Social Science Evaluation of National Water Center Hydrologic Ensemble Forecast Service and National Water Model Output and Technical Support Services

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Contract # EA133C-14-RQ-0018

Objectives and Overview

The purpose of this project was to inform the Water Resources Services Branch (WRSB) of the National Weather Service (NWS), working in close collaboration with the Office of Water Prediction (OWP), in the development of priority hydrologic forecasting products and services. The National Oceanic and Atmospheric Administration (NOAA) has established the National Water Center (NWC) to facilitate partnerships and collaboration across organizations and sectors to deliver a new generation of water information and decision support services (DSS) to meet stakeholder needs. It is a cornerstone of the NOAA Water Initiative, which envisions "a Nation in which everyone from individual citizens to businesses and public officials has timely, actionable information about their vital water resources at their fingertips, and can factor this information wisely into their decisions about water risks, use, management, planning, and security." The goal is "to transform water information service delivery to better meet and support evolving societal needs." More specifically, the initiative aims to:

- Build strategic partnerships for water information services.
- Strengthen water decision support tools and networks.
- Revolutionize water modeling, forecasting, and precipitation prediction.
- Accelerate water information research and development.
- Enhance and sustain water-related observations.

This project builds on stakeholder engagement conducted by the WRSB and OWP over the past several years, which indicated the need to better inform event-driven, high-impact (e.g., flash and river floods, drought) and routine, high-value (e.g., municipal water supply, power generation, navigation, agriculture) decisions by:

- Providing high spatial and temporal resolution analyses and forecasts of the full spectrum of water budget parameters (e.g., soil moisture, evapotranspiration, river flow, groundwater, water quality, snowpack) from "summit to sea."
- Expanding the temporal range, improving the accuracy, and quantifying the certainty of river stage and volume forecasts.
- Linking water resource forecasts to a representation of the areal extent and depth of forecasted flood waters and associated potential socioeconomic impacts.
- Integrating access to geospatial water resource information from multiple federal agencies through a single portal.

Stakeholder Engagements

Past engagements, dating back to late 2012, concluded that stakeholders need a full range of services, including products on flash and riverine floods, droughts, water supply availability, water quality, and the impact of climate change on these hydrologic forecasts. Stakeholders voiced the need for high-resolution products with adequate lead time to inform both routine and emergency water management decisions.

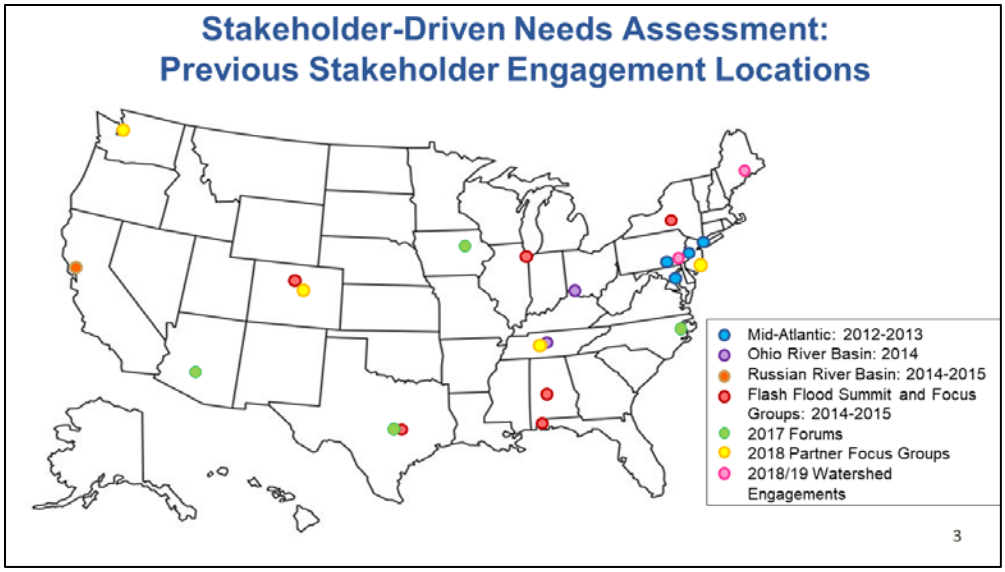

Figure 1. Stakeholder engagement locations for assessing user needs (2012–2019).

