Flood Risk Awareness during the 2011 Floods in the Central United States: Showcasing the Importance of Hydrologic Data and Interagency Collaboration

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ABSTRACT: Floods have long had a major impact on society and the environment, evidenced by the more than 1,500 federal disaster declarations since 1952 that were associated with flooding. Calendar year 2011 was an epic year for floods in the United States, from the flooding on the Red River of the North in late spring to the Ohio, Mississippi, and Missouri River basin floods in the spring and summer to the flooding caused by Hurricane Irene along the eastern seaboard in August. As a society, we continually seek to reduce flood impacts, with these efforts loosely grouped into two categories: mitigation and risk awareness. Mitigation involves such activities as flood assessment, flood control implementation, and regulatory activities such as storm water and floodplain ordinances. Risk awareness ranges from issuance of flood forecasts and warnings to education of lay audiences about the uncertainties inherent in assessing flood probability and risk. This paper concentrates on the issue of flood risk awareness, specifically the importance of hydrologic data and good interagency communication in

providing accurate and timely flood forecasts to maximize risk awareness. The 2011 floods in the central United States provide a case study of the importance of hydrologic data and the value of proper, timely, and organized communication and collaboration around the collection and dissemination of that hydrologic data in enhancing the effectiveness of flood forecasting and flood risk awareness.

Floods have a major impact on society and the environment. More than 9,000 people died from inland flooding from 1905 to 2005 (Subcommittee on Disaster Reduction 2005). One of every three federal disaster declarations is the direct result of flooding, and more than 1,500 federal disaster declarations for flooding have been declared since 1952 (Federal Emergency Management Agency 2011). Globally, the major floods of the 1990s resulted in as much as $250 billion in economic losses, with medium and local flooding resulting in the same loss rate (Munich Re 2005). Thus, in one decade, the world experienced as much as $0.5 trillion in economic losses because of floods. Beyond the death toll and economic losses, the social costs of flooding, including illness and injury, community disruption, homelessness, relocation, and stress, have significant physical and intangible impacts on society.

Two categories of activities aid in reducing flood impact: mitigation and risk awareness, with selected activities falling into both. Mitigation activities involve flood assessment (e.g., flood insurance rate maps), flood control implementation (e.g., construction of flood control reservoirs and floodway outlets), and regulatory activities (e.g., storm water and floodplain ordinances). Risk awareness activities range from issuance of flood forecasts and warnings to education of lay audiences about flood risk. This paper concentrates on flood risk awareness, specifically the importance of hydrologic data and interagency collaboration in the issuance of accurate and timely flood forecasts. The 2011 central United States floods are used as a case study to show how hydrologic data and collaboration enhanced flood risk awareness, river forecast accuracy, flood mitigation through increased warning lead time to flooding, and response to that information.

Flood Risk Awareness and Hydrologic Data

Flood risk awareness is the process of being made aware of the spatial extent and elevation, along with the associated potential, of flooding, be it some future flood of a certain probability of occurrence or near-term pending flooding from current hydrologic and atmospheric conditions. The need for flood risk awareness spans from the average citizen to local officials to decision makers at the federal and state levels of government. In short, the whole of society plays a role in flood risk awareness; government officials bear the responsibility both to get the information out and to make prudent decisions and take actions to protect life and property, while the general public has to be smart consumers of the information and make prudent decisions and take actions that prevent loss of life and minimize damage to property.

Flood risk awareness is made possible only through the collection, communication, and consumption of hydrologic data. A major aspect of flood risk awareness is flood forecasting, which in the United States is the responsibility of the National Weather Service (NWS). Flood forecasts (Fig. 1), made for imminent or expected flooding, are based on NWS computer models that require real-time hydrologic data (snowpack, precipitation, and streamflow) as input for proper calibration. Once calibrated, the NWS hydrologic forecaster works with computer models and a variety of real-time information to determine a best estimate or deterministic forecast and, for many locations, a forecast based on a range of probabilities. Flood forecasts are typically issued twice per day and more frequently as needed. The required hydrologic data for a flood forecast (or any nonflood stream forecast) come from a number of agencies, particularly streamflow data provided by the U.S. Geological Survey (USGS) stream gauges, streamflow, and reservoir operation data from the U.S. Army Corps of Engineers (USACE), and current snowpack and observed and forecast precipitation and temperature information from the NWS. Because multiple agencies are critical to an accurate flood forecast, efficient communication and understanding of the other agencies' operations are required. When regulated reservoirs are involved, a flood forecast may prompt revisions to how the reservoir flow releases are managed. A regulation change or critical streamflow measurement could in turn require further refinements in the forecast, which is done through close collaboration between the NWS, USACE, and USGS. The NWS and USACE often request USGS real-time measurements

