, including uncertainties from choice of bias-correction and spatial downscaling methods.

- Number of responses: 16
- Most frequent priority: High (10)
- Comments on this gap were similar to those offered for Gap 7.01. However, in contrast to Gap 7.01, this gap appeared to resonate more consistently with respondents as all priority ratings were medium or greater. One commenter offering a high priority-rating suggested that there's need to characterize uncertainties introduced by both spatial downscaling and climate model bias-correction. Another commenter suggested that perhaps such research in this area might be scoped at a medium priority, with higher priority efforts spent on improving the skill of regional climate projections.

Gap 7.03: Uncertainty in planning results stemming from method choices on how to use transient characteristics of climate projections in planning scenarios.

- Number of responses: 16
- Most frequent priority: Medium (7)

- Comments on this gap were similar to those offered for Gap 7.01. One Reclamation commenter, offering a high priority rating, recognized the challenges of implementing transient techniques (described as "Time-Developing" application in section 2.4.3) and characterizing associated uncertainties ("*Transient analysis is very interesting but difficult to understand and communicate. Needs lots of work. Big Gap.*"). A similar high priority-rating and comment was offered by a respondent from USACE:

  > "For the LOSLR, we used steady state climate scenarios but recognized the need to evaluate transient scenarios. For the upper lakes study, we hope to address transience via stochastic generation of supplies based on climate change projections."

  Still, the prevalent view was a medium priority rating, with several commenters suggesting that research to improve the credibility of climate projection information should be prioritized over research to characterize uncertainties.

Gap 7.04: For each response analysis on a natural system, uncertainty information on system science and associated ways of portraying this science in a system model and the observations used to customize a model for a specific system.

- Number of responses: 17

- Most frequent priority: High (8)

- On this gap, there was a near even split in priority ratings between medium and high, with a couple of respondents suggesting low priority. Similar comments were offered for this gap as for Gap 7.01. Two commenters offering high priority ratings suggested that this understanding was a limitation in recent climate change impacts assessments within their region—e.g., from Reclamation Pacific Northwest:

  > "The recent RMJOC modeling of the Columbia/Snake has revealed many of the shortcomings of the current [hydrology] models for performing detailed climate change analysis."; from USACE Great Lakes District "We missed this

> step in the LOSLR Study; we have been working on addressing this in the Upper Lakes Study."

Also, one respondent that suggested medium priority for Gaps 7.01–7.03 suggested high priority for this gap, commenting that:

> ". . .here the importance is higher, because we don't necessarily have good process models (e.g., bio, eco, socio) to integrate into climate and hydrology models to actually explore the complex interactions and emergent behaviors that would likely provide the largest challenges for management."

Gap 7.05: For each response analysis on a socioeconomic system, uncertainty information on system science and associated ways of portraying this science in a system model and the observations used to customize a model for a specific system.

- Number of responses: 17
- Most frequent priority: Medium (7)
- Priority ratings were fairly evenly distributed on this gap statement. Many commenters suggested high priority for research in this area, just as they did for Gaps 7.01–7.04. Other commenters shared pessimism about the likelihood of positive research outcomes in this area (e.g., "*Socioeconomics seems like a 'black hole' for climate change research funds. Should not be a Reclamation priority.*").

3.2.8 Step 8 – Assess Socioeconomic Systems Response

Gap 8.01: Guidance on strengths and weaknesses of various methods for communicating results and uncertainties affected by the use of climate projection information.

- Number of responses: 16
- Most frequent priority: High (9)
- Except for a lone exception, all commenters suggested medium or high priority research in this area. One commenter suggested that

"*communicating climate information, results, and uncertainties is very necessary to successful planning; and this area hasn't been well researched*." Another pointed to the challenges of communicating flood risk to individuals and communities even under current climate conditions, suggesting that it will be a challenge to develop "*communication products to convey information with large variability and uncertainty, but with important implications for life-safety*." One commenter relayed a recent experience where their planning process was challenged on the task of communicating uncertain climate information, suggesting that "*there was a lot of misunderstanding and misinterpretation of the current climate results let alone the climate change results*." Another commenter cautioned that communication of uncertainties will have to be applicable to a wide range of audiences that will be receiving climate change information. On research direction, one commenter suggested consideration on how various methods of communication are more or less effective given the target audience and how planning processes are often dealing with multiple audiences. Another comment questioned whether the response to this gap involved research or practitioner education on how to effectively communicate results.