Furthermore, stakeholders desire an integration of services and context to better understand the *impact* of hydrologic conditions, as well as information that is communicated in an *actionable* way. Figure 2 summarizes the conclusions from previous stakeholder engagements; together with input from River Forecast Centers (RFCs) and Weather Forecast Offices (WFOs), these conclusions form the foundation for the development of new and improved hydrologic products and services.

Figure 2. Summary of feedback from previous stakeholder engagements.

This project focused on two primary technologies—the Hydrologic Ensemble Forecast Service (HEFS) and the National Water Model (NWM)—to enhance national, regional, and local hydrologic forecasts and warnings and DSS in support of, and in response to, users' priority needs. To conduct the assessment, ERG developed the process shown in Figure 3 below.

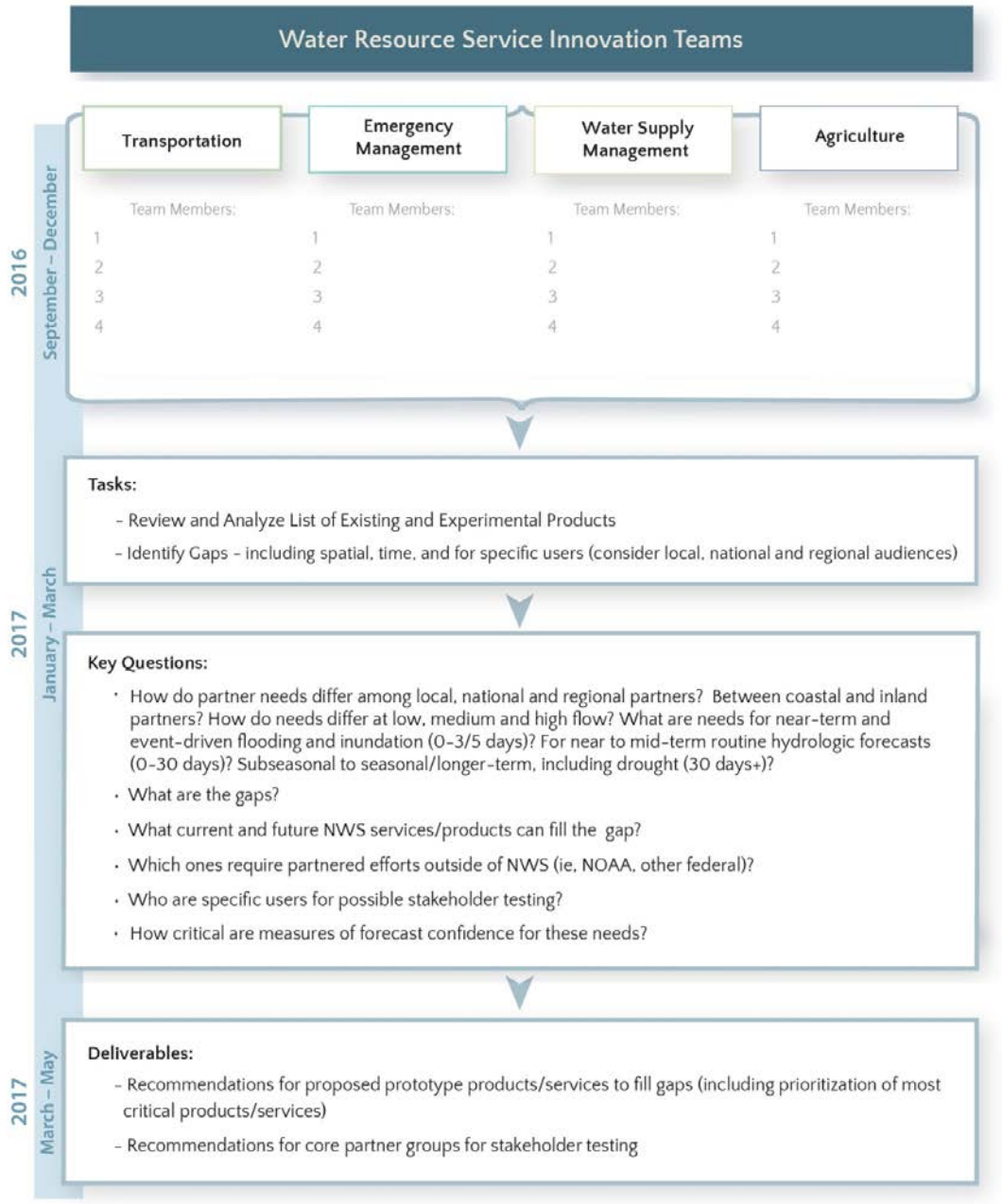

Figure 3. Project process, tasks, evaluation strategy, key questions, and deliverables.

The first phase of this study consisted of internal focus groups to obtain insights about core partner needs. Participants were experts from local and regional NWS offices nationwide who interact with core partners on a daily basis. ERG conducted five internal focus groups to discuss the following core partner groups:

- Transportation and navigation
- Water supply management and utilities
- Watershed management (policy), fisheries, and recreation
- Agriculture

- Emergency mangers (EMs)/media

Identifying core partners' decision-making needs helped prioritize improvements to existing products and services, development of new products and services, and operational improvements. Based on this input, as well as the input from four stakeholder engagement workshops, the WRSB and OWP identified the following top priorities moving forward:

- National, regional, and local flood prediction map services; low flow prediction map services; and water supply forecast data and map services.
- Data and information that reflects routine (baseline), high flow and low flow conditions with antecedent condition overlays, including precipitation and soil moisture.
