STAKEHOLDER ENGAGEMENT TO INFORM NATIONAL WEATHER SERVICE HYDROLOGIC FORECASTING PRODUCTS AND SERVICES

Summary of Watershed Engagements

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Office of Water Prediction and Water Resources Services Branch

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July 8. 2019

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Introduction to Watershed Engagements

As part of NOAA's ongoing efforts to employ social science methods to ensure that products and services meet stakeholder needs, the Office of Water Prediction (OWP) and the Analyze, Forecast and Support Office Water Resources Services Branch engaged stakeholders to solicit their input on prototype hydrologic forecast products developed by the OWP using outputs from the National Water Model (NWM) and the Hydrologic Ensemble Forecasting Service (HEFS). Two watershed-scale engagements were held in the fall of 2018 and the spring of 2019 in the Delaware and Penobscot River Basins, respectively.

The engagement locations of Pennsylvania and Maine were selected to cover a range of multiple use cases for new NWM services – the Delaware Basin prototype services were focused on a widespread rain-driven event with a tropical component; the Penobscot Basin prototype services focused on a snowmelt-dominated event. Planning teams were established for each engagement to help design materials and identify participants, with River Forecast Center (RFC) and Weather Forecast Office (WFO) representatives participating in the planning effort. For both events, the target audience was a cross-section of user groups from multiple sectors, including emergency management, transportation, fisheries, and water management. Most participants were end users that consume RFC and WFO briefing materials before and during an event. Some more technical users including representatives from partner agencies, such as the Federal Emergency Management Agency (FEMA), the U.S. Army Corps of Engineers and the U.S. Geological Survey (USGS), were also present.

These engagements in the Delaware River Basin and Penobscot River Basin were the culmination of several years of stakeholder engagement events across the country that helped define core partner needs and inform priorities for hydrologic services (see Figure 1).

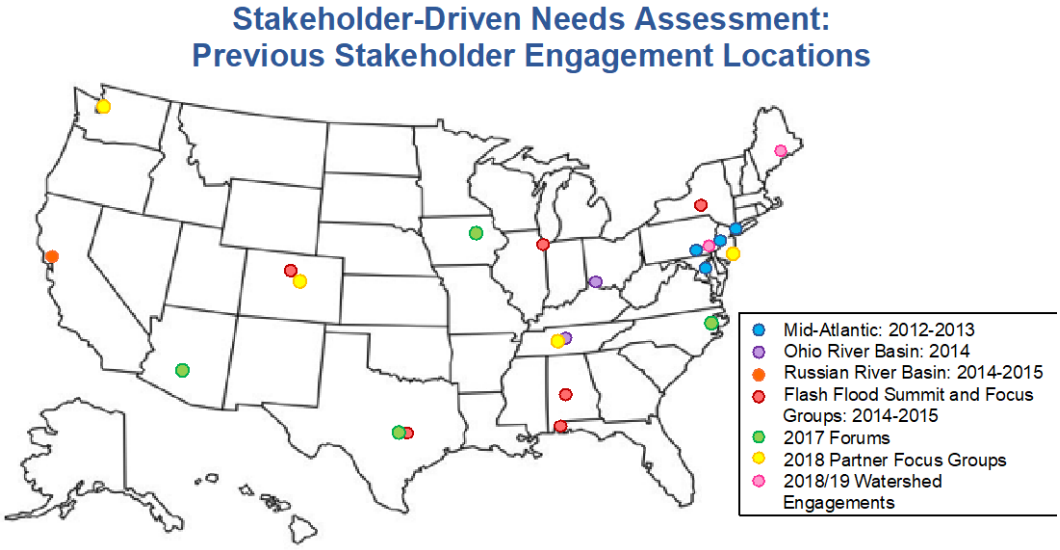

Figure 1. Previous stakeholder engagement locations to assess user needs

Background

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 forecasts. Stakeholders voiced the need for high-resolution products with adequate lead-time to inform both routine and emergency water management decisions. Furthermore, stakeholders desire integration of services and context for better understanding impact of hydrologic conditions, and for the information to be communicated in a way that is *actionable*. Figure 2 below represents over-arching conclusions reached during those previous stakeholder engagements, which, together with internal input from River Forecast Centers (RFCS) and Weather Forecast Offices (WFOS), have formed the foundation for the development of new and improved hydrologic products and services.

Figure 2. Summary of feedback from previous stakeholder engagements

Following input from the internal focus groups with NOAA and NWS subject matter experts representing the needs of core users (transportation/navigation; water supply/utilities; water policy/fisheries/recreation; agriculture; and emergency mangers/media), and four mixed stakeholder forums, a logic model was developed representing user requirements at a range of spatial and temporal scales for NWS water prediction map services as a whole. A set of NWM prototype visualizations that might complement existing services (e.g., HEFS) as part of the logic model was tested with 58 emergency management representatives that attended focus groups from southeastern regional meeting of emergency managers (Nashville, TN), the front range of the Colorado Rocky Mountains (Denver CO), and the northeast coast (Atlantic City, NJ). The final logic model is shown in Figure 3, below:

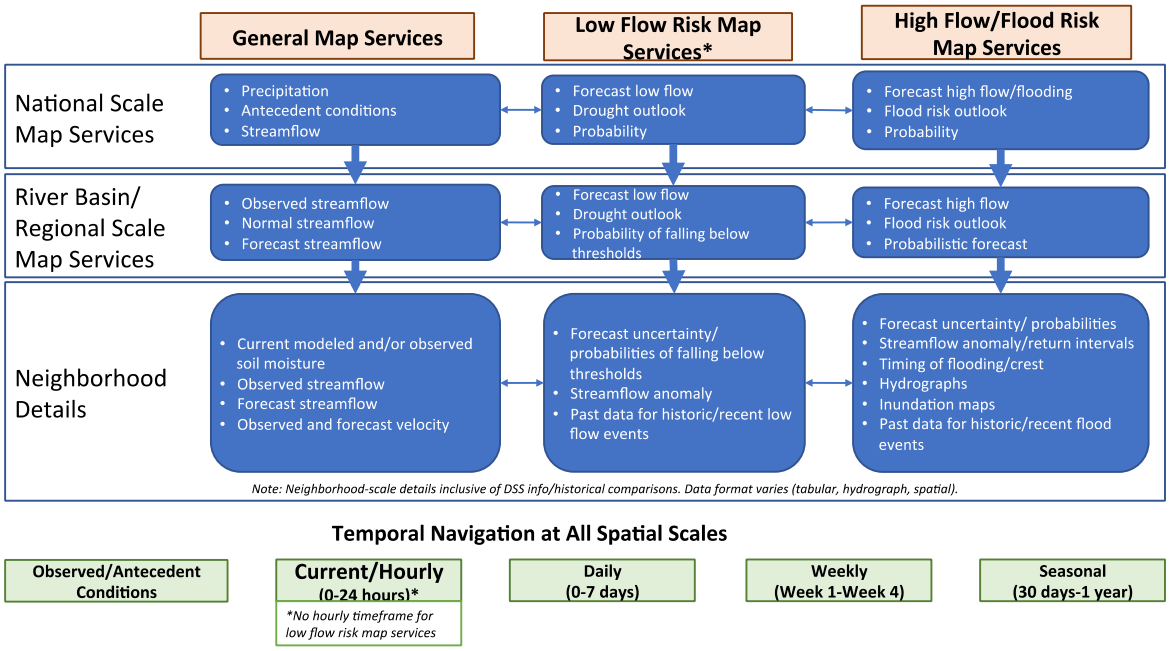

Figure 3. Logic model of National Weather Service Water Prediction Map Services

The prototypes were further refined based on feedback from the emergency managers. The watershed-based stakeholder engagements in the Delaware and Penobscot River Basins tested how several experimental NWM hydrologic forecast and HEFS visualizations could be used to inform watershed-wide decision-making. A mix of users working together to provide services within the same watershed were convened to identify common user needs. These small, watershed-based workshops provided an intimate environment for users of River Forecast Center (RFC) and Weather Forecast Office (WFO) forecast services to provide feedback. This report presents a summary of the watershed engagements and includes the more detailed engagement-specific reports as appendices.

Workshop Objectives and Structure

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 and HEFS forecast visualizations. Including current capabilities and experimental NWM services together was critical in helping participants understand that the NWM services are not meant to replace existing capabilities, but rather can 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 to view and provide feedback on several experimental visualizations.

To design the materials and prototypes services for each engagement, the planning teams identified an historical event that reflected the use cases (widespread rain-driven event with a tropical component in the Delaware and a snowmelt-dominated event in the Penobscot). The OWP then developed prototype services, which ERG used to create presentations using Esri Storymaps, based on scenarios from that event. The scenarios included background information such as antecedent conditions and forecasts for several days leading up to and following an event, with important timesteps (e.g., T-2 days, T-1-day, T) identified by the planning team. Table 1 lists the timesteps selected for each engagement. The historical analog defined both the experimental NWM services and examples of current capabilities presented at each engagement. NWM services were produced for each timestep (T-2, T-1, etc.) using a retrospective analysis. The historical event also allowed RFC and WFO partners to develop situational awareness materials using current capabilities like HEFS that visually match what participants would likely see today.

