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Workshop Handouts

Climate Change & Western Water R& D Group (CCAWWG)

"A Federal R&D workgroup providing scientific collaborations in support of Western water management as climate changes"

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National Oceanic and
Atmospheric Administration

U.S. Department of the Interior
Bureau of Reclamation

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*** Role of Workgroup Members**

R&D Workgroup Management Sponsors will:

- Provide steering and guidance to workgroup to ensure that workgroup efforts are consistent with agency authorities, priorities, and policies.
- Provide a conduit to agency management to ensure activities are appropriately communicated and supported across agency management
- Facilitate making staff and funding resources available to accomplish the workgroup activities.

R&D Workgroup Technical Team Members will:

- Provide the expertise and capability to define, pursue and accomplish work efforts facilitated by this workgroup process.

Disclaimer

The information presented herein is intended solely to facilitate developing a working level collaborative research plan between the federal scientific community, and Reclamation water and environmental resource managers, on climate change research needs in support of Western water management. As such, "this information has not been formally disseminated by the Bureau of Reclamation and should not be construed to represent any agency determination or policy. The findings and conclusions are those of the author(s) and do not necessarily represent the views of any participating agency".[1]

[1] Stated in accordance with Information Quality Act (Public Law 106-554), Final Information Quality Bulletin for Peer Review (Office of Management and Budget, December 16, 2004).

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HANDOUT 1

Relating Climate Change to Longer Term System Evaluations: Analytical Process, Capabilities, and Gaps

February 13, 2008

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BACKGROUND

In 2007, the Climate Change and Western Water R&D workgroup (CCAWWG) was formed with three initial participants: Reclamation, USGS, and NOAA. CCAWWG collaborations are framed by several objectives, including (but not limited to):

- Build a common understanding of which water management decision and planning processes are expected to be affected by climate change.
- Identify current capabilities that already exist to support such decision and planning needs (i.e. knowledge and tools).
- Identify gaps in knowledge and tools that need to be addressed.

With a focus on these objectives, CCAWWG participants held several meetings during November 2007 through January 2008. Discussions were framed by longer-term decision processes that Reclamation commonly undertakes and could conceptually be affected by climate change. For these meetings, Reclamation prepared and distributed vetting materials meant to describe the following:

- An inventory of Reclamation's longer-term decision evaluations.
- A description of an analytical process and elements generally required to incorporate climate change information into these evaluations.
- Initial perceptions on gaps associated with each analytical element.

These materials were also distributed to water operations and technical staff from Reclamation regions to gather their feedback and impressions.

HANDOUT OBJECTIVES

This handout summarizes content from the initial vetting materials as well as feedback gathered from workgroup discussions and from Reclamation regions. The handout initially introduces the inventory of longer-term decision evaluations that were discussed. Discussion then shifts to the analytical process generally required to relate climate change information to these evaluations. And finally, summaries are provided by analytical elements in terms of how the element fits into the analytical process, where Reclamation's current capabilities stand, and which gaps in knowledge and tools were found to be most notable during discussions with CCAWWG participants and Reclamation regions.

DECISIONS INVENTORY

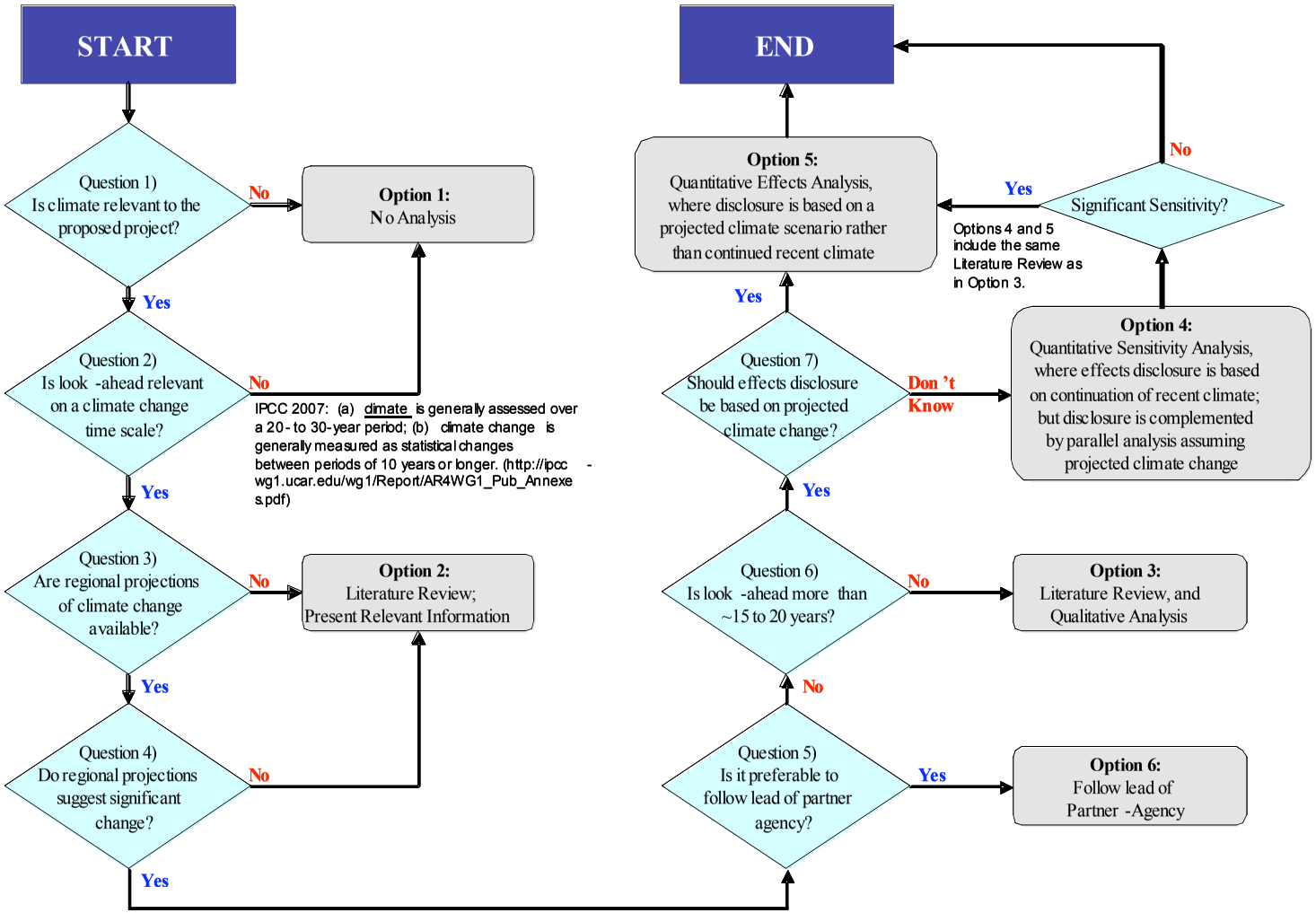
Table 1 summarizes a collection of longer-term decision evaluations that Reclamation commonly undertakes, all of which could be affected by climate change information. These decisions vary in terms of how climate is relevant. Additionally, a given planning effort might vary by look-ahead period of concern (e.g., a proposed operations change that applies through 2015 as opposed to 2040). Depending on climate relevance and plan-specific factors like look-ahead period, the treatment of climate change information might follow a different approach, ranging from literature review and no-analysis, to qualitative analysis, or perhaps quantitative analysis (**Figure 1**).

The inventory in **Table 1** is presented as a representative mix of Reclamation decisions for the purpose of revealing common knowledge and tool gaps that might suggest potential future paths in climate change research led by Reclamation and/or partner agencies. This inventory is not meant to be viewed as a complete survey of Reclamation decisions affected by climate change.

Table 1. Reclamation Decisions potentially affected by Climate Change

OFFICE TYPE	DECISION TYPE
Planning – mainly oversight of evaluations on operations proposals that would affect contemporary or longer-term operations	**NEPA processes on proposed actions** – Operations or system changes are proposed, which then must be analyzed for feasibility and environmental impacts subject to the National Environmental Policy Act (NEPA), followed by decision on "preferred alternative."
	ESA consultations – Operations effects on threatened or listed species under federal or state Endangered Species Act (ESA) are analyzed, followed by biological opinions on Reclamation's options for supporting species recovery. NEPA processes can trigger need for revisiting or conducting ESA consultations.
	General Planning – Exploratory studies of alternative operations and system configurations, which might precede NEPA analyses and related decisions.
Operations Scheduling – mainly involves seasonal to annual operations; however, framed by constraints based on retrospective hydrology and operational rules/requirements adopted after longer-term evaluations were completed	NEPA processes, ESA consultation, General planning
	Flood Control Rule Development – Annual and seasonal water supply operations are constrained in many Reclamation reservoirs by flood control requirements (e.g., winter drafting period, spring refill timing). The U.S. Army Corps of Engineers leads assessments on flood control needs and specifies flood control constraints, or "rules", for Reclamation operations. These rules are periodically revisited (~10 to 15 years) with Reclamation among the interested stakeholders.
Office of Programs and Policy Services (OPPS)	NEPA/ESA implementation policies
Dam Safety Office (DSO)	**CFR and Issue Evaluations** – All Reclamation dams are subjected to periodic review (~ every 6 years) of safety and risks including risks associated with extreme flood events (Comprehensive Facility Review, or CFR). If the Initial Assessment reveals significant risk, subsequent Issue Evaluations may occur, which may lead to decisions to modify operations or facility structures.

Figure 1. Potential Scoping Questions and Answers leading to an Analytical Approach. This chart illustrates general considerations on whether and how to incorporate climate change information into project-specific planning (NEPA, ESA, etc).

