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US ARMY CORPS OF ENGINEERS APPROACH TO WATER RESOURCES CLIMATE CHANGE ADAPTATION

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Abstract- The magnitude of climate change impacts facing water resources managers in the United States has spurred closer interagency cooperation in developing methods supporting planning and engineering for climate change adaptation. The two largest water resources management agencies in the US, the USACE Army Corps of Engineers and the Bureau of Reclamation, have partnered to describe climate change challenges, identify user needs for improving tools and information, and assess capabilities to use weather and climate forecasts in federal water resources management. They have also hosted a forum with national and international experts exploring

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the issue of nonstationary hydrology with respect to climate change. In progress is development of multi-agency guidelines for best practices to select from the portfolio of climate information including global climate scenarios, through general circulation models, through downscaling, to regional or watershed-scale hydrological and operations planning models to account properly for climate change and variability at the scale of water-resource operational decisions. This presentation describes collaborative activities and the resulting methods being used as both agencies plan for and implement climate change adaptation measures.

Keywords: climate change, adaptation, water resources management, hydrology

1. Introduction

The importance of water as a fundamental requirement for life and economic development has resulted in water resources management frameworks that improve the capacity of water managers to absorb change without unduly impacting basic functions while allowing them to balance competing needs (Olsen et al 2010a). Water managers thus provide a potential reservoir of resilience for operations in the face of climate change, *if* they are prepared to act effectively in a timely (White et al 2010) and collaborative manner (Stockton and White, this volume). Water resources planning, engineering, and design are important factors determining the sustainability of projects over their life cycle, and are key elements in management strategies to improve resilience.

The two largest water managers in the US, the US Army Corps of Engineers (USACE) and the Department of Interior's Bureau of Reclamation (Reclamation) recognize that an unprecedented level of collaboration is necessary to meet the combined challenges of climate and global change to water resources management. The agencies are developing and implementing strategies to "manage the unavoidable" climate change effects through planning, engineering, and design of climate change adaptation measures that can also protect against adverse effects of other global changes. This collaboration brings together two agencies with long experience in adjusting to meet new water resource-related challenges. Since 2006, the relationship has proved beneficial to these water managers, their partners and stakeholders, and presents a model for other nations.

This paper describes the USACE collaborative approach to preparing for climate change and the resulting methods being used as we plan for and implement climate change adaptation measures.

2. Roles of USACE and Reclamation in US Water Resources Management

The two largest water resources management agencies in the US are USACE and Reclamation, each having different yet complementary missions and responsibilities. Operating continuously since 1802, USACE operates nationally and internationally, while Reclamation has operated in the seventeen western states since 1902 (Figure 1). The administrative boundaries of both agencies generally coincide with major river basin boundaries, with the exception of Reclamation's eastern boundary.

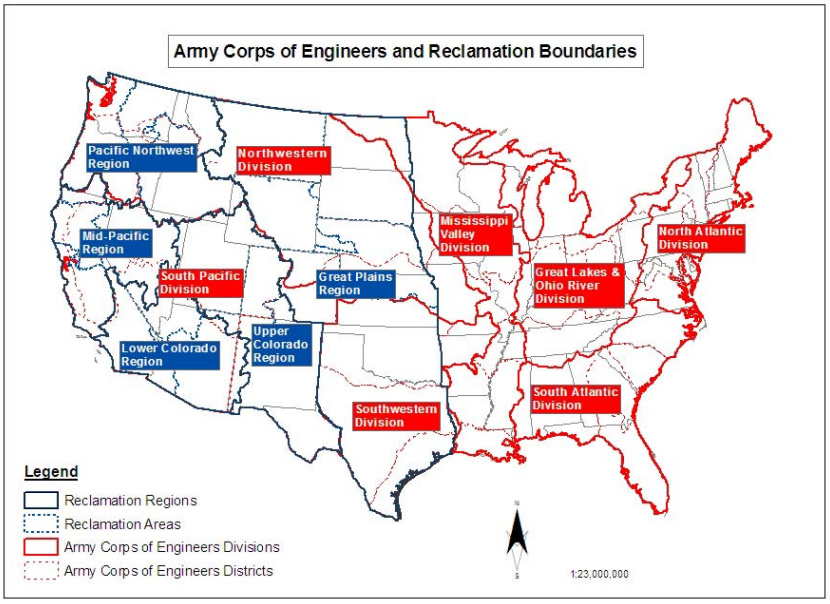

Figure1. Management of the nation's largest water resources managers (USACE and Reclamation) is organized largely by major river basins.

