J13.8 **GAPS IN COMMUNICATING WEATHER AND CLIMATE UNCERTAINTY IN NEAR TERM WATER RESOURCES MANAGEMENT**

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1. INTRODUCTION

1.1 *Background*

As the two major water resources management agencies in the United States, the US Army Corps of Engineers (USACE) and the Bureau of Reclamation (Reclamation), along with their federal and non-federal partners, are responsible for the delivery of water and power on a daily basis, and the scheduling of deliveries over seasons and, in some cases, years in an environmentally responsible manner. This is accomplished using weather and climate information that inform decision-making in order to not only meet water, power, and flood control obligations, but additionally to communicate to stakeholders whose decisions depend in part on expected water supply. In order to meet this mission and facilitate water supply and delivery forecasts, it is prudent to continually evaluate the capabilities and opportunities for improving the use of weather and climate information.

In a changing climate, the uncertainty in a decision varies by the type of climate information that feed the decision. If water scheduling assumptions are based on assumptions of climate stationarity rather than a changing climate, then ultimately the decisions may not capture recent climate trends. Particularly vulnerable are the decisions that are fed by statistical models, which relate historic information to water supply and demand assumptions. Accurately communicating the uncertainty to the stakeholders – who must subsequently rely on the water schedule – is of upmost importance.

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1.2 *Purpose*

In 2007, Reclamation, USACE, the National Oceanic and Atmospheric Administration (NOAA), and the US Geological Survey (USGS) formed a nationwide Climate Change and Water Working Group (CCAWWG). Additional members from the Environmental Protection Agency (EPA), Federal Emergency Management Agency (FEMA) and National Aeronautics and Space Administration (NASA) have since joined the collaboration. CCAWWG was formed to work with the water management community to better understand their needs with respect to climate change, as well as fostering collaborative scientific efforts.

In 2009, CCAWWG developed a two-phase plan to identify research priorities and opportunities for collaborative work within an integrated water resources management and science agency framework. In the first phase, they prepared an assessment of current and desired capabilities and gaps associated with incorporating climate change information into longer-term water resources planning (Brekke et al. 2011). The science agencies will follow this assessment with a corresponding report containing a strategy for meeting the user needs identified. The second phase is meant to identify the capabilities and gaps as they relate to decisions with outlooks from days out to about two years. This is the objective of the report that concentrates on user needs for improving tools and weather and climate information for use in near term water resources operations and management, and is currently still in preparation. Similar to the first phase, a corresponding science agency report will be developed based on this report that will detail a plan to fill the gaps identified. This manuscript is based on excerpts from the yet unpublished second phase report on addressing weather and climate variability in near term water resource operational decisions and management (Soddell et al. 2011, unpublished manuscript).

CCAWWG has preliminarily identified gaps where current capabilities fall short of those needed for water resource operational decisions. One reoccurring theme throughout this process of identifying current capabilities, desired capabilities, and gaps in capabilities was the need to assess, characterize and communicate uncertainties and risks associated with weather and climate information. This manuscript will provide a general overview of the gap categories identified as part of this effort, with emphasis on the categories and gaps specifically associated with communicating uncertainties related to weather forecasts and climate predictions. This manuscript is also aimed at raising awareness for the report on user needs in short term water resource operations and management, and the process used to identify gaps in user needs. Keep in mind this report is still evolving and the final document is likely to develop further. Therefore, the information in this manuscript will likely be subject to further change before final publication of the short term document.

Lessons learned from a CCAWWG hosted workshop (November 2010) designed to "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" (CCAWWG, 2010) will also be utilized in the development of the short term document. Although this workshop concentrated on the use of climate *change* information, which includes climate *projections* and spatial *downscaling* that are more relevant to long term planning, some of the lessons learned are applicable to the use of climate information – such as information regarding *variability* and *predictions* that are more relevant to short term water resource operations. More information on the November 2010 workshop and CCAWWG interagency activities can be found at http://www.corpsclimate.us/docs/ccawwgportfoliowkshpsummaryv03.pdf and http://www.corpsclimate.us/interagencyact.cfm, respectively.