Gap 8.02: Guidance on how to make decisions given the uncertainties introduced by consideration of climate projection information.

- Number of responses: 16
- Most frequent priority: High (9)
- Commenters mostly assigned medium and high priority ratings on research to address this gap area. One commenter summarized their view, suggesting that:

  "...the most important challenge facing planners is how to make decisions under conditions of deep uncertainty. This is the area where research could make a big difference."

  Another commenter suggested that there is a need for Reclamation and USACE:

  "...to establish a common understanding on how climate change should be incorporated in flood risk and dam safety

> evaluations. … If the best available science is not yet adequate to inform decisionmaking, guidance on interim approaches should be developed."

Still others felt that this gap warranted a policy response rather than research, for example:

> "Do we use the climate change information to plan a project or not? It is easier to do the climate analysis and display it in an appendix but not actually act on it because of uncertainty."

Another suggested that research in this area should be a low priority assuming that "*decisionmaking will be influenced more by [nonclimate] factors, including: location, parties involved, statutory environment, regulatory processes, etc.*" Still, most respondents felt that activity in this area was warranted. AWWA and AMWA summed up their view, suggesting that this gap was not only highly important, but that this gap should be separated from the list of gaps and couched as an elevated, overarching issue:

> "Guidance on how to make decisions given the uncertainties of climate change is an extremely important topic and is central to the entire debate on how to adjust to a new planning paradigm. … We would suggest elevating the importance of this knowledge gap. This is not to say that Reclamation and USACE should be responsible for developing this guidance. Instead, they should work with their Federal partners, State, and local water utilities, research organizations, and water sector associations. A collaborative approach that incorporates all the relevant stakeholders is the most effective way to identify best management practices for long-term water resource planning in a changing climate."

3.4 Additional Comments and Feedback

The process of gathering perspectives also led to some entities suggesting other gaps statements to be considered along with those from table 1. Those statements are listed below and are also appended with comments in the record of feedback in appendix C. Note that these other gap statements were not screened relative to those listed in table 1, and they may appear to overlap in some ways with those already listed in table 1. Rather than screen these other gap suggestions, a decision was made to simply list them below:

- Step 1
  - Problem Definition/formulation: Recognized weakness in planning processes that do not focus on clearly defining the problem being studied, or recognizing that many adaptation issues have probably not yet been recognized or problems may exist that may require adaptations, which are ill-defined.
- Step 2
  - Data Management System: An information technology (IT) system/framework that facilitates the mining, extraction, analysis, and distribution of data.
  - Identify gaps and collect new data to inform modeling based upon this new data. Then, as the project develops and is placed online, data collection to inform adaptive management decisions also is needed.
- Step 3
  - Understanding nonstationarity of historical observations.
  - Guidance on when and how a project needs to address climate change.
- Step 4
  - (Watershed Hydrology) Understand impacts on seasonal wetlands.
  - (Watershed Hydrology/Geomorphology) Understanding how soil erosion and land subsidence affect hydrogeomorphology.
  - (Water Quality) Understanding bioaccumulation rates and residence times of contaminates in source water and wetlands.
  - (Sedimentation, River Hydraulics) Understanding sedimentation/ erosion rates in light of changing river hydraulics.

   - (Coastal Dynamics) Coastal issues are not limited to sea level rise but also changes in wave dynamics, or the processes affecting coastal nearshore water levels. Wave Surge-Infragravity, Wave Set-up (radiation stress), Wave Run-up at Shores Edge, Total storm Power, etc.