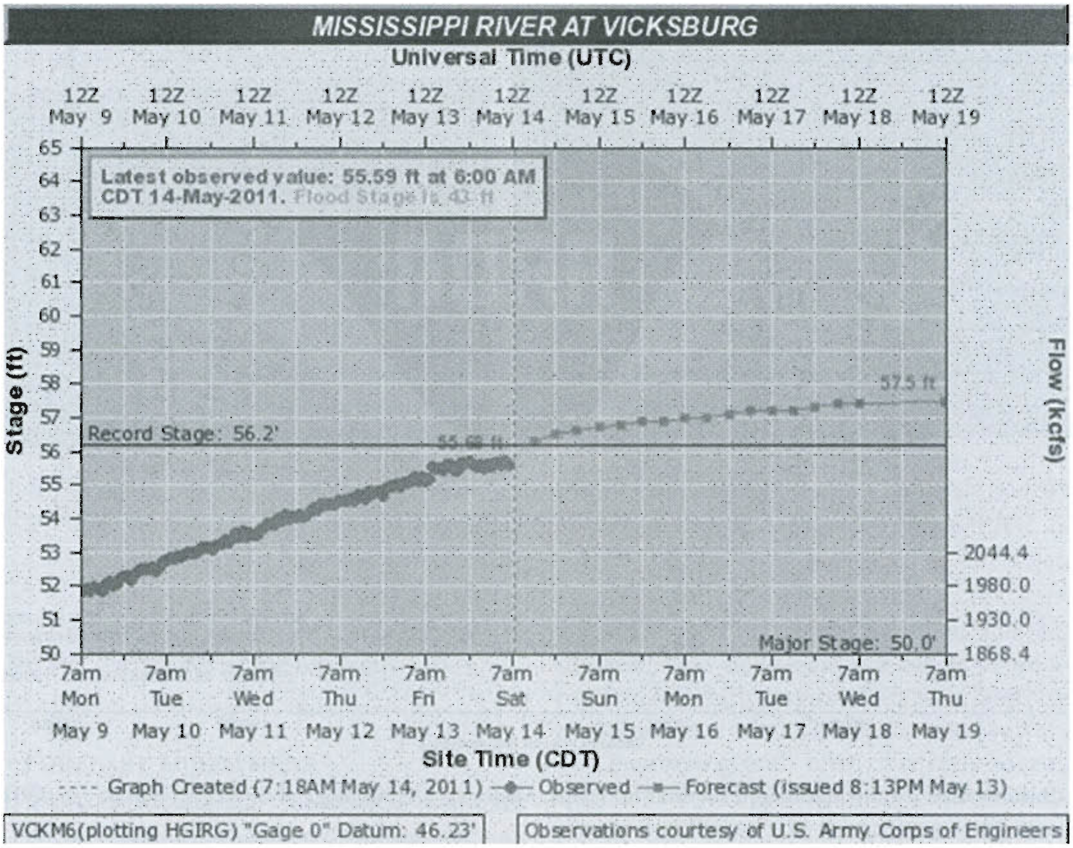

Figure 1. National Weather Service forecast hydrograph, Vicksburg, Mississippi

through mutual prioritization to optimize resources in order to provide the public with the most accurate forecast possible.

The USGS operates more than 7,800 stream gauges nationwide, with water surface elevation (stage) being collected by autonomous stage sensors 24 hours a day, 7 days a week. The stage data are transmitted in near–real time to NWS, USACE, and USGS offices. Stage data are important, but for purposes of flood forecasting (along with the flood risk reduction mission of the USACE), the volumetric streamflow (streamflow) data are also needed. At the typical USGS stream gauge, streamflow is derived from a relation between stage and streamflow that is based on discrete onsite simultaneous measurement of both stage and streamflow (Fig. 2). The relation between stage and streamflow is also known as a rating curve (Fig. 3). Rating curves are developed by the USGS and communicated with the NWS, USACE, and other agencies, entities, and people through a variety of mechanisms, including a daily automated push program (Ratings Depot) and various Web applications, including Waterwatch (waterwatch.usgs.gov).