One of the take-away points from this workshop was the concept of needing to understand the decision requirements BEFORE identifying what sort of information feeds into those decisions. Each decision has a different timeframe, and how far you wish to look ahead and what you envision doing with that information, feeds back in to the type of weather and climate information you need to make those decisions.

1.3 *Audience*

The intended audiences for the phase two report are water resource managers within Reclamation and USACE, as well as other federal and non-federal partners and stakeholders who play a role in the flood control, daily delivery and multi-year scheduling of water in the US. An additional aim is to help bridge the communications gap between researchers and users, with the hope to guide more directed research suitable for water resource operations and management needs.

2. CAPABILITIES ASSESSMENT

2.1 *Overview of Decision Types*

Reclamation and USACE plan and manage water for two primary decision types: operational, which have decision timeframes of less than one day out to two years; and planning, which have decision time frames on the order of years to decades. USACE adds another operational decision type: disaster preparedness and response, which may have decision timeframes from sub-daily during emergency response, up to seasonal for disaster preparedness in the form of advanced measures.

2.2 *Water Operations and Scheduling Timescales and Related Decisions*

The focus of this document is limited to operational decisions that have timeframes from less than one day out to two years. This range of timescales can be divided into three sub-ranges:

1. Sub-daily to Two weeks: These types of timeframes are often used to develop daily to weekly schedules that serve weekly to one-month decisions of water delivery. Information at this time-scale is particularly important for disaster response or preparedness measures.

2. Two weeks to Seasonal: This includes monthly operations scheduling that are developed to serve multi-seasonal or annual decisions. Information at this time scale is important in determining seasonal and/ or reservoir allocations and regulation, and is necessary for disaster preparedness.

3. Multi-Seasonal: This includes multi-seasonal scheduling made to support annual decisions, and occasionally decisions out to two years. Information at this timescale is important in

determining seasonal/reservoir allocations and regulation.

Sub-Daily to Two Weeks

This includes sub-daily to daily decisions made for disaster response purposes, and daily to weekly schedules developed to serve weekly to one-month decisions of water delivery or for disaster response or preparedness measures. Weather forecasts out to 10-14 days are most frequently used on these timescales. Extended range temperature and precipitation outlooks of 6-10 days and 8-14 days are also utilized in order to forecast runoff, streamflow and river stage.

An example of near-term operations is the daily assessment of river stage and flows in a basin. Operational staff will assess any rises or falls in stage and increases or decreases in flow above and below operational reservoirs. Adjustments to reservoir gates may be made on a daily basis (a function of the reservoir and its purposes) to either increase or decrease flows out of the reservoir. These gate adjustments are typically made to meet multiple demand objectives including: (1) calls for water delivery to meet downstream agricultural or municipal demands or (2), specifically, for a quantity of water to be sent through turbines to meet hydropower generation. Operational constraints, such as environmental flows and potential flood flow management, are also taken into account, and can affect the extent to which reservoir gates are either raised or lowered.

Two Week to Seasonal Water Operations and Scheduling

Scheduling of water on a two week to seasonal time frame largely focuses on outlooks of water supply and demand. This includes monthly water operations scheduling that are made to serve multi-seasonal or annual decisions, including disaster preparedness measures. Water supply outlooks are typically provided as seasonal volume forecasts coupled with near term monthly forecasts. Water demand outlooks are typically represented as proposed water delivery schedules. The primary concern is balancing reservoir inflows with user demands. Schedules are developed to meet demand needs given user water supply forecasts.

The principal operational constraint considered at this timeframe is flood allocation storage, which is often a function of water supply forecasts and required downstream environmental flows. For many storage facilities with flood control requirements, the associated rule curves are designed to capture most, if not all, of the spring snowmelt runoff that is described by the water supply forecast. Environmental flow requirements should include in-stream requirements of water quantity and quality.

