Service Assessment

Central United States Flooding of June 2008

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Cover Photograph:

Downtown Cedar Rapids, Iowa, Friday, June 13, 2008, as the Cedar River crested more than 11 feet above its previous record. View is upstream. (Used with permission. ©2008 Iowa Homeland Security and Emergency Management Division. Photograph by the Civil Air Patrol.)

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December 2009

National Weather Service
John L. Hayes, Assistant Administrator for Weather Services

Preface

During June 2008, record or major flooding occurred across large areas of the central United States. The flooding had devastating impacts, with 11 people losing their lives. Damages have been estimated at over $5 billion. The states most severely affected were Illinois, Indiana, Iowa, Missouri, South Dakota, and Wisconsin. Also, heavily impacted were Kansas, Michigan, Minnesota, Nebraska, and Oklahoma. In all, 143 National Weather Service river forecast locations experienced major flooding, with 73 of these locations establishing records.

Because of the severe impact of the flooding, the National Weather Service of the National Oceanic and Atmospheric Administration formed a Service Assessment Team to evaluate National Weather Service performance during the event. Special attention was given to National Weather Service coordination with other Federal, state, local, and private entities. The recommendations from this assessment will lead to improvements in the quality of National Weather Service products and services and enhance the public's ability to make more informed decisions associated with flood events. The ultimate goal of this report is to further the National Weather Service mission of protecting lives and property and enhancing the national economy.

John L. Hayes
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Acknowledgements

The Service Assessment Team would like to thank the many people who made this Service Assessment possible. Contributors to this effort included members of the public directly impacted by the flooding; the media; and officials and staff at all levels of the public, private, and academic sectors. A better future for us all is the legacy of their contributions.

Executive Summary

Primed by greater-than-normal winter snow amounts in late 2007 and a generally wet spring in 2008, many locations in Illinois, Indiana, Iowa, Missouri, South Dakota, and Wisconsin experienced record flooding in June 2008 following heavy rain from late May into early June. Major flooding occurred at many other locations in these states. Flooding also affected Kansas, Michigan, Minnesota, Nebraska, and Oklahoma. (**Appendix C** provides definitions of flood severity levels and **Appendix F** lists the locations with record or major flooding.) In all, 143 National Weather Service (NWS) river forecast locations experienced major flooding, with 73 of these locations establishing records. Large areas of the central United States were devastated. The Federal Emergency Management Agency issued numerous Disaster Declarations. (See **Appendix G** for a map by county.) Although the 2008 flooding event was less severe than that in 1993, which brought devastating flooding to the area, significant portions of the region were hit much harder in 2008.

The damage affected the lives and livelihoods of many people in many communities, sometimes catastrophically. Eleven people in six states lost their lives as a direct result of the flooding; eight of those deaths were vehicle related. Flooding inflicted major damage on residences, agriculture, businesses, public services, and transportation (Section 2). Reports indicate damages of more than $5 billion.

Given the severity and wide geographic coverage of the flooding, the NWS formed a 10-member Service Assessment Team to evaluate NWS products and services during the event. The Service Assessment Team documented the event across the extensive geographic area affected. The team focused its on-site assessment of NWS products and services on Iowa as representative of overall products and services throughout the affected area. Flash flooding and severe weather were not part of the assessment. Areas of particular focus for the team included: usefulness of the tools and data in the forecast process; collaboration among the NWS, the United States Geological Survey (USGS), and the United States Army Corps of Engineers (USACE) in the forecast process; accuracy and effectiveness of service; and societal perceptions.

Because of the multi-agency role in river flood forecasting in the United States (see Section 3 for details), the team included a member from the USGS and a member from the USACE. Because of the extensive societal impacts of the flooding, a representative of the academic community with expertise in the social sciences served on the team. The other seven members were from the National Oceanic and Atmospheric Administration.

From August 18-29, 2008, team members assessed damage areas and interviewed many people in Iowa, Minnesota, and Illinois. Staff members of several NWS forecast offices and key customers and partners were interviewed, including local emergency management offices, flood and levee district offices, television stations, and commercial and institutional entities. Visits were also made to offices of the USGS and USACE.

In all, the team identified 26 facts, 30 findings, 33 recommendations, and 9 best practices. Some are highlighted below. (See Section 4 for details and **Appendix A** for a summary. The definition of these terms is provided in **Appendix C**.)

The broad and continued nature of the event stretched the abilities of the NWS to provide products and services. In interviews with many varied groups, the team consistently and overwhelmingly heard positive assessments about NWS performance from those impacted. The many NWS entities heavily involved in this event, which included the Weather Forecast Offices, River Forecast Centers, and National Centers for Environmental Prediction, provided very useful guidance, outlooks, forecasts, and warnings in advance of and during the event.

These highly rated levels of service were attributable, in part, to increased NWS efforts to get the word out using many types of electronic communication now widely available. Other factors included ongoing efforts to improve modeling data support and reliability, including the use of forecast precipitation. Also, the focus on forecaster training and the development of improved software tools and methods to support the end-to-end flood forecast process all contributed to the high service level.

The following are some of the highlights of the many recommendations of the Service Assessment Team. With respect to river modeling, recommendations were made to update river model calibrations to account for land-use changes and to improve capabilities for rating curve extensions and adjustments. The positive effect of using quantitative precipitation forecasts (QPF) in the models is significant and, therefore, the NWS should pursue its optimal use. Ensemble river forecasts provide insight into uncertainty in river stage forecasts and help provide upper and lower limits for expected river stage and the most likely outcome. NWS should expand the use of these ensemble forecasts among its forecast offices and their partners. This expansion will involve considerable training of users and further study with partners on the benefits and potential shortcoming of using this information.

Levees present unique forecast challenges. The NWS should investigate enhancing access to the inventory of levees, improving methods for levee failure notification, and expanding real-time inundation image collection. Modeling capabilities need to be developed to handle the loss of storage and subsequent return of water to the hydrologic system associated with levee failures and overtopping.

Data from such sources as rain gages and streamgages are especially important in river forecasting. The team encourages efforts to optimize the current networks and expand them, if possible.

User comments indicated collaboration and coordination within the NWS and with its partners were outstanding. The use of Internet-based tools for online chat/instant messaging, conferences, and bulletin-board-style communication should be evaluated and expanded. Interagency coordination should be enhanced with periodic meetings between Federal agencies in water resource management. A process should be established for the exchange of scientific staff among Federal agencies and/or the creation of an interagency group to assess programmatic needs for service support. Assessment of local user needs and forecast office capabilities should be made to determine the costs and benefits of issuing forecast information earlier in the day and at the same time of day during both normal and high-impact environmental conditions. Web information of the Advanced Hydrologic Prediction Service (AHPS) was heavily used and is extremely important to NWS partners and other users of AHPS information. Expanded documentation on the use and interpretation of river information on the AHPS Web pages would improve their benefit even further. The NWS should continue working with local and state officials to update and expand flood impact information on AHPS as a function of river stage.

The use of 100-year and 500-year flood terminology was confusing to members of the public. The NWS should work with USACE, USGS, and other partners to assess how to communicate flood risk more effectively. In addition, the NWS should increase its education and outreach efforts on the meaning of existing flood terminology.

Continued attention should be given to survey and assessment methods for understanding how the public obtains and responds to weather information for both high-impact and benign weather. It is important to understand the significance of the availability of high-impact information on public perception and response to environmental information.

Many of the best practices noted by the team involved the extensive coordination among the NWS, other Federal agencies, and state and local governments. Coordination among the NWS, USGS, and USACE was effective and critical for a flooding event of this magnitude. Coordination included ensemble river forecast products, QPFs, river stage-discharge relationships (also referred to as rating curves), collection of data from local data networks, and monitoring and modeling of levee compromises. Communication among these agencies and partners, such as the media and private interests, was also invaluable in supporting the NWS mission of protecting life and property. Use of electronic tools such as chat rooms/instant messaging, Web conferencing, bulletin boards, and dynamic Web page updates were crucial in ensuring proper communication.

In summary, the following points are highlighted in the report:

- The 2008 flooding was less severe overall than that of 1993, but some locations were hit much more severely in 2008.
- The quality of NWS products and services was high.
- NWS coordination with partners in its role of providing decision support services was extremely successful.
- Collaboration among the NWS, USGS, and USACE was excellent.
- NWS services were enhanced by advances in atmospheric modeling, especially in precipitation prediction; implementation of AHPS and information on the AHPS Web site; and exponential growth of communication capabilities.
- Societal factors played a major role in people's responses to warnings and other flood information. Additional study needs to be done in this area.
- There is still room for improvement in flood forecasting, communicating forecast information to the public, and getting the public to take action.

Service Assessment Report

1. Introduction

1.1 National Weather Service (NWS) Mission

As a line office of the National Oceanic and Atmospheric Administration (NOAA), the NWS provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure that can be used by other governmental agencies, the private sector, the public, and the global community.

These services are delivered through the efforts of staff stationed at 122 Weather Forecast Offices (WFO), 13 River Forecast Centers (RFC), nine National Centers of the National Centers for Environmental Prediction (NCEP), 21 Center Weather Service Units, the Alaska Aviation Weather Unit, 13 Weather Service Offices, two Tsunami Warning Centers, six Regional Headquarters, and a number of other units. Oversight, policy, and support are provided by NWS Headquarters in Silver Spring, Maryland.