- Step 5
   - Understand impacts on land subsidence (associated with groundwater management and potential for overdraft).
   - Understanding on how development of local water management features could impact transportation systems (e.g., features unintentionally acting as flood control features).
   - Understanding municipal and industrial water use on nonirrigated lands, and role of groundwater substitution.
   - Understanding groundwater recharge; changes in return flows to natural water bodies.
   - Asset management and economic tools that allow for the consideration of costs and values in weighing adaptation options, including costs of inaction.
- Step 6
   - Guidance on evaluation of alternatives to build resiliency and incorporate adaptive management into project design and operation.
- Step 7
   - Understanding variability and uncertainty of baseline information (i.e., foundational sense of uncertainty before considering the added uncertainties of introducing climate change information).
   - Guidance on how to communicate and work with decisionmakers to improve use of climate vulnerability assessments.

Some entities also provided letter response to the draft report. Those letters responses are consolidated into appendix D. Among the views and perspectives offered within those letters, two are highlighted.

The first view relates to monitoring and data collection and pertains to Step 2 (Obtaining Climate Change Information) and Step 3 (Making Decisions about How to Use Climate Change Information) and relates to monitoring and data collection. On this subject, the Western States Water Council (WSWC) wrote:

> "This topic is virtually absent from the document (except for a brief mention on page 2), and no discussion is provided on how monitoring and data collection relate to the overall scope of work being planned under the Secure Water Act. While the Council has gone on record as supporting climate change research – especially as it relates to regional climate modeling – it's fair to say that maintaining Federal funding for basic data collection (e.g., USGS stream gages, USDA Snotel sites, NOAA's HRCN/Co-op program) trumps all in terms of priority. We believe that somewhere in the world of Federal climate change adaptation, funding must be provided to maintain important long-term hydroclimate monitoring sites, as well as to add new monitoring sites (e.g., in higher elevation alpine rain to snow transition zones) for change detection and attribution. Data collection and analysis is a basic function of long-term planning (the focus of this document), and needs to be addressed here. Also, research to define needs for new monitoring networks/integration with existing networks would be a valuable addition to this document."

The authors of this document share the view of WSWC that continued support for data collection is crucial as we prepare for climate change impacts on our water systems. Focusing on the spirit of this document, which is to motivate research to address knowledge, tool, and method limitations, the final statement offered by WSWC perhaps suggests a gap statement missing from table 1: Understanding the adequacy of our current monitoring network to support water management in a changing climate and identifying ways to improve hydrological monitoring and data collection to support climate-related decisionmaking.

The second view relates to making decisions under uncertainty. One USACE commenter felt that there is much still to learn about various available methods, and citing appreciation for how USGS Circular 1331

(Brekke et al. 2009) addresses key decisionmaking concepts such as adaptive management, robustness, resilience, and flexibility that water managers might use to deal with climate change. The same commenter suggested that the report should include a gap statement on how managers need to understand the role of robustness, resilience, and adaptive management as tools for dealing with climate change, perhaps building on earlier work.[1] They went further to suggest that a major impediment to robust and resilient design is focusing on the optimal solution, which is, maybe, a matter of planning policy.

In addition to raising questions about decisionmaking criteria, the USACE commenter pointed attention to the need and challenges of adopting a systems view in water resources development rather than a project-specific view. They cited the April 30, 2009, Army Corps of Engineers' document *Building a Stronger Corps: A Snapshot of How the Corps is Applying Lessons Learned from Katrina*,[2] which reported a key finding from the post-Katrina analysis as the need to adopt a systems approach to project planning and development—to move away from a project-by-project view to a more integrated one. The commenter suggested that implementing such integrated water resources management requires fundamental changes in USACE's policies and procedures, but also in the nature of the way the American public views the USACE's role and how they respond to Federal legislation and appropriations that influence how, where, and when USACE can conduct its programs.

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[1] The commenter suggested that the concept of using robustness in water resources planning, engineering, and management has been around since at least the 1970s and has some roots in the concept of ecological resilience introduced by Buzz Holling. James Hanchey, Kyle Schilling, and Gene Stakhiv from the U.S. Army Corps of Engineers' Institute of Water Resources (IWR), in their paper *Water Resources Planning Under Climate Uncertainty* (Congressional Research Service 1989), argued that a robust water resources system is able to absorb the inevitable range of uncertainties associated with the planning and design of a water resources project.