Multi-Seasonal Water Operations and Scheduling

Multi-seasonal scheduling made to support annual to two-year decisions. Multi-seasonal scheduling is informed through assumptions that the near future will represent the near past: There is not necessarily any skill in this assumption. Multi-seasonal scheduling is utilized in systems where the total system storage is usually in excess of the annual water supply. This allows for more flexibility between the current annual water year use and the carryover of water for use in the future. Multi-seasonal scheduling involves making operational decisions at different months throughout the year, while especially taking into account results of mid-term studies. These resulting operational decisions are largely influenced by water availability and supply and demand assumptions. Based on the outlook horizon, varying levels of uncertainty are present in these assumptions. For example, there is less uncertainty associated with the water supply and demand assumptions for the current month, than for a two-year outlook.

Examples of decisions associated with each timescale are described below and also shown in Table 1.

2.3 *Overall Framework for Major Decision Types in Water Resources Management*

Each decision type generally requires the initial gathering of historic weather and climate data. Depending on the decision type, weather forecasts from daily out to 14-days may also be utilized. Weather forecasts and climate predictions – such as extended range forecasts (6-10 day and 10-14 day), monthly (30-day) and seasonal (90-day) outlooks – are also gathered. Weather and climate information in the form of observations, forecasts and predictions are provided to Reclamation, USACE and other Federal water managers by agencies such as NOAA's National Weather Service (NWS), including the River Forecast Centers (RFCs) and Climate Predictions Center (CPC), and the Natural Resources Conservation Service (NRCS).

The next steps involve using the historic information, weather forecasts and climate predictions to forecast streamflow, runoff and river stage and to make assumptions about future water supply, demand and operational constraints that rely on the weather and climate. Precipitation and temperature outlooks, in particular, are important to forecast water supply and demand, particularly in the semi-arid to arid mid-west and southwestern regions (e.g., Colorado River Water Conservation District and Lower Colorado River Basin). It should be noted here that deterministic outlooks commonly yield or convey conservative, or what is perceived to be conservative, results or impacts. In the area corresponding to Reclamation's Mid-Pacific Region and Sacramento Districts, 7 to 30 day outlooks from the NWS and NRCS are used with forecasts of April through July runoff volumes to develop reservoir operational outlooks. Recent hydroclimatic information (i.e. observed or antecedent conditions) may also be used for similar purposes.

The next step involves using supply, demand and operational outlooks and constraint assumptions, along with water supply and demand forecasts, to inform a system simulation tool that describes the system operations at a specific timeframe given those assumptions and forecasts. In general, the outputs of the system simulation models are either optimum allocations to meet downstream requirements or probabilistic estimates of meeting target flows throughout the system. A decision is made for a future time period given some "refresh" cycle on that information to schedule water deliveries or system operations.

The next, and frequently final, step involves communicating scheduling decisions to stakeholders across the system, along with the risks and uncertainties associated with each systems operations timeframe. These risks and uncertainties will be estimated throughout all the steps.

2.4 *Step-by-Step Capabilities and Gaps*

The Phase I report on addressing climate change in long term water resources planning and management contains a good example of the process being used to identify current capabilities, desired capabilities, and critical gaps in the Phase II report. The Phase I report can be found on the Reclamation website at http://www.usbr.gov/climate/userneeds/.

Each of the decision timescales discussed above is informed by weather and climate information to shape supply, demand, and operational constraint assumptions. While this information is readily available, there is always a desire for higher quality information. Depending on the techniques used to integrate observations into weather forecasts and climate predictions, either within the water management agencies themselves or as clients of hydrologic forecast services, there is also a desire to know how these forecasts/predictions may be affected by a changing climate. Thus there are a number of key elements that are necessary to both assess climate and forecast information improvement possibilities, as well as to assess current information vulnerabilities to a changing climate. As they pertain to supply and demand forecasts and operational constraint assumptions, these key elements, along with potential vulnerabilities, capabilities, and gaps in knowledge, are described below for operational decisions as eight general categories or steps. These steps are:

Step #1: Obtain Observations and Compile Datasets;

This step specifically involves the measurement and organization of several different types of data, all of which cannot be described sufficiently here. There are a myriad of weather variables (current step), as well as weather forecasts (Step 2) and climate predictions (Step 3), that feed into models of the hydrological response to weather and climate forcings. A few of the most important variables include precipitation, temperature, humidity, winds, and solar radiation. Precipitation can be broken down into total rainfall, rainfall intensity, snow depth, along with any other type of precipitation that falls in the area.