Nearly every mission of the two agencies is already or very likely will be impacted by climate change, which affect design and operational assumptions about resource supplies, system demands or performance requirements, and operational constraints (Brekke e al 2009a). USACE and Reclamation have shown remarkable resilience in the face of previous environmental and operational changes, but the profound effects of climate change could overtax their capacity and may confound existing challenges.

In part because Reclamation and USACE have some similar and some distinct responsibilities, effective and efficient water management requires coordinated and consistent responses to climate change by the two agencies. Both agencies have a strong life-safety component to decision making. At each agency, the commitment to life safety was re-evaluated and strengthened by internal and external analyses following tragedies: the Teton Dam failure in 1978 for Reclamation and Hurricane Katrina in 2005 for USACE. In both cases, strengthening professional and technical competencies was a priority. The ability to incorporate new and changing information, such as climate change, was a particular concern of the Interagency Performance Evaluation Task Force (IPET 2009).

For all these reasons, Reclamation and USACE are partnering as they move forward to face the challenges posed by climate change to water resources managers (e.g., Brekke et al 2009a, Brekke et al. in review). Both agencies recognize gaps between current and future capabilities required to respond to climate change. Some needs are common, while others are agency-specific, but all these needs will require improved resilience as the agencies include climate change in their water resources planning, engineering design, construction, and operations. A common understanding of how climate is changing, how these changes impact water management resilience, what climate change information is needed to evaluate impacts, responses, and adaptation, and how this information will be used, is fundamental for developing rational, consistent, safe, approaches based on best available science.

2.1. AGENCY MISSIONS: SIMILAR BUT COMPLEMENTARY.

For more than 230 years, USACE has supplied engineering solutions for U.S. water resources needs, including for navigation, flood and coastal storm damage reduction, protection and restoration of aquatic ecosystems, hydropower, water supply, recreation, regulatory, and disaster preparedness and response. Approximately 12 million acres of land and water resources are under the jurisdiction of the USACE as part of its Civil Works portfolio of 2500 water resources projects, programs, and systems. USACE also applies water resources management expertise to support Military program operations worldwide that promote peace and stability.

Reclamation was established with a mission centered on the construction of irrigation and hydropower projects in the Western US that has evolved to include municipal and industrial water supply projects, water recycling, ecosystem restoration, site security, and the protection and management of water supplies. Through this evolution of its mission, Reclamation is

involved with environmental impacts, changing demographics, and periodic drought in the 8.7 million acres they own and administer in the West.

The common missions of the two agencies (hydropower, dam safety and critical infrastructure, water supply, ecosystem restoration and protection, and recreation) are described in more detail below. The differing missions of the two agencies (e.g., navigation, flood and coastal storm risk reduction, regulatory, irrigation, disaster preparedness and response, and war-fighter support) all have a strong water resources management component and thus still share many of the challenges and needs of the common missions.

2.2. COMMON MISSION AREAS IMPACTED BY CLIMATE CHANGE

2.2.1. *Hydropower.*

Hydropower is perhaps the most similar mission area for USACE and Reclamation, which together provide a little more than half the hydropower in the US. According to Hall and Reeves (2006), USACE and Reclamation own 78% of federal hydropower plants providing about 91% of federal hydropower capacity. USACE operates 75 major hydropower projects, with nameplate capacity of more than 21.75 GW, supplying more than 24% of US hydropower. An additional ~2 GW of installed capacity is available through non-federal installations at USACE dams, a number likely to increase in the coming years. The second-largest producer of hydropower in the US after USACE, Reclamation has nameplate capacity of about 13.56 GW, supplying about 18% of US hydropower production. The Bureau of Reclamation and the US Army Corps of Engineers share hydropower production within the Columbia and Missouri River Basins. Figure 2 shows the location of federal hydropower installations at USACE and Reclamation projects.