[2] http://www.mvn.usace.army.mil/pdf/USACEPKUpdateReport_Final.pdf.

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Appendix A: Preliminary Activities

Initial discussions on Reclamation and USACE capability gaps took place at a technology and research scoping workshop in Denver, Colorado, during February 20–21, 2008. The workshop was convened by member Climate Change and Water Working Group (CCAWWG) agencies at the time of the workshop:[1] Bureau of Reclamation (Reclamation), United State Geological Survey (USGS)[2], and National Oceanic and Atmospheric Administration (NOAA).[3] CCAWWG was formed in 2007 with the goal of addressing several basic questions concerning the incorporation of climate change information into longer-term water resources planning:

- What types of information do managers and planning practitioners want, and what are their desired outcomes?
- What knowledge, methods, and tools are available?
- What is needed from the research and development (R&D) and technology development community?
- What is possible to achieve?

Discussion from the February 2008 workshop led to initial listing of capability gaps as well as prioritization of which gaps managers desired to have addressed more immediately through additional research. Highlights from that workshop discussion are summarized in this chapter, along with results from a post-workshop survey where managers were asked to rank gaps for the purpose of revealing their near-term research priorities. These findings serve as starting points for the capability assessment presented in chapter 3.

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[1] United States Army Corps of Engineers (USACE) has since become a member CCAWWG agency.

[2] USGS Colorado Water Science Center, Denver, Colorado, http://co.water.usgs.gov/.

[3] NOAA Earth Systems Research Laboratory - Physical Sciences Division - Climate Analysis Branch, Boulder, Colorado, http://www.cdc.noaa.gov/.

A.1 February 2008 CCAWWG Workshop Summary

The 2-day workshop[1] included over 80 research, management, and practitioner participants, collectively from the CCAWWG agencies (Reclamation, USGS and NOAA) other Federal agencies (i.e., USACE, U.S. Forest Service, the U.S. Fish and Wildlife Service, Bureau of Land Management), and federally supported research entities (i.e., the NOAA Regional Integrated Science and Assessment (RISA) centers “Western Water Assessment” and “Climate Impacts of the Southwest”).

The first day of the workshop was focused on building relationships between all of the participants and sharing knowledge about agency missions and capabilities. Two panel discussions introduced science participants to Reclamation’s water operations and environmental compliance managers and to the types of climate change information needed for their planning and decisionmaking processes.

- The panel of water operations managers included a representative from the Dam Safety Office and a representative from a water operations office in each of Reclamation’s five regions (figure 1). This panel represented “shorter-term” planning perspectives. Operations office managers offered perspectives on preparing operations schedules ranging from hourly schedules over the next week to monthly schedules applying for the next 1 to 2 years. The Dam Safety Office perspective is framed by a need to characterize contemporary potential for hydrologic events affecting safety of structures. Climate variability and forecasting such variations dominates the “shorter term” perspective (e.g., seasonal to interannual climate forecasting, flood event forecasting). However, longer-term historical climate change is also of interest, such as how this affects interpretation of water supply predictions that guide contemporary operations scheduling and how it affects calibration of the prediction models used for characterizing hydrologic hazard potential.

- The panel of environmental compliance managers included planners responsible for evaluating proposed operational or physical system changes in the context of environmental compliance requirements

[1] *R&D Roadmap: Managing Western Water as Climate Changes – Knowledge Gaps and Initial Research Strategies and Projects*, http://www.esrl.noaa.gov/psd/workshops/mwwcc/index.html.

(e.g., National Environmental Policy Act, Endangered Species Act), and also staff from the Office of Program and Policy Services, which provides framework guidance for such planning processes. This panel represented Reclamation's "longer-term" planning perspective where proposed system changes are expected to provide service for up to several decades. In these cases, future climate change considerations are relevant as they affect the context for evaluating the effects of such proposed long-term system changes. However, climate variability possibilities are also relevant in such longer-term evaluations (e.g., portrayal of interannual to interdecadal hydrologic variations that translate into multiyear drought and surplus possibilities, portrayal of possible short-term weather and hydrologic possibilities that manifest into assumed flood control constraints on operations).