1.2 Purpose of the Service Assessment

The NWS may conduct Service Assessments following significant weather-related events resulting in at least one fatality, numerous injuries requiring hospitalization, extensive property damage, widespread media interest, or an unusual level of interest of NWS operations (performance of systems or adequacy of warnings, watches, and forecasts) by the media, emergency management community, or elected officials. It is not practical, however, to assess all significant weather-related events. Service Assessments evaluate the NWS performance and ensure the effectiveness of NWS products and services in meeting its mission. The goal of a Service Assessment is to improve the ability of the NWS to protect life and property by implementing recommendations and best practices that improve products and services.

The NWS Director chartered this Service Assessment Team on August 7, 2008, as the result of extensive flooding in the central United States in June 2008. The team reviewed the event across the extensive geographic area affected by the flooding, but focused its on-site assessment of NWS products and services on Iowa as representative of the products and services of the entire area. Flash flooding and severe weather were not part of the assessment.

The focus areas of this Service Assessment were:

- The meteorological and hydrologic nature of the event and its impacts
- Performance of the end-to-end flood forecast process
- The usefulness of the tools and data in the forecast process
- The collaboration among the NWS, U.S. Army Corps of Engineers (USACE), and United States Geological Survey (USGS) in the flood forecast process
- The accuracy and effectiveness of service
- The societal perceptions, impacts, and responses to the forecasts

The primary purpose of this report is to present the facts, findings, recommendations, and best practices identified by the assessment of NWS performance during the central United States flooding of June 2008. It also documents the meteorology, hydrology, and impacts of the event. Because the end-to-end process for flood forecasting in the United States is not widely known, a portion of this report is devoted to detailing that process.

1.3 Methodology

There were 10 members of the Service Assessment Team. Because of the multi-agency role in river flood forecasting in the United States, the team included a member from the USGS and a member from the USACE. An expert in the social sciences was included to reflect the great societal impacts of the event. The other seven members were from NOAA.

From August 18-29, 2008, team members assessed damage areas and interviewed many people in Iowa, Minnesota, and Illinois. Interviews were conducted with staff of NWS forecast offices. Key NWS customers and partners were also interviewed, including staff of local emergency management offices, flood and levee district offices, television stations, businesses, and institutions. Visits were made to offices of the USGS and USACE. In addition, the team reviewed products and services from a number of NWS offices, including the North Central RFC (NCRFC), the Des Moines and Quad Cities WFOs, the Hydrometeorological Prediction Center, and the National Operational Hydrologic Remote Sensing Center.

After completing the interviews and reviews, the team spent several months discussing and agreeing upon the significant facts, findings, recommendations, and best practices. After internal NOAA review, the Service Assessment was approved and signed by the NOAA Assistant Administrator for Weather Services and issued to the public.

2. Summary of the Meteorology, Hydrology, Damage, and Other Impacts of the Event

In June 2008, many places in the central United States were devastated by flooding. The states most severely impacted were Illinois, Indiana, Iowa, Missouri, South Dakota, and Wisconsin, with less serious flooding in Kansas, Michigan, Minnesota, Nebraska, and Oklahoma. This section reviews the precipitation and flooding associated with the event and the resulting damage and other impacts.

2.1 Rainfall and Flooding Overview

The areas affected by flooding and their upstream drainages saw heavy snowfall in the winter of 2007-2008, with the exception of Indiana and parts of Illinois (**Fig. 1**). Normal to above normal amounts of snow were observed from Missouri and Iowa into the Great Lakes area, with greatest anomalies in portions of Wisconsin. Snow melt and rain (**Fig. 2**) combined to cause spring flooding, notably during March in the lower Ohio River and middle Mississippi River basins and during April in eastern Iowa and adjacent areas in Minnesota and Wisconsin. As shown in **Fig. 3**, by early April, rivers in areas that would flood in June were flowing at very high levels. Immediately prior to the June flooding, wet conditions and flooding (in some cases, major flooding[1]) had occurred in parts of Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, and South Dakota.

Persistent heavy rain started in late May. The first half of June was characterized by localized, intensive convective precipitation (**Fig. 4**). High totals of precipitation for this period were widespread because of repeated episodes. Highest totals were as much as 2-4 times the monthly average. Late May through the first few days of June saw 7-day totals of up to 8 inches of rain in parts of Iowa, Missouri, Nebraska, and South Dakota. The period June 4-9 (**Fig. 5 and Fig. 6**) saw additional rainy conditions, with localized daily amounts of 3-5 inches of rain on various days at some locations in Arkansas, Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin. Totals exceeded a foot of rain in some parts of Illinois and Indiana. Additional rain–up to 11 inches in Michigan–fell June 12-13, the culmination of the very rainy period (**Fig. 7**).

The streamgage[2] locations experiencing record or major flooding are depicted in **Fig. 8.** Locations in flood on June 13, 2008, are shown in **Fig. 9**. Areas hit hardest by flooding included the Cedar, Iowa, and Wapsipinicon River basins in Iowa; the Rock and Kickapoo basins in Wisconsin; locations on the Embarras River in Illinois; the Wabash River in Illinois and Indiana; the White River and the East Fork of the White River basins in Indiana; and portions of the middle

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[1] As summarized in Appendix C, the NWS defines major flooding as causing extensive inundation of structures and roads and/or resulting in significant evacuations of people and/or creating conditions that require transfer of property to higher elevations.

[2] The spelling "gage," as opposed to "gauge," is used throughout this report. This follows the USGS and USACE convention, dating back to practice established in the 1890s by the USGS and consistent with current guidelines in the publication U.S. Geological Survey (1991).

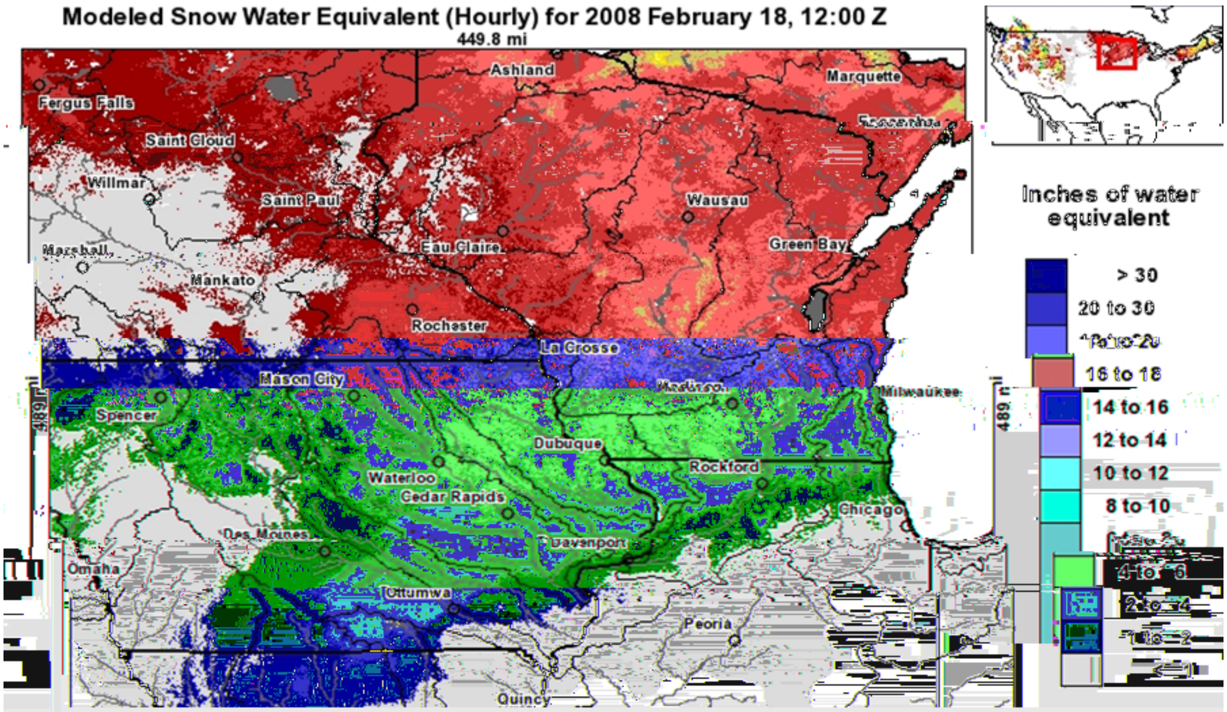

Fig. 1. Water content of snow in mid-February 2008. (Source: NOAA/NWS National Operational Hydrologic Remote Sensing Center, http://www.nohrsc.noaa.gov/interactive/.)

