Short-Term Water Management Decisions

User Needs for Improved Climate, Weather, and Hydrologic Information

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14. ABSTRACT

This report is the second in a series of reports by the Climate Change and Water Working Group that identifies how to improve supporting information for water resources management decisionmaking, motivated by potential climate change impacts on water resources. Adapting to these impacts includes potential enhancements in water resources management decisions over the short term (less than 5 years) through improvements in monitoring and predicting hydrology, weather, and climate and through better use of currently available information. This report identifies how Federal agencies, along with state, local, tribal, and nongovernmental organizations and agencies, are working together to identify and respond to the needs of water resources management in the changing climate. The report describes short-term water management decision processes within U.S. Army Corps of Engineers (USACE) and Bureau of Reclamation (Reclamation), including how decisions are influenced by assumptions of short-term climate, weather, and hydrologic information. An operator use assessment characterized current information uses by USACE and Reclamation within their short-term water resource management activities. This assessment provides a foundation for identifying opportunities based on user needs and gaps in the currently available information. Needs are identified within four categories: Monitoring Product Needs, Forecast Product Needs, Understanding and Utilizing Information in Water Management, and Information Services Enterprise.

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Short-Term Water Management Decisions: User Needs for Improved Climate, Weather and Hydrologic Information

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Abstract

This report is the second in a series of reports by the Climate Change and Water Working Group that identifies how to improve supporting information for water resources management decisionmaking, motivated by potential climate change impacts on water resources. Adapting to these impacts includes potential enhancements in water resources management decisions over the short term (less than 5 years) through improvements in monitoring and predicting hydrology, weather, and climate and through better use of currently available information. This report identifies how Federal agencies, along with state, local, tribal, and nongovernmental organizations and agencies, are working together to identify and respond to the needs of water resources management in the changing climate. The report describes short-term water management decision processes within U.S. Army Corps of Engineers (USACE) and Bureau of Reclamation (Reclamation), including how decisions are influenced by assumptions of short-term climate, weather, and hydrologic information. An operator use assessment characterized current information uses by USACE and Reclamation within their short-term water resource management activities. This assessment provides a foundation for identifying opportunities based on user needs and gaps in the currently available information. Needs are identified within four categories: Monitoring Product Needs, Forecast Product Needs, Understanding and Utilizing Information in Water Management, and Information Services Enterprise.

A Joint Message from the Commissioner, Bureau of Reclamation; the Director of Civil Works, U.S. Army Corps of Engineers; and the Chief of the Hydrology Laboratory, National Oceanic and Atmospheric Administration:

Water resources underpin our quality of life and national economy. Climate change will add to the challenges we face in managing our water supply, water quality, flood risks, wastewater, aquatic ecosystems, and energy production. Close collaboration among water resource management agencies that provide operational information, as well as among stakeholders and the scientific community, is necessary to meet these challenges.

The Bureau of Reclamation, the U.S. Army Corps of Engineers, and the National Oceanic and Atmospheric Administration, as part of the Climate Change and Water Working Group, have developed this publication describing user needs for improved information and tools to meet these challenges for short-term water resources operations. We also acknowledge the other Federal and non-Federal water resource organizations and interest groups that have contributed their perspectives to this document. Invaluable comments and perspectives were contributed by the Western States Water Council, Southern Nevada Water Authority, Salt River Project, Water Utilities Climate Alliance, Central Arizona Water Conservation District, Metropolitan Water District of Southern California, and Family Farm Alliance, to name a few.

We hope that this document builds on the research roadmap published in the 2011 report *Addressing Climate Change in Long-Term Water Resources Planning and Management* and fosters closer collaboration among scientists and managers. We encourage the science community to rally behind these needs with collaborative research and development efforts to build the capabilities that are identified. We look forward to continued collaboration with the broad water resources community, including organizations such as the Department of the Interior Climate Science Centers, National Oceanic and Atmospheric Administration Regional Integrated Science and Assessment Centers, National Integrated Drought Information Service, National Science Foundation, National Aeronautics and Space Administration, and other Federal and non-Federal science organizations. As water resource management agencies and operational information service providers, we stand ready to work with the science community.

Michael L. Connor
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Steven L. Stockton
Director of Civil Works
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Chief, Hydrology Laboratory
NOAA National Weather Service

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Reclamation Reviews Provided by:

Reservoir operations groups from Reclamation's Great Plains, Lower Colorado, Mid-Pacific, Pacific Northwest, and Upper Colorado Regions

USACE Reviews Provided by:

U.S. Army Corps of Engineers Hydrology, Hydraulics, and Coastal Community of Practice Corps Water Management System Advisor Group

NOAA Reviews Provided by:

Northwest Central River Forecast Center

Ohio River Forecast Center

National Climatic Data Center

Pacific River Forecast Center

Independent reviews, perspectives in this report by representatives from the following organizations:

Non-Federal organizations:

Central Arizona Water Conservation District

Metropolitan Water District of Southern California

Southern Nevada Water Authority

Oregon Water Resources Congress

Northwest Power and Conservation Council

Western States Water Council

Salt River Project

Water Utilities Climate Alliance

Family Farm Alliance

Colorado Water Conservation Board

Association of State Dam Safety Officials

Other Federal water and water-related management organizations:

Natural Resources Conservation Service

NOAA Office of Hydrologic Development

Executive Summary

Background

The Bureau of Reclamation (Reclamation), U.S. Army Corps of Engineers (USACE), and National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) recognize that there is a critical need to identify potential enhancements in the development and use of monitoring and forecast information within short-term water resources management beyond the use of current hydroclimatic information (i.e., weather, climate, and water). Reclamation, USACE, and NOAA, along with the United States Geological Survey (USGS), formed an interagency working group, called the Climate Change and Water Working Group (CCAWWG), in 2007 (www.ccawwg.us). The group focuses on scientific collaborations to support water resources management in the changing climate. The scientific collaborations guide future policies, methods, and technologies by building on the foundation established by the 2009 USGS Circular 1331, *Climate Change and Water Resources Management: A Federal Perspective*.

CCAWWG is identifying, in an iterative and ongoing fashion, both the needs of the water resource management agencies in the changing climate and the opportunities to address these needs. CCAWWG is accomplishing this objective through a strategy that identifies two critical timeframes of water resources management: short term and long term. Short term is defined in these reports as being relevant to management or decision outlook horizons of less than 5 years; long term pertains to longer outlooks. These timeframes are not independent. For example, short-term water resources management exists within a long-term planning and management framework that establishes the context in which hourly to annual decisions are made. To address each timeframe, CCAWWG is developing paired reports: the first identifies needs, and the second outlines a scientific strategy to address those needs. The organization of reports associated with the needs and scientific strategy approach is shown in Table E1.

Table E1. Reports produced in support of the CCAWWG effort.

	Water Resources Management Time Scale	
	Less than 5 years	More than 5 years
User Needs	Short-Term Needs (*this document*) CCAWWG leads: USACE, Reclamation, NWS	Long-Term Needs (January 2011) CCAWWG leads: USACE, Reclamation
Science Strategy	Short-Term Science Strategy (pending) CCAWWG leads: NOAA, USGS	Long-Term Science Strategy (pending) CCAWWG leads: USGS, NOAA

This document describes the short-term needs of the water management community for monitoring and forecast information and tools to support operational decisions. The context for the short-term operational decisions that are to be supported is that various Federal, local, state, tribal, and nongovernmental organizations work together to accomplish the goals and missions of the stakeholders they represent. These goals and missions represent various regulatory, legal, budgetary, and institutional frameworks that interact at various time scales of water resources management from long-term planning through minute-by-minute operations.

The primary audience of this document is the broad community of scientists and researchers who develop enhanced monitoring and forecast products that would support short-term water management decisions. This community includes CCAWWG member science agencies (NOAA, USGS, National Aeronautics and Space Administration [NASA]), other Federal entities (e.g., U.S. Department of Agriculture [USDA] Natural Resources Conservation Service [NRCS], National Science Foundation [NSF], state and local government agencies, and academic institutions). Additionally, the report targets participants in formal cooperative efforts, such as the (LCCs), Climate Science Centers, Regional Integrated Sciences and Assessments (RISAs), and National Integrated Drought Information Service. Some of these groups, and other national-scale entities such as the National Research Council and the National Academy of Sciences, have produced reports offering insight on topics related to those addressed here (for example, assessing the adequacy of our Nation's monitoring and prediction enterprises). This report augments and complements existing assessments but does not respond to them directly.

Assessment of Short-Term Water Management Needs

The short-term water management needs identified in this document are based on a "use and needs assessment" conducted with Reclamation and USACE water managers at all Reclamation Regions and USACE Divisions. The assessment categorized information supporting short-term water management as either a monitoring or a prediction (forecast) product, where monitoring products are observations of the current or previous state of the hydroclimate system, and forecast products are projections of the future state of the hydroclimate system. The responses from the use assessment were synthesized into statements of needs that will inform efforts to develop technologies, scientific capabilities, and operations or practices to meet these needs. The assessment responses and associated need statements implicitly recognize the balance and difference between decisionmaking processes, their evolutions, and the science and information that support those processes within the water managers working environments.

The assessment had three primary categories of questions. The first comprised questions about the appropriateness of this document's general characterizations of short-term water management relative to the management situations within the respondent's geographic region. The second centered on questions about what monitoring and forecast products are currently used within their geographic regions, why they are used, and how they are used within water management decisions. The third posed questions about operators' or managers' experiences with new sources of monitoring or forecast information and what new products would support local water resource decisions.

The current use of hydroclimatic information (Chapter 4 and Appendix C) reflects the diversity of water management missions and objectives, both geographically and with respect to the authorities of Reclamation and USACE. Notable themes of the use assessment responses include the strong ties between observations of streamflow, precipitation and water management, as well as official responsibilities and missions of the NWS, NRCS, and water management entities. These aspects are reflected in the use statements of USGS gauges, snow information, NWS official flow forecasts, flood watches and warnings, and NWS and NRCS water supply forecasts.

Need statements (Chapter 4 and Appendix D) synthesize responses about users' experiences with new sources of hydroclimatic information, and they reflect direct statements of product needs. Needs are identified within four categories: Monitoring Product Needs, Forecast Product Needs, Understanding and Utilizing Information in Water Management, and Information Services Enterprise.

Monitoring Product Needs

Monitoring product needs were found to focus primarily on observations of precipitation, snowpack, and streamflow. The needs emphasize the preservation and expansion of existing monitoring systems, which include USGS gauging stations, snow measurement networks, and rainfall gauges. These monitoring systems are identified as being critical to current and future short-term water management decisionmaking. Monitoring systems were also the primary emphasis of perspectives contributed as part of the review process by other Federal and non-Federal reviewers.

Forecast Product Needs

Forecast products identify water management needs with respect to anticipating future climate, weather, and hydrologic conditions. A general need exists to enhance the suite of available hydrologic forecast products from days to seasons to incorporate, or at least be consistent with, key operational weather and climate outlooks. Notable need statements also include making currently available precipitation and hydrologic (e.g., streamflow) forecast products more skillful and reliable. Expanding the geographic coverage of forecast products that aren't currently available for all regions was identified as a need, as well as developing new products that present a suite of hydroclimatic variables or parameters (such as evaporation from open water bodies, soil moisture, water temperature and quality, and ecosystem responses).

Understanding and Utilizing Information Products in Water Management

How products are understood or interpreted and then used for decisionmaking (in contrast to improvement of product information covered in the previous two sections) is the focus of need statements relating to understanding and using information products. Need statements are broadly categorized within four subsets. First, users expressed a need for better communication from forecast providers about the skill and uncertainty associated with available products. Second, practicing water managers need guidance on synthesizing the vast amounts of information available to them. The third and fourth notable needs relate to training resources. Training is identified as needed for nontechnical stakeholders who are not fully informed about water management missions and the policies that govern how information is utilized. Additionally, training is needed to better inform water managers of the principles associated with applying probabilistic forecast information to support risk-based decisionmaking.

Information Services Enterprise

The last category of needs draws attention to the private-public sector interface that provides and utilizes hydroclimatic information for short-term decisionmaking in water resources management. Notable needs include more support for maintaining and updating current forecast information, developing new forecast products, and developing more accessible product dissemination formats within existing water management tools.

Table E2. Synthesis of needs from the water managers' use and needs assessment.

Sub-category	Label	Needs statement
Category: Monitoring		
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions (including runoff and streamflow)
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow water equivalent
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States
Streamflow	M5	Preserved and expanded networks of streamflow observations with a focus on streams and rivers that are currently ungauged
Category: Forecasting		
General	F1	Enhanced suite of hydrologic predictions spanning lead times of days to seasons and consistent with the continuum of weather to climate forecast products
Precipitation, supporting fine-resolution outlooks	F2	More reliable quantitative precipitation forecasts (QPF) with lead times of hours to days
	F3	Improved precipitation forecasts for landfalling storms in coastal areas
Streamflow, supporting fine-resolution outlooks	F4	Enhanced streamflow predictions with lead times of hours to days, particularly during storm events
Streamflow, supporting medium-resolution outlooks	F5	Enhanced streamflow predictions with lead times of days to weeks, particularly during the snowmelt season
Runoff volume, supporting coarse-resolution outlooks	F6	Improved anticipation of runoff volumes with lead times of months to seasons
Water level	F7	Enhanced prediction products characterizing potential water levels during storm events
Other hydroclimate	F8	Multivariate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions with lead times of days to seasons
Category: Understanding and Using Information Products in Water Management		
Information on product development and qualitative attributes	U1	More detailed meta-information describing product skill, reliability, and development
Information synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations
water management and forecasting principles education	U3	Training resources on water management principles spanning multiple time scales
	U4	Training resources on probabilistic forecasting principles and risk-based decisionmaking
Category: Information Services Enterprise		
Product maintenance	E1	Support for product maintenance and evolution to accommodate new observations and research developments
Product format	E2	Development of product deployment formats that interface more readily with information systems commonly used in the water management community

Water resource management is carried out by a community of Federal and non-Federal entities, so it is important to put the needs statements developed by two Federal water management agencies (USACE and Reclamation) with NOAA-NWS in the context of other Federal and non-Federal perspectives. To accomplish this, CCAWWG distributed this document to over 50 additional organizations, inviting them to contribute perspectives. The overall perspectives contributed in response reinforced the needs identified by USACE, Reclamation, and NOAA-NWS. However, these perspectives also highlighted the geographic and mission diversity of water resources management. Large water resource systems that have primary goals of water supply have very different needs than do smaller systems that primarily serve flood control purposes. This complexity reemphasizes the value of this type of synthesis report to communicate broad, national-level water resource management needs as well as the local interactions between water resource management agencies and weather, climate, and hydrologic service and information providers.

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List of Acronyms

AAO	Albuquerque Area Office, Reclamation
AHPS	Advanced Hydrologic Prediction System
AO	Area Office, Reclamation
BCOO	Boulder Canyon Operations Office, Reclamation
CBRFC	Colorado Basin River Forecast Center
CCAO	Columbia-Cascades Area Office, Reclamation
CCAWWG	Climate Change and Water Working Group
CHPS	Community Hydrologic Prediction System
CPC	Climate Prediction Center
CVOO	Central Valley Operations Office, Reclamation
DST	Decision support tool
ENSO	El Niño Southern Oscillation
ESP	Ensemble Streamflow Prediction
ESRL	Earth Systems Research Lab
FEMA	Federal Emergency Management Agency
FEWS	Flood Early Warning System
FIPCCWDI	Federal Interagency Panel on Climate Change and Water Data and Information
GP	Great Plains Region, Reclamation
HEC	Hydrologic Engineering Center, USACE
HPC	Hydrometeorology Prediction Center
IRI	International Research Institute
IWR	Institute for Water Resources, USACE
KBAO	Klamath Basin Area Office, Reclamation
km	Kilometer
LAO	Lahontan Area Office, Reclamation
LCCS	Landscape Conservation Cooperatives
LC	Lower Colorado Region, Reclamation
LRB	Buffalo District, USACE
LRC	Chicago District, USACE

LRD	Great Lakes and Ohio River Division, USACE
LRE	Detroit District, USACE
LRH	Huntington District, USACE
LRL	Louisville District, USACE
LRN	Nashville District, USACE
LRP	Pittsburgh District, USACE
MAO	Montana Area Office, Reclamation
MP	Mid-Pacific Region, Reclamation
MVD	Mississippi Valley Division, USACE
MVK	Vicksburg District, USACE
MVM	Memphis District, USACE
MVN	New Orleans District, USACE
MVP	St Paul District, USACE
MVR	Rock Island District, USACE
MVS	St Louis District, USACE
NAD	North Atlantic Division, USACE
NAE	New England District, USACE
NAP	Philadelphia District, USACE
NASA	National Aeronautics and Space Agency
NCEP	National Centers for Environmental Prediction
NKAO	Nebraska-Kansas Area Office, Reclamation
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NWC	National Water Center
NWCC	National Water and Climate Center
NWD	Northwestern Division, USACE
NWK	Kansas City District, USACE
NWO	Omaha District, USACE
NWP	Numerical weather prediction
NWS	National Weather Service
PAO	Provo Area Office, Reclamation

PMF	Probable maximum flood
PN	Pacific Northwest Region, Reclamation
POA	Alaska District, USACE
POD	Pacific Ocean Division, USACE
QA/QC	Quality assurance/quality control
QPE	Quantitative precipitation estimation
QPF	Quantitative precipitation forecast
QTE	Quantitative temperature estimation
RD&D	Research, development and demonstration
Reclamation	Bureau of Reclamation
RFC	River Forecast Center
RISA	Regional Integrated Science and Assessment
SAD	South Atlantic Division, USACE
SAJ	Jacksonville District, USACE
SAN	Savannah District, USACE
SAW	Wilmington District, USACE
SNOTEL	Snow telemetry
SPD	South Pacific Division, USACE
SPK	Sacramento District, USACE
SPL	Los Angeles District, USACE
SPN	San Francisco District, USACE
SRAO	Snake River Area Office, Reclamation
SWD	Southwestern Division, USACE
SWE	Snow water equivalent
SWF	Forth Worth District, USACE
SWT	Tulsa District, USACE
UC	Upper Colorado Region, Reclamation
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USDM	United States Drought Monitor
USGS	United States Geologic Survey
WAO	Wyoming Area Office, Reclamation
WFO	Weather Forecast Office

WGA	Western Governors Association
WSC	Water Science Center
WSWC	Western States Water Council
WWO	Weather Watch and Outlooks
YAO	Yuma Area Office, Reclamation

Glossary

Actionable Science: Actionable science at the scales of decisionmaking includes the theories, data, analyses, and other information that are available, relevant, reliable, and sufficiently understandable to support multiple scales of decisionmaking, including capital investment decisionmaking. It is one output from "science translation" in which decisionmakers and science producers interact to describe the decisions and actions requiring science support and the relevant, reliable, and applicable science available for translation into that support (United States Global Change Research Program working definition).

Forecast Reliability: Reliability is a specific forecast verification metric that describes the accuracy of a forecast probability function—that is, the degree to which an event is observed with forecasted frequencies. For example, observations should verify in the interquartile range of a probabilistic forecast approximately 50 percent (%) of the time the forecast is made, and observations should exceed the 90^{th} percentile of a forecast only 10% of the time that the forecast is made. Forecast systems that fail to assign sufficient probability to outlying events (e.g., the outlying events occur more frequently than predicted) are called underdispersive or overconfident.

Forecast Skill: The "skill" of a forecast or forecasting system is used here as a general property related to the degree that a series of similar predictions from a forecast system offers more information than would otherwise be available (e.g., climatology, historical average, persistence). Skill as used here may not be attached to a specific metric (e.g., the correlation of forecasts with predictions, the hit rate for a categorical outcome, the percent improvement over climatology) but could be quantified by any specific metric as appropriate to a decision setting.

Forecast Uncertainty: Quantitative forecast uncertainty is a characterization of how different an actual event is expected to be from the forecast prediction across the entire range of result possibilities. Uncertainty is often based on the distribution of errors associated with a forecast system. The total forecast uncertainty includes cascading uncertainties throughout the forecast development process, including observed precipitation measurement, future weather assumptions, watershed state, and hydrologic modeling.

Institutional Decision Space: There are limits to the types and magnitudes of available decisions in any given scenario. Common constraints on water resources decisions include, for example, the congressionally authorized purposes of a water management project, institutional policies, regulatory restrictions (i.e., biological opinions and Endangered Species Act requirements), interagency and stakeholder agreements, and multiobjective decisionmaking concerns. The decisions available to the practicing water resources manager take into account all of these limits and institutional considerations and define the institutional decision space.

Lead Time: Lead time refers to the period of time between the issue time of the forecast and the beginning of the forecasted event.

Long Term: For hydrology and climate purposes, long term refers to 5-year to multidecadal time scales. Recent climate change is more relevant for outlooks shorter than 20 years; projected climate change is relevant for outlooks longer than 20 years.

Operational Outlooks: Operational outlooks represent the schedule of operational targets for reservoir storage, reservoir release, water deliveries, and other conditions that permit satisfaction of one or more water management objectives (e.g., flood risk reduction, water supply, ecosystems support, hydropower generation, recreation). Where management must satisfy multiple objectives, the objectives priority is initially determined by legal, regulatory, and institutional requirements (including service contracts); remaining prioritization occurs through management discretion. Outlooks can have different time resolutions, where resolution is defined by both the time-step of the target and the frequency with which the targets are updated. See the following related definitions:

- **Fine Resolution:** These operational outlooks serve decisions that apply for the coming hours to days and are typically resolved at the hourly to daily level, looking out from several days to up to a week. This type of decision typically deals with matters of emergency response, flood risk management, hydropower generation scheduling, and navigation.

- **Medium Resolution:** These operational outlooks serve decisions that apply for the coming days to weeks and are typically resolved at the daily to weekly level, looking out several weeks. This type of decision may deal with a broader set of operating objectives, including ecosystem support, emergency response, flood risk management, hydropower, navigation, recreation, water supply conservation (e.g., snowmelt management), and water delivery.

- **Coarse Resolution:** T hese operational outlooks are more common in Reclamation and other water supply management agencies than in USACE and other water resources agencies focused on flood risk management and associated emergency response. The outlooks serve decisions that apply for the coming weeks to months and are typically resolved at the monthly level, looking out several seasons (generally up to 1 year). This type of decision also deals with a broader set of operating objectives than do fine-resolution decisions, including ecosystem support (e.g., instream flow and water temperature requirements required for recovery of threatened and endangered species), flood risk management, hydropower, navigation, recreation, water supply allocation, and water delivery.

Update Cycle: This term refers to the frequency of forecast issuance. Some forecasts may be issued at irregular time steps (e.g., flood-only forecast points).

Predictand: The predictand is the variable or suite of variables being predicted in a prediction approach. For example, in water supply forecasting, snow and accumulated precipitation are common predictors of future runoff, which is the predictand.

Resolution: The resolution is the time step or spatial unit of a forecast.

Risk Tolerance: All management decisions, given uncertain information, inherently involve an implicit or explicit definition of acceptable or tolerable outcomes, or risk tolerance, for project objectives that are often competing. For projects with a single authorized purpose, this can be a risk to a single type of potential threat. For projects with competing objectives, risks that constrain operations can be allocated to one or all objectives. Where there is a primary objective with secondary considerations, risk aversion may be the single motivation for meeting the primary objective. For example, a flood control facility has a primary risk aversion to flooding downstream within areas designated as flood damage reduction locations. A secondary objective is to provide hydropower production. Under conditions where flooding becomes a possibility, the project will be operated in a manner that minimizes the probability of flooding without regard to the effect on potential hydropower production.

Short Term: For hydrology and climate purposes, short term refers to time spans from hours to 5 years. Short-term phenomena addressed in this report include weather events during subdaily to 2-week time scales, climate on longer than 2-week time scales, and hydrology across the entire span.

1 Introduction

The U.S. Army Corps of Engineers (USACE) (Figure 1) is the largest water resources operating agency in the United States. For more than 230 years, USACE has supplied engineering solutions for water resources needs, including navigation, flood and coastal storm damage reduction, protection and restoration of aquatic ecosystems, hydropower, water supply, recreation, regulatory, and disaster preparedness and response. The Bureau of Reclamation (Reclamation) (Figure 1) was established 107 years ago with a mission centered on constructing irrigation projects in the Western United States, many of which are still functioning today. Since its creation, Reclamation's mission has evolved to include hydroelectric generation, municipal and industrial water supply projects, water reuse, ecosystem restoration, dam safety, and the protection and management of water supplies. The National Weather Service (NWS) and its parent agency, the National Oceanic and Atmospheric Administration (NOAA), are the primary Federal weather, water, and climate forecast agencies. NWS's functions related to hydrologic monitoring and forecasting are carried out through a national network of River Forecast Centers (RFCs) (Figure 1).

USACE and Reclamation offer separate and complementary water management missions. While the purposes and objectives may vary by system, a common feature of each system is that it was designed to operate within an envelope of climate, weather, and hydrologic variability—also known as hydroclimate variability. Monitoring hydroclimate conditions and anticipating short-term variations in these conditions are a central part of USACE and Reclamation water management. Indeed, it is for this short-term time scale—from subdaily to interannual—where USACE and Reclamation make the most decisions. The processes leading up to these decisions often involve preparing short-term management outlooks that are constrained by authorized purposes and informed by a mix of considerations, including current system conditions, regulatory and institutional constraints, anticipated customer expectations, and consideration of current and forecast hydroclimate conditions. As for the latter, consideration of forecast information varies by agency and system in helping to influence short-term decisions, ranging from explicit, to subjective use, and sometimes to no reliance at all.

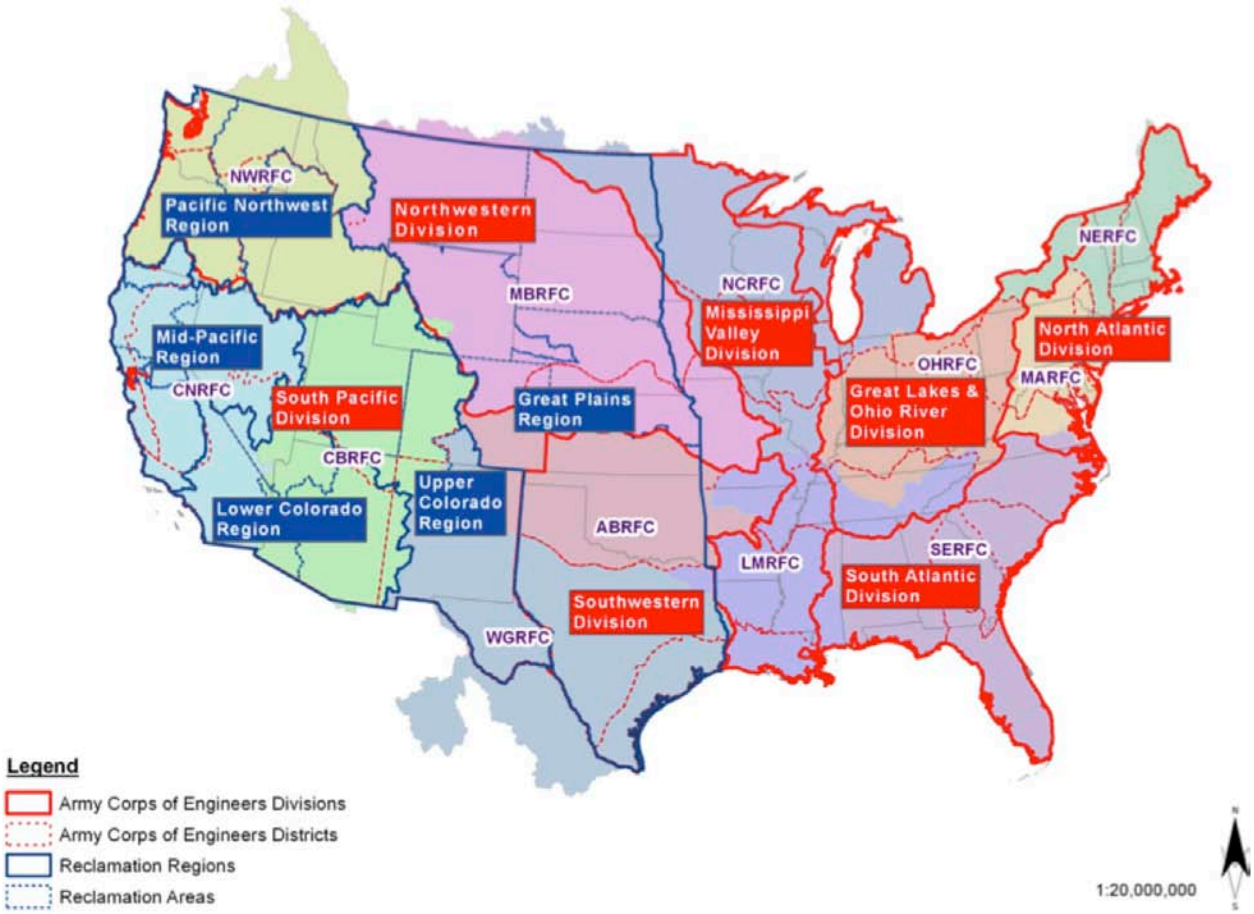

Figure 1. USACE, Reclamation, and NWS RFC geographic units in the contiguous United States. Administrative units in Alaska, Hawaii, and the United States (U.S.) territories are not shown.

The practices used by USACE and Reclamation to develop short-term water management outlooks and associated decisions have been well established over the decades. Complementing these processes is a network of Federal hydroclimate monitoring and forecasting services, led by NOAA's NWS, the U.S. Geological Survey (USGS), and U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS). These forecasting agencies share a long history with management agencies, providing them with a variety of services and products that are meant to be flexible in serving a multitude of management needs.

Both management and forecasting agencies recognize that management agencies currently utilize only a share of the hydroclimate monitoring and forecasting products currently being created by forecasting agencies. The reasons for this are many, including perceptions about product skill and reliability, lack of understanding about the potential decision-support value of the available information products, and limitations in the management agencies' capacity to consume and utilize such products during development. Additionally, decisionmaking processes within Federal and non-Federal agencies are established and evolve in conjunction with management needs and new technologies. Adoption rates and incorporation the development of new information exist in conjunction with these decisionmaking processes.

This document explores these situations and limitations, with the goal of ultimately describing the needs of water managers and operational hydroclimate service providers as they collectively work toward improving short-term water management decisions. It is envisioned that the needs discussed in this document may lead to research, development, and demonstration activities focused on both the improved use of existing hydroclimate monitoring and forecast products by management agencies and the development of superior quality products that might be made available through the forecasting agencies. To that end, this document provides an overview of management agencies' short-term decisionmaking processes as they vary from fine to coarse resolution in the short term, a summary of how hydroclimate information influences these processes, and a description of how current practices in both management and forecasting agencies present challenges and opportunities toward improvement.

1.1 Identifying User Needs

The development of this document was led by three agencies (USACE, Reclamation, and NOAA) from the Federal Climate Change and Water Working Group (CCAWWG, whose background and activities are described in Appendix A), which also includes USGS, the U.S. Environmental Protection Agency, the Federal Emergency Management Agency (FEMA), and the National Aeronautics and Space Agency (NASA). Born initially out of recognition for how climate change can have important impacts on water resources management (Milly et al. 2008; Brekke et al. 2009), CCAWWG has broadened its focus to include hydroclimate variability impacts on water management, considering time scales from days to decades. A primary concern of USACE and Reclamation with respect to these impacts is to protect the enormous Federal investment in water resources by enhancing the resilience of water infrastructure (built and natural) and by reducing their potential vulnerabilities to the effects of these impacts. Both agencies must, therefore, understand and respond effectively to hydroclimate change and variability.

CCAWWG operating agencies require "actionable science" (see Glossary) to improve decisionmaking in the climate change and variability context. While operating agencies continue to use available hydroclimate information to support short-term water management decisions, scientific activity continues to improve knowledge, methods, and tools; and it holds the potential to continue offering improvements. Given this opportunity offered by the science community, it is incumbent on the operating agencies to carefully describe their own user needs and information gaps to the science agencies to inform research and development activity that might address gaps and lead to developing information deemed useful (actionable) in decisionmaking.

Recognizing this situation, CCAWWG agencies have worked together to better characterize user needs and science response strategies on two primary decision time scales—long term and short term (Table 1). These scales recognize a continuum of water resources decisions ranging from long-term planning of Federal investment for infrastructure and planning of water supply and hydropower contracts to short-term operations including allocation and management of available water supplies, flood fighting, and emergency response.

Table 1. CCAWWG time-scale categories for identifying user needs related to climate, weather, and hydrologic information in water resources planning and management.

User need category	"Look-ahead" time scale of water resources planning	Relevant climate, weather and hydrology information
Short term	Less than (<) 5 years	Weather and hydrology during subdaily to multiweek time scales; hydrology and climate on monthly to annual time scales
Long term	Greater than (>) 5 years	Hydrology and climate on annual to multidecadal time scales; recent climate change is more relevant for look-aheads < 20 years; projected climate change is relevant for look-aheads greater > 20 years

1.1.1 Management Context

Short-term water management decisions occur in a coordinated fashion across multiple time scales. Management occurs to satisfy multiple objectives. The priority of objectives is initially determined by legal, regulatory, and institutional requirements (including service contracts). Remaining prioritization is with management discretion and is driven by the goal of achieving mission responsibilities in an economically efficient and environmentally responsible manner.

Some decisions are meant to apply only for the next few days. Others are meant to apply for the next month or so and may be influenced by anticipated system conditions well beyond that timeframe. To illustrate, consider a hypothetical reservoir that serves multiple objectives. Let's assume that the reservoir serves three primary objectives: (1) store and later release water to support irrigated agriculture in a downstream valley, (2) release water in a timing pattern that supports downstream fisheries and aquatic ecosystems, and (3) reduce downstream flood risk during the cold season by reserving empty storage space that may be used to capture runoff during significant storm-runoff or snowmelt events. The last objective is set up because the reservoir happens to sit above a well-developed community and below a snow-dominated basin that frequently experiences rainfall-runoff or rain-on-snow storm events during the cold season.

Now let's consider management of this system. Based on a mix of drivers (e.g., legal, regulatory, stakeholder requests for information about future operations), the operator must continuously evaluate how the multiple objectives will be satisfied during the coming days, weeks, or months. This evaluation involves assessing current basin and system conditions, anticipating future hydrologic events, and anticipating future system performance expectations with respect to each objective. The evaluation leads to developing an operating plan of action that is applicable to the coming days, weeks, or months. This plan of action, referred to here as an operational outlook, describes operating targets through time for various system conditions (e.g., storage, reservoir releases, deliveries) that, if met, would permit the satisfaction of overarching objectives (e.g., providing sustained flood risk reduction service during the cold season or maximizing water deliveries during the irrigation season).

The outlook actually may be a collection of multiple concurrent outlooks addressing the various operating objectives and playing out at different time steps for different schedule periods. To illustrate, let's assume that it is March 1, and the operator is dealing with two tasks: (1) prepare for and manage through a storm event during the next few days, and (2) issue an announcement to water users about what water supply allocation they can anticipate during the coming irrigation season. The operator makes a 5-day operations outlook with respect to the first task and a 7-month operations outlook for the second. Also, the operator makes a 6-week operations outlook that bridges the near-term storm response operations with the longer-term plan serving water supply allocations. While all three plans have operational targets for a variety of conditions, let's consider only the reservoir release targets for discussion purposes (Figure 2), which were developed as follows.

1. ***Providing flood control during the next 5 days*:** The operator inspects the precipitation and runoff forecast information received from the local NWS office. It appears that the reservoir watershed is going to experience a significant runoff event above the reservoir. Since the reservoir's stored water contents already happen to be at the

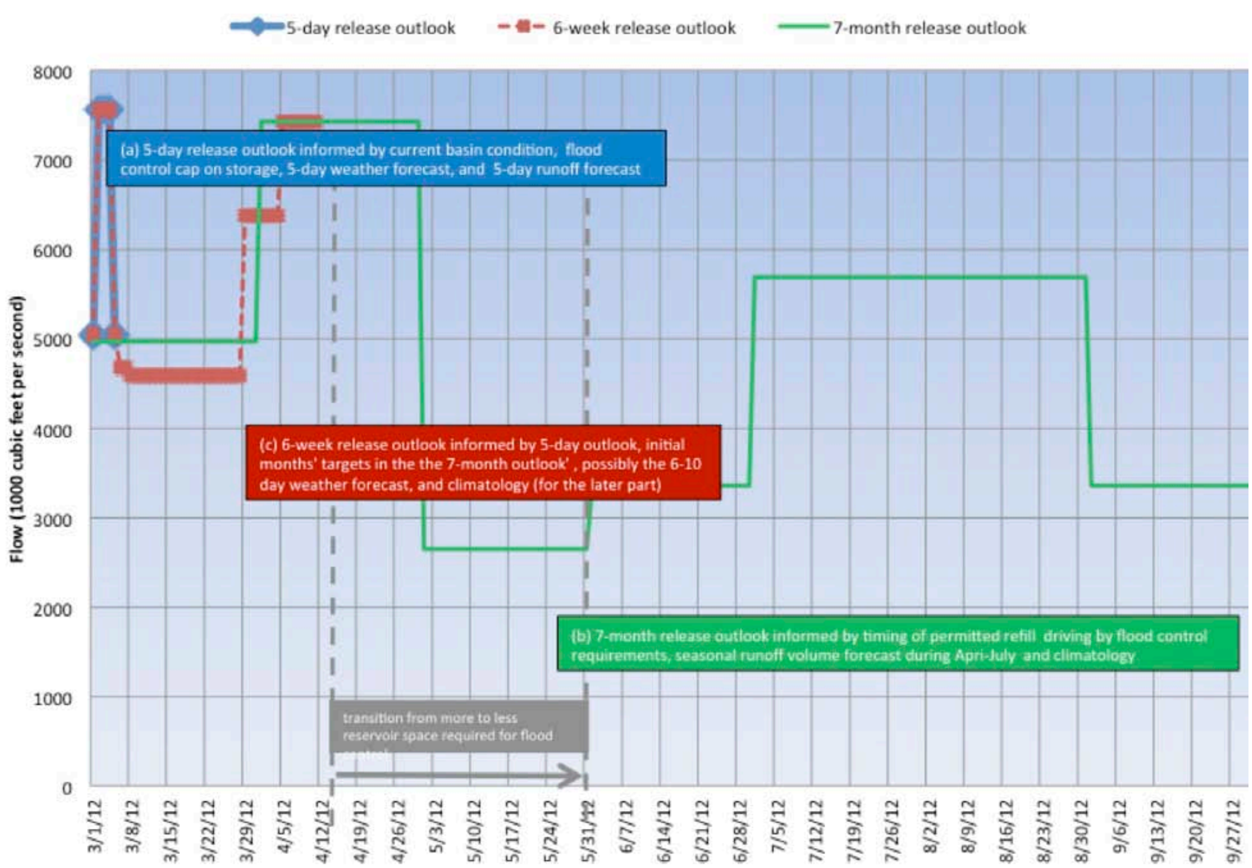

Figure 2. Hypothetical western U.S. reservoir, showing March 1 release outlooks for multiple objectives: (a) providing flood control during the next 5 days; (b) meeting irrigation delivery requirements during the coming summer; and (c) providing flood control and ecosystem support during the next 6 weeks.

"storage cap," it is apparent that any additional water storage will encroach on the empty space for flood control. However, given that this is deemed to be a flood-control event, encroachment into the empty floor-reserve space is reasonable. As such, the operator decides to control the storm runoff by planning to increase reservoir release flows during the next 5 days to pass a portion of the runoff while, at the same time, capturing the remainder of the runoff by filling some of the empty flood space. After the storm event, the operator intends to keep releases elevated until the surcharged flood space has been evacuated (see item 3).

2. ***Meeting irrigation delivery requirements during the coming summer:*** In addition to dealing with the upcoming storm event, the operator must address the water users' expectation of receiving water supply allocation for the coming summer months. This information helps the irrigation users make decisions on planting and related supplies. The operator responds by developing a monthly operations outlook for March—September, in this case, with the goal of shaping storage and release targets in a way that maximizes the summer water delivery to irrigation users. This outlook development is informed by several water supply, water demand, and operational constraint projections for the coming months. A key water supply projection is the forecast April–July seasonal runoff volume, which is largely based on the March 1 snowpack, the water year precipitation to date, and the historical relationships between those two indicators and the April–July runoff volume. A key water demand projection is the monthly pattern of water delivery requests submitted by irrigation users. A key operational constraint is the month-to-month amount of reservoir space that can be used for storage of runoff. This amount of eligible space increases during the transition from the cold season to the warm season as the need for empty flood control space reduces. This transition period tends to coincide with the peak snowmelt season and is sometimes referred to as the "reservoir refill" period, hypothetically shown on Figure 2 as April 15–June 1. In one sense, the operator is trying to maximize the reservoir refill by the end of the refill season in support of maximized irrigation deliveries during the months that follow. This helps to explain why the release rate is greater during April (when the snowmelt runoff increases but is not captured because there is still a significant empty space requirement), lesser during May (when the empty space requirement is significantly relaxed, leading to a more aggressive capture of snowmelt), and greater again during July and August (when irrigation demands are at their

peak, requiring the release of stored water). The monthly release targets change abruptly from one month to the next, but the operator refines the daily to weekly operation outlooks as the month boundaries approach (e.g., as illustrated by the 5-day outlook described above and the 6-week outlook discussed next).

3. **Providing flood control and instream flow support during the next 6 weeks:** While the 5-day outlook is meant to permit sufficient control of the storm-runoff event and the 7-month outlook is meant to support a water supply allocation announcement that maximizes deliveries given anticipated conditions, the operator also prepares an intermediate “weekly” operations outlook that bridges the 5-day and 7-month plans. The intermediate outlook is shown here as a weekly outlook evolving over the next 6 weeks. The outlook addresses how to ease reservoir storage back to within the flood cap. It also is formulated to consider any instream flow requirements meant to support ecosystem objectives during March and early April.

Several themes emerge from this example and are highlighted here to preview the decision process characterizations featured later in this document (Chapter 3):

- An operator of a reservoir system serving multiple objectives often needs to develop multiple, coordinated operations outlooks mapped to objectives playing out on different time frames.
- Each outlook is informed by a different mix of hydroclimate information (i.e., historical information, recent basin monitoring, weather and hydrologic forecasting) with different time and space characteristics depending on the outlook being supported.
- Each outlook exhibits a different time resolution of operational targets, which is affected by the time step of the targets (i.e., the daily, weekly, and monthly schedules of targets shown on Figure 2), the duration of the targets’ schedule (i.e., the 5-day, 6-week, and 7-month periods shown), and the frequency with which the targets are updated (e.g., not shown on Figure 2 but may be a rolling daily basis for the 5-day schedule or a rolling monthly basis for the 7-month schedule); the update process will be discussed further in Chapter 3).

Note that this example did not include other objectives common to reservoir operations, such as hydropower generation, recreation, or municipal water supply. Hydropower operations are interesting because they can involve their own set of multiple subobjectives playing out over multiple time scales (e.g., support of electricity grid management by scheduling hourly generation targets for turbine units over the next several days or support of energy portfolio planning by computing monthly generation targets during the coming seasons).

In summary, water managers make a collection of short-term water management decisions supported by operations outlooks prepared for multiple timeframes. The development of these outlooks is informed by a mix of monitored and predicted hydroclimate information products provided by a community of hydroclimate information services. The next section addresses this hydroclimate context, highlighting how weather and climate phenomena occur at different space and time scales and how their relevance varies with respect to a water management situation.

1.1.2 Hydroclimate Context

The various water resources management decisions for the short and long term require different information sets relative to the weather and climate continuum. The weather and climate continuum includes an array of interrelated phenomena that occur at different spatial and temporal scales (Figure 3). While Table 1 uses exclusive categories to discuss short- and long-term needs, the reality is that the management situations for these categories actually consider an overlapping continuum of climate and weather phenomena. For example, both short- and long-term decisions are concerned with phenomena spanning space scales that range from "micro" to "global" (Figure 3), but they differ in their time scales of concern. Long-term decisions are more apt to be influenced by assumptions about phenomena occurring over durations from days to decades, whereas short-term decisions are focused more on phenomena occurring over minutes to years.

Short-term decisions clearly encompass a wide area of weather to climate phenomena at varying geographic and temporal scales. Concerns within this area become sharpened when the focus is on specific operational goals of specific events, such as floods and droughts. Short-term management for periods of hours to days requires monitoring or prediction information about weather for these durations, including any extremes (e.g.,

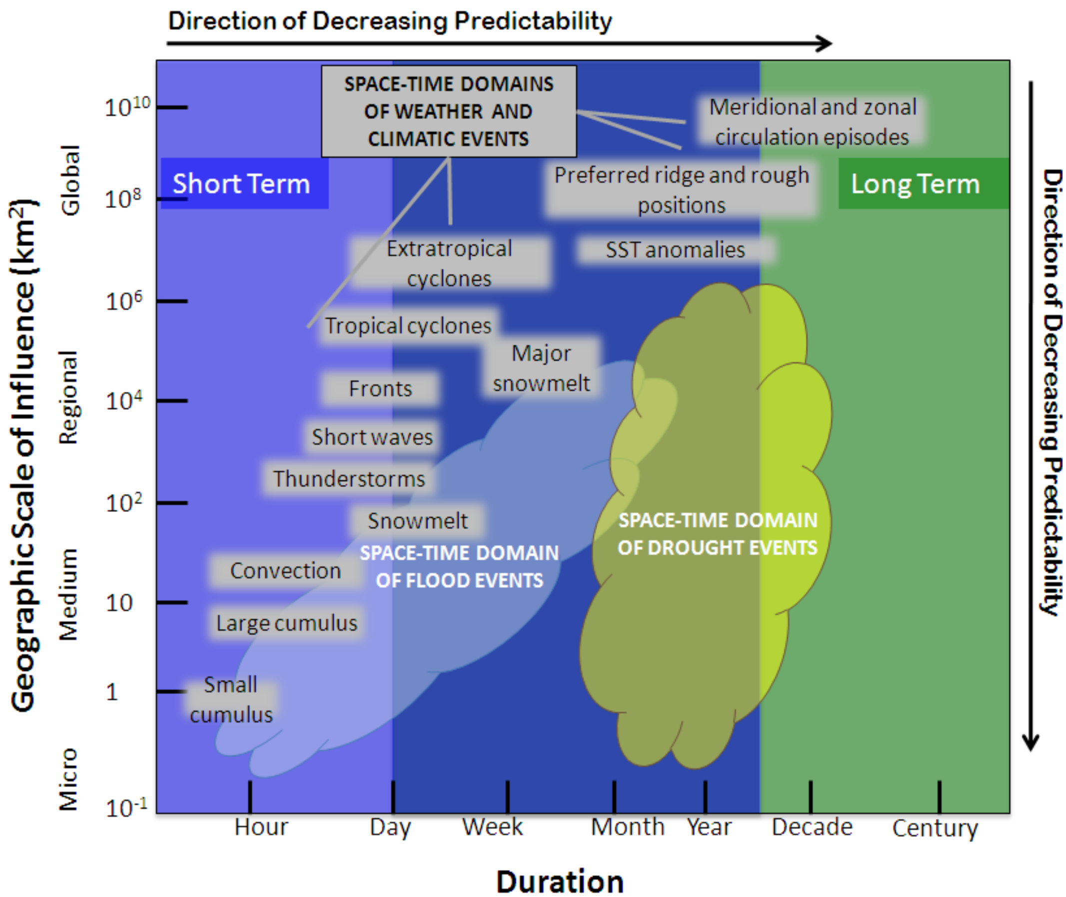

Figure 3. Space and time domains of climate and weather phenomena related to water resources management. (After Hirschboeck 1988.)

temperature minima or maxima, intense or long-duration precipitation) likely to impact water sector activities. Short-term management for days to weeks involves phenomena spanning the weather-climate boundary and may require information about snowmelt, weather fronts, and tropical and extra-tropical cyclones. Lastly, short-term management for months to years relies on climatic information on spatial scales that range from local to global and may consider sea surface temperatures and their influences on local weather patterns. The uncertainties associated with monitoring and forecasting these phenomena at these various time and geographic scales vary greatly.

Within this short-term hydroclimate context, the frameworks for developing operating plans and criteria share some commonality across systems within and across USACE and Reclamation. However, some aspects of plan development are system-specific, constrained by the given project's authorizations. The interface of local hydroclimate context and system-specific project authorizations sets up diverse use of hydroclimate information in water resources management. For example, projects planned and designed to reduce vulnerabilities and enhance life safety during a period of flood require short-term implementation information different from projects planned and designed to supply water in a consistent manner across a wide array of hydrologic conditions. USACE primarily supports navigation, flood risk management, and ecosystem restoration; and Reclamation primarily supports water supply and hydropower; so the two agencies utilize information in different ways. Geography also can influence the types and availability of information to support short-term decisions. Regional differences result from the particular governing physical, system, and socioeconomic processes within the regions, as well as from the different missions, authorizations, partnership/stakeholder agreements and regulatory regimes. Also, the precipitation and runoff characteristics important in short-term water management vary significantly across large hydrologic gradients, such as from the eastern to the western United States. This variation creates a wide range of management objectives and challenges and leads to a wide variation in the information available to meet them.

1.2 Methodology for this Needs Evaluation

Since the publication of USGS Circular 1331, CCAWWG has been involved in two processes to document user needs and science strategies. The first process focuses on the long-term time scale (Table 1) and is further along, with the needs assessment published through the USACE Corps Technical Work Series, titled *Addressing Climate Change in Long-Term Water Resources Planning and Management: User Needs for Improving Tools and Information* (Brekke et al. 2011); the science strategy documentation is currently in development. This document represents the second process, which has some connections to the climate change subject matter framing the first process (see the following text box).

This document considers a range of short-term water management decisions that are affected by hydroclimate conditions, ranging from recent conditions to predictions of hours to years. Compared to Brekke et al. 2011, the methodology for documenting short-term needs is similar in several ways to that used by CCAWWG (Brekke et al. 2009) to document long-term needs.

How Does Climate Change Relate to Short-Term Information Needs?

Climate change is not the central focus of this document, given that the short-term horizon is dominated by variability that is thought to derive from faster-moving climate system properties. Nonetheless, it connects to this assessment of short-term hydroclimate information needs in three ways.

First, climate change has the potential to affect how hydrologic prediction models serving contemporary water management are built and perform, particularly those that depend on historical weather, streamflow, and basin characteristics and data. Given the evidence of climate change or the low-frequency variability in the observed record, the applicability of older portions of these datasets can be called into question. The challenge of accounting for apparent hydrologic "nonstationarity" in water management practice was raised recently by Milly et al. (2008), among others.

Second, and also related to the issue of hydrologic nonstationarity, managers face the challenge of tracking and anticipating future changes in regional climate, hydrology, and water resources. This challenge is related to the topic of hydrometric monitoring. Although the focus of this document is primarily on monitoring, prediction, and operations improvements to support short-term water management, actions that enhance or improve monitoring networks now may lead to better recognition of projected climate change implications. These monitoring networks will be relied on to track hydroclimate change into the future. Understanding the fitness requirements of such monitoring networks is a need touted in Brekke et al. (2011).

Third, it has been suggested that water managers could increase their operational flexibility to adapt to climate change (Brekke et al. 2009). One pathway to increased flexibility is greater incorporation of short-term hydroclimate predictions, which calls for improvements in the predictions themselves as well as improved understanding within the user community of how to take advantage of probabilistic forecast information.

- First, the document aims to communicate the current state of practice in utilizing current and forecast hydroclimate information in short-term decisionmaking, just as Brekke et al. (2011) aimed to communicate current capabilities in utilizing climate change information in long-range water resources assessments.
- Second, the document aims to highlight priority areas of need that would inspire research, development, and demonstration (RD&D)

activities that serve to improve the hydroclimate information serving decisions and/or improve methods for incorporating that information. Hence, a primary audience for this document is the scientific and research community in a position to focus efforts that address information and tool gaps relevant to the water management user community.

- Third, the document provides two sets of perspectives on needs and priorities: those shared by USACE and Reclamation and those offered by other Federal, state, and local agencies.

While the methodology is similar to that used in Brekke et al. (2011), there are also some key differences.