Both panel discussions were influenced by informal surveys conducted of panel participants prior to the workshop. The surveys invited impressions about key capability gaps in relating climate projection information to their planning activities. Region-specific and general summaries of these impressions are available online.[1] Day one ended with presentations on the roles and capabilities of CCAWWG science agencies (USGS and NOAA) and science partners at the NOAA RISA centers.[2]

Day two featured a more structured gap discussion, complementary to the day-one panel discussions and informal pre-workshop surveys. The day-two gaps discussion was framed by a handout prepared prior to the workshop and distributed among workshop participants (one of three handouts;[3] the latter two focused on ongoing and potential research to address gaps). The handout outlined capability gaps within a general analytical framework relating climate to the various supply, demand, and operational constraint assumptions featured in Reclamation's longer-term decision processes. (Chapter 3 builds and expands upon the foundation

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[1] http://www.esrl.noaa.gov/psd/workshops/mwwcc/docs.html. See documents under "*Perspectives from Water Operations Managers on Responsibilities, Challenges, and Needs Related to Climate Change and Western Water*" and "*Perspectives from Environmental Compliance Managers on Responsibilities, Challenges, and Needs Related to Climate Change and Western Water*."

[2] Western Water Assessment (http://wwa.colorado.edu/) and Climate Assessment of the Southwest (http://www.climas.arizona.edu/).

[3] http://www.esrl.noaa.gov/psd/workshops/mwwcc/docs/Handouts_080219_final.pdf,

laid at this workshop.) Day two also featured presentations about the National Integrated Drought Information System (NIDIS), and a NOAA-facilitated discussion about training, knowledge transfer, and outreach.

There were several recurring themes in the 2 days of workshop discussion:

- CCAWWG agencies are taking a proactive approach to addressing climate change within the context of western water management (Reclamation), while serving the national viewpoint (USACE).
- Water management agencies have a need to identify the most appropriate role of climate change information in its longer-term planning processes, operations studies, and dam safety decisions.
- There are climate services within the Federal Government (NOAA, USGS) that may be looked upon for information and guidance on climate data usage.
- Water operations managers need improved weather and climate forecast on time scales varying from days to decades.
- Climate change information is needed for planning assumptions related to supplies, demands and operating constraints; implications for supplies has received considerably more R&D attention than implications for demands and constraints.

A.2 Post-Workshop Survey of Gap Priorities

Workshop participants were surveyed afterwards to provide input on how the gaps ranked in terms of warranting greater research priority on the near-term and in terms of being feasibly addressed through such research. The survey on research priorities for the near-term was targeted to water and environmental managers. The survey on research feasibility to address gaps was targeted to the workshop's science participants.

On the first survey, managers were asked to rate gaps as lower, medium, and higher priority for being addressed through research or technology development on the near-term. Consensus results are listed in table A1. Gaps receiving a "higher" priority included ability to efficiently and consistently document the state of climate change understanding for planning evaluations, being able to address uncertainties introduced by the climate change information, having guidance on how to evaluate hydrologic hazard potential in a changing climate, and having greater ability to understand and anticipate land cover and ecosystem responses in a changing climate. Results from the second survey are not discussed here. It was determined afterwards that the survey was not well suited for the purpose of identifying research or technology development strategies necessary to address capability gaps. This finding motivates a purpose of this document to serve such strategy discussions (e.g., future discussions among participating CCAWWG agencies or other water resources stakeholders).

