EFFECTIVELY COMMUNICATING RISK AND UNCERTAINTY TO THE PUBLIC

Assessing the National Weather Service's Flood Forecast and Warning Tools

BY RACHEL HOGAN CARR, BURRELL MONTZ, KERI MAXFIELD, STEPHANIE HOEKSTRA, KATHRYN SEMMENS, AND ELIZABETH GOLDMAN

Scenario-based focus groups tested NWS forecast and warning products for riverine flood events and found that revisions to the products improved reader comprehension and motivation to act.

Flooding is the most common, costly, and deadly natural disaster in the United States (Perry 2000), resulting in loss of life (an average of 100 lives annually) with human behavior a primary determining factor in flood casualties (Ashley and Ashley 2008). Even with timely and accurate forecasts and warnings, there are many barriers impeding people from taking protective actions in the event of severe storms and flooding. Availability of and access to information are initial barriers, and getting the message to people in times of emergency can be especially challenging when critical infrastructure such as electricity is down. However, even when people have access to warning messages, there are social and psychological factors, and message-related factors that prevent people from taking actions. Phillips and Morrow (2007) describe existing research on responses to warnings and provide a comprehensive review of research needed to understand the complexities that influence responses, for better and for worse. Many of these reasons are personal and include past experience with events (Zaalberg et al. 2009; Dillon et al. 2011) and the influence of social networks (Perry et al. 1981; Parker and Handmer 1998). The process of seeking out and reflecting upon information with family, friends, and neighbors is a critical step in motivating preparedness, as is watching others prepare and discussing plans with trusted sources (Mileti and Derouen Darlington 1997; Mileti 1999; Wood et al. 2009).

How a warning message is framed influences public response as do the source of the warning, consistency in messages, perceived credibility of the

AFFILIATIONS: HOGAN CARR, MAXFIELD, AND SEMMENS—Nurture Nature Center, Easton, Pennsylvania; MONTZ AND HOEKSTRA—Department of Geography, Planning, and Environment, East Carolina University, Greenville, North Carolina; GOLDMAN—RMC Research Corporation, Portsmouth, New Hampshire
CORRESPONDING AUTHOR: Rachel Hogan Carr, Nurture Nature Center, 518 Northampton Street, Easton, PA 18042
E-mail: rhogan@nurturenature.org

The abstract for this article can be found in this issue, following the table of contents.
DOI:10.1175/BAMS-D-14-00248.1

In final form 4 December 2015

source, and accuracy (Mileti and Sorenson 1990). The messages themselves can be a barrier to action when risk probability is overemphasized and the action steps the public should take in response are not highlighted (Wood et al. 2012). For example, including the costs and benefits of precautionary/protective measures have been found to be more effective than simply stating flood risk (Grothmann and Reusswig 2006), and providing specific, localized information on what residents should do and when are recommended (Bradford et al. 2012).

Many of the barriers to action have been extensively studied (Mileti et al. 2006) and provide a basis for understanding how National Weather Service (NWS) forecast tools are received and understood. However, there are other barriers related to individuals receiving and understanding NWS products, including the effect of product presentation on comprehension and motivation to act, that have not been as widely considered. NWS products are particularly important to study because of the role of the NWS as the source of weather (flood) watch and warnings and because much of the data are used by other weather and media outlets. Additionally, NWS forecasters are usually seen as authorities in the field by many groups, including emergency managers and the general public.

One of the complicating factors in motivating response to warning messages is the inclusion of uncertainty (or the probability of occurrence) in forecasts. Uncertainty representations are a necessary component of forecasting, and forecasters routinely express varying levels of forecast certainty or confidence. Uncertainty messages support decision-making by providing information on the confidence in the forecast about an impending event. While we know that recipients of forecasts already anticipate and consider such variables as temperature in uncertainty terms and prefer a forecast representation that includes uncertainty (Morss et al. 2008), uncertainty can also have significant negative impacts on the motivation to prepare. Specifically, people may feel less willing to act when the forecast is seen to suggest a low probability of occurrence despite the potential for significant impacts, or they may interpret the uncertainty as representing "evasiveness or equivocation" (Fischhoff 1995). Uncertainty representations can also present challenges in comprehension and increase ambiguity in messaging (Spiegelhalter et al. 2011).

People differ in how they react to uncertainty; for some, not having a concrete example of what a risk means can make them uncertain of what the actual impacts might entail and thereby impede their decision on whether to take action. Having a "retranslation" or a more concrete, real-world basis can increase understanding and motivation (Marx et al. 2007; Severtson and Myers 2013), such as including a local reference point with forecasted crest levels so that people are clear about what a flood-level forecast would mean on the ground. In addition to these considerations, the choice of

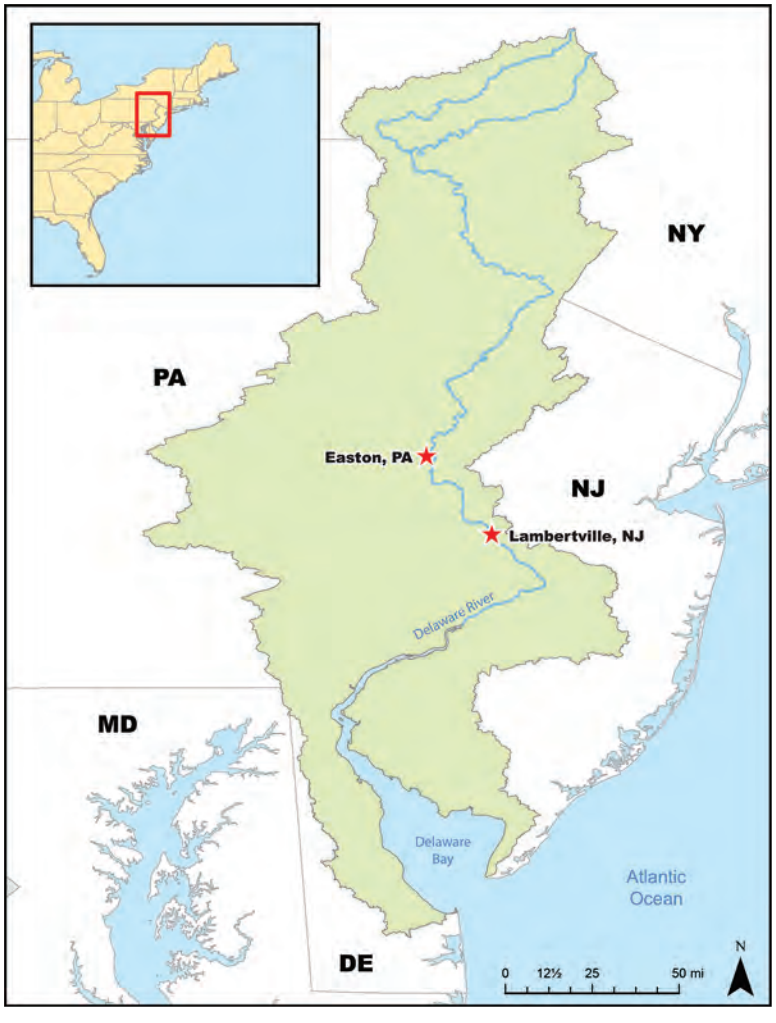


Fig. 1. Study locations along the Delaware River within the Delaware River basin (green shaded watershed).

graphics and color has been found to influence public understanding of risk and uncertainty (Hoffman et al. 1993; Bostrom et al. 2008; Ash et al. 2014).

This research builds upon our understandings of how the presentation of warning messages and forecasts combines with personal, situational, and sociological factors to influence decision-making during extreme weather events. As seen during major flooding in the Susquehanna River basin in 2011, emergency warnings alone can be insufficient to motivate people to take action. During that event, numerous residents required emergency evacuations because they decided not to leave when given flood warnings (D. Nicosia, NWS, 2012, personal communication). In such situations, understanding how warnings are presented and received is critical. Research suggests that a balanced approach that draws on both the emotional and analytical processing systems is superior for communicating statistically complex risk messages (Shome and Marx 2009). This research adds insights about the barriers that prevent flood-prone residents from most effectively using and responding to NWS forecasts.

Table 1. Top 10 highest historical crests from the period 1903–2011; where 1 ft = 0.3048 m.

Delaware River at Easton (flood stage = 22 ft)		Delaware River at New Hope (Lambertville) (flood stage = 13 ft)	
Date of flood	**Crest (ft)**	**Date of flood**	**Crest (ft)**
19 Aug 1955	43.7	20 Aug 1955	24.27
10 Oct 1903	38.1	10 Oct 1903	21.8
4 Apr 2005	37.2	4 Apr 2005	19.6
29 Jun 2006	37.09	29 Jun 2006	19.08
19 Sep 2004	33.35	19 Mar 1936	18
19 Mar 1936	32.8	8 Sep 2011	16.14
20 Jan 1996	30.65	20 Jan 1996	15.34
9 Sep 2011	29.23	24 May 1942	14.23
12 Mar 2011	26.12	30 May 1984	13.21
29 Aug 2011	25.15	12 Mar 2011	13.07

Understanding the barriers to motivating preparedness and communicating risk to the public more effectively is at the heart of the National Weather Service's 2011 strategic plan (NOAA 2011) for developing a "weather-ready nation":

> We must go beyond the production of accurate forecasts and timely warnings and build in improved understanding and anticipation of the likely human and economic impacts of such events. We must enable our users to better exploit NWS information to plan and take preventive actions.