Figure 2. U.S. Geological Survey team making a streamflow measurement (photo by Robert R. Holmes Jr.)

Because rivers are natural systems, the channels change over time (particularly during floods), which

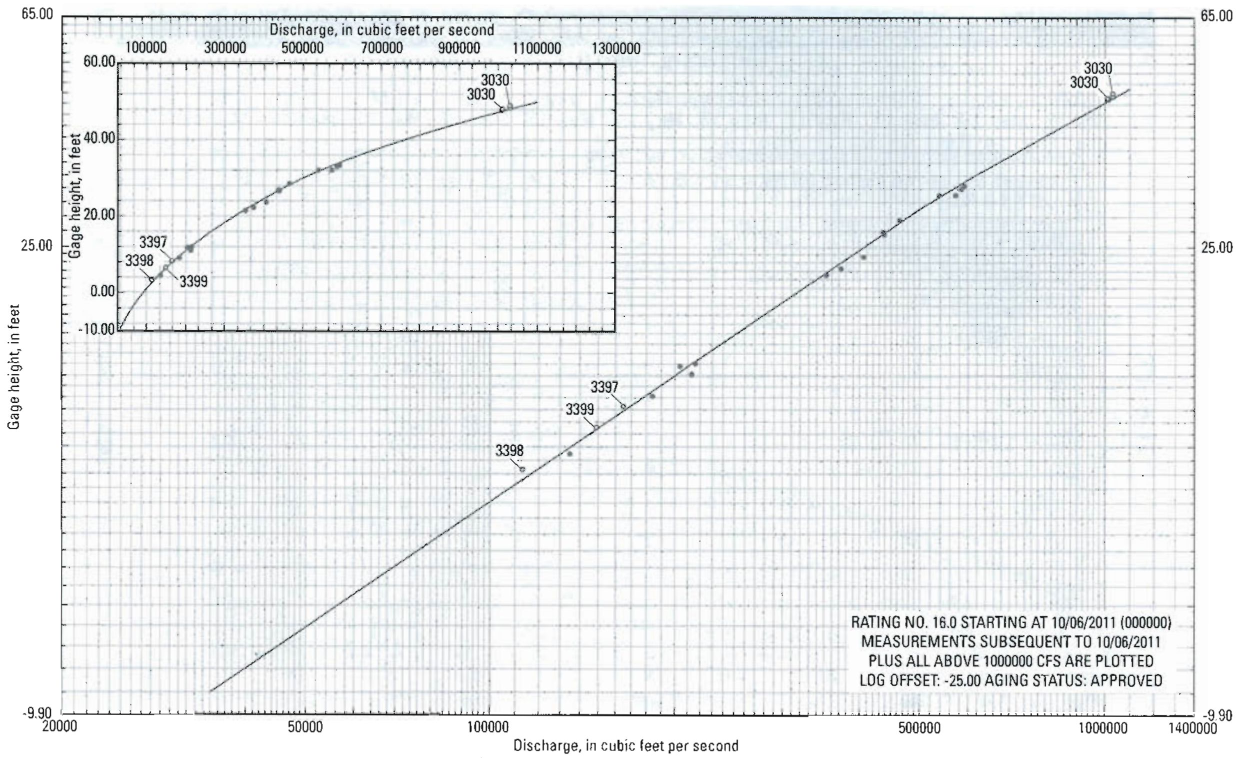

Figure 3. Rating curve for the Mississippi River at St. Louis, Missouri (U.S. Geological Survey stream gauge 070100000)

alters the stream hydraulics and thus the rating curve. As floodwaters rise and extend beyond the banks of the river, the flow is influenced by a variety of obstructions such as bridges, railroads, and highways. Overland flow can cross into other basins and further complicate the behavior of the river. Flow and stage measurements at key locations can provide valuable information about the hydraulic changes because of the high flow of the river and thus enable more accurate characterization and construction of the rating curve. The USGS regularly makes discrete onsite measurements of streamflow and stage to verify and alter the rating curves as necessary to maintain an accurate mechanism to convert stage to streamflow. A large challenge is to make sure these changes, particularly during floods, are properly communicated. Rating curve accuracy is directly related to flood forecast accuracy.