Table A1. Capability gaps and managers' priorities surveyed at the February 2008 R&D Scoping Workshop

Knowledge Gaps discussed in Workshop Handout #1[1]	Managers' Priorities (post-Workshop Survey)
1. Access to Literature Syntheses	
Clearinghouse on scientific literature relating climate change to water resources planning	Low
Region-specific literature summaries	High
2. Access to Climate Projection Data	
Downscaled data at finer spatial resolutions, different variables	High
Downscaled data that isn't based on "stationarity"	Low
3. Ability to Translate Climate Projection Data into Planning Scenarios	
Basis for weighting climate projections	Low
Ability to jointly consider paleoclimate, near-term climate variability, and projected climate information	Medium
Assess extreme meteorological possibilities under climate change	High
4. Ability to Assess Natural Systems Response to Climate Change	
Assess impact on groundwater, interaction with surface water	Medium
Assess impact on land cover and ecosystems	High
Assess extreme hydrologic possibilities relate to flood risk associated with structural safety, flood control rule requirements at reservoirs, etc.	Medium
Understand implications of hydrologic model choice for runoff impacts assessments	Medium

[1] Gaps are ordered as discussed in Workshop Handout number 1.

Table A1. Capability gaps and managers' priorities surveyed at the February 2008 R&D Scoping Workshop (continued)

Knowledge Gaps discussed in Workshop Handout #1[1]	Managers' Priorities (post-Workshop Survey)
5. Ability to Assess Social Systems Response to Climate Change	
Anticipate social responses that constrain reservoir management (e.g., surface water demands at the district level, flood protection values and expected service, environmental protection values and expected service)	Medium
Assess water use requirements for different crops under joint climate and atmospheric carbon dioxide changes	Medium
6. Practices for Assessing Operations and Dependent Resources Response	
Conduct policy search studies (optimization, perfect foresight)	Low
Ability to assess operations impacts based on realistic operator learning under climate change (e.g., by striking a balance between the *reactive* operator depictions featured in traditional scenario analyses and the *perfect foresight* aspects of the "policy search" analyses).	Low
Assess operations impacts *on* climate	Low
7. Ability to Assess, Characterize and Communicate Uncertainties	
Assess and characterize uncertainties for each analytical stage (e.g., climate projections, downscaling methods, natural and social system response analyses, operations analysis, etc)	High
Assess interrelation of uncertainties across analytical stages	High
Ability to effectively communicate uncertainties and their relation to Reclamation planning processes	High

[1] Gaps are ordered as discussed in Workshop Handout number 1.

Appendix B. Survey Results on Gap Prioritization

This appendix reports the count of low, medium ,and high priority ratings for research to address gap statements introduced in section 2.0 and subjected to review and comment by staff from the Bureau of Reclamation (Reclamation), United States Army Corps of Engineers (USACE), non-Federal organizations and other Federal organizations. The process for gathering review and comment was summarized in section 3.0.

Gap Number	Gap Category (Technical Step)	Capability Gap	Count of Priority Ratings						Total Number of Responses
			Reclamation/ USACE			All Respondents Combined			
			Low	Med	High	Low	Med	High	
1.01	Summarize Relevant Literature	Access to a clearinghouse of climate change literature relevant to water management, or access to a bibliography of recommended literature to represent in literature syntheses.	5	3	0	9	5	3	17
1.02	Summarize Relevant Literature	Region-specific literature summaries, regularly maintained and peer-reviewed.	2	3	3	3	7	7	17
2.01	Obtaining Climate Change Information	Improved skill in simulating long-term global to regional climate.	1	2	5	1	6	9	16
2.02	Obtaining Climate Change Information	Downscaled data at finer space and time resolutions and for different variables.	1	1	6	1	4	12	17
2.03	Obtaining Climate Change Information	Information on the strengths and weaknesses of downscaled data and the downscaling methodologies used to develop these data (including both statistical and dynamical methods and associated approaches for climate model bias-correction).	1	2	5	1	6	9	16