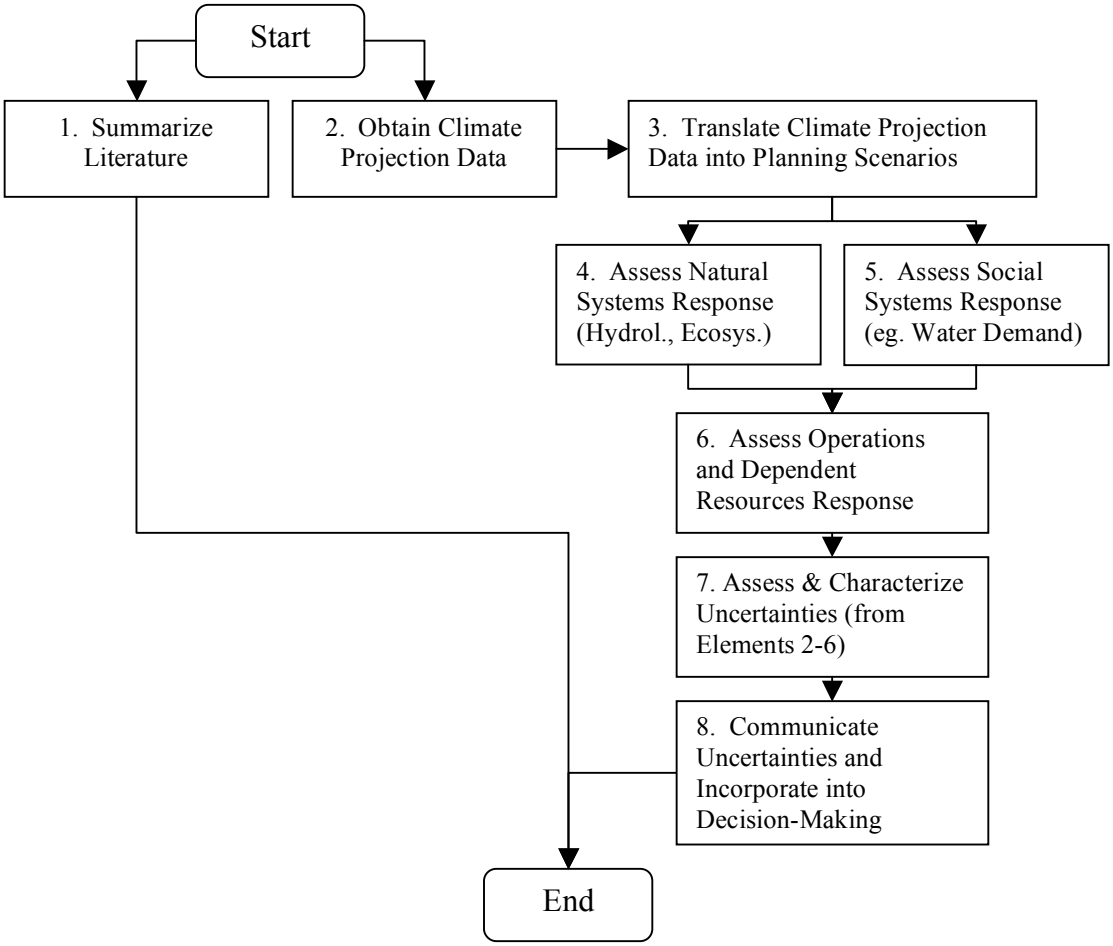


ANALYTICAL PROCESS

Considering the four primary decision processes highlighted in **Table 1**, and assuming that climate is relevant in the decision-making, treatment of climate change information will vary depending on whether *observed* or *projected* climate change is of interest. For example, NEPA and ESA processes would generally be focused on *projected* climate change implications for interpreting future hydrologic possibilities. In contrast, Flood Control Rule updates and CFR processes are also focused on *observed* climate change and how it relates to interpreting retrospective hydrology and estimates of extreme hydrologic event possibilities.

For the purpose of discussing capability gaps, the remainder of this handout focuses mainly on the how *projected* climate change information would be incorporated into longer-term planning processes like NEPA and ESA. **Figure 2** describes an approach that serves qualitative or quantitative analyses (**Figure 1**), where qualitative analysis would require implementation of the Element 1 and quantitative analyses would additionally require completion of Elements 2-8.

Figure 1. Generalized Analytical Sequence and Elements involved with relating *projected* Climate Change Information to Table 1 Decisions



Several Reclamation regions and technical teams have gained experience implementing portions of this analytical sequence. Some examples:

- During 2006-2007, Mid-Pacific Region and the Technical Service Center led an interagency demonstration project "Assessing the Risks of Shifting Climate on Water and Power Operations in Reclamation Regions". Collaborators included the California Department of Water Resources (CDWR), USGS (Mike Dettinger), Santa Clara University (Ed Maurer), and USACE (Sacramento District and Engineering Research and Development Center). The purpose of the study was to apply risk analysis principles in the study of climate change implications for Reclamation and CDWR reservoir operations in California's Central Valley. Study results revealed relative importance of several analytical design choices in determining assessed risk, including: (1) whether to include/exclude precipitation projection information; (2) whether to assume current/modified future flood control constraints on water supply operations; and, (3) whether to assume equally weighted climate projection scenarios (within the surveyed ensemble) or unequally weighted scenarios based on projection distributions fit with or without consideration for climate model skill. It was found that assessed operations risk was more sensitive to (1) and (2) than to (3), given current projection information.

- During 2007, Pacific Northwest Region teamed with the NOAA National Weather Service Northwest River Forecast Center and the NOAA-RISA Climate Impacts Group at the University of Washington to study the effects of climate change on the operation of Boise River reservoirs. Two studies were scoped: (1) The Planning Study, which evaluated the effects of climate change on water supply, reservoir refill, water deliveries, water rights distribution, and minimum streamflows; and, (2) The Flood Risk Study which evaluated the adequacy of existing flood control regulations and practices in the context of climate change. Analyses have been completed, and current work is focused on documentation.

Reclamation also has experience with qualitative treatments of climate change in NEPA and ESA processes. A recent example is the Final Environmental Impact Statement on "Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead" (November 2007), led by Reclamation's LC and UC regions. 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.

SUMMARY OF KNOWLEDGE AND TOOL GAPS

The remainder of this handout summarizes workgroup and Reclamation discussions on each analytical element from **Figure 2**. For each element, a summary is provided on how the element serves the analytical process, Reclamation's current capabilities, and a list of gaps that have been identified. Gaps on treatment of *observed* climate change in Flood Control Rule updates and CFR processes are also noted (e.g., Elements 3 and 4).

Element 1: Summarize Literature

Description

Incorporation of climate change information into longer-term planning processes has to be accompanied by narrative rationalizing why climate change is a relevant consideration (i.e. what do we know, and what's been studied) and rationalizing how it is being treated in the given planning project. The latter rationale is project-specific. However, the former rationale would reference several general topics, including: state of climate science (e.g. Are regional climate and hydrologic norms changing? Can we say whether we can predict future change for these norms?), survey of contemporary climate projections (e.g., what are potential climates in 10-, 30-, or 50-years?), and review of impacts studies focused on the planning region (e.g. given scenario climate changes that have been analyzed, what impacts can we expect for water resources?).

Current Information and Capability

Reclamation has recently produced two narratives, each supporting a NEPA planning process. A longer form narrative was produced as Appendix U for the "Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead" Final EIS (LC/UC joint leads; Reclamation 2007). This narrative commented on general topics for the Colorado River Basin, and also discusses how impressions of future climate are informed by paleoclimate and climate variability information (e.g., for defining climate possibilities during the next few years to couple decades, or time scales shorter than "climate change" time scales). The narrative also identified knowledge and tool gaps related to analyzing climate change implications for Colorado River Basin operations. A shorter form narrative has been included in the "Yakima River Basin Water Storage Feasibility Study" Draft PR/EIS (PN lead; Reclamation 2008). This narrative focused on the general topics, and summarized water resources impacts studies as they related to the Yakima River Basin and/or to the larger Upper Columbia River Basin.

Gap(s) in Information and Capability

1.1 Reclamation doesn't have an internal clearinghouse for climate change literature.

1.2 Reclamation typically oversees multiple longer-term planning processes in each of its five regions (GP, LC, MP, PN, and UC). Currently, these processes are not supported by a common narrative on general topics tailored for the given region (exception: the LC/UC narrative addresses Colorado River Basin issues, which covers large portions of LC and UC service regions. Providing common narrative, tailored by region, could promote consistent discussion of climate change knowledge and implications among region-specific planning studies. The two examples cited above serve as potential forms (i.e. long form from LC/UC; short form from PN-UCAO).

Inventory or Ongoing R&D addressing Gap(s): see Handout 2
Potential Additional Research: see Handout 3

Element 2: Obtain Climate Projection Data (Downscaled and Bias-Corrected)

Description

Any decision to quantitatively relate climate change information to longer-term planning processes sets in motion an implementation of Elements 2 through 8. Element 2 recognizes that the first quantitative step is for water planning analysts to acquire contemporary climate projection data (i.e. temperature and precipitation information, at minimum). The data need to have "area" and "time" resolutions that are relevant to the planning process. Spatially, this means that the data need to be translated from the coarse spatial resolution of global climate models to a finer "basin-relevant" resolution necessary for planning analyses (i.e. spatially downscaled). Further, each global climate model has its own tendencies for being too wet/dry/warm/cool, which needs to either be understood or accounted for in the acquired data (i.e. downscaled and bias-corrected).

Current Information and Capability

Reclamation teamed with Santa Clara University and Lawrence Livermore National Laboratory (LLNL) to produce an *archive* of statistically downscaled translations of climate projections from the World Climate Research Programme (WCRP) Coupled Model Intercomparison Phase 3 (CMIP3) multi-model dataset (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/). The CMIP3 dataset supported development of the Intergovernmental Panel on Climate Change Fourth Assessment Report (Christensen et al. 2007). The statistically downscaled translations were developed using a peer-reviewed technique (Wood et al. 2002, Wood et al. 2004) which has been applied to numerous resource impacts studies (Maurer 2007). The archive contains 112 projections representing 16 global climate models and their multiple simulations of three greenhouse gas emissions pathways. Projection datasets include monthly precipitation and temperature from 1950-2099, downscaled to 1/8º spatial resolution (~12 km^2), over the contiguous United States. Reclamation and LLNL continue to maintain the web-service, which supports user data-subsetting requests.