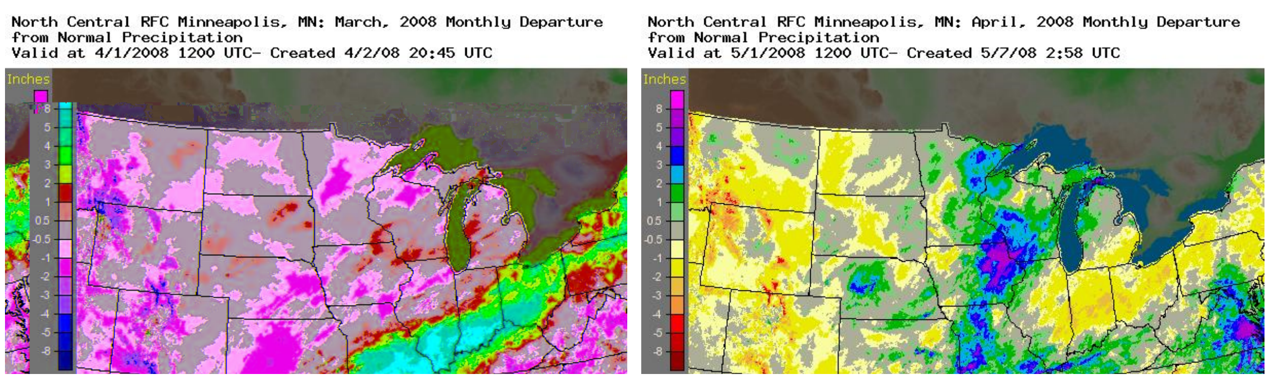

Fig. 2. Precipitation departure from normal: March 2008 (left) and April 2008 (right). (Figure courtesy of NOAA/NWS NCRFC.)

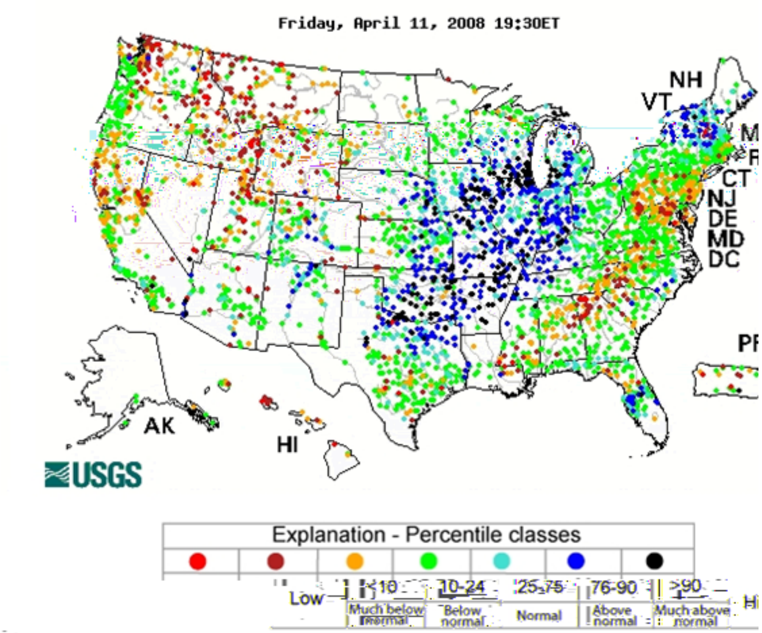

Fig. 3. River flow on April 11, 2008, compared to historical levels. Locations shown in dark blue or black are higher than 90 percent of the years in the historical record. (Figure courtesy of the USGS.)

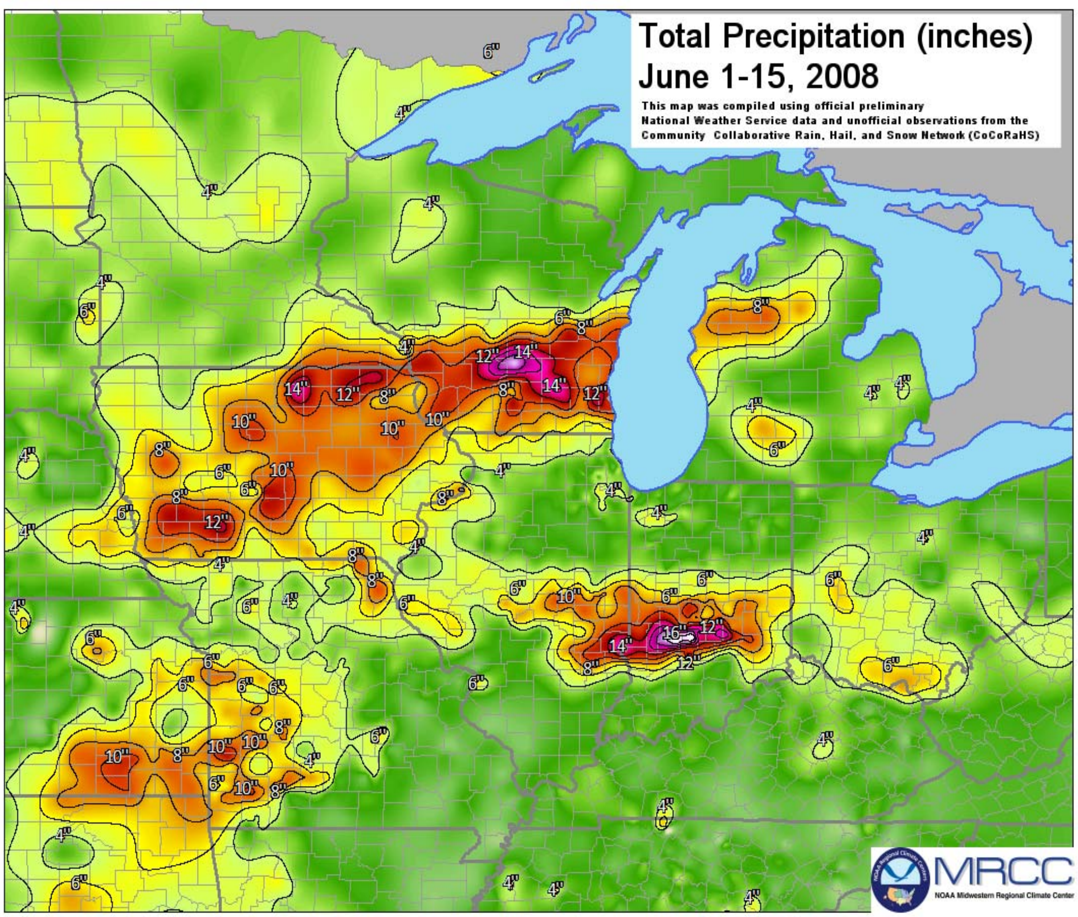

Fig. 4. Precipitation totals for the first half of June 2008. Contour interval is 2 inches, starting at 4 inches. Color scaling: green, about 4 inches or less; yellow to orange to red, about 6 to 12 inches; violet to white, 12 inches or more. (Figure courtesy of the NOAA Midwestern Regional Climate Center.)

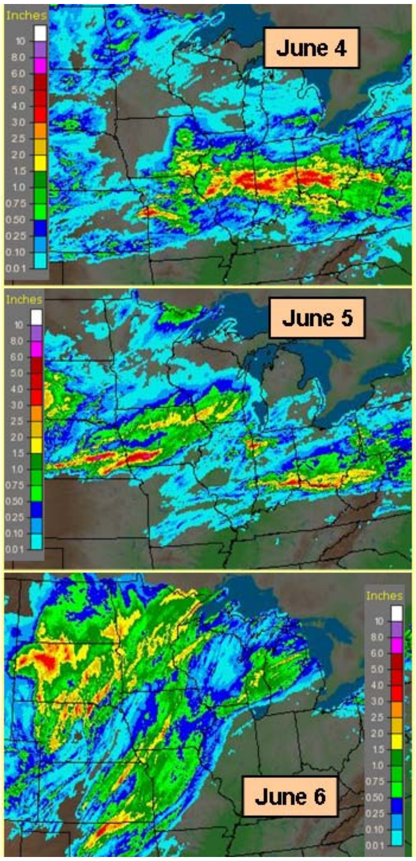

Fig. 5. **Precipitation[3] for 24-hour periods ending 12 Universal Time Coordinated (UTC) June 4-6, 2008. (Source: NOAA/NWS, http://water.weather.gov/.)**

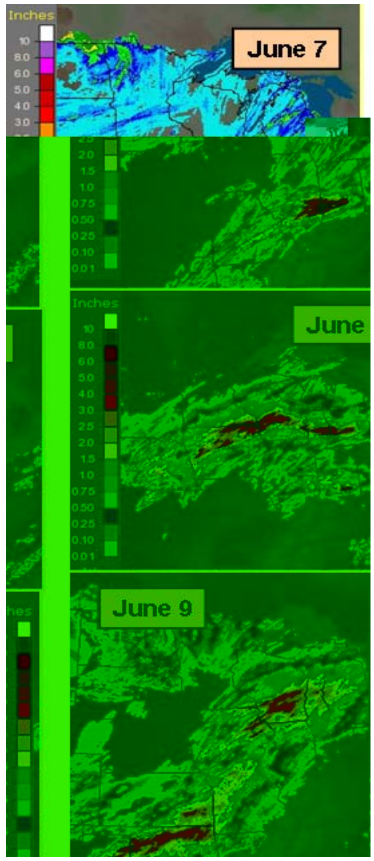

Fig. 6. Precipitation for 24-hour periods ending 12 UTC June 7-9, 2008. (Source: NOAA/NWS, http://water.weather.gov/.)

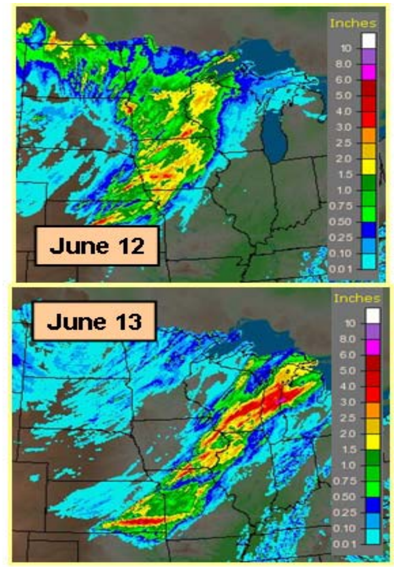

Fig. 7. Precipitation for 24-hour periods ending 12 UTC June 12-13, 2008. (Source: NOAA/NWS, http://water.weather.gov/.)