Table 1 – Timesteps for each engagement

Delaware Basin	Penobscot Basin
Five days prior to event	Five days prior to onset of flooding
One day prior to event	Two days prior to onset of flooding
Day of event	Onset of flooding
One day following event	
Two days following event	

Existing situational awareness materials and experimental services were combined in the Storymap to provide an interactive platform for the breakout group sessions. It was important to present the NWM services in an interactive manner to explore how they could be used and in what context. The Storymap began with a description of the conditions leading up to the hypothetical event and then walked through each timestep, presenting existing capabilities and experimental NWM services at each. A WFO or RFC representative was present at each breakout group to describe the scenario and walk the group through situational awareness materials. Participants were given the opportunity to jump in and ask questions at any time and were encouraged to think of the NWM services and existing capabilities as complementary.

Differences Between Watershed Engagements

Both watershed engagements shared the same objectives and general structure, but lessons learned at the Delaware Engagement were used to refine the approach for the Penobscot Engagement, held six months later. Most notably, for Delaware, the OWP produced all possible experimental NWM services for every timestep shown in Table 1. This resulted in a total of 54 services included in the Storymap. At the engagement the sheer volume of experimental services was overwhelming and made it difficult at times to solicit specific feedback from participants. It also appeared to prevent participants from fully understanding that the NWM services were complementary with existing capabilities. To remedy this, the Penobscot Engagement planning team identified a much smaller targeted subset of NWM services that aligned with the scenario and existing capabilities. Rather than showing participants all possible services, partners at the Northeast River Forecast Center (NERFC) and the Caribou, Maine WFO helped identify those services that seem most useful for each timestep. A total of 10 services were selected across three timesteps, streamlining the presentation and discussion at the Penobscot Engagement.

Common Themes Between Stakeholder Engagements

While differences between the two watersheds are not surprising given the marked differences between use cases, it is interesting to note that there were several common themes that emerged from both watershed engagements.

Summary of Key Findings

- There is significant support for coastal coupling efforts across participant user groups. Stakeholders in the Penobscot Basin specifically provided strong feedback on the importance of better understanding tidally influenced rivers like the Penobscot.
- Stakeholders discussed a 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.
- There is strong interest in "impact-based" forecasts from the NWM, like those currently provided by AHPS/MMEFS/GEFS/HEFS that depict flood levels in terms of stage and not discharge, and reflect key impact levels (action, minor, moderate, major)
- Stakeholders are concerned about the cadence of information and do not want to be overwhelmed with new things. It is important to consider the appropriate cadence of providing NWM services.
- End-users need NWM services placed alongside existing services and with context and definitions to make them more useful. Some end-users lack the technical knowledge to understand details about the NWM services and need factsheets or other supporting information to help them interpret and use the forecasts.
- NWM services need to use terminology that is consistent with other products and need to clearly define what terms mean. For example, many users struggled to understand the concept of "bankfull" and the difference between "high flow" and "peak flow."

Next Steps?

To continue to refine the prototype services that may address current gaps in the logic model, the NWS plans to engage the RFC Service Coordination Hydrologists and a select group of WFO representatives to internally test data services from the National Water Model. This group will be asked to use the services to support their situational awareness, provision of Impact-Based Decision Support Services, as well as watch/warning or other decision-making. They will be tasked with providing feedback on service use and any issues encountered via mechanisms such as bi-monthly calls. The discussion that occurs among this group will help prioritize updates and changes to the data services, visualizations and supporting materials to be incorporated into their workflow for decision support or to be made publicly available. This process and the pathways for feedback and input are expected to evolve in the next several years as the capability for provision of data services and strategy for collecting and prioritizing feedback mature.

Appendix A: Delaware Basin Engagement

Proceedings from Delaware River Basin Workshop

Nurture Nature Center
Easton, PA
October 30, 2018

High Level Findings

Several key issues were identified during the engagement:

- Hydrographs should be incorporated into the NWM data services and made available as point data ("neighborhood" scale)
- Provide antecedent conditions and model forcing information for context (e.g., soil moisture, recent precipitation, snow water equivalent)
- Depict flood thresholds (action, minor, moderate, major) and flooding *impacts* as they relate to NWM outputs – seeing things depicted in terms of discharge is not as useful
- Change the 18-hour timeframe for the short-range forecasts to 24 hours
- Illustrate inundation levels temporally and spatially and include both extent and depth
- NWM needs to incorporate and better model regulated systems (dams, reservoirs, etc.)
- Uncertainty information is crucial – for example: inundation maps showing current forecast and a "best vs. worst case" for inundation, or time series information like spaghetti plots
- Use time-series animation to illustrate changes over time

Introductions and Welcoming Remarks

Arleen O'Donnell (ERG) opened the meeting with a round of introductions and turned to Rachel Hogan Carr, Executive Director of the Nurture Nature Center and Peter Ahnert, Hydrologist-in-Charge of the Middle Atlantic River Forecast Center (National Weather Service) for welcoming remarks.

During introductions, participants indicated their interest in the following topics:

- Early warning systems and source water protection
- Using NWS forecasts for emergency response planning
- Denser forecasts with predictive forecasting for smaller streams and watersheds
- Ongoing monitoring program in the Delaware (DE) Basin that could possibly fit into the National Water Model (NWM). Is there an opportunity for partnership?

Workshop Objectives and Registration Survey Results

Arleen O'Donnell described the workshop objective –To test the usefulness of experimental hydrologic forecast products and services to support local core partners based on a hypothetical flood event in the Delaware River Watershed. She also presented results of the participant poll completed at registration. Participant survey results characterized the timeframes of greatest interest and the sub-basins of interest to registered participants. Most participants indicated that the timeframe of greatest interest was 5 days prior to a flooding event and that their basin of interest was the Central Delaware Basin (see Table 1).

Table 1. Poll Results: *What timeframe is of greatest interest to you during a flood?*

Timeframe	Percentage
5 Days Before an Event	**63%**
Within 24 hours or during the peak of an event	**29%**
Recovery time (24-48 hours) after an event	**7%**

Note: Total does not equal 100% due to rounding.

Table 2. Poll Results: *What part of the basin is of greatest interest to you?*

Basin Area	Percentage
Upper River	**25%**
Central River	**46%**
Lehigh Valley	**13%**
Delaware Estuary	**13%**
Delaware Bay	**4%**

Note: Total does not equal 100% due to rounding.

Presentation on NOAA's Hydrologic Prediction Services

Peter Colohan provided an overview of the NOAA Water Initiative, including its vision and mission, objectives and desired outcomes, and the inter-agency collaboration of Integrated Water Resources Science and Services (IWRSS) partners. Mary Mullusky provided an overview of previous stakeholder engagements and the feedback from those efforts, as well as an overview of the Hydrologic Ensemble Forecast System (HEFS) and the National Water Model (NWM). She also presented the logic model for the development of hydrologic prediction services informed through these engagements and presented the workshop objectives. Kate Abshire provided a preview and explanation of the NWM products and services that would be demonstrated during breakout group sessions.

Figure 1. Participants at Nurture Nature Center learning about hydrologic prediction data services.

Breakout Groups

Participants were separated into 3 breakout groups to view and discuss a variety of experimental forecasting services related to flooding. Groups were assigned to allow participants to focus on interests in either the upper basin, middle basin, or lower basin. Facilitators walked participants through a scenario describing a hypothetical Tropical Storm "Della" (based loosely on Tropical Storm Lee in 2011). Participants were shown examples of current NOAA flood briefing information for the event and then asked how experimental data services could be used to inform decisions before, during, and after the flood event. The time periods offered were:

- Five days prior to the event (T-5)
- Within 24 hours prior to the event (T-1)
- 24-48 hours after the event (T+1)

The Tropical Storm "Della" scenario, presented through a GIS-based Storymap, depicted streamflow, streamflow anomaly, high flow magnitude, maximum inundation extent, high flow arrival time and peak flow arrival time. Depending on which scenario timeframe was selected (e.g., 5 days before the event), services showed current conditions and illustrated changes that could occur in the next 18 hours, 3 days, 5 days and next 10 days.