Gap(s) in Information and Capability

2.1 Some planning processes require temperature and precipitation information at finer resolution in space and time than the *archive* attributes (e.g., for flood studies, ecological studies) or information on variables not in the *archive* (e.g., humidity, daily minimum and maximum temperature, drought indices).

2.2 The *archive* is based on an assumption of "stationarity" in that the relationship between regional atmospheric circulation and locally experienced weather will *not* change as the regional climate changes. In contrast, it would seem possible that climate change could affect this relationship. More research is necessary to reveal where, to what extent, "non-stationarity" is more likely. Application of regional climate models could reveal the significance of such possibilities.

Inventory or Ongoing R&D addressing Gap(s):
Potential Additional Research: see Handout 3

Element 3: Translate Climate Projection Data into Planning Scenarios

Description

After acquiring climate projection data that has been corrected for climate model biases and spatially downscaled (Element 2), the next planning step is to decide how to relate the information to the given planning study. This invites questions on how to use, cull, or translate the data into "climate scenarios". For example, it might be of interest to illustrate how proposed future operations of current systems are sensitive to future climate possibilities, where the latter possibilities are bracketed by the climate projections surveyed in Element 2. Other questions:

- Should projections surveyed in Element 2 be regarded equally? Or should the analyst apply some rationale to cull some projections out of consideration, or retain all of them but weight them unequally (e.g., by perceived climate model skill)?
- Which aspects of the projections should be related to the planning study (e.g., change in climate "norms" like period-monthly means, or complete envelope of projected climate variations which encapsulates change in "norms")?

Answers to these questions reflect climate relevance to the planning study (e.g., variables, statistics, look-ahead) and regard for the credibility of climate projection information.

Current Information and Capability

IPCC 2007 offers guidance on how to relatively regard regional temperature and precipitation projections. Reclamation (2007) discusses temperature and precipitation projections over the Colorado River Basin. Peer review literature offers examples on how climate models might be weighted based on relative skill (e.g., Dettinger 2005; Tebaldi et al 2005; Brekke et al. 2008).

Gap(s) in Information and Capability

3.1 No guidance is available on how to weight emissions pathways.

3.2 We have limited guidance on how to jointly incorporate paleoclimate, near-term decadal climate variability, and projected climate into these planning processes.

3.3 For studies focused on extreme hydrologic possibilities, we do not know if extreme meteorological estimates based on historical information remain valid in a changing climate (e.g., "probable maximum precipitation" (PMP)).

Inventory or Ongoing R&D addressing Gap(s): see Handout 2

Potential Additional Research:

Element 4: Assess Natural Systems Response (e.g., Hydrology, Ecosystems)

Description

Once climate scenarios have been defined for the planning study (i.e. Element 3), the next steps focus on relating those climate scenarios to the inputs of operations analyses. This typically requires two intermediate steps: assessing hydrologic and natural systems response (Element 4) and social systems response (Element 5) as they both relate to assumptions that constrain operations analysis (e.g., water supply, water demand, environmental and social conditions). For this element, assessment of natural systems response (e.g., runoff, land cover, ecosystems) depends on being able to translate the climate scenario information from Element 3 (e.g., change in climate "norms" or projected time series monthly temperature and precipitation) into basin daily or sub-daily meteorology consistent with those climate norms or climatic time series.

Current Information and Capability

We have access to a number of peer-reviewed methodologies (e.g., see summary in Reclamation 2007) for runoff response analyses under climate change. We also have access to runoff model tools that can simulate runoff under assumed climate (weather) and land cover conditions (e.g., using tools provided by NOAA-NWS River Forecast Centers, or University of Washington Climate Impacts Group).

Gap(s) in Information and Capability

4.1 Many of Reclamation's systems feature geographically overlapping groundwater and surface water management activities. Reclamation has limited experience of analyzing climate impacts on groundwater and implicit effects on surface water.

4.2 Land cover and ecosystem responses affect precipitation-runoff relationships. Reclamation has limited understanding on how these changes interact with climate change and ultimately affect water resources, Reclamation operations, and future environmental compliance requirements.

4.3 Flood control rule curves constrain Reclamation's water supply operations, and are based on a retrospective view of hydrology, which may be called into question by a changing climate. Based on recent discussions with USACE, there is limited guidance for factoring past or projected climate change into rule curve updates.

4.4 For analyses focused on extreme events, Reclamation has limited knowledge on how climate change will affect storm type, duration, frequency (see Element 3). And in particular, Reclamation does not know if extreme runoff estimates and related estimation methods based on historical information remain valid in a changing climate (e.g., "probable maximum flood" (PMF)).

4.5 Given common climate scenarios, different methods/tools for assessing runoff produce different results. Reclamation needs guidance on why results depend on tool/method choice, and on tool preference for various planning situations.

Inventory or Ongoing R&D addressing Gap(s): see Handout 2

Potential Additional Research: see Handout 3

Element 5: Assess Social Systems Response (Water Demands)

Description

As mentioned in Element 4, once climate scenarios have been defined for the planning study (i.e. Element 3), the next steps focus on relating those climate scenarios to the inputs of operations analyses: assessing hydrologic and natural systems response (Element 4) and social systems response (Element 5). For this element, assessment of social systems response (water and power service demand and reliability expectations, flood protection values, environmental management values) ranges from aggregate assessments (e.g., "water district" lumped demands and the district's role in a larger "water market") to local assessments (e.g., crop-specific water use requirements given changing meteorology or atmospheric carbon dioxide concentrations).

Current Information and Capability

In an aggregate sense, it is understood that assumptions about future social systems frame longer-term Reclamation operations analyses (e.g., values re: flood protection, environmental protection, water delivery and power generation service reliability). However, projecting developments among those systems remains difficult (e.g., demographic growth, water use efficiency, mixture of water use types, economic drivers on changes in water use requirements in terms of quantity and quality). Assumptions about water needs for specific usage types are relatively easier to estimate.

Gap(s) in Information and Capability

5.1 Reclamation has limited understanding on how climate change could aggregately affect social systems that constrain Reclamation reservoir operations, including socioeconomic values related to water/power service reliability and needs, flood protection, and environmental management.

5.2 Reclamation's methods for assessing crop-specific water demands can accommodate changes in climate. So if projected climate information is made available, crop-specific water demand changes can be estimated. However, the driver underlying such climate projection is a scenario projection for atmospheric carbon dioxide concentrations. Such gas concentrations also affect water use requirements, variably by crop. Reclamation has limited understanding on how to incorporate the joint changes in climate and atmospheric carbon dioxide into crop-specific water demand estimates. Potential changes in cropping patterns in response to climate change also complicates this assessment.

Inventory or Ongoing R&D addressing Gap(s): see Handout 2
Potential Additional Research:

Element 6: Assess Operations and Dependent Resources Response

Description

Given scenarios defined through Elements 4 and 5, a longer-term operations analysis would then be conducted, involving long-term simulation of Reclamation reservoir operations to serve water and power needs. Reclamation is experienced with studies of this nature (i.e. given water demands, operations constraints, and the current system, how do operations unfold under assumed time series hydrology). Once operations analyses have been completed, subsequent "operations-dependent" analysis might be conducted: managed stream temperatures, downstream water quality, power generation, economics, etc. Social and regulatory systems framing these studies may come into question under climate change. These social/regulatory systems have influenced Reclamation methods/tools for operations analysis, which vary geographically (e.g., some areas have complicated water rights issues which motivates use of an operations model well-suited for water rights simulation; some areas feature multi-reservoir systems managed by multiple parties, which motivates use of an operations model that can efficiently deal with this higher dimensionality of decision-making).

Current Information and Capability

Reclamation is experienced with using its current set of operations analysis tools for analyzing scenarios of water supply, demand, and operational rules. Likewise, Reclamation's procedures for conducting operations-dependent analyses are well established. Reclamation has access to two approaches for relating climate change to operations impacts (i.e. [1] "static operator" with current system and no climate foresight, essentially simulating a given policy (e.g., Anderson et al. 2007; many others); and [2] "crystal-ball operator" with perfect climate foresight and relaxed social/regulatory institutions, permitted to identify ideal policy given economic objectives (e.g., Lund et al. 2003)). Reclamation has experience using [1].

Gap(s) in Information and Capability

6.1 For studies focused on longer-term operations vulnerability and adaptability and range of policy options, approach [2] may be useful. However, Reclamation has limited experience applying this approach.

6.2 Neither [1] or [2] may be ideal for revealing operations impact under climate change. The "static operator" may depict exaggerated operations impact while the "crystal-ball operator" could depict underestimated impact. It might be more reasonable to assume something in-between (i.e. evolving social/regulatory systems, responsive operators, and limited foresight), but there is limited guidance on how to set up such an approach.

6.3 Relative to analyzing climate change impact on operations, Reclamation has limited understanding on how to analyze *operations impact on climate* (e.g., CA).

Inventory or Ongoing R&D addressing Gap(s):
Potential Additional Research:

Element 7: Assess and Characterize Uncertainties

Description

The sequence of elements 2-6 would constitute a scenario-impacts analysis, and could be repeated for multiple scenarios, as necessary for the given longer-term planning study. At each element stage, uncertainties are introduced. These uncertainties stem from data and methods. Some examples: Element 2 feature data uncertainties associated with the credibility of climate projection information and underlying procedures for developing those projections (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). Element 3 features method uncertainties associated with bias-correction and spatial downscaling, and projections culling or translation into planning "climate scenarios". Elements 4 and 5 has data uncertainties (i.e. observations used to calibrated response models) and method uncertainties (i.e. structure of the response model and how it relates to reality, how model calibration is performed, how climate is translated into weather inputs to drive these models). Element 6 has similar data and method uncertainties.