To help the NWS improve its communication of flood risk to residents through its forecast and warnings tools, a multipartner project was conducted in Easton, Pennsylvania, and Lambertville, New Jersey, two flood-prone communities in the Delaware River basin (Fig. 1). Focus groups were held in both communities to test a set of NWS products to understand how participants access and comprehend the tools, what actions they would be prompted to undertake, and what changes would make the products more "user friendly." The study sought to answer two questions: 1) How do people living in the Delaware River basin understand and use NWS products and services in assessing their flood risk?; and 2) What changes could be made to NWS products and services to increase use and understanding, and thus to better motivate flood preparedness and warning response?

METHODS AND STUDY AREA. The research questions were addressed through focus groups in Easton and Lambertville, representing urban (Easton) and rural (Lambertville) settings. Both communities are highly flood prone (Table 1) with each located on the Delaware River. Easton is at the confluence of the Delaware and Lehigh Rivers and Lambertville is on the opposite river side approximately 30 miles downstream from Easton (Fig. 1). Easton has a population of just over 27,000, while Lambertville's population in 2013 was estimated at about 3,800, having declined from 4,400 in 1999 (U.S. Census Bureau 2015). The two communities differ in economic status with Easton having a median household income of approximately $37,000 in 2012, while Lambertville had a median income of just under $75,000. Despite these differences, participants in both communities were long-time residents and were similar in terms of motivation and interpretation of the products, allowing the two communities to be treated as one for analysis.

Table 2. Products used in the scenarios.	
Scenario day	**Product**
T – 7	NHC track forecast cone (Fig. 3)
T – 5	NHC track forecast cone
	Significant River Flood Outlook (Fig. 4)
T – 3	NHC track forecast cone
	Significant River Flood Outlook
	QPF (Fig. 5)
	AHPS hydrograph (Fig. 6)
T – 2	NHC track forecast cone
	Flood watch
	AHPS hydrograph
T – 1	NHC track forecast cone
	River flood warning
	AHPS hydrograph
	AHPS inundation map (Fig. 7)
	Flash flood warning
T	AHPS hydrograph
	Flood warning (Fig. 8)
Postscenario	MMEFS GEFS-based stage simulation traces
	MMEFS GEFS-based stage simulations expected value plot (Fig. 9)
	MMEFS GEFS-based stage simulations probability of exceedance plot

Eight focus groups were held, two in each community for Round 1 and two in each community for Round 2. The differences in the rounds are described below. To ensure that the timing of the focus groups did not unintentionally leave out any interested participants, for both rounds one focus group was scheduled for the afternoon and one for the evening. Advertisement for focus groups was conducted primarily through personal contact with community groups and leaders, and by way of a promotional flyer posted in libraries, schools, churches, and other public areas. In addition to this community promotion, flyers were personally delivered to homes in flood-prone neighborhoods, to recruit participants who are likely to have first-hand experience or are interested in flood forecast and warning tools. Selection was made on a first-come, first-served basis. Participants were provided a nominal financial incentive for participating in the focus groups.

The focus groups used a scenario approach, which is a common social science methodology widely used for education and decision-making (Kahn 1962), and which allows participants to reflect upon a hypothetical situation and potential future impacts. The scenario was created in consultation with the Philadelphia, Pennsylvania–Mount Holly, New Jersey, Weather Forecast Office and the Middle Atlantic River Forecast Center, and incorporated products developed by those offices specifically for this scenario. During the 2-hour focus group sessions, participants worked through the scenario as a group, led by a facilitator who presided over all focus groups in order to ensure consistency.

At the beginning of each session, the research team administered a survey to each participant to capture each person's demographic characteristics and flood experiences. Participants also completed a survey at the end of the session, to evaluate the focus group experience and to suggest additional revisions to NWS products.

The scenario presented a hypothetical hurricane approaching the area that was based on the flood of record that occurred in the Delaware River basin in 1955. Showing the National Hurricane Center's track forecast cone on day *T* – 7, the facilitator started each session with the following: "The National Hurricane Center has announced that a new hurricane, Hurricane Rachel, has formed in the Atlantic Ocean. It is expected to move Northward over the next seven days. Current forecasts suggest it may pass in close proximity to the Delaware River." Following this, the facilitator focused discussion on such topics as what the cone is telling them, how they are assessing their own situations, what plans they may be making at this point, and what other information they are looking for and from what sources. The scenario continued, leading up to the hurricane's landfall, using images of NWS weather forecasts and warning products (Table 2). Following the scenario, experimental products known as the Meteorological Model-Based Ensemble Forecasting System (MMEFS) Global Ensemble Forecast System (GEFS)-based stage simulations were shown and discussed in order

to understand how these tools might be helpful to individuals to assess the possibility of flooding where they live.

In addition to discussion about specific days, participants were asked how they interpreted the products, how the tools could be useful, and what would improve the effectiveness of the products. Participants were also asked what other products and services they use, and what information they wish could be made available to them. All focus group discussions were recorded and transcribed for qualitative analysis with NVivo. Following Round 1, the research team, including a professional graphic designer, went through the transcripts and discussed each product (except for the track forecast cone and flood inundation maps) as it was perceived and understood by participants. Changes resulting from this process incorporated design principles for increasing comprehension and communicating risk, and the suggestions and challenges raised by the participants in the focus groups. All changes were undertaken in consultation with the NWS in order to ensure that they would be reasonably feasible for NWS to implement. The new versions of the products were presented to a different set of participants in Round 2 with the same scenario used in Round 1.

RESULTS. The results detailed here center on the products presented in the scenario as they were understood and used by the participants. While discussion in the focus groups also encompassed participants' perceptions of their risk as the storm progressed, the results reported here address the information gathered and the recommendations made relating to the products. These are presented below, in the order in which the products were introduced (see Table 2), following the presentation of characteristics of the focus group participants.

Focus group participants. There was a total of 56 participants in the Round 1 focus groups (26 in Easton and 30 in Lambertville) and 42 in Round 2 (22 in Easton and 20 in Lambertville). All focus groups were rather evenly divided by gender, with females representing 54% of participants. The groups are also similar with respect to years in the Delaware basin (81% of participants in Easton living there more than 6 years and 90% of Lambertville participants) and years in the community (6 or more years for 84% of Easton participants and 85% for Lambertville). Many of the participants were floodplain residents who had experienced flooding; this population's perspective was solicited intentionally because they could provide comments grounded in actual and anticipated behavior. However, some differences also exist, which are important to the results of the focus groups. The Easton participants were younger, somewhat less educated, and fewer live in the floodplain compared to the Lambertville participants (Fig. 2). Despite these differences, discussions in the focus groups were quite similar, leading the research team to treat the respondents as a whole. In fact, it was found that participants in both communities turn to similar information sources (the Internet), prefer information delivered by both text and graphics, and express similar confusions and criticisms of the NWS products that were under discussion. As a result, the emphasis here is on the differences between Rounds 1 and 2 in the discussion of NWS product revisions.

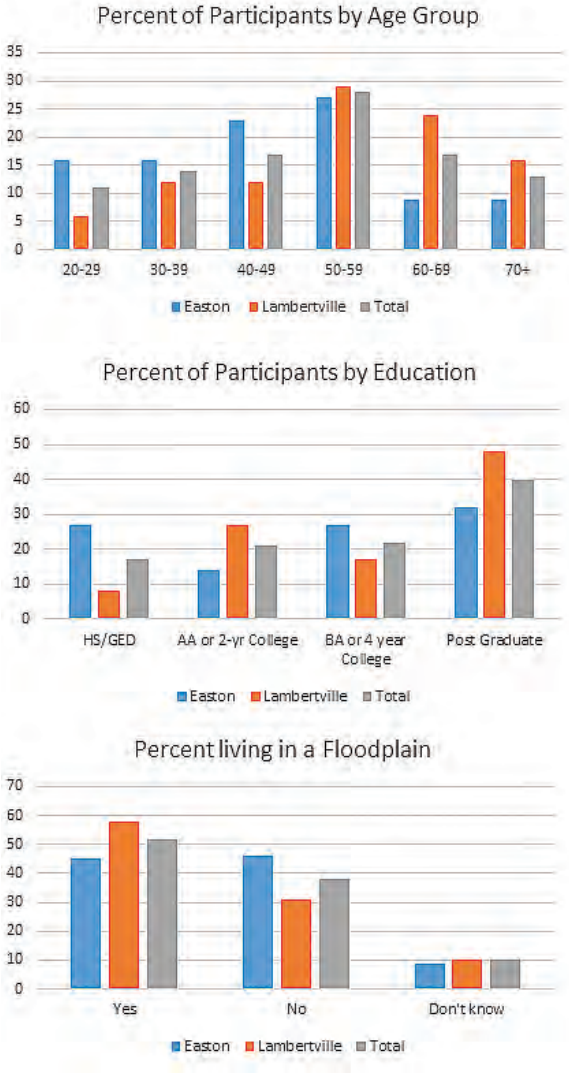


Fig. 2. Characteristics of focus group participants.