- This document must represent the needs of many real, short-term planning and decisionmaking processes with different objectives, time scales, and resolutions (as will be explained in Section 3). By comparison, Brekke et al. (2011) was less burdened by the diversity of decision processes and only had to address the general situation of assessing climate change implications for water system performance several decades into the future.
- Another factor, and one having a bigger impact on the shaping of this document, is the existence of Federal hydroclimate monitoring and forecasting services serving short-term water management. USACE and Reclamation depend on many of these services (Chapter 3). To properly represent perspectives from this Federal forecasting community and perspectives of the water management community's experiences as customers of these services, this document reflects management perspectives on needs but with recognition of forecasting services and challenges voiced by co-authors representing the network of NOAA NWS and other Federal information service providers. In contrast, Brekke et al. (2011) reflected only the perspectives of management needs (led by USACE and Reclamation); no perspective on information services and challenges was offered because there is no operational "Federal climate projections service" that might be represented.
- Lastly, while this document's focus on time scales from days to years is arguably short relative to climate change, it is still relevant with respect to climate change adaptation. One pathway to enhance the adaptive

capacity of the water management community is to improve our ability to anticipate and prepare for hydroclimatic variations—including extremes—as well as our ability to manage through such events. Thus, communicating needs and promoting RD&D activities that lead to the improved use of existing short-term hydroclimate information or the development of superior information also would improve climate change adaptation fitness over the long-term.

2 Agency Roles in Short-Term Water Management

The short-term management of water resources in the United States is a complex interaction of agency mission responsibilities, legal frameworks, and stakeholder interactions guided by inherently uncertain information. Management missions include water supply, hydropower, navigation, flood management, and ecosystem restoration (Section 1), all of which are affected by hydroclimate variability. A complementary set of agencies has evolved to provide hydroclimate information services to support these management missions. Services include collecting and disseminating monitoring information as well as developing a variety of forecast products that vary by time scale and resolution.

Our degree of capability in anticipating climate, weather, and hydrologic conditions clearly affects our approach to water management. Efficient management of USACE and Reclamation water resources systems depends on being able to accurately characterize system and basin conditions and, to the degree forecasts are considered, to reliably forecast relevant aspects of climate, weather, and hydrology from days to years ahead. The manner in which this information is consumed by Reclamation and USACE differs according to differences in agency missions and project authorities, as this chapter will explain. However, a common body of information serves both agencies' missions and is put forth by a community of Federal forecasting services, led in part by the NOAA NWS.

This section provides perspectives from three Federal agencies representing these two communities: USACE, Reclamation, and NOAA NWS. For NOAA NWS, the discussion focuses on mission and responsibilities relevant to providing hydroclimate information to the management community. For USACE and Reclamation, the discussion focuses on missions, authorities, and general use of hydroclimate information to support short-term water management decisions.

2.1 U.S. Army Corps of Engineers

As the largest and oldest water resources operating agency in the United States, USACE (Figure 1) has supplied engineering solutions at a national scope to water resources needs for more than 230 years. USACE's congressionally authorized missions include navigation, flood and coastal storm damage reduction, protection and restoration of aquatic ecosystems, hydropower, water supply, recreation, regulatory, and disaster preparedness and response. Each year, USACE implements new water resources development projects on a cost-sharing basis with non-Federal sponsors, adding to the approximately 12 million acres of land and water resources under USACE jurisdiction.

USACE's infrastructure projects have the primary purposes of serving authorizations for navigation, flood control, or ecosystem restoration. All projects are operated in an environmentally sustainable manner, with secondary objectives that include hydropower, recreation, and water supply. Projects and programs also support disaster preparedness (including advanced measures authorized by Public Law 84-99), response and recovery, and regulatory responsibilities. USACE's reservoir operating plans are developed during the initial planning studies to provide flexibility to adapt to whatever flow conditions are expected (at the time of the studies) to prevail on a daily basis to meet the projects specific authorities (USACE 1982; USACE 1987). These operating plans may be included in the congressional authorizing language for the project development and, thus, may require an act of Congress to change. Additionally, planning for new projects or modifications to existing projects requires significant stakeholder interaction. In passing the Water Resources Development Act of 1986, Congress significantly changed the way USACE planners conducted studies by requiring that a greater share of project costs be borne by local stakeholders. This requirement empowers the stakeholders to play a larger role in decisionmaking, resulting in greater reliance on stakeholder input and increased emphasis on local and regional issues.

USACE is not authorized to deviate from the authorized water control plans other than through approved deviations and/or permanent changes in operating plans. The deviation approval process allows for temporary operational modifications during periods of unusual conditions. 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 the inflow is greater than the downstream needs. System operations also are guided by, and constrained by, environmental objectives, social values (e.g., recreation and cultural resources), and the maintenance of important ecosystems and species habitat.

Most USACE projects have the primary purposes of flood management and navigation and are limited by authority to decisions based on "water on the ground." Regulation is intended to be based solely on, for example, the water contained within a snowpack to define drawdown criteria on a specific date or on the water entering a reservoir to define release (e.g., match outflow to inflow). In both cases, operations are not authorized to be informed by externally prepared forecasts that incorporate precipitation. Hydrologic routing of observed riverflow or rainfall forms a short lead forecast of observed flood surges for points downstream from the observations and are utilized for flood control and navigation by identifying where "water on the ground" will be at a future point in time. However, in some cases, downstream stage forecasts that consider precipitation may be used in a conservative manner to reduce the probabilities of downstream flooding. Characterization of water resources for greater than 6-month look-ahead periods may help inform the development of the most likely higher and lower runoff scenarios. These characterizations guide the development of the long-range regulation plan and are critical with respect to stakeholder coordination and communications at that timeframe. Externally prepared forecasts can be used to request deviations from authorized rule curves; however, these must be approved, which is not common. Short-term forecasts may be used when advanced measures for flood risk reduction are authorized by Public Law 84-99 following a request by the governor of an affected state for USACE technical assistance. In this case, externally prepared forecasts may assist USACE in reducing the threat of unusual flooding through activities such as sandbagging, constructing temporary floodwalls, removing waterway obstructions, or preparing for ice jams or abnormal snowmelt conditions.

Day-to-day operations of existing projects are hard to change due to the congressional authorizations that have established the operating rules. New information that deviates from the initial project planning assumptions, such as a predicted extreme event that has low certainty (either a major flood, drought, or rapid early melt runoff), is not sufficient to alter existing operations. For example, relationships between snowpack and the timing of runoff that identify flood control rule curve objectives may alter in a changing climate, and the timing in a specific year could be informed through forecast methodologies. This, however, may not directly lead to operational modifications if rule curves continue to achieve their desired risk tolerances. Earlier snowmelt runoff without modification to the rule curves may still keep the flood control objectives at the authorized purposes for the project (e.g., 90% confidence interval of the 1% annual exceedance probability flood). Although other operations, such as water supply, may be impacted, this will not necessarily trigger new operations. This type of new information initially might affect new planning and/or re-allocation studies. However, some projects do have the authority or flexibility to adaptively manage operations to optimize certain targets, most often environmental.

2.2 Bureau of Reclamation

Established in 1902, the Bureau of Reclamation is best known for the dams, powerplants, and canals it constructed in the 17 western states. These water projects led to homesteading and promoted the economic development of the West. Reclamation has constructed more than 600 dams and reservoirs, including Hoover Dam on the Colorado River and Grand Coulee on the Columbia River. Today, it is the largest wholesaler of water in the country. Reclamation brings water to more than 31 million people and provides one out of five western farmers (140,000) with irrigation water for 10 million acres of farmland that produces 60% of the Nation's vegetables and 25% of its fruits and nuts. Reclamation is also the second largest producer of hydroelectric power in the western United States. Its 58 powerplants annually provide more than 40 billion kilowatt-hours, generating nearly a billion dollars in power revenues and producing enough electricity to serve 3.5 million people.

Today, Reclamation is a contemporary water management agency with a strategic plan outlining numerous programs, initiatives, and activities that will help the western states, Native American tribes, and others meet new water needs and balance the multitude of competing uses of water in the West. Reclamation's mission is to assist in meeting the increasing water demands of the West while protecting the environment and the public's investment in these structures. Reclamation places great emphasis on fulfilling water delivery obligations, water conservation, and water recycling and reuse; developing partnerships with our customers, states, and Native American tribes; and finding ways to bring together the variety of interests to address the competing needs for our limited water resources.

The majority of Reclamation projects have the primary purposes of water supply and hydropower generation. Whereas USACE uses the term "reservoir regulation" to describe its reservoir system management activities, Reclamation typically refers to such activities as "reservoir operations." Examples of operations decisions include establishing hourly reservoir releases to support hydropower generation objectives, establishing daily to weekly storage and release targets during the snowmelt season to support water supply conservation, supplying water allocations to multiple customers during the next season or year, and supporting ecosystem functions and values in accordance with biological opinions and other legal requirements on a seasonal and yearly basis. Similar to USACE, hydroclimate monitoring is included in the mix of information supporting short-term management decisions. Perhaps contrasting from USACE, it is more commonplace for hydroclimate forecast products also to be considered during outlook development. As Chapter 3 will discuss, the specific types of monitoring and forecast products, as well as the degrees to which these products influence decisionmaking, varies with decision purposes and types of operational outlook (e.g., types of operational targets, time resolution of scheduling these targets, duration of the scheduling period).

2.3 NOAA National Weather Service

NWS and its parent agency, NOAA, are the primary Federal weather, water, and climate forecast agencies. NOAA's mission, "to understand and predict changes in the Earth's environment … to meet our Nation's economic, social, and environmental needs," encompasses monitoring and prediction services as well as applied research to support and improve forecast services. NWS is the main agency within NOAA responsible for providing forecast services. As such, NWS has a long history of generating forecast services in support of many aspects of the Nation's economic and physical security. For water resources in particular, NWS has a long history of generating forecasts to support water management agencies whose mission responsibilities include both emergency management for flooding and reservoir storage for irrigation, navigation, recreation, and the environment.

Both NOAA and NWS are primarily service, rather than management, agencies. The NWS generates weather, water, and climate monitoring and prediction products from various specialized offices. Weather forecasts originate from the numerical weather prediction (NWP) infrastructure at the National Centers for Environmental Prediction (NCEP); scientists at the Environmental Modeling Center and Climate Modeling Branch develop and run climate and weather system models, from which the Climate Prediction Center (CPC) develops and produces a wide range of climate analysis and prediction products (including forecasts of drought, medium range [5- to 15-day] and seasonal forecasts). NCEP models include land, ocean, and atmospheric components that also generate real-time analyses and predictions of variables such as soil moisture and sea surface temperatures, which are used to derive predictions for water sector concerns such as drought and agricultural water management. Professional meteorologists at the Hydrometeorology Prediction Center (HPC) analyze forecasts from numerous centers around the world and manually (subjectively) produce national-scale weather forecasts and other specialized products such as hazard warnings. The 100+ Weather Forecast Offices (WFOs) analyze the HPC forecasts as well as a limited set of model forecasts from the United States, Canada, and Europe and produce weather and related (such as road condition) forecasts tailored to their local service areas. Streamflow forecasts are developed and produced by the 13 River Forecast Centers (RFCs). These forecasts and associated datasets support the flood watch and warning programs at the WFOs (i.e., text descriptions of flood risk) as well as go directly to water managers for use in reservoir regulations. Part of the flood warning program includes the establishing flood stages at river forecast points, an effort in which WFO staff collaborate with the relevant water and emergency management agencies to set flood stages against which river warnings are issued. RFCs use HPC and WFO weather forecasts to produce flood forecasts, and climate analyses and predictions from NCEP provide context for seasonal water supply predictions.

NWS also operates meteorological data collection networks and programs such as the Cooperative Observer network, which leverages a nationwide system of in situ meteorological stations, some of which are telemetered and some of which depend on manual data retrieval by volunteers. In addition to temperature, precipitation, and other near-surface observations, snow depth observations are used for hydrologic assessment, particularly in the eastern United States. A subset of the network contributes to long-term climate monitoring networks (i.e., the Climate Reference Network).

Additionally, a specialized center exists within the NWS for snow analysis (National Operational Hydrologic Remote Sensing Center [NOHRSC]), and a Water Science Center (WSC) is under construction, intended to house NWS, USACE, and USGS personnel and support RFC activities related to water resources and other missions. For the last decade, NOHRSC has provided nationwide gridded snow variable analyses and derived products to support real-time monitoring at RFCs and other entities (public and private). The advent of the Community Hydrologic Prediction System (CHPS; see Section 3.2) within the RFCs lately has facilitated the visualization of NOHRSC datasets in RFC operations, and NOHRSC is now in the process of applying North American Land Data Assimilation System- (NLDAS) based approaches for land surface modeling to expand the suite of hydrologic variables that they will produce operationally (a capability that will be housed at the National Water Center).

Within NOAA but outside of NWS, a number of research centers and programs (such as the International Research Institute [IRI], the Earth System Research Laboratory [ESRL], and Regional Integrated Science and Assessment [RISA]) programs conduct research into climate and streamflow prediction and may maintain quasi-operational services.

The NWS is staffed to issue regular forecast and warning products as required on a continual basis. Forecasts include single-value streamflow and river stage time series with look-ahead periods of several days into the future, ensemble streamflow forecasts with look-ahead periods of days to many months into the future, and various text products generally used for flood watches and warnings. The characteristics (update cycle, variables, lead times, formats, etc.) of forecasts and forecast products vary both regionally and seasonally.

The bulk of RFC monitoring and forecast products are produced by each RFC separately and are restricted to the RFC domain. A few exceptions exist, such as the national-scale water resources outlook Web site, which aggregates and attempts to standardize the presentation and delivery of water supply predictions and datasets across RFCs, providing, where appropriate, national coverage. Another cross-RFC product delivery system is the popular Advanced Hydrologic Prediction Service (AHPS) portal from which, for example, the national-scale datasets such as the multisensor precipitation estimate (MPE) can be obtained.

Coordination with water management agencies can play a key role in the utility and quality of forecast products. In many cases, forecast products have been developed or tailored to support the requirements of water management agencies through active and frequent collaboration between water management agencies and the NWS. In other cases, there is less connection between the NWS and water management agencies, leading to regulation-related uncertainties in simulation and forecasting for riverflows.

In recent years, the United States has seen the development of interagency efforts to implement hydrometeorological or hydroclimate prediction systems that go beyond the capabilities and scope of single NWS components such as the RFCs. For instance, the Green River Atmospheric Rivers Observatory, launched in response to dam safety concerns, deployed an atypically dense monitoring network for rainfall, atmospheric moisture, and other variables, in the area of the concern. The National Integrated Drought Information System initiative has attempted to support drought management by aggregating existing experimental and operational drought assessment and prediction datasets and products and deriving more regionally focused assessments from largely existing materials. Such systems are operational as well as experimental, and a perception that they are successful or offer useful information not present in traditional operational settings has generated interest in applying them to regional-scale hydroclimate challenges (mainly droughts and flooding).

Besides NOAA, prediction services relevant to water resources exist in other Federal and non-Federal agencies. The NRCS, for example, maintains the National Water and Climate Center (NWCC), which generates water supply forecasts in the Western United States in collaboration with NWS RFCs. USACE and Reclamation each have regional prediction capabilities themselves, for example, in the Columbia Basin and at some field-level offices such as the Yakima Field Office (Washington). State and local agencies such as the California Department of Water Resources and the Salt River Project also maintain prediction capabilities often in collaboration with NWS. Water-related centers such as the National Drought Mitigation Center in Lincoln, Nebraska, aggregate NOAA, NWS, and other agency and research information to generate monitoring assessments such as the U.S. Drought Monitor (USDM). Water managers contribute to efforts such as the USDM (e.g., by describing current reservoir contents) and use them in water decisionmaking (e.g., where the USDM drought category is a determining factor to declare a water allocation curtailment).

3 Short-Term Decision Processes and the Current Role of Hydroclimate Information

This chapter describes various types of short-term decisions. The goal is to illustrate how these decisions are informed by various operations outlook developments that address different time scales and resolutions and that are tailored to serve different decision purposes. Short-term management decisions are, in many cases, inherently different from those of long-term water resources planning. For example, long-term water resources planning decisions include infrastructure investments that define a particular system configuration constraining short-term management, establishing new institutional frameworks (e.g., international treaties, interstate basin compacts), establishing water and power service contracts, and establishing long-term criteria constraining other aspects of short-term operations (e.g., long-term adaptive management plans, operating criteria responses to biological opinions). Such long-term water resources decisions and how to incorporate climate change and hydrologic non-stationarity into such decisions are the focus of Brekke et al. (2011). Clearly, these long-term decisions affect short-term water management decisions in that they provide the framework within which short-term decisions are made.

This chapter begins with a general description of short-term decisionmaking processes and their attributes. That discussion is followed by a catalog of available hydroclimate information products that might be considered by operators when developing operations outlooks to support such decisions. Challenges associated with two potential areas of improvement are then discussed: the first concerns developing and serving hydroclimate information to the water management community and the second concerns using such information in water management decisionmaking processes.

3.1 Characterizing Short-Term Decision Processes

This section describes various types of short-term decisions and how they are informed by operations outlooks developed for different time scales and resolutions. The section also characterizes the process of updating these decision processes at various resolutions, highlighting the entry points of hydroclimate information during these updates.

3.1.1 Types of Decisions and Associated Operations Outlooks

As explained in Chapter 2, USACE and Reclamation share short-term water management responsibilities that are driven by separate but complementary missions and authorizations. Collectively, both agencies make a vast array of decisions that feature look-ahead considerations within the “short-term” time scale (Table 1). In addition, there are other Federal, state, and local water management entities making a similar array of decisions for water projects ranging from local to regional scale and with decision processes that vary according to agency missions and project authorities. The focus here is on the decisions that are informed to some degree by hydroclimate information. This section describes the scope of short-term decisions made by members of the greater water management community, particularly the context for how hydroclimate information is considered in each entity’s decision processes and the reasons that some information receives consideration while other information does not. To that end, this section characterizes short-term decisions relative to three types of operations outlooks (Table 2, Figure 4). The types vary primarily by their time attributes:

- ***Fine resolution***: These operations outlooks serve decisions that apply for the coming hours to days and are typically resolved at the hourly to daily level, looking out several days. This type of decision typically deals with matters of emergency response, flood risk management, hydropower generation scheduling, and navigation.

- ***Medium resolution***: These operations outlooks serve decisions that apply for the coming days to weeks and are typically resolved at the daily to weekly level, looking out several weeks. This type of decision may deal with a broader set of operating objectives, including ecosystem support, emergency response, flood risk management, hydropower, navigation, recreation, water supply conservation (e.g., snowmelt management), and water delivery.

- ***Coarse resolution***: These operations outlooks are more common in Reclamation and other water supply management agencies than in USACE and other water resources agencies focused on flood risk management and associated emergency response. The outlooks serve decisions that apply for the coming weeks to months and are typically resolved at the monthly level, looking out several seasons (generally up to 1 year.*) This type of decisions also deals with a broader set of operating objectives relative to fine resolution, including ecosystem support (e.g., water temperature management), flood risk management, hydropower, navigation, recreation, water supply allocation, and water delivery.

Table 2. Outlook attributes, including typical time aspects, decisions supported, objectives, and constraints.

Outlook type	Outlook duration	Update cycle, time resolution	Types of primary objectives[1]	Typical reservoir operation constraints[2, 3]
Fine resolution	Hours to days	Hourly to daily	Keep river stage between flood and minimum thresholds Shape reservoir release rates through time to avoid uncontrolled spill Set hydropower generation duty schedules	Initial water storage (reservoirs, basin wetness) Reservoir regulating curves Downstream control points for flooding Minimum and maximum flow constraints, including ramping rates (water rights, institutional, regulatory) Authorized navigation channel depth Water system capacities (reservoir storage, release, conveyance)
Medium resolution	Days to weeks	Daily to weekly	Shape reservoir release rates through time to maximize conservation of snowmelt runoff (spring-summer), to support fisheries habitat and migration, or to support water and power demand patterns	
Coarse resolution	Seasons to years[3]	Weekly to monthly	Shape reservoir releases rates through time to balance two goals: (1) maximize seasonal to annual water supply allocation for various demands and (2) keep end-of-year storage above carryover goal (relevant to systems that are vulnerable to multiyear drought)	

[1] Primary objectives vary by water system, geography, and time of year. Outlooks include scheduled aspects of other water system targets, including reservoir storage and releases and/or river stage and flows at various locations. These secondary decisions are made during the process of settling on primary decisions.

[2] Constraint types are common across the outlook resolutions, but their time resolutions vary just as the outlook resolutions vary.

[3] Most entities consider durations of a year or less.

* In Reclamation, coarse-resolution outlooks are typically prepared for look-ahead periods of 1 year or less except in the Colorado River Basin. One notable exception is the Colorado River Storage System, where a 24-month study is routinely developed. Although hydroclimate information informing the 24-month study has a look-ahead of 1 year and less (K. Werner, Colorado Basin River Forecast Center [CBRFC]), the vast storage capacity of the basin creates a situation where the initial system condition can significantly influence the anticipated year-two operations, even in the absence of year-two hydroclimate forecasts. Consequently, Reclamation develops year-two operations outlooks for stakeholders of this system.

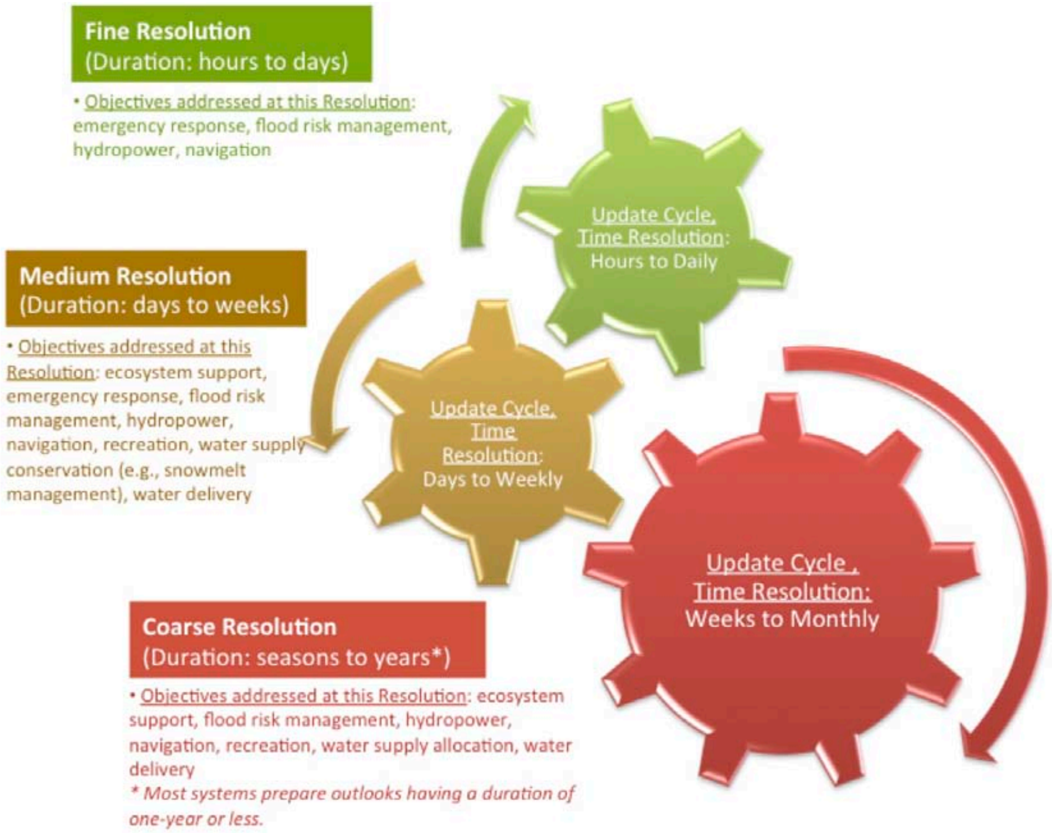

Figure 4. Nested short-term water management outlooks, from coarser to finer resolution.

Although the outlooks have clear differences, they also share several common attributes.

- First, each type is generally oriented toward a primary objective (e.g., flood risk management or emergency response at the finer scale; seasonal water supply allocations at the coarser scale) and involves shaping on a host of system control targets through time,* whereby operating relative to these targets is expected to achieve the primary objective. These targets are established in the context of uncertain current and future information (hydroclimate and otherwise) and are bounded by multiple constraints (Table 2).
- Second, each type of outlook and associated decision has a defined update cycle (Figure 4), described in further detail in the subsequent section. For some types of decisions, the cycle is perpetual (e.g.,

* Shaping refers to establishing a schedule of coordinated targets at water control structures, including reservoir storage, reservoir release, river diversions, and other operations at water control structures.

hydropower generation scheduling). For others, the decisions are updated during certain time windows of the calendar year (e.g., establishing water supply allocations for the coming warm season, initially during winter and with updates continuing into spring).

- Third, each outlook development and operations process influences the others (Figure 4). For example, Reclamation's coarser-resolution decisions often involve setting monthly mean targets for reservoir release and regulated riverflows with the goal of supporting a decision on seasonal to annual supply commitments. Medium-resolution decisions ensue at the daily to weekly scale (e.g., to serve submonthly operations related to ecosystem support, snowmelt management, and other objectives) and with thought given toward maintaining monthly flow and release targets established to support seasonal to annual supply commitments. This is an example of coarser outlooks influencing finer-resolution decisions. The reverse also can be true, as fine-scale events (hydroclimate and otherwise, anticipated or unforeseen) often lead to shorter-term decisions over hours to weeks that have accumulating effects, subsequently determining system conditions and influencing the next coarser-resolution update cycle.

Finally, in a poll of Reclamation and USACE operators (Chapter 4), all responses except one indicated that this framework of multiple outlook resolutions reasonably encapsulates their outlook development responsibilities. For the one exception, the commenting operator felt that there does not exist a single general framework that could adequately characterize the various operational and operations outlook situations faced by water managers.

3.1.2 Process for Updating Operational Outlooks

For each type of outlook, an update cycle occurs that generally features four stages (Figure 5):

- (Start of the cycle): Update the outlook's schedule of system water control targets and begin the operation relative to new targets until the next update.
- (Start of the cycle or shortly thereafter): Communicate the updated outlook, associated decisions, and associated uncertainties to water customers and interested stakeholders.

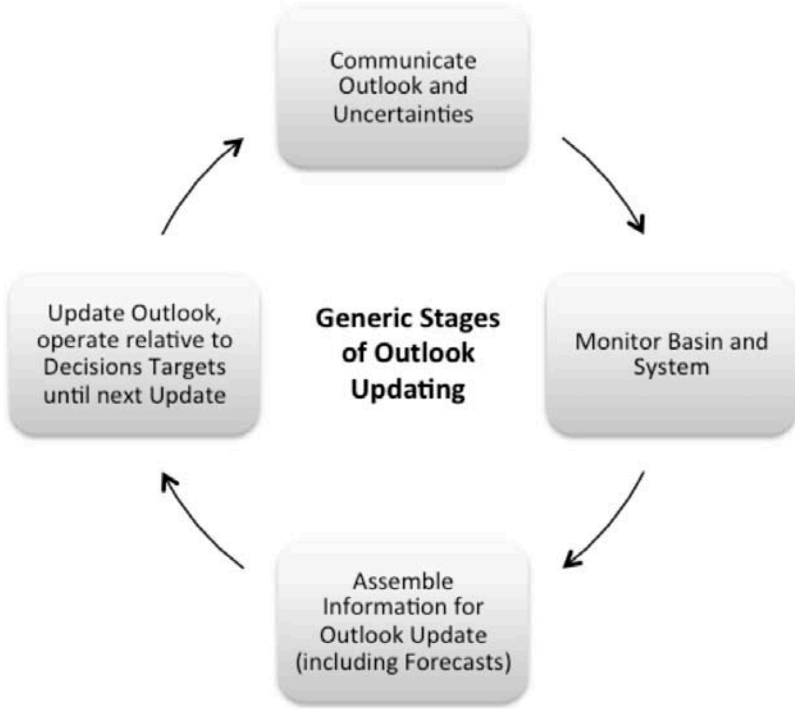

Figure 5. Generic stages of updating outlooks and associated decisions for any resolution.

- (During the cycle): Monitor the basin and system conditions.
- (Nearing the end of the cycle): Assemble information on the system conditions, anticipated service requirements (e.g., customer demands, operating constraints), and hydroclimate information (monitored and predicted) for the outlook update (including forecasts).

The resulting process is a repeating cycle of updating the operating targets and then implementing operations within these targets until the next outlook update, when new information on recent and anticipated system and basin conditions is considered. In some ways, this update cycle is similar to “adaptive management,” where system and basin monitoring informs “learning” that has taken place since the most recent decision (i.e., established outlook of operations targets).

Update types and cycles tend to be nested, meaning that finer-resolution outlooks are cycling inside the update period of coarser-resolution outlooks. To illustrate, consider the example shown on Figure 6, which illustrates a common forecast-informed situation for many Reclamation systems. The situation involves two decisions that are typically made for western U.S. reservoir systems in snowmelt-dominated basins serving

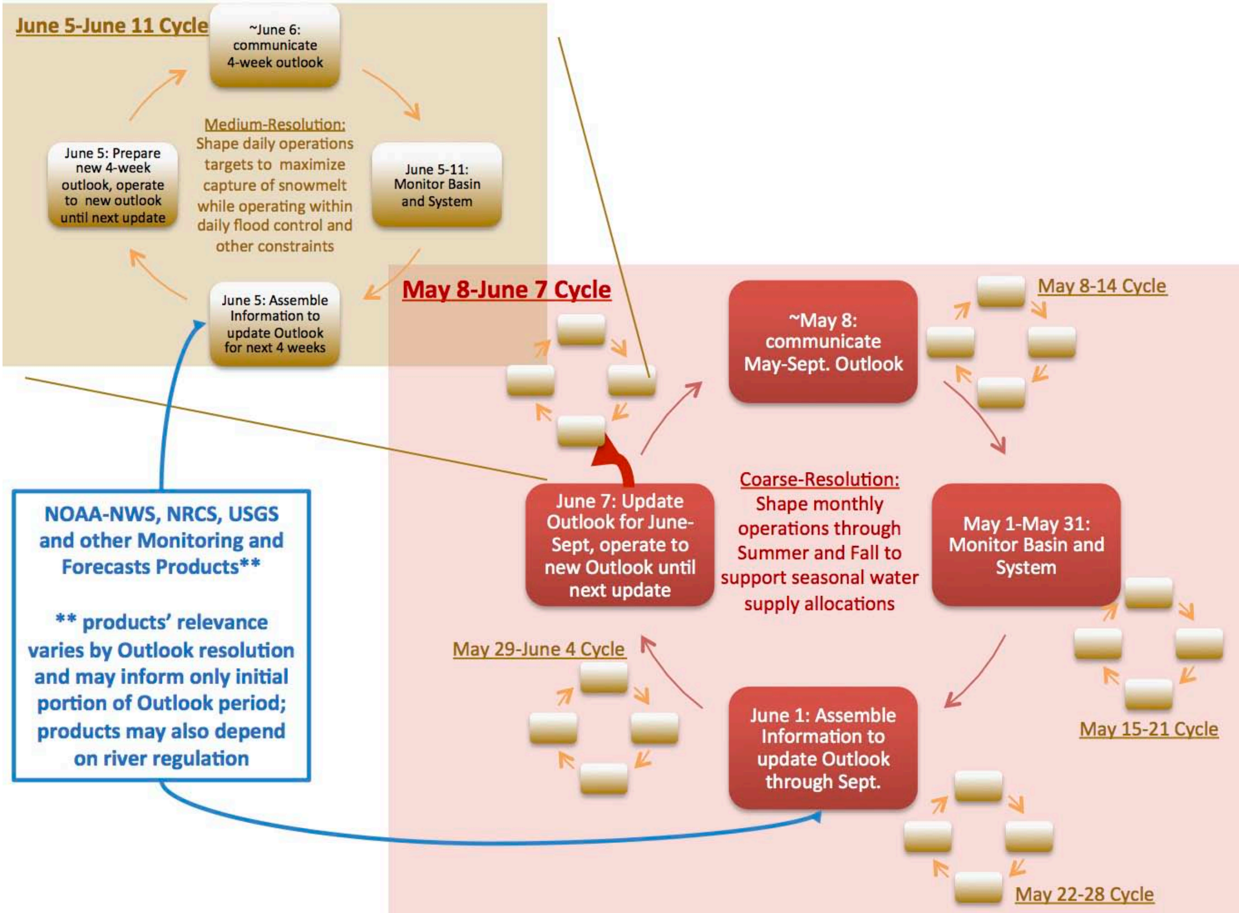

Figure 6. Example update process for Reclamation, showing two nested resolutions for May–June.

water supply objectives. The first involves making an early June update of the upcoming summer–fall water supply commitment issued in early May, based on new system and basin information gathered during May 1–31.* The second and medium-resolution decision occurs within the coarse-resolution update cycle (roughly May 8–June 7) and, for illustration purposes, at a weekly frequency. The second decision involves reconsidering and correcting water control targets to medium-resolution objectives,

* Reclamation aims to issue highly reliable supply commitments. During the winter months, early commitments on water supply tend to be conservative relative to available hydroclimate information. Entering spring and approaching late summer, two things happen: (1) the season unfolds, revealing actual outcomes of snowpack accumulation and melting, which was more uncertain during earlier winter months; and (2) Reclamation aims to increase supply commitments in response to the unfolding season and clarified snowpack/supply information. By early May, the snowpack/supply information leading up to the irrigation season is fairly certain. However, wetter and/or cooler than normal conditions during the month of May can lead to increased early June snowpack conditions that provide some opportunity to increase supply commitments in early June.

including maintaining storage space for flood risk management, maximizing snowmelt capture in support of seasonal water supply commitments, and meeting reservoir release requirements to support downstream environmental objectives.

These two nested cycles both resemble the general cycle shown in Figure 5 in that they each feature the four general stages. They differ in that the submonthly decisions served by the medium-resolution outlook are revisited on, roughly, a weekly basis during the single update period for the allocation decision served by the coarse-resolution outlook. This means that the four general stages of outlook updating, outlook communication, monitoring, and information assembly each occur roughly four times; nested within the single pass through, these four general stages serve the allocation-related, coarse-resolution outlook.

Both outlook processes involve the four stages described above and similar types of information. However, the exact nature and resolution of information differ according to outlook resolution. For example, consider the type of hydroclimate forecasts informing both decisions. The coarser-resolution decision mainly considers seasonal water supply forecast—also referred to as seasonal runoff volumes—informed by the current snowpack, the antecedent weather (and soil moisture development), and the cone of forecast-period weather possibilities based on past observations that ultimately drive the time pattern of runoff (i.e., combination of snowmelt runoff and rainfall runoff). These seasonal water supply forecasts are typically time-disaggregated to monthly reservoir and unregulated[*] inflow assumptions for the sake of developing coarse-resolution outlooks. The medium-resolution decision also requires hydrologic predictions for reservoir and unregulated inflows, but at a finer time resolution (roughly daily to weekly) and a shorter look-ahead period (maybe several weeks). Such hydrologic predictions also are based on current snowpack and soil moisture conditions. However, they also reflect NWS River Forecast Center incorporation of NWS weather forecasts into hydrologic simulations. Beyond a 6- to 10-day period, informed by precipitation forecasts, the cone of forecast-period weather possibilities based on past observations drives the hydrologic simulation for later weeks. The medium-resolution activity also involves more frequent querying of the basin snowpack to support more frequent updating of these multiweek daily-resolution hydrologic forecasts.

[*] For example, runoff into the managed system area from small streams and other tributaries having no control structures.

3.2 Available Hydroclimate Monitoring and Forecast Information

NWS and other agencies produce a suite of forecast and monitoring services and products with look-ahead periods ranging from hours to seasons. Many of these services and products are currently utilized in water management decisionmaking, while others could be used in the future. Within the NWS, forecast and monitoring services originate from different offices. As noted in Section 2.3, RFCs are primarily responsible for generating streamflow forecasts of different formats and lead times. NCEP, which includes CPC and HPC, generates national-scale weather forecasts and monthly to seasonal climate outlooks that support the RFC streamflow forecasting. WFOs rely on RFC streamflow forecasts to generate flood watch, warning, and outlook text products. In addition to NWS, agencies including NRCS, USGS, and others also maintain forecast and/or monitoring programs used by water management. Table 3 summarizes these services and products, classifying them according to the resolution described in Section 3.1 and identifying the agency or NWS office responsible for generating each product. Figure 7 shows the forecast services as a function of resolution together with their production dependencies.

Table 3. Monitoring and forecasting products and services relevant to water management.

Service	Resolution	Lead Time	Update Frequency	Originator	Description
Monitoring					
Precipitation monitoring, e.g., NOAA COOP, ALERT, U.S. Dept. of Agriculture Forest Service RAWS, CoCoRas, etc.	Various	NA	Various	Many, including NOAA, USFS, Reclamation, state/local government, private/ nonprofit sector, etc.	Both in situ (gauge reports) and remotely sensed (by radar and/or satellite) precipitation measurements are ingested into RFC and other precipitation analysis schemes. Additionally, many water management entities utilize and sometimes support “raw” precipitation data themselves in their management operations.
Snow monitoring – snow telemetry (SNOTEL) and snow course	Various	NA	Hourly to monthly	NRCS and some state/local government	NRCS snow survey maintains SNOTEL and snow course measurements in the Western U.S. and Alaska mountains that are primarily used for water supply prediction.
Precipitation analysis	Fine: Hourly	NA	Hourly	RFCs CPC	Real-time analysis of precipitation amounts at hourly or greater time steps are generated that combine gauge, radar, and satellite estimates of precipitation.

Table 3 (continued). Monitoring and forecasting products and services relevant to water management.

Service	Resolution	Lead Time	Update Frequency	Originator	Description
Stream gauging	Fine	NA	Subhourly	USGS	Real-time and historical stream gauge measurements.
Forecasting					
Seasonal outlooks	Coarse	Months to seasons	Monthly	CPC	Probabilistic forecasts for seasonal temperature and precipitation anomalies.
Quantitative precipitation forecasts	Fine to medium/ daily time step	5 days	Twice daily	HPC RFCs WFOs	Precipitation amount time series forecasts typically extending 5 or more days into the future at daily or subdaily time steps.
Weather prediction	Various	Days	Various	WFOs NCEP	NWS generates many weather forecast products at varying lead times and spatial resolutions that are used or may be used by water management agencies.
Official streamflow forecasts	Fine: Subdaily and point specific	5–10 days	Typically daily or when flooding is forecast	RFCs	Deterministic hydrograph forecasts issued either routinely or in support of flood fighting that extend five or more days into the future.
Ensemble Streamflow Prediction	Fine to medium: Point specific with various time steps	Days to seasons	Daily to monthly	RFCs	Probabilistic streamflow forecasts typically generated for lead times of days to seasons. ESP forecasts may be analyzed for various attributes of the hydrograph including volumes, peak flows, etc.
Water supply forecasts	Medium to coarse	Months to seasons	Monthly during winter and spring	RFCs NRCS/NWCC Some Reclamation offices	Probabilistic forecasts targeting seasonal volumes into a reservoir or past a forecast point.
Peak flow forecasts	Medium to coarse	Weeks to months	Weekly to monthly	RFCs	Probabilistic forecast targeting peak flow typically from snowmelt.
Special forecasts	Various	Various	Various	RFCs	Streamflow forecast tailored to specific water management decisions.
Flood warning, watch, and outlooks	Various	Warnings: Hours Watches: Days Outlook: Weeks to months	As required	WFOs	Text products describing current or future hazards based on streamflow forecasts and/or observations.

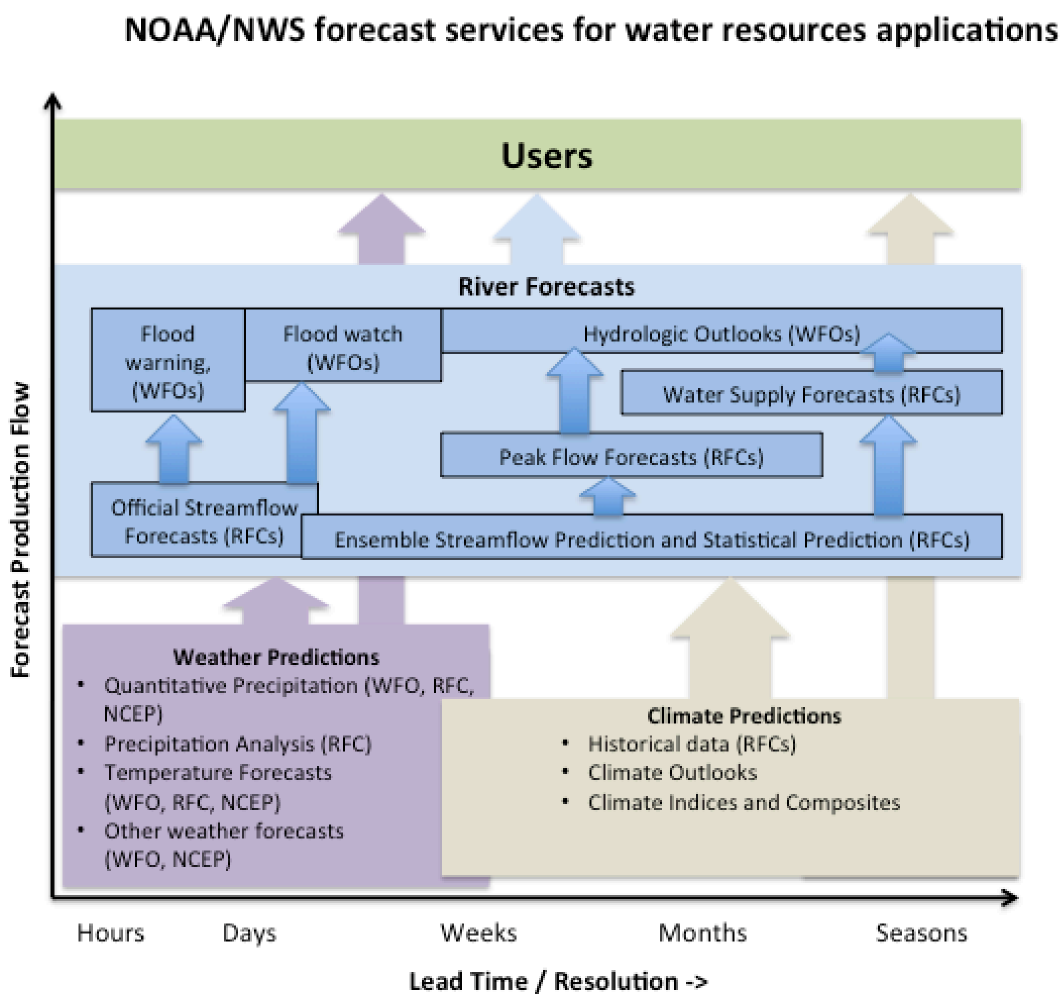

Figure 7. NWS forecast services for water resources applications.

NWS weather and climate forecasts are used by water management agencies, both directly and as important input to the streamflow forecasts generated by the NWS. Weather predictions correspond to the fine and medium time scales described in Section 3.1. The NWS generates a wide variety of weather predictions ranging from large-spatial-scale numerical model output (greater than 32-kilometer [km] grid mesh) to fine-spatial-scale severe weather warnings (e.g., 2.5-km mesh or a tornado warning). These predictions are made by a combination of NCEP, the WFOs, and RFCs. Centers within NCEP generate NWP model outputs and large-scale forecasts that are based on NWP as well as human forecaster assessment, such as HPC precipitation (quantitative precipitation forecasts [QPF]) forecasts and hurricane forecasts.

In contrast, WFOs generate local forecasts based on forecaster modulation of NWP. Climate outlooks cover the medium and coarse resolutions defined in Section 3.1. These outlooks primarily are generated or released by NCEP/CPC, and key products primarily include temperature and precipitation as well as monitoring, prediction, and analyses related to the El Niño Southern Oscillation (ENSO). Additionally, RFCs archive historical meteorological and hydrologic data that are used for calibrating models and defining the meteorological climatology used in ensemble streamflow prediction (ESP) forecasting.

The streamflow forecasts that underlie most of the hydrologic prediction products generated by forecasters using operational data systems that support snow, hydrologic, routing, and reservoir models[*] run at each RFC. RFCs run the models within a software platform called the Community Hydrologic Prediction System, which is an NWS-specific implementation of a generalized forecasting platform, the Deltares Flood Early Warning System (FEWS).[†]

At all time scales, RFC streamflow forecasts support the NWS flood warning, watch, and outlook text products issued by the WFOs. The NWS maintains many text products that describe both current and potential future dangers associated with flooding (as well as drought) that are used primarily by emergency management agencies but also by water management agencies and the general public to mitigate flooding damages.

River forecast production at different resolutions, lead times, and update frequencies are closely tied to each other. Figure 8 shows the relationship between the long lead forecast productions to the daily forecast production at RFCs. The forecast model states (i.e., soil moisture and/or snow conditions at the beginning of a forecast period) are updated on a daily basis; the official streamflow forecasts, based on quality assurance/quality control (QA/QC) data inputs, also are used to initialize long lead ESP forecasts. The remainder of this section describes specific RFC forecast products and the processes used to generate them.

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[*] Models include the Sacramento Soil Moisture Accounting Model and SNOW-17.

[†] See https://publicwiki.deltares.nl/display/FEWSDOC/Home.

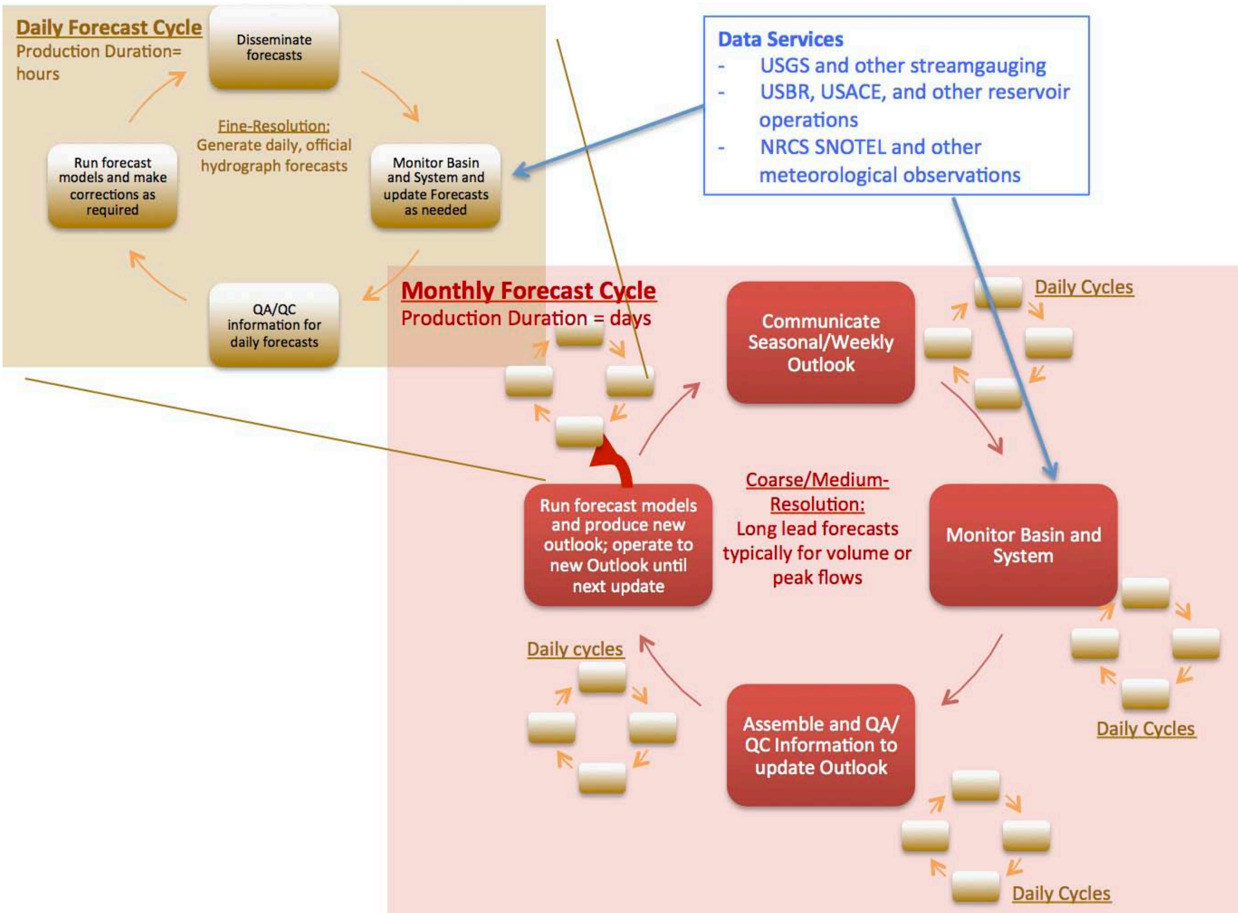

Figure 8. Hydrologic forecast update cycles.

3.2.1 Official Streamflow Forecasts (Fine to Medium Scales)

The official streamflow forecast is the most widely applied streamflow forecast product released by the NWS. These forecasts are generated at each RFC either on a regular frequency (usually daily) or as needed for flood fighting. The forecasts typically have a 6-hour time step, with maximum lead times of between 5–14 days into the future, depending on the producing RFC. Figure 9 shows an example of an official streamflow forecast.

Forecasts typically incorporate some length of forecasted precipitation amounts (QPF) and temperature for precipitation typing and snow modeling. The length of QPF included in the streamflow forecast varies dramatically between RFCs and, to a lesser extent, between seasons ranging from 10 days in the Pacific Northwest to 1 day in much of the Midwest. This variation is a result of subjective appraisal of the uncertainty

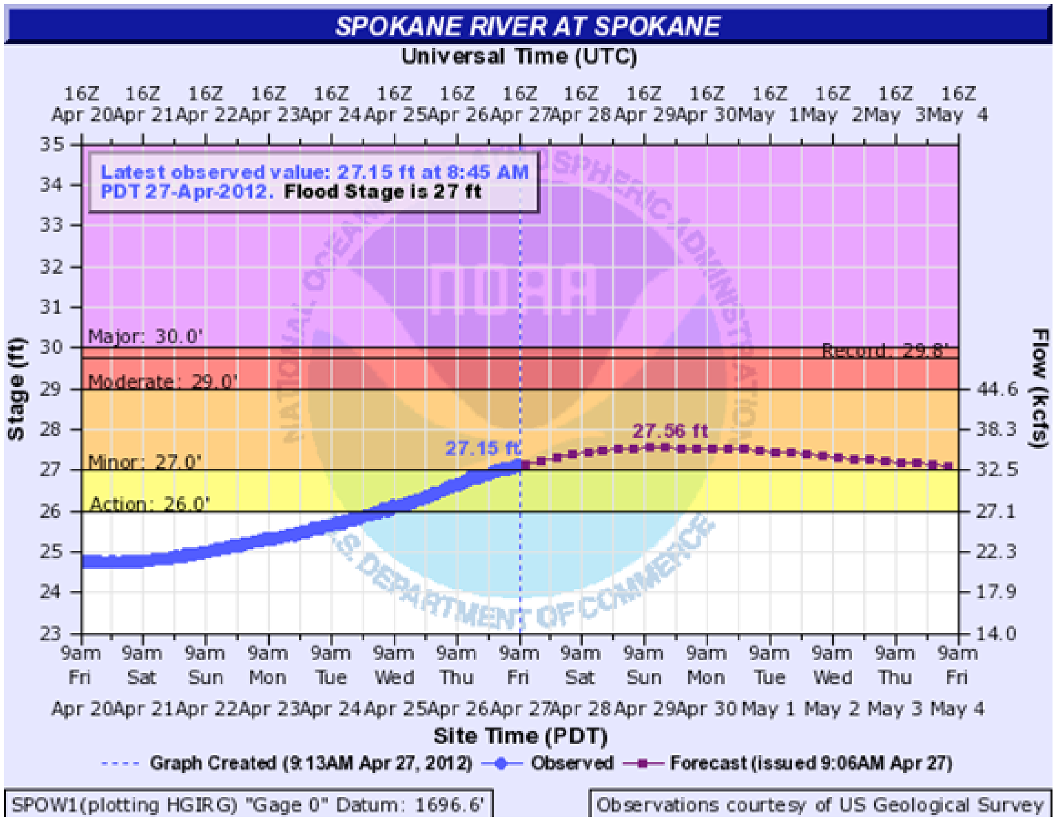

Figure 9. Official NWS streamflow forecast. The blue line indicates observed streamflow values from the USGS. The purple time series indicates forecasted river flows and stages extending 7 days into the future. The horizontal shading indicates the action and flood stages.

of QPF in different locations and seasons and of forecast office preference, but it is not yet guided by objective analysis of the impacts of QPF use on forecast quality. RFCs sometimes deviate from their normal QPF use practices during significant events. For example, during the Nashville floods of May 1–3, 2010, RFCs used up to 72 hours of QPF rather than 24 hours because it was apparent that a large event was imminent and relatively certain to occur at lead times beyond 1 day. RFC forecasters obtain quality control in situ (ground station-based) observations for temperature and precipitation, snow water equivalent and streamflow, atmospheric model outputs for freezing level, and remotely sensed estimations (both radar and satellite) for precipitation for use in real-time model simulations that estimate current catchment conditions. The modeled current conditions are used to initialize model-based flood and seasonal water supply forecasts. Forecast model states typically are updated daily to reflect much of the observed streamflow and meteorological data (described in Table 3) in real time. Hydrologic state updating is accomplished through a combination of objective and manual

QA/QC activities and a manual model state adjustment process in which RFC forecasters alter model moisture states (snow, soil) to match simulated-to-observed streamflow in the period leading up to the current time (typically about 10 days). Forecasts are generated for points defined by the NWS to have both sufficient data and importance to users. Forecast locations often are coordinated with water management agencies and are intended to enable both water resource and emergency management agencies to make more informed decisions about risk-based policies and actions to mitigate the dangers posed by floods and droughts. Forecasts are made available in a variety of ways, but a common vehicle for forecast transmission is the NWS Advanced Hydrologic Prediction Services (AHPS) Web page (available at http://water.weather.gov).