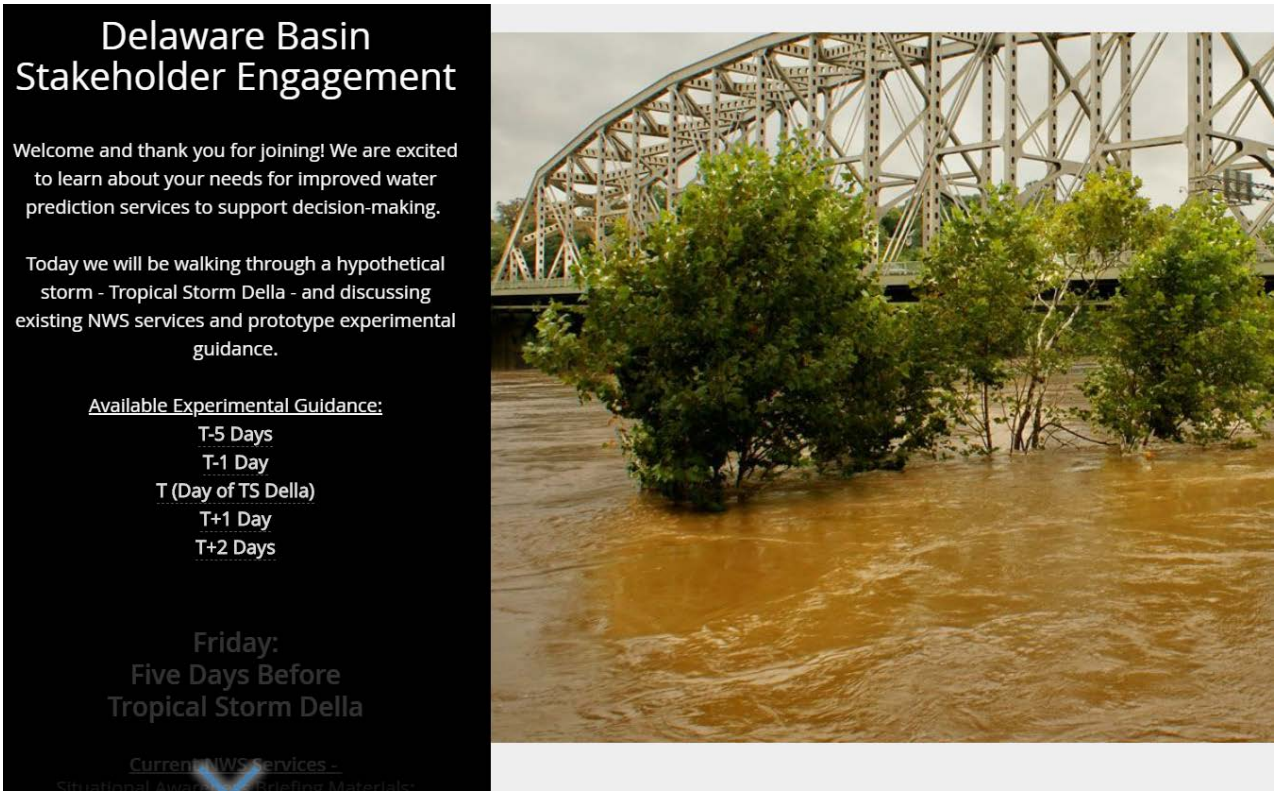

Figure 2. Landing page for Storymap shown during breakout groups. Note the days the experimental guidance was available.

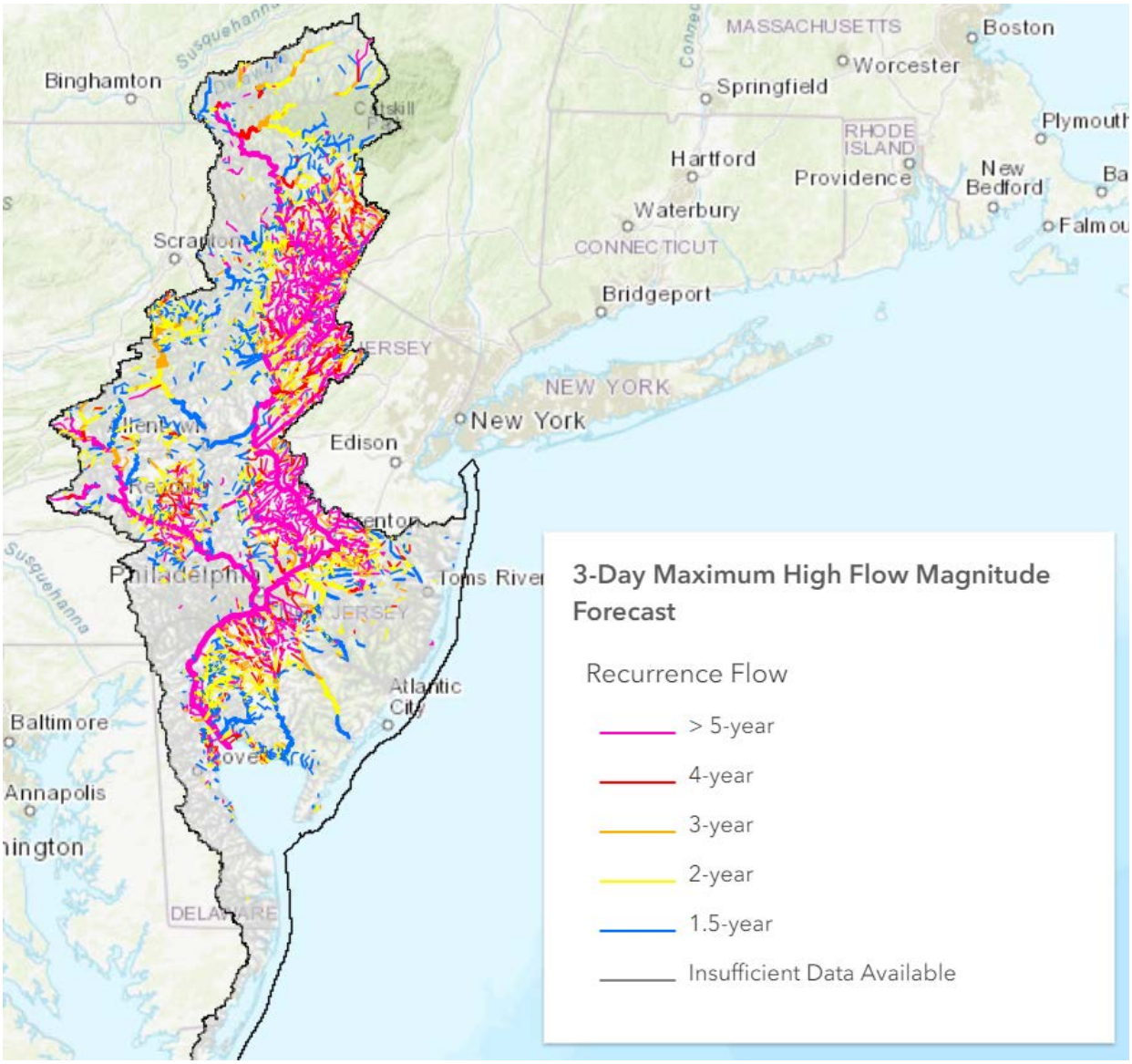

Figure 3. Image of 3-Day Maximum High Flow Magnitude Forecast showing flooding projected throughout much of the basin.

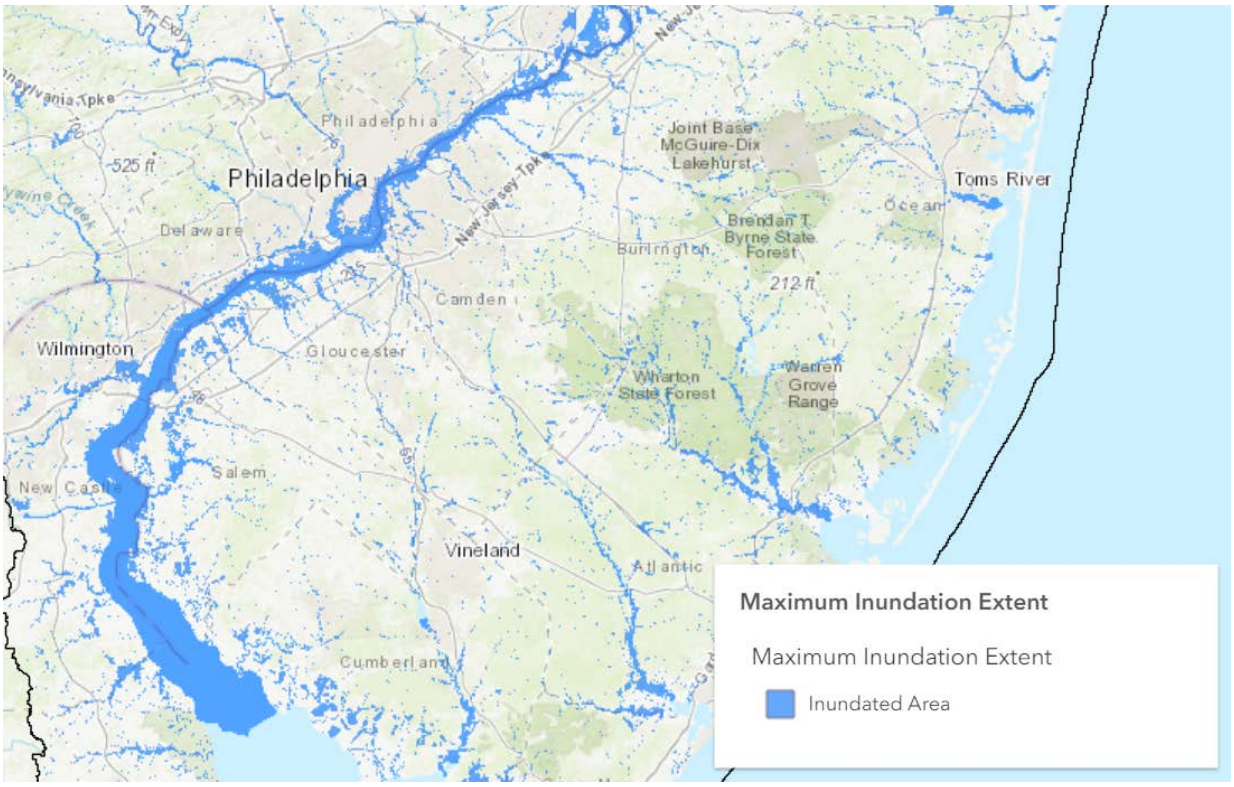

Figure 4. Image of modeled current maximum inundation extent for the lower Delaware Basin.