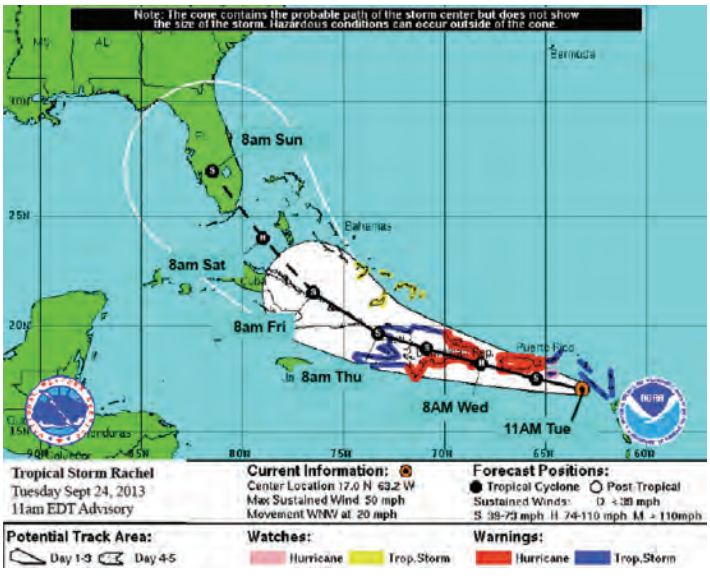


Fig. 3. Track forecast cone graphic.

In general, the participants identified several barriers to successful use of NWS forecast and warning tools, including 1) technical impediments (e.g., lack of electricity or Internet service), 2) communication impediments (e.g., graphics/text being too technical and jargon laden, illegible, and confusing with a lack of adequate explanations), and 3) awareness impediments (e.g., not knowing products existed, where to find them, or not frequent enough updates).

Round 1. National Hurricane Center track forecast cone. At $T-7$, there was interest in what the track forecast cone (Fig. 3), the first graphic in the scenario presentation, was showing, but no one related it to their own situation or personal risk. While it piqued interest in some, it was seen to be too far away to cause concern. A typical response centered on the uncertainty: "Seven days out is way far out to be predicting where it's going to go. It could be anywhere." As the storm (scenario) progressed, participant interest in the cone continued with greater attention paid to the product as the potential track area encompassed Easton and Lambertville. However, by the day before the storm, there was little use of or interest in the cone, because other products took precedence. In fact, interest in using the cone peaked around days $T-5$ to $T-3$. By day $T-1$, participants were taking preparedness actions instead of seeking out more information and looking at the cone. Suggestions about the cone centered on more frequent updates and more of a connection to local (Delaware River basin) conditions as the storm advanced. As noted earlier, the research team did not make changes to this graphic for Round 2.

Significant River Flood Outlook. Despite the fact that some participants wanted a product that would give advance notice of the possibility of a flood, most participants had some difficulty with the original Significant River Flood Outlook product (Fig. 4, top panel). They were generally negative and confused about what it conveyed, particularly with whether the red outline was showing the forecast area or the area with significant flooding. Further, the definition of significant was questioned: "What do they mean by significant? My significant may be different from your significant." Problems with the map centered mainly on the lack of geographic specificity with respect to place names or water boundaries and difficulty in interpreting the differences in color schemes and patterns. The general complaint centered on the graphics, with suggestions to change colors so that different areas could be easier to distinguish. No participants indicated having used this product in the past, and they said they would not use it because it is difficult to interpret, in either $T-5$ or $T-3$, owing to its lack of geographic specificity and poor differentiation among colors.

QPF. Reaction to the original quantitative precipitation forecast (QPF) (Fig. 5, top panel) was mixed. It was preferred to the Significant Flood Outlook in large part because of a better understanding of what it shows, though that understanding turned out to be more perceived than actual as some participants had difficulty interpreting the scale. As one participant stated, "I think that would be easier than the flood warning [Significant Flood Outlook] we saw before. I think that is much easier to understand and shows you where it's going to hit and this much, this much." The ease of understanding is further seen in comments such as, "It gives a better idea where the concentration is…this gets my attention, especially the colors." While some had seen this product, others had not and were not sure they would use it. Some participants had difficulty understanding the scale and wished for more specific geographic identifiers and labeling: "If I could see Allentown or Philadelphia, something, and a line of the state that's bolder would help me to read that much quicker because I understand the colors." While some liked the outlines of the counties, for others information on what was happening in the upper part of the

river basin was more important because flooding often occurs days after the upper regions get a lot of rain. Another comment that suggests it provides useful but not enough information was, "I think its clarity could be misleading. I think it could lead to false comfort, perhaps… thinking that those lines, those colors are set…would want other kinds of information." When asked what other information, the response was, "Well the hydrologic site where they talk about the anticipated cresting of the river." This was a fortunate comment because the next product shown in the scenario was the Advanced Hydrologic Prediction Service (AHPS) hydrograph (Fig. 6, top panel).

AHPS HYDROGRAPH. Participant comments about the hydrograph were generally positive, finding it clear to read and location specific. About half of the participants reported using it, with such comments as "Yeah, we swear by that," "That's about the only thing we have to go by," "You're right, that's really all there is," and "This is what matters the most, is what's real." Most of those who were not aware of it found it to be very useful. "I would have probably looked at this 20 times in the last four days. I live on the [creek]…they have four days warning, we have seven hours." Only a few criticized the original hydrograph (Fig. 6, top panel) as too technical. Nonetheless, knowledge gaps about what the hydrograph shows and how to use

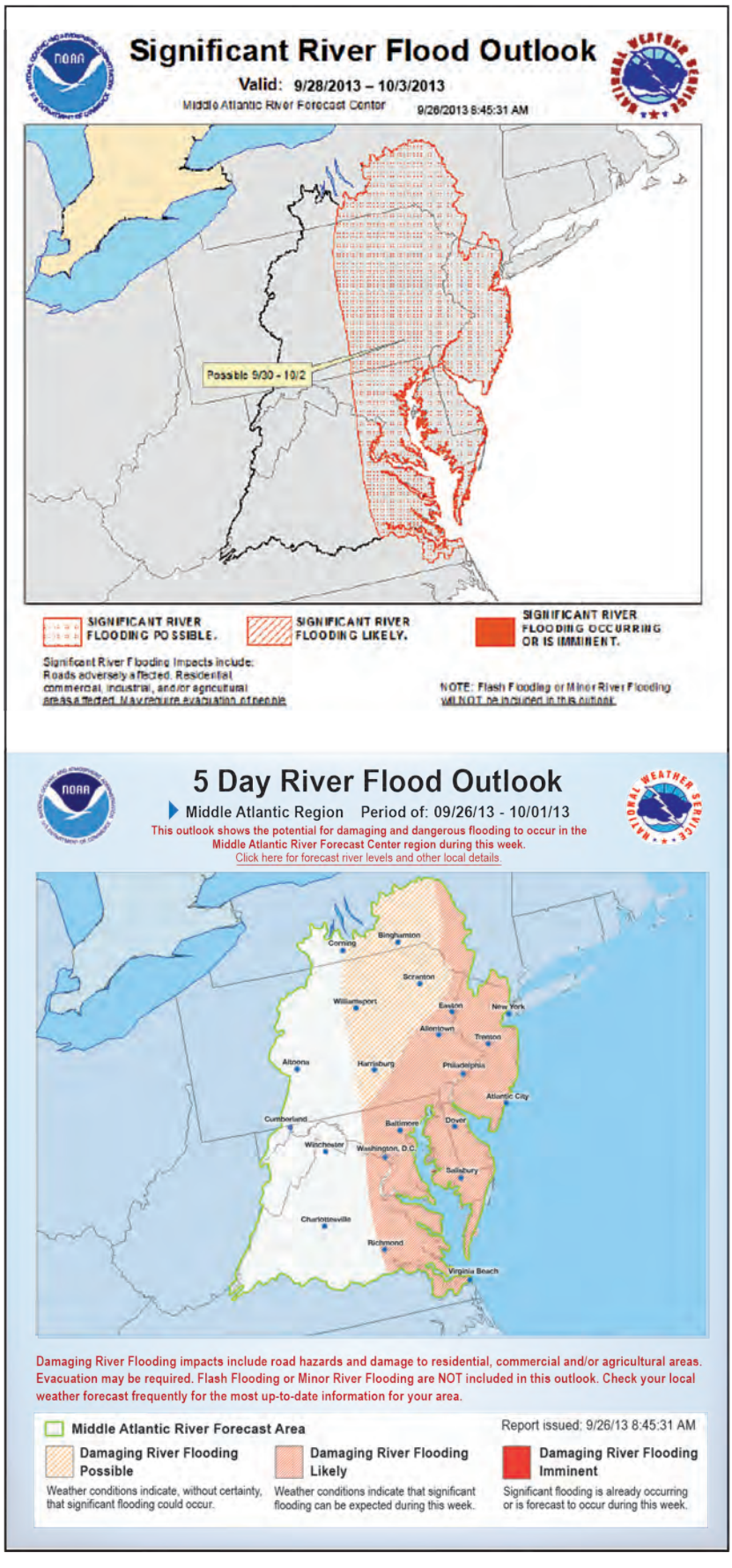
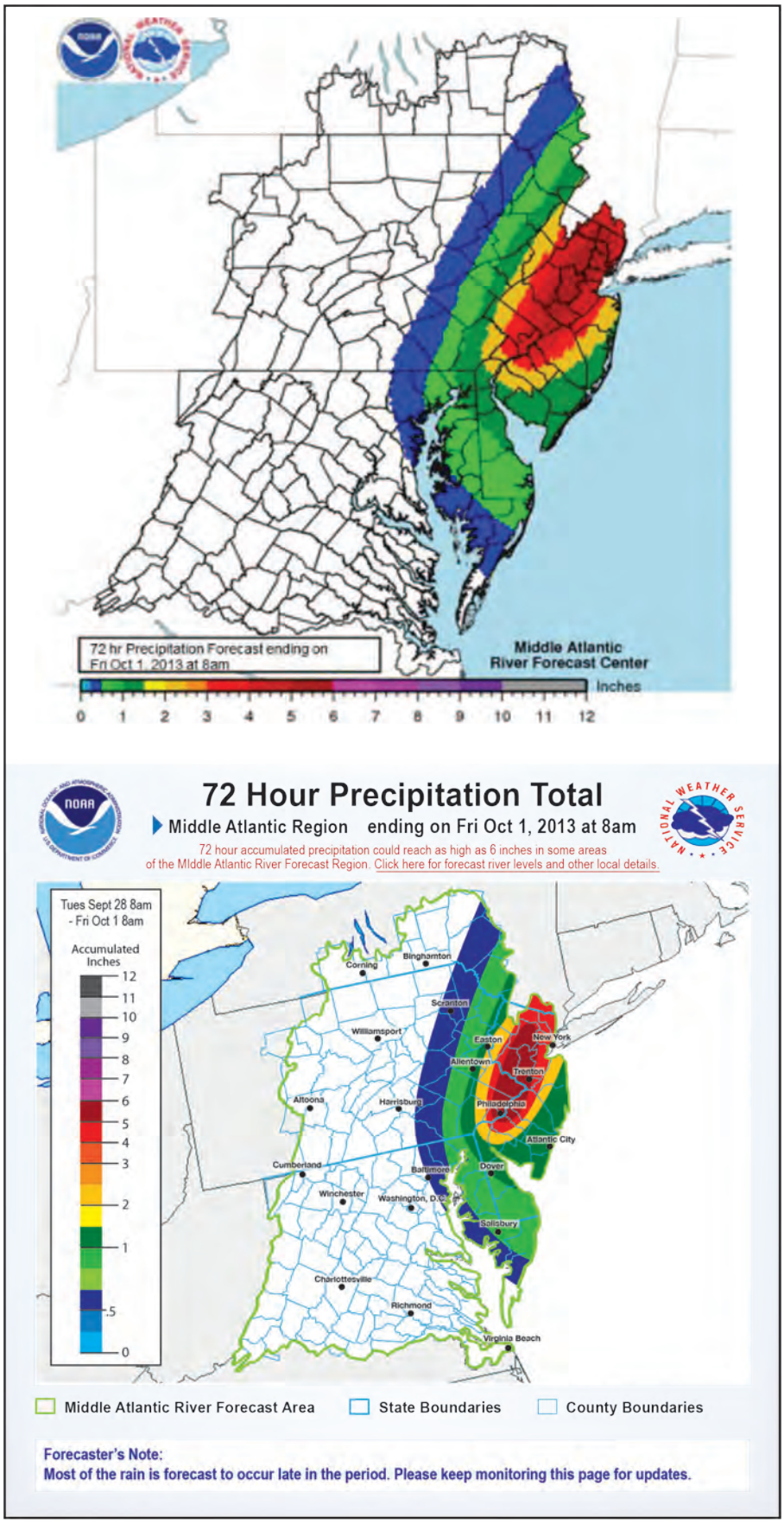