3.2.2 Long Lead Forecasts

On the medium and coarse time and space scales, RFCs utilize the same CHPS forecasting system to produce ESP forecasts that extend weeks and months into the future, with lead times of typically 3–12 months. These forecasts (termed "long lead forecasts" within NWS) define probability distribution functions for hydrologic variables of interest to water management agencies, including monthly and seasonal volumes (i.e., April–July period streamflow), peak flows, and other flow statistics of interest. Long lead forecasts typically are updated on a weekly or monthly basis, but some RFCs release them every day. Figure 10 shows an example of a series of long lead April–July streamflow volume forecasts.

ESP typically utilizes 30–50 different future meteorological sequences for input to the model, producing an equivalent number of future streamflow sequences that can be interpreted as conveying the future streamflow forecast uncertainty that is due to future meteorological uncertainty. Future meteorological sequences typically are sampled with even weighting from the historical model calibration period but may also include fine-scale (1–14 day) QPF. It is also possible for ESP to include adjustments based on seasonal forecasts or on ENSO-related expectations for climate (e.g., Werner et al. 2004). This practice is not used consistently across NWS RFCs at this time.

The resulting streamflow probability functions form the basis for long lead forecasts for water supply and peak flow forecast services in AHPS and elsewhere. ESP forecasts generally are issued in headwater basins and for inflows to major reservoirs. Forecasts below reservoirs require knowledge

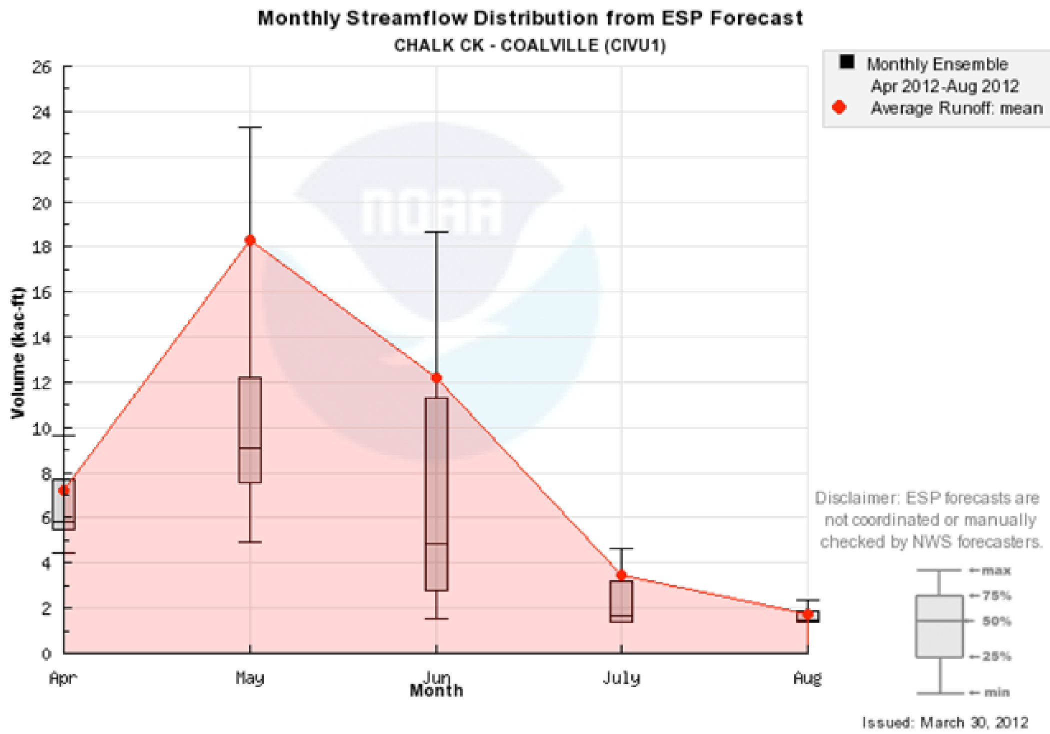

Figure 10. Example of a long lead ESP forecast for monthly volumes. The distribution of forecast monthly runoff volume possibilities is shown as box and whisker distributions. The average monthly volumes based on historical data are presented (in red) for comparison.

of the reservoir release strategies or projections from water managers. Streamflow volume runoff forecasts may be generated with and without the use of reservoir models (represented by internal components of the forecasting system), yielding both regulated and unregulated flow predictions. Where the NWS is not able to simulate or forecast upstream reservoir operations accurately, it cannot generate accurate regulated ESP forecasts, a situation that arises downstream from many major reservoirs.

In addition to the ESP method, western RFCs utilize statistical prediction equations that relate predictors (typically snow water equivalent [SWE] and accumulated precipitation at SNOTEL sites and observed recent streamflow) to forecast runoff targets for the same period described above. These volumes are expressed probabilistically in the form of estimates of prediction quantiles (typically the 10th, 50th, and 90th percentiles). This statistical forecasting practice has been operational within agencies of the western United States since the early part of the 20th century; NWS began using it in the mid-century, and it has used the same principal components regression method (Garen 1992) for about the last 20 years.

3.2.3 Forecast Uncertainty

Every streamflow forecast contains uncertainty. The amount of uncertainty depends on a number of factors, including the quality and extent of the model input and observed flow data in a basin, the lead time of the forecast, the quality of the model calibration, the physical and hydroclimatological nature of the basin, the accuracy of the meteorological forecast, and, within the manual NWS process, the experience of the forecaster. Traditionally, NWS forecasts for fine- to medium-scale lead times (less than one month) have been produced by methods that preclude quantification of uncertainty. The subjective nature of the forecast process, coupled with the single-valued (or “deterministic”) paradigm for forecasting at these lead times, has meant that estimates of forecast skill and uncertainty for products such as the official streamflow forecast are not available to users. One avenue toward quantifying uncertainty is through verification of past forecasts at these lead times; the subjectivity of the forecast process undermines the validity of verification metrics.

In contrast, quantifying forecast uncertainty was a major motivation for the original development of the monthly to seasonal ESP forecasts (Day 1985) as a technique for long lead forecasting (e.g., water supply forecasting), and uncertainty estimates have been a component of the statistical long lead forecasts since the mid 20th century. The current long lead forecast process also involves subjective elements; therefore, the uncertainty estimates provided with long lead ESP-based or coordinated forecasts may not be reliable. In addition, the ESP framework (within a single-valued initial watershed state) accounts only for future meteorological uncertainty, as described in Wood and Schaake (2008). Peak flow forecasts that are based on ESPs include similar partial estimates of uncertainty.

3.2.4 Special and Experimental Streamflow Forecasts

In addition to the traditional forecasts described above, sometimes RFCs make special forecasts tailored to specific water management requirements. Often these are developed in close collaboration with a water management agency to support an operational need at specific locations that are not served by standard RFC products. These forecasts include, for example, forecast ensembles of monthly inflow volumes to reservoirs in the Colorado Basin (where Reclamation receives monthly forecast ensemble traces extending 32 months into the future, updated each month). Another example is the low-flow forecasts for navigation interests along the Mississippi and lower Columbia Rivers. These forecasts estimate streamflow with several days of lead time, have greater temporal resolution, and, in some cases, consider tidal influences. Lead times vary depending on the intended use of the forecast. RFCs also may issue variations on fine-scale forecasts at the request of a WFO or other user. These “contingency” forecasts are not routinely produced but are often used to help determine forecast sensitivity to uncertain inputs during extreme events.

The NWS RFCs also may produce forecasts that are labeled “experimental,” developed either as a result of an independent effort at one or more RFC or based on methods developed at the Office of Hydrologic Development. Recent experimental forecasts of note have centered on efforts to quantify uncertainty for fine- to medium-scale lead times by making ensemble forecasts; another focus is on longer lead forecasts that explicitly include climate predictions as inputs. The latter are associated with the Hydrologic Ensemble Forecast Service led by NOAA’s Office of Hydrologic Development. An example of the former, an RFC-led fine-scale experimental forecast effort, is the Met-Model Ensemble Forecast System that is now run at four RFCs in the eastern United States (Figure 11); similar ensemble fine-scale

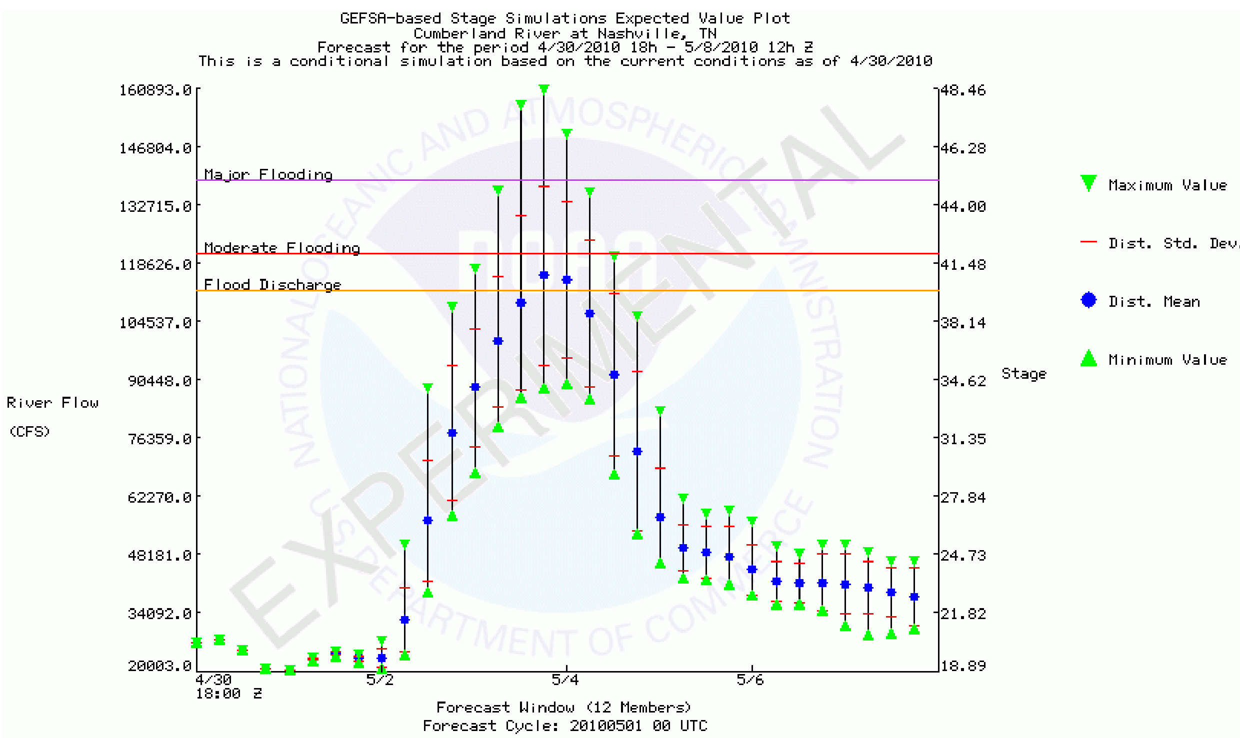

Figure 11. Experimental ensemble fine-scale forecast product issued just prior to the Nashville, Tennessee, flooding of May 2010.

predictions are also routinely produced by CNRFC. These forecasts may be shared by the RFC with a subset of streamflow forecast users. Like the special forecasts, experimental forecasts typically are disseminated by the RFC directly to the user or management agency, rather than via the WFO warning and watch product channel.

3.3 Challenges in Producing Forecasts to Inform Water Management

Operational hydrologic prediction presents many challenges—some of which are common to other prediction enterprises and some of which are unique to hydrology—that ultimately are manifested in the form of imperfect forecasts or that prevent the production of forecasts that meet the users' needs. This section gives a brief overview of key difficulties or features encountered in the current RFC practice of hydrologic forecasting, providing insight into the current state of practice.

As is well documented in research literature (e.g., Kitanis and Bras 1980; Welles et al. 2007; Schaake et al. 2006), most hydrologic predictions, particularly those at time scales longer than a few hours, contain significant uncertainties. It is difficult and arguably misleading to generalize about the characteristics of hydrologic prediction uncertainties because they depend on the hydrologic regime and the degree of regulation. The most certain predictions are found in large, regulated rivers during dry periods, when streamflow is entirely constrained by the water management infrastructure (e.g., controlled reservoir releases). In such cases, forecasts may exhibit, at most, a few percent error for lead times of a few weeks. The most uncertain predictions are found in poorly monitored, uncontrolled watersheds during storm events, during which current and future meteorological and watershed conditions are unknown and/or poorly forecasted, local river gauging has been compromised, and conditions are changing rapidly. In such cases, forecasts may exhibit over 100% error at lead times of 12 hours. Forecasting responsibilities at all RFCs must grapple with this range of variation in hydrologic predictability, using tools, datasets, operational processes, and human resources that are more than adequate to handle the high-predictability endpoint but struggle to perform well for the low-predictability endpoint. This characterization of endpoints highlights some of the major factors leading to uncertainty in hydrologic predictions, which may be broadly categorized into science- and engineering-related uncertainties and institutional factors.

3.3.1 Hydrologic Prediction Uncertainty

Science- and engineering-related challenges in hydrologic prediction arise from deficiencies in hydrologic models, datasets used for input and verification of simulations and predictions, and meteorological forecasts and information resources describing infrastructure controls on streamflow or other watershed impairments.

3.3.1.1 Hydrologic Modeling

Hydrologic simulation modeling has been the central method employed by the RFCs for river forecasting for flood prediction (with lead times of 1–10 days) for decades. Although seasonal-lead water supply predictions in the western United States have been produced by statistical (regressive) methods for more than a half century, in the last several decades, the same modeling system used for flood prediction has been applied to generate a variety of monthly to seasonal lead streamflow prediction products that complement the statistical forecasts. The forecast application of a hydrology model involves running it for a sufficient period of the recent past with observed meteorology to estimate the current watershed moisture conditions (termed forecast "initial conditions") and then running it forward into the future with the predicted meteorology so as to estimate future watershed moisture conditions, including streamflow. The RFC hydrologic models date back to the 1970s and are relatively simple in comparison to modern, spatially distributed, high-resolution, physically oriented land surface water and energy balance models. The NWS models require relatively few parameters (11 and 15 for the snow and soil accounting models, of which approximately 4 and 10, respectively, are routinely used in model calibration). Algorithms, such as the unit hydrograph and Muskingum methods, often are used to represent hydraulic processes and routing, although more detailed models such as HEC-RAS also are used in some RFCs. Rather than explicitly representing detailed spatial variation and physical relationships in many hydrological processes (e.g., the snow energy balance, vegetation canopy effects, surface and subsurface flow routing, channel hydraulics), such models "parameterize" them—that is, they describe them via an algorithm controlled by an index value that can be tuned to account for the processes' aggregate effects in translating meteorological inputs to streamflow at a gauge. The NWS hydrologic models are applied in a "lumped fashion," defined primarily by the river gauging network. Western U.S. RFC models also typically use two or three elevation zones within a gauged/lumped watershed area, the better to account for snowpack influences on runoff. The parameters for the lumped model areas are identified by manual calibration to match modeled streamflow to observed streamflow characteristics.

These "legacy" models are used for a variety of reasons, some of which are institutional. The primary scientific rationale is that the parsimony of the modeling approach is appropriate, given the data limitations, i.e., any given watershed modeled contains a single streamflow gauge, a few meteorological measurements, and/or a few snow measuring stations; thus, identifying larger sets of parameters needed to calibrate more complex models is difficult. Model intercomparison projects have not shown that more complex models offer significantly better streamflow predictions and simulations, though they have other benefits (e.g., Smith and Gupta 2012). Nonetheless, any model is only a representation of the watershed processes with inherent approximations and simplifications that limit the ability of the model to depict all possible configurations of hydrologic conditions within a watershed. Typically, a single set of model parameters is used for all flow regimes (low, high, flooding), a convention that is traditional in hydrology and in the RFCs, but one that implies a limit to the optimality of calibrations in all flow regimes simultaneously. Further complicating the calibration challenge, extreme flow events may be rare in the observed record; thus, robust assessment of the quality of the hydrology model during such events may be impossible.

Modeling is particularly challenging in areas affected by significant unknown modifications to streamflow (not represented in hydrologic models), such as agricultural or other diversions, small storages (ponds), return flow from ground water-based irrigation, other unmeasured consumptive uses, and reservoir regulation in the absence of data from reservoir operators. In such watersheds, the observed flow to which models are calibrated is only an estimate, constructed by combining the measured observed flow with estimates of impairment effects developed from forecaster knowledge, judgment, and supporting datasets. The RFCs have comprehensively estimated the actual water balances (including these impairments) for more U.S. watersheds than any other entity, but these estimates are nonetheless imperfect. Model state adjustment based on observations (termed "data assimilation") is one option for improving model simulations. For instance, snowpack is an important state variable for streamflow forecasts and is measured via in situ and remote sensing of SWE as well as snow-covered area. RFCs are increasingly investigating ways to leverage these resources but do not yet use objective methods for snow data assimilation operationally. In summary, hydrologic models in general, as well as in RFC practice, vary greatly in the degree to which they can reproduce observed streamflow sensitivities to meteorological inputs.

3.3.1.2 Meteorological Model Inputs, Past and Future

In locations where a hydrology model can be considered well calibrated, simulated streamflow (and presumably watershed states) may deviate substantially from observed streamflow. A major source of such simulation errors is the estimation of model meteorological inputs (also called forcings), which for most RFC models includes precipitation (termed "quantitative precipitation estimate" [QPE]), temperature (QTE), and freezing level at either 6-hourly or 1-hourly time resolutions. RFCs devote a large effort toward estimating these inputs, including historical station analysis, retrieval and quality control of real-time station data, quality control and fusion of information from radars, and application of scaling relationships to account for orographic precipitation enhancement. Significantly fewer meteorological observations are available in real time than for retrospective historical periods, whereas radar analyses may be available in real time but not historically. Often, real-time observations are not available within a forecast basin. A common tradeoff in operational hydrologic analysis is the need to maintain consistency between the development of forcings for retrospective model calibration while trying to use as many meteorological observations as possible in both model development and meteorological analysis. RFC approaches to this tradeoff vary, but all are affected by the same degree of unreliability in real-time meteorological analyses (including missing or erroneous station reports or radar retrievals) and systematic reporting errors (e.g., tipping bucket gauges at below-freezing temperatures). Aside from precipitation and temperature, the freezing level, which partitions the fate of precipitation between the snow or rain, is uncertain at watershed scales and may be estimated either from meteorological analysis models, dual polarization radars, or temperature analyses. During some events, the freezing level value is a highly influential input to RFC models; it can make the difference between a major flood forecast and a streamflow decrease forecast. Well-calibrated models in meteorologically benign situations may simulate streamflow accurately even at the short time scales (e.g., hourly) required for river forecasting operations; at other times, meteorological input uncertainties typically lead to errors in current streamflow and watershed initial condition simulations.

Uncertainties associated with weather and climate prediction are often the dominant source of error in streamflow prediction. Streamflow forecasts are heavily dependent on QPF as well as on forecasts of temperature and freezing level. Streamflow prediction requires forecasts at temporal and spatial resolutions that match the streamflow forecast time step (usually 6 hours) and basin scale. While weather forecasting has improved steadily over the past few decades, there remains considerable uncertainty at the scales needed for streamflow prediction, especially for QPF. As discussed in Section 3.2, RFCs differ in the approaches to incorporating weather predictions into their streamflow predictions, especially with respect to QPF. Effectively accounting for and translating the uncertainty in weather forecasts, and QPF in particular, generally requires a probabilistic forecast approach that integrates weather prediction uncertainty as an input to streamflow predictions. While the NWS has heavily invested in the development of such a system in recent years, it is not yet part of the official forecast production at any RFC.

As with weather prediction, large uncertainties exist in climate prediction. In some places where seasonal forecasts are potentially very important—e.g., the Upper Colorado River Basin—minimal forecast skill exists in the official climate forecasts produced by the NWS. As discussed in Section 3.2, climate forecasts typically are not utilized objectively by RFCs in their seasonal forecasts. The NWS has evaluated and developed techniques for translating official CPC forecasts into RFC streamflow forecasts, but these are not used consistently, even in locations where forecast skill is greater (such as the Pacific Northwest).

3.3.1.3 Uncertainties in River Measurements

As noted earlier, RFCs calibrate hydrology models to reproduce the characteristics of observed streamflow during historical periods. In real time, given good calibrations, these models are expected to simulate streamflow that matches real-time observations of flow. RFCs obtain observed flows wherever possible from local, state, and Federal agencies (primarily USGS). While these flow observations overall have a high reliability and accuracy, their quality does vary. Some gauges are designed for either high or low flows and do not perform reliability in the opposite regime. Similarly, some channel locations are much more difficult to gauge than others. Dynamic river channels require frequent re-rating; low-gradient streams may have flow-dependent stage controls, and conditions such as ice may obstruct the functioning of a gauge. Rating tables that convert stage measurements to flow measurements also introduce uncertainties, especially in high-flow regimes and in places where flow is measured infrequently. It is quite common for river gauges to cease functioning, measuring accurately, or reporting during the most critical periods of flooding events, requiring manual/visual estimation of peak flood stages by gauge site visits. In some cases, stream measurements may not be available in real time (i.e., with subhourly frequency of measurement and reporting) or may be provided only on a daily time step.

Uncertainties or errors in riverflow measurements may be introduced directly into the river forecasting environment. NWS forecasters typically modify model states, parameters, or inputs to rectify significant differences in current flow simulations and observed flows, using observed flows to constrain initial modeled watershed states. This practice is, essentially, data assimilation, performed not by an algorithm but by humans. In cases where multiple gauges along a river reach disagree from a river mass-balance standpoint, RFC forecasters typically attempt to reconcile measurements against each other to identify measurement problems, at times discarding flow measurements that violate the river balance indicated by other flow and simulation results. Forecasters also evaluate the behavior of the measured flow itself, using professional judgment to determine if the flow is plausible or may indicate measurement problems (such as gauge icing). Given the inherent difficulties in measuring streamflow, significant uncertainties in the measured flow values can remain, despite forecaster efforts. Forecasts initialized from model states after observed flow information is assimilated will typically contain flow measurement errors during flood-forecasting timeframes, and those errors also affect seasonal forecasts due to their inclusion in model state adjustments.

3.3.1.4 Uncertainties in Reservoir Operation and Water Use information

Reservoirs and other manmade river controls (e.g., tunnels used to transfer water from one river location to another, unmeasured diversions, or consumptive uses) greatly complicate river forecasting, both in simulating observed streamflow (which estimates the initial watershed conditions for a forecast) and in predicting future streamflow. Simulating observed streamflow requires data on current upstream reservoir operations and diversions. In cases where these data either do not exist or are not available to the RFC, the RFC typically attempts to simulate reservoir operations based on rule curves or historical operation or diversion patterns, which may be estimated rather than measured. In cases where data exist and are available to the RFC, there still may be data quality issues similar to those with river measurements. Forecasting reservoir operations and the streamflow below reservoirs requires knowledge of reservoir operational plans or projections during the forecast period. These plans may not be communicated to RFCs before forecasts are created. Even when communication channels to the RFC are in place, operational plans may change in response to the forecast or other considerations. During extreme events, reservoir operation projections may not be known by the operators who are determining outflows in real time because reservoir pools change. If these events are rare, communication practices between the RFC and the water managers may not be adequate to support intensive data exchange.

Reservoir operation projection uncertainty affects both flood forecast horizons and seasonal management horizons, during which release decisions may vary in accordance with observed rather than forecasted runoff. These factors combine to create additional uncertainty associated with forecasting reservoirs and streamflows below them. Most streamflow locations in the United States are affected by upstream water management of some kind. For example, Figure 12 illustrates the connectivity of the Duchesne River watersheds, indicating that the forecast flow at locations

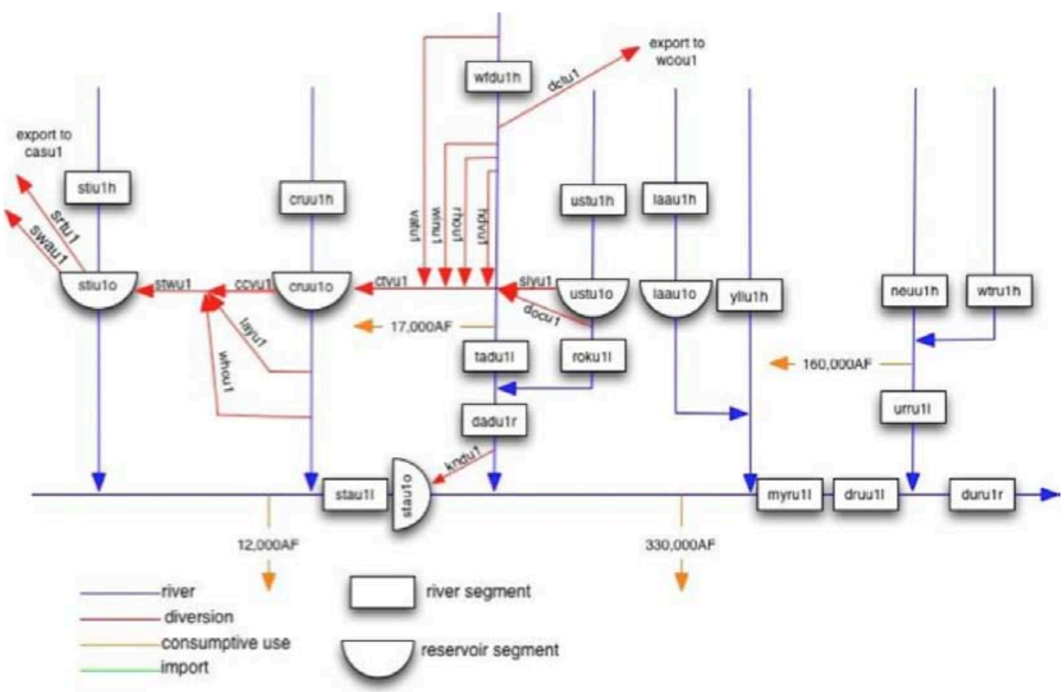

Figure 12. Schematic of the river balance for the Duchesne River in Utah. Of the 16 watersheds ("river segments") shown, only 7 are modeled as unimpaired headwaters. Consumptive uses and diversions vary dynamically, and a number are unmeasured.

such as Duchesne (ID myru1l) at Myton, Utah, is affected by the operations of a number of reservoirs, consumptive uses, and diversions.

Those locations that are not affected by upstream management include mainly headwater basins, and even those may have impairments from small-scale features such as stock ponds and ground water pumping that are not resolved by river forecast models. In some locations and circumstances, nearly all of the error in a forecast may be due to an erroneous projection of a reservoir release or tunnel operation; this error can propagate downstream, at least until reaching another reservoir.

3.3.2 Institutional Factors

Considerable institutional experience exists, both in the RFCs and in the management agencies, with producing and applying river forecasts. This experience has produced three valuable and unique attributes in the RFCs that allow them to perform operational forecasting in ways that only other highly specialized forecasting operations can match: (1) knowledge of catchment data, hydrology, and hydraulics as a result of decades of daily hands-on analysis of the watershed behavior and quality control of its observational network; (2) the most comprehensive set of watershed flow and meteorology data contained in one place, even though it is incomplete in ways noted above; and (3) a set of calibrated hydrology models and subdaily, real-time forcings for the conceptual modeling units defined by the RFCs. The RFC as an institution also has generated rigid forecast operations procedures that govern their interactions with management agencies and the generation of forecasts. Rules exist both explicitly—i.e., in the form of regulations and procedures and also as implemented into software systems—and implicitly in the form of longstanding practices and culture. Changing rules in both contexts is difficult. The interdependence of forecast generation and river regulation or management requires coordination between multiple parties (including stakeholders) at the operational office and possibly regional or national levels, slowing the implementation of new capabilities.

The operational emphasis of the RFCs and the management agency operational centers restricts the incentives, resources, education, and effort at this field level that can be devoted to innovation and capability development; hence, operational offices typically must rely on agency labs to investigate, develop, and transition new capabilities. The success of this arrangement depends on the strength of integration and coordination between the field offices and the labs. Integration issues, among other difficulties in the transition of science or research to operations, are well documented in research literature and agency and academy reports (e.g., National Research Counccil [NRC] 2000).

3.3.3 Operational Forecasting Process

Welles et al. (2007) offered evidence that RFC forecast skill for official streamflow forecasts has not improved in recent decades (e.g., Figure 13) and concluded that the current RFC practice yields "little objective information to describe the skill of [the RFC] forecasts or to guide the work of improving [the RFC] forecasts." The plot of forecast skill (Figure 13) contrasts streamflow predictions made by a watershed hydrology model using QPF forecasts as input (labeled "actual" because it reflects current practice) with a "persistence" forecast in which the current value of streamflow is projected to remain unchanged during the forecast period. Because the current practice requires effort and investment, the degree to which "actual" performance exceeds persistence is a measure of whether the effort and investment are warranted.

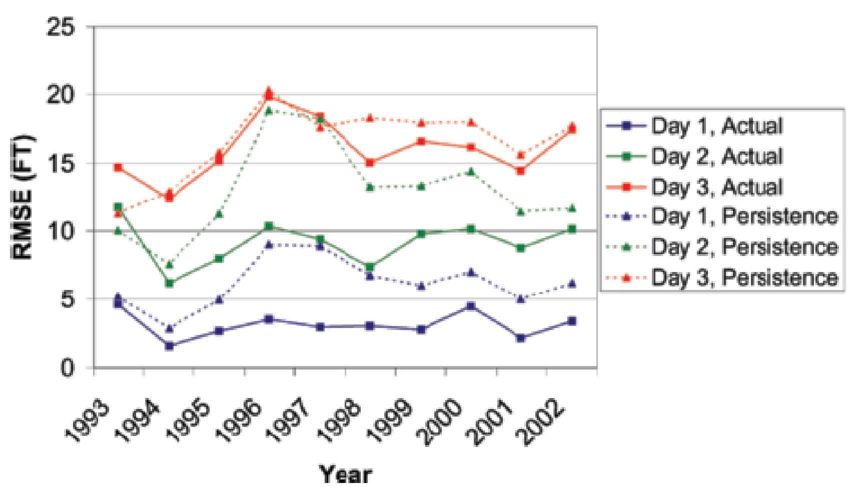

Figure 13. Errors in RFC forecasts above flood stage for four forecast points in Oklahoma (Welles et al. 2007)

Pagano et al. (2004) found that water supply forecast skill in the southwest United States had not increased in the prior 20 years. RFCs employ a subjective and semi-manual forecast process that has evolved as a strategy to correct for the many data, modeling, and science challenges described above but has arguably itself become a challenge hindering innovation, capability enhancement, and provision of services. Manual aspects of the RFC forecast process limit the upscaling of forecast production toward ensembles (uncertainty accounting), finer spatial distribution of hydrologic analysis/models, meaningful verification, the incorporation of objective methods such as automatic data assimilation, and more frequent updating during extreme events. Most RFCs lack the human resources and objective developmental frameworks to assess new variations in forecast approach systematically (e.g., against a benchmark of an existing objective system); thus, a number of potential improvements in forecasting (e.g., the adoption of modern modeling strategies) have been difficult to leverage. While NOAA and NWS have invested in new science and technology to address the challenges described above, NWS also continues to invest heavily in supporting the current streamflow forecast paradigm and in maintaining the reliability of the overall forecasting system. The new software platform (CHPS) within which the RFC forecasting approach is now contained has a valuable flexibility that may allow growth in RFC forecast capabilities but does not inherently alter the typical RFC forecast process.

As noted above, for fine- to medium-scale lead times, manual aspects of the RFC forecast process limit predictions to single-value outlooks that do not convey uncertainty. This paradigm also has resulted from limits in ensemble prediction science and data (though this situation is dramatically improving) and from a demand from some users for single-value forecasts (they may apply a median forecast even where ensemble information is available). With single-value forecasts, there is no reliable method to generate uncertainty (e.g., as to the timing of an event or its spatial coverage); thus, the adherence to this paradigm always will limit the support of risk-based decisionmaking within the water and emergency management sectors. This is a critical point; quoting a water manager,[*] "please don't ever sugarcoat the error associated with these forecasts… it's important for us water managers to understand the uncertainties so that we can manage around them."

3.4 Challenges in Furthering the Use of Monitoring and Forecast Products

The previous section discussed challenges associated with improving forecast information. This section presents a complementary discussion on furthering the use of monitoring and forecast information in Federal water management, drawing attention to perceptions and usage factors that affect further use.

[*] At a CBRFC stakeholder meeting on November 3, 2011.

The use of forecasts for short-term decisionmaking in water resources operations is inherently complex, as has been described throughout this document. Operational guidelines and associated procedures are established by legal authorities, nontrivial multiparty engineering studies, and incremental processes involving operators, planning and management teams, policy makers, stakeholders, and other parties. The complexity of system operations (particularly in multiobjective systems) makes it difficult not only to ascertain the value of forecast information in current operations but also to gauge the potential marginal value of adopting new forecast products.

Several factors should be considered when analyzing the current use, or lack thereof, or future use of forecast products to support water resources management. These considerations include (1) uncertainties over forecast quality, (2) the risk tolerance environment of water resources management, and (3) uncertainties associated with water resource system operations. These three factors are described below, followed by a summary of other factors that may warrant attention.

3.4.1 Forecast Quality Uncertainties

Using forecasts for water resource decisionmaking inherently involves consideration of achieving the desired outcomes with or without using forecasts. To make this choice objectively, without conducting real world risk experiments, a decisionmaker requires a description of the skill and uncertainty of forecast systems. The form of this description may, currently, vary widely, from a detailed assessment of past performance deemed consistent with likely future performance to a qualitative appraisal of past forecast performance in a few critical, system-straining events. Objectively incorporating and understanding changes to potential water resource operations require a quantitative assessment of forecast quality.

There are many sources of hydroclimate prediction information, including forecasts such as NWS RFC single-value river forecasts for 1- to 10-day timeframes or water supply forecasts and ESPs for longer outlooks. Each forecast system supports a different communication of skill and uncertainty. In many cases, such as flood forecasts, verification is not available. Typically, the forecasts currently used in short-term decisionmaking described within Sections 2 and 3.1 have been incorporated for nonquantitative reasons—that is, they have not had a formal assessment of the benefits and costs of forecast use involving water resources system models driven by past forecasts or estimates of forecast skill. Furthermore, incorporating forecast information that alters a decision process is not likely to involve decision trees or flowcharts that formally harness forecasts in a prescribed, documented, and reproducible process. The lack of quantitatively known forecast skill and uncertainty does not preclude the establishment of a specified process that includes the forecast product, but it does preclude quantifying the benefit of the forecasts and optimizing the forecast use process in accordance with forecast skill.

Forecast products currently used within water resources management decision processes are often provided without skill or uncertainty information. When uncertainty information is provided (e.g., some water supply forecasts in the western United States), the quantified forecast uncertainty may be incomplete (i.e., limited to the forecast system's representation of uncertainty). It currently is not possible to define the skill of many forecasts and the uncertainty associated with them. Without a reliable forecast probability distribution, however, it is not possible to design water management decisions to accomplish an exacting management of risks associated with a potential decision or to balance one or more objectives. It is not possible, for example, for a water management decisionmaker to set a target of achieving success with 90% regularity and, therefore, utilize a 90% quantile from a forecast system unless the 90% quantile forecast has been verified as reliable (e.g., corresponding observation occurring at 90% frequency over many cases).

In some cases, particularly for the seasonal water supply forecast, the NWS does provide a range of forecast verification metrics online. Subject to the limitations described above and in Sections 2.3 and 3.3, these metrics may be used by water resources managers to improve the use of forecasts.

3.4.2 Water Management Risk Tolerance Environment

Even if skill and uncertainty were perfectly known for hydroclimatic forecasts, in many cases the institutional decision space is insufficient to enable their quantitative incorporation in the decision process. Water resource management projects may have a single authorized purpose or multiple authorized purposes with a primary objective and secondary considerations. For the latter type, there may be no defined set of risk tolerances between competing objectives (particularly if objectives are nonmonetary).

For example, in an area with an authorized flood control structure upstream in a situation where flooding is possible, the water manager's foremost concern is to eliminate the possibility for flooding if at all possible. Risk-averse decisions are not uncommon, and "false positives" of management decisions are an inherent byproduct. The negative outcome of the "false positive" is not with respect to the flood control objective but competing objectives such as providing flows for hydropower or environmental concerns during the potential flood event. In this way, the system is optimized for a single authorized purpose as opposed to all potential purposes. There is as yet no agreed upon risk of a "false negative" whereby, as an example, flooding of a downstream location is tolerated to reduce the possibility of not achieving competing objectives.

As another example, there are systems where the risk environment is fully defined through congressional authorization by establishing flood control space separate from other use space, such as water supply. In this case, there does not exist the institutional decision space, except for minor deviations, to redistribute risk on a case-by-case (annual) basis based on a forecast product.

Within systems operated for single-purpose and multipurpose objectives, there is inherently little desire to shift risk in a manner that may compromise future successful operations. For these systems, it is hard to advocate in a quantitative manner for where, and how, to incorporate new sources of information within a well-defined process.

3.4.3 Physical System Response Uncertainty

Even if skill and uncertainty were perfectly known and the institutional space existed for optimization against a set of competing objectives, managers may be unable to model the system response in a quantitative manner to achieve some desired level of risk tolerance. The complexity of the water management system is amplified during hydrologic events such as floods and droughts. Unexpected physical responses are common during these types of events, such as failures of culverts or other unexpected water routing phenomena. Adequately accounting for this type of unexpected phenomena or even characterizing the possibilities prior to making decisions to achieve a potentially agreed upon risk is not currently possible. “On the fly” decisions are also not possible because this type of unexpected system behavior could not be managed in an appropriate manner to achieve risk objectives.

Additionally, decision support tools (DSTs), including water resources simulation models and analysis programs, typically are available to practicing water operations managers but may not be able to incorporate probabilistic forecasts. Many DSTs in use today were designed before real-time forecasts (probabilistic or not) were widely available and accessible and would be cumbersome to run in a probabilistic mode. An example is a spreadsheet-based model designed to use a single-value streamflow forecast as an input. Also, the complexity of the physical water management system, hence the model representation, may make it computationally difficult to process forecasts objectively and without manual entry of decisions reflecting operator judgment. These and other factors limit managers’ ability to quantitatively evaluate the system responses to a variety of potential hydroclimatic forecasts and decision scenarios. The result is that, where forecasts are used, it is common for the forecast information to be weighed subjectively by experienced water resource managers against other information sets to achieve a qualitative perception and balancing of risk.

3.4.4 Other Factors

Aside from the three issues above, other factors also may be relevant in specific situations, including legal frameworks and institutional decisionmaking processes. These frameworks and processes may evolve at different time scales than do the availability and development of new information and are intended to meet mission requirements to the best extent possible over time. As in most work environments, the personnel interests, beliefs, experiences, and knowledge of staff and managers, as well as the culture of the office as maintained by the personnel, influence attitudes toward the offices’ strategies for discharging their responsibilities. Top-down agency guidance and training programs may help to standardize attitudes toward innovations (in capabilities, processes, tools, and information) that would alter longstanding practices, but substantial grassroots-level variation in personnel attitudes toward forecasting may exist. At all levels, insufficient expertise, training, and knowledge of existing or potential forecasts may result in the forecasts not being used. Insufficient interaction between forecast producers and users also may limit forecast use, given that such interactions provide a conduit for feedback and user support to aid forecast interpretation. Note that NWS Service Assessments during past floods have identified this factor as a significant component undermining proper forecast use and production. Forecasts may not be available at the correct time, in the correct format, or for the location or predictand required for an operating decision. Lastly, as described in Section 2, agency regulations, directives, and authorities may restrict or prohibit forecast use; in which case they are a significant factor that may outweigh any others described in this section.

4 Use and Needs Assessment

USACE and Reclamation use hydroclimate monitoring and prediction products in different ways, depending on operating objectives, basin setting, system characteristics, and information availability. Given this diversity of operating situations, it is not surprising that access, application, and degree of influence on a decision for a given hydroclimate information product can vary considerably, depending on the management situation.

This chapter characterizes how USACE and Reclamation currently use each hydroclimate product information introduced in Section 3.2. This is to provide a sense of current practice and capabilities in utilizing this information. From there, the chapter goes on to report operators' perceptions about information needs in terms of products and services. In that discussion, needs vary from translational (e.g., product synthesis and/or education, geographic expansion of where a product is offered) to research (e.g., development of improved prediction products, advancement of underlying science to support improved prediction).

4.1 About the Assessment

To support discussion on information usage and related needs, USACE and Reclamation invited operators' from each of their networks of geographic jurisdictions (Table 4) to participate in a use assessment. The activity was conducted during February–March 2012. A copy of the assessment is provided in Appendix B. Each group was invited to respond to several sets of questions. The first set gauged whether the operators agreed with how their situations were being encapsulated by the fine- to coarse-resolution situations described in Section 3.1. All of the respondents confirmed that this was the case, although two indicated that the coarser-resolution time scale was not applicable to their system situation. The subsequent sets of questions addressed information usage and related needs. The sets fell into three categories:

- ***What do we use now?*** Respondents were asked to classify how they access the various products available from NOAA NWS, USGS, and NRCS listed in Section 3.2 (i.e., obtained, available but not obtained, or not available for their region). They were then asked to assess the applicability of a given product for any of the three decision categories and outlook resolutions from Section 3.1 (i.e., fine, medium, and coarse). Lastly, they were asked to classify to what degree the applied product influences short-term water management decisions, where the respondents were given three options:

1. *No Influence*: This product is evaluated for situational awareness but is not used to inform decisions.

2. *Sometimes Subjectively Used*: This product is used at least some of the time to inform decisions. The manner by which it is used is often subjective in nature in that the operator prefers to have the information and weighs its value against other pieces of information before ultimately using professional judgment as to how it may influence an operational decision.

3. *Required to Use*: There is law, policy, procedure, or general practice that dictates how this product is used within one or more decision processes.

Table 4. USACE and Reclamation offices responding to the use and needs assessment.

Agency	Jurisdictions (Figure 1)	
USACE Divisions and Districts	Great Lakes and Ohio River Division (LRD)	Division Office and the following Districts: Buffalo (LRB), Chicago (LRC), Detroit (LRE), Huntington (LRH), Louisville (LRL), Nashville (LRN) and Pittsburgh (LRP)
	Mississippi Valley Division (MVD)	Division Office and the following Districts: Vicksburg (MVK), Memphis (MVM), New Orleans (MVN), St Paul (MVP), Rock Island (MVR) and St Louis (MVS)
	North Atlantic Division (NAD)	Districts: New England (NAE) and Philadelphia (NAP)
	Northwestern Division (NWD)	Districts: Kansas City (NWK) and Omaha (NWO)
	Pacific Ocean Division (POD)	Districts: Alaska (POA)
	South Atlantic Division (SAD)	Districts: Jacksonville (SAJ), Savannah (SAN) and Wilmington (SAW)
	South Pacific Division (SPD)	Districts: Sacramento (SPK), Los Angeles (SPL) and San Francisco (SPN)
	Southwestern Division (SWD)	Districts: Fort Worth (SWF) and Tulsa (SWT)
	Institute for Water Resources (IWR)	Hydrologic Engineering Center (HEC)
Reclamation	Great Plains Region (GP)	Regional Office and the following Area Offices (AO): Montana (MAO), Nebraska-Kansas (NKAO) and Wyoming (WAO)
	Lower Colorado Region (LC)	Boulder Canyon Operations Office (BCOO) and Yuma Area Office (YAO)
	Mid-Pacific Region (MP)	Central Valley Operations Office (CVOO), the Klamath Basin and Lahontan Area Offices (KBAO and LAO, respectively)
	Pacific Northwest Region (PN)	Region Office and the Columbia-Cascades and Snake River Area Offices (CCAO and SRAO, respectively)
	Upper Colorado Region (UC)	Region Office and the Albuquerque and Provo Area Offices (AAO and PAO, respectively)

Subsequent to those three questions, the operators were invited to explain the classifications they offered. Some respondents took the opportunity to explain specific product responses, while others provided overarching explanations on how they approached this assessment section as a whole. Other respondents also took the opportunity to identify information products that they rely on that were not included in this use assessment.

- ***What have we tried to use but didn't adopt?*** Respondents were asked to consider situations where they piloted the use of a new hydroclimate information product or service to support the development of operational outlooks at any of the resolutions discussed above. Respondents were then asked to cull out the situations where they adopted the products for outlook development and decision support (which should be reflected in the "*What do we use now?*" section) and instead to focus only on the situations where the outcome was to *not* adopt the product for further use. For the latter situations, respondents were asked to describe the pilot situation and explain their reasons for no adoption.

- ***What are some of the wish-list products and services that we can envision?*** Lastly, respondents were invited to offer their perceptions about needed products and services. The section approached the question in two ways: (1) to what extent were operators aware of products and services offered outside their region that would be useful in their jurisdiction, and (2) what products could they envision being produced by NWS or other services that would be beneficial to their operation if made available.

A total of 41 responses were gathered within USACE and 22 within Reclamation distributed across the offices listed in Table 4. This pool of respondents includes operators from all USACE Division and Reclamation Region jurisdictions shown on Figure 1, as well as the USACE Pacific Ocean Division. The next section addresses feedback gathered with respect to each of the assessment questions.

4.2 What Do We Use Now?

This section addresses the first assessment section and complements Appendix C, which provides product-specific summaries of information usage and decision influence associated with the products in Table 3. Appendix C offers two types of summaries: agency-aggregated and geographically distributed. The agency-aggregated view is useful to consolidate feedback and set up a view of relative usage and influence across the products and across the agencies. The geographically distributed view provides more evaluation granularity, which will allow the opportunity for more focused discussion of results among basin-specific jurisdictions.

4.2.1 Product Use Summaries

Each summary is structured as follows:

- Agency aggregate use
- Geographically distributed use
- Synthesis of quotes (for products that had a significant number of quotes)
- Quotes

To preview the first two parts of each product summary in Appendix C, consider the NWS CPC Seasonal Climate Outlooks as an example. Agency aggregations of responses on access, application, and influence are shown on Figure 14 (top, middle, and bottom panels, respectively). Respondents were permitted to select one response for access and decision influence and multiple responses for application. The results show that roughly 90% of the 41 USACE respondents indicated that they obtain the Seasonal Climate Outlooks, while roughly 80% of the 22 Reclamation respondents also obtained it. The remaining respondents for both agencies claimed that they were aware that the product was available but chose to not obtain it. For application and influence feedback, the focus is only on the subset of respondents who obtained the Seasonal Climate Outlooks (i.e., 41 from USACE and 22 from Reclamation). Roughly, 90% of respondents from both agencies said that the product would be applicable to coarse-resolution operations outlooks. A significant fraction of respondents also felt that the product would be applicable to medium-resolution operations outlooks, although considerably more so for USACE. On the matter of influencing decisions, very few respondents indicated that they were required to use the Seasonal Climate Outlooks. Most respondents indicated that the product was sometimes subjectively used (i.e., roughly 60% for USACE and 80% for Reclamation).

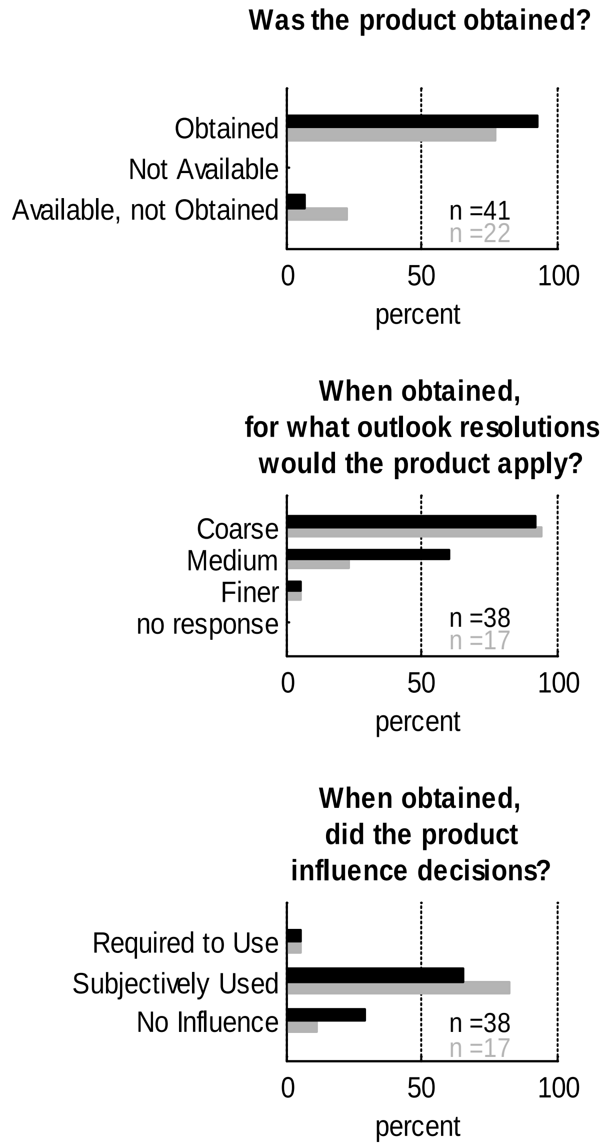

Figure 14. Example product summary, showing feedback about access, applicability, and influence associated with the NOAA NWS CPC Seasonal Climate Outlooks (Table 3). USACE and Reclamation results are indicated by black and gray bars, respectively. In each display, agency responses are pooled across geographic jurisdictions; Appendix C provides a complementary summary that is geographically distributed. The count of responses per agency (n) is indicated in the lower right corner of each panel, following the same color scheme to indicate agency. For the top and bottom panels, respondents were permitted to make only one choice, so the bar values by agency should sum to 100% across the categories. For the middle panel, respondents were permitted to make multiple choices, so the bar values by agency do not sum to 100% across categories.

The responses can be sorted to show the agency geographic distributions of use. Reclamation responses were organized by the finest geographic administrative boundary resolution available, which is Reclamation Area Offices. Reclamation Regional Office responses that did not indicate to be particular for a specific Area Office were attributed to Area Offices within that region that did not have other responses. USACE responses were organized by the finest geographic administrative boundary resolution available, which is USACE District Offices. USACE Water Management Centers and Division responses were attributed to all USACE District Offices with intersecting administrative boundaries.