Hydropower production is typically operated using sub-hourly weather information but does also rely on climate forecasts and projections on scales ranging from monthly to multi-decadal. Operating hydropower projects with multiple purposes (e.g., flood risk reduction, irrigation, municipal and industrial water supply, navigation, in-stream flow augmentation, or recreation) requires knowledge of the full range of hydrological and meteorological climate change impacts as well as the expected frequency of these projected impacts. Though stationarity – the assumption that future hydrologic events will occur within the historically recorded range of variations in frequency and intensity – is an important factor in planning future hydropower operations, recent studies (e.g., Milly et al 2008) indicate that the potential for nonstationarity must be considered.

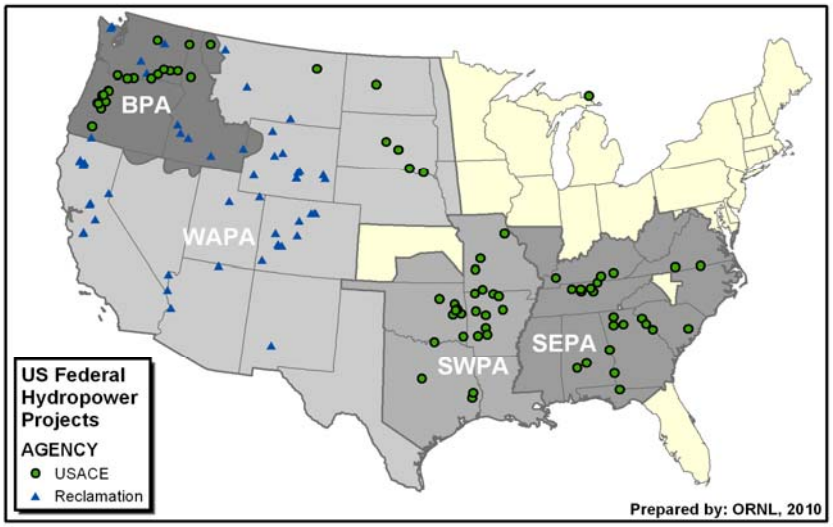

Figure 2. Existing federal hydropower projects at Reclamation and USACE) projects. Four power market administration areas are shown: Bonneville Power Administration (BPA), Southeastern Power Administration (SEPA), Southwestern Power Administration (SWPA) , and Western Area Power Administration (WAPA). (Prepared by National Hydropower Asset Assessment Project Team, Oak Ridge National Laboratory).

2.2.2. *Dam and Critical Infrastructure Safety.*

USACE has over 600 dams nationwide and Reclamation has approximately 500. These agencies have begun standardizing their approaches to dam safety in ways similar to their partnering on climate change effects. Reclamation and the USACE are in development of similar risk based tools and approaches for assessing downstream consequences from natural hazards. Climate change effects on hydrologic stationarity can potentially result in changes to design inflows and outflows at projects that may affect safety. This is because often the upper estimates of risk for a dam are based on the Probable Maximum Precipitation (PMP) that could occur. The PMP is based on the moisture content in the atmosphere, which will change as air temperature warms and the thickness of the atmosphere changes.

A joint Reclamation and USACE project is exploring the potential changes in PMP through an analysis of dynamically downscaled climate projections from the North American Regional Climate Change Assessment Program (NARCCAP). An additional joint project between Reclamation and USACE is exploring reasonable methods for the use of climate projections to assess changes and vulnerabilities of current practices. An important

aspect is characterizing probabilistic flood risk affecting other critical infrastructure such as levees. Other USACE critical infrastructure will benefit from this collaborative work, including more than 250 navigation locks and about 8500 miles of levees, together with associated flood gates, pumping stations, and other components.