FIG. 4. (top) Before and (bottom) after graphics of the Significant River Flood Outlook.



it were evident. Many did not understand that part of the hydrograph is a forecast with inherent uncertainty. Discussion about the hydrograph among several participants is illustrative. Given the scenario at $T - 3$, one participant said that, "A lot of it is speculation what's going to happen but the hydrograph knows," which was followed by statements by others, including "They're pretty accurate" and "Accurate within the inch." At the same time, all agreed that the hydrograph motivates action. When they see it reaching flood level, preparations begin. Frequently, when presented with other forecast products, participants indicated their next step would be to check the hydrograph.

Flood inundation map. The response to the flood inundation map (Fig. 7) was mixed. The ability to check on neighbors and see the extent of flooding in the area was valued, but the use of color confused participants. Specifically, there was difficulty understanding the relation of the blue color variations to water depth. Greater interactivity potential and more landmarks were suggested. Because most did not see this as a priority tool during a weather event and regarded it as primarily useful either as an advanced planning tool or, alternatively, as a last-minute check about impending

Fig. 5. (top) Before and (bottom) after graphics of QPF.

conditions on day *T*, the product was not revised.

Flood and flash flood watch and warnings. More than half of the participants responded negatively to the flood and flash flood watch and warnings (Fig. 8, top panel) mainly because of difficulty in reading the text. The use of uppercase fonts was interpreted as "yelling" and not user friendly, as indicated by "I just think the formatting on these is abysmal. I mean you just have to read every word of this, I mean, it's all caps, you can hardly read it," and "It'd be nice if there was just some summary of the real information right at the top or something." Several participants mentioned that formatting is even worse on their phones, which they are most likely to be using as they are preparing for the flood or are evacuating. A desire for greater geographic specificity came up again: "It would be better to have the names of the towns along the river, not the whole county," because much of the county is not flood prone.

Meteorological Model-Based Ensemble Forecast System Products. In contrast to the other products in the scenario, the MMEFS (Fig. 9, top

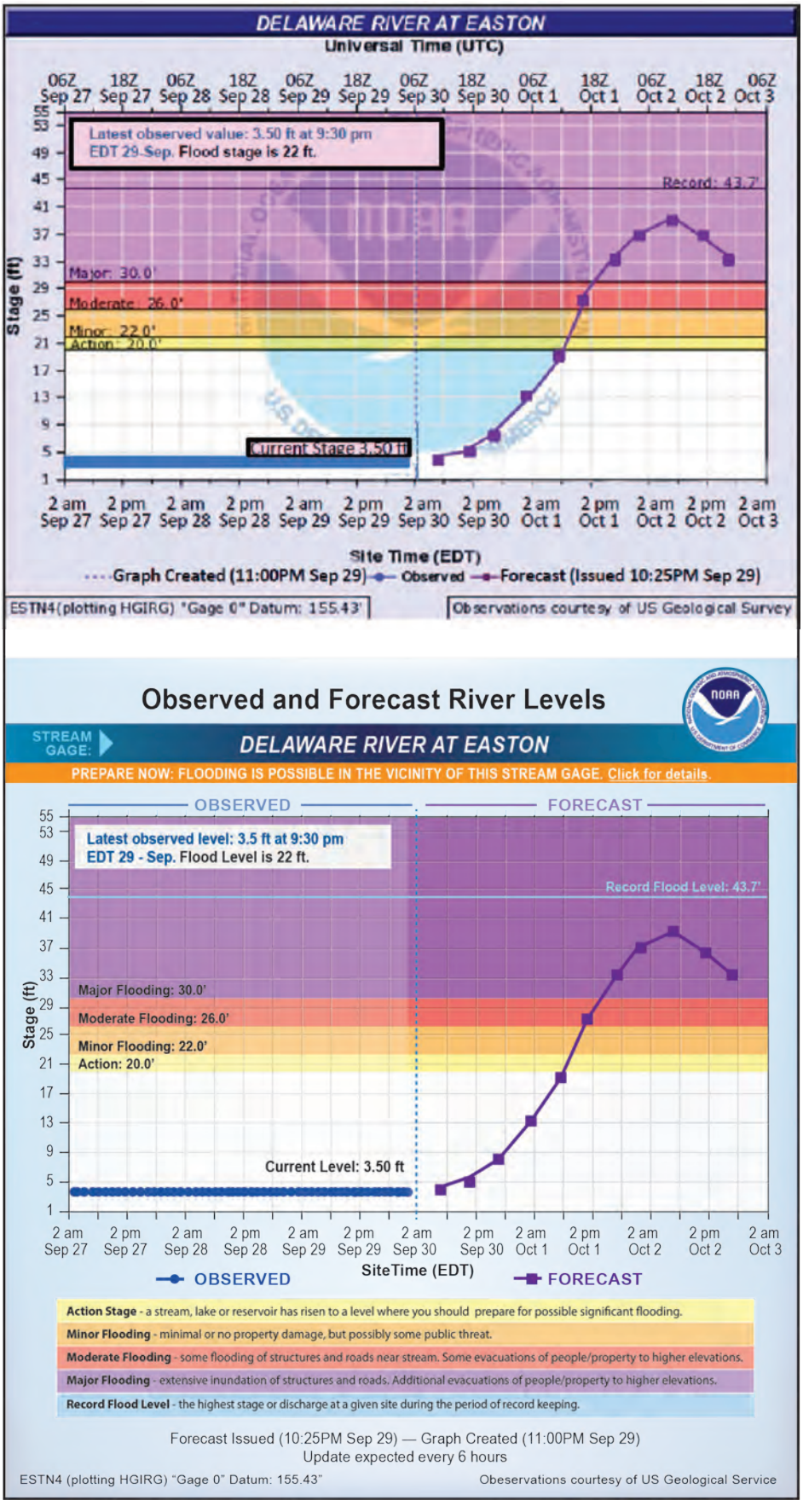


Fig. 6. (top) Before and (bottom) after graphics of the NWS hydrograph.