The USACE operates 386 flood control reservoirs and numerous flood control operations and features (e.g., levees, floodways, diversions) in the United States with the primary or secondary purpose of flood risk reduction (Fig. 4), as well as 230 navigation locks. The NWS stream forecast models are dependent on knowledge of USACE reservoir release rates, but USACE reservoir release rates are also dependent on the stream forecasts, particularly as they are influenced by the forecasted rainfall. Both the NWS and USACE use rating curves in modeling to forecast runoff discharges and stages; thus, the accuracy of those rating curves is essential to the forecasting process.

During flood events, the USGS is often requested to make special measurements to verify stream discharges and reservoir releases and to adjust rating curves, including extending the rating curves when discharges significantly exceed previous measurements. Given the importance of rating curves and associated streamflow data to the whole flood forecasting and reservoir operation process, there is a cycle of dependency between the USACE, NWS, and USGS. Any changes in rainfall or stream forecasts or in discharges from reservoirs can have significant effects on stream stages in the vicinities of the reservoirs. Likewise, both the NWS and the USACE need timely updates and changes in discharge–stage rating curves. Communication and collaboration between NWS forecasters, USACE water managers, and USGS hydrographers are critical to ensure that the latest information is

Figure 4. Aerial photographs of the Morganza floodway adjacent to the Mississippi River in Louisiana and Wappapello Reservoir in southeast Missouri (aerial oblique photographs courtesy of the U.S. Army Corps of Engineers)

available to update forecasts for stream stages and to determine the operations of the reservoirs.

Flood Forecast Operations

For each flood control reservoir, the USACE maintains a water control manual/plan and an operation manual. These documents identify the authorized purposes of the reservoirs and the normal (often seasonal) operating range at which the pool levels should be maintained, in part to keep pool or upstream stages below flooding levels. Reservoir discharges are regulated to prevent downstream flooding as much as possible. Reservoir operations are designed first and foremost to protect the safety of the dam in order to prevent overtopping and catastrophic dam failure and the resultant damages downstream from a dam break. During minor to moderate rainfall and runoff events, USACE water control managers are normally able to prevent or minimize upstream and downstream flooding, usually without exceeding their flood pools. However, during major floods, experienced water managers seek to optimize or balance pool elevation with downstream stages to reduce potential disastrous flood levels.

During these major events, the risk of exceeding the available flood storage in the reservoirs exists. To avoid exceeding storage capacity as much as possible, water managers need timely forecasts on precipitation and inflows to the reservoirs. The water managers work to discharge as much as possible without exceeding downstream flood stages to keep or increase available storage in the reservoirs. Water managers operating one or a series of reservoirs within a basin must also balance the flows and stages with upstream and downstream interests in mind, which can become fairly complicated in a large basin with numerous reservoirs. This operation involves continuous monitoring and, often, frequent adjustments to reservoir releases to balance both upstream and downstream conditions and minimize overall damages.

USACE water managers rely on timely and accurate rainfall and stream discharge information from the NWS and USGS to predict inflows to reservoirs and pool elevations and to determine downstream discharges. Likewise, the NWS relies on timely information from the USACE and USGS on discharges to prepare forecast updates. Decisions are made (often many times a day) on holding and releasing flows from the reservoirs depending on forecasted amounts and durations to ensure maximum releases with minimal downstream flooding while optimizing flood storage in the reservoir. During times of flooding, collaboration is made particularly difficult because of the added chaos or what is called fog of war that envelops the agencies with direct responsibilities. NWS River Forecast Centers expand to 24/7 operation and often make extra model runs to update forecasts in response to changing meteorological conditions, holding briefings for stakeholders who have crucial decisions to make based on the forecast. The USACE intensifies its hydrologic analysis to evaluate flood control operations and, during major flooding, begins formal flood fight operations, providing technical and asset assistance to levee districts and municipalities. USGS offices and staff begin flood surveillance, making hundreds of special flood surveillance visits to stream gauges along with hundreds of extra streamflow measurements (Fig. 2) to verify or calibrate rating curves (Fig. 3), communicating the data corrections or rating curve changes to other agencies, and installing rapid deployment gauges at locations where streamflow data are critical for flood risk awareness but where no long-term stream gauge exists. Coordination of the collection, formulation, and dissemination of these hydrologic data during floods is crucial.