Each breakout table had a facilitator, a representative from the MARFC and/or WFOs, and a technical representative available to answer questions about the products. The MARFC and WFO representatives walked the participants through the Storymap, providing a high-level overview of the storm scenario presented through a series of slides showing products currently issued by the WFO/RFC. After review of current products and services, the facilitators probed participants' decision-making needs at each time step, how they would be using current services and what else they would be need at that time. Then, at each time step, the facilitator led a discussion of the prototype products, asking questions to elicit discussion about product usefulness and what else is needed to meet their decision-making needs.

Summary of Comments on Experimental Data Services

Comments recorded during breakout group discussions were summarized as they relate to specific data services, suggestions for how NWM data services could be used and improved, and what's missing from the current suite of NWM data services (See Table 1 below). Appendix B provides a complete list of participant comments.

Table 1. Summary of Breakout Group Responses

How NWM Data Services Could Be Used and Improved?
Add hydrographs into the NWM data services. Make available as point data.
Define what information should be shared with the public.
Include antecedent conditions (e.g., soil moisture, recent total precipitation, snow water equivalent).
Provide NWM data with more contextual information e.g., comparison to past events, inundation forecasts for the past 5 days, inundation maps for previous events, comparison with flows observed at gaged locations during the past 30 days).
Depict flood thresholds (action, minor, moderate, major, record) and flooding *impacts* as they relate to NWM outputs.
Change the 18-hour timeframe to 24 hours.
Illustrate Inundation levels temporally and spatially, illustrating extent and depth.
What's Missing from the NWM Data Services?
Modifications along the rivers/streams e.g., dams and reservoirs.
Duration as a data service/layer to understand peak flow and return to normal timeframes.
Historical data to help predict economic losses from storm events.
Time series animation for illustrating changes over time (e.g., 6, 12, 18 hours).
Stormwater-modeling data to illustrate potential impacts.
Uncertainty information (e.g. inundation maps showing current forecast as well as 'best' and 'worst' case inundation, time series displays such as spaghetti plots)
Model Forcing Information (e.g. precipitation, temperature, snowmelt, reservoir releases)
7-day timeframe data service to inform water supply releases in advance of a flood event for downstream flow considerations including:
Water flow velocity and volumes (some endangered species rely on certain flow/volumes).
Total volumetric inflows to reservoirs (and volumetric flows passing any point selected on a river) over various durations and ending at any forecast time (e.g. the volume of water passing point X over the 1, 7, 30, 60, 90 day periods ending at selected time Y).
Flow requirements for watersheds with inter-basin transfer agreements.

Comments on Specific Data Services	
NWM Experimental Guidance Layer	**Feedback Summary**
All Services	Why focus on just past month of precipitation? Weekly detail during the month is needed.
All Services	The colors are difficult to interpret.
All Services	The Coast Guard is concerned with wind and wave height. To the extent that NWM services can incorporate this information, that would best inform their decisions.
Streamflow Anomaly	Can the NWM overlay past, current, and future streamflow projections in the streamflow anomaly layers so that users can visualize the change temporally?
Streamflow Anomaly	Consider adding HEFS information to streamflow anomaly data service. This would show streamflow prediction and confidence interval. Show percentiles on the map.
High Flow Magnitude	Adjust 1.5-year return interval to coincide with flood stage action levels (e.g., 2-year, minor flood stage)?
High Flow Magnitude	Combine peak flow arrival time with high flow magnitude.
High Flow Magnitude	Combine high flow magnitude, streamflow anomaly, and flood stage action level.
High Flow Magnitude	The 1.5-year return interval is not appropriate for every user – Would like ability to define that threshold based on decisions that need to be made.
High Flow Magnitude	Higher flows than the 5-year flow need to be discriminated. As shown, the 5-year return period is the max. Would like to see higher categories. One way to accomplish would be add higher categories in multiplicative intervals of the 5-year flow (e.g. 2x 5-year flow, 5x the 5-year flow, 10x the 5-year flow, etc.).
Inundation	Current forecast products vs. maximum inundation extent. Can the NWM show the difference, and change, over time?
Inundation	Would it be helpful to overlay the 100-year floodplain? This is all one color. Represent uncertainty through gradations of color and for depth of inundation. Consider a fader bar.
Inundation	Consider adding depth to inundation extent.
Inundation	Consider adding pollutant source inventory to this map service.
High Flow Arrival Time	Confusion with time to high flow expression. For example, is it 180 hours from the start of the model simulation or time of peak flow? Consider adding a map/layer start time. Pop-up boxes should display the actual time of the peak (e.g. “8 PM THU 11/20”) rather than the number of hours to peak.
High Flow Arrival Time	Add stream velocities to understand time of travel for pollutants/contaminants.

Coastal Coupling – Overview of Experimental Services

Peter Colohan and Whitney Flynn provided an overview of the emerging capacity to model inundation that incorporates river flows as well as storm surge. Participants asked questions about the ability of the model to provide parcel level data. They also asked to include critical infrastructure data; potential contaminant inventories, and high and low tide cycles that may generate double peaks on hydrographs (e.g. separate displays for peak inundation during the 1st, 2nd, 3rd upcoming high tide cycles). Participants wondered when this service would be available, and they asked whether core users could see this data with password-protected access sooner than the 5 years it is anticipated to go live.

Next Steps and Wrap Up

NWS staff thanked participants for attending the workshop and providing valuable input on NWS products and services. Mary explained that many of the suggestions could be incorporated but that some ideas will be more difficult to incorporate and will be considered in the future. Specifically, how to relate NWM information to impacts will require additional time and resources. The goal is to understand users' needs for decision-making and make sure the WFOs and RFCs have access to the services that they need to provide that back to their local and regional users.

List of Attendees

First Name	Last Name	Organization	Email Address
David	Burd	Lambertville/NJ + DRJTBC	Burdsnest@comcast.net
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The Delaware Basin Stakeholder Engagement Coordinating Team included:

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Peter Colohan, NWS
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Whitney Flynn, NWS
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George McKillop, NWS
Rob Shedd, NWS
Peter Ahnert, NWS
Jim Brewster, NWS
Ray Kruzdlo, NWS
James Brinkley, NWS
Arleen O'Donnell, ERG, Inc.
Braden Rosenberg, ERG, Inc.
Kathleen McAllister, Horsley Witten Group
Rachel Hogan Carr, Nurture Nature Center

Breakout Group Discussion Notes

Common Themes from Breakout Groups

How Data Services Could Be Used and Improved

- Stakeholders identified various uses for the NWM data services:
  - Visualization for RFC and WFO briefings before, during, and after a flood event.
  - Informing emergency managers' (EM) resource deployment decisions, regarding when and where to locate resources (i.e., do not locate in a potentially inundated area).
  - Planning for road detours, evacuation routes, shelters (i.e., communicate with red cross)
  - Informing decisions on when to contact mutual aid organizations.
- Hydrographs are helpful and easily understood. Consider adding hydrographs into the NWM data services available as point data.
- To maximize usefulness, NOAA should define what information should be shared with certain stakeholders – public vs. EMs, for example. What information should be publicly shared?
- Understanding antecedent conditions is important (e.g., soil moisture, recent total precipitation)
- River Forecast Centers/Weather Forecast Offices (RFCs/WFOs) provide NOAA's official forecast but they could also provide stakeholders with the NWM data. It may be worthwhile to provide contextual information to accompany a service. More descriptive information could be provided to stakeholders. For example, if we are looking at a forecast 5 days out, peak flow might be at XYZ time.
- Stakeholders want the ability to compare NWM forecasts to historical forecasts (e.g., actual forecasts from the past week or month) to assess or validate NWM forecast performance.
- A data service that depicts flood stage action levels would be helpful. Is there a way to align the NWM with flood stage designations?
- It would be helpful to demonstrate flooding *impacts* as they relate to NWM outputs.
  - NOAA could consider adding a critical facilities layer to data services.
  - Looking at NWM forecasts for historical events could also illustrate impacts/thresholds given the modeled forecast.
- The 18-hour timeframe should be changed to 24 hours. Stakeholders need the 24-hour forecast at high resolution.
- Stakeholders like to see forecasted inundation level illustrated temporally and spatially, and extent of inundation displayed (i.e., current product from select RFC websites).
- Inundation at the parcel level would be helpful for land value assessment (i.e., tax assessment).