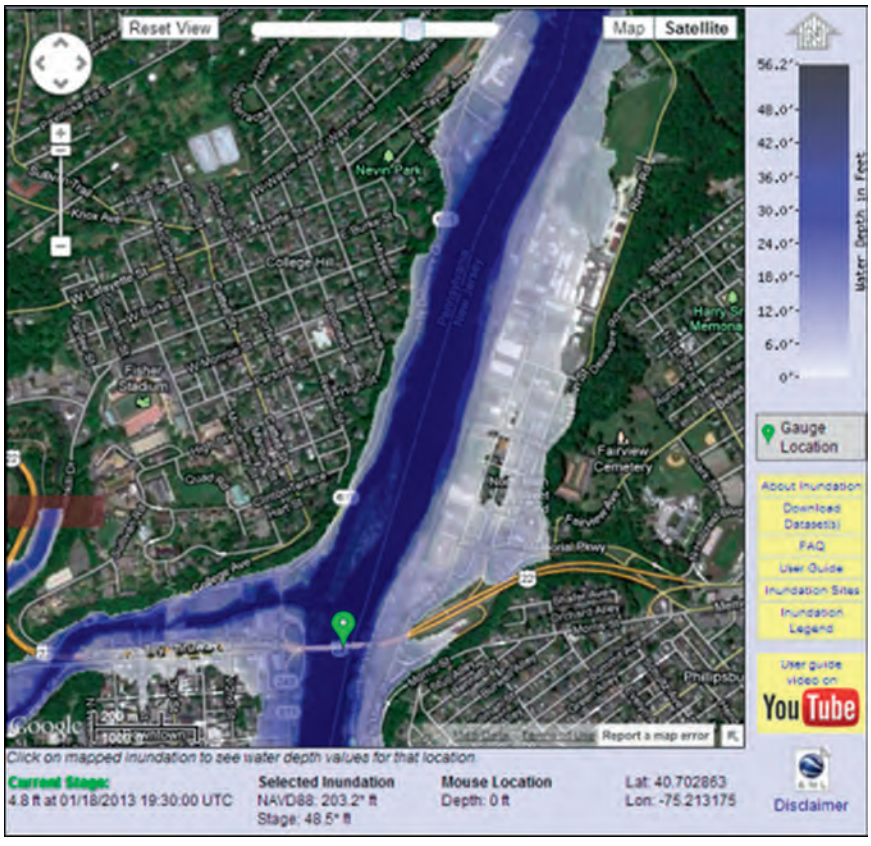


Fig. 7. Flood inundation mapping graphic.

panel) products were designed with a professional user in mind, and specifically have been used by emergency management offices. This study examined whether these products have any utility for residential users. Although a few participants found the MMEFS to be useful in showing the range of uncertainty, most found the products difficult or impossible to read, not useful, and confusing. Most struggled to understand what was being conveyed. A typical comment when asked if the products might be useful was, "If it's something I might have a chance to study it might be…I don't want to say it's ridiculous but right now I can't read it. What is it showing us?" A great deal of time was spent in the focus groups explaining what the graphs show, putting into question their utility for all but a few residential users. However, as the products were explained, some participants suggested the information could be helpful if able to be expressed more simply, with one participant responding, "The normal person doesn't know all this technicality."

Themes emerging from Round 1. The track forecast cone, the AHPS hydrograph, and flood and flash flood warnings were familiar to participants and were generally trusted. Although the hydrograph appeared to be familiar to only about half of Round 1 participants, discussion about it was vigorous as the hypothetical hurricane approached. At *T* – 3, interest and trust in the hydrograph were strong; most Round 1 participants were definite in their perception of its value—the hydrograph was all that many Round 1 participants consulted. River levels appeared to matter more than any other piece of information for participants as they tried to determine their risk and the preparations they would undertake.

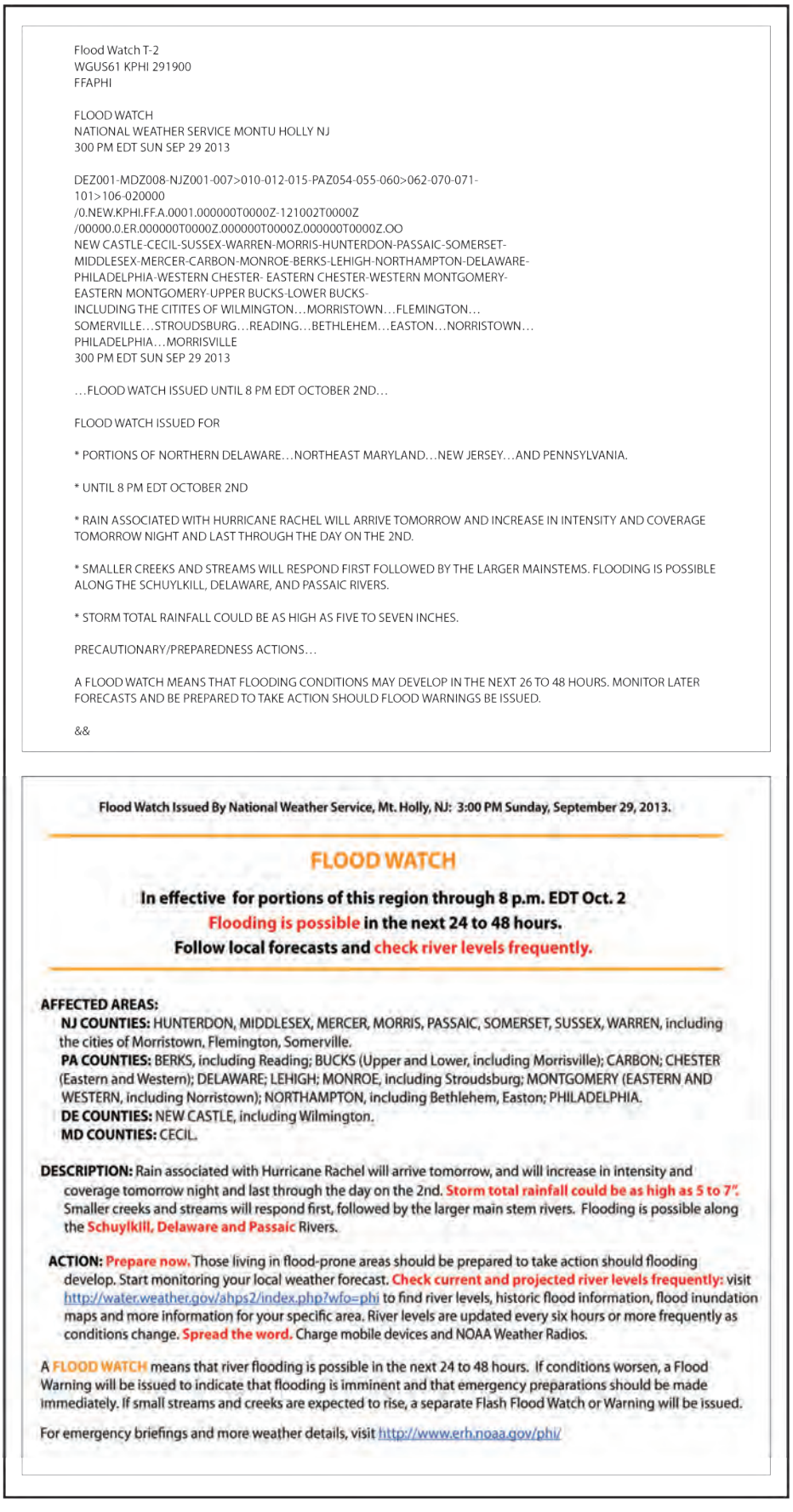
Whether addressing familiar or not-so-familiar products, responses focused on common elements across products, including the use of color and patterning, clarity of the language used, and the level of geographic specificity. These elements were taken into consideration in the revisions of products. Revisions were made to all products, with the exception of the track forecast cone and inundation maps, as noted above. The revised products were then presented in Round 2 of focus groups using the same scenario but with different participants.

Product revisions and Round 2. Significant river flood outlook. To improve the Significant River Flood Outlook, a new color scheme was employed to more clearly delineate areas likely to have damaging river flooding (Fig. 4, bottom panel). Cities were added and labeled to help viewers locate their areas. Importantly, a note was included under the map about potential damaging river flooding impacts (the word *damaging* was selected rather than *significant* because participants questioned the meaning of *significant*). The time period of the outlook was emphasized in the title (i.e., "5 Day River Flood Outlook").

Most participants were not aware of the product and were lukewarm in response toward it: "I would look at it once and say oh flood likely but would get more details that are available from other graphics." Color and language revisions made a difference, making

it clearer that one's home was in the area of forecast and what impacts might occur. Several participants focused on the language about damaging flooding, with one noting that it motivates action: "Well, when it says damage and flooding possible, I'm calling my friends along the river and asking if they're paying attention." Thus, while the revised Significant Flood Outlook (SFO) remains of lesser interest or perceived utility, participants understood the revised map better and in some instances, they were motivated to take action and to include it in the suite of tools they might reference.