Flood forecasts deal with the future outlook for the river stage and streamflow, but often additional types of information and data are needed for emergency managers and those responsible for making decisions regarding public safety. In addition to the warnings provided by the flood forecast, the actual observed stage and streamflow data, along with ancillary hydrologic data such as river velocity, depth of the river, and relation between the river elevation and streamflow, are often critical for situational awareness and decision making during major floods. Decisions for such things as river closure, road closure, evacuation, flood fighting (e.g., levee raises), and bridge closure are dependent on the aforementioned types of data.

While the deterministic forecast and situational awareness of floods are crucial, knowledge of the probability of a certain magnitude of flooding is also part of being aware of flood risk and is vitally important in understanding the chance for flooding at a certain location. Flood probability analysis depends on long-term streamflow data collection, with uncertainty of the analysis decreasing with length of record. Flood probability is critical to an understanding of potential flooding extent and decisions about building infrastructure. Efforts have been made to provide lay education on flood probability, such as explaining the concept of a 100-year flood (Holmes and Dinicola 2010); of particular importance is education about the uncertainty inherent in an estimate of a given flood probability. Probabilistic flood forecasts provide valuable information that contributes to the confidence one can have regarding the magnitude of the flood. Like probability analysis, probabilistic forecasts depend on a long-term record of streamflow, precipitation, and air temperature. NWS staff conduct extensive outreach efforts to help lay audiences understand how to use these probabilistic forecasts to assess risk.

The standard stream forecast provides a forecasted water elevation at a given point. A host of agencies, including the NWS, USACE, and USGS, are collaborating in the development of maps of forecasted inundated surface (Fig. 5), another tool that emergency managers and others can use to make risk-based decisions. The inundation map displays a view of an area that is expected to flood based on the level of the river. The accuracy of these maps is highly dependent on accurate digital models of land surface and accutate stream hydraulics and, therefore, the accuracy of the stream level to streamflow rating curve.

The 2011 Floods in the Central United States

Major flooding occurred along several rivers in the central United States at various times of the year during 2011. Depending on the river, the flooding was the result of either melting snow combined with precipitation or simply heavy precipitation. At the beginning of the winter of 2010–2011, much of the soils in the north-central United States were water saturated [National Oceanic and Atmospheric Administration (NOAA) 2011a], and in these same areas, large snowpack lasted well into spring 2011 from below-normal temperatures and above-average precipitation (NOAA 2011a). Widespread above-average precipitation occurred at various times across the central United States in April and May, causing swollen rivers to rise to major flood status.

The first major flooding occurred in South Dakota along the Big Sioux and James Rivers and in Minnesota along the upper Mississippi River in March 2011 as the result of rapid snowmelt and spring rains. Continued rapid snowmelt and heavy spring rainfall produced flooding in the Red River of the North basin of North Dakota and Minnesota in early April. In mid-April, widespread and heavy precipitation across the Ohio River basin (NOAA 2011b) coupled with high streamflows in the middle Mississippi River resulted in major flooding in the Ohio River in April and May and along the lower Mississippi River from late April to late June 2011. The middle Mississippi River is the reach of the Mississippi River from the Missouri River inflow to the Ohio River inflow, and the lower Mississippi River is the reach of the Mississippi River from the Ohio River inflow to the outflow into the Gulf of Mexico. The last major flooding in the central United States resulted from a later than normal rapid snowmelt in the Rockies during May coupled with extended and widespread above-normal, and in some cases record rainfall that resulted in major flooding along the Missouri River from May through August.