What's Missing from the Data Services?

- Inputs and outputs along the rivers/streams e.g., anthropogenic modifications.
- Reservoir impacts.
- Duration illustrated as its own data service/layer so that decision makers can better understand peak flow and return to normal timeframes.
- Historical data could enhance decision making by illustrating inundated areas during certain events and helping to calculate economic losses from those storm events.
- Time series animation for illustrating changes over time (e.g., 6, 12, 18 hours).
- Incorporate stormwater-modeling data to illustrate potential impacts.

- Uncertainty information is needed. Can the NWM show a range of possibilities within a watershed?
- Flow considerations – Adding a 7-day timeframe data service would help to inform water supply releases in advance of a flood event. This timeframe aligns more closely with existing decision support needs for flow/ water supply/flood control. Downstream flow considerations include:
    - Endangered species rely on certain flow/volumes.
    - Legal implications (e.g., flow requirements) for watersheds with inter-basin transfer agreements.
- Low-flow planning needs were not addressed. Specific data needs mentioned include:
    - 7-day low-flow risk products needed for reservoir operation to maintain stream flow for wildlife, recreation, drinking water supply, etc.
    - One-year low flow forecast at the mouth of the river for saltwater intrusion prediction.
- Coastal coupling is needed in tidal areas because the map visualization could be misleading.

Breakout Group Debriefs

The three breakout groups reconvened in plenary session to share the results of their breakout sessions, with a focus on watershed-based decision making. The following summarizes the report-back discussion.

What decisions are you making and how do these products help?

- Current high flow magnitude is useful for showing current tributaries that are flooding now.
- 5-Day maximum inundation extent is helpful - mixed feelings about pushing that to the public.
- Could be useful for deployment decisions and knowing where to stage equipment
- Reservoir management: don't want to release unless it's necessary – too much dewatering may cause federally protected mussel species in Upper DE to see habitat impacts
- Products could be used in communicating with residents and managing questions from visitors to recreational sites; EMs is thinking about moving resources and evacuating residents.
- Maximum high flow magnitude Forecast could help identify creeks likely to flash flood, useful planning for EM purposes.
- Delaware River Basin Commission (DRBC) is monitoring MMEFS, providing messages to each of the state commissioners such as "There is potential for flooding in Basin." For Major River flooding, need to notify stakeholders earlier. (T-5)
- Most states have an EMAC compact – This information is helpful so EMs know if they should keep resources at home vs. sending them to another affected state. Start discussion relative to making resources available.
- Peak flow arrival time – definitely a good tool for DRBC to push out messaging.
- USACE: Consider controlled release from reservoirs. Water supply reservoirs might also consider this at 5 days out.
- DRBC: as storm approaches, users need to know what areas will flood and the extent of flooding
- EMs need 48 and 72-hour time steps because they need to pay for equipment and resources.
- After the event: is it safe to put boats in the water (Coast Guard)?
- After the event: Is rain still falling? Need to know the 18-hour peak flow again, and 3 and 5-day time steps to see when the streams will recede. In addition to time of peak, need a map showing when flows are expected to return to within bank levels.

Information needs:

- One-year outlook helpful for low-flow forecast; concerned about salt-water intrusion impacts.
- Understanding antecedent conditions is important (soil moisture, recent precipitation).
- Hydrographs are helpful for a day out. Can we look back at storms of records a few weeks out?
- Tidal areas – don't show coastal data unless you are showing coastal coupling.
- Need to know flow over time. Accumulated inflow volumes. Total volume of inflow tomorrow – 3 days, 7 days and even out to a year to make inflow and release decisions.
- Low-flow planning needs: 7-day data services needed.
- Smaller communities in basin looking at 5-day forecasts for planning.
- Want uncertainty in forecast products – peak flow, magnitude.
- Need to connect NWM outputs with actual impacts.
- When will peak flow occur? Actual volume would be great. Could also be displayed as anomaly.
- Can the flood stage information be added to these data services? Major, moderate, minor.
- NYC uses ensemble forecasts and would find it helpful to know how the range of streamflow forecasts compare to past observed streamflow
- Duration of events – need help with interpreting when it will it peak and when it will recede. Maybe it's a different map than high flow arrival time.
- Coast Guard needs wave height, even 5 days out.
- From pollution prediction perspective: A lot of discharges during events – 18 hours to 3-day maximum. Need hourly progress and velocity (transport time).
- T minus 48-72 hours is a critical time step.
- Emergency managers need this hydrologic information tied to winds.
- Coastal coupling is critical because map services may be inadequate without this information.

Product considerations and suggestions:

- How useful is the 1.5-year interval? How would you use that information? Maybe we need to talk about a more appropriate return interval to represent flooding.
- Giving a previous month of precipitation is insufficient – need weekly detail.
- How this is delivered is important: Could forecasters provide a live walk-through of NWM products to assist local EMs and others in translating the data – i.e., through calls, video recordings? A decision-tree might be helpful.
- The hydrograph is a useful tool because it tells us where we are and where we are going to be, and it incorporates it in a fashion that is easy to communicate it to the public. What does that number mean and what has it meant before? NWM data may be more information than smaller communities need to communicate.
- Peak flow arrival time: It would be helpful to have days shown – 117 hours is difficult to translate quickly – but when duration is only 3 hours, that is hard to represent in days. Could it simply state the time? If there is a gray area, does that mean no data or no flooding? Need a legend clarification to understand.
- Question: is it 180 hours from the start of the simulation or 180 hours from the peak?
- Maps need start times.
- These products are oriented to the basins as shown, but state employees need to look statewide: could it be arranged so parameters could be defined that way?

- 5-Day maximum high flow magnitude forecast – Want to toggle between magnitude and inundation; in a briefing you would want all the maps layered together – timing, magnitude and inundation all layered together.
- Lambertville needs more interpretation.
- FEMA should reach out to NY/NJ state representatives to make sure the agencies have the NWM information available.
- Put a time and date on peak flow.
- Duration needs to be more explicit (i.e., on time to peak flow products).
- Can you use this information historically to show impacts and costs – for planning purposes/economic considerations/future events? Then it's very meaningful.
- Maximum inundation forecast: Could you overlay the 100-year floodplain? Can you show depth and uncertainty in gradations of color? Perhaps a fading layer could show depth/uncertainty.
- Can we connect this data to impacts?
- Need longer return period. We need to aim for higher tier events because that is the future.
- Add hydrograph to point services.
- Integrate NWM data services in the NOAA dashboard "IRMA," specifically related to oil spills.
- Wave height one to two miles offshore would be useful to incorporate for coastal areas. Wind and current information are not adequate now.
- Reference data back to a historic storm.

Appendix B: Penobscot Basin Engagement

Proceedings from Penobscot River Basin Workshop

Bangor County Government Office
Bangor, ME
May 8, 2019

High Level Findings

Several key issues were identified during the engagement:

- Incorporating tidal influence into stream flow forecasting is critical
- Forecast accuracy is most important for short-range timeframes
- National Water Model forecasting could be very helpful for remote parts of the basin where forecasting capabilities are currently limited
- Inundation extent and depth are needed to assess impacts
- Information on return-to-normal flow timing (when the river will recede) is important for decision making
- Ice flow and low flow products are needed
- It would be useful to depict anticipated impacts of an upcoming event
- Terminology should be reviewed and/or better defined (e.g., “high flow” versus “peak flow”, “bankfull”, “normal”) to improve understanding.

Introductions and Welcoming Remarks

Arleen O’Donnell (ERG) opened the meeting with a round of introductions and turned to Mary Mullusky (Chief, Water Resources Services Branch, Forecast Services Division of NWS), David Vallee (Hydrologist-in-Charge of the Northeast River Forecast Center), and Donny Dumont (Warning Coordination Meteorologist, Caribou Maine WFO) for welcoming remarks.

During introductions, participants indicated their interest in the following topics:

- Using National Weather Service (NWS) forecasts for emergency response planning
- Higher resolution forecasts with predictive forecasting for smaller streams and watersheds

Workshop Objectives and Registration Survey Results

Arleen O’Donnell described the workshop objective –To test the usefulness of experimental hydrologic forecast products and services to support local core partners based on a hypothetical flood event in the Penobscot River Watershed. She also presented results of the participant poll completed at registration. Participant survey results characterized the sector of workshop attendees, timeframes of greatest interest, source of current information on river forecasts, and the top challenges and issues facing the Penobscot River Watershed. Most participants worked in the following sectors (see Table 1):

- Emergency management and support
- Water policy/planning
- Community resilience

Attendees also indicated that, while all timeframes, including seasonal and climate, were of greatest interest, 24 hours to 5 days prior to a flooding event were evenly indicated to be of high priority, and participants noted much less need following a flooding event (see Table 2). Participants currently access information on river forecasts directly from NWS forecast products (Table 3). Finally, attendees indicated that riverine flooding and combined riverine and coastal flooding were the top challenges in the Penobscot River Watershed (Table 4).