Figure 15 shows the resulting geographic diversity of access and influence for the NWS CPC Seasonal Climate Outlooks example. Within Figure 15,

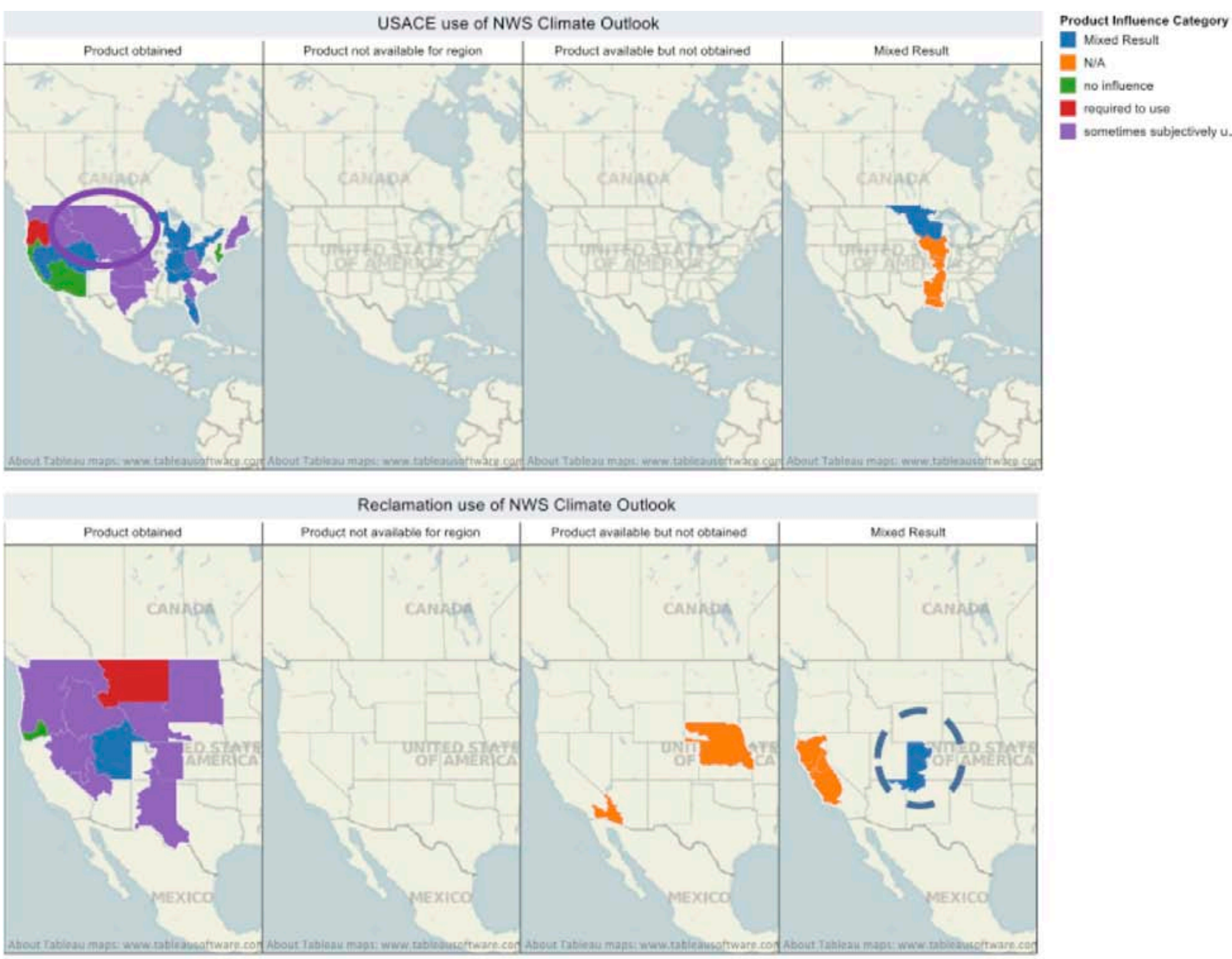

Figure 15. Geographic distribution showing feedback about access and influence category associated with the NOAA NWS CPC Seasonal Climate Outlooks. Results are shown to indicate the geographic diversity of responses for both USACE and Reclamation. The columns represent the product access. Results were considered mixed when two overlapping administrative units replied differently. The circled regions are explained in the text.

rows indicate agency responses; the top row is USACE, and the bottom row is Reclamation. Columns indicate product access. For example, USACE's use of NWS Climate Outlooks for its Northwest Division, Omaha District, which is representative of two responses, the Missouri River Water Management and the Omaha District Office, are circled in solid purple in Figure 15. The responses indicate that the NWS CPC Seasonal Climate Outlooks are obtained and are sometimes subjectively used to influence decision for both responses. A second example is Reclamation's Western Colorado Area Office, which represents two responses for the Gunnison River and the Colorado River. In this case, the two responses had a mixed result for both access and influence. For the Gunnison River, the product is available but not obtained; so there is no applicable response for influence. For the Colorado River, the product is obtained but has no influence on decisions.

4.2.2 Key Themes on Product Use (Agency Aggregated)

Collections of agency-aggregated responses with respect to access, application, and influence are shown on Figures 16, 17, and 18, respectively. The feedback on the use of NWS CPC Seasonal Climate Outlooks from Figure 14 is once again shown on these three figures (the first prediction product in the second row, second column).

For product access (Figure 16), the product obtained most prevalently is USGS stream gauging information, followed closely by NWS COOP Network weather station observations and NWS RFC/CPC precipitation analysis. Monitored snow products also are obtained by many respondents, seemingly more so by Reclamation operators. This is not surprising, given the utility of snowpack information in support of water supply management within the mountainous Western United States. As for predictions products, product access was similar across the two agencies. Where differences arose, they seemed to relate to the different and complementary management objectives addressed by USACE and Reclamation (e.g., more prevalent Reclamation access of NWS RFC and NRCS Water Supply Forecast and more prevalent USACE access of NWS RFC flood warnings, watches, and outlooks). It is interesting to compare access results for NWS RFC Official Streamflow Forecasts with and without QPF, where responses suggest that both are routinely obtained by the majority of USACE and Reclamation operators and that USACE operators more prevalently access the forecasts with QPF.

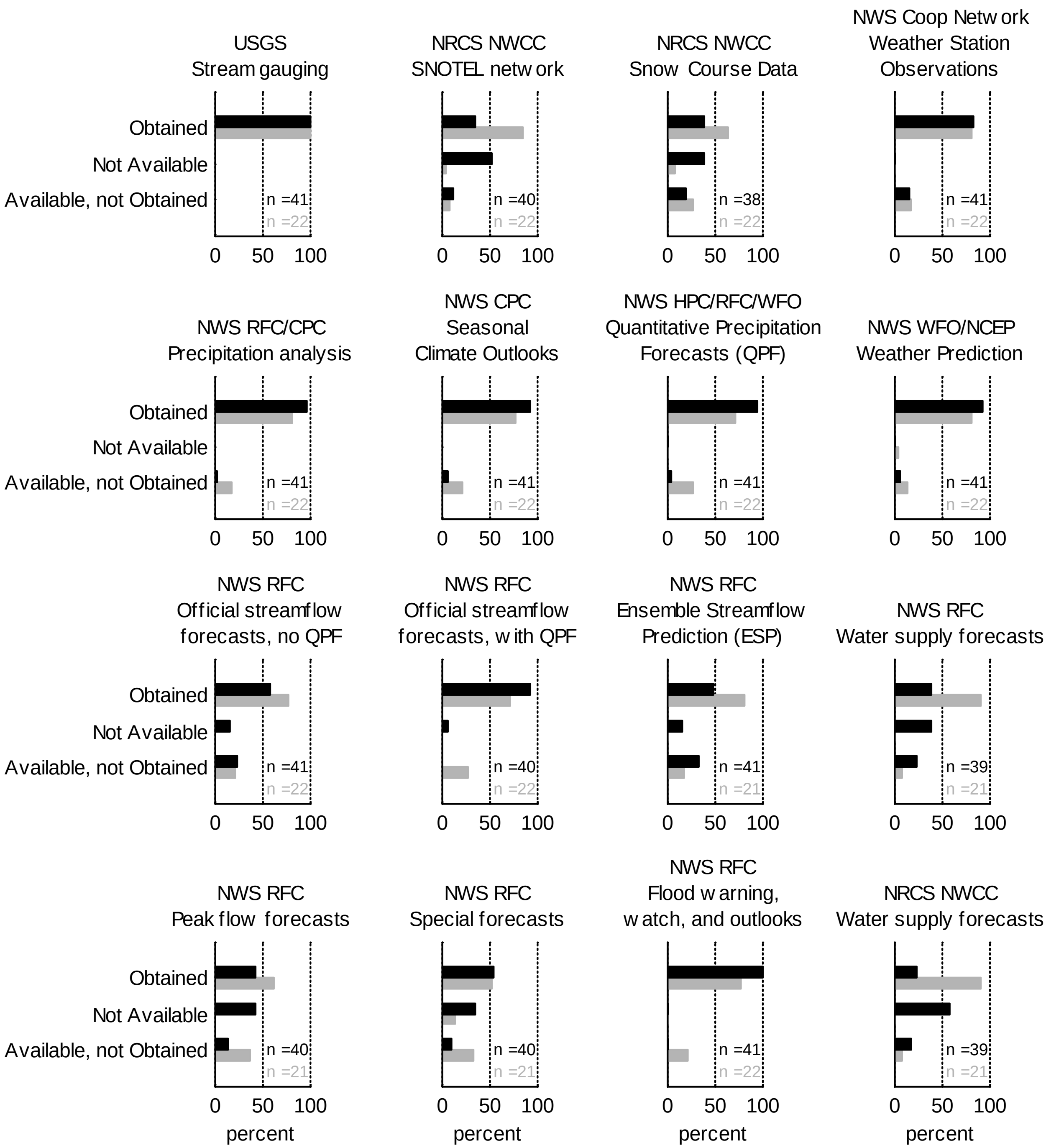

Figure 16. Summary of access results for all products. Results are shown using the format from the top panel of Figure 14. The first five panels correspond to monitoring products listed in Table 3, and the next 11 panels correspond to prediction products listed in Table 3. USACE and Reclamation results are indicated by black and gray bars, respectively.

For product application (Figure 17), results show that most of the products were viewed to be applicable to multiple resolutions of operations outlook development. (Only responses involving "product obtained" were evaluated for application.) For example, significant fractions of USACE and Reclamation operators found USGS stream gauging information to be applicable at all three outlook resolutions (fine, medium, coarse), with the fraction of respondents increasing as the outlooks resolution transitioned from coarser to finer. Both USACE and Reclamation operators found this product to be applicable at the finer resolution. For forecast products, both agencies linked seasonal prediction products (NWS CPC Seasonal Climate Outlooks and water supply forecasts from both NWS RFC and NRCS) to coarse-resolution outlooks. Many operators also felt that such seasonal products were applicable to medium-resolution outlooks, which are concerned with operations over the coming weeks or month. As for the NWS RFC Official Streamflow Forecasts, operators from both agencies felt that the forecasts with and without QPF were similarly applicable, although views across the agencies differed slightly, with the USACE primarily feeling that these products were applicable to the medium- and fine-resolution situations, whereas Reclamation operators saw some applicability at the coarser resolution.

Finally, for product influence on decisionmaking (Figure 18), results show that all of the monitored products have some level of influence on decisions, varying between "required to use" and "subjectively used" by product and agency. (Only responses involving "product obtained" were evaluated for influence.) For forecasting products, the influence classification includes more instances where a product is gathered for situational awareness ("no influence"). The majority of prediction products were primarily classified as being "subjectively used." One exception to this rule appears to be the water supply forecasts (e.g., the majority of respondents from USACE who access NRCS product claim that they do so because they're required to use it; the same goes for Reclamation respondents and the NWS RFC product). Another exception is the QPF product, where the majority of USACE respondents claiming that they obtain this product also viewed it as being required for use. Lastly, for the comparison between NWS RFC Official Streamflow Forecasts with and without QPF, the variation of decision influence across the categories is similar for the two products for both agencies.

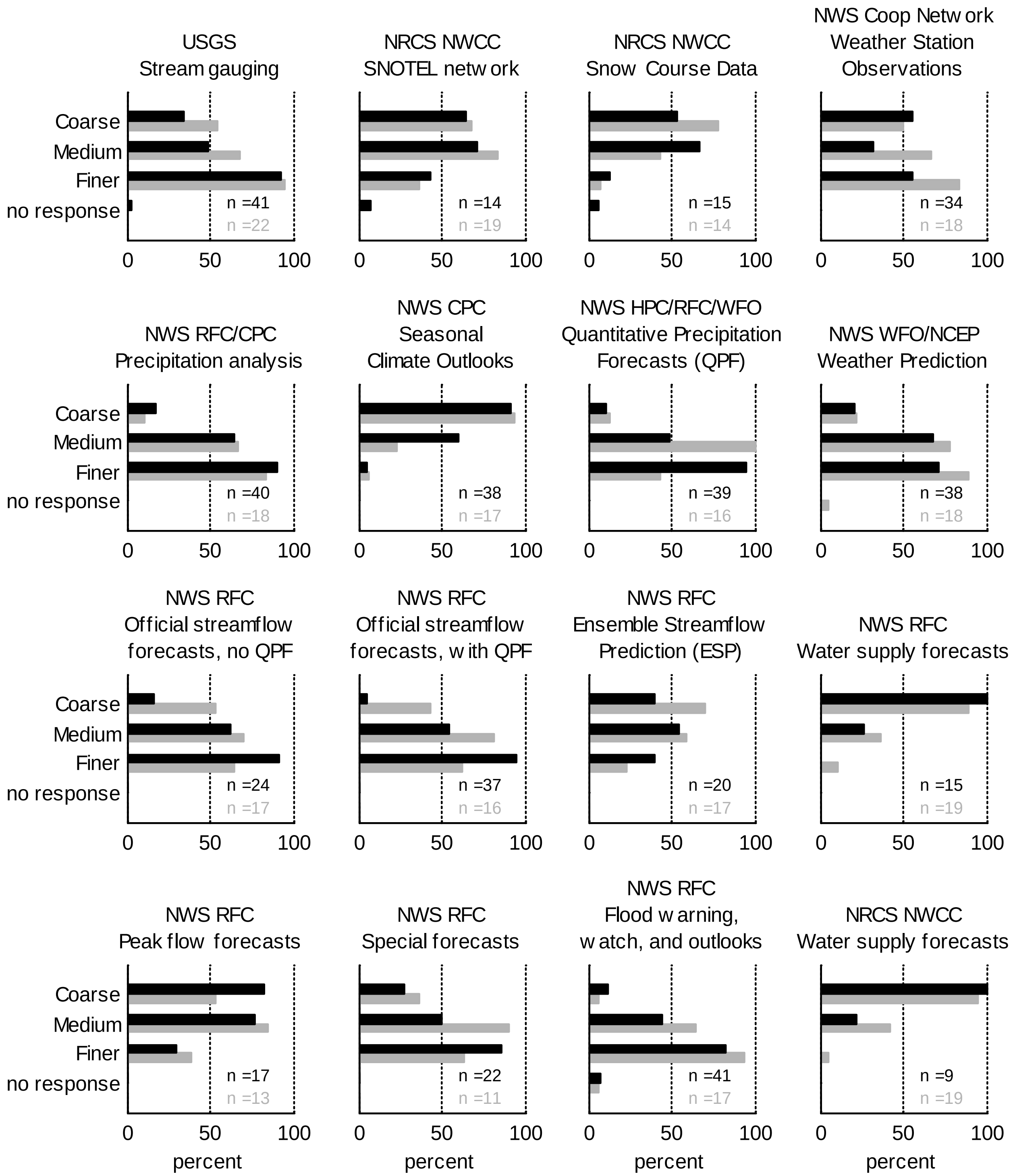

Figure 17. Summary of applicability results for all products. Results are shown using the format from the middle panel of Figure 9. The first five panels correspond to monitoring products listed inTable 3, and the next 11 panels correspond to prediction products listed in Table 3. USACE and Reclamation results are indicated by black and gray bars, respectively.

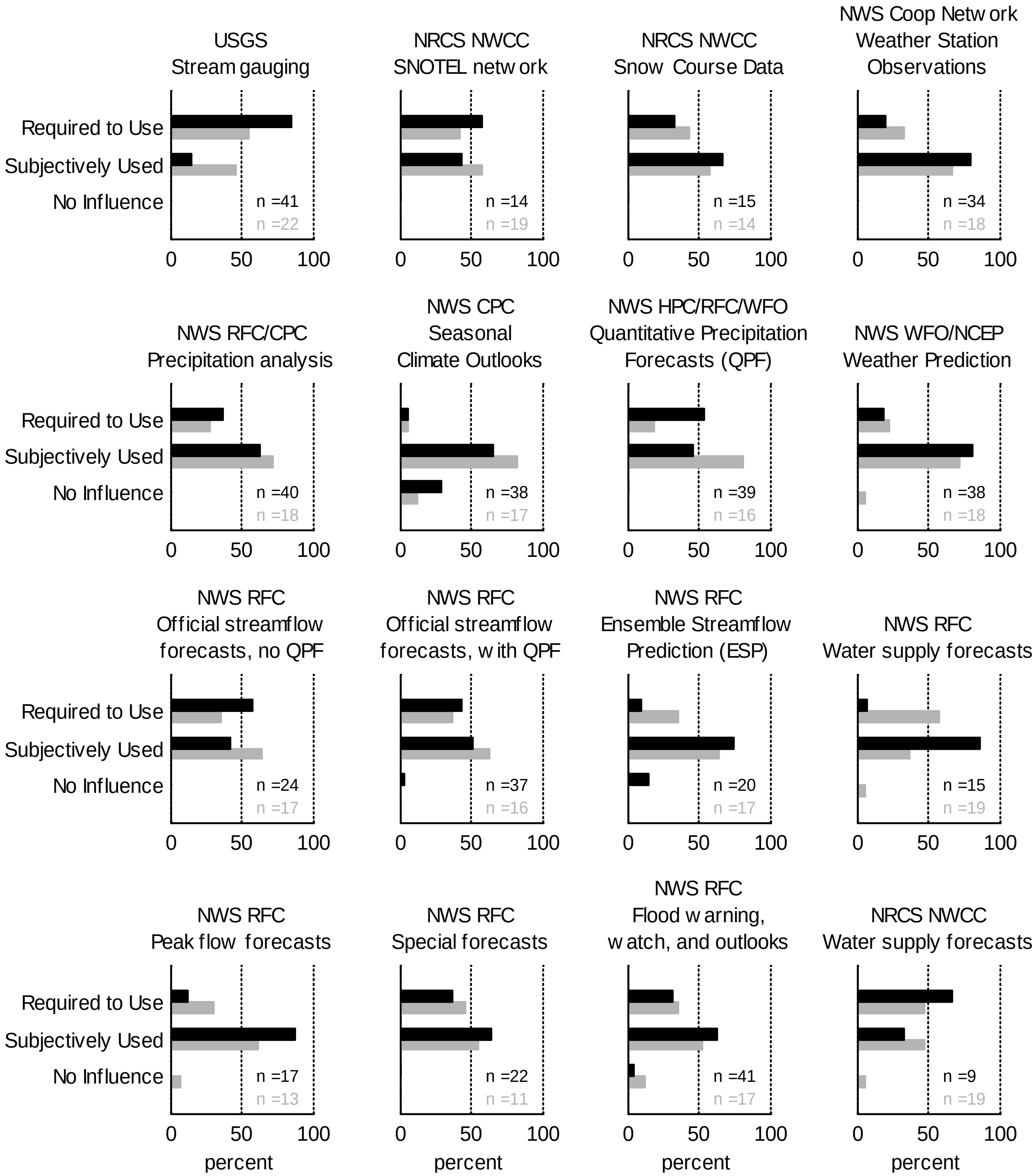

Figure 18. Summary of influence results for all products. Results are shown using the format from the bottom panel of Figure 9. The first five panels correspond to monitoring products listed in Table 3, and the next 11 panels correspond to prediction products listed in Table 3. USACE and Reclamation results indicated by black and gray bars, respectively

4.3 What Do We Need?

This section presents summary needs interpreted from the collection of operator comments in Appendix D on wish list items and attempted pilots. Comments were evaluated and classified according to four needs categories: (1) monitoring products, (2) forecast products, (3) understanding on product relationships and utilization in water management, and (4) information services enterprise. Within each category, several needs statements are offered, along with brief descriptions of operator comments indicating that need. Monitoring and forecast product needs are focused on enhancing or improving products issued by Federal forecasting services, and it is assumed that any achievement in addressing these needs would lead to corresponding enhancement and improvement of extension analyses and products (e.g., Drought Monitor).

4.3.1 Monitoring Products

This section offers several summary statements interpreted from operators' comments concerning precipitation, snowpack, and streamflow observations. Other needs assessments have recognized the need to preserve and expand monitoring networks (e.g., Ingram et al. 2008; Mantua et al. 2008; Western Governors' Association [WGA] 2006; WGA 2008; Johnston et al. 2009; and Federal Interagency Panel on Climate Change and Water Data and Information [FIPCCWDI] 2011).

M1. Sustained support for monitoring networks that provide observations of weather and hydrologic conditions. Hydroclimate observations are essential to the development of prediction models and also are used to guide contemporary operations in multiple water management situations (especially at the finer resolution).

4.3.1.1 Precipitation

M2. Expanded networks of weather stations in water management regions that are currently served by relatively low station density. This needs statement applies to much of the western United States. Operators specifically cited needs in the Desert Southwest and Great Plains. Much of the western U.S. mountain regions also possess sparse station density.

4.3.1.2 Snowpack

M3. More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent. Several operators acknowledged information currently available from NWS NOHRSC and suggested that this information could be enhanced to permit more flexible user interaction with the analyzed products (e.g., region selection, contour analysis). Interactive snow products also could permit user assistance in the quality assurance of snow information that informs forecasting and water management decisions.

M4. Expanded networks of snow-observing stations in the central and eastern United States. Several operators from the Great Plains and Great Lakes regions expressed interest in having access to station snow information similar to that afforded by western U.S. SNOTEL and snow course networks.

4.3.1.3 Streamflow

M5. Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged. Several operators stressed the importance of preserving gauges that have a long history, as well as the historical streamflow information that guides both the development of hydrologic prediction models and the contemporary operation of reservoir and river systems (especially at the finer resolution). Improving streamflow measurement and data collection networks, which includes developing more cost-effective measurement technologies, would also support longer-term efforts focused on climate change and water resource vulnerabilities.

4.3.2 Forecast Products

The section draws attention to operators' needs with respect to anticipating climate, weather, and hydrologic conditions. Comments here are grouped by recurring themes, including precipitation prediction supporting finer-resolution operations outlooks (Figure 4), streamflow to runoff volume predictions supporting all outlook resolutions, water level forecasts, and predictions of other hydroclimate conditions. Other needs assessments also have recognized the need to improve hydroclimate prediction supporting short-term water management (e.g., Ingram et al. 2008; Mantua et al. 2008; WGA 2008; and Reclamation 2010).

F1. Enhanced suite of hydrologic predictions spanning lead times of days to seasons and consistent with the continuum of weather to climate forecast products. This need is interpreted from the collective of operator comments targeting various aspects of this suite, including prediction of precipitation at lead times of hours to days, streamflow at lead times of hours to seasons, and other hydrologic conditions (e.g., see C.2.2, comment by SAD SAJ). Note that this need, as well as needs F5–F8, would contribute to improved drought anticipation and preparedness.

4.3.2.1 Precipitation, Supporting Finer-Resolution Operations Outlooks

F2. More reliable Quantitative Precipitation Forecasts at lead times of hours to days. Several operators stressed that precipitation anticipation is important in their water management situations and that the current level of QPF skill and reliability is often not sufficient for them to confidently base decisions on QPF. This was particularly emphasized for water systems affected by prediction of thunderstorm activity and associated runoff.[*]

F3. Improved precipitation forecasts for landfalling storms in coastal areas. Several operators identified challenges associated with water management in coastal areas exposed to landfalling storms (e.g., hurricanes and atmospheric rivers).

4.3.2.2 Streamflow, Supporting Finer-Resolution Operations Outlooks

F4. Enhanced streamflow predictions at lead times of hours to days, particularly during storm events. A number of operators indicated a need to improve streamflow prediction accuracy at these lead times. Others called for enhancements that involve developing prediction models for locations where products are currently not available, bolstering forecast verification efforts at NWS, and migrating to finer-time-resolution prediction models and forecast products.

4.3.2.3 Streamflow, Supporting Medium-Resolution Operations Outlooks

F5. Enhanced streamflow predictions at lead times of days to weeks, particularly during the snowmelt season. Operators from both the western and eastern United States expressed interest in improved anticipation of snowmelt runoff patterns and the timing of peak runoff.

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[*] One operator also spoke of the need to have an updated understanding of storms that could produce a Probable Maximum Flood (PMF). While this is an analyzed product based on historical information and other assumptions, it does speak to the importance of sustained precipitation monitoring and the value of such information during water management situations.

Other operators spoke of a more general need for improved forecasting during this time scale.

4.3.2.4 Runoff Volume, Supporting Coarse-Resolution Operations Outlooks

F6. Improved anticipation of runoff volumes during lead times of months to seasons. Numerous operators in the western United States expressed interest in having either more reliable predictions at existing forecast locations or expansion of prediction locations, and potentially seasons, that are not currently targeted (e.g., the subbasins contributing Colorado River runoff between Lake Powell and Lake Mead and elsewhere in the Lower Basin). Perhaps more surprising is that several central and eastern U.S operators, including those from the Great Plains, Great Lakes, and South Atlantic regions, indicated interest in having access to such seasonal runoff volume, or "water supply," forecasts. There was also the suggestion to connect them to larger-scale states of climate variability (e.g., El Niño or La Niña states of the El Niño Southern Oscillation).

4.3.2.5 Water Level

F7. Enhanced prediction products characterizing potential water levels during storm events. Several operators emphasized the importance of water level anticipation, particularly in systems that have relatively little storage and are exposed to intense rainfall-runoff possibilities. Requested enhancements included more reliable river stage and coastal storm surge forecasts, as well as integration of Flood Weather Watch Outlooks (WWO) (Table 3) with predicted riverflow and stage products to ease information consumption during such events.

4.3.2.6 Other Hydroclimate Predictions (Seasonal Climate, Snow Accumulation, Evaporation from Open-Water Bodies, Soil Moisture, and Ecosystem Metrics)

F8. Multivariate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions at lead times of days to seasons.[*] Several operators suggested that it would be useful to have predictions of hydrologic states and processes that help characterize the relationship between weather and

[*] Reclamation operators have previously indicated an interest in having longer-lead climate and hydrologic forecast information (e.g., 1- to 5-year lead times) with the interest of being able to better anticipate and prepare for multiple-year drought events (Reclamation 2010).

runoff. Several operators spoke of interest in improved seasonal climate anticipation, with one operator in the Pacific Northwest connecting such improvements to an interest in better anticipation of cold-season snowpack development preceding the spring-summer snowmelt and irrigation seasons. Other operators expressed interest in having improved characterization and anticipation of reservoir evaporation, soil moisture, and aquatic habitat (where hydrologic and air temperature forecasts are linked to biological activity in water bodies).

4.3.3 Understanding on Product Relationships and Utilization in Water Management

The section draws attention to needs statements about the use and understanding of information, which contrasts from the preceding two sections that focused on improving the quality of the information. Comments here are grouped by recurring themes, including (1) information on product development and quality attributes, (2) information synthesis, (3) training on water management and forecasting principles, and (4) a need for enhanced meta-information about available products, including how they were developed and their quality attributes. Other assessments also have indicated needs associated with product development, product quality, reconciliation of products from multiple sources, and/or understanding about how a given product might be better utilized in short-term water resources management (e.g., NRC 2006; Ingram et al. 2008; Mantua et al. 2008; WGA 2008; and Reclamation 2010).

4.3.3.1 Information on Product Development and Quality Attributes

U1. More detailed meta-information describing product skill, reliability, and development. Numerous operators indicated that it's a challenge to confidently determine how to use a product in water management without having a good understanding about the historical skill and reliability of the product (for both monitoring and forecasting products). Several operators felt that skill information is currently lacking for various prediction products and that, in addition to skill, it would be useful to have a better understanding on how prediction models were developed and verified.

4.3.3.2 Information Synthesis

U2. Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations. Several operators expressed "information overload" as a challenge when accessing available information, determining each product's applicability, and making decisions on how the product should be used in water management. One operator emphasized that many managers and stakeholders experience difficultly when trying to decipher how to effectively utilize this wealth of information across the time scales of management situations depicted on Figure 4. Understanding how the information fits together is one aspect of addressing this challenge. The other aspect is an education issue, as described in the next section.

4.3.3.3 Education on Water Management and Forecasting Principles

U3. Training resources on water management principles spanning multiple time scales. Operators face the challenge of working with a diverse set of stakeholders in which individual parties often have a strong understanding of the information and management decisions made at the scales they care about (e.g., finer-scale interests) but not necessarily at the scales of interest to other stakeholders. Balancing concerns across these stakeholders and dealing with the limited mutual understanding sets up difficulty in finalizing operations outlooks, making associated decisions, and explaining them to the stakeholder community. To address this challenge, it would be useful to develop training resources targeted to interested stakeholders and designed to help them develop a better understanding of the time scales of short-term water management, which span hours to years. Such resources might feature learning objectives such as being able to understand hydroclimate information products and their potential synthesis relative to various water management situations, how they're presently used in reservoir operations, and how their use relates to the needs of various water customers.

U4. Training resources on probabilistic forecasting principles and risk-based decisionmaking. Several operators spoke of challenges of connecting probabilistic forecasting information to water management situations. Some spoke of the unreliable nature of probabilistic forecasts, while others spoke of situations where a rare outcome occurred and was "missed" by the forecast. This situation raises a number of questions related to management expectations when using probabilistic forecasts in support of risk-based decisionmaking: What are the development, skill, and reliability characteristics of these probabilistic forecasts? Is a rare outcome in the tail of the forecast a "miss" or a reasonable outcome given the uncertainty bounds on that forecast and the skill of that forecast model? Is the probabilistic forecast being communicated in a way that draws attention to centrally expected outcomes or the breadth of outcome possibilities? What are the risk attitudes of the forecast customer and how are those attitudes influencing how the probabilistic forecast is being used? It seems that it would be beneficial to develop training resources designed to improve understanding of these probabilistic forecasting principles and their relation to risk-based water management. As part of developing training resources, it also may be useful to develop a common "risk" language with definitions and metrics that reasonably apply to the situations of operators and stakeholders (which is a recommendation from Reclamation [2010] that also seems appropriate in this context). One also might interpret the supporting comments to highlight the importance of understanding rare outcomes in the context of probabilistic forecasts. The missed prediction of rare outcomes may be interpreted negatively and may contribute to reduced confidence in using such forecasts long after the missed prediction has occurred.

4.3.4 Information Services Enterprise

The section focuses on the business of providing hydroclimate information services. It presents needs statements that draw attention to desired improvements in model and data maintenance that support products and investment in product deployment formats that more flexibly interface with the information systems used by various water customers. Other needs assessments also have drawn attention to opportunities for improving the interface between hydroclimate information services and water management communities (e.g., NRC 2006; Mantua et al. 2008; Reclamation 2010; and FIPCCWDI 2011).

4.3.4.1 Product Maintenance

E1. Support product maintenance and evolution to accommodate new observations and research developments. Several operators suggested that prediction models should be improved and updated more frequently. One western operator commented on new capabilities to characterize dust on snow, suggesting that such hydrologic forcing should be integrated into snowmelt-related hydrologic predictions.

4.3.4.2 Product Format

E2. Develop product deployment formats that interface more readily with information systems commonly used in the water management community. Several operators commented on the need to receive products in a format that more directly interfaces with the information systems that support their management activities (e.g., USACE's Corps Water Management System). Admittedly, this is a difficult need to characterize, given the diversity of the water management community and its information systems.

4.4 Limitations on Interpreting These Results

The results of the use assessment should be interpreted with some care. They represent the views and perspectives of individual water operators working within a complex framework of policies, stakeholder requirements, authorized purposes, and objectives that would be difficult to convey in any use assessment. When evaluating the results of the use assessment as well as the synthesized needs statements, it is best to keep in mind a few considerations. These include the aggregation of information across each agency, the geographic distrubitons of use, and the classification of influence, among others. Due to the limitations described below and a number of other limitations that are possible, the reader is encouraged to interpret the use assessment responses as a guiding description of responses and not necessarily as a static or comprehensive set of responses.

When evaluating the agency aggregation of usage responses, it is best to bear in mind not only the different interpretations that are possible across use assessment responders but also the diversity of projects represented across the Nation within the aggregation. During considerations of the geographic diversity of responses, there are three notable considerations on interpretation. The first is relating the geographic origin of the response to the authorized purposes of the water operations and objectives in that area. There are multiple projects in every geographic jurisdiction where a response was provided; thus, the response could represent a significant variety of authorized purposes of projects and specific-project operation considerations. Secondly, where multiple scales of geographic jurisdiction responded (e.g., USACE Division and District), the responses could represent either an interpretation difference (described in part below) or a difference in operational responsibilities of those two offices. Lastly, the geographic presentation of information represents the administrative boundary of the jurisdiction, which may not necessarily coincide directly with the watershed boundaries for which operational decisions are made. For example, the Sacramento District of USACE has operational decisionmaking responsibilities ranging from the Great Basin of northeastern and north-central Utah to the Russian River Basin of the north coast of California, to the Truckee River Basin spanning California and Nevada in the eastern Sierra Mountain Range, among a number of other basins. Responses pertaining to this wide range of applications, however, are all lumped within the geographic presentation.

Perhaps the the most complex aspect of the use assessment questionnaire was asking the operators to classify how pieces of information influence their decisions. The complexity of this question has multiple levels. First, operators gather multiple sources of information to inform any decision, and parsing the degree to which any individual component of that process is informed by a single product is difficult. Additionally, the questions posed within the use assessment that related to forecast impact allowed three possible responses: no influence, sometimes subjectively used, and required to use. The “sometimes subjectively used” category reflected a large range of subjectivity. Within the “required to use” category were a multitude of considerations including law, policy, procedure, or general practice. These wide response categories permit multiple interpretations, and use assessment responders indicated that it is easy in some cases to respond that a usage fits in either of the two categories. In that sense, it is difficult to carve a distinction between these two responses in all cases. The same could be said between the “no influence” and “sometimes subjectively used” categories.

The limitations inherent in the use assessment response interpretations also should be carried through to interpreting needs statements. Although needs statements are synthesized directly from use assessment responses, they represent the responses received and various interpretations of the questions asked.

4.5 Summary

This chapter presents USACE and Reclamation operators’ current use and needs for monitoring and forecast information to support short-term water management decisions. These water managers were asked to identify what monitoring and forecast products they currently access, which decisions the products are applicable for, and how these products influence their decisions. Additionally, water managers identify what products they have attempted to utilize unsuccessfully and what products would be beneficial to them in the future if developed.

The results of the use assessment indicate a very dynamic and productive relationship between information service providers and water managers. Product usage reflects the authorized purposes of water management products, the availability of information, and the defined or perceived utility of information that is geographically diverse.

Needs have been classified with respect to four categories: Monitoring Product Needs, Forecast Product Needs, Understanding Product Relationships and Utilization in Water Management, and Information Services Enterprise. Notable needs across these categories include the perseveration and expansion of monitoring systems, improved and expanded issuance of forecast products, educational needs for both water managers and the stakeholder community, and better unification of product delivery with operational tools.

5 Perspectives from Other Water Management Organizations

The preceding sections prepared by USACE, Reclamation, and NOAA NWS are intended to be viewed as a joint agency perspective on improved information and tools that the agencies can use to manage water resources from days to multiyear time scales. This section of the report shares views and reactions to that information offered by other Federal agencies and non-Federal entities, as well as additional perspectives offered by internal managers within USACE and Reclamation. The common attribute of entities providing these additional perspectives is that they all play a critical role in managing water and water-related resources.

The purpose of this section is to provide a summary of views and perspectives offered, including opinions on how to prioritize the needs identified previously in this document. This section first describes the process for gathering additional perspectives, followed by a discussion of key themes of the gathered perspectives.

5.1 Process for Gathering Perspectives

A draft version of this document completed through Section 4 was distributed to internal Reclamation, USACE, and NOAA NWS offices, as well as non-Federal organizations and other Federal organizations. These entities also received a summary of needs statements, and the respondents could indicate the priority for each needs statement, and offer comments. The entities receiving distribution materials include (also in Appendix E):

- Reclamation's regional and area offices
- USACE Water Hydrology and Hydraulics Community of Practice
- Non-Federal organizations
    - American Water Works Association
    - American Society of Civil Engineers
    - Association of Fish and Wildlife Agencies

- Association of State and Interstate Water Pollution Control Authorities
- Association of State Dam Safety Officers
- Association of California Water Agencies
- Association of State Wetland Managers
- BC Hydro
- California Energy Commission
- California Department of Water Resources
- Central Arizona Project
- Family Farm Alliance
- Interstate Council on Water Policy
- National Association of Flood and Stormwater Management Agencies
- National Water Resources Association
- National Waterways Conference
- Northwest Power and Conservation Council
- Colorado Water Conservation Board
- Colorado River Water Conservation District
- Salt River Project
- Imperial Irrigation District
- Southern Nevada Water Authority
- Metropolitan Water District of Southern California
- Denver Water Board
- Northern Colorado Water Conservancy District
- Trout Unlimited

- Water Utility Climate Alliance
- Waterways Council, Inc.
- Western Governors' Association
- Western States Water Council

- Other Federal water and water-related management organizations
  - Bonneville Power Administration
  - Department of Health and Homeland Security, Federal Emergency Management Agency
  - Department of the Army
  - Department of Defense
  - Department of the Interior
  - Tennessee Valley Authority
  - Environmental Protection Agency
  - Department of Agriculture, Forest Service
  - Department of Agriculture, Natural Resources Conservation Service
  - Western Area Power Administration
  - Department of Health and Homeland Security, Centers for Disease Control and Prevention
- Potential Facilitators of Engagement
  - Council on Environmental Quality, Water Resources and Climate Change Interagency Workgroup
  - U.S. Global Change Research Program
  - Office of Science and Technology Policy, Subcommittee on Water Availability and Quality
  - Western States Federal Agency Support Team

5.2 Summary of Messages Heard

Contributed perspectives include those from the Federal agencies that authored this report as well as the Central Arizona Water Conservation District, Metropolitan Water District of Southern California, Southern Nevada Water Authority, Oregon Water Resources Congress, Northwest Power and Conservation Council, Western States Water Council, Salt River Project, Water Utilities Climate Alliance, and the Family Farm Alliance, which are tallied by needs statement in Table 5. For each needs statement, the percentage of priority-level responses is indicated. This provides a potential indication of priorities across all respondents for addressing a particular need. A complete record of responses is included in Appendix E.

Table 5. Summary of priority rankings based on survey responses.

Subcategory	Label	Needs statement	How would you rank the priority of addressing this need, relative to the other needs?		
			Low	Medium	High
Category: Monitoring					
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.	0%	0%	100%
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.	11%	33%	56%
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and SWE.	11%	33%	56%
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.	29%	29%	43%
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.	11%	11%	78%
Category: Forecasting					
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.	13%	62%	25%

Table 6 (continued). Summary of priority rankings based on survey responses.

Subcategory	Label	Needs statement	How would you rank the priority of addressing this need, relative to the other needs?		
			Low	Medium	High
Precipitation, supporting fine-resolution outlooks	F2	More reliable quantitative precipitation forecasts (on lead times of hours to days.	0%	56%	44%
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.	20%	40%	40%
Streamflow, supporting fine-resolution outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.	0%	12%	88%
Streamflow, supporting medium-resolution outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.	11%	22%	67%
Runoff volume, supporting coarse-resolution outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.	20%	40%	40%
Water level	F7	Enhanced prediction products characterizing potential water levels during storm events.	14%	71%	14%
Other hydroclimate	F8	Multivariate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.	22%	22%	56%
Category: Understanding on Product Relationships and Utilization in Water Management					
Information on product development and qualitative attributes	U1	More detailed meta-information describing product skill, reliability, and development.	33%	33%	33%
Information synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.	33%	33%	33%
Education on water management and forecasting principles	U3	Training resources on water management principles spanning multiple time scales.	44%	44%	11%
	U4	Training resources on probabilistic forecasting principles and risk-based decisionmaking.	30%	30%	40%
Category: Information Services Enterprise					
Product maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.	22%	44%	33%
Product format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.	22%	22%	56%

USACE and Reclamation together serve the entire United States for water management, so these need statements are intended to be nationally relevant. The gaps presented were intended to be relevant to all water resources management agencies engaged in water services on the time scales of days to less than 5 years. Responses to this request for additional perspectives reinforce that the needs statements identified through the use assessment are a reasonable representation of needs for operations of water management systems.

Focusing on the four categories of needs, the contributed perspectives reiterate the value placed on observations and monitoring networks that had been found in other assessments of needs to support water resources management (WGA 2006; FIPCCWDI 2011). Forecasting needs were given a high priority, but not as high as observation needs. There was less priority placed on understanding product relationships and information services enterprise information than on the monitoring and forecast needs statements.

The submitted perspectives also pointed out that the needs statements represent a subset of those faced by a wide range of state, local, and tribal governments, as well as non-government organizations. The other sets of needs statements and short-term operations not covered by this document deal with everything from seasonal drought declarations required to trigger reallocation of resources to some types of regulatory and legislative evaluations and compliance. Thus, the evaluation of needs statements in this document should be viewed as an overlap between Federal water resource operations and those of other water management agencies but not an exhaustive representation of the Federal/non-Federal water community's needs.

5.3 Perspectives Summaries for Each Needs Statement

This section summarizes information on gathered feedback and priority rankings by needs statement. A complete record of comments and feedback is provided in Appendix E.

5.3.1 Monitoring

Needs Statement M1: Sustained support for monitoring networks that provide observations of weather and hydrologic conditions

Most frequent priority: High (100%)

By far the clearest message delivered from outside perspectives was the need to support monitoring networks that provide observations of weather and hydrologic conditions. This is consistent with efforts by Federal agencies and states in recent time to protect the networks that provide information (e.g., SECURE Water Act Report 9506; Western States Water Council). Multiple responses indicate the need to maintain continuous records of precipitation and streamflow to support operations but also within the context of detecting climate change. One comment indicated that there may be an opportunity to make networks more efficient by integrating in situ and remotely sensed information and evaluating where duplication of sensors may exist.

Needs Statement M2: Expanded networks of weather stations in water management regions that are currently served by relatively low station density

Most Frequent Priority: High (56%)

Although this need was identified as a high priority, a number of comments indicated that the expansion of observation networks should not be done in an ad hoc manner. A variety of metrics were provided to identify where new sensors would be helpful to support water resources management. This includes areas of high variability, where increased observations would support assessment and characterization of that variability. Additionally, areas of significant water supply that are under-measured would benefit from increased monitoring. A last example is to place additional sensors in a geographic arrangement so that they can detect changing weather patterns. Sensors must be added using the uniform procedures established for like sensors that already exist. Any additional measurements would benefit a variety of water resources activities, including estimation of drought durations and intensities.

Needs Statement M3: More interactive snow analysis products characterizing basin distributed snow covered area and snow water equivalent

Most Frequent Priority: High (56%)

In aggregate, the responses suggest that a relatively high priority should be placed on addressing this need; however, there was a geographic contrast in responses that aligned with the degree to which snow analyses influenced local water resources management. Perspectives placed a high priority on enhanced snow analysis that could be used to make better predictions of water supply on the seasonal to annual timeframes. Perspectives submitted from outside snowmelt-dominated watersheds indicated that there is not much value to them, for obvious reasons.

Needs Statement M4: Expanded networks of snow-observing stations in the central and eastern United States

Most Frequent Priority: High (43%)

Perspectives submitted with respect to snow observations in the central and eastern United States reflect a geographic applicability of this needs statement similar to statement M3. For water resources agencies operating in the western United States responders did not see increased observations outside their jurisdictions as being a high priority. However, for perspectives submitted from geographic areas where snowmelt influences water management decisions, submitted perspectives indicated that increased observations of snowpack could directly benefit reservoir operations for navigation, flood control, and water supply.

Needs Statement M5: Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged

Most Frequent Priority: High (78%)

With a similar focus to direct observations of existing streamflow networks discussed earlier, preserving and expanding networks of streamflow observations focusing on ungauged watersheds were also characterized as a high priority. Respondents placed high priority on monitoring streams and rivers that are modeled outputs of existing operations models that could better help simulate and validate system operations. This contributed perspective applies to more than just ungauged streams, but it reinforces the needs for ungauged streams, as well as need statement M1. One perspective put this need in the context of existing streamflow networks, saying that expanding to ungauged watersheds should be a secondary goal to the maintenance of existing long-term observation networks.

5.3.2 Forecasting

Needs Statement F1: Enhanced suite of hydrologic predictions spanning lead-times of days to seasons and consistent with the continuum of weather to climate forecast products

Most Frequent Priority: Medium (63%)

Perspectives submitted for this needs statement identified enhanced hydrologic predictions spanning lead times of days to seasons consistent with various weather phenomena as a goal that is well worth pursuing. However, several perspectives indicated that, depending on the time scales for new product development, it is not directly known how the information could directly tie into current operations practices. Nevertheless, the perspectives show that it is likely that enhanced hydrologic forecast information on these time scales would lead to better water management, which potentially indicates that water resource agencies would find new ways to use such enhanced information.

Needs Statement F2: More reliable QPF on lead times of hours to days

Most Frequent Priority: Medium (56%)

Most respondents placed this needs statement in a "medium" priority category. Prioritization results include a number of responses that recognize the potential utility to local flood forecasting efforts while also recognizing that QPF improvement may not directly inform the mission priorities of some responding entities. For example, some respondents did not see how more reliable QPF would inform water supply forecasts. Additional perspectives indicate that, among other potential needs, this one is already funded at a level consistent with its development needs.

Needs Statement F3: Improved precipitation forecasts for landfalling storms in coastal areas

Most Frequent Priority: High/Medium (40%)

Filling the need identified for improved forecasts of landfalling storms also prompted responses that varied geographically. Perspectives reflect that, for inland water management systems, this is not a critical priority; whereas for coastal entities, it is a high priority. Perspectives contributed also reflect the relationship between this needs statement and the specific purposes of water management systems. For flood control or stormwater management, this is seen as a high priority; whereas for water supply, it may not be as critical.

Needs Statement F4: Enhanced streamflow predictions at lead times of hours to days, particularly during storm events

Most Frequent Priority: High (88%)

The needs statement related to enhanced streamflow predictions at lead times of hours to days, particularly during storm events, received a very high priority ranking. Most respondents saw this need as being critical for more efficient water resource management. Some felt it could allow for sharper operational tradeoff decisions involving the purposes of water supply and storm water management. For example, improved forecasts might support refined decisions on reservoir storage drawdown in advance of storms so that risks to the system flood control purposes are still alleviated while retained storage is better managed to secure water supply allocations later in the season. For some respondents representing systems having only one purpose that is not impacted by storm runoff, this need statement was not characterized as a high priority. In terms of addressing this priority, it was noted that this could be particularly difficult to accomplish.

Needs Statement F5: Enhanced streamflow predictions at lead times of days to weeks, particularly during the snowmelt season

Most Frequent Priority: High (67%)

Enhancing streamflow predictions at lead times of days to weeks during the snowmelt season also was seen as a high priority. However, this too reflects the diversity of purpose for various water management systems and the geographic context of the needs statement. For example, perspectives from water managers outside of snowmelt-dominated seasons do not see filling this need as a high priority. However, for those who rely on snowmelt for water supply purposes, increasing predictability would be extremely beneficial for anticipating the available supply and managing the system accordingly. Respondents also noted that this can be useful at a variety of watershed scales from the very small to the very large.

Needs Statement F6: Improved anticipation of runoff volumes during lead times of months to seasons

Most Frequent Priority: High/Medium (40%)

Perspectives submitted reinforce that the idea that improved water volume forecasts with lead times of months to seasons are a high priority to be addressed for large river systems that rely on these types of forecasts. Further, multiple responders emphasized that currently available products do not have much skill at long lead times, which suggests that improvements might focus on enhancing longer-lead products.

Needs Statement F7: Enhanced prediction products characterizing potential water levels during storm events

Most Frequent Priority: Medium (71%)

Enhanced prediction products characterizing potential water levels during storm events, like other needs statements related to storm events, were characterized as being potentially valuable for water resources management where missions are related to floods. For water supply systems, respondents did not see this as a priority. Other respondents suggested that, if performance of inflow forecasts to reservoirs could be better defined, then those water levels would be better defined. Lastly, one respondent said that it would be more beneficial to characterize storm response as a river function and not to continue to try to produce single-point hydrographs.

Needs Statement F8: Multivariate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons

Most Frequent Priority: High (56%)

All contributed responses noted that a multivariate suite of climate to hydrologic predictions would be beneficial for a wide range of water resources management responsibilities. These include drought prediction, water supply management, regulatory responsibilities, and flood control. These perspectives identified some of the complexities of trying to accomplish the goals of this needs statement, as well as currently available products.

5.3.3 Understanding on Product Relationships and Utilization in Water Management

Needs Statement U1: More detailed meta-information describing product skill, reliability, and development

Most Frequent Priority: High/Medium/Low (33%)

More detailed meta-information received mixed priorities from contributed perspectives. While the desire for consistent quality assurance and control is an identified need, there is also the perspective that this isn't as high a priority as needs statements that tie more directly into water resources management operations.

Needs Statement U2: Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations

Most Frequent Priority: High/Medium/Low (33%)

Synthesis of available hydroclimate information also received a mixed response in terms of priority. Contributors overall said that better synthesis of information will result in more efficient use of the information, which will result in better water resources management as well as saving money. An additional benefit identified was that, when information is utilized in similar manners across different resource management agencies, the result is improved communication across those agencies. However, one respondent said that, where information is already being utilized, there is already understanding about what the information means and how it can best be utilized within local applications.

Needs Statement U3: Training resources on water management principles spanning multiple time scales

Most Frequent Priority: Medium/Low (44%)

Of all the needs statements, training resources on water management principles received the lowest priority ranking. This reflects the likelihood that there is a belief that information is being both produced and utilized in a relatively informed manner already. However, respondents did identify an opportunity to train both the water management community and stakeholders on the use of information available, opportunities, and constraints.

Needs Statement U4: Training resources on probabilistic forecasting principles and risk-based decisionmaking

Most Frequent Priority: High 40%

Perspectives submitted with respect to training on probabilistic forecasting principles and risk-based decisionmaking set this needs statement as a high priority. This reflects the ties of forecast and water management to the decisionmaking environment. Respondents recognized that a better understanding of the process of information production for water management decisions would benefit both the decisionmaking process and communications with stakeholders. There appears to be a strong desire to better understand the risks associated with water resources management decisions, which can be accomplished through probabilistic forecasts as well as clarification of the limitations of probabilistic forecasts.

5.3.4 Information Services Enterprise

Needs Statement E1: Support product maintenance and evolution to accommodate new observations and research developments

Most Frequent Priority: Medium 44%

Supporting product maintenance and evolution received the most priority votes within the medium category. This reflects contributed perspectives that value that data systems need be kept up to date and able to handle new sources of information. However, it was not rated as high as several needs statements discussed under monitoring and forecasting, where responses to needs were apparently viewed to hold more immediate benefit to water resources management.

Needs Statement E2: Develop product deployment formats that interface more readily with information systems commonly used in the water management community

Most Frequent Priority: High 56%

Developing formats that interface more readily with information systems is characterized as a high priority. Perspectives identified a strong need to put information into formats that can be utilized efficiently. Further, consistent formats lead to better communications between various water resource agencies that are potentially utilizing the same information.

Current capabilities identified by respondents showed that the requirement of having personnel experienced in the use and manipulation of various information types can be redundant across various water resource management agencies. However, there are various efforts at both the Federal and academic levels that are striving for consistently deployed formats, including through Geographic Information System technology, the USACE-USGS-NOAA Memorandum of Understanding on data interoperability, and WaterML.

6 Summary

This report presents a discussion of needs related to improved development and utilization of weather, climate, and hydrologic information in support of short-term water resources management. In the context of this report, short term is identified as water resource decisions that look out less than 5 years This is the second in a series of reports from the Climate Change and Water Working Group (CCAWWG) to identify the needs of the water resource management community in using climate information. The report has been generated by the two largest Federal water resource agencies—the U.S. Army Corps of Engineers and the Bureau of Reclamation—as well as the major provider of weather, climate, and water prediction information—the National Weather Service. The purpose of the document is to both characterize the current state of practice and, more importantly, to inform the broad scientific community of needs with respect to short-term water management such that they can be addressed.