In addition to weather, hydrological observations also need to be made in order to calibrate and validate the hydrology models used. Some of the major variables required are discharge rates, water levels, runoff, infiltration rates, soil moisture, and evaporation/ evapotranspiration (ET) rates.

Step #2: Generate and Utilize Weather Forecasts;

This step involves the generation of various types of weather forecasts to be used to inform outlooks of hydrological forecasts such as streamflow and runoff. Weather forecasts are typically used by the NWS to create streamflow and other hydrological forecasts. These are then used by operators and decision-makers to determine adjustments that need to be made to reservoir elevation targets.

Extended range temperature and precipitation outlooks (6-10 days and 10-14 days) produced by the National Weather Service (NWS) which can also be found on the Climate Prediction Center (CPC) website, providing an additional source of information on temperature and precipitation deviations from the climatological average that can be issued as both a “sensible” weather forecast and climate prediction (R. Mazur 2010, NWS, personal communication).

Step #3: Generate and Utilize Climate Predictions;

This involves the generation of various types of climate predictions to be used along with weather forecasts to inform outlooks of hydrological forecasts such as streamflow and runoff. As opposed to a weather forecast, a climate prediction is of a longer timescale. The term *climate prediction* is used in this document with respect to forecasts ranging from sub-monthly to two years. In addition, *climate projections*, generally based on different scenarios, are more “commonly used for longer-range predictions that have a higher degree of uncertainty and lesser degree of specificity” (AMS, 2000). *Climate projections* are more frequently associated with *climate change* scenarios associated with long term planning, rather than the *climate predictions* used for the shorter timescales associated with this document.

Step #4: Generate Runoff, Streamflow, and River Stage Forecasts;

This step involves using the weather forecast and climate prediction information from the previous two steps to model the resulting hydrological forcings and come up with some sort of outlook on streamflows. The resulting outlooks vary from 1-day to 2-years. This is the information the operators and decision-makers are particularly interested in. The models are physically-based conceptual models and are primarily by the NWS-RFCs to create forecast ensembles of a range of possible flows based on historic temperature and precipitation patterns. The hydrologic model is the same as the one used for daily forecasting (e.g. Sacramento Soil Moisture Accounting (SAC-SMA) Model coupled to the SNOW-17 temperature index snow model).

Step #5: Develop Supply and Demand Forecasts;

This step involves using a combination of weather forecasts, climate outlooks, and streamflow forecasts to make assumptions related to water supply forecasts. In addition, demand forecasts can also be affected by the amount of water available and by changes in the climate.

Water supply assumptions for sub-daily to monthly forecasts are often fed by information ingested from federal agencies, such as the NWS, who produce daily to multi-weekly predictions of streamflows. These predictions generally come in the form of water supply forecasts, which employ hydrologic tools to develop time sequences of runoff at desired locations. The resulting products vary from 1-day to 120-day forecasts and can either be ensembles of daily or monthly values, or a single best estimate, of streamflow at a location. The ensemble forecast traces are available from the RFC’s and are typically given on a weekly basis. The models used are calibrated to historical events with parameterization schemes that set constants for physical relationships such as potential evapotranspiration (ET) and infiltration. This information may be used to inform water supply assumptions, which can be used either for flood control or water storage allocation purposes. Note that many USACE projects are limited by authority to operating according to “water on the ground.”

Agricultural demand at the sub-monthly operational timescale is generally defined through sub-monthly scheduling decisions. Actual calls for water are coordinated with state and local agencies and/or irrigation districts and often reflect current and forecasted weather. Reclamation Mid-Pacific Region is also working on the use of potential ET estimates and measurements of actual evapotranspiration rates to further assess future demand assumptions. Demand assumptions at the intra-annual scale are often shaped through seasonal water supply forecasts. In addition, most reservoir operators typically look at historical demand and use that information to inform projected future demands. This is particularly true for operational timescales of over one year. These future demands, though, do not include uncertainty.