- Data and information in a variety of formats, including maps, tables, and hydrographs.
- Forecasted information at various timescales, including hourly, daily, weekly, and seasonal.
- Flood inundation illustrations (extent and depth).

Following input from the internal focus groups, ERG developed a logic model to depict user requirements for a range of spatial and temporal scales for water prediction map services. ERG tested a set of NWM prototype visualizations that could complement existing services as part of the logic model with 58 EMs who attended regional focus groups in Nashville, Tennessee; Denver, Colorado; and Atlantic City, New Jersey. The prototypes were further refined based on feedback from the EMs.

The next step was to convene watershed-based stakeholders in the Delaware and Penobscot River Basins to test how the experimental NWM hydrologic forecast visualizations could be used to inform watershed-wide decision-making. A mix of users working together within the same watershed identified common user needs. These watershed-based workshops provided an environment for users of RFC and WFO forecast services to provide feedback and to highlight competing needs and diverse uses of the services for managing shared water resources.

Major Accomplishments

Through engagements and direct discussions with key stakeholders, the NWS and ERG gained meaningful insights about user needs and used this information to develop key refinements and new features for NWM forecast services. The logic model (see Figure 4) was a major accomplishment of this work and helps to lay out a path forward for ongoing service development. One key feature of the logic model is how it presents the universe of relevant services for several topic areas (i.e., general, low flow, and high flow) at decreasing spatial scales—from the national to neighborhood level. It also shows how these services would be available at a range of temporal scales that align with NWS forecast capabilities, as well as the enhanced services produced through the NWM. The logic model can be used to guide future development of priority services and to explain to stakeholders how different combinations of services are available at multiple spatial and temporal scales.