The needs statements in this report are grouped in four categories: Monitoring Information, Forecast Information, Understanding on Product Relationships and Utilization in Water Management, and Information Services Enterprise. The needs reflect the synthesis of information identified by USACE and Reclamation water resource managers through a use assessment distributed to all USACE Divisions and Districts and all Reclamation Regions and Area Offices. The results of the assessment indicate a tremendous diversity of current utilization of various products and the needs of different resource managers based in part on different geographical and hydrologic systems in which they operate as well as different mission responsibilities and authorities. There are numerous opportunities to utilize new and better information, from more skilled forecasts to better management of the information that is already produced. There are, however, constraints within water management institutions that limit the ability to produce and use information and that guide the needs identified within this document.

Water resource management is carried out by a community of Federal and non-Federal entities, so it is important to put the needs statements developed by two Federal water management agencies (USACE and Reclamation) in the context of other Federal and non-Federal perspectives. To accomplish this, this document was distributed to over 50 additional organizations, inviting them to contribute perspectives. Overall perspectives contributed in response to the needs identified within this document reinforced the needs identified by USACE, Reclamation, and NOAA NWS. However, these perspectives also highlight the geographic and mission diversity of water resources management. Large water resource systems that have primary goals of water supply have very different needs than do smaller systems that primarily serve flood control purposes. This complexity re-emphasizes the value of this type of synthesis report to communicate broad, national-level, water resource management needs as well as the local interactions between water resource management agencies and weather, climate, and hydrologic service and information providers.

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Appendix A: CCAWWG Background and Activities

Managing water resources is a mission shared by many Federal, state, tribal, and local agencies and stakeholder groups. Understanding how climate variability and change will affect future hydrologic conditions (e.g., water supply, water demands, water quality, floods, and aquatic ecosystems) and identifying adaptation strategies to manage risks is a shared priority across these entities. Understanding shared priorities, building working relationships, and bringing capabilities together across the Federal/non-Federal spectrum is central to building solutions that have impact.

Working-level engineers, scientists, and managers in two of the primary Federal water management agencies (Bureau of Reclamation [Reclamation] and U.S. Army Corps of Engineers [USACE]) and scientists and managers in two of the primary Federal water- and climate-related science agencies (United States Geological Survey [USGS] and National Oceanic and Atmospheric Administration) formed the Climate Change and Water Working Group (CCAWWG) in 2007 to help address these issues. The Environmental Protection Agency, Federal Emergency Management Agency, and National Aeronautics and Space Administration have since joined CCAWWG.

One common goal of the CCAWWG partners is to assess hydroclimate impacts on water resources and to identify user needs to fill knowledge and technology gaps that support improved management of water resources in a changing climate. This section describes recent activities that support this goal (Figure A1). Activities stem from a foundational document that CCAWWG agencies began working on in 2007 in an effort to present a Federal perspective on climate change impacts to water resources management (Brekke et al. 2009), also known as USGS Circular 1331, *Climate Change and Water Resources Management: A Federal Perspective*. They also fall into two categories: (1) facilitating guidance development on how to address current challenges with respect to hydroclimate change and variability while making best use of existing knowledge, methods, and tools and (2) fostering science-management dialogue and documentation of user needs and science response that

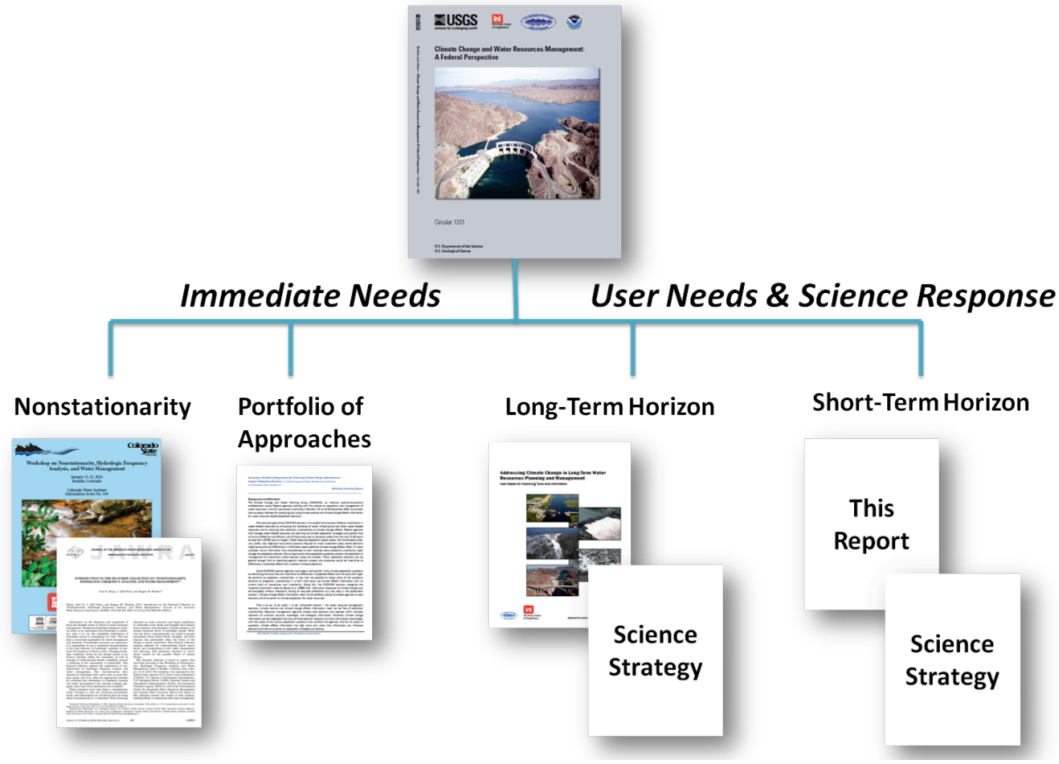


Figure A1. CCAWWG activities stemming from USGS Circular 1331.

would eventually lead to improved knowledge, methods, and tools. This report stems from the latter type of activity and serves as the second needs documentation effort sponsored by CCAWWG. The first is the 2011 report: *Addressing Climate Change in Long-Term Water Resources Planning and Management: User Needs for Improving Tools and Information* (http://www.usbr.gov/climate/userneeds), which summarizes Reclamation and USACE science needs, along with providing a perspective on these needs from other local, state, and Federal water management agencies.

USGS Circular 1331 identified a set of high-priority needs as defined through workshops and discussions with water managers on how to deal with nonstationary hydrology resulting from climate change and other causes. Also, the document draws attention to knowledge gaps on how to characterize natural and social system responses to climate change that, in part, has led to a proliferation of assumptions and approaches for conducting such assessments using existing knowledge, methods, and tools. In response to these situations, CCAWWG convened two workshops during 2010, both of which were targeted to initiate conversation leading to guidance for planning and management.

Appendix B: Use and Needs Assessment Distributed to Operators

This appendix presents the assessment form as it was distributed to U.S. Army Corps of Engineers and Bureau of Reclamation operators. For discussion of assessment development, see Section 4.1 of the main report.

Use Assessment of Use of Weather and Hydrologic Forecasts for Short-Term Water Management
2/02/12

BACKGROUND

This use assessment is being conducted to support development of a report entitled "Short-Term Water Management Decisions: User Needs for Improved Weather and Climate Prediction Information" (ST Doc). The ST Doc is the second in a series of reports by USACE and Reclamation that deal with how use of hydroclimate information in water resources management can be improved. The first focused on user needs related to incorporating climate change information in longer-term assessments (LT Doc), and is available at http://www.usbr.gov/climate/userneeds/.

The ST Doc aims to identify research, development and demonstration needs related to better use of climate, weather and hydrologic information (i.e. monitoring and/or forecasts) in short-term water management decisions. Short-term decisions in this case are those associated with look-ahead periods of generally 1 year or less.

This use assessment is meant to gather real world decision maker perspectives to inform the ST Doc. We would like your help in identifying the following:

- whether the ST Doc description of decision time scales is relevant to your operations.
- which climate, weather and hydrologic monitoring forecast products (hydroclimate products) you currently obtain from NOAA NWS, USGS, NRCS and others; and how they inform your decisions.
- what hydroclimate products would be beneficial to your operation if they were available.
- what types of hydroclimate products you have attempted to use in the past, but ultimately decided to not incorporate formally into your decision processes.

USACE Division / Reclamation Region	
USACE District / Reclamation Area Office	
Primary River Basin	
Location (City, State)	

USE ASSESSMENT

I. Characterization of Operational Outlook Types and related Decisions

Within the ST Doc decision time scales are generally categorized by how far they look into the future (look-ahead). The general terms of coarse (monthly to seasonal), medium (weekly), and fine (hours to days) are used. Figure 1 and Table 1, from the ST Doc, are intended to communicate these concepts to the reader audience.

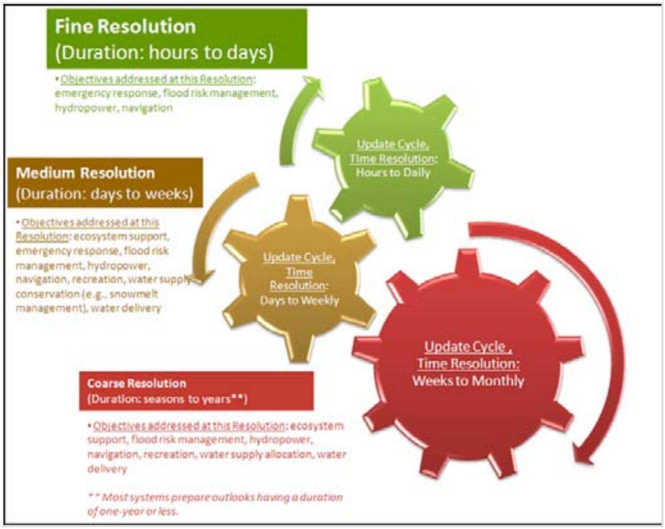
Table 1: Short-Term Decisions: Time Scales, Decisions Supported, Objectives and Constraints.

Outlook Type	Outlook Duration	Update Cycle, Time Resolution	Types of Primary Objectives*	Typical Constraints **
Fine Resolution	hours to days	hourly to daily	-keep river stage between flood and minimum thresholds -shape reservoir release to avoid uncontrolled spill -set hydropower generation duty schedules	-initial water storage (reservoirs, basin wetness) -reservoir regulating curves -downstream control points for flooding
Medium Resolution	days to weeks	daily to weekly	-shape reservoir release to maximize conservation of snowmelt runoff (spring-summer) -… or to support fisheries habitat and migration -… or to support water and power demand patterns	-minimum and maximum flow constraints, including ramping rates (water rights, institutional, regulatory)
Coarse Resolution	seasons to years**	weekly to monthly	-shape reservoir releases to balance two goals: (1) maximize seasonal to annual water supply allocation for various demands and (2) keep end-of-year storage above carryover goal (relevant to systems that are vulnerable to multi-year drought)	-authorized navigation channel depth -any current reductions in system capacities (storage, release, conveyance)

* Primary Objectives vary by system, geography, and time of year. Outlooks include scheduled aspects of other system targets, including reservoir storage and releases and/or river stage and flows at various locations. These secondary decisions are made during the process of settling on primary decisions.

** constraint types are common across the outlook resolutions, but their time-resolutions vary just as the outlook resolutions vary.

Table 2. Outlook Attributes - typical Time Aspects, Decisions Supported, Objectives and Constraints.



Use Assessment Questions:

1. Does this decision time scale framework reasonably encapsulate your groups operations, ranging from finer to coarser resolution?

   Select one

2. Are the time scales, decisions supported, objectives and constraints described in Table 1 and inter-relationships described in Figure 1 reasonable?

   Select one

3. If you feel your operations do not fit within this framework, how would you edit/ refine the general frame to better represent your group?

   Comment here

II. Current Use of Monitoring and Forecast Products

The next set of questions involve identifying which hydroclimate products you use and how they're used for your operational decisions. We have attempted to identify available monitoring (Table 3) and forecasting (Table 4) products from a variety of sources (USGS, NRCS, NWS). For each product we would like to know if you:

a) obtain and evaluate it,
b) in relation to which types of operational decisions,
c) how it is used during your decision process (see Table 2).

Table 2: Classification of how monitoring and forecast information may support decision processes.

Classification	Description
No influence	This product is evaluated for situational awareness, but is not used to inform decisions.
Sometimes Subjectively Used	This product is used at least some of the time to inform decisions. The manner by which it is used is often subjective in nature in that you like to have the information and weigh its value against other pieces of information and use your professional judgement as to how it may influence your decision.
Required To Use	There is either law, policy, procedure, or general practice that dictates how this product is use within your decision processes.

Table 3. Monitoring Information relevant to water management

Please indicate which of the following monitoring products are "obtained and evaluated" by your group and in association with which decision time scales and how they are used. If you use monitoring information that is not listed please add at bottom of table.

Monitoring Information	Originator	Description	Product Obtained	Decision Time Scale Supported	Classification
Stream Gauging	USGS	[monitoring] real time and historical stream gauge measurements	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
SNOTEL Network	NRCS NWCC	[monitoring] recent precipitation and temperature conditions; current snow water equivalent conditions	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Snow Course Data	NRCS NWCC	{monitoring] current snow water equivalent conditions	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Weather Station Observations	NWS COOP Network	[monitoring] recent and longer-term historical precipitation and temperature conditions.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Precipitation Analysis	RFCs CPC	[monitoring] real time analysis of precipitation amounts at hourly or greater time steps that combine gauge, radar, and satellite estimates of precipitation.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use

Table 4. Forecast services relevant to water management
Please indicate which of the following forecast products are "obtained and evaluated" by your group and in association with which decision time scales and how they are used. If you use forecast information not identified please add at bottom of table.

Forecast Information	Originator	Description	Product Obtained	Decision Time Scale Supported	Classification
Seasonal Climate Outlooks	CPC	[forecasts] probabilistic forecasts for seasonal temperature and precipitation anomalies	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Quantitative Precipitation Forecasts (QPF)	HPC RFCs WFOs	[forecasts] precipitation magnitude forecasts typically extending five or more days into the future at daily or sub-daily tie steps.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Weather Prediction	WFOs NCEP	[forecasts] other NWS weather forecast products of varying lead times and spatial resolutions.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Official Streamflow Forecasts, no QPF	RFCs	[forecasts] other NWS weather forecast products at varying lead times and spatial resolutions.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Official Streamflow Forecasts, with QPF	RFCs	[forecasts] deterministic hydrograph forecasts extending five or more days into the future, includes incorporation of QPF.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Ensemble Streamflow Prediction (ESP)	RFCs	[forecasts] probabilistic streamflow forecasts typically generated for lead times of days to seasons.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Water Supply Forecasts	RFCs	[forecasts] probabilistic runoff volume forecasts targeting seasonal periods for larger sub-basins, including those above major reservoirs (coordinated with NRCS NWCC).	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use

Table 4. Forecast services relevant to water management (continued)

Please indicate which of the following forecast products are "obtained and evaluated" by your group and in association with which decision time scales and how they are used. If you use forecast information not identified please add at bottom of table.

Forecast Information	Originator	Description	Product Obtained	Decision Time Scale Supported	Classification
Snowmelt Peak Flow Forecasts	RFCs	[forecasts] probabilistic forecast targeting peak flow typically from snowmelt.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Special Forecasts	RFCs	[forecasts] streamflow forecast tailored to specific water management decisions.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Flood Warning, Watch, and Outlook	WFOs	[monitoring/forecasts] text products describing current or future hazards based on streamflow forecasts and/or observations.	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use
Water Supply Forecasts	NRCS NWCC	[forecasts] probabilistic runoff volume forecasts targeting seasonal periods for larger sub-basins, including those above major reservoirs (coordinated with RFCs).	◯ Product obtained ◯ Product available but not obtained ◯ Product not available for region	◯ (Coarse) seasonal to monthly ◯ (Medium) weekly ◯ (Fine) hourly to daily ◯ Not characterized	◯ no influence ◯ sometimes subjectively used ◯ required to use

Use Assessment Questions:

4. Please focus on a few of the products you identified in Tables 3 and 4 (e.g., perhaps one from each usage type in Table 2). Please write a few sentences to explain how you classified them and describe what factors determine the selected level of consideration (e.g., information reliability, motive for basing decisions on this information, consequences of information being wrong). E.g., for forecast products that are obtained and evaluated, we would be interested in understanding why your use level implies "no influence" on decisions rather than "sometimes subjectively used" or "required for use".

Comment here

III. Desired Hydroclimate Products and Services currently not available:

We also wish to communicate a "wish-list" of products that our operators can envision using if they were available. Example items may include: (1) transfer of geographic-specific services and products to being available in other areas, (2) development of add-value products extending from existing services (e.g., novel analysis and communication of currently monitored or predicted information) and (3) fundamentally new products predicated on science advancements (e.g., development of new or better skilled 1 to 3 month climate outlooks making better use of global to local climate system information).

User Assessment Questions

5. Are there products identified in Part II or elsewhere that are not available in your geographic region that would be useful for the development of operational outlooks? If so, please describe the product and what decisions it would potentially serve.

Comment here

6. Are there products that you can envision that would be useful for decisions if they were available? If so, please describe the product and what decisions it would potentially serve.

Comment here

IV. Attempted additional uses of Hydroclimate Products [OPTIONAL]

Within this section we are hoping to communicate information about previous attempts your group has made to modify your decision to use new hydroclimate products. If the demonstrations successfully led to integration, then your responses to Part II should reflect that. In this section, we only want to hear about the demonstrations that did not lead to integration (unsuccessful demonstrations).

User Assessment Questions:

1. For any unsuccessful demonstrations, what were the monitoring products, forecast products and/or product usage methods targeted for being integrated?

Comment here

2. Why were the demonstrations unsuccessful (e.g., lack of product quality, computational resources, work load)? Feel free to focus on one or a couple of examples.

Comment here

Appendix C: Use and Needs Assessment Responses on Current Product Use

This appendix supports the discussion in Section 4.2 of the main report. It provides product-specific summaries of use for the 16 monitoring and prediction products that were included in the use assessment, along with product-specific quotes regarding access, application, and decision-influence (Sections C1–C16). Each product-specific summary has four parts:

1. *Agency Aggregate Use*: This summary describes product use collectively across the various regional jurisdictions within USACE and Reclamation. These narratives refer to results shown on Figures 10–12 in the main report, which depict the agency-aggregated usage attributes of access, application, and decision-influence, respectively. An example interpretation of these agency-aggregated results is provided in Section 4.2.

2. *Geographically Distributed Use*: This summary characterizes how product use varies regionally within both agencies, focusing on the attributes of access and decision-influence. Maps of these geographically distributed usage attributes are provided in this appendix. An example interpretation of these agency-aggregated results is provided in Section 4.2.

3. *Synthesis and List of Quotes*: Operator comments explaining their use of a given product are listed in each summary, preceded by a brief summary of key themes across these quotes. For some products, there were few to no quotes; and, consequently, no synthesis was made.

This appendix also includes operators' descriptions of additional information products that they use (C17) as well as comments on other miscellaneous usage topics (C18). Before reviewing each summary in C1–C16, it is important to recognize that some respondents also had over-arching quotes that explained their responses to multiple products. Such quotes are listed below rather than listed duplicatively under each product. Note that in the comments listed below and in subsequent sections, the quote sources are denoted by office abbreviations listed in the main report (Table 4). Product acronyms also are defined in the main report (Table 3) and will not be redefined in this appendix.

- *(GP NKAO) Forecasting precipitation magnitude, storm runoff amounts, probabilistic volume forecast targeting seasonal periods are unreliable in our geographical area. Determining runoff and future water supplies varies with each individual event in our part of the world. Each storm system is capable of delivering a large volume of water or none at all. We see storms that deliver 3+ inches of rain in one location and less than an inch of rain just 3 miles away. It is very difficult to provide water supply estimates to irrigators based on potential rainfall/runoff events.*

- *(LC BCOO) Products that are classified as "required to use" include 1) flood control operations, 2) the Colorado River Annual Operating Plan (AOP) and 24-Month Study modeling, 3) Mid-term Operations probabilistic modeling, and 4) Daily and Hourly modeling. Products that are classified as "sometimes subjectively used" can be used when making decisions for real-time and short-term operations, as needed.*

- *(PN SRAO) My responses are dominated by "sometimes subjectively used." The rationale include: 1. Snake headwaters abut both Missouri and Colorado Basins, and the most productive portions of the watershed are near the divides. When other than zonal atmospheric flow persists, subjective use of data from outside the basin may be more useful for operations than the coarse, spatial scale projections from the Northwest River Forecast Center. 2. Some of our project authorizations define an interagency coordination process for forecasts used in flood control. That has allowed significant use of professional judgement in choosing forecast procedures (e.g., stochastic blended with deterministic) and adjustment of climate normals to incorporate long lead precipitation forecasts. 3. Many forecast points are downstream from some storage facilities so forecasts require iteration, and implementation may be required before forecasts are final.*

- *(UC 1) My answers to "Product Obtained," were viewed as this: if we actually collect the information and store it in our database for further analysis, then I marked it as "Product obtained." If I use a product over the Web as occasion permits, then I marked it as "Product available but not obtained."*

- *(PN 2) First of all, I had a hard time with the category "required for use," I was uncertain where to put products that we routinely use but are not necessarily required. I probably classified these as "sometimes subjectively used" but I did not really feel comfortable with either category to describe how I use some products.*

- *(MVD MVN) We produce our own internal river stage forecasts, but during major flood events we want to both be and give the appearance of being in agreement with the National Weather Service (NWS) and their forecasts. Therefore, during a major flood, we may be required to operate our structures based on the official NWS forecast, so I chose "required to use" for official NWS river forecasts without a quantitative precipitation forcast (QPF). Though this is not the case most of the time, the form does not allow multiple selections in this column, so I decided this would be the best answer.*

- *(NAD NAE) NAE's river basins have very short response times relative to most U.S. Army Corps of Engineer districts. Therefore, most long-term forecast products like the Water Supply Forecasts are either not available for the Northeast, or they are not reliable enough to base use in making water management decisions.*

- *(NWD NOW) No influence - nothing fell into this category. Required - Tend to be shorter pieces of data or have direct input to our forecasting/decisionmaking process. Sometimes subjectively used - More subjective pieces of data that may not be directly related to a project, but may be in the vicinity or may give an example of what has happened in the past. Several of these products are considered in regulation decisions but not required, such a forecast that contains QPF or that extends beyond 5 days.*

- *(NWD NWK 1) No influence - nothing fell into this category.*

- *(SAD SAJ 1) CPC/HPC – "Required to use" represents products that are utilized as an item in the water control plan to determine the "allowable range of release values." WFO/RFC – "Sometimes Subjectively used" represents products that can be utilized in the the decisionmaking process for water management operations to best achieve a balance among the multiple project purposes.*

- *(SAD SAJ 2) CPC/HPC/WFO/RFC – "Sometimes Subjectively used" represents products that can be utilized in the the decisionmaking process for water management operations to best achieve a balance among the multiple project purposes.*

- *(SAD SAW) There are few if any products available in our region that I would classify as having "no influence." Nearly all of the products I'm aware of have at least some subjective value. However, I do consider the real-time and near real-time streamflow and precip products to have the most significant value in our day-to-day operations.*

- *(NWD NWS) With the RFC streamflows, we use these as the baseline for our assumed inflow, but not a given. They can often be 50%+ high or low. We used U.S. Geological Survey (USGS) stream gauging to verify patterns we would expect for inflow/local flow. Then we make estimates of actual flows to be seen by looking at observed rainfall, snowmelt,radar and project weather. We look at almost any piece of relevant data we can find and use it to supplement our decisions. There is little data I can think of that would have "no influence" and is related to our operations.*

C1 USGS Stream Gauging

Agency-Aggregated Use

All USACE and Reclamation respondents indicated that they access these data. Roughly 90 percent (%) of respondents suggested that these data are applicable to finer-resolution outlook development; for medium- and coarser-resolution application, there appeared to be greater applicability within Reclamation. On decision-influence, the prevalent response within USACE was "required to use," meaning that these data were indeed featured in operational outlooks and implicitly inform decisionmaking. For Reclamation, there was roughly an even count of responses of "required to use" and "subjectively used."

Geographically Distributed Use (Figure C1)

USGS stream gauging, which includes stream gauge sites funded by USACE and the Bureau of Reclamation (Reclamation), as well as stream gauges owned and operated by USACE, are obtained for all geographic administrative boundaries that responded. The influence of the gauges is largely considered to be required to be used or sometimes subjectively used throughout the geographic distribution.

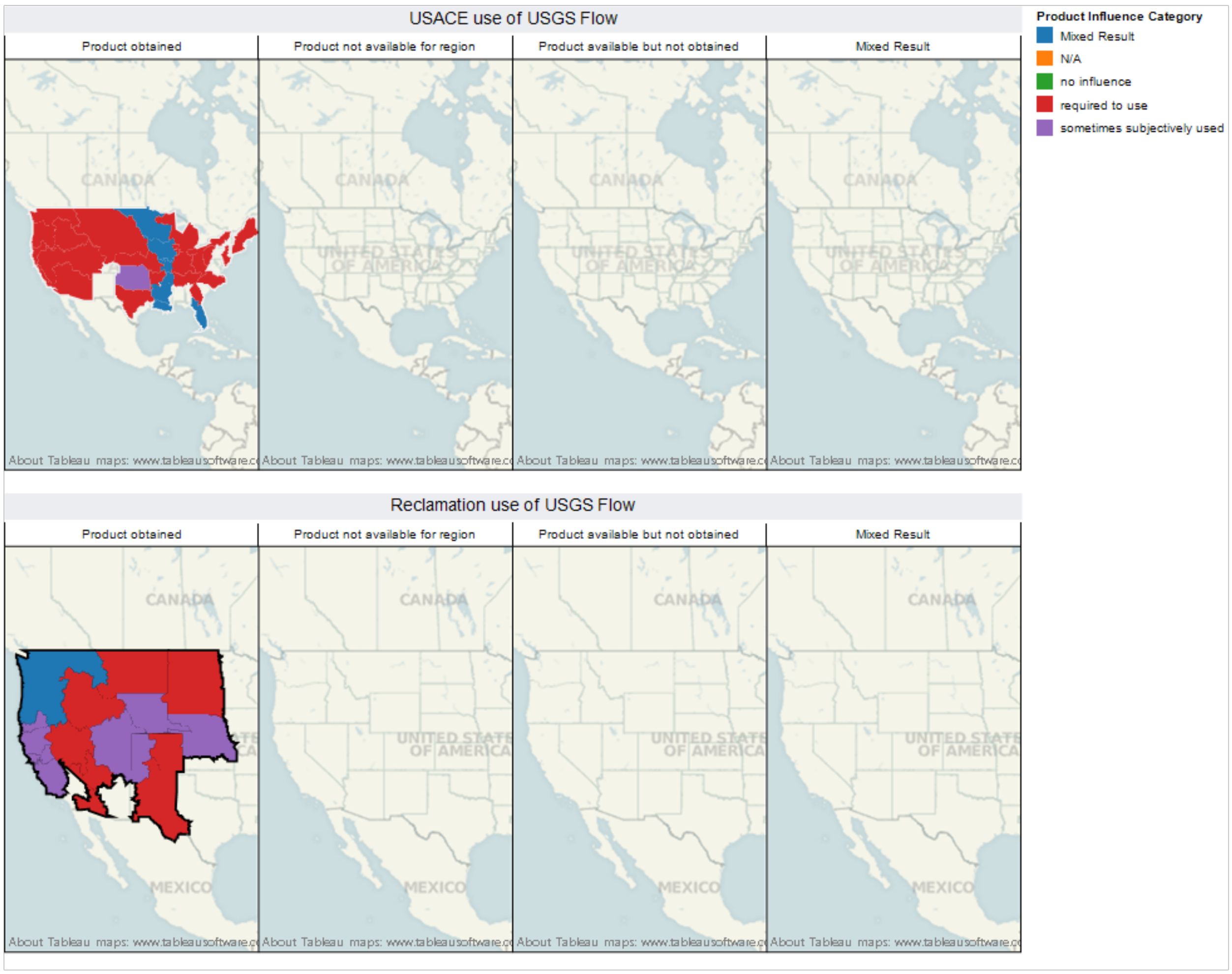


Figure C1. Spatially distributed access and influence by agency for USGS Flow. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

Synthesis of Quotes

Operators from both agencies clearly use this product to support a variety of finer- to coarser-resolution operating decisions. Both agencies emphasize that stream gauging data are critical to support their short-term decisions. Some indicated that the uniqueness of USGS stream gauging information and the critical need for this type of information led them to classify this product influence as "required to use." Some also indicated reliance on other non-USGS stream gauging networks (e.g., internal, state, local).

- *(PN) I said the USGS and Snotel data were "required to use" they're not "required" but provide the only means to get this hydrometeorological data.*

- *(LRD-LRC) The District supports flood control and navigation operations. The major factors affecting flood risk and emergency management operations are real-time precipitation and river stage forecast. Therefore, the USGS' stream gauging and National Weather Service's QPF and Advanced Hydrologic Prediction System (AHPS) products are useful tools. Other products may provide additional information but would not be directly linked to decisionmaking to a large extent.*

- *(LRD LRN) Stream gauges - Classified as "Required to use." Availability and real-time data are extremely important to verify and/or calibrate hydrologic models.*

- *(LRD LRP) Monitoring Information: Stream Gauging Daily reservoir operations heavily rely on stream levels within the watershed; therefore, stream gauging information is critical and required to be used. We use stream gauge data on an hourly basis to monitor critical river levels, weekly when providing 3- and 5-day reservoir and river forecasts, and seasonally when analyzing trends associated with the current weather pattern.*

- *(MVD) Stream Gauging by the USGS was classified as fine required product, since it is important to see what is happening upstream in order to react downstream. This is one of the more important aspects in water management on the Mississippi River, because the way a stream gauge reacts upstream will have a correlation to the way the downstream gauge reacts.*

- *(NAD NAP) USGS stream gauge data is required for use. Specified gauge heights at damage centers trigger impoundment of inflows at three of our flood control projects.*

- *(SAD SAS) We live off of gauge data. Primarily the USGS stream gauges and the RFC precipitation analysis. We use this data to schedule our daily releases from the projects.*

- *(SPD SPL 1 and SPK 6) Stream Gauging - Use to monitor current river/reservoir conditions.*

- *(SPD SPK 2 through SPK 5 and SPK 7) Stream Gauging - Sites are used to assure downstream operational limits will not be exceeded and to assist with inflows.*

- *(SWD SWF) Stream Gauging - Fine-resolution. Information reliable, motive for basing decisions on this information. Use of upstream and downstream gauges to assist in computing inflows into reservoirs, with the possibility of needing to make flood releases. Use of downstream gauges to measure flows at control points necessary to determine the accuracy and need to adjust flood releases without exceeding channel capacity if possible. These decisions have serious consequences if the data has errors.*

- *(NWD NWP) Real-time information is critical for making reservoir release dcisions. Historical data is used for planning and guidance for real-time operations - learn by experience.*

- *(SWD SWL) (SWD SWL) USGS stream gauging is necessary for updating rating curves and for monitoring key regulating stations during flood events.*

- *(SPD SPL 2) The Los Angeles Basin is very flashy, and most operational decisions are made base on readily available real-time data (streamflow and precipitation) with consideration given to the latest short-term (<1 day) and medium-term (<5 days) rainfall and runoff forecasts. Seasonal or longer-term forecasts are not useful to our operations. Another significant source of data for us is the network of stream and precipitation gauges operated by non-USGS agencies, especially local county and flood control agencies.*

C2 National Resources Conservation Service (NRCS) National Water and Climate Center (NWCC) Snow Telemetry (SNOTEL) Network

Agency-Aggregated Use

The access tendencies for this product differed between USACE and Reclamation, with roughly 80% of Reclamation indicating that they obtain SNOTEL data, while greater than 60% of USACE indicated that they did not obtain the data, either because that was their choice or because it was not available. This result is understandable, given that USACE usage was assessed throughout the contiguous United States (CONUS), and SNOTEL measurements are only available in the the western-most 11 states of the CONUS plus South Dakota and Alaska. When obtained, the majority of respondents felt that the information was applicable to medium- to coarse-resolution outook development, although a significant fraction of respondents also found it to be applicable at finer resolution. When applied, USACE and Reclamation groups offered similar counts of “required to use” and “subjectively used” responses.

Geographically Distributed Use (Figure C2)

The access and use of SNOTEL information represents the availability of the information that is highly available in the western United States and throughout the midwestern United States as well as in part the Northeast. In areas in the East and Southeast where snow is not a dominant driver of operations, the information is not available and not used. The influence of the products is required or subjective throughout the areas where it is accessed.

Synthesis of Quotes

Operators in the mountainous western United States indicated that SNOTEL data are integral information, supporting short-term operating decisions. As with USGS stream gauging, some indicated that the uniqueness of SNOTEL information and the critical need for this type of information led them to classify the SNOTEL product influence as “required to use.”

- *(GP NKAO) Snow water equivalents do not have much of an impact in our geographical area. Runoff/inflows result primarily from random thunderstorms with very little effect from snowmelt.*

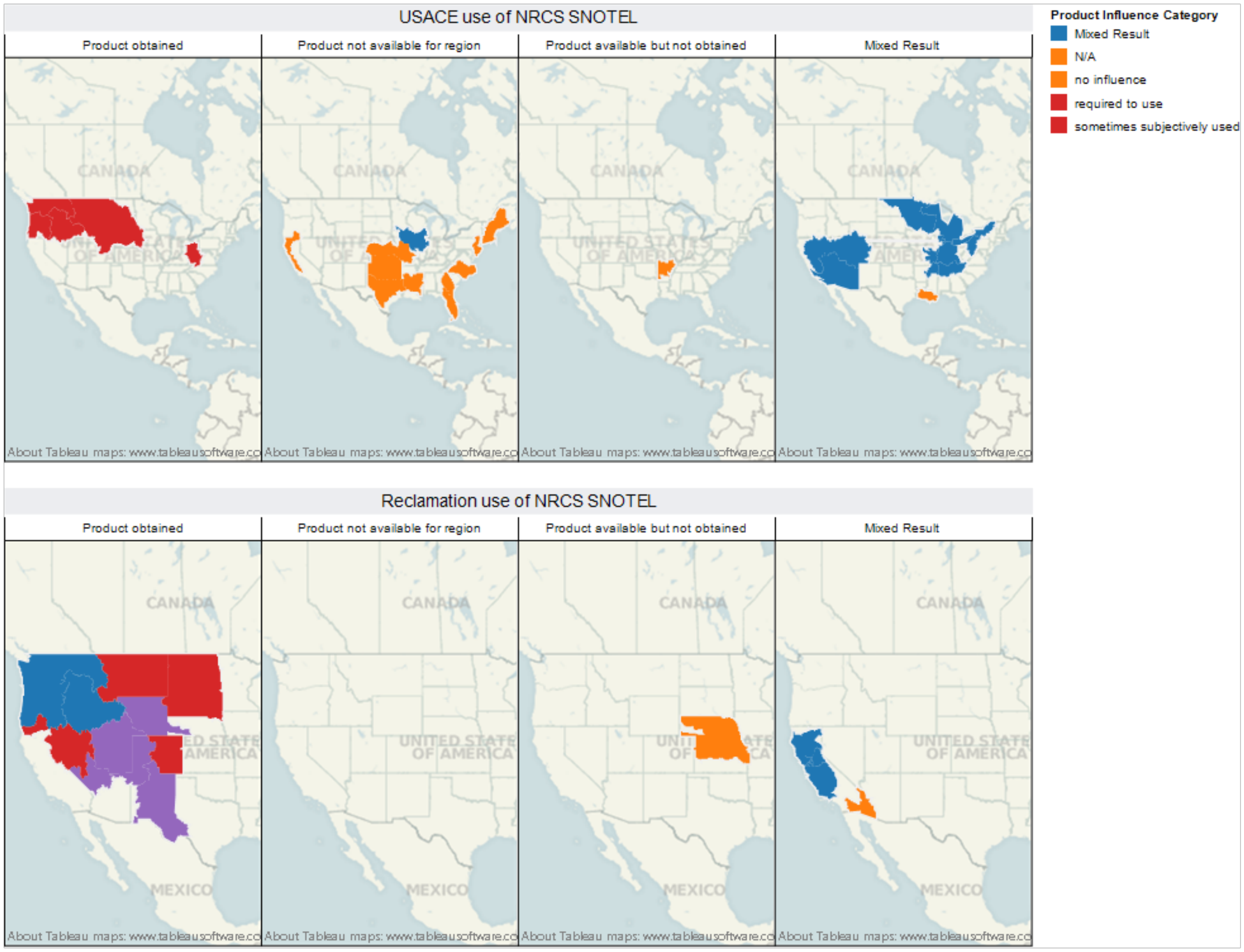


Figure C2. Spatially distributed access and influence by agency for NRCS SNOTEL Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

- *(PN SRAO) Shorter-term products such as RFC streamflow forecasts, current snow water equivalent (SWE) and 5- to 10-day QPF forecasts are among the most important to daily operations. We seldom have the luxury of missing our targets, so certainty is important.*

- *(PN) I said the USGS and SNOTEL data were "required to use"; they're not "required" but provide the only means to get this hydrometeorological data.*

- *(NWD NWK 1) Required for Use - SNOTEL and Snow Course data are an integral part in developing long-term runoff forecasts for the system. The data is used objectively to compute runoff during the May-June-July runoff period.*

C3 NRCS NWCC Snow Course Data

Agency-Aggregated Use

The access, application, and influence responses for this product were similar to those for the NRCS NWCC SNOTEL product, with a few minor exceptions. One is that Reclamation accessed the SNOTEL information more prevalently than the Snow Course Data. Another is that, while most identified the product as being applicable to coarse- and medium-resolution outlooks, there was some different perceptions between coarse and medium for Snow Course Data compared to SNOTEL. Likewise for influence, the respondents generally felt using Snow Course Data, like SNOTEL, was either required or subjective; a slightly greater fraction of respondents felt that Snow Course Data use was subjective compared to SNOTEL.

Geographically Distributed Use (Figure C3)

The access and use of Snow Course information represents the availability of the information, which is highly available in the western United States and throughout the Midwest as well as in part of the Northeast. In areas in the East and Southeast where snow is not a dominant driver of operations, the information is not available and not used. The influence of the products is required or subjective throughout the areas where it is accessed.

Synthesis of Quotes

NRCS NWCC Snow Course Data.

- *(GP NKAO) see NRCS NWCC Snow Course Data.*
- *(PN SRAO) see NRCS NWCC Snow Course Data.*
- *(NWD NWK 1) see NRCS NWCC Snow Course Data.*

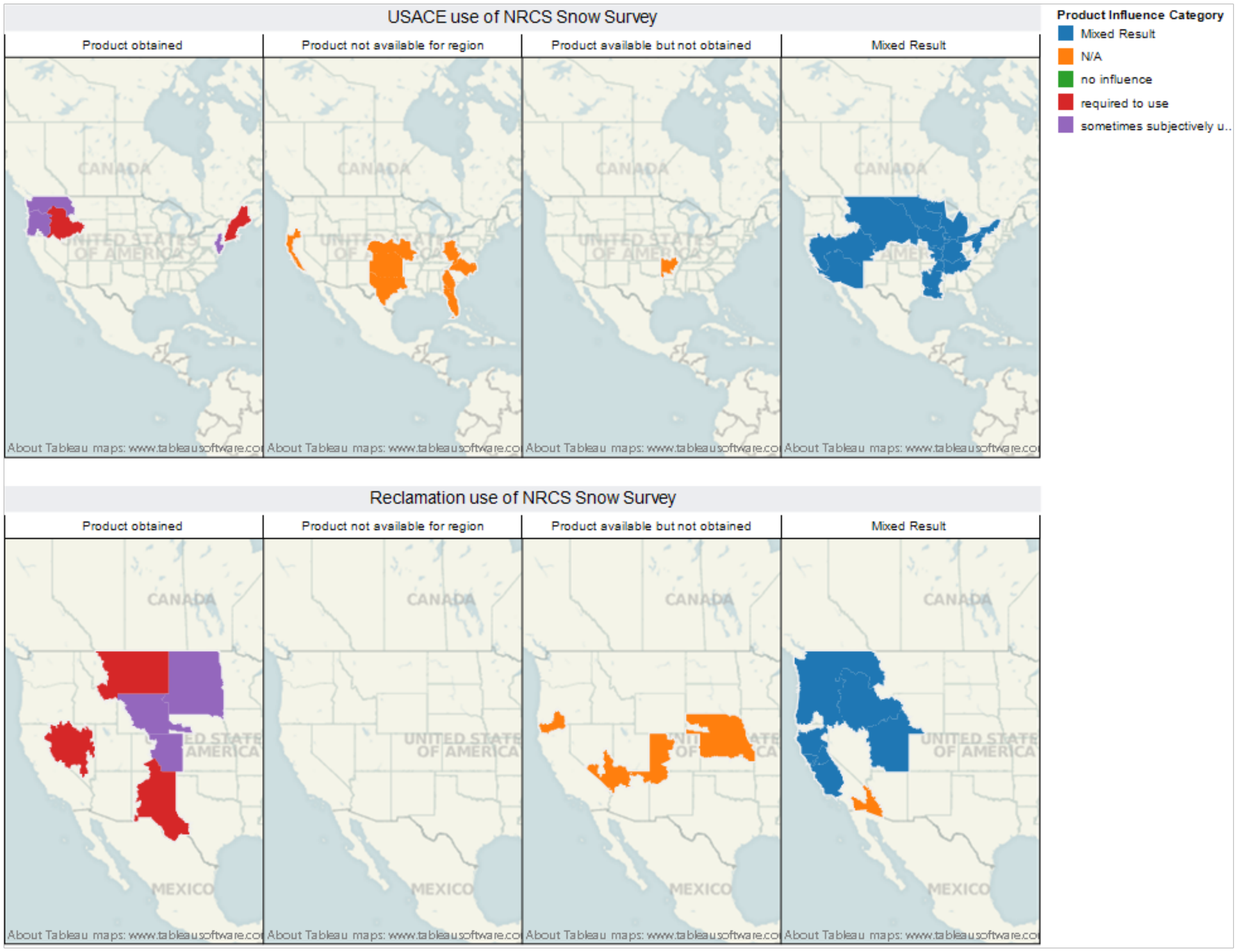


Figure C3. Spatially distributed access and influence by agency for NRCS Snow Survey Data. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

C4 NWS COOP Network Weather Station Observations

Agency-Aggregated Use

USACE and Reclamation groups were similar in that roughly 80% indicated that they obtain these products, while the remainder chose not to obtain them even though they are available. When obtained, USACE respondents found the data to be most applicable to coarse- and finer-resolution outlooks, while 50% to a greater majority of Reclamation respondents found the data to be appliable to each outlook resolution. Progressing to decision-influence, when obtained, all USACE and Reclamation respondents felt these data were either “required to use” or in the category of “subjectively used,” with the latter being more prevalent.

Geographically Distributed Use (Figure C4)

Weather station observations are largely obtained throughout both USACE and Reclamation geographic administrative boundaries, with few exceptions. There appears to be a strong tendency towards required use, with some sometimes subjectively used responses.

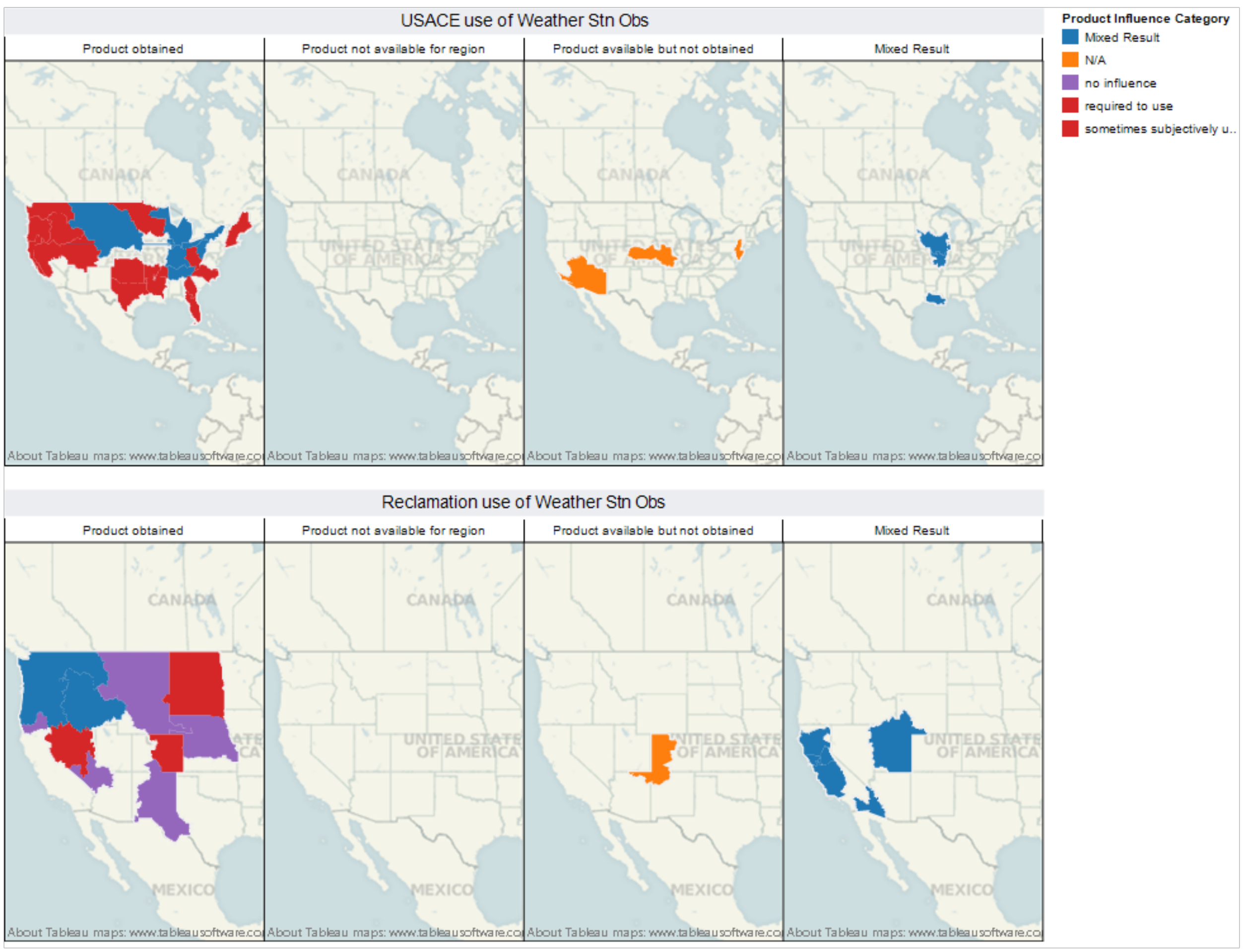


Figure C4. Spatially distributed access and influence by agency for Weather Station Observations. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

Synthesis of Quotes

- *(LRD-LRB) For Weather Station Observations (NWS COOP Network), we wouldn't typically use this data as we either use an integrated hydrologic product (forecast streamflow) or use gridded precipitation.*

C5 NWS RFC/CPC Precipitation Analysis

Agency-Aggregated Use

All USACE respondents except one indicated that they obtain this product, while roughly 80% of Reclamation respondents obtain it. For these respondents, the preponderance of applications were finer- and medium-resolution outlook development, although a few respondents felt that the precipitation analyses were also applicable to coarser-resolution outlooks. Decision-influence for this product is similar to that of the COOP Weather Station Observations, with the respondents feeling that the products were either used per requirement or subjectively.

Geographically Distributed Use (Figure C5)

Precipitation analysis is obtained throughout the USACE geographic domain, with one district in the Mississipppi having a mixed result. The information is required to be used or sometimes subjectively used for USACE. Reclamation also shows a strong tendency toward obtaining the information with some additional mixed responses or not obtained in the southwest and midwestern United States.

Synthesis of Quotes

Reclamation operators in both the Pacific Northwest and Great Plains Regions emphasized that this is a very useful product supporting their operations.

- *(GP NKAO) Real time analysis of precipitation and streamflow are the most utilized tools due to the variability of storm runoff events in our area.*

- *(PN 1) This product provides very useful information to help determine reservoir inflows and required discharges either for local flood control or to control reservoir rate of fill. However, only used to help make stream flow predictions but perhaps not final decisions until actual stream flow trends are observed. Precip data helps to get* *moving in the right direction (i.e., start ramping up releases), also precip rate can indicate how fast a stream will respond.*

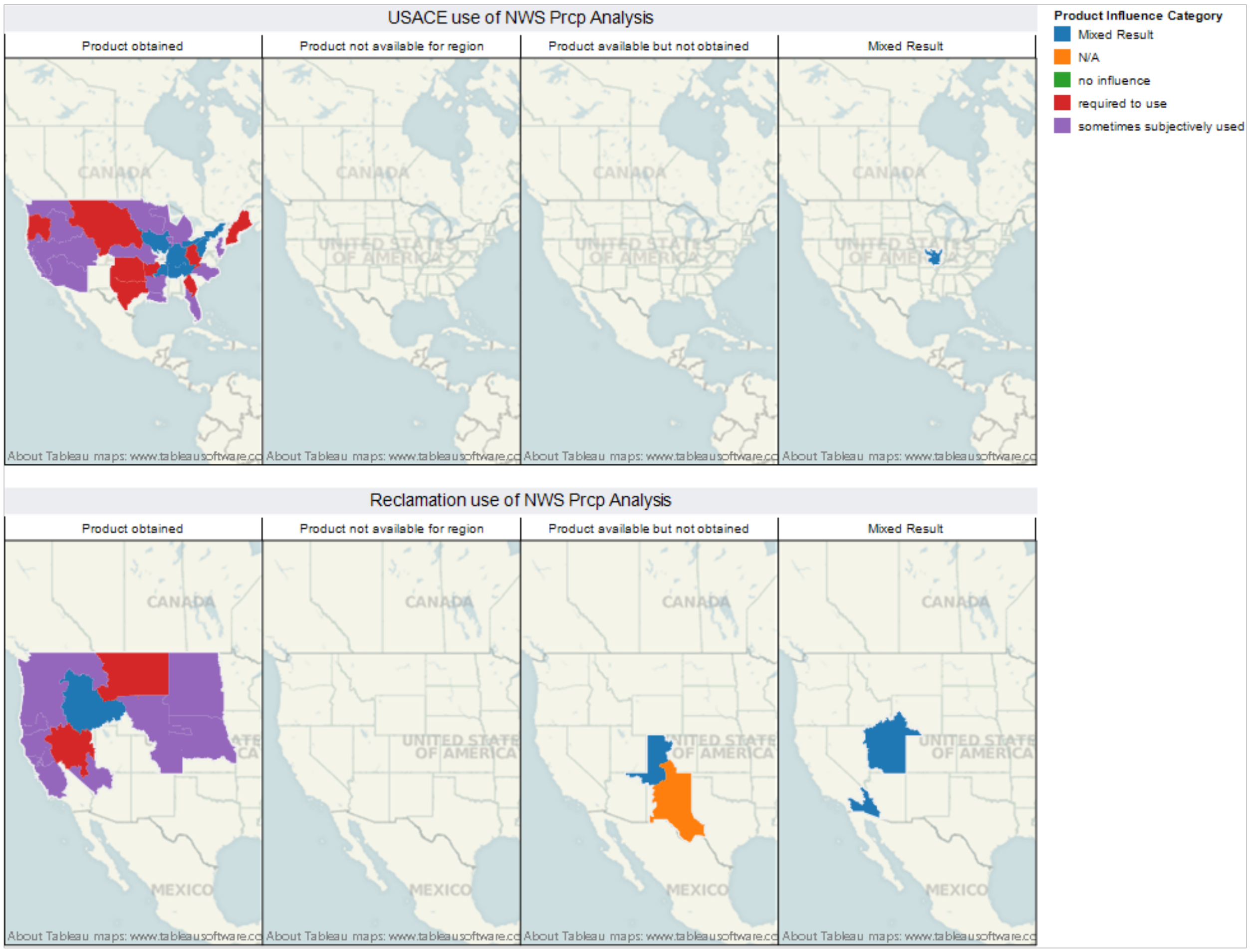


Figure C5. Spatially distributed access and influence by agency for NWS Precipitation Analysis. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

C6 NWS CPC Seasonal Climate Outlooks

Agency-Aggregated Use

Roughly 90% of USACE respondents indicated that they obtain this prediction product, compared to roughly 80% for Reclamation. The remainder of respondents indicated that they were aware of the product availability but chose not to obtain it. When obtained, most respondents felt the Seasonal Climate Outlooks were applicable to coarse-resolution operations outlook development; some respondents also felt the product was applicable to medium resolution, particularly within USACE. On decision-influence, most respondents indicated that the product was either sometimes subjectively used or beared no influence on operations outlook development.