Current Information and Capability

Reclamation has some methods and tools that permit element-specific analysis of uncertainty. For example, Reclamation has used tools like "@Risk" or custom-built computer algorithms to conduct Monte Carlo studies on how the outputs of hydrologic or operations models relate to inputs and model-parameter possibilities.

Gap(s) in Information and Capability

7.1 Reclamation has limited understanding on how to assess and characterize element-specific uncertainties, notably data and method uncertainties for Element 3, and many of the data uncertainties for Elements 4-6.

7.2 Reclamation has limited understanding on how to assess and characterize compounding uncertainties across these elements, recognizing where uncertainties are introduced independently or in an interrelated fashion.

Inventory or Ongoing R&D addressing Gap(s): see Handout 2
Additional Research Needed: see Handout 3

Element 8: Communicate Uncertainties and Incorporate into Decision-Making

Description

After assessing and characterizing uncertainties associated with Elements 2-6, it is ultimately necessary to package and communicate these uncertainties to the decision-makers and stakeholders involved in the planning effort.

Current Information and Capability

Reclamation is experienced with general communication of planning uncertainties to decision-makers and stakeholder groups. Such communication is a common feature of planning documentation (NEPA, ESA, etc.)

Gap(s) in Information and Capability

8.1 The subject of climate change as a source of planning uncertainty has not been a traditionally common discussion item in Reclamation planning studies (e.g., its implications for natural resources, social systems, and operations). Reclamation has relatively limited experience communicating uncertainties associated with this specific topic.

Inventory or Ongoing R&D addressing Gap(s):
Potential Additional Research:

GAP and PROJECT SUMMARY

Table 2. Handout 1 has presented 8 analytical elements the relates how climate change could be considered within Reclamation's long-term decision making. Handouts 2 and 3 will present ongoing projects and proposed projects, respectively that may address identified gaps from Handout 1. The following table summarizes which projects from Handouts 2 and 3 relate to the gaps identified in Handout 1.

Analytical Element . Gap	Ongoing Projects	Proposed Projects
1.1		
1.2	II.1, II.7	III.1
2.1		III.2, III.9
2.2		III.9
3.1		
3.2	II.2	
3.3	II.6	
4.1		III.3
4.2		III.4, III.8
4.1	II.8	
4.2		III.5, III.9, III.10
4.3		
4.4	II.6	
4.5	II.3, II.4, II.5	III.6
5.1		III.4, III.11
5.2		III.8
6.1		
6.2		
6.3		
7.1	II.9	III.7, III.10
7.2	II.9	III.8, III.10
8.1		

HANDOUT 2

Relating Climate Change to Longer Term System Evaluations: Ongoing Projects that Address Gaps (HANDOUT 1)

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The following projects listed are ongoing projects that CCAWWG is aware of relevant to the analytical elements described in Handout 1. The projects as they address the analytical elements and gaps are also tabularized in Table 1.

Project	Title	Gap
II.1	Literature Reviews - Climate Change Science & Regional Studies	1.2
II.2	Development and Comparison of Long-Term Planning Hydrologies using Alternate Climate Information Sets	3.2
II.3	Technology Transfer and Orientation – VIC Hydrologic Models	4.5
II.4	Reconciling Projections of Future Colorado River Stream Flow	4.5
II.5	Hydroclimatic Index for Drought Monitoring in the Colorado River Basin	4.5
II.6	Exploring the use of Climate Change Information within the Dam Safety Office Comprehensive Facility Review Process	3.3, 4.4
II.7	Economics Of Climate Change	1.2
II.8	Past Climate Change and Groundwater Influences to Historic Streamflow Traces	4.1
II.9	Assessing and Reducing the Uncertainty of Predictions from Hydraulic and Hydrologic Models	7.1, 7.2

Title: **Project II.1** -- Literature Reviews - Climate Change Science & Regional Studies

Related Gap: Gap 1.2 (Handout 1)

Purpose: This project involves summarizing climate change science and assessments on a region-specific basis. The project does not involve new analyses. Instead its purpose is to synthesize available science and assessment information in a way that provides cross-project support for each region's various long-term system evaluations (e.g., NEPA, ESA). Objectives are to provide a document framework that serves regions planning efforts for several years and to provide a framework that can be easily supplemented by new information that may/will become available.

Contact: Levi Brekke, Reclamation TSC, lbrekke@do.usbr.gov
Participants: Technical Service Center 86-68210 (2 writers; 2 data analysts)
Special Notes: Exceptions include LC and the Colorado River basin portion of UC, such region-specific literature summaries have not been developed Reclamation.)

Task Outline:

1. Literature Review and Summary
    a. Familiarize with global-to-regional assessments on climate change science
    b. Survey and summarize region-specific impacts studies on water resources
2. Summarize Contemporary Climate Projection Information
    a. Acquire data (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections)
    b. Develop summary graphics (region distributed, look-ahead horizons, etc)
3. Decide on Narrative Framework
    a. Consult with Regions – decide on document model (e.g., two forms referenced in Handout 1, discussion of Element 1: a longer form (e.g., Reclamation 2007) and a shorter form (e.g., Reclamation 2008))
        i. *Current level of funding is for shorter form narrative development.*
    b. Develop Narratives Outline and incorporate Regions feedback
4. Develop Region-Specific Narratives and Standalone Reports
    a. Develop Narratives with two Regions review stages
    b. Convert into standalone Reclamation Reports

Schedule: March – August, 2008
Budget: 61K Reclamation R&D Office; 14K Reclamation Regions' *in-kind*

Title: **Project II.2** -- Development and Comparison of Long-Term Planning Hydrologies using Alternate Climate Information Sets

Related Gap: Gap 3.2 (Handout 1)

Purpose: Reclamation is aware that various climate information sets might be used to represent future climate possibilities, including information from paleoclimate proxies, instrumental record, and projected climate simulations. Scoping questions emerge for NEPA, ESA, and long-term system evaluation teams as to which information set(s) to use and why. Further, if there is desire for using a blend of paleoclimate and projected climate information, a methods question emerges on how those information types should be combined and represented in the time series hydrologic sequence(s) that frame the operations analyses.

This project has been designed to illustrate how long-term hydrologic planning hydrologies differ when developed relative to these different climate information sets. Further, it includes scope to develop a methodology that blend "spells/sequencing" information from the paleoclimate record with runoff conditions shifted to reflect projected climate information. Case study basins: Gunnison above Colorado River and Missouri above Toston.

Contact: Levi Brekke, Reclamation TSC, lbrekke@do.usbr.gov

Participants: Technical Service Center 86-68210 (2 analysts); UC Regional Office (1 analyst; peer-review; data provision), MT Area Office & GP Regional Office (peer-review; data provision); NOAA-RISA Western Water Assessment (supporting methods and data development by Balaji Rajagopalan and Connie Woodhouse); USACE Omaha District (peer-review)

Task Outline:

1. Data Collection and Development
    a. Null: Monthly long-term hydrologies based on Instrument Record
    b. Paleoclimate reconstructions of annual natural flow, both basins
    c. A1b projections at (gdo-dcp.ucllnl.org/dowscaled_cmip3_projections)
2. Develop Alternate long-term hydrologies
    a. Reflecting either: (1) paleoclimate spells/sequences, (2) magnitudes shifted to reflect change in projected climate "norms", (3) magnitudes evolving with "transient" projected climate, blend of (1) and (2) or (3).
3. Evaluate and document findings.

Schedule: January – September, 2008

Budget: 66K Reclamation R&D Office; 15K each GP/UC Regions; *in-kind* 20K NOAA-RISA Western Water Assessment and 5K USACE

Title: **Project II.3** -- Technology Transfer and Orientation – VIC Hydrologic Models

Related Gap: Gap 4.5 (Handout 1)

Purpose: The Variable Infiltration Capacity (VIC) macroscale hydrologic model is a "state-of-the-art" runoff modeling tool that computes both surface water and energy balances. Legacy rainfall-runoff modeling systems (e.g., Sacramento Soil Moisture Accounting / Snow17, or SacSMA/Snow17) typically compute only surface water balance and require a key energy term, potential evapotranspiration (ET), to be pre-processed as a model input.

Different runoff models can be used to explore runoff implications under climate change (e.g., VIC, SacSMA/Snow17, USGS Precipitation Runoff Modeling System (PRMS) and the USGS Thornthwaite Monthly Water Balance (TMWB)). Scoping questions emerge for NEPA, ESA, and long-term system evaluation teams as to which model to use and why. For example, NEPA scoping might ask "What's the best available tool?"

This project involves Reclamation collaborating with University of Washington (UW) to acquire VIC applications developed for Western U.S. basins. Reclamation would review and improve the VIC calibrations, as possible, and return improved models to UW.

Becoming oriented with multiple runoff platforms permits tool preference questions to be explored (e.g., how do calibration-validation characteristics differ when watershed applications are built on different platforms (e.g., VIC, SacSMA/Snow17)?).

Contact: Levi Brekke, Reclamation TSC, lbrekke@do.usbr.gov
Participants: Technical Service Center 86-68210; PN Regional Office
Staff Reqts: 4 modeling analysts (3 TSC, 1 PN)
Notes: University of Washington contact has been Dr. Andrew Wood.
Task Outline:

4. Reclamation acquires VIC applications from University of Washington (UW)
    a. The applications are currently featured in the UW Westwide Streamflow Forecasting System (www.hydro.washington.edu/forecast/westwide)
    b. Large-basin applications would be shared (e.g., Columbia-Snake, Colorado, Central Valley, Upper Missouri)
5. Reclamation orients with VIC calibration routines and revisits application calibrations in several sub-basins; returns applications to UW.