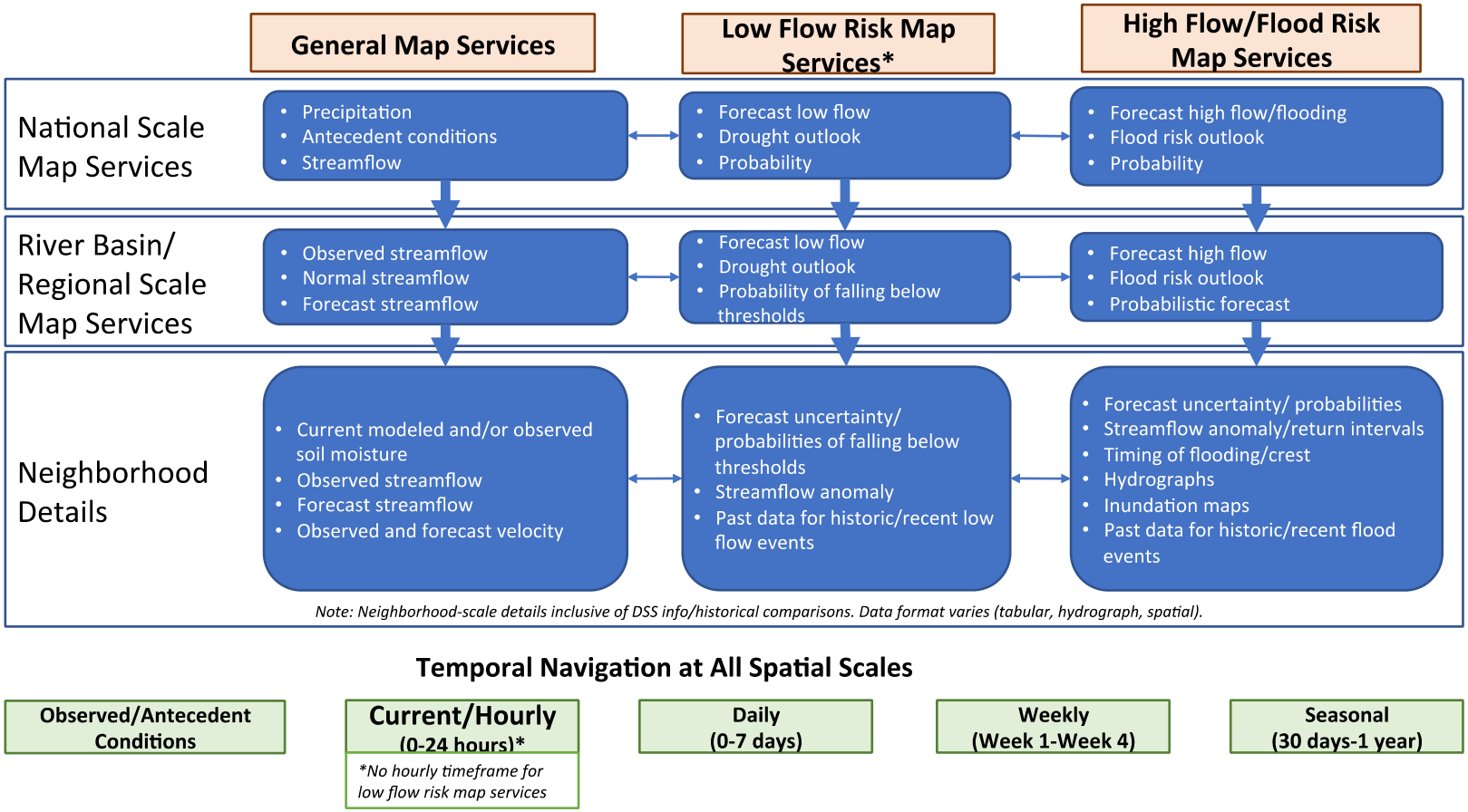

Figure 4. Logic model of NWS water prediction map services.

While the logic model is useful on its own, it also helped the NWS and ERG develop prototypes to facilitate more detailed discussion with stakeholders. Although the NWM was not fully operational during this project, the NWC was able to produce prototype interactive services using the 24-year retrospective analysis for example scenarios. Prototypes were developed primarily for high flow services, including the following:

- High flow magnitude (streamflow presented in reference to recurrence flow).
- High flow and peak flow arrival time (forecast arrival of "bankfull" flow and maximum flow, respectively).
- Maximum inundation extent.