QPF. As can be seen in Fig. 5 (bottom panel), the QPF was revised to include cities and towns and more easily interpretable colors for state and county boundaries in order to improve understanding of how much precipitation was forecast. The scale was changed and the graphic labeled as "Forecast: 72 Hour Precipitation Total," with a clear description of the time period the graphic encompasses (i.e., "ending on Fri Oct 1, 2013 at 8 am"). A forecaster's note box was added to allow the forecaster to report the timing of the rainfall, among other



Flood Watch T-2
WGUS61 KPHI 291900
FFAPHI

FLOOD WATCH
NATIONAL WEATHER SERVICE MONTU HOLLY NJ
300 PM EDT SUN SEP 29 2013

DEZ001-MDZ008-NJZ001-007>010-012-015-PAZ054-055-060>062-070-071-
101>106-020000
/0.NEW.KPHI.FF.A.0001.000000T0000Z-121002T0000Z
/00000.0.ER.000000T0000Z.000000T0000Z.000000T0000Z.OO
NEW CASTLE-CECIL-SUSSEX-WARREN-MORRIS-HUNTERDON-PASSAIC-SOMERSET-
MIDDLESEX-MERCER-CARBON-MONROE-BERKS-LEHIGH-NORTHAMPTON-DELAWARE-
PHILADELPHIA-WESTERN CHESTER- EASTERN CHESTER-WESTERN MONTGOMERY-
EASTERN MONTGOMERY-UPPER BUCKS-LOWER BUCKS-
INCLUDING THE CITITES OF WILMINGTON…MORRISTOWN…FLEMINGTON…
SOMERVILLE…STROUDSBURG…READING…BETHLEHEM…EASTON…NORRISTOWN…
PHILADELPHIA…MORRISVILLE
300 PM EDT SUN SEP 29 2013

…FLOOD WATCH ISSUED UNTIL 8 PM EDT OCTOBER 2ND…

FLOOD WATCH ISSUED FOR

* PORTIONS OF NORTHERN DELAWARE…NORTHEAST MARYLAND…NEW JERSEY…AND PENNSYLVANIA.

* UNTIL 8 PM EDT OCTOBER 2ND

* RAIN ASSOCIATED WITH HURRICANE RACHEL WILL ARRIVE TOMORROW AND INCREASE IN INTENSITY AND COVERAGE TOMORROW NIGHT AND LAST THROUGH THE DAY ON THE 2ND.

* SMALLER CREEKS AND STREAMS WILL RESPOND FIRST FOLLOWED BY THE LARGER MAINSTEMS. FLOODING IS POSSIBLE ALONG THE SCHUYLKILL, DELAWARE, AND PASSAIC RIVERS.

* STORM TOTAL RAINFALL COULD BE AS HIGH AS FIVE TO SEVEN INCHES.

PRECAUTIONARY/PREPAREDNESS ACTIONS…

A FLOOD WATCH MEANS THAT FLOODING CONDITIONS MAY DEVELOP IN THE NEXT 26 TO 48 HOURS. MONITOR LATER FORECASTS AND BE PREPARED TO TAKE ACTION SHOULD FLOOD WARNINGS BE ISSUED.

&&

Flood Watch Issued By National Weather Service, Mt. Holly, NJ: 3:00 PM Sunday, September 29, 2013.

FLOOD WATCH

In effective for portions of this region through 8 p.m. EDT Oct. 2
Flooding is possible in the next 24 to 48 hours.
Follow local forecasts and check river levels frequently.

AFFECTED AREAS:
NJ COUNTIES: HUNTERDON, MIDDLESEX, MERCER, MORRIS, PASSAIC, SOMERSET, SUSSEX, WARREN, including the cities of Morristown, Flemington, Somerville.
PA COUNTIES: BERKS, including Reading; BUCKS (Upper and Lower, including Morrisville); CARBON; CHESTER (Eastern and Western); DELAWARE; LEHIGH; MONROE, including Stroudsburg; MONTGOMERY (EASTERN AND WESTERN, including Norristown); NORTHAMPTON, including Bethlehem, Easton; PHILADELPHIA.
DE COUNTIES: NEW CASTLE, including Wilmington.
MD COUNTIES: CECIL.

DESCRIPTION: Rain associated with Hurricane Rachel will arrive tomorrow, and will increase in intensity and coverage tomorrow night and last through the day on the 2nd. **Storm total rainfall could be as high as 5 to 7".** Smaller creeks and streams will respond first, followed by the larger main stem rivers. Flooding is possible along the **Schuylkill, Delaware and Passaic** Rivers.

ACTION: Prepare now. Those living in flood-prone areas should be prepared to take action should flooding develop. Start monitoring your local weather forecast. **Check current and projected river levels frequently:** visit http://water.weather.gov/ahps2/index.php?wfo=phi to find river levels, historic flood information, flood inundation maps and more information for your specific area. River levels are updated every six hours or more frequently as conditions change. **Spread the word.** Charge mobile devices and NOAA Weather Radios.

A **FLOOD WATCH** means that river flooding is possible in the next 24 to 48 hours. If conditions worsen, a Flood Warning will be issued to indicate that flooding is imminent and that emergency preparations should be made immediately. If small streams and creeks are expected to rise, a separate Flash Flood Watch or Warning will be issued.

For emergency briefings and more weather details, visit http://www.erh.noaa.gov/phi/

Fig. 8. (top) Original and (bottom) revised flood watch issued by the NWS Forecast Office in Mount Holly.

pertinent information. Finally, a link to the hydrograph was added.

Participant reaction to the revised QPF reflected the importance of precipitation information to participants' decision-making. As in the first round, it was preferred to the Significant Flood Outlook; participants in Round 2 generally agreed that the tool was useful. Conversation about the revised product focused heavily on when the rain would fall, with participants noting that they would be checking for updates—"I'm watching that frequently, I'm checking the precipitation, I'm keeping an eye on it"—and also noting the importance of the forecaster's note about when the rainfall would occur—"I rarely see that. And that would be extremely valuable." While there remained some confusion as to what it was showing, as a few did not immediately understand the legend clearly, participants did like the use of color; as one said, "Yeah, it bounces."

AHPS HYDROGRAPH. Despite the overall positive comments about the hydrograph, it became clear in Round 1 that many were not interpreting it properly, so revisions were made to increase clarity (Fig. 6, bottom panel). Several terms were replaced: "stage" was replaced with "river level" and the graph was titled "Observed and Forecast River Levels" to make it easier to interpret. The observed-versus-forecast portions of the graph were shaded differently and labeled clearly. The levels of flooding (action, minor, moderate, and major) were bolded and explained in a key underneath the chart. Importantly, a "Prepare Now" orange banner across the top was added, which appears when an active flood watch is in effect, and links to that product; similarly, an "Act Now" red banner appears when an active flood warning is in effect, and links accordingly. The revised product also includes hyperlinks to more information.

The link to more details was requested by many of the focus group participants, with the rate of rainfall as a specific request. The hydrograph remained the product with the "gold star." No discussion in Round 2 centered on the changes in format, suggesting that they are subtle and not disruptively different to familiar users. While some participants did not understand how the data are derived for the hydrograph, they favored it for its ability to provide detailed geographic information, including regional information, such as nearby river gauges, which participants used to triangulate their own anticipated risk. For instance, recommendations that the data be presented by zip code rather than river gauge may be technically challenging, but they emphasize the importance of local specificity in understanding potential impacts.

FLOOD AND FLASH FLOOD WATCH AND WARNINGS. For the watch and warnings, suggestions were made in Round 1 to have a summary of critical information at the beginning and a focus on affected towns instead of just county names. These products were revised, making use of colors (red and orange), bold text, indents, and varying text cases (Fig. 8, bottom panel). A summary at the top showing affected areas and actions was highlighted, and a link to AHPS was added to direct users to review local hydrograph forecasts.

Responses of Round 2 participants to the revised watch were divided with half feeling that it was too dense and half saying they would be paying attention to it at that stage of the storm. On the other hand, respondents were largely positive about the flood and flash flood warnings, describing them as useful, crucial, and signifying immediate danger. Negative comments included the fact that weather reporters provide the same information and that "so many" warnings are received.

MMEFS. As noted in the previous section, participants did not respond positively to the MMEFS original graph (Fig. 9, top panel). The product was modified to include colors for the 25th–75th quartiles to indicate the degree of certainty in the forecasted flood level and explanatory text on the right and bottom of the graph (Fig. 9, bottom panel). Links to additional information explaining the graph were included. Horizontal and vertical lines help the viewer determine river levels and times (which are relabeled to be more easily understood). The title highlights and clarifies the time period of the dataset (i.e., "7 Day River Level Probabilities").

Participants found the revised MMEFS (Fig. 9, bottom panel) easier to understand, sparking discussion of uncertainty in weather forecasts. There was much more discussion of these products in Round 2 and, in general, it was a richer discussion, focusing on the content of the information being conveyed and the design of the graphics. While in Round 1 much time was initially spent explaining the graphics to participants, during Round 2 participants quickly understood what the products were attempting to convey and were able to move the conversation toward improving messaging. Indeed, at times, the graphic design input was quite specific from participants, who explained ways in which the presentation was hindering their understanding. For instance, one

participant "particularly liked the shaded part of the last graph, and then the lines were like woah…I feel maybe the shading would be nice in this approach instead of the bars because the bars look like they're not attached, so it doesn't look like they represent the same body of data." In other instances, product feedback focused on the various audiences and/or uses for the products: "I find this one interesting…I think for the general public this has not much value…For first responders and academics of course, love it. Don't want to take that away from them."