2.2.3. *Municipal and Industrial Water Supply.*

As noted above, water supply is a primary mission for Reclamation, but a secondary mission for UASCE. Reclamation is the largest wholesaler of water in the US, supplying water to more than 31 million people. Reclamation projects provide irrigation water to one out of five Western farmers (140,000) for 10 million acres of farmland, producing 60% of the nation's vegetables and 25% of its fruits and nuts. Reclamation delivers 10 trillion gallons of water to more than 31 million people each year from a total storage capacity of approximately 245 million acre-feet.

Water supply is an authorized use for the USACE as part of multi-purpose projects, but is not currently authorized as a primary or single purpose for a project. The total capacity of major USACE lakes is about 329 million acre-feet (MAF). There are 136 USACE projects with authorized municipal & industrial (M&I) water supply storage in 25 states plus Puerto Rico. Total authorized M&I water supply storage of over 9 MAF is provided through 316 water supply agreements with states, counties, cities, industries as well as private individuals. 48 USACE projects have authorized irrigation storage.

2.2.4. *Ecosystem Restoration and Protection.*

Water managers carry out Reclamation's official mission to "manage, develop and protect water and related resources in an environmentally and economically sound manner in the interest of the American public."[1] In doing so, they incorporate ecosystem considerations (e.g., fish, wildlife, and other environmental factors), into their water and power operations. They include aquatic ecosystem requirements as they identify and plan for future consumptive and non-consumptive water supply needs.

The USACE Civil Works program includes ecosystem restoration as a primary mission, with specific guidance dating to 1990 (Donohue 2005). USACE ecosystem restoration can be categorized as restoration, protection, and stewardship of natural resources associated with its projects. USACE and the Nature Conservancy have been working together since 2005 on the

[1] Reclamation Mission Statement: http://www.usbr.gov/gpra/

Sustainable Rivers Project, which has resulted in reoperations at UASCE dams to support ecologically sustainable flow, joint training, and tools to support evaluation of hydrologic regime alternatives. In 2008, USACE reaffirmed the integration of ecosystem in all its mission areas through the development of the Environmental Operating Principles[2] .

2.2.5. *Recreation.*

Recreation is a major economic benefit associated with the water resources managed by USACE and Reclamation and relies on adequate water quality, quantity, and ecosystem health. Reclamation receives over 90 million visits per year at its 289 recreational areas, which include 350 campgrounds. USACE receives about 368 million visits per year at 456 lakes in 43 states, supporting activities such as fishing, boating, hiking, camping, snorkeling, whitewater rafting, mountain biking, windsurfing and programs for people with disabilities. USACE recreation provides over 4300 recreation areas with 101,000 campsites, 80% of which are within 50 miles of a large US city. USACE lakes host a third of all freshwater lake fishing in the US, and support about 200,000 fishing tournaments per year. With some 3,800 boat launch ramps, 56,000 miles of shoreline, and 5,000 miles of trails, USACE host 20% of all federal government recreation visits on 2% of federal lands. Reclamation has approximately 6.5 million acres of land and water, most of which are available for public outdoor recreation. This includes 289 developed recreation areas that contribute approximately $6B per year to the economy and support about 27,000 jobs.

3. Collaborative Activities

Over the past several years, USACE and Reclamation have led and participated in a variety of collaborative activities directed at understanding the impacts of climate change and exploring possible adaptation measures for their complementary missions. The activities have also included other agencies, partners and stakeholders, for improving transparency and knowledge transfer. These activities are primarily related to inland hydrology affecting the operation of UASCE and Reclamation projects, with one exception, sea-level change.

[2] See http://www.corpsresults.us/environment/envprinciples.htm

3.1. FIRST STEPS: BASIN-WIDE STUDIES

The Reclamation-USACE partnership on climate change activities began in 2006 when the USACE was directed by the FY06 Energy and Appropriations Act (PL 109-103[3]) to conduct "at full federal expense, comprehensive analyses that examine multi-jurisdictional use and management of water resources on a watershed or regional scale." These planning studies were intended to demonstrate true multi-agency collaboration. Two different large-scale proposals centering on observed climate change impacts to western states were developed by USACE teams, both with Reclamation and other agencies. During the development of study proposals, Reclamation and USACE scientists and engineers formed relationships and learned how much they had in common as members of water resources operating agencies.