Step #6: Consideration of Operational Analysis and Constraints;

Operating constraint assumptions are similar to demand assumptions in that both physical and non-physical factors determine these assumptions. For USACE, reservoir regulation for a specific reservoir is based on the congressionally authorized project purposes, storage capacity and other over-arching local and Federal regulations and rights. For example, the principal regulating goal of a USACE flood reservoir is to reserve space to store flood waters when necessary, whereas reservoirs planned and constructed to support navigation (or other downstream needs) store water whenever inflow is greater than downstream needs. System operations are also guided by, and constrained by, environmental objectives, social values (e.g., recreation), and the maintenance of important ecosystems and species habitat. Accomplishment of these objectives also must occur within project authorities and projected climatic conditions.

Step #7: Assess and Characterize Uncertainties; and

There is a level of risk and uncertainty associated with each of the previous steps #1-6. Reservoir operators incorporate risk and uncertainty procedures in to their water operations. There is also additional uncertainty when it comes to policy. Reservoirs and dams have to operate within current laws and policies, but there is always the possibility of new laws and policies coming in to affect. These changes may affect water operations and must be considered.

A balanced water delivery system not only needs improvements in the various types of forecasts described in the previous steps, but also a standard method for computing and communicating the risk and uncertainty associated with each step. Step # 7 is concerned with how uncertainty is actually characterized, while the next step will deal with issues associated with the communication of uncertainty and risk to the stakeholders.

Uncertainty in operational outlooks depends on uncertainty in forecasts of water supply. The accuracy of water supply forecasts depends specifically on the uncertainty in hydrological forecasts, which in turn depend on the uncertainty in weather forecasts and climate predictions. It should be noted that operational outlooks do not solely depend on hydroclimatological predictions; in Reclamation they are also dependent on demand outlooks.

Step #8: Communicating Results and Uncertainties to Decision-Makers

Steps #7 and #8 are, in essence, the two most important steps, as computations of risk and uncertainty reveal where the most improvements in the process need to be made. There is no set number that can be assigned to any of steps #1-6, and it is a range of numbers that should be considered. In addition to being the most important steps in the entire process, risk and uncertainty are the least understood steps, especially in how they are computed and in the meaning of the final results.

2.5 Communicating Results and Uncertainties

The findings in this section were initially developed from a June 2009 Reclamation Workshop to Review Current Operations Practices focusing on Communicating Risk, Uncertainty and Incorporating Climate Information (see Jerla et al. 2010). As this workshop was Reclamation centric, many of the capabilities and gaps identified may not currently be representative of USACE needs. Since the final report will be a collaborative effort between multiple agencies, all information, including the technical steps, capabilities and gaps in knowledge are subject to change before the finalization of the document addressing climate variability in short-term water resource operations and management.

Current and Desired Capabilities

Presentations, spreadsheets, reports, and graphs are all commonly used by Reclamation and USACE when communicating with stakeholders. During the June 2009 Workshop, stakeholders expressed varying degrees of satisfaction with the methodology that Reclamation uses to communicate risk and uncertainty. However, nearly all stakeholders have requested, and continue to request, more information regarding uncertainty in Reclamation outlooks. In general, stakeholders would like to see increased communication regarding uncertainty on varying timescales (e.g. less than two weeks, seasonal and multi-seasonal timescales). Most stakeholders found the information regarding forecast uncertainty on RFC websites to be helpful.

Capability Gaps

Using information obtained during the June 2009 Reclamation Workshop, including stakeholder survey information; a number of major gaps related to the communication of uncertainties were identified by stakeholders. Their specific areas of concern included the need for:

- Better communication;

- Improved partnerships with between stakeholders;
- More interactive means of communication;
- Incorporation of stakeholder input into the display of information and data; and
- The development of common terminology, particularly common risk and uncertainty language.

Strengthening partnerships and working on better communication between stakeholders, operational agencies and science agencies – such as decision-makers, operations staff, forecasters, and researchers/scientists – is vital to understanding stakeholder needs and tailoring weather and climate information to user needs. Improving partnerships and communication will also help to facilitate a constant stream of information so as to improve stakeholder knowledge and to enhance the water operations decision-making process in preparation for updates and changes made to forecasts. This information should be obtained via more interactive means, and needs to go beyond what can currently be obtained from websites, namely giving users the opportunity to clarify the information they have received and to ask specific questions that will help improve the decision-making process. Improved communications with stakeholders will also provide users with information on where and whom they can direct their questions, helping to reduce gaps in knowledge.