Table 1. Poll Results: *Which sector do you represent (select all that apply)?*

Sector	Percentage
Emergency management and support	**23%**
Water policy, planning, and community resilience	**23%**
Ecosystem management	**20%**
Water supply management	**11%**
Transportation	**9%**
Utilities	**9%**
Academia	**9%**
Flood control	**6%**

Table 2. Poll Results: *What timeframe is of greatest interest to you during a flood?*

Timeframe	Percentage
5 Days	**26%**
2 to 3 days	**17%**
24 Hours	**20%**
Recovery	**6%**
Other*	**31%**

*Other: All the above; seasonal; climate-scale.

Table 3. Poll Results: *How do you currently access information on river forecasts (select all that apply)?*

Source of Information	Percentage
Directly from NWS forecast products	**37%**
From other regional, state or local agencies	**34%**
From both RFC and WFO materials	**17%**
From WFO office	**14%**
From RFC briefings	**6%**

Table 4. Poll Results: *Top challenges and issues (select all that apply).*

Top Challenges	Percentage
Riverine flooding	**66%**
Combined riverine and coastal flooding	**60%**
Flash flooding	**31%**
Low flow/drought	**29%**
Water quality	**14%**

Other: USGS Gauges

Presentation on NOAA's Hydrologic Prediction Services

Mary Mullusky provided an overview of previous stakeholder engagements and the feedback from those efforts, as well as an overview of the Hydrologic Ensemble Forecast System (HEFS) and the National Water Model (NWM). She also presented the logic model for the development of hydrologic prediction services informed through these engagements and presented the workshop objectives. Kate Abshire (NWS) provided a preview and explanation of the NWM products and services that would be demonstrated during the breakout group sessions, as well as other NWM capabilities that would not be shown.

Breakout Groups

Participants were randomly separated into three breakout groups to view and discuss experimental forecasting services related to flooding. Facilitators walked participants through a scenario at three different time frames to test product usefulness before and during an epic flood event in the Penobscot Basin. The visuals used to illustrate this scenario were developed by the National Water Center using the National Water Model (NWM). The NWM geospatial data services created for this workshop illustrate flooding impact in the Penobscot Basin as it relates to time to peak and high flow, high flow magnitude, and inundation in the Basin.

Participants were shown these three prototype services (timing, magnitude and inundation) and asked how these services could be used to inform decisions before and during flood events as a supplement to existing forecasting capabilities. Additionally, participants were asked about what improvements or additions could be made to further inform decision-making. Facilitators walked participants through the following three scenarios leading up to the onset of a flood event (zero hour). The three-time steps of the scenario were presented as:

- Five days prior to onset of flooding
- Two days prior to onset of flooding
- Onset of flooding

The NWM map services, presented through a GIS-based Storymap, depicted high flow magnitude, maximum inundation extent, high flow arrival time and peak flow arrival time. Depending on which scenario timeframe was selected (e.g., 5 days before the event), participants were shown current conditions and NWM forecasts that depicted flooding conditions for the next 10 days, 5 days, 3 days, and 18 hours from whichever timeframe was selected.

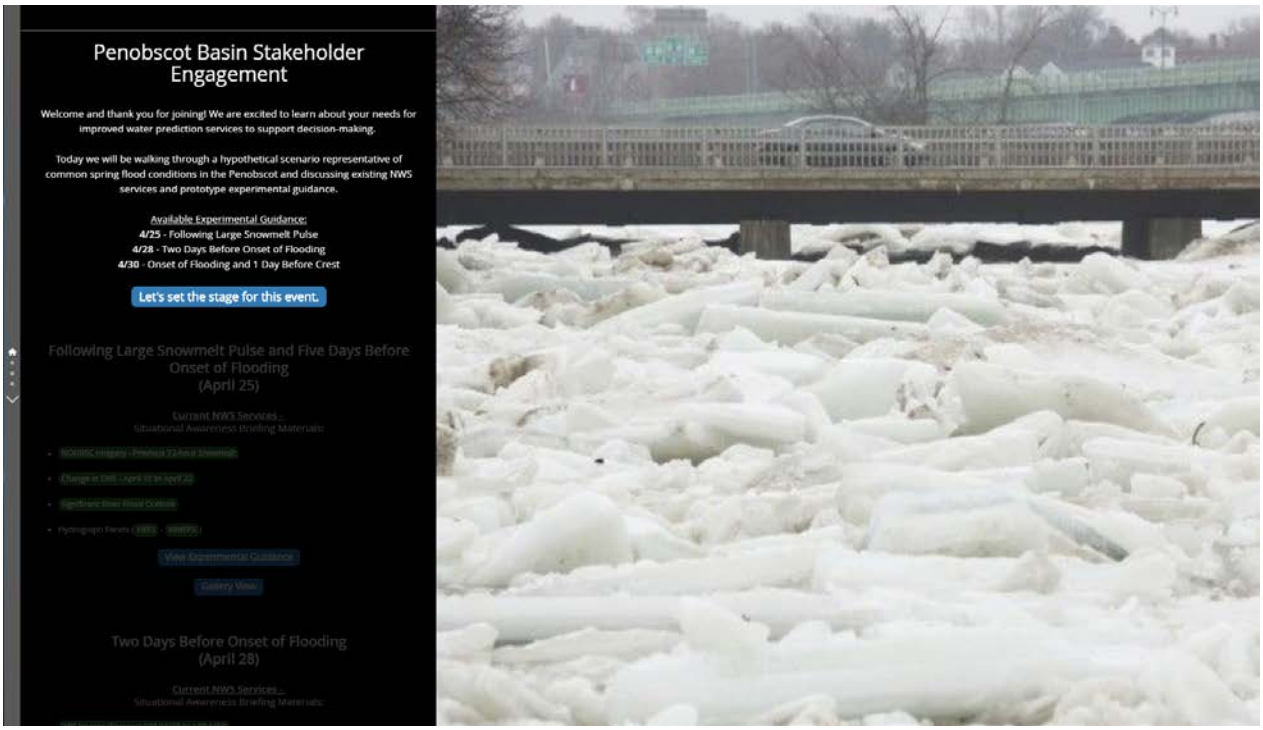

Figure 1. Landing page for Storymap shown during breakout groups.

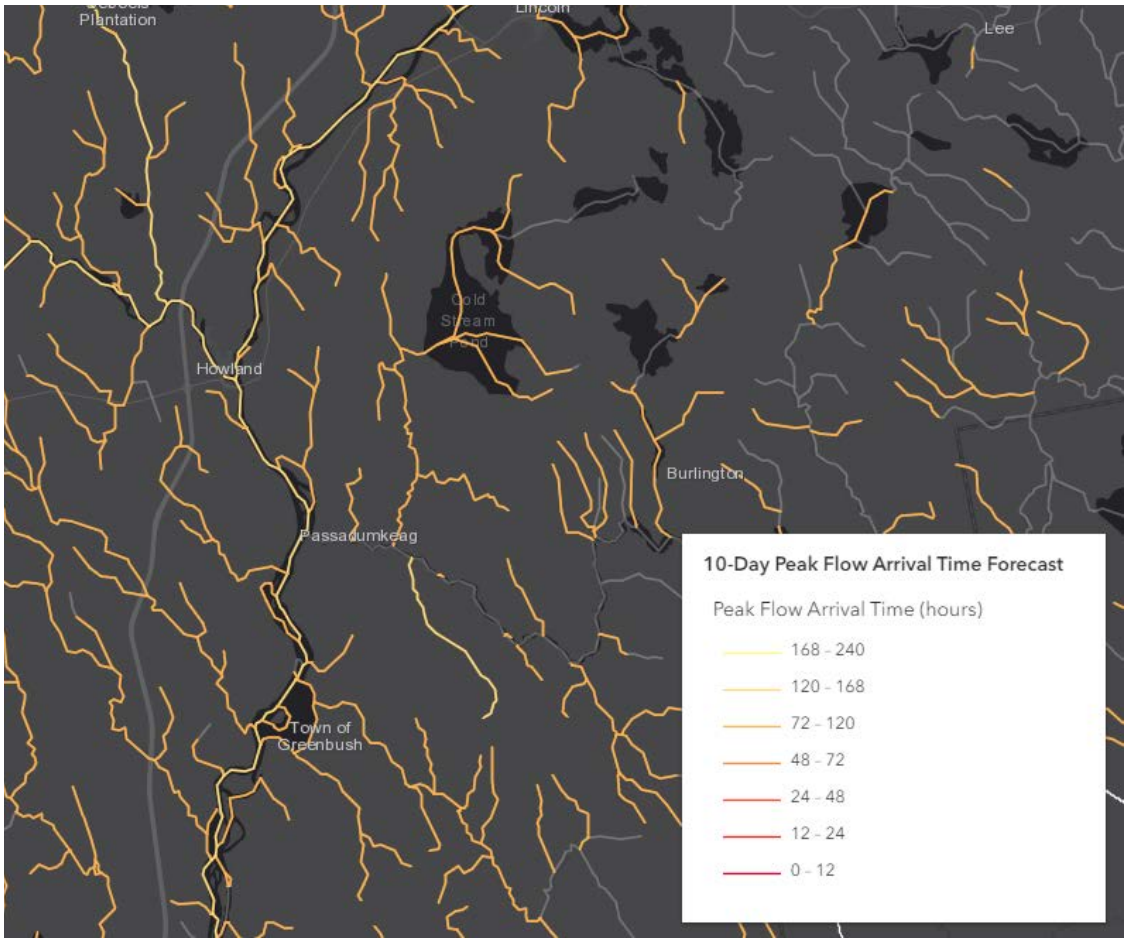

Figure 2. Image of peak flow arrival time forecast five days before onset of flooding (West Enfield, ME)