[3] Precipitation estimates shown in **Figs. 5-7** are based on both radar data and rain gages. Although these analyses typically provide good estimates of the volume of water falling over basins used in river forecast models, extreme precipitation amounts at individual rain gages may be underestimated. Additional details are available at the following website: http://water.weather.gov/about.php.

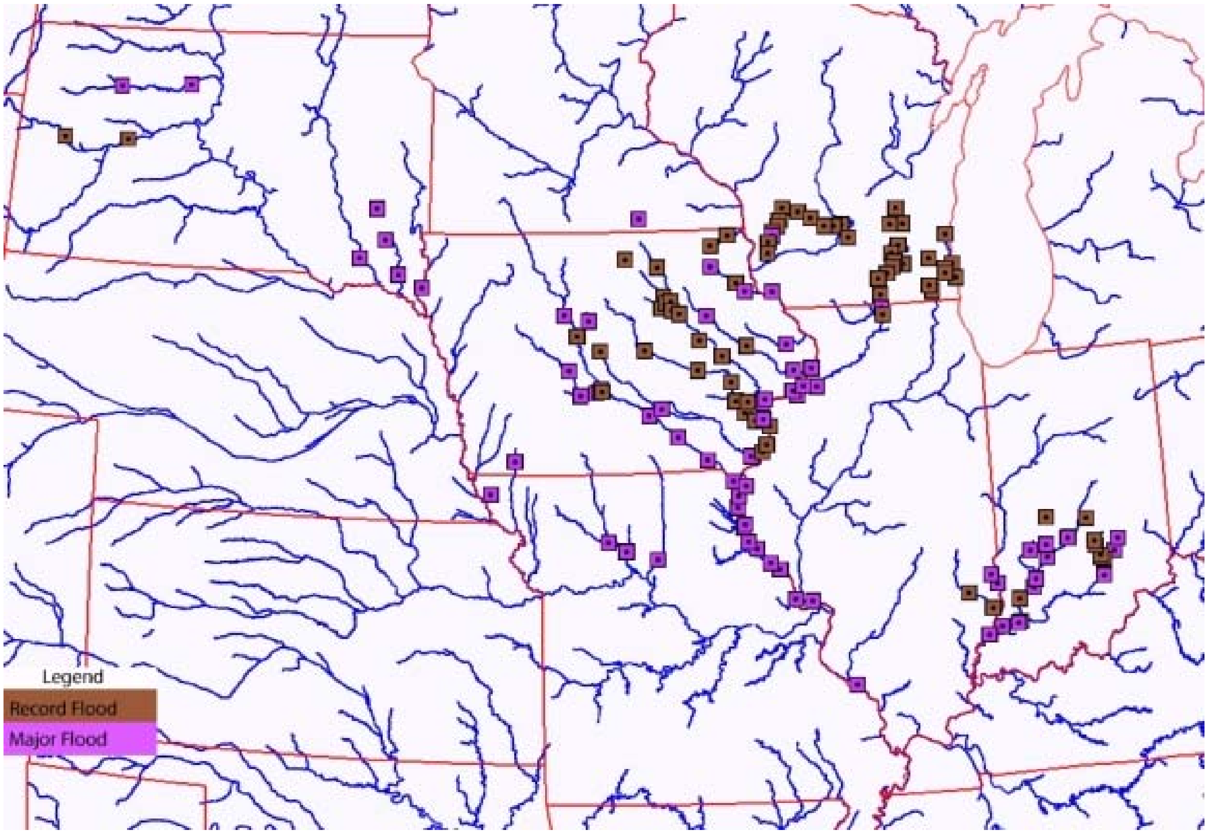

Fig. 8. Streamgage locations reaching record flood stage (brown squares) or major flood stage (lavender squares) during June 2008. Many more sites were above flood stage. (Source: NOAA/NWS Service Assessment Team.)

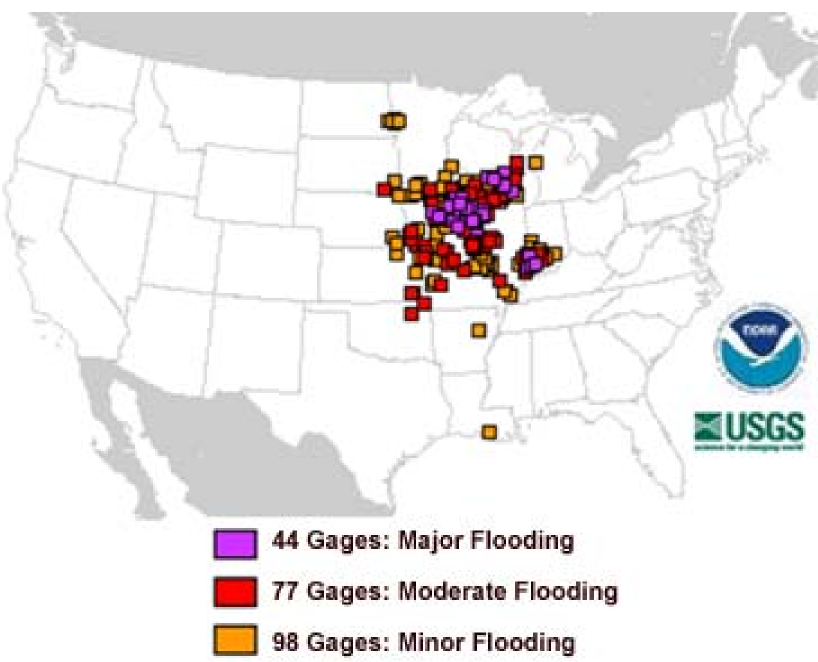

Fig. 9. Streamgage locations in flood at 12:30 p.m. CDT on June 13, 2008, which was one of the days of most serious flooding. (Source: NOAA/NWS, http://www.weather.gov/ahps/.)

Mississippi River, especially in Illinois, Iowa, and Missouri. All NWS forecast points on the Cedar and Iowa Rivers had record crests during June.

Flooding on some of the larger rivers that reached major or record flood levels continued well into July, as water worked its way downstream. Notable was the long-duration flooding on the Des Moines River, Iowa River, and Cedar River in Iowa and the Rock River in Wisconsin and Illinois. The White and East Fork of the White basins in Indiana and the Wabash basin in Illinois and Indiana also experienced prolonged flooding of up to 3 weeks.

There were 143 forecast locations experiencing major flooding, with 73 of these locations establishing records. (See **Appendix F** for the locations of record or major flooding, Morlock et al. (2008) for details of the flooding in central and southern Indiana, and Fitzpatrick et al. (2008) for details for southern Wisconsin.) In some locations, the records were considerably higher than the previous crests. The most significant example was the Cedar River at Cedar Rapids, Iowa, where the crest exceeded the previous record set in 1851 by more than 11 feet.

2.2 Impacts

The June 2008 flooding resulted in 11 direct fatalities in six states (**Table 1**). Eight of these were vehicle related. Total damages from the flooding were estimated in excess of $5 billion. Of this, more than half was estimated to be in the agricultural sector, with much of the rest from infrastructure damage to buildings, roads, railroads, levees, and dams. Clean up alone is expected to exceed several hundred million dollars. Damages from the June flooding are somewhat difficult to estimate because the central United States was hit by numerous storms in the May-June 2008 time frame, with published estimates often the aggregate of all weather events, not just the June flooding.

In a number of states, disaster declarations were made through the Federal Emergency Management Agency (FEMA) as a result of the flooding. See **Appendix G** for areas designated eligible for Federal disaster assistance.

Transportation was heavily affected by the flooding. Thousands of roads and hundreds of bridges were closed, including Interstate highways I-39, I-90, and I-94 at several places in Wisconsin; I-80 (**Fig. 10**) and I-380 in Iowa; and I-65 and I-70 in Indiana. Numerous rail lines were closed across the flooded area.

Fig. 10. Cedar River overtopping Interstate 80 in eastern Iowa, June 13, 2008 (looking east). (Used with permission. ©2008 Iowa Department of Transportation. Photograph by Kevin Arrowsmith.)

Table 1. Fatalities directly attributable to June 2008 flooding. (Source: NOAA National Climatic Data Center, 2008.)

Date (2008)	State	County	Gender	Age	Notes
June 4	Indiana	Henry	Female	44	Died attempting to drive across flooded bridge over Slow Run Creek
June 5	Illinois	Coles	Male	72	Died trying to drive across bridge flooded by Kaskaskia River west of city of Humboldt
June 7	Indiana	Bartholomew	Male	54	Drowned after car swept off road near flooded Haw Creek
June 7	Indiana	Hendricks	Male	44	Drowned after boat capsized in floodwaters of Mill Creek
June 8	Iowa	Hamilton	Male	33	Died after driving into flood waters on Interstate 35
June 8	Iowa	Wright	Male	50	Died after being sucked into culvert by flood waters while checking drain tiles in farm field
June 8	Michigan	Allegan	Female	51	Drowned when car fell into deep ravine created when rain-swollen creek washed out road
			Male	17	
June 8	Michigan	Ottawa	Male	76	Drowned when overtaken by rising waters while tending to Worley Drain Dam
June 11	Minnesota	Freeborn	Male	52	Died after driving into washed out roadbed
June 12	Wisconsin	Waukesha	Male	67	Drowned after trying to leave vehicle engulfed in flood waters

The following includes some of the additional impacts for the states most severely affected by the flooding.