3.1.1. *Western States Watershed Study.*

One of five basin-wide studies funded under PL 109-103 was the Western States Watershed Study (WSWS). The study proposal was prepared jointly by the three western USACE Divisions – Southwest Division (SWD), Northwest Division (NWD), and South Pacific Division (SPD) (see Figure 1 for locations) – and the study proponent was the Western States Water Council (WSWC). The study area encompassed the three major western watersheds (Columbia River, Colorado River, and Missouri River) as well as many other significant watersheds. The study was designed to support the development of collaborative and strategic plans for implementing several recommendations contained in the Western Governors' Association (WGA) 2006 report "Water Needs and Strategies for a Sustainable Future." Reclamation and USACE worked closely together on the tasks related to federal infrastructure, and also on a pilot study led by the State of California to explore reservoir regulation.

The pilot study was particularly important because numerous studies since the mid 1980s showed that impacts from climate variability and change were particularly significant to snow-dominated western mountain watersheds (Gleick 1986; Lettenmaier and Gan 1990; Dettinger and Cayan 1995; Service 2004; Reganda et al. 2004, Stewart et al. 2005; Mote et al. 2005). The observed impacts had serious implications for water management operations, especially the extremes of flood and drought. Because snow was prominent among the impacts (e.g., reductions in spring snowpack, earlier snowmelt and peak runoff, loss of glacial mass, increases

[3] http://www.usace.army.mil/CECW/Documents/cecwm/cra/pl_109-103.pdf

in streamflow in winter and decreases in streamflow in summer), there was a temptation by many to begin revising the projects' authorized reservoir regulation curves to respond to these changes.

But, decision-making by operating agencies like the USACE and Reclamation about reservoir regulation, particularly when flood storage is involved, requires careful study and consideration of project authorizations and other legal issues. Brekke et al (2009b) explored the use of risk-based planning to identify alternative operational strategies under climate changes and found that flood control constraints were critical in the development and evaluation of strategies. However, the pilot highlighted the need for further research on the role of flood constraints and potential study approaches.

3.1.2. *Widening Collaborative Activities.*

A second proposal team, though unsuccessful in obtaining funding for a planning study, nonetheless found success in developing new relationships and networks critical for climate change. This group intended to develop and test a multi-jurisdictional approach to improve the collaborative process for managing water resources in the Western United States in response to climate variability. They planned to build on existing networks through pilot studies in the Columbia and Sacramento-San Joaquin systems. The proposal included USACE district and Division contacts, a representative from the Washington Climate Impacts Group, a Regional Integrated Science and Assessment (RISA) Center of the National Oceanic and Atmospheric Administration (NOAA). Other federal agencies included in the proposal are Reclamation, the NOAA National Weather Service, the US Geological Survey (USGS); other non-federal governmental organizations include The Nature Conservancy, state partners such as California Department of Water Resources, and Canadian partners for the Columbia River project. Though the proposal was not funded, team members collaborated on a series of conference and journal papers (White and Vaddey 2007, Vaddey and White 2007, White et al 2006, Vaddey et al 2006). Team members also participated in reservoir operations studies in collaboration with the WSWS (Brekke et al 2009b).

3.2. DEFINING THE FEDERAL PERSPECTIVE

Over the past several years, Reclamation and USACE have made a intensive effort to encourage interagency activities related to climate change because they recognize that climate change impacts are critical to current and future water resources management, and that the challenges to water resource management posed by climate change cannot be effectively met by

one agency acting alone. One major activity was to partner with the two major water resources data and science agencies – USGS and NOAA – to examine the effects of climate change on US Federal water resources management agencies. This effort resulted in a jointly authored report titled *Climate change and water resources management—A federal perspective* (Brekke et al 2009a).