Schedule: March – August, 2008
Budget: 35K Reclamation R&D Office; 8K PN Region *direct*

Title: **Project II.4** -- Reconciling Projections of Future Colorado River Stream Flow

Related Gap: Gap 4.5 (Handout 1)

Purpose: Longer-term evaluations on runoff possibilities must convey to policy and decision maker the nature of the uncertainties associated with the material being provided. Users are particularly challenged when they cannot reconcile what appear to be disparate research findings. For example, recently hydrologic studies on the Upper Colorado River Basin have reported average-annual reductions in naturalized flow by the mid 21st century ranging from -6% to -45%. To planning analysts, questions emerge on how to regard this range of uncertainty: how much is attributable to uncertainty in the hydroclimate response; or, how much is attributable to differences in approach (e.g., model biases)?

This project questions surround runoff modeling approach differences, and involves collaboration among the four NOAA-RISAs. Considering the methodologies used to develop CRB runoff estimates that varied from -6% to -45%, the project explores several questions: (1) How well do these methodologies and models reproduce the recent past departures from long term averages? (2) What was the primary cause of these departures? (3) Will similar conditions occur more frequently in the future?

Although the study is focused on methods intercomparison for Western U.S. basins, results from the intercomparison are expected to be readily applicable to address the needs of water planners elsewhere, especially other middle latitude continental settings where water resources are heavily dependent on snowmelt runoff from mountainous headwater areas.

Contact: Robin Webb (NOAA ESRL, Robert.S.Webb@noaa.gov)
Participants: Nick Graham (HRC)/Dan Cayan (CAP), Dennis Lettenmaier/Andy Wood (CIG), Robert Webb/Martin Hoerling (WWA), Jonathan Overpeck/Holly Hartman (CLIMAS)
Notes: University of Washington contact has been Dr. Andrew Wood.

Task Outline:

1. Workshops to present methodologies and reconcile method differences (e.g., September 2007 workshop, La Jolla, CA)
2. Climate sensitivity analyses implemented in common fashion, all methods.

Schedule: completion by September 2008
Budget: 250K NOAA-RISAs

Title: **Project II.5** -- Hydroclimatic Index for Drought Monitoring in the Colorado River Basin

Related Gap: 4.5

Purpose: **Research Objectives: A**pply a recently derived method of representing Hydroclimatic variability, the Hydroclimatic Index (HI), to monitoring and predicting drought occurrence across the Colorado River Basin (CRB) within the southwestern. The index will represent conditions for a higher spatial resolution than what is commonly used in drought monitoring with in the CRB. The secondary goal is to use various downscaled global climate model forecasts of changes in temperature and precipitation across the CRB during the 21st century to assess the likelihood of more intense, pervasive, and lengthier droughts.

Hydroclimatic Index: The HI stops short of representing soil moisture in its characterization of the hydroclimatic conditions, which is a difficult endeavor given typical variability in land surface characteristics rather, the HI represents the difference between precipitation (P) and potential evapotranspiration (PE) (P-PE) through time at a given location. Negative P-PE values indicate the amount by which the climatic demand for water cannot be met by precipitation and actual soil moisture would decline. Positive vales represent the amount of excess water from precipitation that would recharge soil moisture, recharge ground water, or run to streams and reservoirs through overland flow, interflow, or base flow within the natural environment. Percentiles of P-PE are constructed for periods of 1-, 3-, 6-, 12-, 24-, 36,- and 48-months to form the HI, while percentiles of the HIWS are constructed for the periods of 12 months or greater. Percentile values of the HI and HIWS can then be stratified into drought categories, such as those determined by the National Drought Mitigation Center.

Contact: Andrew Ellis PhD, ASU (andrew.w.ellis@asu.edu)

Participants: Pat Gober, Robert Balling, David Tompkins/ASU; Greg Garfin/UofA; Bruce Hallin, Mark Hubble/SRP; Eric Kamienski/City of Tempe; and Mitchell Haws/Reclamation

Project presented: 9th Biennial Conference of Research on the Colorado Plateau (October 29 thru November 1, Flagstaff, Arizona)

Schedule: completion by September 2009

Budget: 75K Reclamation, NOAA is also a sponsor

Website: http://www.public.asu.edu/~dellis/hydro_index.html

Title: **Project II.6** -- Exploring the use of Climate Change Information within the Dam Safety Office Comprehensive Facility Review Process

Related Gap: Gap 3.3, 4.4 (Handout 1)

Purpose: The Comprehensive Facility Review Process (CFR) is a cyclical evaluation of Reclamation facilities that include a hazard assessment relative to flood risk. The process by which information is presented for evaluation by the Dam Safety Office is most often a flood frequency curve that is based on statistical analyses of antecedent information. The horizon of risk characterization is often well beyond 100 years and most commonly all antecedent information, which requires a stationarity assumption is used in the analysis.

This project is an attempt to determine whether antecedent climate change can be detected in the historical record and how it may be accounted for in developing flood frequency curves. Further the study is an attempt to determine whether the expectation is for flood frequency curves to change given downscaled climate projections developed as part of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. The last aspect of the project is to determine whether changes in extreme rainfall events can be detected in the historical record that may influence how Probable Maximum Precipitations (PMP) and Probable Maximum Floods (PMF) are determined.

Contact: David Raff (Reclamation TSC, draff@do.usbr.gov)
Participants: Kate White (US Army Corps of Engineers, RDO - Reclamation
Notes:

Task Outline:

3. Study of changes to antecedent flood frequency analysis using gaged stream flows in western US
4. Study of changes in antecedent rainfall statistics using gaged rainfall in western US
5. Use projected daily temp and precip to force runoff model for 2000 -2100 and calculate flood frequency estimates – compare to antecedent estimates.

Schedule: completion by December 2008
Budget: 125K (50K Reclamation Dam Safety Office, 50K Army Corps of Engineers, 25K Reclamation R&D Office)

Title: **Project II.7** -- Economics Of Climate Change

Related Gap 1.2 (Handout 1)

Background: The potential economic impacts of climate change and, more specifically, the impacts on water use in the western United States depend on several factors. Obviously one of these factors is the extent to which climate change actually occurs in the future. This change is more than simply a change in the mean value of climatic variables (such as temperature, precipitation, etc.), but increased variability of climatic variables. There has historically been a great deal of climate variability and damages to agricultural production, increases in the cost of providing water supplies, reduced recreational opportunities, and other impacts have been estimated in previous studies as a result of drought.

Purpose/Approach: The primary purpose of this research will be to review and summarize the available research on the economic impacts of climate change as it pertains to western water issues. These issues include likely impacts on water supply costs, potential mitigation strategies and the costs of these strategies, the role and costs associated with uncertainty, the range of benefits from taking preventive actions and how these costs may differ from more reactive actions. Specific questions that will be addressed include:

1. What are the existing data on the economics of climate impacts on water?
2. What are the key gaps regarding the possible economic impacts on Reclamation's mission, particularly hydropower generation, flood control, water delivery, recreation, and protection of T&E species? How do economic factors influence water management decisions and will these factors become more relevant as a result of climate change?
3. What data and models exist that could provide a framework for estimating the economic benefits of policies designed to address climate change issues?
4. What is the effect of uncertainty on economic activities as is pertains to climate change? How do social preferences, such as risk aversion, affect economic choices and activities?
5. Based on the results of previous research, to what extent can the effects of climate change be mitigated? Of particular interest will be the extent to which the quantity of water used for various purposes can be adjusted to compensate for climate change. Which mitigation strategies may be applicable to Reclamation activities?
6. What analyses could be done with existing climate projections to fill gaps in number 2 above?

Project Lead: Steven Piper (TSC Reclamation spiper@do.usbr.gov)

Schedule: Completed by February 2008

Budget: *27,840* – Reclamation R&D Office

Title: **Project II.8** -- Past Climate Change and Groundwater Influences to Historic Streamflow Traces

Related Gap 4.1 (Handout 1)

Purpose: The statistical analysis which is key to the successful planning of flood operations is nearly always constructed from historic (past) streamflows. However, these streamflows, which often span a century or more of record, have been influenced by climate change. In addition, groundwater pumping and the infiltration of water from surface irrigation have affected groundwater discharge to the river. The purpose of this research is to investigate the consequences of using historic streamflows in flood operations by removing the effects of climate change and groundwater development from historic unregulated streamflows. The approach and methods will be demonstrated using the Upper Snake River Basin.

Related Gap: Climate change effects (temperature and precipitation) downscaled to the Upper Snake River Basin

Project Lead: Leslie Stillwater, Reclamation PNRO, lstillwater@pn.usbr.gov
Participants:
Staff Reqts: 1 hydrologic modeler/researcher, 1 engineering student trainee, and 3 internal reviewers

Task Outline:

5. Acquire downscaled temperature and precipitation trends for the past century for the Upper Snake Basin, based on model output summarized by the IPCC, and downscaled by others.
6. Apply adjustments for surface water infiltration and groundwater pumping to unregulated daily streamflows of the Upper Snake. The adjustments are already available on a monthly basis.
7. Develop climate affected daily natural streamflows using the Variable Infiltration Capacity streamflow routing model.
8. Using the climate affected streamflows, develop adjustments to the daily unregulated flows in the existing Upper Snake flood operations model.
9. Compare resulting modeled flood operations using adjusted and unadjusted streamflows for the Upper Snake
10. Prepare summary reports.