Illinois:

Flood waters from tributaries drained into the Mississippi River, causing the river to rise well after the rains ceased. A levee along the Mississippi overtopped and waters flowing through the breach forced evacuation of Keithsburg and knocked out the water treatment plant.

A levee was compromised in Henderson County near the town of Gulfport. Workers trying to shore up the levee had to be rescued. A second levee protecting Gulfport could not withstand the onrush of water and was compromised. Gulfport and the surrounding area sustained considerable damage, with dewatering efforts still ongoing 2 months after the flood.

Two levees were overtopped and breached near the town of Meyer about 25 miles upstream of Quincy, deluging roads and farmland and prompting authorities to mandate evacuation of about 50 people from their homes. A levee break along the Embarras River in Lawrence County forced the evacuation of some 200 residences as water rose to the roofs of some homes. In nearby Westport, another levee break along the Wabash River forced residents of St. Francisville and Lawrenceville from their homes.

Indiana:

Hundreds of people were evacuated in parts of Indiana. A dam break at Prince's Lake in Johnson County forced the evacuation of about 100 people. Hundreds of roads were closed and a number of motorists were rescued from their vehicles. Considerable road damage occurred, including damage to several rural bridges. For a brief period, nearly all roads in Columbus were flooded, isolating the city. About 15 percent of the structures in the city were flooded, including Columbus Regional Hospital, forcing evacuation of more than 150 patients.

Most of the town of Paragon and nearly half of Martinsville were inundated by flood waters. In Franklin, the Johnson County Hospital was flooded. Water and gas lines were washed out in west-central Indiana. Jasonville, Hope, Lawrenceville, and other communities lost drinking water because of broken water lines or flooded well fields. There was considerable residential flooding in Vigo, Johnson, and Morgan Counties in central Indiana with more than 1,000 people evacuated.

Iowa:

In spite of extensive flood fighting efforts, orders were given to evacuate large portions of Cedar Rapids as the Cedar River made its historic rise. A levee protecting the city was in jeopardy and pumps were unable to keep up with the flooding. Electricity was cut to all parts of Cedar Rapids within the floodplain of the 0.2 percent annual chance flood.[4] The Cedar Rapids Emergency Operations Center (EOC) had to be relocated to the Linn County EOC. All bridges over the Cedar River, except the I-380 bridge, were closed. Mercy Medical Center in Cedar Rapids was forced to evacuate 205 patients. More than 300 inmates evacuated from the Linn County jail on Mary's Island in the Cedar River had to be transported by bus over a bridge awash with flood waters. The Cedar River crested June 13 in Cedar Rapids more than 11 feet above the previous high water mark (cover photograph). More than 24,000 people were displaced in Cedar Rapids as around 14 percent of the city was under water. Fortunately there were no fatalities or serious injuries despite the historic nature of the flooding. Nearly 5,400 houses and 700 businesses in Cedar Rapids were damaged or destroyed.

As part of flood protection efforts on the Iowa River at the University of Iowa at Iowa City, classes were cancelled and portions of the university were closed. By the time the Iowa River crested almost 10 feet above flood stage on June 14, about 23 acres of the campus had flooded.

[4] In this report the probabilities of flooding in a given year are specified in terms of percentages rather than years in accordance with new policy coordinated with FEMA, USACE, U.S. Bureau of Reclamation, USGS, and several associations of emergency managers. For example, the 0.2 percent annual chance flood has a 1 in 500 chance of occurring during any given year.

Damage to the university was estimated at $740 million. Upstream of the city, the Coralville Reservoir rapidly filled in spite of increased releases. Water flowing over the spillway (**Fig. 11**) exacerbated flooding downstream in Iowa City and nearby Coralville. Flood waters came within a few inches of inundating the AT&T Communications Center in Coralville. The Cedar Rapids and Iowa City Railway Company (CRANDIC) embankment, which served as a levee, failed, sending Iowa River flood waters into the Coralville area. In rural areas of Johnson County outside Iowa City, 55 homes were evacuated. In nearby Jones County, a dike was compromised along the Wapsipinicon River in Anamosa, flooding 32 homes and three businesses.

Fig. 11. Coralville Dam shown with water flowing over the spillway, June 15, 2008. (Used with permission. ©2008 Iowa Homeland Security and Emergency Management Division. Photograph by the Civil Air Patrol.)

Flooding along the Winnebago River in the vicinity of Mason City resulted in a levee failure inundating a number of homes. The city's water works flooded, leaving the city without potable water. A levee failure in Grundy County forced evacuations in the New Hartford area. Other evacuations occurred in Dubuque and Allamakee Counties. Thousands of roads in central Iowa were closed by flood waters, with hundreds of roads and a number of bridges damaged. In Charles City, the two main bridges connecting the city had to be closed. In rural portions of central and eastern Iowa, several hundred homes and farms and scores of businesses were damaged.

Mandatory evacuations were ordered for parts of Des Moines, including inmates housed in the Polk County jail. A number of downtown bridges were closed. Just after the Des Moines River crested June 14, a levee failed. More than 200 homes and about 30 businesses in the Birdland area of Des Moines were flooded.

A portion of a railroad bridge across the Cedar River in Waterloo was swept away and struck a street bridge. City officials closed five bridges around the city and asked downtown residents to evacuate. In nearby Cedar Falls, downtown residents were forced to evacuate because of concern about the integrity of levees along the Cedar River. Evacuations were also necessary in Charles City, Decorah, Greene, Nashua, New Hartford, Sheffield, and Chelsea in northeastern Iowa. For a time, Chelsea could be reached only by boat.

There were evacuations in Palo and Ottumwa in the southeastern part of the state. The levee along the Iowa River at County Road 99 near Wapello overtopped and flooded some 17,000 acres. The Iowa River levee near Oakville overtopped, flooding 19,000 acres, including the community of Oakville (**Fig. 12 and Fig. 13**). Fortunately, evacuation orders were issued prior to the levees being overtopped.

Fig. 12. Flooding of Oakville, Iowa, and vicinity, June 15, 2008. (Used with permission. ©2008 Iowa Homeland Security and Emergency Management Division. Photograph by the Civil Air Patrol.)

<u>Missouri</u>:

In anticipation of the flood crest along the Mississippi River, 23 floodgates were installed in the St. Louis area. A levee was compromised at Iatan prompting evacuation of more than 100 people. In Clark County in northeastern Missouri, a levee was breached, forcing evacuations of some rural residents, and another levee failed in the LaGrange area of Lewis County. A structure associated with Lock and Dam 25 on the Mississippi River in the Winfield area overtopped. This, coupled with other overtopped levees, inundated more than 35,000 acres. As a result, residents of about 60 homes were advised to evacuate.

Problems occurred with two levees in Lincoln County, one between Elsberry and Foley and the other at Cap au Gris, just northeast of Winfield. More than 6,000 acres were flooded and almost 100 people were evacuated. Multiple levee breaks occurred in St. Charles County. The Elm Point levee breach in St. Charles resulted in evacuations and numerous road closures. The failure of the Pin Oak levee near Winfield damaged or destroyed dozens of homes and required the evacuation of 100-150 people.

Fig. 13. Iowa River rushing through a break in the levee just upstream of Oakville, Iowa, June 15, 2008. (Used with permission. ©2008 Iowa Homeland Security and Emergency Management Division. Photograph by the Civil Air Patrol.)

The city of Tarkio in northwestern Missouri declared a state of emergency as the Tarkio River flooded parts of the city. In addition, voluntary evacuations took place in parts of St. Joseph, where the city's water treatment plant was threatened.

Wisconsin:

The rain caused serious urban flooding in the Milwaukee area, inundating basements and floating cars. Dozens of people were evacuated in the La Farge and Ontario areas in the Kickapoo River basin. Flooding forced evacuations in the La Crosse area and surrounding portions of Minnesota and Iowa in the Winnebago Valley. Numerous rural roads in this same area were washed out. A strip of land between Lake Delton and the Wisconsin River in Sauk County gave way, emptying the lake into the river. (See **Fig. 14**.) The spectacular failure was widely broadcast as several homes were torn apart and swept away. Lake Delton is a popular tourist area and the empty lake crippled local businesses.

Fig. 14. Homes were destroyed on Lake Delton in Wisconsin when the 245-acre lake quickly emptied after Dell Creek cut a new channel into the Wisconsin River, bypassing the dam. (U.S. Air Force photograph by Master Sergeant Paul Gorman.)

A number of bridges over the Fox River in Waukesha were closed. Evacuations of residents of dozens of homes took place in Waupun and Aztalan in southern Wisconsin. Major flooding affected Lancaster, Potosi, Platteville, Ripon, and Fond du Lac in southern Wisconsin. A number of residences in these cities and towns were destroyed with many others damaged. Street flooding was extensive, with more than three-fourths of the roads in Ripon under water—as much as 4 feet deep in some places. Residents below the Pardeeville Dam (about 30 miles north of Madison) were evacuated as a precaution.