The NWS and ERG produced the prototypes at multiple temporal scales consistent with the logic model and incorporated them into an Esri Storymap template to facilitate interactive presentations and discussion. These were combined with examples of current products and services that stakeholders may receive during flood events to demonstrate the complementary experimental guidance that might be available through the NWM. Forecast timeframes included 18-hour, 3-day, 5-day, and 10-day forecasts. Figure 5 shows the scenario page from an interactive Storymap developed for the Penobscot Basin stakeholder engagement event. RFC and WFO partners were integrally involved in developing the scenario.

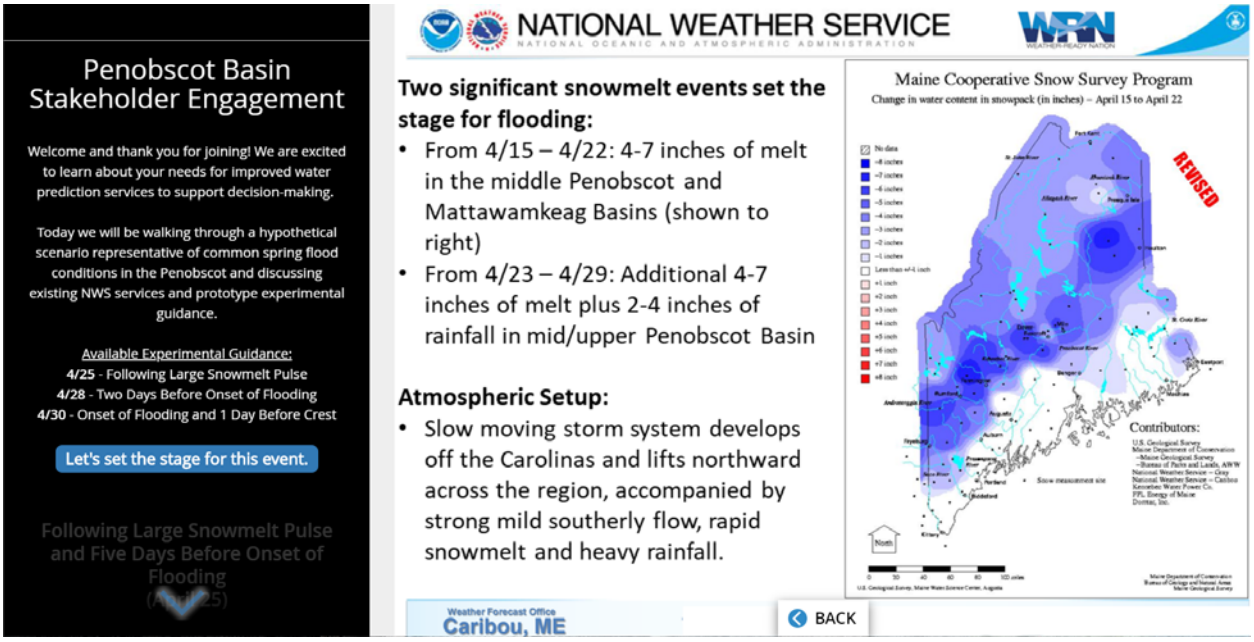

Figure 5. Screenshot of Storymap used to present prototype NWM services in Bangor, Maine.

Table 1 presents the list of services developed for the focus groups and watershed engagements.