Geographically Distributed Use (Figure C6)

USACE use of climate outlooks was generally found throughout the continental United States, although within the Mississippi Region, there is mixed access. The influence of use is generally subjective or with no influence. Reclamation also generally obtains the climate outlooks with more predominance of influence within the sometimes subjectively used category.

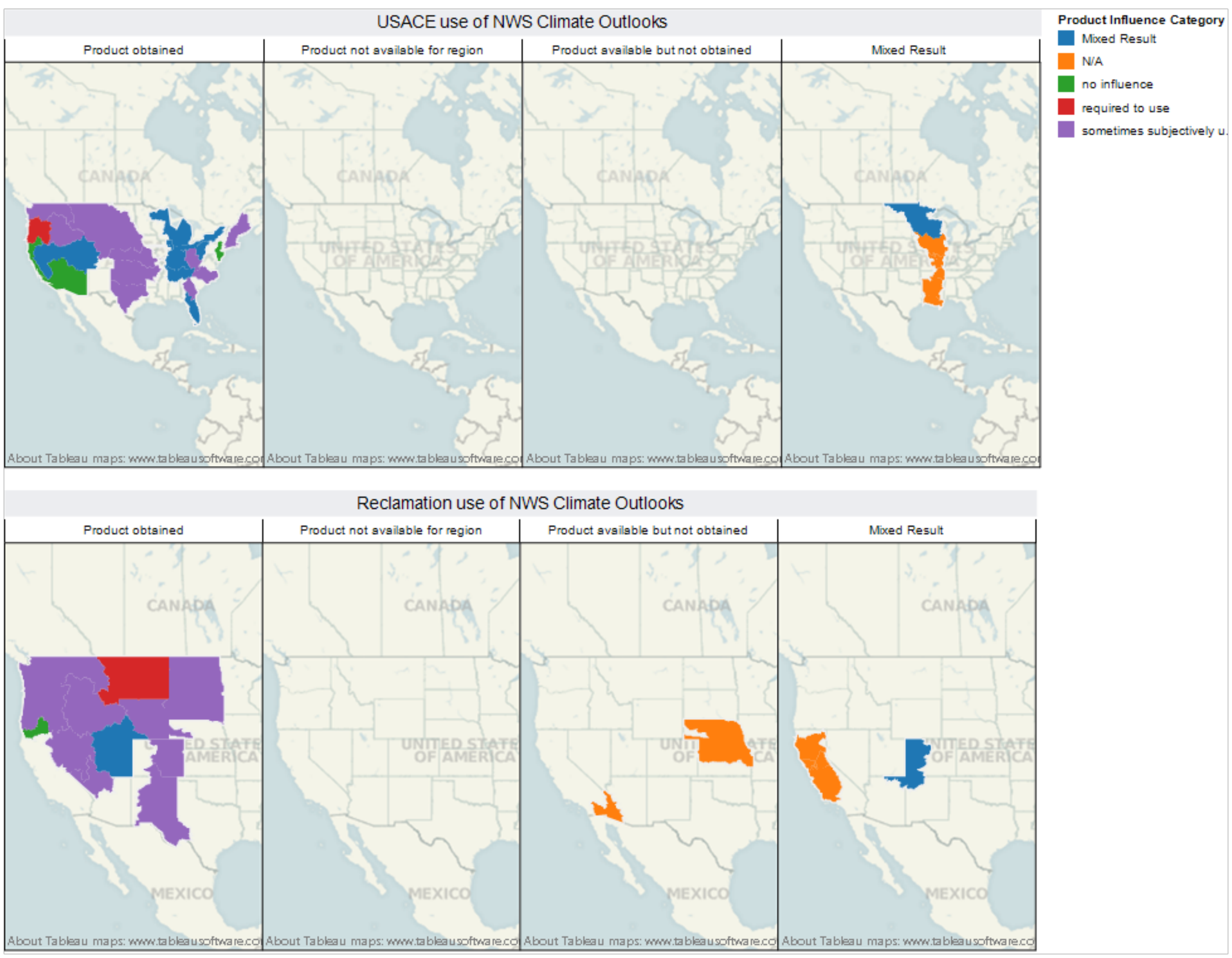


Figure C6. Spatially distributed access and influence by agency for NWS Climate Outlooks. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

Synthesis of Quotes

The USACE operators' responses indicates that the tendency to obtain and evaluate this product depends on the spatial scale and characteristics of the water systems they manage. For example, operators of smaller, "flashier" systems tend to be less concerned about seasonal climate anticipation, whereas operators of reservoir and river systems in large basins tend to give this product more consideration. Still, the latter group has varied tendencies in terms of letting this product information influence outlook development.

- *(LRD LRB) For Seasonal Climate Outlooks (CPC), we wouldn't use as the Mount Morris Dam (Genesee River) is a dry dam used solely for flood control, i.e., we are concerned only about short-term storm impacts.*

- *(LRD) We use seasonal outlooks to anticipate flood season but do not make decisions on them. We use weekly and monthly outlooks sometimes to determine whether to early spring fill a reservoir, as well as soil moisture conditions. We also look at snow water equivalent for both the Great Lakes, the Ohio Valley and the Upper Mississippi Valley to anticipate spring flooding conditions.*

- *(MVD MVR) Seasonal Climate Outlooks - MVR utilizes these outlooks as indicators; additional verification for NWS the 90-day probabilistic.*

- *(NAD NAP) Seasonal Climate forecast have no influence on our operation decisions due to the nature of our basins. Our reservoirs respond quickly to precipitation on the ground.*

- *(NWD NWK 1) Sometimes Used Subjectively - The CPC Outlooks are used on a monthly basis to assist us in developing the long-term runoff calendar year runoff forecasts for the Missouri River reservoir system; however, there is not enough context to equate a precipitation or temperature probability into runoff. Water Supply Forecasts are used as a comparison to calendar year runoff forecasts.*

- *(SWD SWF) Seasonal Climate Outlooks - Coarse-resolution. Information could be somewhat useful in making flood releases based on the current seasonal pattern. Flood releases could be made* *conservatively during forecasted extremely dry conditions and visa versa for extremely wet conditions. The "No influence" category was not selected.*

C7 NWS HPC/RFC/WFO Quantitative Precipitation Forecasts (QPF)

Agency-Aggregated Use

Access feedback on the QPF product is similar to that for the Seasonal Climate Outlooks within USACE and Reclamation, respectively. Applicability perceptions differed between the two agencies. For Reclamation, when this product was obtained, all respondents felt that the QPF products were applicable to the medium-resolution outlook development; for USACE, less than half the respondents felt that this was the case. For the finer-resolution application, the agencies reversed perspectives, with nearly all USACE rspondents indicating applicability and less than half of Reclamation respondents indicating the same. On decision-influence, all respondents indicated that QPF bears some influence on decision, but that influence varies from "required to use" to "subjectively used." There was also a difference in agency perspective, where the majority influence category for USACE was "required to use" whereas it was "subjectively used" for Reclamation.

Geographically Distributed Use (Figure C7)

With one District exception, USACE obtains QPF information. Within the western United States, there is a tendency towards a requirement of influence. Within the Missouri and Mississippi systems, there is more of a tendency towards mixed influence and sometimes subjectively used. Within the western United States and Pacific Northwest, Reclamation also obtains the QPF information. There is more mixed influence and sometimes subjectively used in these areas when compared to USACE.

Synthesis of Quotes

There is a strong tendency to acquire QPF products within USACE and use them for administrative purposes, such as scheduling staff and to remain situationally aware of potential future rainfall events. Actual USACE decisions are based on water on the ground, which is supported by being situationally aware of potential future changes to rainfall inputs to the system.

- *(LC YAO) Our office handling water delivery on a daily basis. I am more interested in flooding scenarios with potential releases from the Colorado Basin and Gila Basin. I would use this data to help me manage delivery to the customers. The forecasted precipitation would be helpful in managing daily delivery but is not required for use by law.*

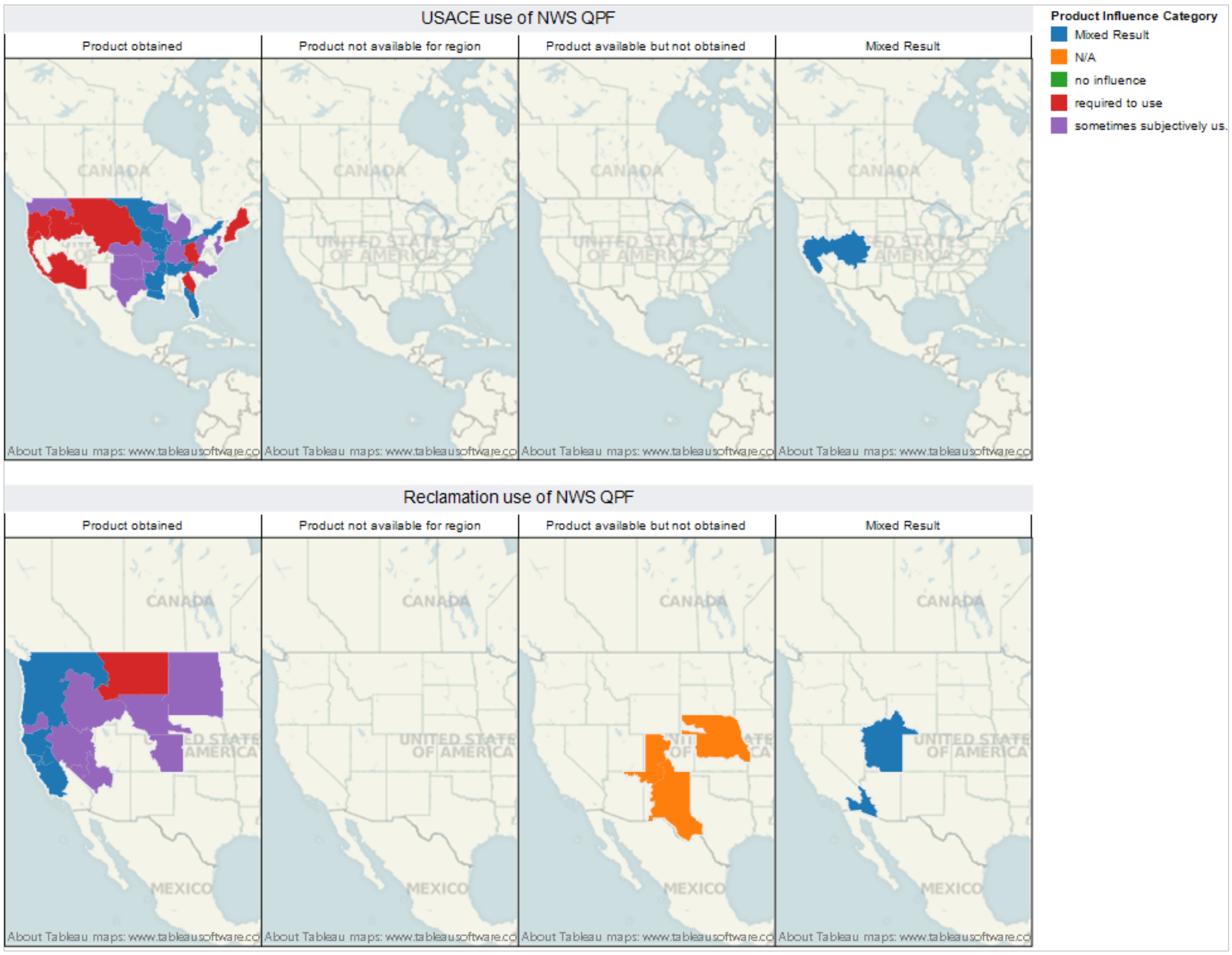


Figure C7. Spatially distributed access and influence by agency for NWS QPF. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed results, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

- *(MP CVOO 1) RFC QPFs and reservoir inflow/river guidance products are routinely used for short-term operations.*

- *(PN SRAO) See "NRCS NWCC SNOTEL Network."*

- *(LRD-LRC) See "USGS Streamgauging."*

- *(LRD LRH) There has been no discernible need for Non-QPF forecasts. Rain on the ground has historically been the best indicator and a sufficient indicator for reservoir operations, excepting flood control operations for the Ohio River mainstem which has flow contributions from more than one Corps of Engineers District. Rainfall forecasts are useful for scheduling staff availability outside normal duty hours and level of vigilance.*

- *(LRD LRP) Forecast Information: QPF We use daily and 5-day cumulative QPF forecasts when gauging approximately how much rainfall will enter the watershed. We refer to these forecasts throughout the week and season to gauge the weather patterns. QPF forecasts are frequently updated and often successive forecasts will offset the previous forecast. For example, one forecast may show a 5-day total precipitation of 5 inches, but then the following forecast will show only 2 inches because perhaps a rainfall event didn't plan out as forecasted. As a result, we use the QPF forecasts subjectively, meaning that we look at the overall trend and don't focus our reservoir operations on one specific forecast.*

- *(LRD) While we use QPF to be situationally aware and to inform and anticipate future decisions, USACE regulations require we do not use QPF in our reservoir regulation decisions. Recently in the 2011 Mississippi Flood, we did request the RFCs to produce 5 day QPF forecasts, but regulation decisions were based on rain on the ground.*

- *(MVD MVS) We don't make operational decisions based on QPF. The local weather seems to be more accurate than QPF forecasts. From past experiences, the stream flow forecast with QPF seems to be overstated.*

- *(NAD NAP) QPF are subjectively used. The QPF is used in conjunction with observed conditions in the basin.*

- *(SAD SAS) We understand that the QPF is subject to variations; and, therefore, we re-calculate out required releases as the QPF changes.*

- *(SWD SWT) The QPF is the most useful product used in water management awareness, however, QPF's have huge variabilities in* *accuracy. Next are RFC stage forecasts that are used to validate Corps Reservoir forecasts.*

- *(SWD SWL) The QPF is the most useful product used in water management awareness; however, QPF's have huge variabilities in accuracy, and we do not make operational changes based on forecast. The QPF is used for situational awareness only! RFC stage forecasts are used to validate Corps Reservoir and downstream gauge forecasts.*

C8 National Weather Service (NWS) Weather Forecast Office (WFO)/National Centers for Environmental Prediction (NCEP) Weather Prediction

Agency-Aggregated Use

USACE and Reclamation access to this product appears to be similar to that of QPF. Applicability perceptions for this product were also similar to that of QPF, with the minor exceptions of more respondents indicated that weather prediction products were applicable to coarser-resolution operations outlook, and there was greater consistency in USACE and Reclamation views on finer- and medium-resolution applicability. On decision-influence, most respondents in both USACE and Reclamation (roughly 70% or more) indicated that the product was "subjectively used."

Geographically Distributed Use (Figure C8)

There is broad geographic acccess to weather prediction information for both USACE and Reclamation. The influence of the product is largely subjective for both agencies.

Synthesis of Quotes

As with seasonal outlooks, USACE decisions are based on water on the ground; however, outlooks of WFO/NCEP Weather Prediction may be useful for anticipating future storm events.

- *(LRD) see "NWS CPC Seasonal Climate Outlooks."*

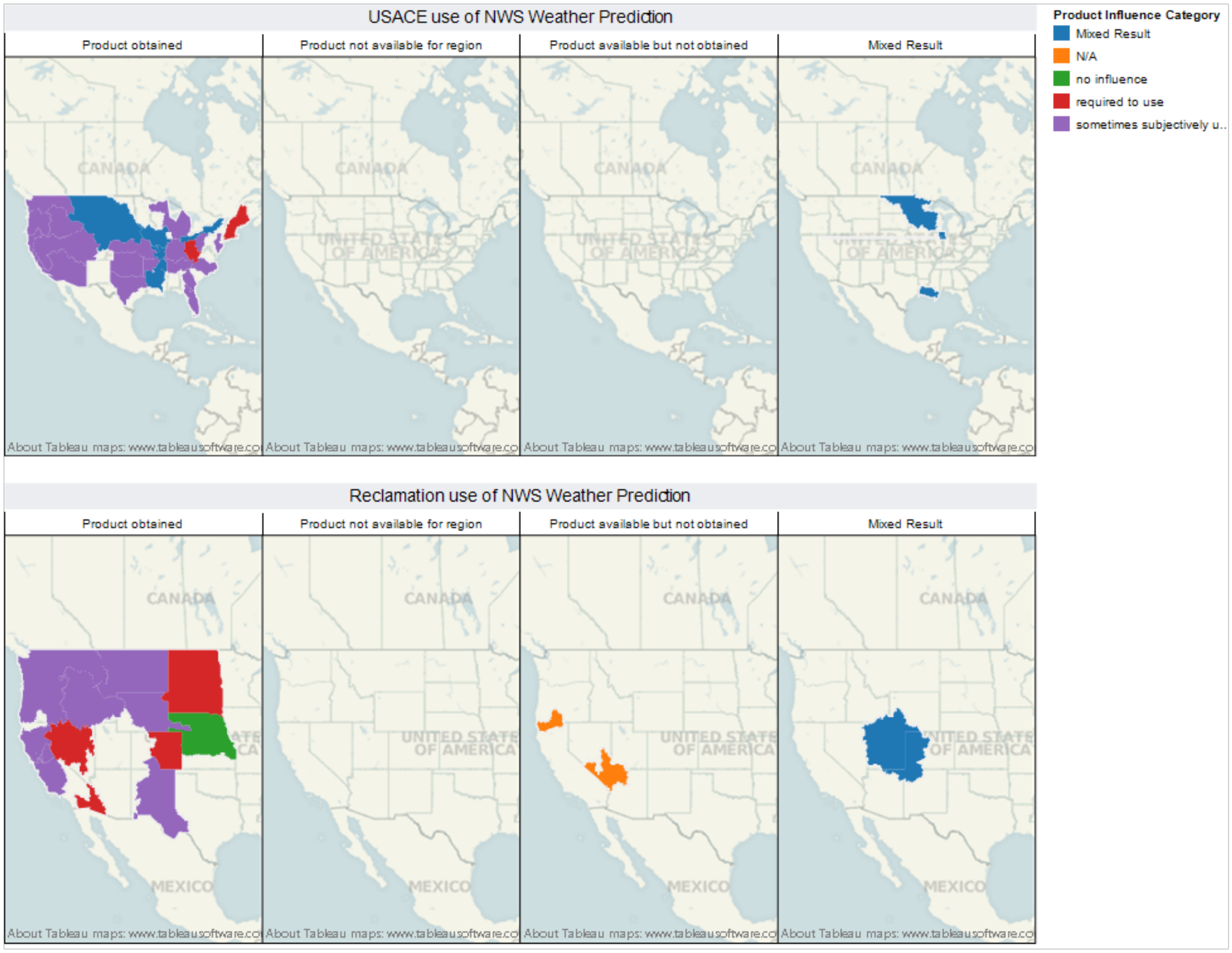


Figure C8. Spatially distributed access and influence by agency for NWS Weather Prediction. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

C9 NWS RFC Official Streamflow Forecasts, No QPF

Agency-Aggregated Use

For this product, roughly 50% of USACE respondents and 70% of Reclamation respondents indicated that they obtain this hydrologic product. Other Reclamation respondents indicated that they were aware of this product but chose not to obtain it. For USACE, the reasons for not obtaining the product varied between choice and no availability. When obtained, the Reclamation group indicated similar frequencies of applicability across the three outlook resolutions (varying between roughly 50–70%). For USACE, the frequencies were less consistent, with few respondents indicating applicability to coarse, about half indicating applicability to medium, and roughly 90% indicating applicability to finer-resolution outlook development. On decision-influence, all respondents indicated that there was some influence, though it varied by situation between "required to use" and "subjectively used."

Geographically Distributed Use (Figure C9)

USACE access to official flow forecasts without QPF includes the Missouri, portions of the northeast and southeast United States with mixed results in the Mississippi River Basin. In areas where the product is obtained, its use is a mix of requirement and sometimes subjectively used. Reclamation access is throughout the Pacific Northwest, with some offices in the Midwest obtaining the product. Where it is obtained, influence is a mix of required to use and sometimes subjectively used.

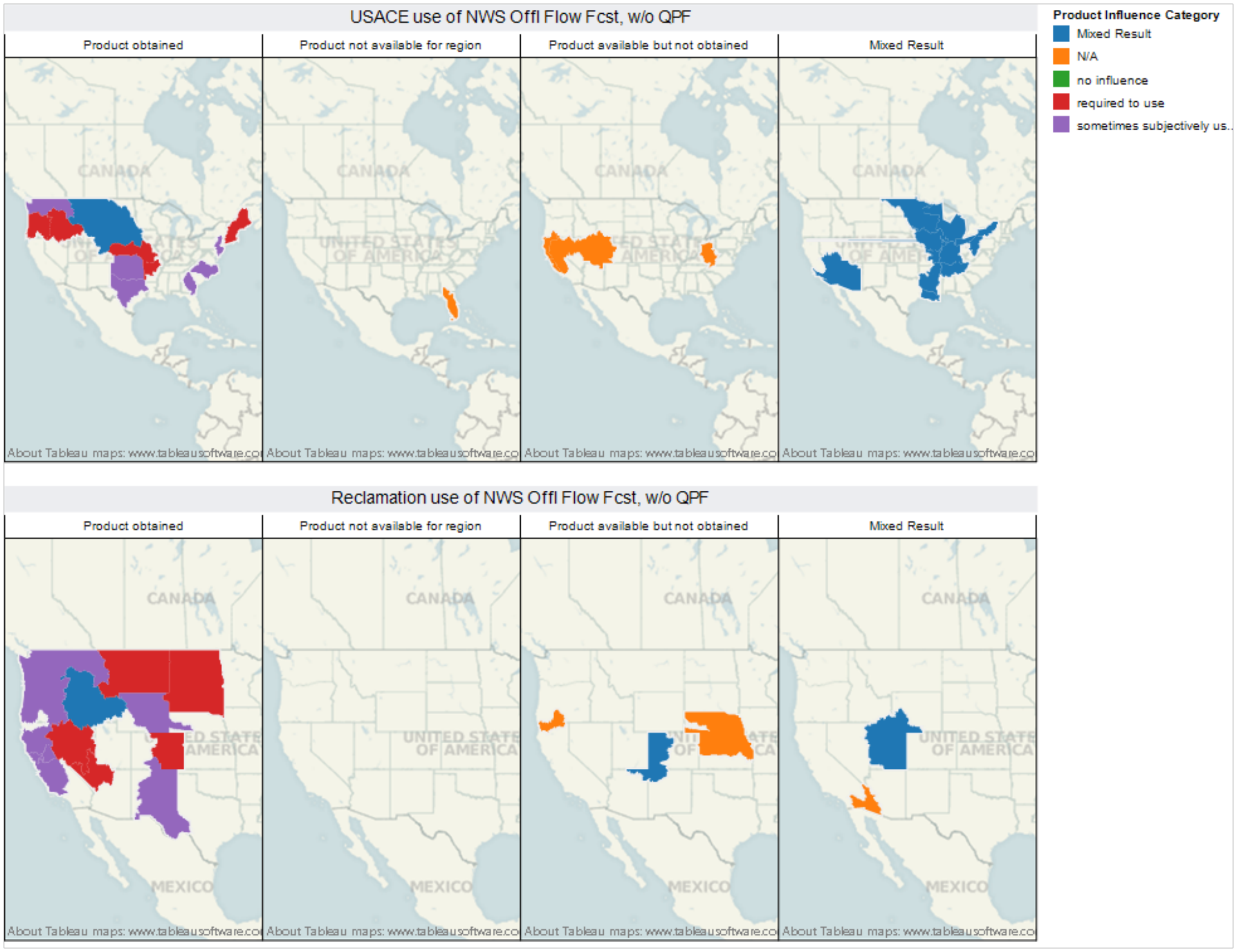


Figure C9. Spatially distributed access and influence by agency for NWS Official Streamflow Forecasts without QPF. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

Synthesis of Quotes

Official forecasts without QPF are used in a variety of manners to be situationally aware of future streamflows. Often, they are used to validate internal forecasts based on stream gauge measurements.

- *(PN SRAO) See "NRCS NWCC SNOTEL Network."*
- *(SAD SAS) We may use the river forecasts to adjust our release strategy to minimise downstream damages or maximize storage conservation depending on the sircumstance.*
- *(SWD SWT) See "NWS HPC/RFC/WFO Quantitative Precipitation Forecasts (QPF)."*

- *(NWD NWW) We use the RFC streamflows as an indicator of a reasonable forecast, then verify with other relevant data. We view the RFC forecasts as the primary data source. However, we have found associated errors to be as large as +-50% in the RFC forecasts. We feel it is imperative to use all the available data in the decision process.*

C10 NWS RFC Official Streamflow Forecasts, with QPF

Agency-Aggregated Use

Reclamation access tendencies for this product are similar to those for the Official Streamflow Forecasts, no QPF, with roughly 70% of respondents indicating they obtained this product. For USACE, roughly 90% indiated they obtained this QPF-informed product, which is notably greater than the 50% of respondents who indicated they obtained the companion no-QPF product. When obtained, the perception about applicability for this QPF-informed product was found to be very similar to those of the companion no-QPF product. The same can be said for the feedback on decision-influence.

Geographically Distributed Use (Figure C10)

In general, USACE obtains official streamflow forecasts with QPF where they are available. The influence of the product varies significantly by administrative boundary. Reclamation generally also obtains the product except for areas within the Missouri and the Rio Grande. The influence of the product is also significantly varied by administrative boundary.

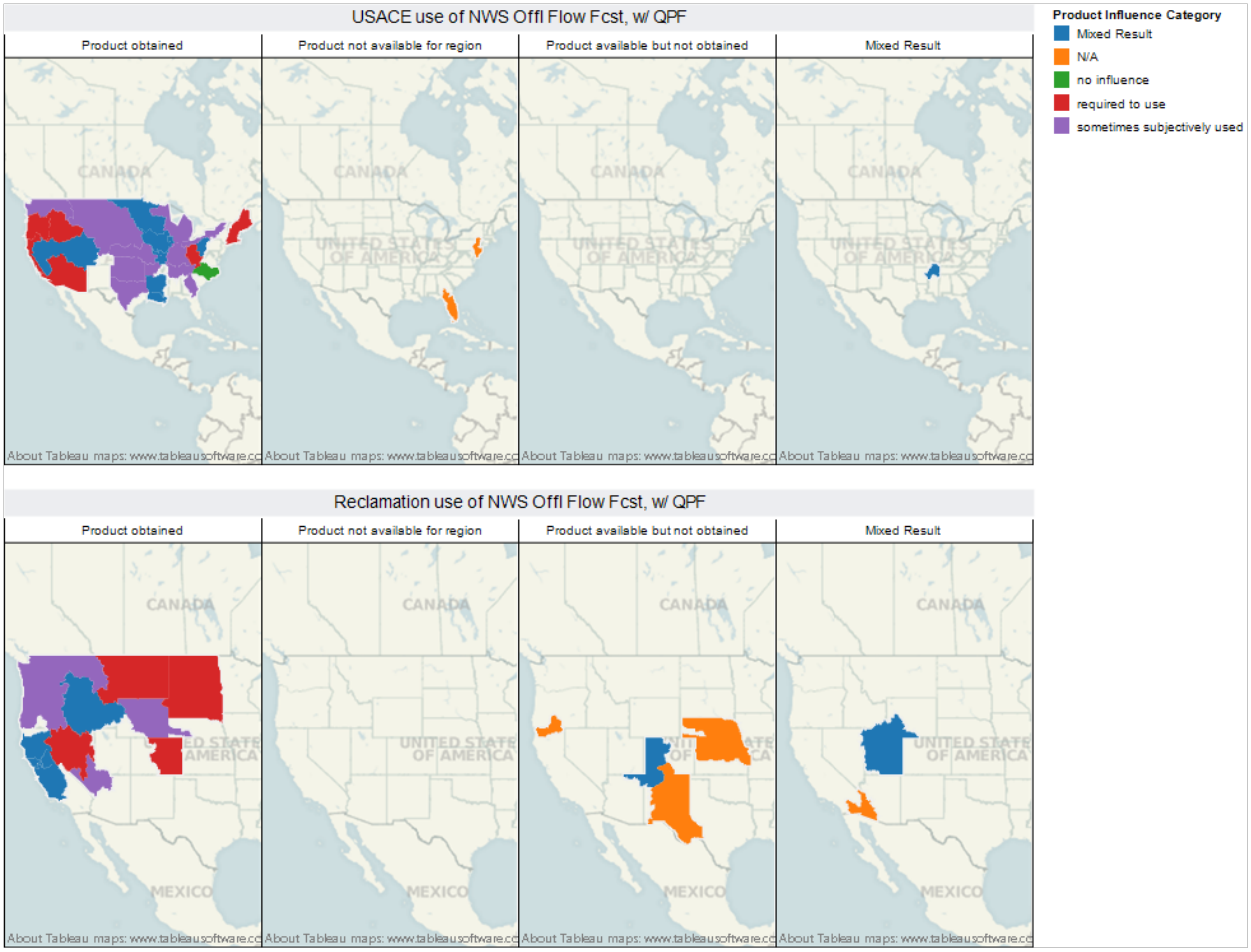


Figure C10. Spatially distributed access and influence by agency for NWS Official Flow Forecast, with QPF. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

Synthesis of Quotes

Comments indicated a wide range of access and use of QPF forecasts, primarily at fine outlooks within primarily USACE. Hourly to daily decisions often are based on in-house information and water on the ground. Where QPF forecasts are informative out to a week, they may influence those schedules or be used to validate forecasts produced in-house. In areas where QPF is incorporated within official streamflow forecasts, this is incorporated within decisions as would other official streamflow forecasts.

- *(PN SRAO) See “NRCS NWCC SNOTEL Network.”*

- *(LRD LRB) For Streamflow Forecasts, we use forecast with QPF, extending only 48 hours.*

- *(MVD MVR) NWS Streamflow Forecasts w/QPF - The NCRFC's official river forecast incorporates 24-hours of QPF. MVR use those tributary flows as input to its unsteady flow models on the Mississippi and Illinois Waterway and for reservoir inflows which serve as input to RESSIM. Day 1 operational instructions at reservoirs and navigation dams are based only on observed rainfall, not forecasted. However, the days 2-7 forecasts reflect the forecasted rainfall as well.*

- *(MVD MVS) see "NWS HPC/RFC/WFO Quantitative Precipitation Forecasts (QPF)"*

- *(POD POA) Official Streamflow Forecasts, with QPF are obtained from the Alaska RFC. These are used in conjunction with in-house streamflow forecasts to make decisions on the hourly to daily basis. We generate in-house streamflow forecasts and compare/discuss the results with the RFC forecasts. The results from the RFC forecasts are subjectively used to increase our confidence and/or better understand the uncertainty in the predicted project streamflow.*

- *(SAD SAS) see "NWS RFC Official Streamflow Forecasts, no QPF"*

- *(SPD SPK 2 through SPK 5 and SPK 7) Official Streamflow Forecasts, with QPF - Used to calculate inflow to reservoirs and determine required releases.*

- *(SWD SWT) See "NWS HPC/RFC/WFO Quantitative Precipitation Forecasts (QPF)"*

C11 NWS RFC Ensemble Streamflow Prediction (ESP)

Agency-Aggregated Use

Access tendencies for this product differed somewhat between USACE and Reclamation. Roughly 40% of USACE respondents obtain this product, while the remainder either indicated that it was not available or they elected to not obtain it. For Reclamation, all respondents indicated that they had access to this product, while roughly 80% indicated that they obtained it. The difference in this outcome may speak to the geographic diversity of prediction enterprises across RFC and the greater prevalence of ESP product service among the western RFCs. When obtained, the USACE group indicated similar frequencies of applicability for coarse-, medium- and finer-resolution outlook development, while Reclamation indicated greater applicability to medium- and coarser-resolution situations. On decision-influence, both agencies indicated that ESP products were most often "subjectively used." The remainder of Reclamation responses indicated "required to use" compared to most the remainder of USACE responses indicating "no influence."

Geographically Distributed Use (Figure C11)

There are many administrative areas within USACE where ESP is not available. For those areas where the product is available, it generally is obtained in the Missouri and Mississippi River Basins. It is generally sometimes used subjectively or has mixed results. Within Reclamation, ESP generally is obtained except for portions of the Missouri and Rio Grande Basins. For the areas where ESP is obtained, it is generally sometimes subjectively used with some mixed results and required use.

Synthesis of Quotes

Comments indicated that the utility of the ESP is limited, based on an assessment of accuracy and uncertainties associated with the drivers of operational decisionmaking.

- *(LRD LRN) Ensemble stream flow prediction* - *Classified as "no influence." Rainfall predictions, soil moisture, recent stramflow, and current reservoir levels are main drivers for reservoir management. We continually assess our "risk" levels and schedule accordingly. ESPs are just not that useful in our daily operations.*

- *(MVD) Probabilistic streamflow forecasts by the National Weather Service are available for the region but are not very useful. We are more interested in what will occur rather than in the probability of flows in a certain range. Each year is unique in respect to weather patterns, reservoir content, and soil moisture content. These factors are more important in determining the operation of the projects along the Mississippi River.*

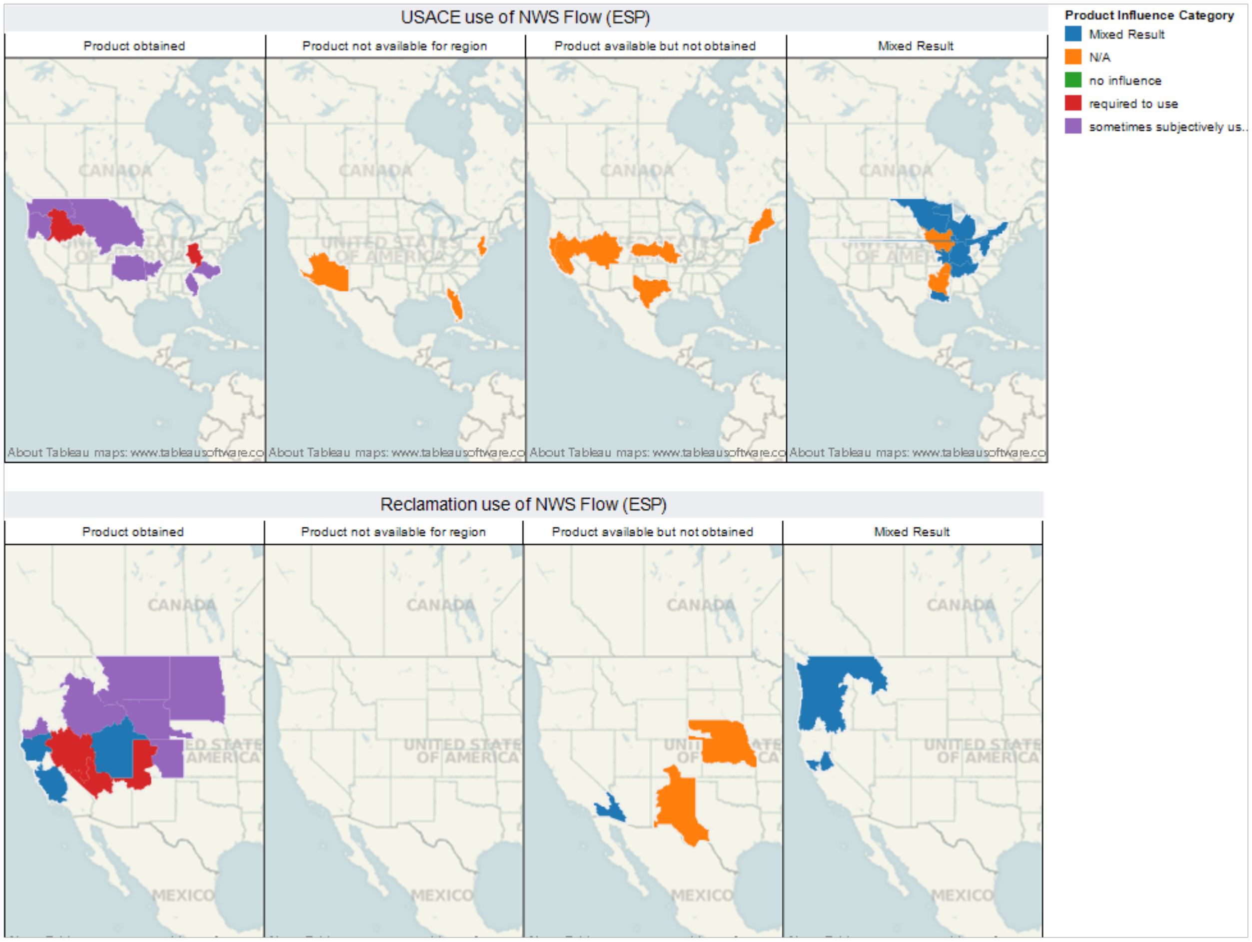


Figure C11. Spatially distributed access and influence by agency for NWS Flow (ESP). Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

- *(NWD NWL 2) Ensemble Streamflow Predictions RFC - We do not use the probabilistic streamflow forecasts, as our decisions are necessary to be made considering measured flows, and we use our judgement to evaluate likelihood of streamflows at target locations*

- *(NWD NWP) NRCS water supply forecast is official for our use. ESP is used to supplement information when NRCS analyses are unavailble.*

- *(NWD NWW) The ESP traces are useful, but often analog historic data is just as relevant in our snowmelt basins.*

C12 NWS RFC Water Supply Forecasts

Agency-Aggregated Use

The access feedback on this product is similar to that found for the ESP product just discussed. When obtained, the perceived applicability of these RFC water supply forecasts by Reclamation respondents is similar to that of ESP products. For USACE, the applicability between the products differed, with all respondents indicating applicability to coarser-resolution outlook development compared to less than half indicating this for the ESP product, and roughly 10 and 0% indicating applicability to the medium- and finer-resolutions compared to roughly 50 and 40% for the ESP product at those resolutions. For decision-influence, USACE respondents offered similar feedback on this product as they did for ESP. In contrast, more than 50% of Reclamation respondents indicated that this product influenced decisions under the “required to use” category, which was a greater frequency than that found for the ESP product.

Geographically Distributed Use (Figure C12)

Generally, USACE does not obtain NWS water supply forecasts for the majority of the eastern and southeastern United States. There is mixed access in the West. Where the product is obtained, there is mixed use for USACE. Reclamation generally does obtain the NWS water supply forecasts throughout its administrative boundaries with the exception of portions of California and the Missouri Basin. Where Reclamation accesses the information, it is generally required use with some mixed influence.

Synthesis of Quotes

Comments indicate that the level of product influence varies depending on the availability of competing information (e.g., forecast developed in-house for Reclamation Pacific Northwest [PN] Region) and institutional situations determining level of use (e.g., required use of RFC water supply forecasts for some PN locations or required use of this type of product to guide water allocation decisions in Reclamation’s California Central Valley Project). Where institutional requirements are absent, use level tends to range from sometimes subjective to situational awareness only.

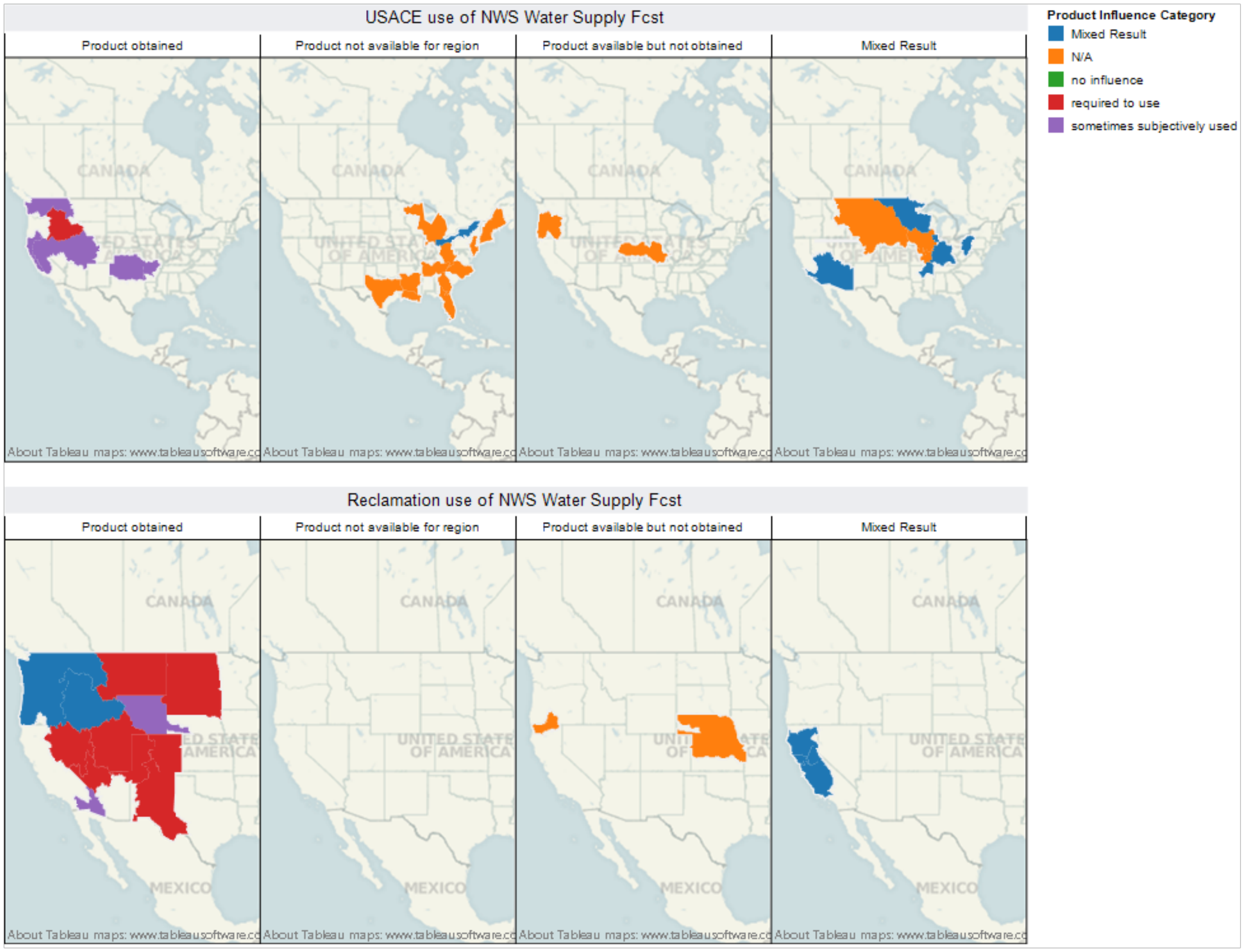


Figure C12. Spatially distributed access and influence by agency for NWS Water Supply Forecast. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

- *(MP CVOO 1) Use of the (coarse) water supply/snowmelt forecast products are required for long-term Central Vally Project operations and water supply allocations.*

- *(PN SRAO) Since most of the decisions made are shorter term, the long-lead products (i.e., Water Supply, Peak Flow, etc) are of limited value. We can use this information subjectively to “shade” our decisions. For example, we cannot release too much water too early for flood control unless we’re reasonably certain the snow/water is going to show up.*

- *(PN 1) RFC's water supply forecast for several locations is required to be used to set flood control elevation (i.e., The Dalles forecast is used to determine flood control at Grand Coulee). PN Region generates … water supply forecasts for many basins, sub-basins, projects that determine required flood control operations and operations planning decisions (see Section C17).*

- *(PN 2) The water supply forecasts from the NRCS and NWS had "no influence" because we make our own volume forecasts for our reservoirs. We do use theirs for situational awareness but not much more.*

- *(UC 2) Water Supply Forecasts are useful because they are of a consistent format the has been designed to fit within our modeling outlook process. Products that are not specifically designed for use are difficult to incorporate. We have to be able to compare the forecast conditions that are current with what has been forecasted in the past. This puts the forecast product into perspective. Products that are useful have hard numbers and specify specific levels of probability. I find colored maps to be the least useful forecast products.*

- *(NWD NWK 1) See "NWS CPC Seasonal Climate Outlooks."*

- *(SPD SPK 1 and SPK 6) Water Supply Forecasts - Used to estimate required space needed in reservoirs (fill but not release damaging flows - as much as possible).*

C13 NRCS NWCC Water Supply Forecasts

Agency-Aggregated Use

The NWCC Water Supply Forecast product is similar to the RFC product in that a seasonal runoff volume expectation is being communicated to water managers. Also, in the past, there has been coordination between the NWCC and the western RFCs when issuing these products. Product differences arise in terms of how the probabilistic forecasts are communicated and served through NWCC versus RFC Web portals. When comparing feedback on the NRCS product to that on the RFC product, it is apparent that both agencies access the products consistently, with most Reclamation operators obtaining the Water Supply Forecast product and most USACE operators not obtaining it, either by choice or because it's unavailable. Applicability feedback on the two products is also generally consistent for both agencies. What's interesting is that the decision-influence feedback seems somewhat different between the two products. This is more apparent for the USACE group, where 12 respondents indicated they obtain the RFC product but that, when it's incorporated into outlook development, it's done so subjectively. In contrast, where six respondents indicated they obtain the NRCS product, four of them indicated that it influences outlook development per requirement, while two indicated the product is used subjectively.

Geographically Distributed Use (Figure C13)

Generally, USACE does not obtain NRCS water supply forecasts for the majority of the eastern and southeastern United States. There is mixed access in the West. Where the product is obtained, there is mixed use for USACE. Reclamation generally does obtain the NRCS water supply forecasts throughout its administrative boundaries, with the exception of the Pacific Northwest and portions of the Missouri and Lower Colorado Basins. Where Reclamation accesses the information, it is generally a required use with some mixed and subjective influence.

Synthesis of Quotes

See Section 4.2.12; similar synthesis of quotes for this NRCS product.

- *(MP KAO) Accuracy of the NRCS forecasts is critical because the Upper Klamath Lake has no carry over storage. Knowing when inflows will likely peak also would be very helpful information in trying to manage very limited supplies.*

- *(PN SRAO) see "NWS RFC Water Supply Forecasts."*

- *(PN 2) see "NWS RFC Water Supply Forecasts."*

- *(POD POA) Water Supply Forecasts from the NRCS NWCC are available but generally not obtained nor used. Project operating conditions (diversion regulation) generally are based on peak flows rather than inflow volume.*

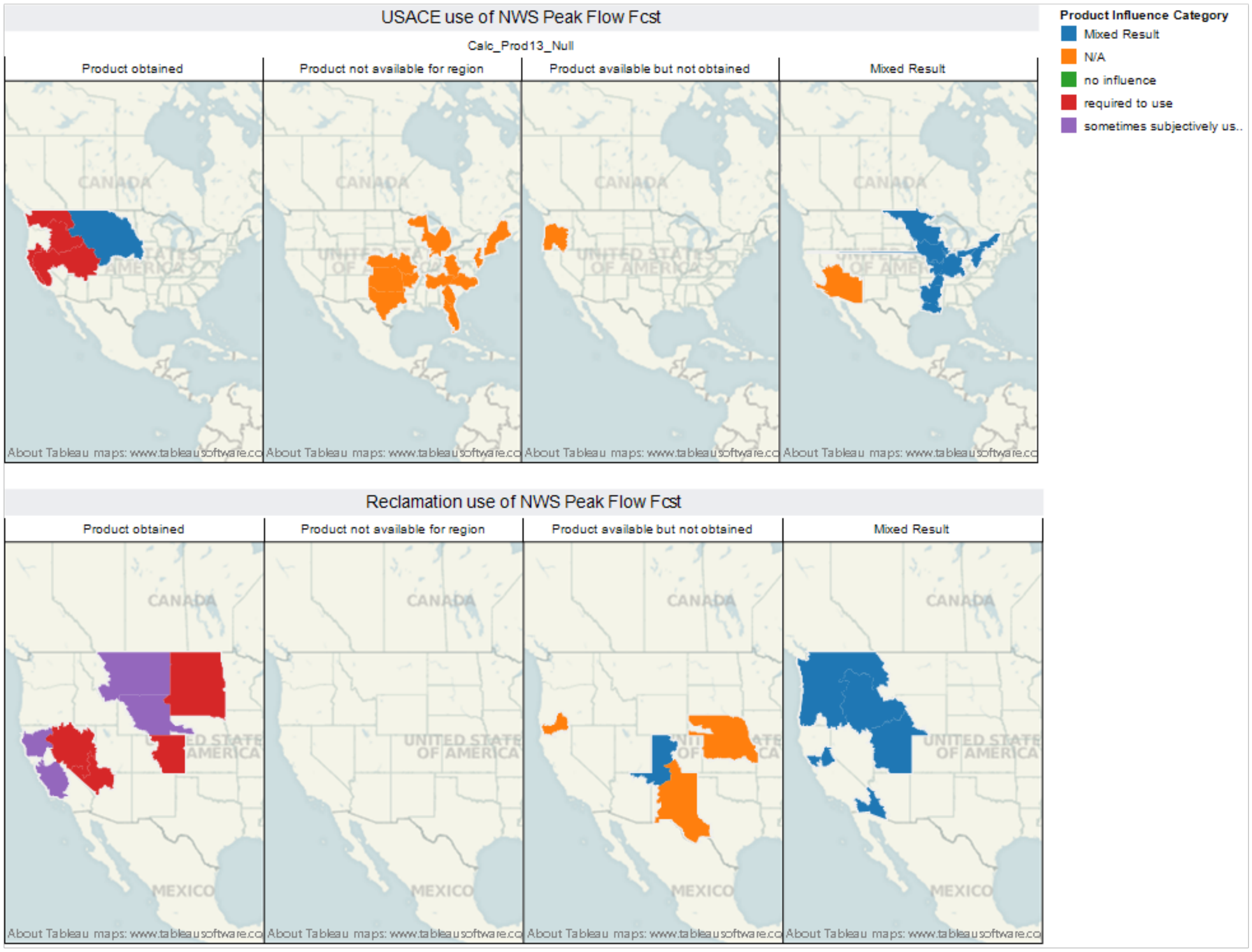


Figure C13. Spatially distributed access and influence by agency for NRCS Water Supply Forecast. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

C14 NWS RFC Peak Flow Forecasts

Agency-Aggregated Use

For USACE, roughly 40% indicated that they obtained this forecast, while roughly 15% indicated that they chose not to obtain it; the remaining 45% of respondents indicated that they did not have access to this product. For Reclamation, all respondents indicated that they had access to this product (again, potentially speaking to differences between the product services of western versus eastern RFCs), and the majority indicated that they obtain it. When obtained, most USACE respondents (70% or greater) indicated that the product was applicable to coarse- or medium-resolution outlook development. Reclamation likewise indicated greatest applicability for these two resolutions, though there was tendency for Reclamation operators to view this product as being most often applicable to medium resolution. Also, both agencies indicated that the product also can be applicable to finer-resolution outlooks, depending on the situation. On decision-influence, the majority of respondents in both agencies indicated that this product was “subjectively” used, with roughly 80% of USACE operators providing this response and roughly 60% of Reclamation operators agreeing. In most other situations, the respondents felt the product was used per requirement.

Geographically Distributed Use (Figure C14)

Reclamation has mixed access to peak flow forecasts for the Pacific Northwest and portions of California. Generally speaking, in the Missouri Basin and areas of California, the product generally is required or sometimes subjectively used. USACE generally does not obtain the information for the eastern United States. Within the Mississippi Basin, there are mixed results, and for portions of the West and Missouri, the product is obtained. The influence is mixed.