2.3 Comparison to Flooding of 1993

Many areas impacted by significant flooding in 2008 were also affected by catastrophic flooding in 1993. There has been considerable interest in comparing the two floods. Overall, flooding in 1993 affected a larger area, was more severe, and lasted longer. Some of the specific aspects of the events are compared below.

- Antecedent conditions: Soils were moist and river levels were already elevated at the onset of flooding in both 1993 and 2008.

- Precipitation: In 1993, significant rain fell for about 6 weeks, while in 2008 intense rains were limited to about 2 weeks. Rainfall totals for June through August 1993 reached 24-36 inches in many locations, which is 200-350 percent of normal. In 2008, 12-20 inches of rain was common over substantial areas for the May through July period; this amounted to

150-250 percent of normal. While total rainfall was generally higher in 1993, the typical spatial variation associated with convective precipitation resulted in some areas with more intense rain and higher totals in 2008.

- Flooding: In 1993, river levels at 118 NWS river forecast locations established records, compared to 73 in 2008. Overall, about 750 NWS river forecast sites exceeded flood stage in 1993, compared with about 250 locations in 2008. Even though the 1993 flooding was more severe overall than 2008, some areas were hit harder in 2008 as the result, in part, of more intense localized rainfall. Many of the records set in eastern Iowa in 2008 broke records set in 1993. In some areas, such as Cedar Rapids, levels were reached for which the probability of occurrence in any one year was only 0.2 percent. Some locations remained in flood as long as 4-6 weeks in 2008, while in 1993 a number of locations exceeded flood stage for 4-6 months.

- Levees: In 2008, fewer than 100 levees were compromised (via overtopping, overtopping and failure, or catastrophic geotechnical failure), while in 1993, almost 1,000 levees were compromised.

- Damages: Although final estimates were not available at the time this assessment was prepared, damages in 2008 were expected to total more than $5 billion. Inflation-adjusted damages from flooding in 1993 totaled about $25 billion.

3. Summary of NWS Flood Forecasting Operations for the Event

The NWS employs a complex end-to-end flood forecasting process involving River Forecast Centers (RFC), Weather Forecast Offices (WFO), and the National Centers for Environmental Prediction (NCEP); USGS, USACE, and other Federal agencies; emergency managers at the national, regional, state, and local levels; and the news media. (See **Appendix B**.) This process varies in its details for different parts of the country and types of events, but much of it is common to all offices and events. This section provides an overview of processes used by NWS offices during the 2008 flooding in the central United States, focusing on operations within the North Central River Forecast Center (NCRFC) in Chanhassen, Minnesota, and WFOs within the NCRFC service area. This region had the highest geographic concentration of severe flooding. Significant flooding, however, also occurred elsewhere, particularly in the service areas of the Ohio RFC (OHRFC) and Missouri Basin RFC (MBRFC). (See **Fig. 15** for map of RFC service areas.)

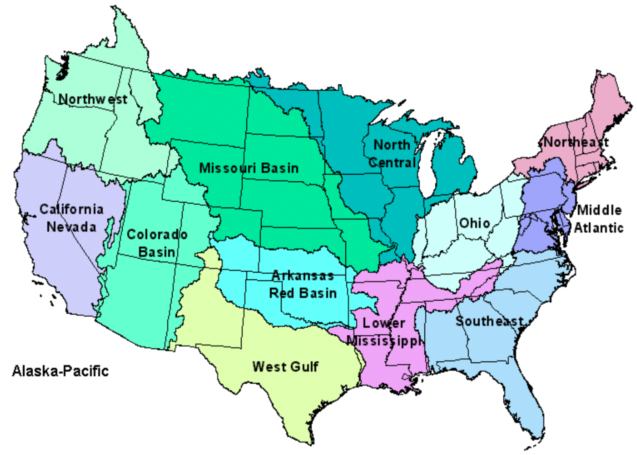

Fig. 15. Service areas of the thirteen RFCs. Most of the significant flooding occurred in the areas of the MBRFC, NCRFC, and OHRFC. (Source: NOAA/NWS, http://www.weather.gov/ahps/.)

NWS Central Region forecast offices issued 2,833 flood warnings and 8,483 flood statements during June 2008, about three times the average for that time of year. The large number can be attributed to the extent and severity of the flooding and the NWS effort to ensure users always had up-to-date information. To ensure continued delivery of high-quality services, Central Region staff worked more than 3,300 hours of overtime.

As indicated in the previous section, science and technology supported staff members in assessing, analyzing, and forecasting the June 2008 flooding. One of the most notable aspects of the services provided by the NWS during this event was coordination and communication. Significantly, NWS staff leveraged a range of contemporary and emerging communications tools and technology to take coordination and communication to a new level.

Major floods extending for periods of weeks or months create a considerable challenge. In June 2008, extensive overtime and significant, long-duration flooding placed tremendous stress on office staff. As the duration of an event increased, it became more difficult to maintain peak performance because fatigue started to offset adrenaline. Even offices with full staffing had to work very hard to sustain quality services.

3.1 Internal Operations

The extent and duration of flooding proved a serious challenge to operations at WFOs and RFCs. At WFO Des Moines, the Senior Service Hydrologist position was vacant. Hydrologists from three other offices temporarily rotated through the office during the flood event. NCRFC was also short-staffed and was supplemented by staff from two other RFCs.

Flood forecast responsibility at some WFOs was shared among the staff members. At WFO Des Moines, specific personnel were designated as focal points for given geographic areas throughout the flooding. These designations allowed consistent communication between experts in the local community and a WFO person well versed in what was going on meteorologically and hydrologically in that area. At WFO Quad Cities, staff divided up the hydrologic workload, with the most experienced staff focusing on the highest impact basins.

Considerable use of conference calls, chat rooms/instant messaging, and Web collaboration tools supported effective coordination among WFOs and with NCRFC, as well as with the Hydrometeorological Prediction Center (HPC). For example, during the event holding conference calls daily before issuing forecast guidance ensured all offices were in agreement ahead of time. Any differences of opinions about forecasts were addressed early in the process, rather than after NCRFC had issued forecast guidance.

3.2 Intragovernmental Cooperation

Long-standing relationships exist between the NWS and key Federal partners. In particular, the NWS works closely with the USGS, which supplies data and hydrologic expertise. The NWS also works closely with the USACE, which manages reservoir operations, which are intimately linked to the NWS forecast function. USACE staff members are also responsible for inventorying levees and has considerable expertise in the performance of levees during flooding. During the June 2008 flooding, these established relationships helped facilitate coordination among the agencies, leading to improved services to the public.

Because RFC forecasts rely on rating curves, once rivers exceed previously observed levels—record flooding—forecasting becomes much more difficult. As part of its role in taking observations used to define rating curves, the USGS has developed expertise in extrapolating rating curves beyond observed levels. During the flood, the USGS detailed a person to NCRFC to support rating curve extensions necessary for credible forecasts of record flooding.

Major floods stress levees. An underlying component of NWS river forecasting tracks water as it moves downstream, known as routing. Although models are calibrated for existing channel characteristics, levee breaks alter the conditions for which the models were calibrated, making forecasting much more difficult. Because of USACE expertise dealing with levee breaks, at the NWS request, the USACE detailed a person to work with staff at NCRFC to help address the impact on river forecasts. The USACE staff member assisted with the hydraulic aspect of forecasts impacted by failed levees.

3.3 Emergency Management Community

The emergency management community uses NWS forecasts as integral components of its decision process. Based on these forecasts, emergency managers identify risk areas, develop and implement response strategies, and support recovery efforts. It is critical the science and forecasts provided by the NWS are communicated in a way that allows emergency managers to make effective decisions. Because NWS staff and emergency managers generally have different backgrounds and objectives, ongoing communication between them is crucial. Focus groups and customer satisfaction surveys conducted by the NWS Hydrologic Services Program clearly document the benefit of direct contact between NWS staff and the emergency management community.

During this flood, extensive information was provided to the emergency management community, using traditional conference calls as well as emerging communications technologies such as chat rooms/instant messaging and Web-based collaboration tools. Emergency management officials said they were able to obtain critical forecast information during these exchanges. These exchanges also provided an opportunity for emergency managers to obtain information not included in public forecasts, such as contingency forecasts. Emergency managers had the opportunity to gain insight into forecaster confidence, which improved their decision-making process. Feedback was overwhelmingly positive.

In addition, NWS staff also worked directly at emergency operations centers. For instance, WFO personnel staffed the NWS liaison desk at the Iowa State Emergency Operations Center (SEOC) near Des Moines.

3.4 Media/Public

News media serve a critical role in communicating NWS information to the public. Ensuring media have the information they need to fulfill this function can impose a substantial workload on NWS staff.

WFO Quad Cities conducted news conference calls to brief multiple media outlets simultaneously. One staff member served as the WFO Public Information Officer and was the primary contact for the media and public. This staff member ensured a consistent message was delivered to the media and public and afforded WFO operational staff more time to focus on hydrologic issues, coordination, and collaboration. Media partners appreciated the information.

The use of chat rooms/instant messaging that included the media also proved very successful. Adam Frederick, Chief Meteorologist with KIMT-TV in Mason City, Iowa, stated the chat/instant messaging capability "is stupendous and Des Moines and La Crosse NWS offices use it really, really well." Use of the chat room consolidated communications and dissemination into one spot, limited the need for phone calls or other contacts, and saved staff a significant amount of time.