NWM Forecast Period	Prototype Service (Metric)
Analysis and Assimilation ("Current Conditions")	Current Streamflow (discharge in cubic feet per second.)
	Current Streamflow Anomaly (departure from "normal")
	Current Maximum Inundation (modeled maximum spatial extent)
Short-Range Forecasts	18-Hour High Flow Arrival Time (hours to reach "bankfull")
	18-Hour Peak Flow Arrival Time (hours to reach maximum flow)
	18-Hour High Flow Magnitude (modeled maximum discharge)
	18-Hour Maximum Inundation
Medium-Range Forecasts	10-Day High Flow Arrival Time
	10-Day Peak Flow Arrival Time
	5-Day High Flow Magnitude
	5-Day Maximum Inundation Extent
	3-Day High Flow Magnitude
	3-Day Maximum Inundation Forecast

Table 1. Prototype Services for Various NWM Forecast Periods

The NWS and ERG developed the services in Table 1 for multiple scenario timesteps before and after a hypothetical event. The specific timesteps were selected based on discussion with RFC and WFO partners. For example, for the Delaware Basin engagement, services were developed at the following timesteps: T-5, T-1, T (day of event), T+1, T+2.

Summary of Key Findings

Through the engagements discussed earlier in this report, the NWS and ERG gathered highly valuable information from the practitioners that are likely to use and will hopefully benefit from the enhanced capabilities of the NWM. Across all the engagements (summaries of which are presented below), several common themes and key takeaways emerged that are critical to the ongoing development and rollout of the NWM. Key stakeholder findings include the following:

- Significant support for coastal coupling efforts. Stakeholders provided strong feedback on the importance of better understanding tidally influenced rivers.
- Need for an expanded presentation of uncertainty, especially for inundation services. This included presenting uncertainty in the forecast itself (i.e., confidence intervals) and describing how forecasts have changed over time.
- Strong interest in "impact-based" forecasts from the NWM, similar to current Advanced Hydrologic Prediction Service (AHPS) forecasts that depict flood levels in terms of stage tied to key impact thresholds (action, minor, moderate, major) and/or inundation depth.

- Concerns about the pace of new information. Stakeholders do not want to be overwhelmed by new services without appropriate context and guidance. It is important to consider the appropriate cadence of providing NWM services.
- Need for new/improved NWM services alongside existing services.
- Need for more context (e.g., relate flood event to past record event), terminology that is consistent with other products, and clear definitions to make products more useful. Some end-users lack the technical knowledge to understand details about NWM services and need fact sheets or other supporting information to help them interpret and use the forecasts. Moreover, many users struggled to understand the concept of "bankfull" and the difference between "high flow" and "peak flow."
- Interest in finding out how to best integrate these new services and datasets into existing service pathways (DSS, etc.). Stakeholders will need support from their RFCs and WFOs to best interpret and fully understand how they can and should use NWM services.

For the last step of this project, the WRSB began (and is continuing) to test the services and gathering feedback from RFCs and WFOs in collaboration with NOAA's Water Prediction Operations Division (WPOD) and Geospatial Intelligence Division (GID). This is the logical next step from the detailed watershed engagements because it provides the first users of this guidance—RFCs and WFOs—with new, enhanced information and an opportunity to give feedback on the data services. This feedback will help frame ongoing development of new services and refinement of existing services, and the WRSB, WPOD, and GID are committed to being responsive and ensuring that the NWM services are useful for both internal and external end-users.

Summaries of Stakeholder Engagements and Economic Methodology

Internal Focus Groups

The NWS and ERG conducted five focus groups with 41 experts from RFCs, WFOs, and other line offices who regularly interact with and could provide perspective on the following core partner groups:

- EMs and media
- Water supply management and utilities
- Transportation and navigation
- Watershed management (policy), fisheries, and recreation
- Agriculture

Participants across all groups ranked the products and services in Table 2 (listed in descending order) as the most important for meeting core partner needs.