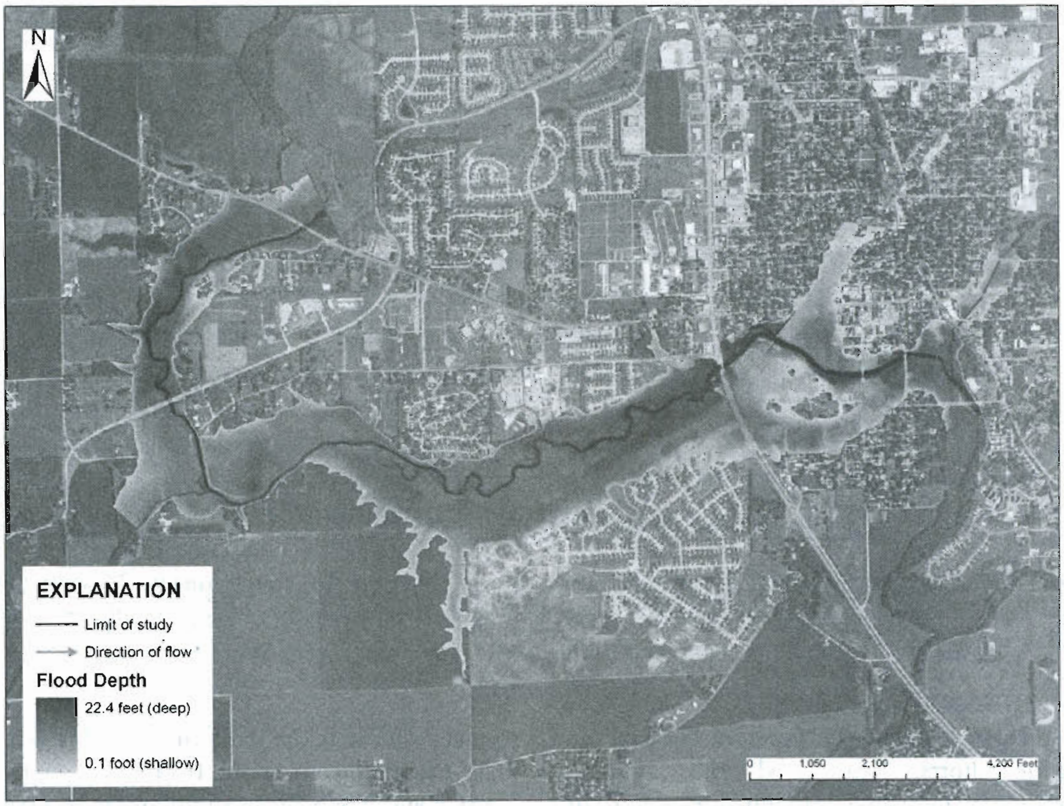

Figure 5. Example of a flood inundation map (image courtesy of the U.S. Geological Survey)

Although the USACE, NWS, and USGS have had a long history of working together toward flood risk awareness through the federal issuance of flood forecasts, that collaboration rose to new levels during the 2011 floods in the Mississippi River basin. The unprecedented collaboration was the result of three factors:

1. Annual tri-agency meetings have been held since 1998 between the USACE, NWS, and USGS, in which operational staff from each agency throughout the Mississippi River basin come together to discuss issues that allow for better flood risk awareness. These meetings allow agency staff to get to know their counterparts in other agencies, which enables and facilitates better communication during crisis times.
2. The Midwest Rivers–Weather Forecasting Fusion Team was established to work explicitly toward the goal of enhanced river forecasting in the Mississippi River basin. The Fusion Team got its start in the aftermath of the 2008 floods in the Midwest (Holmes et al. 2010); after a meeting with stakeholders in October 2008, the president of the Mississippi River Commission proposed the idea of the Fusion Team. The idea of enhancement of flood forecasting included not simply the improvement of the river forecast but also the development of additional forecast products and communication strategies. The Fusion Team, with representatives of the USACE, NWS, and USGS, began working in late 2008 and continues at present (2012) to meet goals that were negotiated with stakeholders. The Fusion Team has remained accountable to stakeholders through additional meetings in 2009 and 2010 and annual reporting to the president of the Mississippi River Commission on progress toward goals.
3. The three agencies made a commitment at all levels to collaborate for the good of the citizens of the United States, going beyond previous communication barriers to enable the fullest collaboration possible.

These three factors laid the foundation for the flood risk awareness success during the 2011 floods.