The Advanced Hydrologic Prediction Service (AHPS) Web pages were particularly helpful to media and the public. They provided answers to many questions, undoubtedly eliminating many calls to the NWS field offices, emergency operations centers, and other partners.

4. Facts, Findings, Recommendations, and Best Practices

Primarily through face-to-face meetings and teleconferences, the Service Assessment Team talked with many people directly affected by the central United States flooding of June 2008. Among those interviewed were NWS, USGS, and USACE employees; other Federal, state, and local partners involved with public safety and welfare; the media; businesses; and the general public. Much was learned from these conversations, including ways for the NWS to improve products and services in the future. Discussed below are four key areas:

1. Tools and data used in the river forecast process
2. Collaboration among the NWS, USGS, and USACE in the forecast process
3. Accuracy and effectiveness of products and services
4. Societal reactions to the flooding.

4.1 Usefulness of the Tools and Data in the Forecast Process

The NWS uses observed and forecast precipitation and observed river stages as the primary inputs to the hydrologic forecast process. There are several analysis and modeling tools for assimilating the data, developing data inputs into the river models, generating river forecasts, and disseminating those forecasts to other NWS offices, partners and customers, and the public. During extreme events, the hydrologic forecast process can be complicated by factors such as levee failures and land-use changes since the last hydrologic model calibration. In addition, technological advances have provided tools enhancing the ability for the NWS to communicate and collaborate with the media and emergency management community, as well as internally among NWS offices. This section describes the usefulness of the data and tools used by the NWS in the forecast process.

4.1.1 Observed Precipitation

The primary tool used to analyze observed precipitation by the North Central River Forecast Center (NCRFC) is the multisensor precipitation estimator (MPE). MPE mosaics hourly rainfall estimates produced by the WSR-88D radar with rain-gage data to produce a best estimate of rainfall. NCRFC forecasters used the MPE tool to generate mean areal precipitation estimates for input to the hydrologic models. For the most part, there were no major issues with the observed precipitation analysis. In some instances, the forecasters significantly adjusted the radar-based precipitation analysis used as input to the hydrologic model, because the MPE tool was unable to correct for all errors in the raw radar-based precipitation estimates.

The image on the left in **Fig. 16** shows the raw radar mosaic for the 24-hour period ending 12 UTC June 8, 2008. Note the 6-8 inch amount across northern Iowa (darker purple shade). The image on the right in that figure depicts the quality-controlled 24-hour precipitation amounts, ending at the same time, used as input to the hydrologic model. The 6-8-inch amounts over northern Iowa were reduced by the forecaster to 4-6 inches due to overestimates, likely caused by hail, from the radars at WFOs Des Moines and Quad Cities.

The northern Iowa area represents a challenge in generating accurate precipitation estimates as the area is not within optimum distance for accurate radar rainfall estimates. During convective

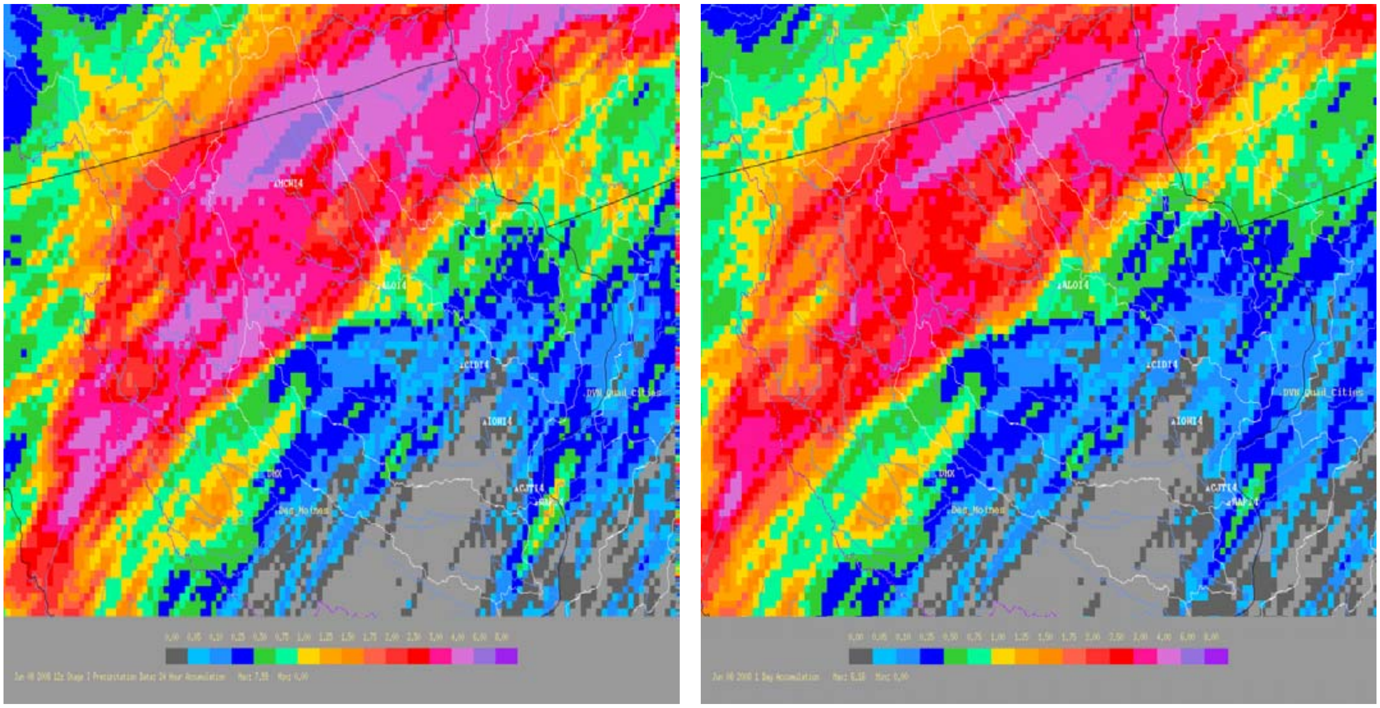

Fig. 16. Rainfall accumulations for the 24-hour period ending 12 UTC June 8, 2008, for northern Iowa and vicinity. Image on the left represents the raw radar accumulation. Image on the right is the precipitation total following forecaster quality control. (Figure courtesy of NOAA/NWS NCRFC.)

events, the radar beam might sample a region with significant ice or hail presence, resulting in bright-banding effects and overestimated precipitation. During more stratiform precipitation events, the radar beam might overshoot the clouds and precipitation, resulting in underestimated precipitation.

In areas where radar precipitation estimation is difficult, rain gages are important to ensure accurate precipitation estimates. **Fig. 17** depicts the location of rain gages in northern Iowa. Steve O'Neil, Director of Emergency Management for Cerro Gordo County in northern Iowa, felt there was a scarcity of rain gages upstream of the river forecast point at Mason City and expressed his desire for additional rain gages. In addition, Joyce Flinn, Readiness/Response Chief of the Iowa Homeland Security and Emergency Management Division, stated the desire for additional rain gages throughout the state.

Finding 1: State and local officials believed additional rain gages would enhance the ability to anticipate and monitor flooding events.

Recommendation 1: The NWS should work with state and local officials to determine an optimum rain-gage network for Iowa and to investigate options available for installing additional rain gages.

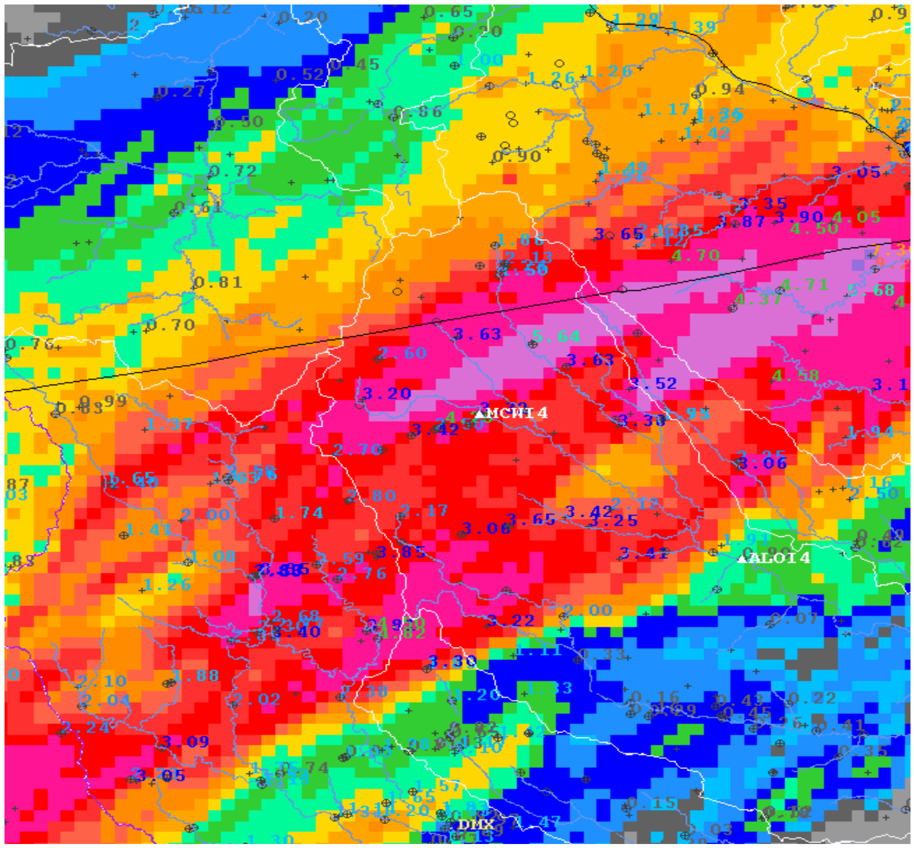

Fig. 17. Depiction of rain gages and 24-hour precipitation amounts valid at 12 UTC, June 8, 2008. The location MCWI4 near the center of the figure is the Mason City forecast point in north-central Iowa. (Figure courtesy of the NOAA/NWS NCRFC.)