Schedule: March – August, 2008
Budget: $35,000 – Reclamation R&D Office

Title: **Project II.9** -- Assessing and Reducing the Uncertainty of Predictions from Hydraulic and Hydrologic Models

Related Gap: 7.1, 7.2 (Handout 1)

Purpose: The goal of this project is to develop a methodology and associated software to assess parameter uncertainty and its impact on the predictions of hydrologic, hydraulic, and sediment transport models. Reclamation relies on computer models in a wide range of activities from analysis of dam safety to prediction of bank erosion. These models are typically used to predict the behavior of a system for conditions that cannot be directly observed. Unfortunately, model predictions always contain some degree of error. A key source of error lies in the values of the model parameters, which are constants that control the model's behavior. The parameter values are usually determined by calibrating the model output to reproduce some available observations. Unfortunately, multiple sets of parameter values can often reproduce such observations, while these parameter sets may produce very different predictions for the unobserved conditions. The research will help identify such cases.

Project Lead: Blair Greimann, Reclamation TSC, bgreimann@do.usbr.gov

Participants: Jeffery Niemann, Professor, Department of Civil Engineering, Colorado State University, Fort Collins, CO

Task Outline:

1. To perform the proposed uncertainty analyses, we will require run numerous simulations with hydrologic and hydraulic models. Because these models can require significant computation time, we plan to use a parallel computing strategy where a central processor starts model simulations on other processors as they become available.
2. The second task is to formalize the methodology and develop the software to assess the parameter uncertainty and the model structure uncertainty as described above. Visualization tools will also be developed as part of this task.
3. The third task is the development of an improved method to generate the parameter sets for consideration. While random parameter sets can be generated as described above for simpler models, this approach produces large computational requirements for complex models. To reduce these requirements, parameters that have little impact on the model results should be discarded from consideration. In addition, only parameter sets that are reasonably likely to match observations should be used in the model. This task will develop methods to confront this issue.
4. Once the methodology and software are developed, they will be tested using two data sources. One is the sediment load data on the Trinity River project. The other is the deposition and erosion on the Rio Grande. In these two cases, we will use the methodology to assess the uncertainty of the model when predicting time varying sediment loads and erosion and deposition volumes. The model used for both tasks will be SRH-1D.

Schedule: October, 2008 – August, 2010

Budget: 50K Reclamation R&D Office

HANDOUT 3

Relating Climate Change to Longer Term System Evaluations: Proposed Projects that would further Address Gaps (HANDOUT 1)

February 13, 2008

Edited by:

Levi Brekke, Bureau of Reclamation (Technical Service Center, 86-68210)

David Raff, Bureau of Reclamation (Technical Service Center, 86-68250)

The following projects listed are proposed projects that CCAWWG is aware of relevant to the analytical elements described in Handout 1. The projects as they address the analytical elements and gaps are also tabularized in Table 1.

Proposed project costs and cost-sharing only represents an initial, conceptual collaboration as a starting point for discussions and does not represent a commitment by an agency at this time. As projects move forward toward implementation; the scope of work, collaborator participation, and project budgets will need further development.

Project	Title	Gap
III.1	Potential impacts to riparian ecosystems under conditions of elevated CO_2	1.2
III.2	Archive and Website Enhancements ("Statistically Downscaled WCRP CMIP3 Climate Projections")	2.1
III.3	Technology Transfer and Evaluation – GSFlow	4.1
III.4	Climate change, reservoir management, and the differential success of invasive and native riparian plants	4.2, 5.1
III.5	Reclamation Collaboration with USGS Modeling of Watershed Systems project in the Upper Gunnison River Basin (GRB)	4.2
III.6	Sensitivity of Runoff Model Development to Climate Regime and Implications for Application under Climate Change	4.5
III.7	Significance of Operations Model Uncertainty for Comparative Studies	7.1
III.8	Vulnerability of US Water Supply	4.2, 5.2, 7.2
III.9	Assessing Snowpack and Runoff from Colorado's Headwater Basins Using a Very High Resolution Fully Coupled Atmospheric-Hydrologic Model	2, 4.2
III.10	Eco-hydrology Impact Analysis	4.2, 7.1, 7.2
III.11	Predicting Colonization of Reservoir Margins by Invasive Plants	5.1

Title: **Project III.1** - Potential impacts to riparian ecosystems under conditions of elevated CO_2

Related Gap: 1.2 (Handout 1)

Purpose: This project involves producing a summary of existing literature on the potential impacts to riverine backwater habitats and riparian ecosystems under elevated atmospheric CO_2 concentrations.

Increased atmospheric CO_2 is known to be altering both production and decomposition of plant materials, but likely impacts to western riverine ecosystems is almost totally unknown. Among the most valued ecosystem types in the arid west are riparian areas containing cottonwood/willow and other mesic herbaceous plants. These riparian areas tend to be centers of biodiversity because of their disproportionately high habitat values which are contained in mosaics across the floodplain. These areas also often contain species of special status that are uncommon elsewhere in the arid western landscape.

Plants grown under conditions of elevated CO_2 may possess characteristics that could result in decreased biodiversity along floodplains. Changes in leaf chemistry may result in decreased decomposition rates in both aquatic and terrestrial environments and result in the buildup of fuel sources on floodplains, making them more susceptible to fire. Additionally, alterations of organic food source quality may change the invasion trajectory of herbivorous pests that feed on riparian plants, resulting in changes in floodplain productivity. Backwater areas may be especially susceptible to environmental alterations resulting from changes in woody plant leaf or herbaceous plant material. Large concentrations of leaf material in isolated backwaters could result in increased concentrations of toxic compounds from plants grown under conditions of elevated CO_2. This could impact invertebrate production and fishes using these areas as nurseries.

Contact: Doug Andersen, USGS, doug_andersen@usgs.gov
Participants: USGS, Reclamation
Staff Reqts: 2 writers, literature reviewers

Task Outline:

1. Generate bibliography
2. Assemble, review and synthesize pertinent literature

Schedule: 3-month timeline
Budget: ~10K Reclamation R&D Office, ~25K *in-kind* USGS

Title: **Project III.2** -- Archive and Website Enhancements ("Statistically Downscaled WCRP CMIP3 Climate Projections")

Related Gap: 2.1 (Handout 1)

Purpose: Several archive enhancements have been suggested since the archive was activated in November 2007:

- Additional downscaled variables, U.S. coverage:
  - monthly mean "daily minimum temperature (T)" and "daily maximum T" (rather than monthly mean T variable that is currently archived) which are needed for ecosystem response studies.
- New derived variables, U.S. coverage:
  - monthly drought indices (e.g., Palmer Drought Severity Index and Standardized Precipitation Index) for quick (coarse) assessment of future drought possibilities, region-specific and consistent with archived climate projections
- Community Page on the Archive Website:
  - Clearinghouse for method descriptions on use of archive data for water resources impacts studies

This project involves developing additional downscaled and new derived variables

Contact: Levi Brekke, Reclamation TSC, lbrekke@do.usbr.gov

Participants: Technical Service Center 86-68210 (Tmin/Tmax implementation; data archiving; website modification); NOAA-CIRES (J. Barsugli – drought indices calculations); Santa Clara University (E. Maurer – Tmin/Tmax algorithm set up)

Task Outline:

1. Tmin/Tax algorithm development (Maurer) and implementation (86-68210).
2. Derived data development – drought indices (CIRES).
3. Derived data development – runoff (USGS).
4. Archive update and Website Enhancements (86-68210).

Schedule: January – September, 2008

Budget: 60K Reclamation R&D Office; 30K *in-kind* by NOAA

Title: **Project III.3** -- Technology Transfer and Evaluation – GSFlow

Related Gap: 4.1 (Handout 1)

Purpose: Typical runoff response analyses under climate change have been focused on changes in surface water balance, and applied in basins where interaction between groundwater and surface water transpire over relatively short time scales (e.g., mountain headwater basins). Such analyses and model tools are less appropriate when the goal is to study how climate change might affect groundwater and surface water interactions in valley lowlands (which are where Reclamation service areas are typically located) or areas where groundwater and surface waters are jointly managed.

For these latter applications, GSFlow potentially serves as a useful analysis tool GSFlow is a new technology from USGS that fully couples a surface water model (USGS' Precipitation Runoff Modeling System, or PRMS) with the groundwater model, Modflow.

The proposed project involves USGS and Reclamation teaming to evaluate GSFlow application under historical and projected climate simulation where PRMS and Modflow applications have already been developed. Initially focusing on basins where PRMS and Modflow applications already exist should accelerate GSFlow calibration. PRMS applications have been developed in many Western U.S. headwater basins. Reclamation's PN region has developed Modflow applications in several system basins. PN would seem to offer some ideal case study basins to evaluate this technology.

Contact: Steve Markstrom, USGS NRP, smarkstro@usgs.gov
Participants: USGS, PN region, Technical Service Center 86-68210

Task Outline:

1. GSflow application development(s) for PN system(s) where Modflow and PRMS applications have already been developed
2. Comparative hydrologic simulations under historical meteorology, first by PRMS & Modflow, then by GSflow
3. Comparative hydrologic simulations, as in Task (2), but with meteorological inputs adjusted to reflect several chosen climate projections.
4. Evaluation and documentation of results.

Schedule: January – September, 2008
Budget: 60K – Reclamation R&D Office, 15K PN *direct*; 30K *in-kind* USGS

Title: **Project III.4 --** Climate change, reservoir management, and the differential success of invasive and native riparian plants

Related Gap: 4.2, 5.1 (Handout 1)

Purpose: Climate change in the western U.S. is expected to result in earlier snowmelt and associated runoff and lower summer baseflows on many river systems. These changes, combined with water management, will influence the distribution and abundance of native and invasive riparian plants. The response of riparian vegetation to climate change (an environmental demand) has potential implications for invasive species distributional change and associated management, and changes to habitat for threatened and endangered (T&E) wildlife species. In addition, warmer temperatures alone may lead to range shifts for some species. We propose to conduct a set of integrated studies to develop predictions of future distributions of key invasive and potentially threatened plant species, as well as key habitats that support wildlife species of concern.