During the 2011 central United States floods, flood risk awareness, at least anecdotally, was the best it had

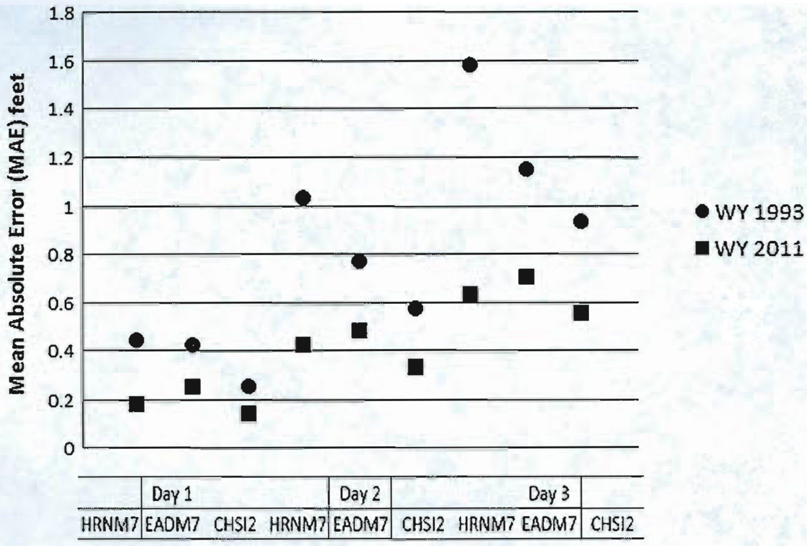

Figure 6. Mean absolute error of the forecast at three locations—Missouri River at Hermann, Missouri (HRNM7); Mississippi River at St. Louis, Missouri (EADM7); and Mississippi River at Chester, Illinois (CHSI2)—for 1993 and 2011 (WY = water year)

been during the past 100 years of societal and government efforts. The flood risk awareness performance was measured through interaction with stakeholder groups, increased accuracy of flood forecasts, lack of fatalities, and losses averted during the record flooding. Fig. 6 shows error statistics (mean absolute error) at three forecast locations [Hermann, Missouri (HRNM7); St. Louis, Missouri (EADM7); and Chester, Illinois (CHSI2)] for water year 2011 (the water year runs from October to September) compared to 1993 that verify the increased forecasting accuracy in 2011. The increased flood risk awareness was due to unprecedented amounts of hydrologic data, the development of sophisticated hydrologic models, increased collaboration among the three federal agencies, and frequent briefings for congressional and tribal delegations, emergency managers, and other stakeholders. During the 2011 floods, the USGS installed 51 rapid deployment gauges, made more than 2,300 special flood surveillance streamflow measurements, and made emergency extensions of rating curves at more than 70 sites to provide the necessary hydrologic data to the NWS and USACE.

The collaboration and communication among the agencies, particularly regarding the sharing of hydrologic data and other hydrologic information (such as flood control operation), were greatly enhanced as an outgrowth of the tri-agency meetings and Fusion Team efforts. Communication was enhanced through the use of NWSChat (Fig. 7), a relatively new collaboration tool that enables one person to send information to many others at the same time. In this way, USGS field measurements could be relayed to numerous USACE and NWS offices simultaneously. Live discussions regarding gauge issues, prioritization of gauge maintenance or measurements, placement of rapid deployment gauges, river ice coverage, and physical qualities of the snowpack could be disseminated quickly and used for quantitative or qualitative input to the forecasts.

In the lower Mississippi River, the flood damage losses averted are currently estimated at about $110 billion and were attributable to operation of the Mississippi Rivers and Tributaries project (Mississippi River Commission 2011) and an unprecedented flood fight by the USACE. However, the operation of the project and concurrent flood fighting operations were dependent on accurate and timely flood forecasts issued by the NWS. In addition, communication with stakeholder groups through daily coordination and informational meetings by the various agencies was crucial to increasing flood risk awareness. The NWS was alerting stakeholder groups to the high potential for major flooding in the Mississippi River basin as early as January 2011.

Obtaining additional hydrologic data at ungauged locations proved to be another key to successful flood risk awareness. As the flooding reached record levels for the Mississippi–Ohio River confluence at Cairo, Illinois, the 61 km long × 8 km wide Birds Point–New Madrid floodway was activated to provide a lowering of upstream water levels through a

All times are in Coordinated Universal Time for June 20, 2011:

[14:13:25] <nws–jeff...> Kris ... I see an upward jump in stage for the Fox River near Bloomfield. Do you know if techs are there and reset it?