This document, published as USGS Circular 1331, is the first jointly prepared document by the four agencies, and features all agency logos and transmittal letters signed by leaders of all four agencies. It provides a uniquely federal view of climate change impacts, decision-making, climate change adaptation, and identification of gaps and needs. Case studies of planning studies using climate information are presented, as well as a review of paleoclimate reconstruction and downscaling.

3.3. DESCRIBING AGENCY CLIMATE INFORMATION NEEDS.

USGS Circular 1331 includes a table of knowledge gaps identified by water managers at a February 20–21, 2008 federal agency workshop addressing capabilities for incorporating climate change into western U.S. water resources management[4]. Knowledge gaps intended to drive future research and development scoping and framing were identified in two major categories: access to information and new capabilities. Water management users desired access to literature syntheses (both regional and application-specific) and climate projection data (particularly downscaled data). They also desired new capabilities to:

- Translate climate projection data into planning scenarios
- Assess the response of natural and social systems to climate
- Assess the response of operations and dependent resources
- Assess, characterize, and communicate uncertainties

This workshop, though initially focused on the western states, was the nucleus of the nationwide Climate Change and Water Working Group (CCAWWG).

CCAWWG was formed by Reclamation, USACE, NOAA and USGS in 2008 to work with the water management community to understand their needs with respect to climate change. A second goal of CCAWWG is to foster collaborative federal and non-federal scientific efforts address these

[4] See http://www.esrl.noaa.gov/psd/workshops/ccawwg/2008/ for more information.

needs in a way that capitalizes on interdisciplinary expertise, shares information, and avoids duplication.

3.3.1. *Describing Climate Information Needed for Long-Term Water Resources Planning*

In 2009, the CCAWWG began a two-phase process of identifying required capabilities, current capabilities and gaps associated with incorporating climate change information into longer-term water resources planning and then developing strategies to meet these needs. The operating agencies (UASCE and Reclamation), with additional input from the Environmental Protection Agency (EPA), Federal Emergency Management Agency (FEMA), and Federal Highway Administration (FHWA) prepared an assessment of user needs: *Addressing Climate Change in Long-Term Water Resources Planning and Management: User Needs for Improving Tools and Information*[5] (Brekke et al in review 2010).

This report provides a detailed discussion of the steps necessary to conduct resource management studies and hydrologic hazards evaluations, which are generally taken on the multi-decadal time scale; it also summarized knowledge gaps as they relate to these types of studies and to the list of gaps presented in Brekke et al (2009a).

New gaps identified included improved understanding and guidance (Table 1). Internal and external reviewers provided their perspectives on the user needs. Thirty respondents from seven federal agencies, one state, and one local government agency, and six nongovernmental agencies provided comments. Comment resolution will be conducted in June and July 2010 and the report is expected to be finalized in September 2010.This will be followed by a report presenting the views of the science agencies, led by NOAA and USGS, on how to meet the identified needs. USGS and NOAA are currently conducting initial planning activities on the science agency response.

[5] See http://www.usbr.gov/climate/userneeds/

Table 1. Climate information for long-term planning identified by UASCE and Reclamation (after Brekke et al in review).

Long-Term Planning Need	Description
Understanding	How to interpret observed historical climate variability and climate projections' simulated climate variability from daily to multi-decadal time scales[6]
	Synthesis of sea level projection information and guidance on consistent use in planning for all Reclamation and USACE coastal areas[7]
	How climate change could impact potential evapotranspiration, and how that is represented in watershed hydrologic models
	How source water quality characteristics depend on climatic variables, and how dependencies may evolve in a changing climate
	How climate and/or land cover changes will change watershed sediment yield, changes in sediment constituency, and the resulting impacts on water resources
	How climate, land cover, and/or sedimentation changes will affect river and reservoir ice-event potential
	How to improve skill in simulating long-term global to regional climate
	How institutional realities currently control socioeconomic responses to climate variability, and could control socioeconomic responses under a changing climate
Guidance[8]	Strengths and weaknesses of downscaled data and the downscaling methodologies
	Strengths and weaknesses of available versions of spatially distributed hydrologic weather data
	Appropriate methods to relate planning assumptions to specific classes of climate projections, when deciding how to use retained projections in planning
	How to make decisions given the uncertainties introduced by considering climate projection information