Project Lead: Pat Shafroth, USGS, shafrothp@usgs.gov

Participants: Post-doctoral associate (USGS); Jonathan Friedman (USGS); Reclamation and NOAA collaborators; David Merritt (US Forest Service)

Staff Reqts: Post-doctoral associate (through USGS in-house contractor)

Task Outline:

11. Identify focal invasive and threatened taxa
    > consult with Reclamation managers
    > literature
2. Identify multiple river segments that contain these taxa for more detailed study
3. Work with NOAA and Reclamation to develop a range of climate and flow scenarios
4. Develop key biological response curves associated with climate and flow changes for the key taxa identified under 1 (above)
    > literature, theory, other existing data
    > new field studies
5. Combine biological response information with climate and flow scenarios to generate predictions

Schedule: Summer 2008 – Summer 2010

Budget: will require ~75k net/year for 2 years

Title: **Project III.5** -- Reclamation Collaboration with USGS Modeling of Watershed Systems project in the Upper Gunnison River Basin (GRB)

Related Gap: 4.2 (Handout 1)

Purpose: The Upper GRB is defined from the headwaters to below the outlet of Crystal Reservoir on the main stem of the Gunnison River. USGS has previously worked with Reclamation on runoff assessements in this basin. This project is motivated by both current interest in the Upper Colorado runoff response to climate change, and USGS desire to update the Precipitation Runoff Modeling System (PRMS) in the GRB.

The project focuses on demonstrating and further developing advanced techniques in runoff model calibration. (1) Implementing "Dynamic Parameters" in the GRB PRMS, previously demonstrated in the Flint River Basin (GA), which could allow for simulated joint changes in climate and land use over time; (2) incorporation of MODIS remotely sensed snow cover area (SCA) data product as an additional constraint on model calibration.

Project Lead: Lauren Hay, USGS, lhay@do.usbr.gov
Participants: 1 Reclamation hydrologist, 1 USGS modeler (under Lauren's direction)

Task Outline:

1. Design comparative calibration experiments using old and proposed techniques.
2. Implement schemes.
3. Evaluate and document findings.

Schedule: FY2009?
Budget: ~50K Reclamation R&D Office, ~50K USGS

Title: **Project III.6** -- Sensitivity of Runoff Model Development to Climate Regime and Implications for Application under Climate Change

Related Gap: 4.5 (Handout 1)

Background: Different runoff models can be used to study climate change implications for water supply. Several models have been applied for such studies the Western United States (e.g., SacSMA/Snow17, VIC, PRMS, Thorthwaite Monthly Water Balance). For Reclamation's NEPA, ESA, and long-term system evaluations, scoping teams must address several questions: among available runoff model-tools, which is the preferred tool of choice (if one exists) and for what reasons?

NOAA-RISAs are currently sponsoring research that explores tool differences (see Handout 2) and results variability under common climate change scenarios. Although the RISAs project should reveal differences how results depend on tool choice, it won't necessarily reveal tool preference.

Purpose: This project would begin to target the issue of tool preference, focusing on model re-development under calibration and validation schemes that involve contrasting antecedent climate periods (e.g., calibration on early cool/wet regime and application (validation) on later warm/dry regime). The objective is to show how model structures are variably more or less robust in simulating runoff under climate regimes that differ from calibration climate.

Project Lead: Levi Brekke, Reclamation TSC, lbrekke@do.usbr.gov
Participants: (*conceptual, not confirmed*) 3 TSC hydrologic modelers (2 VIC, 1 SacSMA/Snow17), 1 USGS modeler (G. McCabe, Thorthwaite modeling), potentially collaborate with interested researchers from NOAA NWS WRH, or academia

Task Outline:

4. Choose study basins (~4, diverse) and comparative antecedent climate-periods
5. Re-calibrate and validate runoff model applications
6. Evaluate and document findings.

Schedule: April – September, 2008 (or FY2009?)
Budget: *depends on scoping details and staff availability; rough estimate ~100K?*

Title: **Project III.7** -- Significance of Operations Model Uncertainty for Comparative Studies

Related Gap: 7.1 (Handout 1)

Purpose: Reclamation has explored the use of Monte Carlo analysis to reveal output uncertainties associated with the operations model structure and inputs (e.g., Central Valley Project and State Water Project planning model, CALSIM II (Brekke et al. 2006)). These methods have been applied to "single version" of decision models (where version is defined by: management priorities/rules, system configuration, land use, hydrology, etc). In application, Reclamation typically uses decision models in "comparative mode", assessing differences in simulation results between alternative versions of the system, separately represented in parallel versions of the model (e.g., action-alternatives analyses for NEPA planning; operations baselines for ESA consultations).

Questions remain about the significance of "single version" model uncertainty relative to "comparative studies" application. This project would demonstrate and document a methodology for exploring this question. The key feature is to coordinate Monte Carlo analyses on two versions of a decision model (e.g., CALSIM II, differing by land use scenario and associated water demands: existing versus 2030). Each Monte Carlo realization reflects a potential collection of inputs within assumed limits of variation (i.e. water supply, demand, hydrologic, and environmental parameters) and is applied, as possible, to both CALSIM II study versions, "existing" and "future". Such "single version" analyses have recently been completed for prior project purposes. This research would leverage those results with further analysis and documentation. Analysis would evaluate uncertainty envelopes about each "single version" for different operations metrics, and compare them to evaluated uncertainty envelope about study *differences* ("future - existing") for the same metrics. Methods and approach would be documented for peer-review

Contact: Levi Brekke, Reclamation TSC, lbrekke@do.usbr.gov
Participants: Technical Service Center 86-68210 (2 analysts)

Task Outline:

1. Data Analysis
2. Presentation and documentation (journal article; applications focused)

Schedule: April – July, 2008
Budget: 15K Reclamation R&D Office

Title: **Project III.8** -- Vulnerability of US Water Supply
Related Gap: 4.2, 5.2, 7.2 (Handout 1)

Background: For Reclamations long-term planning decisions including NEPA processes and ESA consultations consideration must be given to assessing the vulnerability of the system to change. There are various ongoing projects that are looking at downscaling options and alternatives (e.g. BOR-Archive, NARCCAP, Matanaga hybrid) and projects that are looking at watershed response choices (e.g. Brekke sensitivity project). However, no projects are aimed at evaluating the system vulnerabilities. Vulnerability to droughts or other weather-related phenomena is principally a matter of extreme events and of how the frequency of extreme events will change over time. That is, it is not sufficient to quantify the potential effects of climatic change on the mean values of hydrological, ecological, and meteorological variables of interest, but most importantly, it is necessary to quantify the changes in the inherent variability of those variables. An essential task of evaluating regional hydrologic vulnerability to droughts is the quantification of potential changes in the frequency, magnitude and duration of extreme events as a result of climate variability and change.

Purpose: We will assess the vulnerability of the United States water supply to shortage over the next 50 years. Vulnerability will be assessed both assuming a continuation of recent climate conditions and assuming alternative possible future climates. Vulnerability will be characterized as the probability of shortage, with shortage defined as the inability to satisfy consumptive use requests while also meeting minimum streamflow requirements. Available water for diversion in a basin will be estimated using the Statistical-Dynamical Ecohydrology Model (SDEM) of Kochendorfer and Ramirez (2008a; 2008b), taking into account runoff from upstream basins, basin reservoir storage and evaporation, inter-basin transfers, and instream flow constraints. Future water availability under altered climates will be estimated using downscaled GCM projections via a comparison of GCM and WBM estimates for the past 50 years. Water will be allocated over time and space using a water routing model.

Contact: David Raff, Reclamation TSC, draff@do.usbr.gov
Participants: Jorge A. Ramirez, Colorado State University, 1 PhD student TBD
Schedule: June 2008 – September 2010
Budget: *120K*
Notes: Tools: SDEM, Reclamation GCM downscaling Archive
Basins: (a) Some Colorado River Basin.

Title: **Project III.9** -- Assessing Snowpack and Runoff from Colorado's Headwater Basins Using a Very High Resolution Fully Coupled Atmospheric-Hydrologic Model

Related Gap: 2, 4.2 (Handout 1)

Background: Snowpack is the most important water source in the western U.S., and thus it is critical that water managers be provided with, as accurately as possible, 1) an improved understanding of the mechanisms that give rise to snow pack variability from year-to-year and 2) estimates of the likely changes expected of this resource in the future under various assumptions about future global climate. The Rocky Mountain region is a particularly difficult area for global climate models (GCMs) to properly handle, as it is dominated by complex topography that are not well represented in GCMs. It is critical to examine climate variability and change in this region using high resolution atmospheric models in order to more realistically simulate hydrometorological processes.

Purpose/Approach: The Weather Research and Forecasting (WRF) model adapted for climate simulations will be deployed in a nested configuration, with the higher resolution nest as fine as 1 km over Colorado and Utah. A second nest of 12 km resolution will cover the rest of the western states, and a 36 km grid resolution domain will cover North America. The Noah land surface model with its snow module will be used for these simulations in order to depict snowpack accumulation, sublimation, evapotranspiration, runoff and streamflow. The first year effort would include model simulations of past winter seasons (normal, wet, and dry) to verify the performance of the model and improve our understanding of seasonal climate variability. Efforts in future years will focus on the use of this model to simulate future snowpack conditions under global warming scenarios.

Contact: David Raff, Reclamation TSC, draff@do.usbr.gov

Participants: 2 NCAR atmospheric scientists/WRF modeler; 2 NCAR hydroclimatologists.

Schedule: Option 1) 12 month period, May 2008 through April 2009, run and analysis of historical cases; Option 2) 24 month period, May 2008 through April 2010, conduct both historical and future climate simulations and analysis.

Budget: *Option 1) 125K to 160k; Option 2) 200K to 300K*

Notes:

Basins: Focus area would be the Headwaters Region (Platte, Arkansas, Colorado, Rio Grange) with the highest resolution domain; Lower resolution domains would cover a large portion of the western US.