Table 2. Highest Priority Ranking of Existing Products and Services to Meet Core Partner Needs

1	Deterministic Hydrologic Forecast (RVF)
2	24-Hour Quantitative Precipitation Forecast (Day 1–3)
3	NWS Hydrologic Services Program Web Presence (AHPS)
4	Weather Prediction Center Quantitative Precipitation Forecast (QPF)
5	Short-Range River Forecast Uncertainty (AHPS)

Table 2. Highest Priority Ranking of Existing Products and Services to Meet Core Partner Needs	
6	Flood Warning for Forecast Points (FLW)
7	Extended-Range Streamflow Prediction (ESP)
8	Long-Range River Forecast Risk Webpage (AHPS)

Focus group participants also discussed products and services needed to inform key decisions that core partners must make. Several new and improved products and services, recommended by multiple focus groups, included the following:

- Improvements to gauging networks.
- River flow predictions at every mile and hour (including velocity).
- Water quality forecasting.
- Longer-term, consistent quantitative precipitation forecasting.
- More robust inundation mapping.
- Full implementation of HEFS.
- Seasonal flows and longer-term forecasts.
- Data services to allow users to import data into local tools and set their own thresholds for local needs.

Based on this input, as well as input from four stakeholder engagement workshops, the WRSB and OWP identified the top priorities moving forward:

- Develop national, regional, and local flood prediction map services; low flow prediction map services; and water supply forecast data and map services.
- Present data and information that reflects routine (baseline), high flow and low flow conditions with antecedent conditions, including precipitation and soil moisture overlays.
- Display data and information in a variety of formats, including maps, tables, and hydrographs.
- Provide forecasted information at various timescales, including hourly, daily, weekly and seasonal,
- Illustrate flood inundation (extent and depth).

Water Resources Monitor and Outlook

As shown in the logic model, it is important to consider a range of flow conditions, including low flow and drought. Water resource management, although often focused on water scarcity, can benefit from NWM forecasts, along with other existing products like the Drought Monitor. To gather information from stakeholders involved in water resource management, ERG worked with NOAA staff in the Colorado Basin River Forecast Center and National Integrated Drought Information System to plan and host a focus group at the American Water Works Association Sustainable Water Management Conference in 2018. Unlike other engagements, this focus group presented experimental products external to the NWM—specifically, the Water Resources Monitor and Outlook (WRMO), a product in development through a collaboration of several western RFCs. The WRMO provides forecasts of water accumulation at key locations for water resource managers and supplements other capabilities of the

RFCs. One key question for the focus group participants was whether it makes sense for the WRMO, designed for western locales, to be scaled up nationally to fit within the NWM framework. The group discussed the pros and cons of scaling the WRMO and determined that the hydrologic character of the western United States—and subsequently how the forecasts underpinning the WRMO function—makes it difficult or impossible to scale the WRMO appropriately to snowmelt-dominated systems like the Colorado River and precipitation-driven systems like the Mid-Atlantic. Furthermore, although the WRMO could hypothetically be useful for water resource managers outside of western states, the management decisions they make are not the same and the WRMO may not fit well within their existing DSS.

Emergency Managers Focus Group

Following input from internal focus groups and initial stakeholder workshops conducted under a related task order in 2017, ERG conducted a series of focus groups with EMs in 2018 in three locations: Nashville, Tennessee; Atlantic City, New Jersey; and Denver, Colorado. Prior to the events, the logic model was developed and populated with user requirements at various spatial scales, and it served as a key facilitation tool for the EM focus groups. The NWC developed prototype map services for high flow scenarios and integrated them into presentations for the EM focus groups. A hypothetical flood event in the Lower Ohio River Basin was used to create the prototype NWM services. Participants were shown the logic model and several existing and experimental products. Poll questions embedded within the presentation were used to gather feedback from the larger groups on specific items. Most of the content presented to the EMs was in the "Flood Risk Map Services" column of the logic model. Focus group participants provided feedback that echoed the key takeaways summarized earlier in this report.

Watershed-Based Workshops

The main objective of the watershed engagements was to present experimental NWM services in a watershed context alongside existing capabilities to solicit feedback from participants on the utility and presentation of new NWM forecast visualizations. Including current capabilities and experimental NWM services together was critical in helping participants understand that NWM services are not meant to replace existing capabilities but can instead supplement these existing products and provide complementary guidance—especially in areas with limited river gauge coverage, where forecasts are not currently available. Each workshop had between 20 and 30 participants and consisted of a plenary session followed by small group breakout sessions, where attendees could view and provide feedback on several experimental visualizations.