Echoing input from Round 1 participants about the need for clear text explanations of graphic products (which was incorporated into products through forecasters' notes and other approaches), Round 2 feedback acknowledged that for some, even the modified versions of MMEFS graphics were more challenging than helpful: "If this could be reduced to one sentence text, I think it could save a lot of people a lot of grief." Revisions made

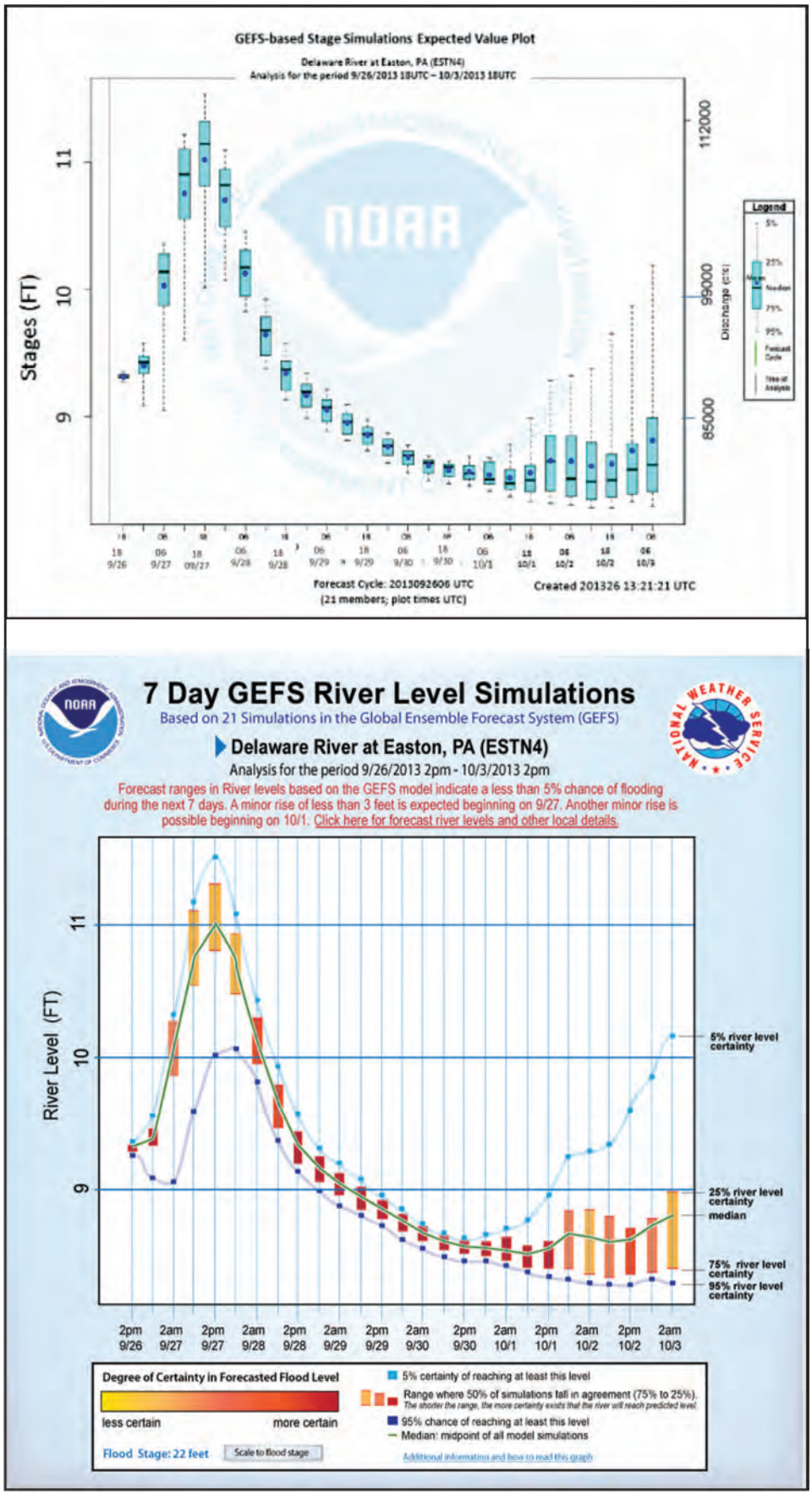


Fig. 9. (top) Before and (bottom) after graphics of box plot uncertainty in river levels.

meaningful improvements to public understanding, but even with revisions, most of the participants had difficulty interpreting and understanding the MMEFS products. While only the box-and-whisker plot is shown here, two other formats (spaghetti and dot-and-line plots) were discussed during the focus groups. The spaghetti plot created confusion with too much information and jargon and too many lines. The dot-and-line graph was similarly not well received, and many stated they would not use it for information. Thus, the products' utility for motivating public action and understanding appears to require additional enhancements.

Summary of findings. There were modifications common to all products that improved understanding of the forecast, leading to a reported increased motivation to prepare and take action. These improvements could be beneficial to other forecast products and tools for a range of natural hazards. Table 3 summarizes these findings that incorporate the feedback from the focus groups and the graphic design principles used in the product revisions.

DISCUSSION AND CONCLUSIONS. This project led to findings in several areas that have direct relevance to achieving a "weather-ready nation," particularly, as presented here, the utility and understandability of NWS products. During both the first and second rounds of focus groups, participant responses to the various NWS riverine flood forecast and warning tools focused on common elements, including the use of color and patterning, use of language, and the level of geographic specificity included in the products. In both rounds, participants strongly favored the hydrograph as a go-to resource for deciding what actions steps to take.

As shown in Table 3, the use of color emerged as very important in helping participants make sense of the information being conveyed. For instance, the use of light and dark blue on the flood inundation map was confusing to participants, who associated deeper water with darker colors. The inundation map reserves the darkest blue for the river channel, so as river levels increase—and the extent of flooding worsens—the color on the map gets lighter, which was counterintuitive to some people. The use of patterning and color on the significant river flood outlook was confusing to Round 1 participants, who could not easily distinguish between the two patterns indicating either "possible" or "likely" significant flooding, nor could they distinguish boundaries between areas at risk. Further, participants cited the lack of a distinguishing color, font, or typeface characteristic of the flood watches and warnings as a barrier to quickly identifying their personal risk, and in some instances they gave clear requests for information to be called out in color or bold text for this purpose. The ability of participants to clearly distinguish information by use of color, font, and patterning often drove much of the focus group discussions.

For residents, motivation for action came from knowing what was forecast for their specific town, and knowing what neighbors, friends, and family were doing to prepare. As one respondent stated, "What matters to me is whether it gets to 25.2 or 26.8, it's how high it is at my house." Further to this point, many participants spoke of using sticks in their yard and on their property to see for themselves how fast the water levels were rising. This hyperlocal approach was well trusted and widely used, with some arguing that, "if your power goes out and your internet is out, you don't have access to the internet so using your stick

Table 3. Summary of modifications to improve forecast products and tools.

Characteristic	Improvement
Location	Geographic specificity is valued. Residents want to know whether the forecast relates to them directly.
Language	Overly technical language and acronyms need to be avoided. Titles have to be easily understood.
Design	Different type style makes it possible to distinguish important information and to highlight key information. Consistency in logos and titles helps with interpretation and understanding, as does the prominence of date, time, and location information.
Color	Color schemes should be intuitive. Residents need colors that are distinguishable from each other and that do not mask text, boundaries, or contours. A limit on the number of different colors to no more than seven enhances understanding.
Product presentation	Combination of graphics and text is preferred. Graphic should provide a quick visual of risk, while text provides concise explanation.

is pretty smart." In addition to underscoring the importance of geographically specific information, this behavior also stimulated discussion about the participants' need to know not only the quantity but the *rate* of rainfall, which is not offered elsewhere in the tested NWS products.

The lack of local specificity in some of the flood products presented major limitations. For instance, the flood inundation maps were criticized for the lack of detail: "That's where flood maps kind of fail in a sense, in a region if you're in the flood plain it doesn't give you the level of detail you might want. I mean if I knew that every house around there would flood I guess I would empty my house anyway."

Even as graphic clarity emerged as critical, clear text was still important. Participants in both rounds preferred a mixture of graphics and text, with graphics providing quick information and text allowing for explanation and detail. The general sentiment was captured by one respondent's statement, "Graphics with limited text is the way to go. We look at weather all the time on TV and those maps are amazing… they've got so many good graphics and they're moving and they're very specific. So to go back to something that looks like somebody typed up in 1955…looks crazy to me." Revisions to graphic design incorporated "forecaster's note" boxes and additional text statements in order to address these requests.

The role of uncertainty on decision-making emerged throughout the focus group discussions. In certain instances, participants acknowledged that when the forecast was uncertain, they actively sought additional information before deciding to prepare. Participants often find this information in other NWS products, such as the hydrograph, which they deemed definitive and so used it for additional confirmation of the forecast. The MMEFS graphics, which center on representations of uncertainty, were too complex to be motivational because they lack any concrete or physical reference point, or historical analysis point, against which participants could make comparisons. Residents often confuse probabilistic forecast products with forecast confidence, and care must be taken to clearly define uncertainty, probabilistic forecasting, and confidence. Future research might test modifications that incorporate these elements. To mitigate the effect of uncertainty on perceptions of credibility, it has been suggested that risk messages should be deemphasized and actions to prepare emphasized (Wood et al. 2012), which will also serve to reduce confusion.

Nonetheless, the subtle product modifications tested here with the MMEFS were able to reduce confusion about these products and were helpful in encouraging products' use. Providing enhanced visual clarity and easier-to-interpret representations allowed participants to more carefully deliberate on the representations of uncertainty and to help avoid some of the issues presented by Spiegelhalter et al. (2011).

The changes to the NWS's products shown in this paper are relatively easy to implement and are a cost-effective way of improving product use and forecast dissemination. Focus group participants wanted to hear from the National Oceanic and Atmospheric Administration (NOAA)/NWS as the authoritative source: "We're also inundated with weathermen and weatherwomen, weather forecasters, who really don't know what they're talking about. And so I would much rather get information from NOAA, the National Weather Service and not listen to affiliate news stations." However, participants required information with enhanced clarity and ease of use in order to motivate their decisions to take action.