Title: **Project III.10** -- Eco-hydrology Impact Analysis
Related Gap: 7.2, 7.1, 4.2 (Handout 1)

Background: For Reclamations long-term planning decisions including NEPA processes and ESA consultations consideration must be given to scenario planning and modeling. There are various ongoing projects that are looking at downscaling options and alternatives (e.g. BOR-Archive, NARCCAP, Matanaga hybrid) and projects that are looking at watershed response choices (e.g. Brekke sensitivity project). However, there remains a component of the landcover and municipal response to atmospheric drivers. Further there remains a missing component related to the methodological (and tool) uncertainties that aggregate throughout an analytical process.

Purpose: This proposal focuses on filling the need to examine eco-hydrological response (namely landcover) as well as various municipal trajectories given a set of atmospheric forcings and a watershed tool (The SDEM model). The further objective is to put these methods and tools into a scheme that will allow for examination of uncertainty sources and propagation. The end result will be a description of eco-hydrological change throughout a watershed and watershed response to climate change given a set of municipality trajectories. Within a Bayesian framework new information can be incorporated as time marches on helping determine the actual trajectory in question and reducing the uncertainty in model output.

Related Gap: This project addresses analytical element #4, #5, and #7 in the draft long-term gap assessment (DecisionsAndGaps_071107.pdf). This project will provide information that will assist scoping of NEPA, ESA, or other long-term system evaluations through determination of physical system response to climate change as well as specific tool / method uncertainties.

Contact: David Raff, Reclamation TSC, draff@do.usbr.gov
Participants: Jorge A. Ramirez, Colorado State University, 1 PhD student TBD
Schedule: June 2008 – September 2010
Budget: *120K*
Notes: Tools: Statistical-Dynamical Eco-Hydrology Model (SDEM) (Kochendorfer and Ramirez, 2008a;b), VIC daily simulation, Reclamation GCM downscaling Archive
Basins: (a) Some Colorado River Basin.

Title: **Project III.11** -- Predicting Colonization of Reservoir Margins by Invasive Plants

Related Gap:

Purpose: The vegetation along reservoir margins changes in response to water-level fluctuations driven by climate and water management. Sustained drawdown often results in temporary development of regionally important populations of invasive species. For example, drawdown of Fort Peck and other reservoirs during recent drought produced some of the largest known populations of saltcedar in the northern Great Plains. Large areas of invasive vegetation complicate reservoir management, produce seeds that are transported to the surrounding landscape, and may serve as habitat for rare animals such as southwest willow flycatcher in lake Mead. We propose to survey existing populations of invasive species along margins of key reservoirs, and to develop models predicting future changes in these populations resulting from shifts in climate and demand for water.

Related Gap: Analytical element 5 – assess demand and social system responses. Colonization of reservoir margins by invasive plants (an environmental demand) could interfere with reservoir operations, change invasive plant species distribution, and alter habitat for T&E wildlife species.

Project Lead: Jonathan Friedman, USGS, friedmanj@usgs.gov

Participants: Gregor Auble (USGS); Pat Shafroth (USGS); Reclamation and NOAA collaborators; Graduate Student (USGS);

Staff Reqts: Graduate Student (through USGS in-house contractor)

Task Outline:

12. Select key reservoirs with potential for large areas of invasive vegetation
2. Relate invasive populations at these reservoirs to reservoir stage and bathymetry
3. Model establishment of invasive vegetation as a function of duration, magnitude, timing and frequency of reservoir drawdown.
4. Work with NOAA and Reclamation to develop climate and water management scenarios
5. Combine biological response information with scenarios to generate predictions

Schedule: Summer 2008 – Summer 2010

Budget: will require ~65k net/year for 2 years

Other proposed projects:

- **Project III.X1 --** (No specified gap) Region-support and Corporate Knowledge Building: R&D and Technical Service Center would plan and host workshops, potentially in concert with Region/Area offices and/or various state water institutes, on how to incorporate climate change information into long-term water supply evaluations. The workshops would be targeted toward an audience of "Contracting Officer Technical Representatives" and/or technical staff charged with implementing such methods. Workshop goals would be to expand corporate knowledge on analytical process, element-specific issues, and project scoping issues. Outcome would ideally be a transfer of ideas and knowledge to project-planning teams located at Reclamation's Region & Area offices.

Other proposed investments:

- **Project III.X2** -- (Gap 3.2) Support Decadal Scale Climate Prediction Research (relates to Element 3, Handout 1) Many of Reclamation's operations and planning decisions are focused on shorter- to medium-term time scales (e.g., 20 years or less), where *climate variability* may hold more control than longer-term trends in climatology. In particular, climate predictability limits on 2- to 10-year times scales are not well understood and happen to be very relevant to "drought preparedness" planning. Although Reclamation does not conduct research on decadal-scale climate predictability, Reclamation look for other ways to support or promote research in this area by science agencies or research collaborations that might address it. For example, the Arizona Water Institute and NOAA-RISA Climate Impacts Group convened a workshop in March 2007, designed to outline a research plan to explore limitations in decadal-scale climate predictability and now-casting of climate oscillations. Outcomes from such research would benefit Reclamation by offering information on the limits of climate predictability for drought preparedness planning, and also on interpreting potential climate variability that would be superimposed on near-term climate change trends (and potentially induce climate "swings" that seem out-of-synch with expected trends).

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SURVEY FORM A: Management Priorities (Resource Managers)

Agency: _____, Name (Optional):_____

Gaps (Abbreviated Description)	**Priority Assignment**					
	for Immediate Use			**for Longer-Term Use**		
	Low	**Med.**	**High**	**Low**	**Med.**	**High**
1. Summarize Literature						
1.1 Clearinghouse, Scientific Literature						
1.2 Region-specific Literature Summaries						
2. Obtain Climate Projection Data (Downscaled and Bias-Corrected)						
2.1 Downscaled data at finer resolutions (space and/or time) and different variables						
2.2 Downscaled data that isn't based on "stationarity" (e.g., potentially revealed using regional climate models)						
3. Translate Climate Projection Data into Planning Scenarios						
3.1 Basis for weighting Emissions Paths						
3.2 How to jointly consider paleoclimate, near-term climate variability, and projected climate						
3.3 How to assess extreme meteorological possibilities in a changing climate						
4. Assess Natural Systems Response (e.g., Hydrology, Ecosystems)						
4.1 Climate impact on groundwater and interaction with surface water						
4.2 Climate impact on land cover and ecosystems						
4.3 How to assess flood control rule requirements in a changing climate						
4.4 How to assess extreme hydrologic possibilities related to dam safety in a changing climate						
4.5 Guidance on runoff analysis dependence on method/tool; and method/tool preference						
5. Assess Social Systems Response (Water Demands)						
5.1 How to project social responses to that constrain operations (e.g., water demands, flood protection, environmental values)						
5.2 Crop water demand response to climate and atmospheric carbon dioxide changes						
6. Assess Operations and Dependent Resources Response						
6.1 Experience conducting policy-search studies (e.g., "crystal-ball" operator, optimization)						
6.2 How to blend "static" and "crystal-ball" operator depictions into realistic portrayal of operations unfolding under climate change						
6.3 How to analyze operations impacts on climate						
7. Assess and Characterize Uncertainties						
7.1 How to assess and characterize uncertainties by element						
7.2 How to how uncertainties interrelate and/or compound across elements						
8. Communicate Uncertainties and Incorporate into Decision-Making						
8.1 Experience communicating uncertainties associated with climate change and its relation to Reclamation planning processes						

Please write any additional thoughts and comments on the back of this form.

SURVEY FORM B: Research Priorities (Science Agencies)

Agency: _____, Name (Optional):_____

Gaps (Abbreviated Description)	**Priority Assignment**					
	Relevancy to Agency			**Feasibility to Address**		
	Low	**Med.**	**High**	**Low**	**Med.**	**High**
1. Summarize Literature						
1.1 Clearinghouse, Scientific Literature						
1.2 Region-specific Literature Summaries						
2. Obtain Climate Projection Data (Downscaled and Bias-Corrected)						
2.1 Downscaled data at finer resolutions (space and/or time) and different variables						
2.2 Downscaled data that isn't based on "stationarity" (e.g., potentially revealed using regional climate models)						
3. Translate Climate Projection Data into Planning Scenarios						
3.1 Basis for weighting Emissions Paths						
3.2 How to jointly consider paleoclimate, near-term climate variability, and projected climate						
3.3 How to assess extreme meteorological possibilities in a changing climate						
4. Assess Natural Systems Response (e.g., Hydrology, Ecosystems)						
4.1 Climate impact on groundwater and interaction with surface water						
4.2 Climate impact on land cover and ecosystems						
4.3 How to assess flood control rule requirements in a changing climate						
4.4 How to assess extreme hydrologic possibilities related to dam safety in a changing climate						
4.5 Guidance on runoff analysis dependence on method/tool; and method/tool preference						
5. Assess Social Systems Response (Water Demands)						
5.1 How to project social responses to that constrain operations (e.g., water demands, flood protection, environmental values)						
5.2 Crop water demand response to climate and atmospheric carbon dioxide changes						
6. Assess Operations and Dependent Resources Response						
6.1 Experience conducting policy-search studies (e.g., "crystal-ball" operator, optimization)						
6.2 How to blend "static" and "crystal-ball" operator depictions into realistic portrayal of operations unfolding under climate change						
6.3 How to analyze operations impacts on climate						
7. Assess and Characterize Uncertainties						
7.1 How to assess and characterize uncertainties by element						
7.2 How to how uncertainties interrelate and/or compound across elements						
8. Communicate Uncertainties and Incorporate into Decision-Making						
8.1 Experience communicating uncertainties associated with climate change and its relation to Reclamation planning processes						

Please write any additional thoughts and comments on the back of this form.