Gap Number	Gap Category (Technical Step)	Capability Gap	Count of Priority Ratings						Total Number of Responses
			Reclamation/ USACE			All Respondents Combined			
			Low	Med	High	Low	Med	High	
2.04	Obtaining Climate Change Information	Indication of conditions of where and when the stationarity assumption of statistical downscaling may not hold (defined above) and should motivate use of dynamical downscaling techniques rather than statistical.	1	3	3	1	9	5	15
2.05	Obtaining Climate Change Information	Synthesis of sea level projection information and guidance on consistent use in planning for all Reclamation and USACE coastal areas.	4	1	3	6	6	5	17
3.01	Make Decisions About How to Use the Climate Change Info.	Understanding on observed climate variability from daily to multidecadal time scales, which underpins interpretation of future variability in climate projections and it's relation to planning assumptions.	0	3	5	0	8	9	17
3.02	Make Decisions About How to Use the Climate Change Info.	Understanding on how to interpret future variability in climate projections and relevance to operating constraints on shorter- to longer-term time scales (from daily to multidecadal).	1	3	4	1	4	10	15
3.03	Make Decisions About How to Use the Climate Change Info.	Basis for culling or weighting climate projections (if at all) when deciding which projections to use in planning.	1	4	2	3	8	3	14
3.04	Make Decisions About How to Use the Climate Change Info.	Guidance on how to appropriately relate planning assumptions to either *Period-Change* or *Time-Developing* aspects of climate projections, when deciding how to use projections in planning.	4	3	1	5	7	4	16
3.05	Make Decisions About How to Use the Climate Change Info.	Guidance on how to jointly utilize the longer-term climate variability from observed records, paleoclimate, and projected climate information when portraying drought and surplus possibilities in planning.	1	4	3	1	6	9	16

Gap Number	Gap Category (Technical Step)	Capability Gap	Count of Priority Ratings						Total Number of Responses
			Reclamation/ USACE			All Respondents Combined			
			Low	Med	High	Low	Med	High	
3.06	Make Decisions About How to Use the Climate Change Info.	Method and basis for estimating extreme meteorological event possibilities, deterministically or probabilistically, in a changing climate.	2	1	4	3	2	10	15
4.01	Assess Natural Systems Response	(Watershed Hydrology) Guidance on strengths and weaknesses of watershed hydrologic models/methods to support scoping decisions in planning.	4	2	3	6	5	5	16
4.02	Assess Natural Systems Response	(Watershed Hydrology) Understanding on how climate change should impact potential evapotranspiration, and how it is represented in watershed hydrologic models.	2	1	5	3	5	7	15
4.03	Assess Natural Systems Response	(Watershed Hydrology) Method and basis for estimating extreme hydrologic event possibilities, deterministically or probabilistically, in a changing climate. (Similar to Gap 3.4, but focused here on hydrology rather than meteorological variables)	2	1	5	3	2	11	16
4.04	Assess Natural Systems Response	(Watershed Hydrology) Guidance on strengths and weaknesses of available versions of spatially distributed hydrologic weather data that may be used for both watershed hydrologic model development (Step 4) and in climate model bias-correction (Step 2).	0	6	2	3	9	4	16
4.05	Assess Natural Systems Response	(Watershed Hydrology) Understanding on how climate change should impact groundwater recharge and groundwater interaction with surface water supplies.	2	4	2	3	8	5	16
4.06	Assess Natural Systems Response	(Ecosystems) Understanding on how climate change should impact inland and coastal anadromous fisheries.	2	2	2	6	3	5	14