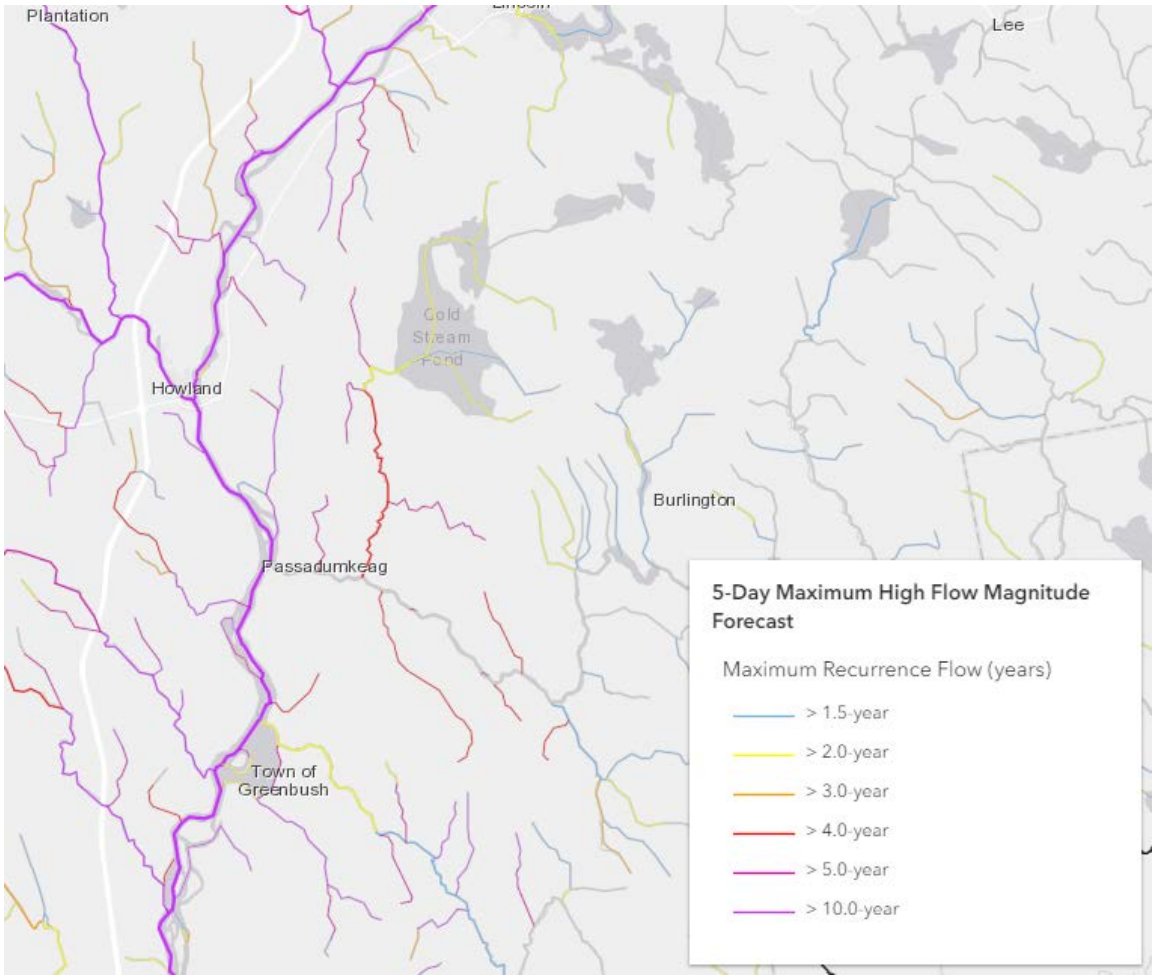

Figure 3. Image of high flow magnitude forecast two days before onset of flooding (West Enfield, ME)

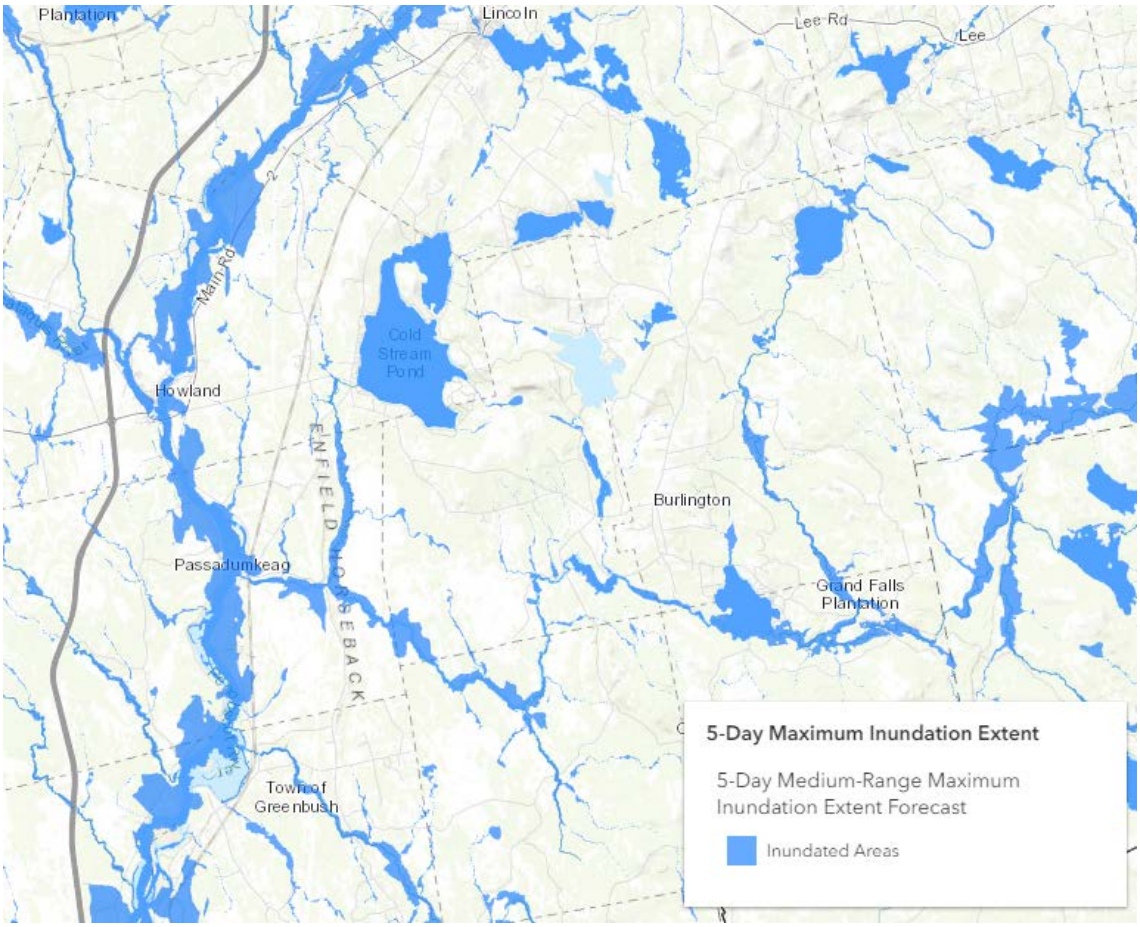

Figure 4. Image of modeled current maximum inundation extent for the Penobscot Basin (West Enfield, ME).

Each breakout group had a facilitator, a representative from the NERFC and/or WFO, and a technical representative available to answer questions about the NWM services. The NERFC and WFO representatives walked participants through the Storymap, providing a high-level overview of the flood scenario presented through a series of slides showing forecasting products currently issued by the WFO/RFC. After each group reviewed the current suite of NWS forecasting products and services, the facilitators probed participants' decision-making needs at each time step. Participants were asked how prototype services could be used in combination with current forecasting services and what other information would be helpful at each timestep. Breakout group participants were also asked additional questions to elicit discussion about usefulness of the NWM services and how they could be used to meet specific decision-making needs.