[6] See sections 3.3.1 and 3.3.2 in this paper
[7] See section 3.6
[8] See section 3.5

3.3.2. *Describing Climate Information Needed for Water Resources Adaptation Planning and Operations*

Water management planning, design, and operations also require climate information on the shorter time scale to guide sub-hourly to monthly, seasonal and annual decisions. USACE and Reclamation identified a need to improve capabilities to forecast and use climate variability involving fluctuations in climate conditions on these shorter time scales to enhance the ability of water managers and water users to plan short term-operations and water delivery schedules. To meet this need, CCAWWG is using a similar two-phase plan that includes a user needs report by operating agencies, followed by a report outlining a strategy to meet these needs by science agencies. Raff et al (in prep) are currently preparing a user needs document: *Use of Weather and Climate Forecasts in Near Term Federal Water Resources Management: Current Capabilities, Required Capabilities, and Gaps.* This document provides a review of the current uses of weather and climate in short-term decisions followed by an assessment of current capabilities and gaps. Special attention is paid to risk and uncertainty analyses and communication. The document is expected to be finalized in spring 2011 following internal and external review.

3.4. ADDRESSING NONSTATIONARY HYDROLOGY

One of the topics raised in USGS Circular 1331 was how to understand and incorporate nonstationarity concepts in planning and engineering design. Though engineers have long assumed a geophysical stationarity of hydrologic forces for making their long-range designs and plans, they also recognized that the assumption can be violated. Recently, Milly et al (2008) suggested that with climate change impacts increasingly being observed, it was now time to develop methods to deal with nonstationarity. This is particularly important in water resources management areas with a life-safety component such as flood frequency analyses and dam safety assessments. It is imperative that any new guidance be developed considering agency mission areas and needs to support consistent interagency interpretation and application.

In response to this identified need, USACE hosted a CCAWWG expert workshop on "*Nonstationarity*[9]*, Hydrologic Frequency Analysis, and Water*

[9] Stationarity is defined by Milly *et al* (2008) as "the idea that natural systems fluctuate within an unchanging envelope of variability", worked while we had factors of safety, now we recognize that global and climate change expand the potential future states beyond the past and must take a dynamic, rather than equilibrium view.

Management" in Boulder, CO during January 2010 (Olsen et al 2010b). The organizing committee included representatives from Reclamation, USGS, NOAA, EPA, the International Center for Integrated Water Resources Management, and Colorado State University. International experts on climate change hydrology from the United Kingdom, Poland, Japan, Canada and Greece joined members from the US academic community, and agency representatives from FEMA, FHWA, NRCS, US Forest Service, and Navy. Other attendees represented Denver Water, the western Governors Association, Manitoba Hydro, and Quebec Hydro.

Discussions during the workshop addressed whether assumptions of stationarity are valid, the use of different statistical models in nonstationarity conditions, trend analyses, how to use the output from global climate models (GCM), and how to treat uncertainty in planning, design, and operations. This will result in a special issue of the Journal of the American Water Resources Association, which is part of our approach to develop peer-reviewed, legally justifiable methods to support water management. Other workshop outcomes are to initiate mechanisms for a continuing dialog between water managers and scientists on methods to deal with the water resource-related effects of climate variability and uncertainty, and to formulate an action plan to produce practical guidance for water managers to develop, test, and implement methods. Reclamation and USACE will work closely to be sure the workshop outcomes result in usable information for the eater management community.