Synthesis of Quotes

- *(PN SRAO) see “NWS RFC Water Supply Forecasts.”*
- *(PN 2) Peak flow forecasts, never use them to make decisions, look at them just to look.*
- *(POD POA) See “NRCS NWCC Water Supply Forecast.”*

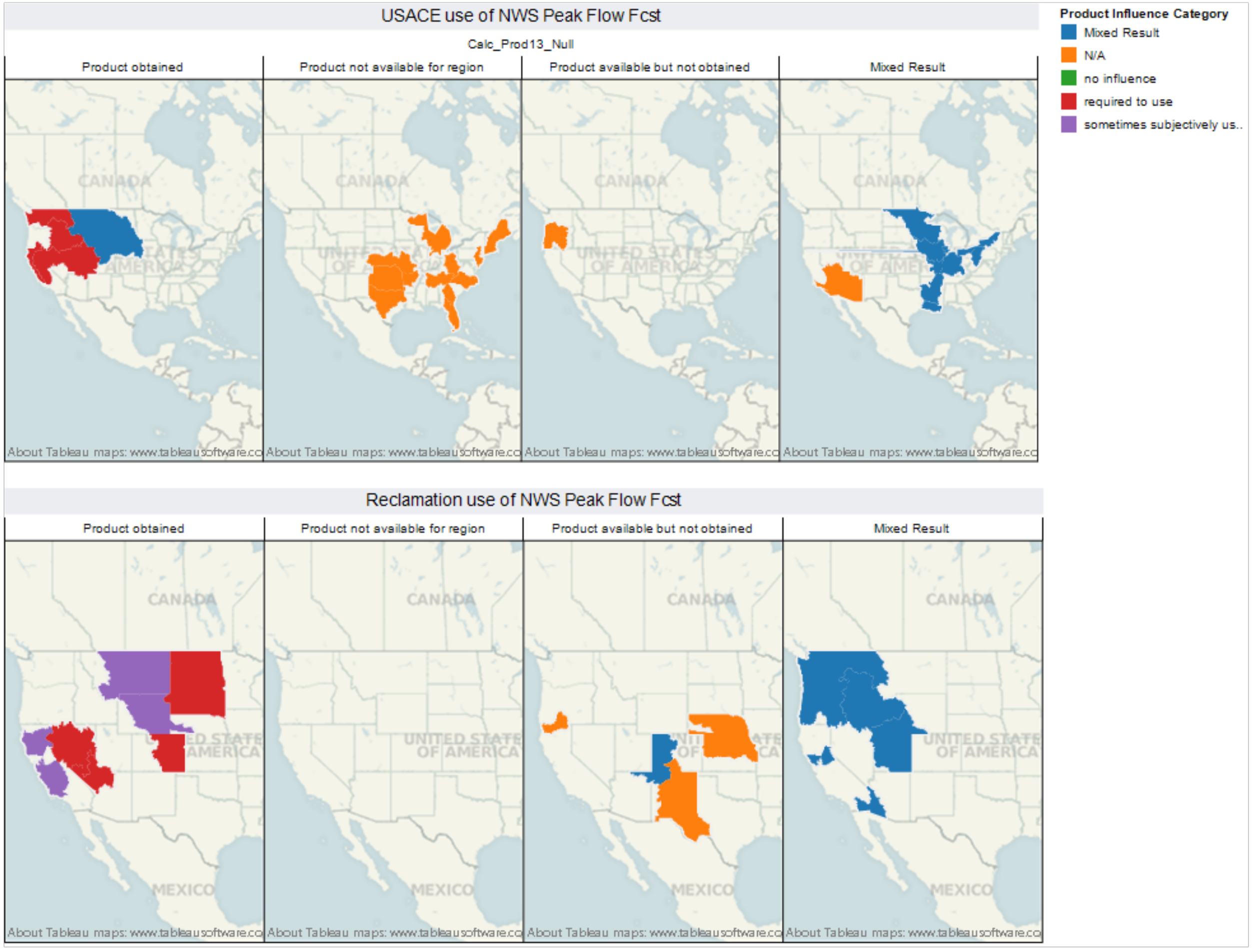


Figure C14. Spatially distributed access and influence by agency for NWS Peak Flow Forecast. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

C15 NWS RFC Special Forecasts

Agency-Aggregated Use

As discussed in Section 3.2, sometimes RFCs prepare and disseminate forecast products to meet the specific needs of individual customer entities. Roughly 50% of respondents from both agencies indicated they obtain these types of forecast products from the RFC serving their jurisdiction. When obtained, most respondents felt that they were applicable to medium- or finer-resolution outlook development (more often medium for Reclamation and finer for USACE). On influence, all respondents indicated that these forecasts had some influence on decisions when obtained, either per requirement or subjective use.

Geographically Distributed Use (Figure C15)

Reclamation has mixed access to special forecasts for the Pacific Northwest and portions of California. Generally speaking, in the Missouri and Rio Grande Basins, the product is not obtained by Reclamation. The influence of the special forecasts for Reclamation is mixed or sometimes subjective, with the exception of the Lahontan Area Office and the Lower Colorado Area Office, where the product is required. USACE generally obtains special forecasts within the Missouri Basin, with mixed results in the Ohio and Mississippi Basins and throughout the North Atlantic. For areas where it is obtained, there is mixed influence with areas of required use.

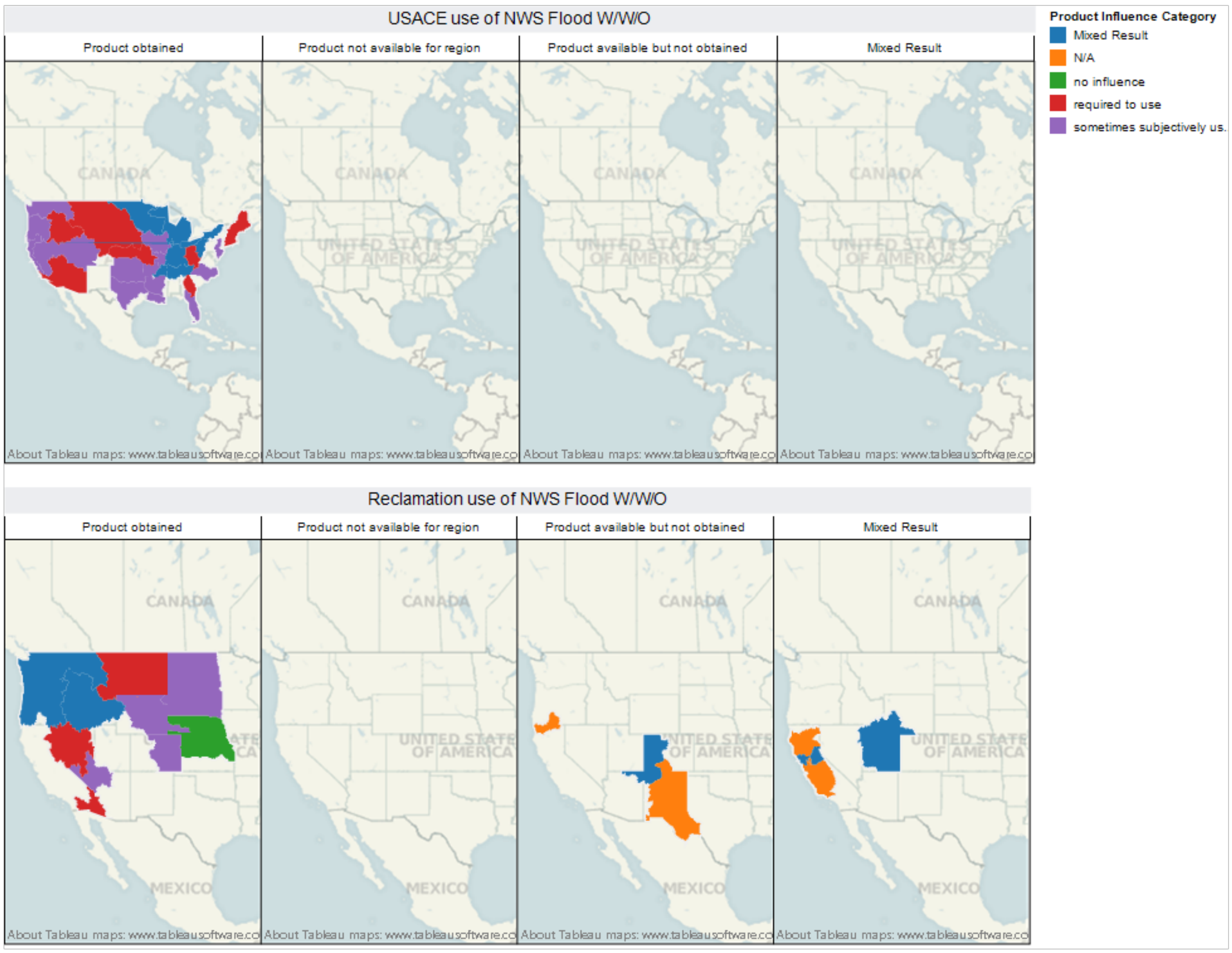


Figure C15. Spatially distributed access and influence by agency for NWS Special Forecast. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

Synthesis of Quotes

- *(NWD NWK 2) Special Forecasts from the Missouri River Basin RFC - we are in close contact with the RFC and often request special forecasts on the Missouri River considering both QPF and no QPF to make real-time decisions at flow target locations.*

- *(LRD LRH) "Special forecasts" in above table is assumed to be a different product than MMEFS.*

C16 NWS RFC Flood Warning, Watch, and Outlooks

Agency-Aggregated Use

All USACE respondents indicated that they obtain this product, while roughly 80% of Reclamation respondents indicated that they also obtain it. When obtained, these flood information products were found to be most often applicable to finer-resolution outlook development, although they were also often applicable to medium-resolution situations (roughly 40% for USACE and 60% for Reclamation, respectively). When applied, the most frequent response on decision-influence for both agencies was that they were subjectively used (roughly 50–60% of respondents), with required use being the next most frequent response (roughly 30%).

Geographically Distributed Use (Figure C16)

USACE obtains flood warning, watch, and outlooks for all administrative units that responded to the use assessment. The influence of the product for USACE is either required, mixed, or sometimes subjectively used. Reclamation obtains the information for most parts of the Pacific Northwest, Sierra Nevada-fed watersheds and Missouri Basin areas. The influence for Reclamation is mixed, required, and sometimes subjective. Areas of the Rio Grande and Colorado River Basins have mixed responses or do not obtain the information.

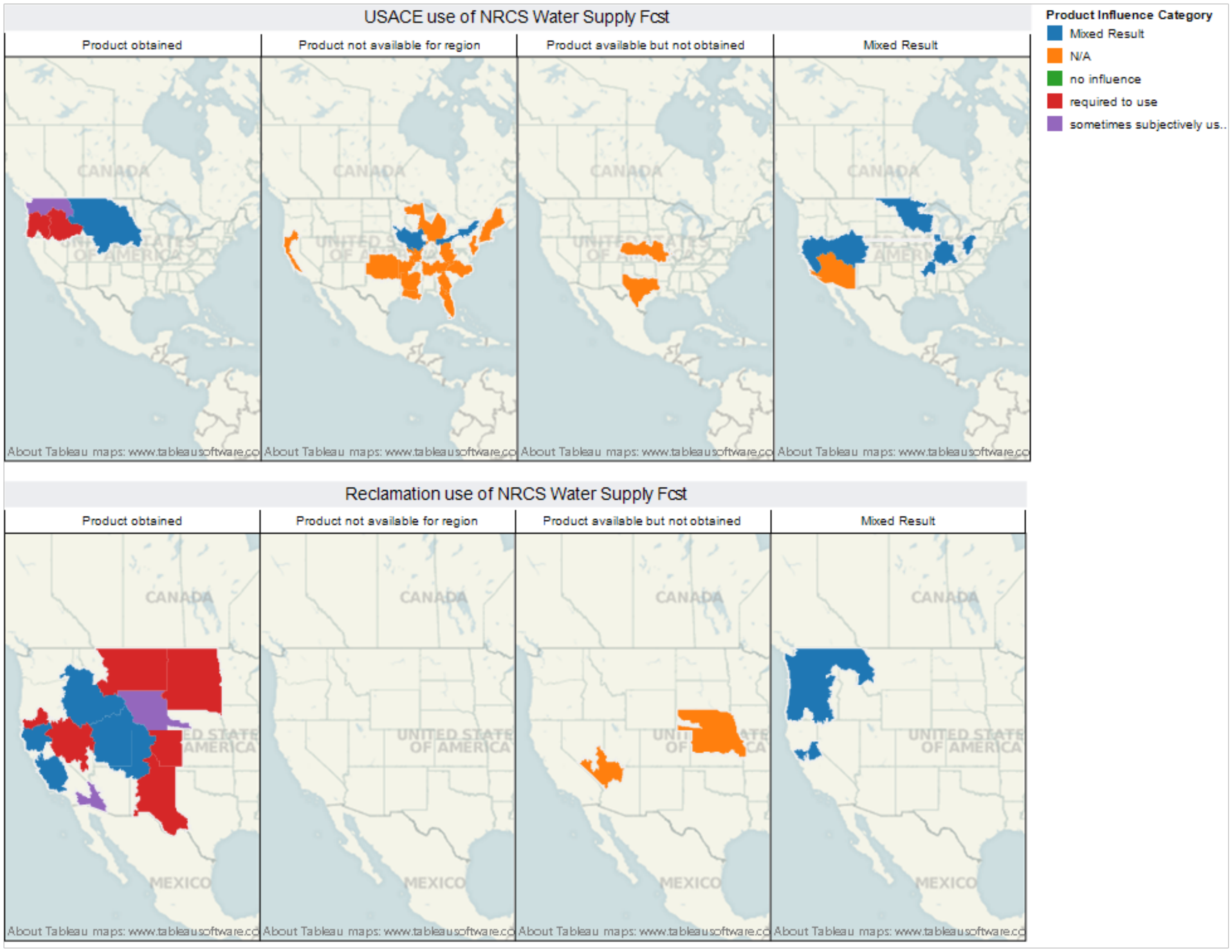


Figure C16. Spatially distributed access and influence by agency for NWS Flood Weather/Watch/Outlooks. Access is denoted by columns from left to right of product obtained, product not available for region, product available for region, and mixed result, respectively. Colors denote product infuence of no influence, required to use, sometimes subjectively used, mixed results, and not applicable.

C17 Operator Comments on Additional Products Used

During the use and needs assessment, several respondents took the opportunity to highlight other hydroclimate information products that they obtain and apply to various operations scheduling situations. Products are described in the quotes below and include Reclamation streamflow monitoring in the Lower Colorado Basin, NWS local 3-month temperature outlooks application in Reclamation's Central Valley Project, seasonal water supply forecasts developed by Reclamation for its PN Region, NWS estimates of snow water equivalent, NWS Advanced Hydrologic Prediction Service (AHPS) outlooks, and the NWS Hourly Precipitation tool.

Quotes

- *(LC BCOO) Reclamation's LC Region also maintains its own stream gauging network that is used in real-time, short-term, and mid-term operations.*

- *(MP CVOO 1) Since spring 2011, a pilot application of Local Three-Month Temperature Outlooks, developed at the Technnical Service Center, has been used to enhance Sacramento River temperature management. The L3MTO application was developed for the April–July planning period; an extension of this application for the February–March period may provide some guidance during developed of the Shasta and Trinity cold-water pools.*

- *(PN 1) Table 4 should also include "Water Supply Forecasts-other" Reclamation, PN Region generates MLR and PCA water supply forecasts for many basins, sub-basins, projects, which determine required flood control operations and operations planning decisions. We also use (sometimes subjectively use) the National Operational Hydrologic Remote Sensing Center (NOHRSC) to analyze basin snowpack (combination of observed and modeled data)**

- *(LRD) see "NWS CPC Seasonal Climate Outlooks" regarding snow water equivalent.*

- *(MVD MVP) MVP obtains National Operational Hydrologic Remote Sensing Center's Interactive Snow Information for SWE estimates in the basin. We sometimes subjectively use this data. We haven't had water supply issues in years – therefore I do not know if the product is available in our region or not.*

- *(MVD MVR) AHPS outlooks. While these outlooks are not used to make operational decisions per se, we have used them to support decisions regarding whether to increase spring pool levels at our reservoirs to aid fish spawning.*

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* ECAO comment during document review: "Similarly to the comment attributed to PN 1, ECAO internally generates seasonal water supply forecasts of April-July runoff volumes on a monthly basis. The statistical technique is also similar, multiple linear regressions of observed data. ECAO uniquely uses observed April–July precipitation in the regressions, and uses averages or forecast values during the actual forecast."

- *(NWD NOW) An example of a recent useful product is the NWS Hourly Precip tool. The District monitored this product to track the intensity of thunderstorms approaching Jamestown, North Dakota, all summer to determine if reductions in releases were needed due to bankful flow and potential local runoff.*

C18 Additional Operator Comments on Use

Various respondents also shared general thoughts on products they access, how those products are applied in varous operational situations, and how one might classify the ultimate influence of those products on decisionmaking. These comments are reported in the list below. Many of the comments suggest that it is difficult to classify product influence on decisionmaking, and they emphasize the general practice of consulting as much information as possible when making operational decisions, even though much of the information ultimately gets used only for situational awareness.

Quotes

- *(MP LAO) Most of these are a grey area between subjectively used and required to use. To a degree, we can subjectively use this information; but for the most part, it is either law, policy, procedure or general practice in how we use this information. We obtain as much information as we can in operating the reservoirs. An example of how we use this data is this past year; we were making precautionary releases from a reservoir and RFC put out a forecast which we strongly felt was off. We had a conference call and they said they felt their forecast was accurate. They were wrong and partially because of this we missed filling our reservoir by ~10,000 af. Even though we felt strongly the forecast was off, we could not ignore their forecast and possibly flood someone downstream.*

- *(MP CVOO 1) Most of the products are utilized/consulted, at some level, for operation of the Central Valley Project (CVP).*

- *(MP CVOO 2) In California, the Department of Water Resources produces many similar products as described above. In this region, the RFC, DWR, and the major water infrastructure operators are all located in the same building known as the Joint Operations Center. This co-location facilities many levels of cross discussion and* *coordination beyond the "data products." This may be an unique situation, but it has tremendously improved coordinated, dissemination, and communication of hydrologic products.*

- *(UC PAO) Our focus is on the coordinated RFC/NRCS runoff volume forecast for the seasonal/monthly decisionmaking, followed by the RFC tools available for the daily/weekly decisionmaking. We try to utilize as many of the tools available in our decisionmaking process.*

- *(UC AAO) In the Rio Grande Basin, accurate snowmelt volume prediction is a driving factor in planning and decisionmaking. Almost all reservoir operations hinge on that. Daily weather is primarily a concern during the monsoon season (Jul–Sep), but it is difficult to make decisions due to the extremely spotty nature of storms. Antecedent conditions also play a major role in predicting runoff be it from snow or rainfall. There can be a tremendous variability in end results based on the conditions that exist at the time. It's this variability which makes us take most forecasts of any type with many grains of salt. Perhaps it's because of this that, once the snow is gone, there is very little use of any type of forecast except in a qualitative sense. If it could be shown that the runoff and hydrograph from a particular thunderstorm or other storm event could be accurately predicted, even a day before, it would be a tool that could be used in better reservoir control.*

- *(UC WCD) I am required to base my operations on official RFC/NRCS coordinated forecasts, which are issued in monthly and seasonal (April–July) inflow volumes. I am interested in other products, such as CPC outlooks, but this information cannot be used to change the input values into my operations models. The consequences for this data being wrong can result in too much water released early, resulting in a lower water supply, which puts the overall water supply at risk in a multi-year drought. The accuracy of hourly to weekly river flow forecasts can also influence short-term operations. I have experienced inaccurate data directly resulting in too much reservoir release, or too little, causing environmental commitments to not be met.*

- *(LRD LRE) For regulation decisions of Lake Superior, the process is currently very prescribed and NONE of these products are used.*

When regulating Lake Winnebago, we look at many of these products, but the information from various sources (including our own models) is weighed before regulation decisions are made. In addition, some products (such as the RFC streamflow forecasts) have tended to not be reliable in the past.

- *(SPD SPL 1) There is limited snow coverage information in the Bill Williams and Gila River Basins, and snow melt runoff can be a source of moderately significant inflow, especially for the Gila River, but the primary flood threat in these basins is runoff generated by rainfall. USGS streamflow data, RFC runoff forecasts, and RFC/NWS weather forecasts are all critical information used by water managers to make operational decisions. However, all of these products can have reliability issues for a variety of different reasons. Given this reality I would have liked a classification in between "sometimes subjectively used" and "required to use." I marked some items "required to use" because we heavily rely on the particular information if we feel it is valid; but often if we feel information is erroneous or unreliable, we will disregard it.*

Appendix D: Use and Needs Assessment Responses on Pilot Attempts and Wish List Products

This appendix supports the discussion in Section 4.3 of the main report. It first lists operator responses relative to two use and needs assesment questions (Section 4.1):

- What have we tried to use but did not adopt?
- What are some of the wish list products and services that we can envision?

Operators' comments with respect to these two questions are listed in Sections D1 and D2, respectively. For the second question, operators were invited to react to the question from two perspectives: products available elsewhere that would be useful to the respondent (D2.1) and products not available that the respondent envisioned (D2.2).

These comments provide the basis for needs statements shared in Section 4.3. To support understanding on which operator comments supported which statements, abbreviated comments from Sections D1 and D2 are relisted in Section D3, but according to the needs categories from Section 4.3.

Note that, in the comments listed below and in subsequent sections, the quote sources are denoted by office abbreviations listed in the main report (Table 4) and are not defined again within this appendix.

D1 What We Have Tried To Use But Did Not Adopt?

Each quote has two bullets: the first bullet is the pilot description, and the second is why the outcomes resulted in the product not being adopted for further use.

- *LC BCOO*
  - *We receive a 3-month inflow forecast of intervening flows between Glen Canyon and Hoover Dams from the CBRFC. We currently use these forecasts for informational purposes only.*
  - *We have analyzed these forecasts for potential inclusion in 24-Month Study modeling, but have not made this change. The methodology used to compute these inflows is based on type of gauging method; we have asked the CBRFC to modify the methodology to a mass balance method.*
- *MP LAO*
  - *Would not quite describe this as unsuccessful or successful yet. We were working with Desert Research Institute and NRCS on PRMS in our area, hoping to get a better seasonal forecast with a physically based model. The modelers at DRI left for new jobs a little over a year ago and not sure what has happened to this effort since then.*
  - *Takes time, effort, and staff to work with these models. NRCS has a dedicated but limited staff, and they also had some issues with IT which made it difficult for them to directly take the models from DRI.*
- *MP CVOO 2*
  - *See previous comments. The difficulty is the education of water management principles and hydrologic timeframes; many interests simply don't care about any timeframe but the one that affects their interest.*
  - *See previous comments. These are water management principles education issues - not product issues.*
- *PN 2*
  - *This is just another comment: I think the reason that we are not able to trust the La Nina, and El Nino predictions and the 1- and*

3-month outlooks because of some big busts in these forecasts in the last 10 years. 2001 was a big bust saying that we would have above normal conditions under La Nina conditions, and it was a very dry year. This year (2012) has been touted as an above normal year and we are below normal. It is hard to believe and operate reservoir with this kind of uncertainty. Maybe the climate change work will help to give more realistic expectations of snowpack and precipitation in some of these years that are supposed to be La Nina conditions or El Nino conditions. So anything that can be done to give a more believable outlook of the winter snowpack building period would be useful.

  - *This is an answer for the question above and this one. Levi Brekke did some volume forecast development using teleconnections from indexes out in the Pacific. This study did not seem to add much value to the existing PCA forecasts and was not worth the time and money spent on it.*

- *PN CCAO*

  - *In cooperation with the USGS we developed a rainfall runoff model for the Yakima Basin, which was designed to use coarse and fine climate data. The USGS obtained historical data from NOAA that was used in the development of the model but was then not available real time. This diminished the quality of the output.*

  - *Real-time weather data was not accessible. Its retrieval and loading routine could not be automated.*

- *UC WCD*

  - *I tried to use historic rate of SWE loss with lag times, to estimate peak flow of the river in the basin. Also, looked at a magical percent of the remaining snow to the season's maximum snowpack as an indicator. These did not correlate well, but couldn't find another statistic that would provide a correlation.*

  - *Too many variables involved. Maybe would work if there was better representation of the actual remaining snowpack, rather than relying on specific SNOTEL sites. I currently* *rely on the RFC peak flow forecast, but timing of the peak is still far from the accuracy I would like to have.*

- *IWR HEC*

  - *There seems to be to be lack of an efficient way for the field to utilize short-term climate-based forecasts that are quantitative in nature. Presenting products based on a probability rather than transforming to some discrete value makes it difficult to use in operations. This is true with long-lead climate outlooks. Also with respect to water supply forecasts, the most probable forecast is typically used. However the having the ability to efficiently sample other probabilistic forecasts or even adjusting the underlying probabilistic distributions based on current conditions would also be useful. A conditional probabilistic distribution could be sampled from many times to analyze a proposed operation and risk for that operation. Also, the conditionally based distribution could be used in conjunction with an optimization tool to provide a longer-term solution that maximizes the objective for high priority purposes subject to hard and soft constraints. The idea is that any information that is presented in a more useful way can help the water manager make better informed decisions.*

  - *The challenges with products like these and GCM model output is workload, general lack of knowledge in the Corps, related time and knowledge to absorb a more abstract product, and the need for a more concrete usable product. A book useful for education purposes in this area is titled, Using Meteorology Probability Forecasts in Operational Hydrology Thomas E. Croley II, ASCE Press. Building capability via tools, usable products, knowledge sharing, and through actual experiences will probably enhance the use of these products for short-term and long-term operations that are within the authorized purposes of the project and according to current Corps policy regarding water management.*

- *LRD LRE*

  - *We have previously attempted to incorporate radar-based precipitation forecasts (and are going through another attempt currently).*

- *Data size, availability, processing capabilities, and questions regarding how the data was ground-truthed (especially for precipitation estimated over the Great Lakes) have all been issues with utilizing radar-based precipitation data.*

- *LRD LRH*
  - *Ensemble flow forecasts at critical USACE flood control projects needed for CWMS.*
  - *Flow forecasts of ensembles could not be directly ingested into CWMS.*
- *LRD*
  - *In the IJC Upper Lakes Study, we explored using climate indices for improving net basin supply forecasts. We found only limited improvement in skill for Lake Superior in the spring, but not for any of the other lakes or seasons.*
  - *We believe the demonstration was unsuccessful due to the limitations of seasonal weather forecasting at this time.*
- *MVD MVS*
  - *Shifts of rating curves at times have not been accurate due to measurements. QPF products at times are not accurate. Updates to QPF don't necessarily match (1-, 3-, and 5-day).*
  - *Measurement conditions are not always good, and a shift should not always be made. We operate projects real-time, and the USGS has the option of changing curves several weeks/months later. QPF and extended forecasts have proven not accurate. Sometimes the amounts may be correct, but the location is not.*
- *NWD NWS*
  - *We used precipitation data in Canada for our water supply forecasting on the Kootenai River at Libby Dam. We have come to learn that Canada no longer QA/QCs its data. This*

has led to erroneous values for this site, which is affecting our water supply forecast. This site is needing to be replaced.

D2 What Are Some Wish List Products That We Can Envision?

D2.1 Products Available Elsewhere That Would Be Useful To The Respondent

- *(GP NKAO) No, we develop our own operational outlooks primarily based on historical data analysis and current hydrological conditions. Forecasting a potential flooding event or future water supplies with any accuracy is difficult in our geographical area.*

- *(LC YAO) Better and accurate prediction of precipitation within 1 to 2 days would be great. The travel time from Parker Dam to Imperial Dam is 3 days.*

- *(MP LAO) We work with the RFC, NRCS, NWS, and USGS' and they are all extremely responsive to our needs. The one concern is that the NRCS forecasts are still based on regressions and with improvements in physically based models; it seems this is the direction they should be headed. For example, last year in our basin it was a very late runoff period. The NRCS forecast expected range was so wide it did not add any value to our decisions.*

- *(MP CVOO 2) In California, there are many, many hydrologic products available. The California DWR also manages an electronic clearinghouse known as CDEC. This is a major hub of information set and facilitates much cross discussion. This is also a problem, in that, some amount of information overload does occur, because many managers or stakeholder interests have a difficult time deciphering how to effectively utilize information as the kind of cross time scales discussed. To a significant degree, this problem is an education product related issue. More interests need to understand how water projects and hydrologic datasets begin to function together at multiple timeframes, rather than singular points in time, i.e., the hydrologic datasets are only useful - if you understand what there useful for and how long in time their useful.*

- *(PN 2) I would like to have some indication other than the 1- and 3-month outlooks that would tell me how much more snowpack is* *going to build before April 1st. Right now we do volume forecasts using MLR and PCA procedures that forecast the amount of runoff to expect from the current date through the end of July. These procedures have to make some assumptions on what kind of snowpack will exist before the runoff begins. If I knew how much snow would build in the next 2 months over the water shed, it would be very useful information. Right now I am operating a reservoir and I am discharging some water over minimum flows because we have high carryover. The snowpack is not impressive at this time, so I have to make the decision now whether we need to release water early or not. I am assuming that we will get more snow this winter over the watershed, but what if that does not happen? Then I should not have been releasing water in February. So, a product that would tell me how much more snow we'll get this season would be good. I know this is probably pie in the sky stuff, but you asked for ideas!*

- *(PN SRAO) Some of the products that are already available have not been revised and calibrated enough to be as useful as they could be. Some problems may be division of basins by administrative boundaries and effects of topography that are felt windward or leeward of the feature or lack of consideration for the direction of prevailing flow.*

- *(UC AAO) I think the bigger problem is not knowing ALL of the tools that are out there. Navigating many different Web sites can be a daunting task. Valuable products/tools may be out there, but getting to them or even knowing about them is a major issue. Keeping up with the exploding technology and data availability is almost a full-time job. Many agencies have really cool toys out there, but it can be sometimes hard to play with them.*

- *(UC WCD) I'm not sure. It would be nice to have a workshop (or some sort of gathering of like-minded folks) to learn of innovative products being used in other regions that may help us with our operations.*

- *(IWR HEC) The products identified in Part II are a comprehensive list. There may be some GCM models that have been downscaled to a basin level that might be useful from a subjective standpoint to inform where basin conditions are heading. The issue with these types of products is skill regarding these forecasts. However, as Water*

Managers become familiar with these products, perhaps they may become part of the tool kit that could be utilized.

- *(LRD LRB) We get regional snow analyses from NOHRSC. It would be helpful if we could get this in more detail—e.g., ability to zoom in on map, and/or query for amounts in specific regions (e.g. to get a better idea of the modeled range and variability).*

- *(LRD LRE) SNOTEL and snow course data. We are actively investigating opportunities to collaborate with other agencies and non-Federal entities to obtain snow course data.*

- *(LRD LRN) Availability to see NWS hydrologic forecasts for same region. These would be used to compare to our model results. We could then hedge our reservoir management plan depending on any discrepancies between the two.*

- *(MVD MVN) The products in Part II that are not available for our region are largely covered by the spring flood outlooks and associated conference calls with the NWS, so we do not think making them available for us would influence our operations greatly.*

- *(MVD MVR) Ensemble Probabilistic Forecasts would be more useful if those forecasts were checked and verified prior to dissemination. It is my understanding that those ensemble forecasts are auto-generated and not checked prior to dissemination due to manpower constraints within the NWS.*

- *(NAD NAE) We rely heavily on Official Streamflow Forecasts, with QPF. These products are not available for all desired locations. We have been working with the NWS to add forecast points, with success. We plan to continue this effort. Also, any effort that can be made to increase the accuracy of these forecasts would be helpful.*

- *(NWD NWO) NWS WFO in Riverton, WY supplies a water supply forecast graphic for streams and reservoirs that gives volume in acre-feet and the percent of normal. This product is a useful tool to check forecast numbers and provides a visual look at high and low forecast areas. It would not be a direct input but a valuable reference if provided in other states.*

- *(NWD MRBWM) Snowmelt peak flow forecasts are rarely seen or reviewed by NWD-MRBWM. This would be a useful forecast to consider when determining reservoir releases during the snowmelt runoff season.*

- *(SAD SAJ 1 and SAJ 2) Stream gauging USGS for this Assessment is interpreted to be all stream gauging available to Jacksonville District, not limited to USGS derived. Special Forecasts for this Assessment is interpreted to include National Hurricane Center products.*

- *(SAD SAS) We need to establish a standardized access method to many of your products other than FTP. We would like to establish LDM feeds from the RFCs for most of your products. Would also like to have Forecast-based Flood inundation map estimates for the Savannah River below Turmond Dam.*

- *(SAD SAW) I'm not familiar with the water supply forecasts in other regions--perhaps those would have some potential value.*

- *(SPD SPK 2 through SPK 5 and SPK 7) None ... We also receive information/data/forecasts from State of California, Dept. of Water Resources that are used in conjunction with the addressed forecasts to better operate the reservoirs.*

- *(SPD SPL) I believe the RFC is now adopting processes that can generate <6-hr time step models. When/if that happens, we will be able to more directly use the RFC runoff forecasts for more projects in the Los Angeles Basin.*

- *(SWD SWT) No. There is already too much information to sort thru.*

- *(NWD NWS) Overall, our region has a wide array of products available, but we could use help from the Canadian portion of the Columbia.*

- *(NWD NWW 1) ESP traces without a deterministic weather forecast or a shorter period than 10 days.*

- *(NWD NWW 2) Snodas (NOHRSC) gridded snow water equivalent data should be identified in Table 3. We are beginning to use this data in hydrologic modeling.*

D2.2 Products Not Available That The Respondent Envisioned

- *(GP NKAO) We currently utilize some of the available products in our decisions. Have not found and do not foresee a product that can more accurately predict the amount of water resulting from a potential storm. We monitor real time rain events and stream flows, analyze and estimate potential effects and base our decisions accordingly.*

- *(LC BCOO) Improved forecasts of side inflow for reaches in the lower Colorado River Basin. Forecasts for reservoir evaporation in the lower basin. These products would potentially be used in mid-term operational modeling.*

- *(LC YAO) Additional desert rain gauges would be useful to identify precipitation events that may affect flows and water user demand in the Colorado River downstream from Parker Dam and flows in the Gila River downstream from Painted Rock Dam.*

- *(MP CVOO 2) See previous comment. I believe that until a synthesis of water management principles and hydrologic dataset is better understood at multiple timeframes; decision support will be a challenging goal.*

- *(PN SRAO) More accurate RFC-style 5-day streamflow forecasts would be the top of my wishlist. Frequently I find that they're inaccurate by the time I get them, and I have to use my own judgment and data from other sources to make decisions.*

- *(PN 1) Similar to the info from NOHRSC, basin wide snow data (snow covered area and SWE) would be very useful in determining overall water supply. Sometimes the snow sites that are monitored do not always accurately represent actual conditions. Most current snow sites are at similar elevation bands; therefore, more data (SCA and SWE) at all elevation zones would be better. However, it would take several years to build up a data base of historic conditions in order to correlate with past runoff volumes. I believe some of this is already being done but not everywhere and not easy to find.*

- *(PN 2) This is continued from the previous question. Is there some way that a product looks at each basin and gives a probability of getting normal snowpack? This would not look at historic statistics but rather at the condition of the atmosphere and what the potential is?*

- *(PN CCAO) The RFC produces short term forecasts and longer term ESP runs for specific locations in the Yakima Basin. It would be beneficial to have them in more easily obtainable and transferable format. It is also difficult to obtain fine, medium, and coarse temperature and precip data from NOAA. The process should be easy, accessible, and dependable.*

- *(UC AAO) I think continued refinement of what is out there is the best approach. There are also a lot of cool things out there with limited practical application. A prime example is the program to define the effects of dust on snow. It's nice research but it needs to somehow be tied into other data/products to either refine forecasts or be a stand-alone tool to better predict runoff.*

- *(UC 2) As operators, we understand the difficulty of providing a precise and accurate forecast. I think that forecasts should always be presented with a description of the skill of that forecast product. I sometimes find this information lacking when we receive the forecast product.*

- *(UC WCD) I can envision a contour map using all available data (SNOTEL, snow course, and local geographical/topological features such as slope aspect and tree cover) to estimate SWE at any given point in the basin. This can also be used to calculate an estimated total volume. Some SNOTEL stations may be more representative of the basin, or may should carry more weight based on a variety of factors. This information is lost when stations are simply averaged together, which is often done.*

- *(IWR HEC) The products in Table 4 such as Seasonal Climate Outlooks, Official Streamflow Forecasts with and without QPF, and ESP traces that are presented in an more ingestible format to models would be very useful. There has been research done on the incorporation of long-lead climate outlooks in water supply forecast equations that might be useful.*

- *(LRD LRB) Our model of the Genesee Basin (HEC-HMS) requires input of a soil moisture content related variable (initial deficit). It would be helpful to have a published modeled soil moisture content (e.g. in regional map form).*

- *(LRD LRC) Include the effect of snow melt into river forecast.*

- *(LRD LRE) Better climate outlooks up to 6 months out would be very useful for Great Lakes water level forecasting. Any products that extend across the border and cover the Canadian portions of the basin would also be helpful. Better data on evaporation (estimates based on cloud cover, etc.) and soil moisture.*

- *(LRD LRH) Wish list products: Gridded QPF in CWMS-compatible format. Soil moisture antecedent conditions in CWMS-compatible format. Ohio River stage forecasts in CWMS-compatible or HEC-RAS-compatible format.*

- *(LRD LRL) We are currently developing our CWMS models. It has been a very slow and timely process, There are not many resources available to aid in their development. When fully developed they will provide us with an invaluable tool. I believe there are enough climate products available now, more funds should be spent on expanding our real time network of streamflow gauges, as of now the Corps of Engineers and the USGS on providing for the majority of funds, without these gauges to verify models every thing else is moot.*

- *(LRD LRN) QPFs based on probability. For example, the current 24-hour QPF might be for 1 inch of rainfall, with a 75% chance of 0.6 inch and a 10% chance of 2 or more inches.*

- *(LRD LRP) There are many forecast products available, often more than we could possibly use. Instead of suggesting new products, we have provided suggestions for improving the current products: 1. When issuing Flood Warning, Watch, and Outlook forecasts, include specific river stages and flows so that we don't have to look at multiple forecasts to get the full information. 2. Update the SNOTEL network forecasts to provide more up-to-date information. Currently the forecasts are a day behind; and during precipitation events, it's critical to have the most updated* *information when assessing the remaining snowpack. 3. Provide more than one river forecast during normal business hours.*

- *(LRD) Yes, in the Great Lakes, we need net basin supply forecasts on daily, weekly, and monthly to annual time scales with improved skill. We also need forecasts of St. Lawrence River local drainage flows on daily to monthly time scales. Recent work by the IJC Upper Lakes Study showed the utility of regional climate models. We are also in need of linking hydrologic and temperature forecasts to forecasts of biological activity to manage reservoirs for fish spawning and nesting.*

- *(MVD MVN) Any improvement to hurricane storm surge forecasts that would make them finer in resolution, earlier in issuance, and/or probabilistic would be very helpful. An overall inundation forecast including storm surge, rainfall, and river flooding for tropical events would be very informative for emergency operations and for operation of coastal water control structures.*

- *(MVD) I can envision a product that would show probabilistic stream flow based on ENSO climatic conditions. In other words if a La Nina event is occurring, then a probabilistic stream flow should be developed based on previous La Nina events.*

- *(NAD NAE) See above. Also, since the travel time from some dams in the Connecticut River Basin is greater than the river stage forecast time, it would be helpful if the stage forecasts for the Connecticut River at Hartford CT extended to 4 days. Note: river stage forecasts in the New England area are limited to 2+ days ahead, currently, due to quick response times making longer forecasts less reliable.*

- *(NWD NWO) 1. Better plains snow measurements, perhaps automated, to improve runoff forecasts. 2. More rain gauges to ground truth radar estimates. Rainfall totals have a huge influence on regulation decisions, and there are huge coverage gaps in Montana and the Dakotas and in the mountains. This data is vital for convective storms; the May 2011 rainstorms are an example. Perhaps an ASOS or AWOS site to help fill the gaps? Data is critical to short- and long-term regulation decisions. 3. Recommend that CPC outlooks provide an actual forecast as opposed to the percent chances they* *currently give. They need to be explained better as the information shown is not easily interpreted. This would influence long-term or seasonal forecasts and regulation plans. 4. Gridded temperature and snow water equivalent data from the NWS RFC similar to the gridded precipitation data we already receive from MBRFC via LDM. We need these three pieces of gridded data for inputs to plains snowmelt runoff models to improve runoff forecasts. 5. Precipitation data from all streamgauge locations to improve NWS estimated radar estimates and to use in regulation decisions and record-keeping. Lack of funding has resulted in some precipitation gauges to be removed from streamgauge sites. 6. Additional streamgauges on currently ungauged tributary sites would result in more accurate inflow forecasting during high flow events. Gauges not currently installed due to lack of funding.*

- *(NWD MRBWM) 1. Better plains snow measurements, perhaps automated, to improve March–April runoff forecasts. 2. More rain gauges to ground truth radar estimates. Rainfall totals have a huge influence on regulation decisions and there are huge coverage gaps in Montana and the Dakotas and in the mountains. This data is vital for convective storms; the May 2011 rainstorms are an example. Perhaps an ASOS or AWOS site to help fill the gaps? Data is critical to short and long term regulation decisions. 3. Recommend that CPC outlooks provide an actual forecast as opposed to the percent chances they currently give. They need to be explained better as the information shown is not easily interpreted. This would influence long-term or seasonal forecasts and regulation plans. 4. Recommend increasing the number of observation sites for soil moisture and soil temperature across the Northern Plains. This information is vital to runoff forecasts performed by both the NWS RFCs and the Corps. 5. Gridded temperature (observed and forecast) and snow water equivalent data from the NWS RFC in an XMRG format. We need these three pieces of gridded data for inputs to plains snowmelt runoff models to improve runoff forecasts. 5. Additional streamgauges on currently ungauged tributary sites would result in more accurate inflow forecasting during high flow events. Gauges not currently installed due to lack of funding.*

- *(SAD SAJ 1 and SAJ 2) Weekly, monthly, seasonal, basin specific comprehensive quantitative streamflow/runoff forecast derived from*

QPF, actual soil moisture, forecasted soil moisture, actual evapotranspiration, forecasted evapotranspiration, ENSO (El Nino, neutral, La Nina), Bermuda High, Jet Stream, etc for upstream and downstream of projects. Tool for use in the decision making process for water management operations.

- *(SAD SAS) Need Inflow Forecasts bases on RFC QPFs as a standard product. Would like to have 3- to 5-day forecast of hourly inflow values to our projects, several upstream projects, and to several downstream control points on the river. I understand that the downstream river forecasts are based on our releases. Would also like to have daily evaporation estimates for the USACE reservoirs. Would also like to have updated PMF storms developed for each of our projects.*

- *(SAD SAW) None that I can think of, but I would be interested in any responses others may have to this question.*

- *(SPD SPL) Anything that helps to better define the timing, spatial distribution, and quantities of precipitation as it comes off of the ocean would be helpful. Radar doesn't extend very far off of the coast and the orographic effects can be significant because of coastal mountain ranges.*

- *(SWD SWF) New models with more accurate weather forecasts as well as river forecast.*

- *(SWD SWT) No. All current tools meet SWT needs. There is already too much information to sort thru.*

- *(NWD NWP) Perhaps correlate between NOHRSC data and runoff. i.e. a given SWE/by data might produce XXX runoff [volume].*

- *(NWD NWS) One of our basin, the Kootenai is mostly located in Canada. There is very little snow data available for this area. We are starting to explore NASA's MODIS snow cover data to help determine the amount of potential snowmelt. Remote sensing data could be very helpful for areas like these where there is very little actual measurements available.*

- *(NWD NWW) Gridded QPF data could be supplied for use by districts in model-based forecasts.*

D3 Operators Comments Supporting Needs Statements (Section 4.3)

D3.1 Improved Monitoring Products

Precipitation

- *(D2.1) (LC YAO) Additional desert rain gauges would be useful to identify precipitation events that may affect flows and water user demand in the Colorado River downstream from Parker Dam and flows in the Gila River downstream from Painted Rock Dam.*

- *(D2.2) (NWD NWO) … More rain gauges to ground truth radar estimates. Rainfall totals have a huge influence on regulation decisions and there are huge coverage gaps in Montana and the Dakotas and in the mountains. This data is vital for convective storms; the May 2011 rainstorms are an example. Perhaps an ASOS or AWOS site to help fill the gaps? Data is critical to short- and long-term regulation decisions.*

- *(D2.2) (NWD NWO) … Precipitation data from all streamgauge locations to improve NWS estimated radar estimates and to use in regulation decisions and record-keeping. Lack of funding has resulted in some precipitation gauges to be removed from streamgauge sites.*

Snowpack

- *(D2.2) (PN 1) Similar to the info from NOHRSC, basin wide snow data (snow covered area and SWE) would be very useful in determining overall water supply. … Most current snow sites are at similar elevation bands therefore more data (SCA and SWE) at all elevation zones would be better.*[*]

- *(D2.2) (UC WCD) I can envision a contour map using all available data (SNOTEL, snow course, and local geographical/topological*

[*] ECAO comment during document review: "We see a need to have SNOTEL data quality checked at the hourly, rather than daily level."

features such as slope aspect and tree cover) to estimate SWE at any given point in the basin.