[14:22:01] <usgs–kris...> Jeff, re Fox, yes, we're looking into it. We will probably apply a correction factor today, and hope to get there tomorrow.

[14:28:12] <nws–jeff...> OK, thanks, Kris.

[15:00:35] <coe–christopher...> NCRFC [North Central River Forecast Center]: Final Des Moines forecasts are now out there. Several iterations were pushed out this morning.

[15:05:21] <nws–mike...> Got it, Chris, thanks.

[17:10:33] <coe–christopher...> NCRFC: New Lake Red Rock forecast out there now. We cut –5,000 cfs.

[17:15:34] <nws–laura...> Thanks, Chris.

[20:39:15] <usgs–kris...> Cedar River at Conesville, IA (CNEI4): Technician inspected gage today and found it was reading within 0.15 ft due to surge.

[20:40:48] <nws-larry...> Thanks, Kris.

[21:31:46] <usgs-kris...> South Skunk River at Colfax, IA (CFXI4): 13:48 CDT [Central Daylight Time], GH [gage height] = 11.07 ft, Q [flow] = 2,620 cfs [ft^3/s], +1.35 shift from base rating, measurement rated good. Indian Creek at Mingo, IA (MGOI4): 16:02 CDT, GH = 6.43 ft, Q = 628 cfs, –0.17 shift from base rating, measurement rated fair.

[21:33:54] <nws-larry...> Thanks, Kris.

Figure 7. Transcript of a portion of the NWSChat log from June 20, 2011

controlled demolition of approximately 3,300 m of levee at 10:00 p.m. on May 2, 2011. Prior to and following activation of the floodway, the USGS made daily streamflow measurements upstream of the confluence of the Ohio and Mississippi Rivers, within the floodway opening and outlets, and on the Mississippi River downstream of the floodway opening, providing the USACE and NWS with valuable data for both flood fighting efforts of the USACE and flood forecasting by the NWS.

Conclusion

The collection of accurate and timely hydrologic data and information and the sharing of those data through excellent collaboration between the USACE, NWS, and USGS were keys to increased flood risk awareness and response during the 2011 floods in the central United States. The collaboration keys to success involved getting critical operational personnel together regularly in nonflood times when stress levels were lower and staff could get to know each other, setting up a dedicated USGS/USACE/NWS Fusion Team to consistently and regularly work through collaboration issues, and making the commitment at all levels of the three federal agencies to increase flood risk awareness for the common goal of protecting the public and our nation's economy.

References

Federal Emergency Management Agency. (2011). "2011 federal disaster declarations." ⟨http://www.fema.gov/news/disasters.fema⟩ (Oct. 11, 2011).

Holmes, R. R., Jr., and Dinicola, K. (2010). "100-year flood—It's all about chance." *General Information Product 106*, U.S. Geological Survey, Washington, DC. ⟨http://pubs.er.usgs.gov/publication/gip106⟩ (Oct. 11, 2011).

Holmes, R. R., Jr., Koenig, T. A., and Karstensen, K. A. (2010). "Flooding in the United States Midwest, 2008." *Professional Paper 1775*, U.S. Geological Survey, Washington, DC. ⟨http://pubs.usgs.gov/pp/1775/⟩ (Oct. 11, 2011).

Mississippi River Commission. (2011). "2011 MR&T flood report." ⟨http://www.mvd.usace.army.mil/mrc/pdf/MRC_2011_Flood_Report.pdf⟩ (Oct. 11, 2011).

Münchener Rück Munich Re Group. (2005). "Risk factor of water [Special feature issue]." *Schadenspiegel*, 48(3).

National Oceanic and Atmospheric Administration. (2011a). "Another spring of major flooding likely in north central U.S." ⟨http://www.noaanews.noaa.gov/stories2011/20110218_floodoutlook.html⟩ (Nov. 3, 2011).

National Oceanic and Atmospheric Administration. (2011b). "Spring 2011 U.S. climate extremes." ⟨http://www.ncdc.noaa.gov/special-reports/2011-spring-extremes/⟩ (Nov. 3, 2011).

Subcommittee on Disaster Reduction. (2005). "Grand challenges for disaster reduction." *Report of the Subcommittee on Disaster Reduction*, Committee on Environment and Natural Resources, National Science and Technology Council, Executive Office of the President, Washington, DC.

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Features