Gap Number	Gap Category (Technical Step)	Capability Gap	Count of Priority Ratings						Total Number of Responses
			Reclamation/ USACE			All Respondents Combined			
			Low	Med	High	Low	Med	High	
4.07	Assess Natural Systems Response	(Ecosystems) Understanding on how climate change may impact riparian ecosystems and vegetation that affect both longer-term water budgets and ecological resources.	0	3	4	2	7	6	15
4.08	Assess Natural Systems Response	(Ecosystems) Understanding translated into model frameworks for assessing climate change responses for fisheries, non-native riparian vegetation, and other species or habitat conditions.	0	3	4	3	6	6	15
4.09	Assess Natural Systems Response	(Land Cover) Understanding on how climate and/or carbon dioxide changes should impact land cover communities that control natural evapotranspiration and soil erosion potential.	1	3	3	5	4	5	14
4.10	Assess Natural Systems Response	(Water Quality) Understanding on how water quality characteristics depend on climatic variables, and how dependencies may evolve in a changing climate.	1	2	6	3	4	10	17
4.11	Assess Natural Systems Response	(Consumptive Use in Irrigated Areas) Understanding on how climate and carbon dioxide changes should impact plant physiology, how impacts vary with crop type, and how impacts affect irrigation demand.	1	4	2	4	7	3	14
4.12	Assess Natural Systems Response	(Sedimentation and River Hydraulics) Understanding how climate and/or land cover changes will change watershed sediment yield, changes in sediment constituency, and the resulting impacts on water resources.	1	4	2	2	9	3	14
4.13	Assess Natural Systems Response	(Sedimentation and River Hydraulics) Understanding how climate, land cover, and/or sedimentation changes will affect river and reservoir ice-event potential.	2	4	1	5	5	4	14

Gap Number	Gap Category (Technical Step)	Capability Gap	Count of Priority Ratings						Total Number of Responses
			Reclamation/ USACE			All Respondents Combined			
			Low	Med	High	Low	Med	High	
5.01	Assess Socioeconomic and Institutional Response	Understanding on how socioeconomic factors may affect flood risk reduction and reservoir regulation objectives in a changing climate (e.g., flood protection values, land management).	0	4	3	2	6	7	15
5.02	Assess Socioeconomic and Institutional Response	Understanding on how socioeconomic factors may affect water and power delivery reliability, water allocations, as well as decisions on source of supply under a changing climate (e.g., groundwater pumping versus surface water diversion).	1	0	5	3	1	10	14
5.03	Assess Socioeconomic and Institutional Response	Understanding on how institutional realities currently control socioeconomic responses to climate variability and could control socioeconomic responses under a changing climate.	1	3	3	6	5	4	15
6.01	Assess System Risks and Evaluate Alternatives	Guidance on how to conduct an adaptation evaluation that efficiently explores and rank strategy options, potentially using optimization techniques.	1	3	4	4	5	8	17
6.02	Assess System Risks and Evaluate Alternatives	Guidance on how to portray realistic operator "learning" in evaluations supporting planning for climate change adaptation.	5	0	1	9	2	1	12
6.03	Assess System Risks and Evaluate Alternatives	Guidance on how to assess the effect of planning proposals on climate.	5	4	0	8	9	0	17
7.01	Assess and Characterize Uncertainties	Uncertainty information on global climate projections data, including uncertainties about climate system science, portrayal in climate models, emissions scenario development, and simulation methods.	0	3	5	4	5	8	17

Gap Number	Gap Category (Technical Step)	Capability Gap	Count of Priority Ratings						Total Number of Responses
			Reclamation/ USACE			All Respondents Combined			
			Low	Med	High	Low	Med	High	
7.02	Assess and Characterize Uncertainties	Uncertainty information on regional climate projections data, including uncertainties from choice of bias-correction and spatial downscaling methods.	0	2	6	0	6	10	16
7.03	Assess and Characterize Uncertainties	Uncertainty in planning results stemming from method choices on how to use transient characteristics of climate projections in planning scenarios.	2	3	3	3	7	6	16
7.04	Assess and Characterize Uncertainties	For each response analysis on a natural system, uncertainty information on system science and associated ways of portraying this science in a system model, and the observations used to customize a model for a specific system.	1	2	5	2	7	8	17
7.05	Assess and Characterize Uncertainties	For each response analysis on a socioeconomic system, uncertainty information on system science and associated ways of portraying this science in a system model, and the observations used to customize a model for a specific system.	2	3	3	5	7	5	17
8.01	Communicating Results and Uncertainties to Decisionmakers	Guidance on strengths and weaknesses of various methods for communicating results and uncertainties affected by the use of climate projection information.	0	3	5	1	7	9	17
8.02	Communicating Results and Uncertainties to Decisionmakers	Guidance on how to make decisions given the uncertainties introduced by consideration of climate projection information.	1	1	5	3	4	9	16