Clearly defining the terminology used in the water resources management is extremely important, not only to allow stakeholders who have limited knowledge in this area an opportunity to understand what is being said, but also to allow scientists and engineers from varying fields (e.g. climatologists, hydrologists, meteorologists, etc.) to understand each other. Often different disciplines use the same terminology, but with slightly different meanings. For example, the contributing authors of this document struggled with how define terms. The small difference between interpretations has the potential to lead to misunderstanding and confusion. Establishing a common set of criteria, terminology and plain language for use in water resource management may help to alleviate misinterpretations.

3. WHERE WILL WE GO FROM HERE?

Following the same methodology as the earlier document addressing climate change in long-term water resources planning and management (i.e. Brekke et al. 2011, unpublished manuscript), a draft version of the document addressing gaps in meeting user needs for climate information in near-term water resources management will be distributed to various internal USACE and Reclamation offices, as well as other federal and non-federal organizations. Respondents from these organizations will be asked to prioritize their need for research on each of the gaps identified in the report, and will have the opportunity to comment more extensively on each of the gaps. This information will then be summarized and presented in the report.

4. CONCLUSION

Ultimately all water delivery schedules and operational outlooks are subject to uncertainty. That uncertainty is important both in the making of the schedule as well as communicating the uncertainty to the stakeholders who must subsequently rely on the schedule. In terms of operational constraints, much of the uncertainty has to do with policy, but legally little can be done except to consider how water operations would be affected by a new policy.

Areas for improvement in communicating uncertainty to stakeholders include the need for better communication; improved partnerships between stakeholders, researchers, and various agencies responsible for water resources; the use of consistent and common terminology; and stakeholders should have more input regarding the display of results.

5. DISCLAIMER

The information in this manuscript is based on an interim product, and is subject to change. CCAWWG exists as a collaboration between multiple agencies with differing missions. These agencies will continue to work together to identify current and desired capabilities and primary gaps according to their priorities, and it is likely the formal and finalized document will contain gaps different to what have been identified in the current dynamic interim document and subsequently presented here.

6. REFERENCES

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7. ACRONYMS

EPA	Environment Protection Agency
ESP	Ensemble Streamflow Prediction
ET	Evaportranspiration
FEMA	Federal Emergency Management Agency
FWS	Fish and Wildlife Service
NASA	National Aeronautical and Space Administration
NRCS	Natural Resources Conservation Service
NWCC	National Weather and Climate Center
RFC	River Forecasting Center
USACE	US Army Corps of Engineers

Plan Type	Schedule Period	Decision Outlook Period	Decisions Supported	Operational Constraints	Forecast Temporal Resolution
River Stage/Flow Assessment	Sub-daily to daily	Daily to Monthly	- Downstream agricultural and municipal demands - Hydropower generation demands - Disaster Response	- Environmental flows/Flood flow management	Weather: 24 to 36 hours
Water Supply Schedule	Monthly	Multi-seasonal to annual	- Users' needs vs. water available - Patterns, quantities, and types of crops to plant - Disaster Preparedness	- Flood allocation storage - Minimum downstream flows	weather: 7 to 14 days; climate: 6-14 & 30 days; runoff: seasonal
Water Delivery Schedule	Monthly	Multi-seasonal to annual	- Users' needs vs. water available - Patterns, quantities, and types of crops to plant	- Flood allocation storage - Minimum downstream flows	weather: 7 to 14 days; climate: 6-14 & 30 days; runoff: seasonal
Operating plans for systems where storage > annual supply	Seasonal to multi-seasonal	One year or greater	- Will water demands be met under surplus, normal, or shortage conditions?	- Flood allocation storage - Minimum downstream flows	runoff: seasonal

Table 1: Examples of plan types for each of the three schedule time periods along with information on decisions supported, operational constraints, schedule and input forecast temporal resolutions, and the input forecast spatial resolution (From Soddell et al. 2011, unpublished manuscript).