Summary of Comments on Experimental Data Services

Comments recorded during breakout group discussions were summarized as they relate to specific data services, suggestions for how NWM data services could be used and improved, and what's missing from the current suite of NWM data services (See Table 5 below). Appendix B provides a complete list of participant comments.

Table 1. Summary of Breakout Group Responses

How NWM Data Services Could Be Used and Improved?
Understanding where, when, and how much captures the essence of community planning. The NWM has potential to inform community and land use planning.
The NWM data services can be used to inform emergency management decisions (e.g., staging equipment, communicating vulnerabilities, where to send staff).
These services can help with resource allocation based on areas with most severe flood forecasts.
These services can inform fishery stocking strategies and fishery resource allocation (e.g., may not send sampling vessels out during times of potential flooding).
It may be better to show 24- and 12-hour forecasts opposed to an 18-hour forecast. This will capture one entire and one-half of a complete "cycle" of human activity and may be more digestible for stakeholders. This is only relevant if the NWM could show a 24-hour forecast with comparable confidence to the 18-hour forecast.
It may be useful to incorporate actions to reduce flood risk by modeling "what-if" scenarios to help stakeholders and users understand potential impacts.
Showing uncertainty may help users understand their vulnerability.
Including calibration quality as it relates to gage density provides users additional context to support forecasts. Class 1 (high gage density) forecasts versus class 4 (low gage density) forecasts contextualizes information and may equip communities with lower gage densities with information to advocate for more gages.
It would be more digestible to display actual time and number of days (opposed to hours) in forecasts. In Bangor, showing tidal cycles would also be helpful.
These services may be able to inform restoration projects to enhance community resilience to flooding.
Terminology is a big issue. All NWM terminology should be clearly defined (e.g., high flow versus peak flow, bankfull, what are *normal* conditions, etc.). It is critical that these definitions are constructed with input from other agencies, or at least other parts of NOAA, so they are consistent. For example, the term *normal* is extremely challenging in the climate arena; including climatologists in the discussion would be beneficial.
Including the duration of inundation would be useful to know so authorities can switch gears from response to recovery.
The ability to incorporate local GIS data layers will be extremely useful to understand impacts to critical infrastructure, vulnerability, and potential extent of impacts.
Scales and legends need to be clear and consistent across services.
It will enhance user understanding to link inundation to cause (e.g., severe rain, snowmelt, etc.).

What's Missing from the NWM Data Services?
Inundation depth is a "must have." Even high-level depth bins would be helpful (e.g., one-three inches or even one-three feet). Additionally, above ground level (AGL) would be useful to know (e.g., how deep is the water on the ground).
Tidal information/ coastal coupling is critical in the Penobscot River Watershed. It would be extremely useful to know times between bankfull and peak water levels, number of tidal cycles within forecasted time periods, etc.
Displaying ambient temperature provides context for flood forecasts (e.g., snowmelt). While this may be difficult to do at national level, maybe the NWM can show temperature at the local level.
Low-flow forecasts would be beneficial and might help with water quality forecasting.
Longer-term hindcasts linked to a type of or historic event will provide communities with important context and visualizations of what is to come.
Clearly including duration of high flow above bankfull so community members know how long event will last will enhance recovery response and efficiency.
Hydrologic changes (ice) and anthropogenic processes (e.g., dam removals) are critical. For example, a dam was just removed from the Penobscot and there is little understanding of future impacts to flooding. Since removing dam, Bangor is experiencing significant differences in ice impacts. These impacts are decreasing gage accuracy.
Discharge flow and velocity forecasts would be useful to contextualize vulnerabilities and potential extent of event.
Include baseline snowpack estimates so users understand how much snow there was, how much has melted, and how much is left.

Overview of Direction of NWM

David Vallee provided an overview of the future goals and direction of the National Water Model. David spoke specifically on coastal coupling considerations, inundation mapping services, and NWS coordination with partners (e.g., USGS, USACE, FEMA) and use of existing models (e.g., HEC-RAS, ADCIRC, SLOSH) to expand the NWM's capabilities. Participants asked questions on the state of tidal surge models and the NWM's future incorporation of tidal data. David concluded by reiterating that the NWM is not intended to replace existing tools, rather, it is intended to provide additional information, especially in communities where forecast information is limited due to lack of monitoring data.

Next Steps and Wrap Up

NWS staff thanked participants for attending the workshop and providing valuable input on future NWS hydrologic forecasting products and services. Mary Mullusky explained that the goal of this engagement was to understand users' needs for decision-making and ensure that the WFO and RFC can distribute relevant forecasting information to their local and regional users. She also stated that many of the suggestions from the workshop could be incorporated but that some suggestions will be difficult to address immediately and can be considered in the future. More specifically, she mentioned that relating NWM information to flooding impacts will require additional time and resources.

List of Attendees

First Name	Last Name	Organization	Email Address
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The Penobscot Basin Stakeholder Engagement Coordinating Team included:

Mary Mullusky, NWS
David Vallee, NWS
Edward Capone, NWS
Kate Abshire, NWS
Whitney Flynn, NWS
Joseph Hewitt, NWS Caribou, ME
Donald Dumont, NWS Caribou, ME
Ellen Mecray, NWS
Arleen O'Donnell, ERG, Inc.
Braden Rosenberg, ERG, Inc.
Douglas Lyons, ERG, Inc.
Kathleen McAllister, Horsley Witten Group

Breakout Group Discussion Notes

Common Themes and Summary Information from Breakout Groups

How Data Services Could Be Used and Improved

- Stakeholders identified various uses for the NWM data services:
    - Community and land use planning (e.g., critical infrastructure outside of regular hazard zones).
    - Resilience and project planning and initiation.
    - Fishery management and decision-making.
    - Informing emergency managers' (EM) resource deployment decisions, regarding when and where resource allocation (e.g., do not locate in a potentially inundated area).
    - Planning for and communicating vulnerabilities (e.g., road detours, evacuation routes, shelters, etc.)
    - Informing decisions on when to contact mutual aid organizations.
    - Inform decisions on when to shift from response to recovery.
- Stakeholders want the ability to compare NWM forecasts to historical forecasts, and potentially events (e.g., actual forecasts from the past week or month) to assess or validate NWM forecast performance.
- Change the 18-hour timestep to 12- or 24-hours so that it is more digestible for stakeholders (captures full or half of human cycle).
- Including calibration quality would be useful.
- Including uncertainty would provide context.
- It may be useful to model what-if scenarios.

What's Missing from the Data Services?

- Inundation depth.
- Tidal information/ coastal coupling.
- Ambient temperature.
- Low-flow and water quality forecasts.
- Longer-term hindcasts connected to events.
- Hydrology changes (**ice**) and anthropogenic processes.
- Discharge flow and velocity forecasts.
- Uncertainty.
- Calibration quality.
- Actual time and days rather than hours.
- Clear definitions of terminology.
- Include baseline snowmelt so users and community members know how much snow is left.

Other Key Questions, Suggestions, and Discussion

- Consider de-emphasizing "1.5-year high-flow" in the 18-hour high-flow forecast. This may confuse users and community members, consider referring to it simply as "bankfull."

- It would be useful for longer-term hindcasts that are connected to events. This will enhance users' and community members' contextual understanding of forecasts.
- The following services are critical for Penobscot region:
    - Ice and anthropogenic processes (e.g., dam removal)
    - Tidal information/ coastal coupling
- Terminology: It is important that the NWM includes very clear definitions of terms used (if not in NWM, somewhere easily accessible). This is important because terms may vary regionally, or people may not be aware of nuances of high-flow, peak-flow, bankfull, etc.
    - The term "normal" is challenging. NWM should have a definition for "normal" that aligns with other NOAA definitions – consider conferring with climatologists or other NOAA entities. If "normal" cannot be defined, consider resorting to phrases like, "return to bankfull."
- NWM should consider using 12- to 24-hour timesteps so that information is more easily digested by community members.
    - Showing actual time on forecasts would also be helpful.
- **Question:** Is this analogous to USGS pages?
    - **Answer:** Yes, that is correct. The NWM contains different formulas but is modeled after the USGS platform so it feels somewhat familiar for users.
- **Question:** How far back can the NWM be run?
    - **Answer:** The data network goes back to 1979.
- **Question:** How small does the NWM go for streamflow?
    - **Answer:** The NWM is modeled for 2.7 million stream reaches across the country.
- **Question:** Does NWM provide better digital elevation models (DEMs)?
    - **Answer:** Right now, it uses 10-meter DEM. NWM is working on incorporating best available local data (LIDAR), though this is likely down the road.
- **Question:** How did you develop inundation maps?
    - **Answer:** Inundation amps were developed using the HAND (Height Above Nearest Drainage) method.
- **Question:** Do forecasts follow political boundaries?
    - **Answer:** No, these forecasts just came out this way.
- **Question:** Is there a baseline snow estimate, so you know what level of snowmelt may be left? For example, 14 days out, snowpack was X, snowmelt was Y. In 72 hours, what would be left?
    - **Answer:** Information is in NWM, but not publicly available.