- *(D2.1) (LRD LRB) We get regional snow analyses from NOHRSC. It would be helpful if we could get this in more detail – e.g., ability to zoom in on map, and/or query for amounts in specific regions (e.g., to get a better idea of the modeled range and variability).*

- *(D2.1) (LRD LRE) SNOTEL and snow course data. We are actively investigating opportunities to collaborate with other agencies and non-Federal entities to obtain snow course data.*

- *(D2.2) (LRD LRP) … Update the SNOTEL network forecasts to provide more up-to-date information. Currently the forecasts are a day behind and during precipitation events, it's critical to have the most updated information when assessing the remaining snowpack.*

- *(D2.2) (NWD NWO) Better plains snow measurements, perhaps automated, to improve runoff forecasts.*

Streamflow

- *(D2.2) (LRD LRL) … more funds should be spent on expanding our real time network of streamflow gauges, as of now the Corps of Engineers and the USGS on providing for the majority of funds, without these gauges to verify models everything else is moot.*

- *(D2.2) (NWD NWO) … additional stream gauges on currently ungauged tributary sites would result in more accurate inflow forecasting during high flow events. Gauges not currently installed due to lack of funding.*

D3.2 Improved Forecast Products

Precipitation, Supporting Finer-Resolution Operations Outlooks

- *(4.2) GP-NKAO Forecasting precipitation magnitude, storm runoff amounts … are unreliable in our geographical area. (D.2.2) (GP NKAO) … have not found and do not foresee a product that can more accurately predict the amount of water resulting from a potential storm.*

- *(D2.1) (LC YAO) Better and accurate prediction of precipitation within 1 to 2 days would be great.*

- *(4.2.18) (UC AAO) If it could be shown that the runoff and hydrograph from a particular thunderstorm or other storm event could be accurately predicted, even a day before, it would be a tool that could be used in better reservoir control.*

- *(D.2.2) (LRD) Any improvement to hurricane storm surge forecasts that would make them finer in resolution, earlier in issuance, and/or probabilistic would be very helpful. An overall inundation forecast including storm surge, rainfall, and river flooding for tropical events would be very informative for emergency operations and for operation of coastal water control structures.*

- *(D.2.2) (LRD LRN) QPFs based on probability. For example, the current 24-hour QPF might be for 1 inch of rainfall, with a 75% chance of 0.6 inch and a 10% chance of 2 or more inches.*

- *(D.1) (MVD MVS) Shifts of rating curves at times have not been accurate due to measurements. QPF products at times are not accurate. Updates to QPF don't necessarily match (1-, 3- and 5-day). Measurement conditions are not always good and a shift should not always be made. We operate projects real-time and the USGS has the option of changing curves several weeks/months later. QPF and extended forecasts have proven not accurate. Sometimes the amounts may be correct, but the location is not.*

- *(D.2.2) (SPD SPL) Anything that helps to better define the timing, spatial distribution, and quantities of precipitation as it comes off of the ocean would be helpful. Radar doesn't extend very far off of the coast and the orographic effects can be significant because of coastal mountain ranges.*

- *(D.2.2) (SWD SWF) New models with more accurate weather forecasts as well as river forecast.*

- *(D.2.2) (SAD SAS) Would also like to have updated PMF storms developed for each of our projects.*

Streamflow, Supporting Finer-Resolution Operations Outlooks

- *(D2.2) (PN SRAO) More accurate RFC-style 5-day streamflow forecasts would be the top of my wish list.*
- *(D1) (PN CCAO) In cooperation with the USGS, we developed a rainfall runoff model for the Yakima Basin which was designed to use coarse and fine climate data. The USGS obtained historical data from NOAA that was used in the development of the model but was then not available real time. This diminished the quality of the output. … Real time weather data was not accessible. It retrieval and loading routine could not be automated.*
- *(D2.1) (MVD MVR) Ensemble Probabilistic Forecasts would be more useful if those forecasts were checked and verified prior to dissemination. It is my understanding that those ensemble forecasts are auto-generated and not checked prior to dissemination due to manpower constraints within the NWS.*
- *(D2.1) (NAD NAE) We rely heavily on Official Streamflow Forecasts, with QPF. These products are not available for all desired locations. We have been working with the NWS to add forecast points, with success. We plan to continue this effort. Also, any effort that can be made to increase the accuracy of these forecasts would be helpful.*
- *(D2.2) (LRD LRP) Provide more than one river forecast during normal business hours.*
- *(D2.1) (SPD SPL) I believe the RFC is now adopting processes that can generate <6hr time step models. When/if that happens we will be able to more directly use the RFC runoff forecasts for more projects in the Los Angeles Basin.*
- *(D2.2) (SAD SAS) Need Inflow Forecasts bases on RFC QPFs as a standard product. Would like to have 3- to 5-day forecast of hourly inflow values to our projects, several upstream projects, and to several downstream control points on the river. I understand that the downstream river forecasts are based on our releases.*
- *(D2.2) (SWD SWF) New models with more accurate weather forecasts as well as river forecast.*

- *(D2.1) (NWD NWW 1) ESP traces without a deterministic weather forecast or a shorter period than 10 days.*
- *(D2.2) (NWD NWW) Gridded QPF data could be supplied for use by districts in model-based forecasts.*

Streamflow Predictions Supporting Medium-Resolution Operations Outlooks

- *(D1) (UC WCD) I tried to use historic rate of SWE loss with lag times, to estimate peak flow of the river in the basin [during the snowmelt season]. Also, looked at a magical percent of the remaining snow to the season's maximum snowpack as an indicator. … Too many variables involved. Maybe would work if there was better representation of the actual remaining snowpack, rather than relying on specific SNOTEL sites. I currently rely on the RFC peak flow forecast, but timing of the peak is still far from the accuracy I would like to have.*
- *(D2.1) (NWD MRBWM) Snowmelt peak flow forecasts are rarely seen or reviewed by NWD-MRBWM. This would be a useful forecast to consider when determining reservoir releases during the snowmelt runoff season.*
- *(D2.2) (LRD) … We also need forecasts of St. Lawrence River local drainage flows on daily to monthly time scales.*
- *(D.2.2) (LRD LRC) Include the effect of snow melt into river forecast.*
- *(D2.2) (SAD SAJ) Weekly, monthly, seasonal, basin specific comprehensive quantitative streamflow/runoff forecast derived from QPF, actual soil moisture, forecasted soil moisture, actual evapotranspiration, forecasted evapotranspiration, ENSO (El Nino, neutral, La Nina), Bermuda High, Jet Stream, etc for upstream and downstream of projects. Tool for use in the decisionmaking process for water management operations.*
- *(D1) (LRD LRH) Ensemble flow forecasts at critical USACE flood control projects needed for CWMS. Flow forecasts of ensembles could not be directly ingested into CWMS.*

Runoff Volume Predictions Supporting Coarse Resolution Operations Outlooks

- *(Appendix B, introduction)(GP-NKAO) Forecasting … probabilistic volume forecast targeting seasonal periods are unreliable in our geographical area.*

- *(D1) (LC BCOO) We receive a 3-month inflow forecast of intervening flows between Glen Canyon and Hoover Dams from the CBRFC. … The methodology used to compute these inflows is based on type of gauging method; we have asked the CBRFC to modify the methodology to a mass balance method.*

- *(D2.2) (LC BCOO) Improved forecasts of side inflow for reaches in the lower Colorado River Basin.*

- *(D1) (MP LAO) We were working with Desert Research Institute and NRCS on PRMS in our area, hoping to get a better seasonal forecast with a physically based model. … Takes time, effort, and staff to work with these models. NRCS has a dedicated but limited staff, and they also had some issues with IT, which made it difficult for them to directly take the models from DRI.*

- *(D2.1) (SAD SAW) I'm not familiar with the water supply forecasts in other regions—perhaps those would have some potential value.*

- *(D2.2) (LRD) …in the Great Lakes, we need net basin supply forecasts on daily, weekly, and monthly to annual time scales with improved skill.*

- *(D2.2) (MVD) I can envision a product that would show probabilistic streamflow based on ENSO climatic conditions. In other words, if a La Nina event is occurring then a probabilistic streamflow should be developed based on previous La Nina events.*

- *(D2.2) (NWD NWO) …Gridded temperature and snow water equivalent data from the NWS RFC similar to the gridded precipitation data we already receive from MBRFC via LDM. We need these three pieces of gridded data for inputs to plains snowmelt runoff models to improve runoff forecasts.*

- *(D2.2) (NWD NWP) Perhaps correlate between NOHRSC data and runoff. I.e., Given SWE/by data might produce XXX runoff [volume].*

- *(D1) (NWD NWS) We used precipitation data in Canada for our water supply forecasting on the Kootenai River at Libby Dam. We have come to learn that Canada no longer QA/QCs its data. This has led to erroneous values for this site, which is affecting our water supply forecast. This site is needing to be replaced.*

- *(D2.2) (NWD NWS) One of our basin, the Kootenai is mostly located in Canada. There is very little snow data available for this area. We are starting to explore NASA's MODIS snow cover data to help determine the amount of potential snowmelt. Remote sensing data could be very helpful for areas like these where there is very little actual measurements available.*

- *(NWD NWW 2) Snodas (NOHRSC) gridded snow water equivalent data should be identified in the Table 3. We are beginning to use this data in hydrologic modeling.*

Water Level

- *(D2.2) (LRD) Any improvement to hurricane storm surge forecasts that would make them finer in resolution, earlier in issuance, and/or probabilistic would be very helpful. An overall inundation forecast including storm surge, rainfall, and river flooding for tropical events would be very informative for emergency operations and for operation of coastal water control structures.*

- *(D2.2) (LRD LRP) When issuing Flood Warning, Watch, and Outlook forecasts, include specific river stages and flows so that we don't have to look at multiple forecasts to get the full information.*

- *(D2.2) (NAD NAE) …since the travel time from some dams in the Connecticut River Basin is greater than the river stage forecast time, it would be helpful if the stage forecasts for the Connecticut River at Hartford CT extended to 4 days. Note: river stage forecasts in the New England area are limited to 2+ days ahead, currently, due to quick response times making longer forecasts less reliable.*

Other Hydroclimate Predictions (Seasonal Climate, Snow Accumulation, Evaporation From Open-Water Bodies, Soil Moisture, and Ecosystem Metrics)

- *(D1) (PN 2) … anything that can be done to give a more believable outlook of the winter snowpack building period would be useful.*
- *(D2.1) (PN 2) I would like to have some indication other than the 1- and 3-month outlooks that would tell me how much more snowpack is going to build before April 1st. (D2.2) (PN 2) Is there some way that a product looks at each basin and gives a probability of getting normal snowpack? This would not look at historic statistics but rather at the condition of the atmosphere and what the potential is?*
- *(D1) (LRD) We found only limited improvement in skill for Lake Superior in the spring, but not for any of the other lakes or seasons. We believe the demonstration was unsuccessful due to the limitations of seasonal weather forecasting at this time.*
- *(D2.2) (LRD LRE) Better climate outlooks up to 6-months out would be very useful for Great Lakes water level forecasting. Any products that extend across the border and cover the Canadian portions of the basin would also be helpful. Better data on evaporation (estimates based on cloud cover, etc.) and soil moisture.*
- *(D2.2) (LC BCOO) Forecasts for reservoir evaporation in the lower basin.*
- *(D2.2) (SAD SAS) …. Would also like to have daily evaporation estimates for the USACE reservoirs.*
- *(D2.2) (LRD LRB) Our model of the Genesee Basin (HEC-HMS) requires input of a soil moisture content related variable (initial deficit). It would be helpful to have a published modeled soil moisture content (e.g. in regional map form).*
- *(D2.2) (LRD) Recent work by the IJC Upper Lakes Study showed the utility of regional climate models. We are also in need of linking hydrologic and temperature forecasts to forecasts of biological activity to manage reservoirs for fish spawning and nesting.*

D3.3 Understanding on Product Relationships and Utilization in Water Management

Information on Product Development and Quality Attributes

- *(C12) (UC 2) We have to be able to compare the forecast conditions that are current with what has been forecasted in the past. This puts the forecast product into perspective.*

- *(D2.2) (UC 2) I think that forecasts should always be presented with a description of the skill of that forecast product. I sometimes find this information lacking when we receive the forecast product.*

- *(D1) (LRD LRE) We have previously attempted to incorporate radar-based precipitation forecasts. Data size, availability, processing capabilities, and questions regarding how the data was ground-truthed … have all been issues with utilizing radar-based precipitation data.*

- *(C11) (NWD-NWL 2) We do not use the probabilistic streamflow forecasts, as our decisions are necessary to be made considering measured flows and we use our judgment to evaluate likelihood of streamflows at target locations.*

Information Synthesis

- *(D2.2) (SWD SWT) All current tools meet SWT needs. There is already too much information to sort thru.*

- *(D2.1) (MP CVOO 2) In California, there are many, many hydrologic products available. … some amount of information overload does occur … many managers or stakeholder interests have a difficult time deciphering how to effectively utilize information as the kind of cross time scales discussed. To a significant degree, this problem is an education product related issue. … need to understand how water projects and hydrologic datasets begin to function together at multiple timeframes, rather than singular points in time. I.e., the hydrologic datasets are only useful if you understand what they are useful for and how long in time they are useful.*

- *(D2.2) (MP CVOO 2) I believe that until a synthesis of water management principles and hydrologic dataset is better understood at multiple timeframes, decision support will be a challenging goal.*

- *(D2.1) (UC AAO) I think the bigger problem is not knowing ALL of the tools that are out there. Navigating many different websites can be a daunting task. Valuable products/tools may be out there, but getting to them or even knowing about them is a major issue. Keeping up with the exploding technology and data availability is almost a full-time job. Many agencies have really cool toys out there, but it can be sometimes hard to play with them.*

- *(D2.1) (UC WCD) It would be nice to have a workshop (or some sort of gathering of like-minded folks) to learn of innovative products being used in other regions that may help us with our operations.*

- *(D1) (IWR HEC) The challenges with products like these and GCM model output is workload, general lack of knowledge in the Corps, related time and knowledge to absorb a more abstract product, and the need for a more concrete usable product. Building capability via tools, usable products, knowledge sharing, and through actual experiences will probably enhance the use of these products for short-term and long-term operations that is within the authorized purposes of the project and according to current Corps policy regarding water management*

- *(LRD LRN) Availability to see NWS hydrologic forecasts for same region. These would be used to compare to our model results. We could then hedge our reservoir management plan depending on any discrepancies between the two.*

- *(D2.1) (SPD SPK) We also receive information/data/forecasts from State of California, Dept. of Water Resources that are used in conjunction with the addressed forecasts to better operate the reservoirs.*

Education on Water Management and Forecasting Principles

- *(D2.1) (MP CVOO 2) In California, there are many, many hydrologic products available. … some amount of information overload does occur … many managers or stakeholder interests have a difficult time* *deciphering how to effectively utilize information as the kind of cross time scales discussed. To a significant degree, this problem is an education product related issue. … need to understand how water projects and hydrologic datasets begin to function together at multiple timeframes, rather than singular points in time. I.e., the hydrologic datasets are only useful - if you understand what there useful for and how long in time their useful.*

- *(D2.2) (MP CVOO 2) I believe that until a synthesis of water management principles and hydrologic dataset is better understood at multiple timeframes, decision support will be a challenging goal.*

- *(D1) (MP CVOO 2) The difficulty is the education of water management principles and hydrologic timeframes, many interests simply don't care about any time frame but the one that affects their interest.*

- *(D1) (PN 2) I think the reason that we are not able to trust the La Nina, and El Nino predictions and the 1- and 3-month outlooks because of some big busts in these forecasts in the last 10 years. 2001 was a big bust saying that we would have above normal conditions under La Nina conditions and it was a very dry year. … It is hard to believe and operate reservoir with this kind of uncertainty.*

D3.4 Information Services Enterprise

Product Maintenance

- *(D2.1) (PN SRAO) Some of the products that are already available have not been revised and calibrated enough to be as useful as they could be.*

- *(D2.2) (UC AAO) I think continued refinement of what is out there is the best approach. There are also a lot of cool things out there with limited practical application. A prime example is the program to define the effects of dust on snow. It's nice research but it needs to somehow be tied into other data/products to either refine forecasts or be a stand-alone tool to better predict runoff.*

Product Format

- *(D2.2) (PN CCAO) The RFC produces short-term forecasts and longer-term ESP runs for specific locations in the Yakima Basin. It would be beneficial to have them in more easily obtainable and transferable format.*

- *(C12) (UC 2) Products that are not specifically designed for use are difficult to incorporate.*

- *(D2.1) (SAD SAS) We need to establish a standardized access method to many of your products other than FTP. We would like to establish LDM feeds from the RFCs for most of your products. Would also like to have Forecast based Flood inundation map estimates for the Savannah River below Turmond Dam.*

- *(D1) (LRD LRH) Ensemble flow forecasts at critical USACE flood control projects needed for CWMS. Flow forecasts of ensembles could not be directly ingested into CWMS.*

- *(D2.2) (LRD LRH) Gridded QPF in CWMS-compatible format. Soil moisture antecedent conditions in CWMS-compatible format. Ohio River stage forecasts in CWMS-compatible or HEC-RAS-compatible format.*

- *(D2.2) (IWR HEC) The products in Table 4 such as Seasonal Climate Outlooks, Official Streamflow Forecasts with and without QPF, and ESP traces in an easily ingestible format would be good.*

Other

- *(D2.1) (PN SRAO) Some problems may be division of basins by administrative boundaries and effects of topography that are felt windward or leeward of the feature or lack of consideration for the direction of prevailing flow.*

- *(D2.1) (NWD NWO) NWS WFO in Riverton, WY supplies a water supply forecast graphic for streams and reservoirs that gives volume in acre-feet and the percent of normal. This product is a useful tool to check forecast numbers and provides a visual look at high and low* *forecast areas. It would not be a direct input but a valuable reference if provided in other states.*

- *(D2.2) (PN CCA) It is also difficult to obtain fine, medium and coarse temperature and precipitation data from NOAA. The process should be easy, accessible, and dependable.*

- *(D2.2) (NWD NWO) Recommend that CPC outlooks provide an actual forecast as opposed to the percent chances they currently give. They need to be explained better as the information shown is not easily interpreted. This would influence long-term or seasonal forecasts and regulation plans.*

- *(D2.1) (NWD NWS) Overall, our region has a wide array of products available, but we could use help from the Canadian portion of the Columbia.*

Appendix E: Record of Perspectives Contributed by Other Organizations

In May 2012, letters were distributed to over 80 Federal and non-Federal agencies and organizations inviting review and to provide perspectives on this document. In response, a number of comment and perspectives were received and are presented within this appendix in the exact manner in which they were received. The first two tables are lists of non-Federal and Federal invitees whose perspectives were requested. The second set of documents are the letters received in response to the request for perspectives. The third set of documents within this appendix are the tables documenting the prioritization of needs statements that were received.

The submitted perspectives highlight the significant interaction and interdependency between Federal and non-Federal water management agencies and the necessity for this interaction. For the most part, the perspectives received reinforce the needs statements characterized through the use assessment described in the main body of the report. There remains a significant heterogeneity among water management operations and needs, both geographically and through agency fulfillment of individual missions. Some commonalities do exist though. Non-Federal interests require the best available information within a context of recognizing the burden of costs and regulatory restraints within water management. Key messages received from outside respondents include the necessity to maintain and even expand observational networks to support real-time operations but also within the context of tracking climate change impacts. Further, the development of improved forecast models at time scales that support seasonal to multi-annual outlooks appears to be a common need across a variety of water management agencies. These needs are characterized within the context that there is already a lot of information and that there is a need to manage the information in a manner that supports decisions.

Non-Federal and Federal Perspective Invitees

Table E1. Other non-Federal organizations that have responsibility for water and water-related resource management and stewardship that have been invited to contribute their perspectives to the initial release of the document.*

Organization	First Name	Last Name
American Water Works Association	Michelle	Maddous
ASCE- Environmental & Water Resources Institute	Brian	Parsons
ASCE Task Committee on Sustainable Design	Michael	Sanio
Association of Fish and Wildlife Agencies	Arpita	Choudhury
Association of State and Interstate Water Pollution Control Authorities	Linda	Eichmiller
Association of State Dam Safety Officers	Lori	Spragens
Association of State Drinking Water Administrators		
Association of State Flood Plain Managers		
Association of California Water Agencies	Mark	Rentz
Association of State Wetland Managers	Jeanne	Christie
BC Hydro	Frank	Weber
California Energy Commission	Linda	Spiegel
California Department of Water Resources	Michael	Anderson
Central Arizona Project	Larry	Dozier
Family Farm Alliance	Dan	Keppen
Interstate Council on Water Policy	Earl	Smith
National Association of Flood & Stormwater Management Agencies	Susan	Gilson
National Water Resources Association	Tom	Donnelly
National Waterways Conference	Amy	Larson
Northwest Power and Conservation Council	Jim	Ruff
Colorado Water Conservation Board	Jennifer	Gimbel
Colorado River Water Conservation District	Eric	Kuhn
Salt River Project	John	Sullivan
Imperial Irrigation District	Brian	Brady
Southern Nevada Water Authority	Kay	Brothers
Southern Nevada Water Authority	Bill	Rinne
Metropolitan Water District of Southern California	Roger	Patterson
Denver Water Board	Marc	Waage
Northern Colorado Water Conservancy District	Eric	Wilkinson
The Nature Conservancy	Terry	Sullivan
Trout Unlimited	Chris	Wood
Water Utility Climate Alliance	David	Behar
Water Utility Climate Alliance	Paul	Fleming

Table E1 (continued). Other non-Federal organizations that have responsibility for water and water-related resource management and stewardship that have been invited to contribute their perspectives to the initial release of the document.*

Organization	First Name	Last Name
Water Utility Climate Alliance	Laurna	Kaatz
Waterways Council, Inc.	John	Doyle
Western Governors' Association	Tom	Iseman
Western States Water Council	Tony	Willardson
Western States Water Council	Jonne	Hower
Western States Water Council	Jeanine	Jones
Western Regional Climate Center	Tim	Brown
High Plain Regional Climate Center	Martha	Shulski
Southern Regional Climate Center	Kevin	Robbins
Midwest Regional Climate Center	Beth	Hall
Northeast Regional Climate Center	Arthur	DeGaetano
Southeast Regional Climate Center	Charles	Konrad
CLIMAS	Jonathan	Overpeck
WWA	Bradley	Udall
CNAP	Dan	Cayan
CIRC	Phil	Mote
ACCAP	Sarah	Trainer
Pacific RISA	Nancy	Lewis
SCIPP	Mark	Shafer
SECC	Keith	Ingram
GLISA	Donald	Scavia
CCRUN	Cynthia	Rosenzweig
CISA	Greg	Carbone

* The goal for the initial release was to "seed" the document with a representative cross-section of the Federal and non-Federal water and water-related resource management communities. We attempted to identify organizations that can provide this sampling in our invitation to contribute perspectives in the initial release. We recognize that this invited list does not include all organizations that can offer relevant contributions. We hope to obtain other contributed perspectives through online web collaboration after the initial release of the document.

Table E2. Other <u>Federal</u> organizations that have responsibility for water and water-related resource management and stewardship that have been invited to contribute their perspectives to the initial release of the document.*

Agency	First Name	Last Name
Council on Environmental Quality - Water Resources and Climate Interagency Workgroup	Jeff	Peterson
U. S. Global Change Research Program	Tom	Armstrong
U. S. Global Change Research Program	Kathy	Jacobs
OSTP - Subcommittee on Water Availability and Quality	Jerad	Bales
Western States Federal Agency Support Team	Roger	Gorke
Bonneville Power Administration	Nancy	Stephan
DHHS - Centers for Disease Control and Prevention	Joan	Brunkard
DHHS - Centers for Disease Control and Prevention	Rob	Blake
DHHS – FEMA	David	Kaufman
DoA – Assistant Secretary of the Army for Installations and Environment (ASA-I&E)	David	Guldenzopf
DoA – Assistant Secretary of the Army for Installations and Environment (ASA-I&E)	Thomas	Mooney
DoD – Navy	Tim	Gallaudet
DoD – OSD I&E	Maureen	Sullivan
DoD – OSD SERDP	Jeffrey	Marqusee
DOI – Bureau of Indian Affairs	Mohammed	Baloch
DOI – Bureau of Land Management	Dan	Lechefsky
DOI – National Park Service	Leigh	Welling
DOI – U.S. Fish and Wildlife Service	Dan	Ashe
DOI – U.S. Fish and Wildlife Service	Kurt	Johnson
Tennessee Valley Authority	Anda	Ray
U.S. Environmental Protection Agency	Karen	Metchis
USDA - Forest Service	Linda	Joyce
USDA- Forest Service	Chuck	Rhoades
USDA-Forest Service	Tom	Brown
USDA-Forest Service	Polly	Hays
USDA - NRCS	Tom	Perkings
USDA - NRCS	Mike	Strobel
USDA - NRCS	David	Garen
Western Area Power Administration	Shane	Collins

* The goal for the initial release was to "seed" the document with a representative cross-section of the Federal and non-Federal water and water-related resource management communities. We attempted to identify organizations that can provide this sampling in our invitation to contribute perspectives in the initial release. We recognize that this invited list does not include all organizations that can offer relevant contributions. We hope to obtain other contributed perspectives through online web collaboration after the initial release of the document.

Record of Letters Received

Central Arizona Water Conservation District
Metropolitan Water District of Southern California
Southern Nevada Water Authority

June 28, 2012

Bureau of Reclamation Research and Development Office PO Box 25007 Denver, CO 80225	National Oceanic and Atmospheric Administration Office of Hydrologic Development 1325 East West Highway Silver Spring, MD 20910	U.S. Army Corps of Engineers Institute of Water Resources Casey Building, 7701 Telegraph Road Alexandria, VA 22315

Dear Messrs. Brown, Pietrowsky, and Carter:

The Southern Nevada Water Authority, Metropolitan Water District of California, and Central Arizona Water Conservation District, collectively herein, the "Lower Basin Water Users" appreciate your invitation to provide a Non-Federal Organizational perspective of Water and Water Resources Management on the document titled *Short-Term Water Management Decisions.* The Lower Basin Water Users collectively represent the majority of municipal water users in the Lower Colorado River Basin as well as some agricultural and tribal interests in Arizona. Our agencies are each individually responsible for managing a diverse portfolio of water resources and providing a firm and reliable water supply to our customer base.

As such, the Lower Basin Water Users work regularly with the Bureau of Reclamation (Reclamation) and the Colorado Basin River Forecast Center to understand and forecast future water supply conditions on the Colorado River both short-term and long-term. These forecasts are ultimately incorporated into a short-term operations model, the 24-Month Study, and a mid-term planning model, the MTOM. These models are maintained and operated by Reclamation and the data from them is heavily relied upon by not only the Lower Basin Water Users but also every major water entity in the Colorado River Basin. The collective response we provide to this survey is a perspective of the needs of the Colorado River Basin as a whole. It is designed to look at the macro scale needs that would lead to better refinement of the forecasts and models that are relied upon most by our agencies.

Additionally, it appears there are many federal programs currently focusing on these same issues. We encourage the group responsible for this document to interact closely with other overlapping and parallel efforts. For example, the Landscape Conservation Cooperatives (LCC's) established under Secretarial Order No. 3289, are providing federal funding to similar projects. This collective document and agency perspective could help inform and guide funding decisions for the LCC's as well as other programs such as the work of the Climate Science Centers.

If you have any questions, please feel free to contact us.

Sincerely,

Dennis A. Rule, CAWCD CAGRD Manager	William Hasencamp, MET Colorado River Resources Manager	John Entsminger, SNWA Senior Deputy General Manager

Oregon Water Resources Congress
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June 29, 2012

Submitted via email to: david.a.raff@us.army.mil and lbrekke@usbr.gov

OWRC Comments on the Federal Climate Change and Water Working Group's "Short-Term Water Management Decisions: User Needs for Improved Climate, Weather and Hydrologic Information – May 2012 Review Draft"

The Oregon Water Resources Congress (OWRC) is a nonprofit trade association representing agricultural water suppliers in Oregon, primarily irrigation districts, as well as other special districts and local governments that deliver irrigation water. OWRC was established in 1912 to support member needs to protect water rights and encourage conservation and water management statewide. OWRC members operate complex water management systems, including water supply reservoirs, canal, pipelines, and hydropower production, delivering water to more than 560,728 acres of farm land state-wide, roughly 1/3 of all irrigated land in Oregon. About half of our members have contracts with or are in Bureau of Reclamation projects.

OWRC is also a member of the National Water Resources Association (NWRA), and the Family Farm Alliance (Alliance), both of which received an invite to provide feedback regarding the *Short Term Water Management Decisions: User Needs for Improved Climate, Weather and Hydrologic Performance* Draft Report, using your online feedback form. OWRC has provided our rankings to both organizations for inclusion in their submitted comments. However, upon our review of the underlying document we felt it necessary to send along this letter for clarification and to comment on some areas that don't necessarily fit the feedback form.

First and foremost, we are appreciative of the work conducted by the various federal agencies to develop practical climate, weather, and hydraulic information for water managers to use in identifying and responding to climate change impacts to water resources. Our membership will be interested in the future development of research strategies to meet these needs as referenced in your cover letter. We are presently undergoing similar efforts here in the State of Oregon and our members are always interested in how federal agencies intend to address issues such as these that have likely consequences for our members.

We are encouraged by your intent to keep this document updated and to utilize the various perspectives of water users to make revisions. As that occurs, we would encourage you to use the list of email addresses generated by responses through the Feedback forms as a means for letting parties know of the updates.

OWRC concurs with the identified need for a robust program of streamgauges for short term decision-making (page 7). OWRC has been an active member in a larger coalition working to secure greater funding for USGS Water Data and Science Programs. We also agree with the need for an expanded geographic coverage of forecast products, particularly as state and federal funding has led to discontinuing existing sites. And we also thoroughly agree that there is a need for training on using and understanding the information generated, as well as a common format. Consistent and user-friendly data is essential to provide utility to water managers and water users. However, these apt observations leads us to wonder why there isn't already a common place to find this information and how will other data sets fit into this effort?

We recognize that the report is still in draft form with further review and revisions to be conducted. However, there are a few areas where the lack of detail is concerning as the implications vary depending on what the detail is, particularly relating to the nature of federal agency decision-making. In the spirit of constructive criticism we are providing questions that arose during our review that would be helpful to have addressed in future work.

- Is this document consistent with the Secretarial (Interior) Order on Climate Change? How is this document different?
- How are the needs of other Interior Department agencies addressed in the decision-making process? What is the hierarchy in such issues as man versus fish? Structural versus non-structural? Building versus conserving?
- Are these operation decisions for Federal projects or for state and local projects in a given watershed? Are they for quantity or quality purposes? Intrastate or Interstate?
- How are the legal requirements for Endangered Species Act or Clean Water Act issues addressed to allow for decision-making on the short term?
- How has hydroclimatic information specifically been used as referenced on page 5?
- Lastly, is there any consideration given to cost in the decision-making?

Additionally, given OWRC's ongoing efforts to seek funding for streamgauging programs, we wonder if this effort has or will identify some optimum number of gauges for purposes of the requisite decision-making referenced. Is it a technology issue? The document appears to allude to the set of circumstances that if the same "strategy" approaches continue to be used there will be continued failures to recognize climate in the future of water decision-making.

As an aside, we would point out a concern with this documents failure to include or address, maybe reference the needs of the Native American community in this effort. Oregon and the other Northwest states have a large Native American community that should be involved and benefit from your work.

This report called to memory the recommendations from the National Drought Policy Commission some dozen years ago. Ironically, the Corps and the Bureau were a major part of that effort but the lessons learned do not appear reflected in this document.

We have provided the following excerpted Policy Statement to reiterate those recommendations:

> "National Drought Policy should use the resources of the Federal Government to support but not supplant nor interfere with state, regional, local, tribal and personal efforts to reduce drought impacts. The guiding principles of national drought policy should be: Favor preparedness over insurance, insurance over relief, and incentives over regulation; Set research priorities based on the potential of the research results to reduce drought impacts; Coordinate the delivery of federal services through cooperation and collaboration with non-federal entities."[1]

We raise this policy because nowhere in the document do we see any reference with regard to concerns for economic development in the short-term decision-making process. There are threads throughout the document referencing the value of addressing the natural system impacts, but nothing in this regard. We would add that strong consideration should be given to the idea of building on the Drought Monitor tool that was developed coincidently during the National Drought Policy Commission effort. We believe there is great value in using the familiar rather than the foreign to move forward in this area.

Chapter 3 appears to be the strongest component of the draft report. Our plan is to make use of the educational material contained in this document and use it with our managers and others in the state and region, particularly in assisting new water managers. And we would like to thank you for the strength of this information. We would like to note, however, concern with message that emanates toward the end of the Chapter. Section 3.4.4 (page 65) states:

> "As in most work environments, the personnel interests, beliefs, past experiences, knowledge of staff and managers, and the culture of the office as maintained by the personnel influence attitudes toward the offices' strategies for discharging their responsibilities. Top-down agency guidance and training programs may help to standardize attitudes toward innovations (in capabilities, processes, tools, information) that would alter long standing practices, but substantial grassroots level variation in personnel attitudes toward forecasting may exist. At all levels, insufficient expertise, training, and knowledge of existing or potential forecasts may result in the nonuse of forecasts. Insufficient interaction between forecast produces and users also may limit forecast use, given that such interactions provide a conduit for feedback and user support to aid forecast interpretation. Note that NWS Service Assessments during past floods have identified this factor as a significant factor in undermining proper forecast use and production. Forecast may not be available at the correct time, in the correct format, or for the location or predictand required for an operating decision. Lastly, as described in section 2, agency regulations, directives, and

[1] http://govinfo.library.unt.edu/drought/finalreport/fullreport/ndpcfullreport/ndpcreportpg35.htm

authorities may restrict or prohibit forecast use; in which case, they are a significant factor that may outweigh any others described in this section."

We find this to be rather disturbing indictment buried within this document. At a minimum it seems to suggest that until you – the federal agency partners - get your house in order, success is anything but assured. It simply does not make sense to proceed on the efforts identified in this paper until such corrective actions occur and are continually monitored for success.

In conclusion, we appreciate the efforts put into the 2012 Review Draft and look forward to further revisions and the final water data products that our members can use and benefit from. Although we may have other questions and concerns with some of the material our intention is to continue to be involved and work with your personnel in the region to resolve the issues we have highlighted in this letter.

Thank you again for inviting our national organizations to provide the collective perspectives of their membership and for your consideration of our additional comments.

Sincerely,

April Snell
Executive Director

Some Suggested Improvements in Runoff Forecasting, Data Needs and Technical Assistance for Pacific Northwest Regional Drought and Flood Risk Assessments

June 29, 2012

FROM: James Ruff, Northwest Power and Conservation Council

If future climate conditions are indicating warmer winters, coupled with greater frequency of rain on snow events and earlier runoff peaks, then it will be important to develop seasonal runoff forecast products earlier in the fall-winter period, as well as improve our existing runoff forecast procedures.

- River and water management decisions in fall and early winter period[1] are made under large uncertainty without the benefit of "official" runoff forecasts, which currently are not provided until January 1 of each year.
- Pacific NW should continue to build ENSO and/or PDO conditions into early season runoff forecasts and/or, at a minimum, as early season warning indicators.
- The Columbia River Forecast Group (formed under a requirement of NOAA Fisheries FCRPS BiOp) could use some assistance in continuing to improve the accuracy of monthly in-season runoff forecast products at key Columbia River system projects, including incorporating climatic variables into the forecasts. In particular, we need to improve seasonal runoff forecast procedures and products to facilitate the analysis and comparison of both current year and historic statistical water supply and streamflow (ESP) forecast products used to support operations of key Columbia Basin hydrosystem projects.

Data Needs

- Coordination should occur between and among the various federal and provincial agencies on need for additional SNOTEL and soil moisture station enhancements in/near the Columbia River Basin, as well as improved information on actual water use based on LANDSAT data.
- Runoff forecasts should incorporate greater and/or better snowpack, ground water and soil moisture data:
    - ~2000 new SNOTEL stations to replace manual snow survey stations
    - ~3000 new SCAN stations (nationwide) for improved soil moisture, soil temperature and meteorological data
- Maintenance and possible expansion of existing stream gaging station network

Technical Assistance

- NOAA Climate Service could provide peer review of various GCM downscaling methods and hydrologic models and provide a clearinghouse and coordinating role for regional climate change modeling in West.
- NOAA could develop and provide the Pacific Northwest with both drought and atmospheric river early warning systems.

[1] For example, before the first official season runoff forecasts are provided, the Corps of Engineers has a mandatory flood control draft of up to 2 Maf (or 48 feet from full pool) of the Libby Project on Kootenai River in Montana by the end of December of each year. A problem associated with this early flood control evacuation is that it limits the flexibility of the reservoir's operation during the winter months, e.g., it limits the ability to refill the reservoir in a low water year, which limits the volume of water available for instream flows for listed species.

- The Corps of Engineers should continue to develop and complete its water temperature modeling for the mainstem Snake and Columbia rivers.

Disclaimer: The comments and viewpoints expressed above are based on personal experience and judgment and thus do not necessarily represent the viewpoint of the Council.

w:\jh\ww\2012\4-3-12 suggested improvements in runoff forecasting.docx

Charlie Ester
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June 29, 2012

VIA Email

Dr. David Raff
US Army Corps of Engineers
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7701 Telegraph Road
Alexandria, VA 22315
david.raff@usace.army.mil

Dear Dr. Raff:

The Salt River Project appreciates the opportunity to contribute our own unique perspectives on the draft document, "Short-Term Water Management Decisions: User Needs for Improved Climate, Weather, and Hydrologic Information." We have utilized the Excel Feedback Form which was provided at the report's website to report many of the Salt River Project's perspectives.

The Salt River Project utilizes many of the programs and products which this report discusses, and works closely with the Bureau of Reclamation and several branches of the National Oceanic and Atmospheric Administration. SRP has found that adopting technology advancements and incorporating additional data streams into our water resource management decision making has both informed and improved that decision making. However, at the same time, we have found that complex modeling or simulation efforts are not always improved over a more simple application of technological advancements. There needs to be a balance between the science and the ability of the water manager to incorporate the new science into the existing or more slowly evolving decision making structure of the organization.

The value of basic stream and precipitation data can sometimes be overlooked. SRP is happy to see in the report the discussion of stream flow monitoring sites and weather stations. We strongly support the maintenance of the existing network and the expansion of the network where obvious gaps exist. A long historical data series can be priceless when evaluating climate change scenarios and potential impacts.

I hope these perspectives offer some insight into SRP's water management philosophy. Please contact me if I can be of further assistance. Thank you for your collaborative work on this report.

Charlie Ester

Charlie Ester
Manager, Water Resource Operations
Salt River Project

Record of Tables Received

Response from Steve Buan, Service Coordination Hydrologist, National Weather Service/NCRFC

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs: Low	Med	High	Perspectives	Citation or link to supporting information
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			x		
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.		x			
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent			x		
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.			x		
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.			x		
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.					
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.		x		I believe this is already a reasonably well funded/researched endeavor.	
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.					

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.			x	Because the NWS is for the most part a non-grant making agency, it is difficult to engage the research community to investigate and find solutions to hydrologic forecasting problems. It has been my experience that it is difficult for university researchers to acquire grant dollars to support investigating solutions to applied science problems. There seems to be plenty of money for "new" science investigations, but for the most part these are no help to operational science problems.	
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.			x	Same as above.	
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.			x	This can be an acute problem when dealing with relatively small volumes in the central and eastern US.	
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.			x	NWS must continue forging ahead to get away form exclusive reliance on single point hydrographs to characterize storm response in the river. Flood inundation area is only one possible mechanism.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.					
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.			x		
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.		x			
Education on Water Management and Forecasting Principles	U3	Training resources on water management principles spanning multiple time –scales.		x			
	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.			x	This needs to be linked with end user adoption of decision tools to use probabilistic information. It is my experience that personal intuition and experience play the largest role in water management decisionmaking.	
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.					
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.			x	I think this needs to be reversed. The water management community needs to develop systems to utilize what is already available.	

Response from FFA

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			x	We need to improve the spatial distribution of hydrometer stations rather than eliminate them.	
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.			x	Through hydrometer monitoring we need better method to estimate drought duration and intensity at the local spatial scale.	
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent		x			
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.	x				
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.			x		
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.		x			
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.		x		We need some solid research on whether storms are becoming more intense as it relates to infrastructure design.	
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.		x			

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.			x		
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.			x		
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.		x			
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.		x			
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.		x			
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.		x			
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.		x			
Education on Water Management and	U3	Training resources on water management principles spanning multiple time –scales.		x			
	U4	Training resources on probabilistic forecasting		x			

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Forecasting Principles		principles and risk-based decision-making.					
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.		x			
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.		x			

Response from Randall Kerr, USACE, LRD (LRN)

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			X	We don't necessarily need overkill on data, but you have to have it.	
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.	X			Could use radar data, but need ground proof stations	
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent	X			Not a big need in our area	
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.	X				
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.	X			I would rate this HIGH if the stream is a modeled output	
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.	X			Better short term (days) products would benefit us	
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.			X	If they are truly reliable	
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.	X			Not a big need in our area	
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.			X	Extremely hard to do, especially if using QPF	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.	X			Not a big need in our area	
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.	X			Not a big need in our area	
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.	X			This all depends on forecasting inflows, if you improve inflow forecasts then water levels should follow	
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.	X				
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.	X			Just want the numbers, not an explanation. Hedge the bet in the numbers themselves.	
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.	X				
Education on Water Management and Forecasting Principles	U3	Training resources on water management principles spanning multiple time –scales.	X				
	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.	X				

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.	X				
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.	X				

Response from MWD_CAP_SNWA

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs: Low	Med	High	Perspectives	Citation or link to supporting information
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			x	Existing networks are the underpinning of the major forecast tools used in the basin. Their long-term availability is critical for effective water management.	
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.		x		Local interest may drive a need for this data. From a basin wide perspective, enhancements are only necessary in areas that contribute large volumes of runoff. Put another way, it does not make sense to increase station density in an area where little water is contributed to the system as a whole.	
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent			x	Snowpack in the Upper Basin is a key driver for water supply. More thorough and accurate products are seen as highly valuable (along with expansion of SNOTEL network of snow stations in the Colorado River Basin, particularly at locations where runoff contribution is high and forecasting skill is low).	
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.				Not applicable	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.			x	Preserving existing networks is of very high importance; expanding these networks is desirable in the Colorado River system	
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.			x	As it relates to the major Colorado River Basin operational forecast, the 24-month study by the USBR, the "out year" forecast is always average conditions. A more advanced prediction (such as incorporation of long lead time indicators as ENSO climatic conditions in the Lower Basin) would greatly enhance the tool.	
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.		x		Local interest may drive a need for this data (ex. Localized flooding forecasts in parts of the Colorado River with active water recreational businesses) however, from a water supply perspective for the Basin as a whole, this data is not critical.	
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.		x		Local interest may drive a need for this data (and as more research showing connection between landfalling storms in coastal areas and precipitation impact inland including certain parts of the Colorado River basin), the forecasts deserve attention/ better understanding.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.		x		Local interest may drive a need for this data (ex. Localized flooding forecasts in parts of the Colorado River with active water recreational businesses). However, from a water supply perspective for the Basin as a whole, this data is not critical.	
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.		x		Local interest may drive a need for this data (ex. Localized flooding forecasts in parts of the Upper Colorado River with active water recreational businesses) however, from a water supply perspective for the Basin as a whole, this data is not critical.	
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.			x	As it relates to the 24-month study, the "out year" forecast is always average conditions. A more comprehensive forecast would greatly enhance ability to improve assessment and to manage water supplies, especially during critical periods (ex. when approaching trigger elevations for shortage declarations in the Lower Basin, approaching reservoirs flood control space, etc.)	
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.		x		As above, local interest may drive a need for this data. However, from a water supply perspective for the Basin as a whole, this data is not critical.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.			x	As it relates to the 24-month study, the "out year" forecast is always average conditions. A more comprehensive forecast would greatly enhance ability to improve assessment and to manage water supplies, especially during critical periods (ex. when approaching trigger elevations for shortage declarations in the Lower Basin, approaching reservoirs flood control space, etc.)	
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.		x		With less of a direct impact on water management, product development is necessary to improve the quality of information and (forecast) products.	
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.		x		The idea of an electronic clearinghouse (CA) could be beneficial for both in-state and intrastate coordination. It could enhance understanding, streamline information sharing, and avoid duplicative efforts when coordinating the management of water supplies.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Education on Water Management and Forecasting Principles	U3	Training resources on water management principles spanning multiple time –scales.	x			The Colorado River Basin State water management entities are well versed in these principals. Training improves ability of water utility professionals to understand, utilize, and stay abreast of advances in management and forecasting principles.	
	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.	x			The Colorado River Basin State water management entities are well versed in these principals. Training improves ability of water utility professionals to understand, utilize, and stay abreast of advances in management and forecasting principles.	
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.		x		In pursuit of improving and advancing short term water management, water utilities support maintenance and development of information-related products.	
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.		x		Water utilities welcome development of products and interfaces for the purpose of better integration and use of the vast amount of available weather-related information.	

Response from Michael Strobel (Director), Tom Perkins (Water and Climate Services Team Leader), and Jan Curtis (Applied Climatologist), National Water and Climate Center, Natural Resources Conservation Service (NRCS)

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			x	Adequate data distribution and continuity of period of record is critical for evaluating trends and making decisions related to hydrologic conditions. Declining budgets and staff directly impact the operation and maintenance of observation networks. It would be useful to have effective real-time integration of remotely-sensed data with in-situ data. There should be an evaluation of where duplications of sensor coverage exists.	
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.		x		Additional weather stations in areas of sparse station density and large spatial variability over short distances would be beneficial. It is important that data are collected in uniform procedures with standardized tools and sensors. Using an analytical method to identify new station locations will produce data both effectively and economically. A task force could prioritize new sensor deployments and sites considered for decommission.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent			x	Increased interaction between NOAA (NOHRSC) and NRCS (NWCC) could produce better tools for evaluating snow cover and SWE. Utilizing coverages of snow covered areas could improve the accuracy of water supply forecasts.	
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.		x		NRCS presently operates SCAN stations in much of the US, and these could be instrumented for snow observations. NRCS also is exploring the possibility of expanding SNOTEL into these areas.	
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.		X		Streamflow data is critical for making accurate hydrologic assessments. Similar to weather stations and snow-observing stations, new streamflow gaging stations should be located based on value of data point for the analysis and specific needs of the customer	
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.		X		Important for overall assessment, but uncertain how NRCS would incorporate this into present operations	
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.		x		Important for overall assessment, but uncertain how NRCS would incorporate this into present operations	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs: Low	Med	High	Perspectives	Citation or link to supporting information
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.					
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.					
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.			x	This is a current activity for NRCS and an operational system that can be maintained for headwater and agricultural interests is about 1-2 years away.	
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.	x		x	High priority for the shorter lead times where there is sufficient quality in NRCS forecast products. Lower priority for poor performing long-term products	
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.					
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.			x	NRCS currently reflects this in our monthly and daily statistical water supply models. This will also be reflected in our hydrologic model operations.	
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.			x	It is important to have a standardized QA/QC of all environmental network data and data should be in a standardized data format, such as CUAHSI, SHEF and PRISM (for spatial climate data). All data should be coordinated through the Federal Geographic Data Committee.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
						NRCS is currently redesigning operational databases to provide more metadata	
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.			x	Consider the effectiveness of using "Cloud" technology for universal data access	
Education on Water Management and Forecasting Principles	U3	Training resources on water management principles spanning multiple time –scales.					
	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.			x		
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.			x		
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.			X	There has been much effort by numerous agencies to move towards formats that are compatible between data sets. NRCS is currently deploying new products that are compatible with GIS technology, WaterML format, CSV format and other formats that allow data transfer and incorporation between groups	

Response from Kellie Bergman, Chief, Water Control and Water Quality Section, USACE-NWO

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			x		
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.			x		
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent			x		
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.			x		
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.			x		
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.		x			
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.			x		
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.				Not applicable to NWO Water Management	
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.			x		

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.			x	This is important for water management support to Emergency Management regarding potential snowmelt flooding.	
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.		x			
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.		x			
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.		x			
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.	x				

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs: Low	Med	High	Perspectives	Citation or link to supporting information
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.			x	Along with Label U2, this is key to saving taxpayers money while enabling each agency to meets its mission. When organizations use the same data to make different decisions it is essential to improve communication and data transferability among agencies. Current capability: Transferring data among agencies requires manual effort and monitoring from engineers/technicians/IT personnel from each office. Desired capability: A streamlined process to simplify data transfer among agencies.	
Education on Water Management and Forecasting Principles	U3	Training resources on water management principles spanning multiple time –scales.		x			
	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.		x			
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.		x			

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.			x	Along with Label U2, this is key to saving taxpayers money while enabling each agency to meets its mission. When organizations use the same data to make different decisions it is essential to improve communication and data transferability among agencies. Current capability: Transferring data among agencies requires manual effort and monitoring from engineers/technicians/IT personnel from each office. Desired capability: A streamlined process to simplify data transfer among agencies.	

Response from Charlie Ester, Manager, Water Resource Operations, Salt River Project

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			X	Maintaining and sustaining existing wx and hydro networks is critical to continuous historical record and ability to detect trends in climate	
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.			X	Increased station density helps inform hydrologic decisionmaking.	
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent		X			
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.				Can't fairly assess the need when living way out west in Arizona.	
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.			X	Preserve higher priority to maintain integrity of historical hydrologic record, then venture into ungauged streams.	
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.		X			
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.		X			
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.				Because not impacted by these events, it is not appropriate to set a priority.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.			X	Any improvement in streamflow predictions better informs water management decisionmaking	
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.			X	Any improvement in streamflow predictions better informs water management decisionmaking	
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.		X		Any improvement in streamflow predictions better informs water management decisionmaking	
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.				Unable to assess priority	
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.	X			Sounds exciting but also very complex…sometimes, simple is better. Believe we could get more utility from efforts in other areas.	
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.			X	Understanding tools and limitations are key to using them correctly	
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.	X			Seems that someone accessing these data already have a pretty good understanding of how to use them.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.					
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.					
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.					
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.			x	Since reservoir releases are also made seasonally to account for downstream regulatory requirements (fisheries/ ecosystem support) under Biological Opinions and other legal mandates that must be layered in with all other project purposes, this type of forecasting would be invaluable.	
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.					
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.					

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Education on Water Management and Forecasting Principles	U3	Training resources on water management principles spanning multiple time –scales.			X	I liked the aspect of including the stakeholder perspective in the training resource expansion as they are so integral to many of our water management decisions.	
	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.			X	Stakeholder and water manager training in this area would definitely help to clarify the limitations on probabilistic forecasting and the utility of these tools in future water management decisions.	
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.			X	The process should be reiterative and evolve as the technology and monitoring/evaluation techniques advance.	
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.					

Response from Bonnie Van Pelt, Natural Resources Specialist, USBR

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			X	Include monitoring networks that cross regional boundaries and geographic jurisdictions	
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.					
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent					
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.					
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.					
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.					
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.					
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.					
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.					

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs: Low	Med	High	Perspectives	Citation or link to supporting information
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.					
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.					
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.					
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.			x	Since reservoir releases are also made seasonally to account for downstream regulatory requirements (fisheries/ ecosystem support) under Biological Opinions and other legal mandates that must be layered in with all other project purposes, this type of forecasting would be invaluable.	
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.					
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.					

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Education on Water Management and Forecasting Principles	U3	Training resources on water management principles spanning multiple time –scales.			X	I liked the aspect of including the stakeholder perspective in the training resource expansion as they are so integral to many of our water management decisions.	
	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.			X	Stakeholder and water manager training in this area would definitely help to clarify the limitations on probabilistic forecasting and the utility of these tools in future water management decisions.	
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.			X	The process should be reiterative and evolve as the technology and monitoring/evaluation techniques advance.	
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.					

Response from Jeanine Jones, WSWC

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			X		
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.			X		
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent		X			
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.			X		
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.			X		
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.		X			
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.			X		
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.			X	Together with improved forecasts in other Western areas covered under the October 2011 whitepaper prepared by Ralph et al for WSWC.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.			X		
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.		X			
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.			X	Key metric for drought	
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.		X			
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.			X	Again, key metric for drought. This ranks higher than F1 because hydrologic variables (F1) are only one aspect of drought prediction	
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.	X				
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.	X				
Education on Water	U3	Training resources on water management principles spanning multiple time –scales.	X				

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Management and Forecasting Principles	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.	X				
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.	X				
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.	X				

Response from Paul Fleming, WUCA Chair (Member from Seattle Public Utilities), Water Utility Climate Alliance (WUCA)

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs: Low	Med	High	Perspectives	Citation or link to supporting information
Category: Monitoring							
General	M1	Sustained support for monitoring networks that provide observations of weather and hydrologic conditions.			X	Important base for all aspects of water management. WUCA has supported this need in several past comments and testimony on NCS and cap and trade bills. For those basins that have Federal and Non-Federal Projects that are important to municipal supplies the existing networks are vital to forecasting and real time operations which is a critical need. Also important to maintaining reliable long term records.	WUCA Websitehttp://www.wucaonline.org/html/actions_federal.html
Precipitation	M2	Expanded networks of weather stations in water management regions that are currently served by relatively low station density.			X	A good idea overall in order to assess if weather patterns are changing and to capture more detail within the large geography of the West. Higher need in areas of significant variability in rainfall especially where runoff is direct source of water supplies, or areas of larger runoff, but may not be needed in basins with low contribution to runoff. An exception would be high altitude stations that enhance knowledge of snow melt contributions.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs: Low	Med	High	Perspectives	Citation or link to supporting information
Snowpack	M3	More interactive snow analysis products characterizing basin-distributed snow-covered area and snow-water equivalent			X	The value of meeting this need for water providers is to improve water supply predictions on an annual and seasonal basis as well as to capture headwater/high altitude contributions.	
	M4	Expanded networks of snow-observing stations in the Central and Eastern United States.		X			
Streamflow	M5	Preserving and expanding networks of streamflow observations with a focus on streams and rivers that are currently ungauged.			X	The preservation of streamflow observations is very important to retaining historic records against which climate change hydrologies can be compared or where synthesized records must be developed where streams/rivers are ungauged.	
Category: Forecasting							
General	F1	Enhanced suite of hydrologic predictions spanning lead -times of days to seasons and consistent with the continuum of weather to climate forecast products.			X	The link between shorter term forecasts and longer term climate change projections would potentially allow water managers to recognize trends over time and to support management adjustments	WUCA White Paper Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change (website location http://www.wucaonline.org/html/actions_publications.html
Precipitation, supporting Fine resolution Outlooks	F2	More reliable quantitative precipitation forecasts (QPF) on lead times of hours to days.			X	Meeting this need is important in areas where summer convection precipitation is a dominant pattern such as in Florida. Seattle uses this forecast to manage rivers for redd protection for in-stream resources. QPFs are the	1) Stefanova, L., V. Misra, S.C. Chan, M. Griffin, J.J. O'Brien, and T.J. Smith III, 2012: A proxy for high-resolution regional reanalysis for the Southeast United

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
						most foundation aspect of a forecast.	States: assessment of precipitation variability in dynamically downscaled reanalyses. Climate Dynamics, 38, 2449-2466, doi:10.1007/s00382-011-1230-y. 2) Stefanova, L., V. Misra, S.C. Chan, M. Griffin, J. . O'Brien, and T.J. Smith III, 2012: A proxy for high-resolution regional reanalysis for the Southeast United States: assessment of precipitation variability in dynamically downscaled reanalyses. Climate Dynamics, 38, 2449-2466, doi:10.1007/s00382-011-1230-y. 3) Stefanova, L., V. et. al. , 2012: A proxy for high-resolution regional reanalysis for the Southeast United States: assessment of precipitation variability in dynamically downscaled reanalyses. Climate Dynamics, 38, 2449-2466, doi:10.1007/s00382-011-1230

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs: Low	Med	High	Perspectives	Citation or link to supporting information
	F3	Improved precipitation forecasts for landfalling storms in coastal areas.			X	High percentage of precipitation comes in AR's on the West Coast, also presents major issues for stormwater management operation and facility design	Dettinger, Michael, 2011. Climate Change, Atmospheric Rivers, and Floods in California – A Multimodel Analysis of Storm Frequency and Magnitude Changes. Journal of the American Water Resources Association (JAWRA) 47(3):514-523. DOI: 10.1111/j.1752-1688.2011.00546.x
Streamflow, supporting Fine resolution Outlooks	F4	Enhanced streamflow predictions on lead times of hours to days, particularly during storm events.			X	Important for getting lead times quantity of river flow available to withdraw for water supplies especially during the transition from dry period t start of rainy season in places such as Florida and west side of the Pacific NW, turbidity events, stormwater management, and flooding. Water managers need to have as much lead time as possible to the above events, particularly as climate change predicts increasing extreme events.	
Streamflow, supporting Medium resolution Outlooks	F5	Enhanced streamflow predictions on lead times of days to weeks, particularly during the snowmelt season.			X	Allows water managers to improve options for management of water storage projects for municipal supplies.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Runoff Volume, supporting Coarse resolution Outlooks	F6	Improved anticipation of runoff volumes during lead times of months to seasons.		X		This need seems to apply more to larger river systems such as Columbia and Colorado, so improved assessments of runoff volumes there would be significant. Is specifically useful for evaluating infiltration on the larger scale.	
Water Level	F7	Enhanced prediction products characterizing potential water levels during storm events.		X			
Other Hydroclimate	F8	Multi-variate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions on lead times of days to seasons.			X	Information and tools to evaluate hydroclimate data to evaluate future behavior of the basin and local watershed hydrologic systems would be useful. Particularly useful to balance other resource needs such as fish/ESA/flows/habitat conditions. Would provide better information to manage for permit conditions (water rights, HCP, NPDES, TMDL)	
Category: Understanding on Product Relationships and Utilization in Water Management							
Information on Product Development and Qualitative Attributes	U1	More detailed meta-information describing product skill, reliability, and development.		X		Useful for making links between local data collection and that collected at the federal level. Documentation of product reliability and development is necessary to support the use of the tool or data set.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Information Synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations.			X	Meeting this need would enhance local understanding and therefore potential use of information that exists and saves duplication, or allow local water managers to target their investments better. Guidance documents on standard and innovative methods to synthesize and apply hydroclimate data would be useful to provide standardization in applications and alternative analysis methods.	
Education on Water Management and Forecasting Principles	U3	Training resources on water management principles spanning multiple time –scales.		X		Improves ability of water managers to both understand and utilize monitoring and forecasting data products. In basins well versed in the use of specific forecasting tools this benefit might be small (comment also applies to U4)	
	U4	Training resources on probabilistic forecasting principles and risk-based decision-making.			X	Water managers would benefit greatly from understanding the strengths and weaknesses of regularly available probabilistic forecasts. Improved support for the water community in understanding risks associated with using or not using forecasts, also can point to gaps where water managers could direct their funding to improve their own data systems or collaborate with other partners to accomplish this objective.	

Sub-category	Label	Need statement	Priority of addressing this need, relative to the other needs			Perspectives	Citation or link to supporting information
			Low	Med	High		
Category: Information Services Enterprise							
Product Maintenance	E1	Support product maintenance and evolution to accommodate new observations and research developments.		X		An effective data management and reporting system is key to the success and usefulness of a hydrologic monitoring program. Data needs to be accessible in a timely manner and have quality control designations associated with the information. The data management systems need to accommodate existing data networks as well as research study results.	
Product Format	E2	Develop product deployment formats that interface more readily with information systems commonly used in the water management community.			X	This need should be incorporated into education and training programs under U 3&4 so that the areas for improvement can be identified between the stakeholders. Data systems need to allow for easy data transfer to common databases and analysis software	