Economic Benefits Methodology

NOAA and ERG sought to estimate the economic benefits of enhanced NWC hydrologic forecasting products and services through NWM advancements. ERG worked with NOAA economists to develop a high-level methodology that is transferable across sectors as a framework to estimate economic benefits across all users of NWM products and services. ERG and NOAA decided to narrow the scope of the economics task to the freight trucking industry because data are available via the Freight Analysis Framework, many high-value products move through the freight trucking industry, and improved hydrologic forecasting can inform freight trucking industry decisions about routing. Thus, there are more opportunities for enhanced flood forecasts to mitigate operational losses and spoilage/revenue losses, as well as to quantify those losses and, conversely, benefits.

ERG researched the potential benefits of better flood forecasts, developed theoretical value chains, and ground-truthed the value chains with experts through a series of in-person and virtual discussions. It is difficult to directly estimate the economic benefits of enhanced flood forecasts, as data related to flood-

based impacts to the freight trucking industry are limited, the industry is very fragmented and competitive (much information is proprietary or otherwise closely held), and the majority of freight trucking companies are not familiar with more sophisticated hydrologic forecasting concepts. Under this task, ERG developed a methodology that could be implemented to assess the economic benefits of the NWM's enhanced flood forecasting capabilities, with limited testing of the initial steps. The outcomes of this effort include:

- A valuation methodology to estimate the economic benefits of the NWM's enhanced flood forecasting capabilities.
- Ground-truthed value chains describing how the NWM can provide benefits to the freight trucking industry.
- Industry input (both qualitative and quantitative) on how the NWM could potentially enhance decision-making in the freight trucking industry.
- Recommendations for future research to understand and monetize the benefits of the NWM.

Full reports from each engagement can be found at the following links:

Water Resources Monitor and Outlook Focus Group:
https://www.weather.gov/media/water/Water%20Resources%20Managers%20Engagement%20Summary.pdf

Internal Focus Groups and Emergency Managers Focus Group:
https://www.weather.gov/media/water/StakeholderEngagementtoInformNWMProductsServices2019.pdf

Watershed-Based Workshops:
https://www.weather.gov/media/water/Watershed%20Engagement%20Summary_Delaware_Penobscot.pdf

Economic Benefits Methodology:
https://www.weather.gov/media/water/Final%20Report_Economics%20of%20Enhanced%20Flood%20Forecasts_10-23-2019.pdf

Recommendations and Remaining Needs

The extensive stakeholder engagement conducted for this project helped to define priorities for ongoing development of the NWM, provided important information on how end-users might respond to these new services, and gave insights into how the NWS NWC, working with the WRSB, can best provide this information. ERG has several recommendations based on the lessons learned throughout this project:

- Conduct an organizational assessment to determine how these services can/should be packaged to best serve user needs. The NWS and ERG discussed this early in the project but did not have sufficient information to populate an organizational strategy that outlines how certain services can be combined to meet specific needs.
- Continue pushing out experimental products with RFCs and WFOs and provide a venue for monthly feedback based on event-specific experience. The current testing program provides a template and form for RFCs and WFOs to provide feedback on NWM services, and monthly meetings are an excellent opportunity for field offices to discuss how they used the services, what issues they encountered, and any feedback they received from their end-users.

- Further refine and tailor the value chains for other transportation sectors to expand the quantitative analysis as discussed in the final economic analysis report. Engaging industry members and stakeholders via surveys, webinars, and interviews will help refine these value chains based on how the NWM informs operational and logistical decision-making.
- Collaborate with groups already interested in NWM services, such as state or local departments of transportation. Feedback from these groups on how the NWM compares to current products could inform valuation.
- Explore how new services can be integrated into existing systems and develop guidance for RFCs, WFOs, and end-users that helps them understand how they can use the new services in combination with existing products. This also includes providing users with the context they need to understand and use NWM services appropriately. Feedback from the RFC and WFO testing can help establish these contextual needs.