3.5. ASSESSING THE PORTFOLIO OF CLIMATE INFORMATION

Among the first problems identified by USACE and Reclamation was the large discontinuity between the available science on climate and climate change on one hand and the dearth of information for using that information or guidance appropriately in decision-making over important water-resources choices. In an effort to develop a consistent water resources management agency approach to this issue, they, along with the other CCAWWG agencies, planned a workshop for late 2010. The workshop (*Assessing a Portfolio of Approaches for Producing Climate Change Information to Support Adaptation Decisions*) will help characterize the strengths, limitations, variability, and uncertainties of approaches for producing and using climate change information to inform US Federal water resources adaptation planning and operations. The desired outcome will be a strategy to develop guidance that provides principles and approaches for assessing the strengths and limits of the various methods for producing and using climate information at specific choice-points. Ideally, the guidance will be structured to be flexible enough to apply to current

state-of-the-science information as well as to future developments as climate science moves ahead.

3.6. SEA-LEVEL CHANGE CONSIDERATIONS

USACE has had a sea-level change policy in place since 1986, incorporating information contained in the National Research Council's 1987 report *Responding to Changes in Sea Level: Engineering Implications*, a study supported in part by USACE. Following Hurricane Katrina, USACE identified a requirement to develop a standardized vertical datum and to update the sea-level change guidance. We developed new guidance on vertical control in collaboration with NOAA (USACE 2009a, b). USACE also updated existing guidance (USACE 2000) on sea-level change to reflect best available science in collaboration with NOAA National Ocean Service and USGS, plus numerous external reviewers (USACE 2009c).

The USACE (2009c) sea-level guidance applies to engineering and planning for all USACE civil works projects within tidally influenced waters, including new and ongoing projects. The updated guidance takes a scenario approach with three plausible futures considered. USACE considered the IPCC (2007) results as potentially too low to use alone for planning and design, despite the use of information obtained since 1987, since the IPCC results adopted a less-sophisticated approach to the dynamics of ice discharge from polar ice caps and do not reproduce historical trends in sea level rise. USACE is currently working on follow-on guidance on sea-level change impacts, responses and adaptation (as identified in Table 1 above). The interagency team includes a representative of Reclamation's Mid-Pacific Regions as well as NOAA, USGS, Navy, FHWA, and international experts.

Reclamation does not have specific guidance on how to plan, design, or operate projects impacted by changing sea levels. However, the Reclamation Mid-Pacific Region in 2009 commissioned a review of existing procedures in the Sacramento-San Joaquin Delta area[10]. The review cited the USACE (2009c) guidance, IPCC (2007), and sea-level change assessments conducted by California Department of Water Resources (CA DWR) and the CALFED Independent Science Board (CALFED ISB). Reclamation summarized the CALFED ISB position that IPCC 2007 should be considered as a minimum future condition, with upper bounds estimated using empirical modeling approaches such as Rahmstorf (2007). CALFED

[10] Levi D. Brekke, personal communication April 2010.

ISB noted numerical model weaknesses and limitations, and recommended that engineering design criteria address low-probability events. CADWR suggested a similar approach considering both global sea-level change and extreme events

4. Summary

Given the magnitude of climate change impacts facing water resources managers in the United States, collaboration is essential. With similar but complementary mission areas, the two largest water resources management agencies in the US, the USACE Army Corps of Engineers and the Bureau of Reclamation, are working together to develop a consistent approach to climate change adaptation. Beginning with basin-wide studies in the western US in 2006, an area particularly impacted by observed climate changes to snow-dominated watershed, they have partnered to address climate challenges by first identifying the issues, assessing user needs, and working to fill the user needs required for climate change adaptation. They joined with water resources science agencies to define the federal water resources management perspective, including user needs for improving tools and information supporting long-term planning and operations and assessing capabilities to use weather and climate forecasts in federal water resources management. They have explored the issue of nonstationary hydrology with respect to climate change through a workshop that will provide a basis for updated policies. They are also working with other water resources agencies to develop standardized methods to select decision-scale procedures from the sometimes overwhelming portfolio of climate information. Though much of the interagency collaboration centers on hydrology-related issues, the two agencies are also moving forward with guidance development for sea-level changes. USACE is committed to a consistent yet flexible national approach to climate change adaptation that recognizes the requirement to act now, and to adapt approaches based on new knowledge. We believe that this approach is one that can prove useful to others facing climate change adaptation challenges.

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