Additionally, the focus group process emerged as valuable not only for informing the NWS about the utility of its products but for participants themselves. Focus group participants reported on surveys that they were more likely to share information, seek out NWS information, and create emergency plans after having gone through the sessions, and in unsolicited written and verbal notes, expressed thanks for the opportunity to learn through the process. This increased motivation provides evidence that a scenario-based context for discussing flood forecast tools resulted in greater understanding and commitment to action and information sharing, and should be considered for outreach purposes.

It is important to note that some of the products reviewed in this study are created and disseminated from national offices (such as the track forecast cone), while others are generated on a regional basis (such as the SFO and the MMEFS). As a result, implementing changes to these products must be handled on a product-by-product basis, and at least one NWS office, the Eastern Region headquarters of NWS, has started a plan to operationalize some recommendations for the MMEFS products. This study was limited to flood-prone communities in the Delaware River based in New Jersey and Pennsylvania, and it is possible that other communities may have different specific needs for information from some of these products. The focus group participants were self-selected and most had first-hand experience with flooding; thus, the results and recommendations presented here may not be generalizable to other populations. Members

of the public who do not have significant experience with flooding or with NWS forecast and warning products may still be at risk and may be potential users of the information. These populations and those in other geographic regions may have differing opinions about, interpretations of, and preferences for the products than were found in this study. Thus, future research should replicate this study in different geographic locations, which can be easily accomplished with the methodology employed here, and can identify barriers to people's understanding and use of NWS products that can be combined with the results of this project. Additionally, this study presented each product directly to focus group participants, which removed one significant barrier to their use, which is the ability to locate the product when it is needed. Future research should look specifically at the ways that people access these products, and identify which delivery vehicles are most helpful for public audiences. Further, future research should address how the findings related to visual design and clarity apply across other NWS forecast products and hazard types.

ACKNOWLEDGMENTS. This paper was prepared by the Nurture Nature Center (NNC) in Easton, Pennsylvania, under Award NA12OAR4590115, a Social Science Weather Research project funded as part of the Weather-Ready Nation Initiative under the Office of Water and Air Quality in NOAA's Office of Oceanic and Atmospheric Research. The project was directed by co–Principal Investigators Rachel Hogan Carr, NNC executive director, and Dr. Burrell Montz, professor and chair of the Department of Geography, Planning, and Environment at East Carolina University and a noted hazards researcher. The authors thank the National Weather Service offices and staff that helped implement this project. Specifically, for their help in drafting the scenario for the project, reviewing proposed revisions for technical accuracy, and disseminating findings to professional audiences, a sincere thank you to Peter Ahnert, hydrologist in charge, and Patricia Wnek, service coordination hydrologist, of the NWS Middle Atlantic River Forecast Center; Gary Szatkowski, meteorologist in charge, and Raymond Kruzdlo, meteorologist, of the Mount Holly, New Jersey–Philadelphia, Pennsylvania, Weather Forecast Office; and David Nicosia and Erik Heden of the Binghamton, New York, Weather Forecast Office. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the view of NOAA or the U.S. Department of Commerce.

REFERENCES

Ash, K. D., R. L. Schumann III, and G. C. Bowser, 2014: Tornado warning trade-offs: Evaluating choices for visually communicating risk. *Wea. Climate Soc.*, **6**, 104–118, doi:10.1175/WCAS-D-13-00021.1.

Ashley, S. T., and W. S. Ashley, 2008: Flood fatalities in the United States. *J. Appl. Meteor. Climatol.*, **47**, 805–818, doi:10.1175/2007JAMC1611.1.

Bostrom, A., L. Anselin, and J. Farris, 2008: Visualizing seismic risk and uncertainty. *Ann. N. Y. Acad. Sci.*, **1128**, 29–40, doi:10.1196/annals.1399.005.

Bradford, R. A., and Coauthors, 2012: Risk perception—Issues for flood management in Europe. *Nat. Hazards Earth Syst. Sci.*, **12**, 2299–2309, doi:10.5194/nhess-12-2299-2012.

Dillon, R. L., C. H. Tinsley, and M. Cronin, 2011: Why near-miss events can decrease an individual's protective response to hurricanes. *Risk Anal.*, **31**, 440–449, doi:10.1111/j.1539-6924.2010.01506.x.

Fischhoff, B., 1995: Risk perception and communication unplugged: Twenty years of process. *Risk Anal.*, **15**, 137–145, doi:10.1111/j.1539-6924.1995.tb00308.x.

Grothmann, T., and F. Reusswig, 2006: People at risk of flooding: Why some residents take precautionary action while others do not. *Nat. Hazards*, **38**, 101–120, doi:10.1007/s11069-005-8604-6.

Hoffman, R. R., M. Detweiler, J. A. Conway, and K. Lipton, 1993: Some considerations in using color in meteorological displays. *Wea. Forecasting*, **8**, 505–518, doi:10.1175/1520-0434(1993)008<0505:SCIUCI>2.0.CO;2.

Kahn, H., 1962: *Thinking about the Unthinkable*. Horizon Press, 254 pp.

Marx, S. M., E. U. Weber, B. S. Orlove, A. Leiserowitz, D. H. Krantz, C. Roncoli, and J. Phillips, 2007: Communication and mental processes: Experiential and analytic processing of uncertain climate information. *Global Environ. Change*, **17**, 47–58, doi:10.1016/j.gloenvcha.2006.10.004.

Mileti, D. S., 1999: *Disasters by Design: A Reassessment of Natural Hazards in the United States*. Joseph Henry Press, 376 pp., doi:10.17226/5782.

——, and J. H. Sorenson, 1990: Communication of emergency public warnings: A social science perspective and state-of-the-art assessment. Oak Ridge National Laboratory Rep. ORNL-6609, 145 pp. [Available online at www.cires.org.mx/docs_info/CIRES_003.pdf.]

——, and J. Derouen Darlington, 1997: The role of searching in shaping reactions to earthquake risk information. *Soc. Probl.*, **44**, 89–103, doi:10.2307/3096875.

——, R. Bandy, L. B. Bourque, A. Johnson, M. Kano, L. Peek, J. Sutton, and M. Wood, 2006: Bibliography for public risk communication on warnings for public protective actions response and public education: Revision 4. Natural Hazards Center, University of Colorado Boulder, 347 pp. [Available online at https://coast.noaa.gov/data/digitalcoast/pdf/annotated-bibliography-risk-communication.pdf.]

Morss, R. E., J. L. Demuth, and J. K. Lazo, 2008: Communicating uncertainty in weather forecasts: A survey of the U.S. public. *Wea. Forecasting*, **23**, 974–991, doi:10.1175/2008WAF2007088.1.

NOAA, 2011: Weather-ready nation: NOAA's national weather service strategic plan 2011. 44 pp. [Available online at www.nws.noaa.gov/com/weatherreadynation/files/strategic_plan.pdf.]

Parker, D. J., and J. W. Handmer, 1998: The role of unofficial flood warning systems. *J. Contingencies Crisis Manage.*, **6**, 45–60, doi:10.1111/1468-5973.00067.

Perry, C. A., 2000: Significant floods in the United States during the 20th century—USGS measures a century of floods. USGS Fact Sheet 024-00, 4 pp. [Available online at http://pubs.usgs.gov/fs/2000/0024/report.pdf.]

Perry, R. W., M. K. Lindell, and M. R. Greene, 1981: *Evacuation Planning in Emergency Management*. Battelle Human Affairs Research Centers Series, Lexington Books, 199 pp.

Phillips, B. D., and B. H. Morrow, 2007: Social science research needs: Focus on vulnerable populations, forecasting and warnings. *Nat. Hazards Rev.*, **8**, 61–68, doi:10.1061/(ASCE)1527-6988(2007)8:3(61).

Severtson, D. J., and J. D. Myers, 2013: The influence of uncertain map features on risk beliefs and perceived ambiguity for maps of modeled cancer risk from air pollution. *Risk Anal.*, **33**, 818–837, doi:10.1111/j.1539-6924.2012.01893.x.

Shome, D., and S. M. Marx, 2009: The psychology of climate change communication: A guide for scientists, journalists, educators, political aides, and the interested public. Center for Research on Environmental Decisions, 49 pp. [Available online at http://guide.cred.columbia.edu/pdfs/CREDguide_full-res.pdf.]

Spiegelhalter, D., M. Pearson, and I. Short, 2011: Visualizing uncertainty about the future. *Science*, **333**, 1393–1400, doi:10.1126/science.1191181.

U.S. Census Bureau, 2015: State and county quickfacts. U.S. Census Bureau. Subset: Easton, Pennsylvania, accessed 12 November 2015. [Available online at http://quickfacts.census.gov/qfd/states/42/4221648.html?cssp=SERP.]

Wood, M. M., M. Kano, D. S. Mileti, and L. B. Bourque, 2009: Reconceptualizing household disaster readiness: The "get ready" pyramid. *J. Emerg. Manage.*, **7**, 25–37.

——, D. S. Mileti, M. Kano, M. M. Kelley, R. Regan, and L. B. Bourque, 2012: Communicating actionable risk for terrorism and other hazards. *Risk Anal.*, **32**, 601–615, doi:10.1111/j.1539-6924.2011.01645.x.

Zaalberg, R., C. Midden, A. Meijnders, and T. McCalley, 2009: Prevention, adaptation, and threat denial: Flooding experiences in the Netherlands. *Risk Anal.*, **29**, 1759–1778, doi:10.1111/j.1539-6924.2009.01316.x.