4.1.2 Forecast Precipitation

Operational river forecasts issued by NWS RFCs can include forecasts of quantitative precipitation. NWS Instruction 10-911, RFC Operations, does not specify the time horizon for QPF use in the operational river forecasts. During this event, NCRFC used a maximum of 24 hours of QPF in their official forecasts.

Finding 2: NCRFC personnel believed they were limited by policy to using no more than 24 hours of QPF in their official forecasts. In fact, there is no such limitation in NWS Instruction 10-911, RFC Operations.

Recommendation 2: NWS Regional Headquarters should ensure RFCs are aware of their options regarding the use of extended QPF in generating official river forecasts.

NCRFC uses the Intersite Coordination capabilities within the Graphical Forecast Editor tool of the Advanced Weather Interactive Processing System (AWIPS) to view WFO QPF grids. HPC QPFs are also viewed. Prior to the 1200 UTC hydrologic forecast cycle, RFCs collaborate with WFOs regarding the amount of QPF to be included in the forecast. Collaboration can also involve HPC. During significant events, NCRFC generates an 1800 UTC forecast cycle. HPC produces an 1800 UTC QPF, which is typically available around 1730 UTC. In order for data to be used in the 1800 UTC hydrologic forecast, it has to be received at NCRFC by 1830 UTC. The WFO staffs, however, were not always able to provide input on QPFs for this 1800 UTC forecast cycle, depending upon their office forecast processes and availability of model data on AWIPS. When RFCs are staffed around the clock, the same scenario also occurs 12 hours later for the 0600 UTC forecast cycle.

Finding 3: It was difficult to coordinate between WFOs and the NCRFC regarding the amount of QPF to use in some hydrologic forecast updates as a result of differing forecast processes and schedules at the WFOs and RFC.

Recommendation 3: NCRFC and Central Region Headquarters should discuss QPF coordination and collaboration issues with its WFOs and develop procedures to govern input of QPF during forecast updates. Procedures governing input of QPF should be developed at other RFCs and WFOs if they do not already exist.

As part of their forecast process, WFO forecasters frequently analyze additional weather information to determine the need to update gridded forecasts of precipitation and other forecast fields such as temperature and wind. If the forecasts are updated, the grids receive a new update time. If the forecasters decide an update is not necessary, the update time on the grids remains that of the previous update. As a result, it was sometimes unclear to NCRFC forecasters whether a WFO had been able to review the updated model data and HPC inputs and determined there was no need to update the grids, or whether the WFO had not had time to review the input information and had not reviewed the QPF grids. The only way to obtain clarification is via collaboration with the site. Current operational procedures recommend the use of 12Planet (See 5.1.6.2) to clarify this situation.

Finding 4: Sometimes WFOs analyzed additional information during a forecast cycle and decided there was no need to update the QPF grid. In such cases, the grid update times were not modified by the Graphical Forecast Editor because the WFO did not distribute a new grid to the RFC and other users. The RFC could not tell from the grid information whether a WFO had decided not to update a grid or had simply not updated it yet in the cycle.

Recommendation 4: A methodology should be developed within the Intersite Coordination capabilities of the Graphical Forecast Editor to allow a site to modify the update time of the Intersite Coordination grids when the site has analyzed all the relevant data and does not issue a set of modified grids.

4.1.3 River Flow Observations/Rating Curves

River stage observations are generally recorded by the Data Collection Platform (DCP). These observations are reported via satellite to the Geostationary Operational Environmental Satellite (GOES) downlink at NOAA's Command and Data Acquisition Station at Wallops, Virginia. From Wallops, data are transferred to the NWS Telecommunication Operations Center in Silver Spring, Maryland, where they are encoded in Standard Hydrologic Exchange Format (SHEF) and provided to field offices via AWIPS. The observed river data are used by the RFCs as input to hydrologic modeling activities. WFO staffs post observed data to the AHPS Web pages, where most users and customers obtain river information.

Some river observations are available from streamgages by local communities using the Automatic Local Evaluation in Real Time (ALERT) technology. The delivery of data from these ALERT gages differs from satellite DCP. Delivery requires WFO staff to work with the local community to acquire the data and then establish a mechanism to ingest the data into AWIPS. One example of such collaboration exists in Story County, Iowa, where an ALERT network has been established in Ames. WFO Des Moines is able to ingest the Ames ALERT data into AWIPS and display it on the AHPS Web page, providing a valuable service to the community.

In a number of cases, river observations exceeded the top of the rating curve established for a particular forecast point. For some of these high water events, the USGS dispatched staff to make river flow measurements and provide preliminary, updated rating curves.

Fact: The top of the rating curve was exceeded at 17 of 21 forecast locations on the Cedar and Iowa Rivers. The top of the rating curve was exceeded at 37 locations in Illinois, Iowa, and Wisconsin.

Fact: The USGS deployed staff to make real-time river flow measurements at several locations where the observed river stage/river flow exceeded the existing rating curve.

Best Practice 1: WFO Des Moines collaborated with Story County, Iowa, to place streamgage data of the Ames ALERT Network on the AHPS Web page.

4.1.4 Time Series Analysis

WFOs use the AWIPS Time Series tool to view and modify observed and forecast river stage information. This tool is heavily used for quality control. At times during this event, WFOs had to modify forecast values, especially when it was obvious forecast values in the early part of the time series were not matching observations. This modification was done in collaboration with NCRFC.

To view data in the time series application, the user must first select a geographic location, then select from a list of available SHEF Physical Elements (PE). The SHEF PEs are listed with the associated Duration and Type/Source codes. If there are multiple Duration and/or Type Source codes for a given PE, they are listed alphabetically by the Type/Source code. For the river stage PE, there are about 10-15 duration and type/source combinations. The user must scroll through the list to find the appropriate PE-Duration-Type/Source combination, leading to inefficiencies in operations.

Fact: A WFO’s ability to use the graphical time series analysis tool efficiently was hampered by having to scroll through a list of elements to find the observed and forecast river stage information. AWIPS Discrepancy Report 19013 had been opened for this feature, but resources were not available to correct the problem before the June 2008 flooding.

4.1.5 River Flow Modeling

The NWS has implemented several river modeling capabilities at WFOs and RFCs. WFOs have a site-specific modeling capability based on simple rainfall-runoff relationships. In addition, RFCs use the NWS River Forecast System (NWSRFS). Details of these modeling capabilities follow.

4.1.5.1 Site-Specific Headwater Modeling

WFOs have a site-specific headwater modeling tool on AWIPS, which allows them to generate river stage forecasts for locations in small, headwater basins for which the RFCs do not forecast. For at least two locations in and around Des Moines, WFO Des Moines generates site-specific forecasts upon request by local emergency managers. Precipitation and river stage information for these locations are recorded as part of a local ALERT network. The emergency managers use these site-specific forecasts as the basis for subsequent action.

Finding 5: Although WFO Des Moines has an ALERT base station in the office, river stage data from several forecast sites are not automatically transferred to AWIPS. As a result, users must manually enter observed river stage information when executing the site-specific application for these locations.

Recommendation 5: WFO Des Moines should ensure the automatic transfer of ALERT data to AWIPS.

Best Practice 2: WFO Des Moines generated site-specific forecasts for locations on Walnut Creek and Four Mile Creek at user request. These forecasts assisted local emergency managers in planning and mitigation activities.

4.1.5.2 NWS River Forecast System Modeling

NWSRFS is used to carry out hydrologic modeling processes at the RFCs. NWSRFS is a vast collection of models and procedures used by RFCs to execute their hydrologic modeling responsibilities. The software architecture supporting NWSRFS, however, incorporates dated technology. NWS is engaged in an effort to develop and implement a Community Hydrologic Prediction System (CHPS) in a modern, service-oriented software architecture.

4.1.5.2.1 Impacts Regarding Rating Curve Extensions

The river forecasting procedure is assisted by ground-truth stage-flow relationships (rating curves) updated by the USGS at NWS forecast points as necessary. During the June 2008 flooding, many forecast locations had forecast stages extending beyond the limit of the rating curves existing at the time. In a post-event review, the USGS determined a number of these ratings had been cutoff inadvertently by a new records computation process of the USGS. This problem has now been corrected.

When the observed or forecast river stage exceeds the current rating curve, the hydrologic modeling process becomes more complicated because the relationship between river flow and river stage is undefined. As a result, the rating curve must be extended by a specialist before proceeding with the forecast. A best estimate of the extension of each curve was done by the USGS by direct measurement during the flood and/or by a best estimate of the conditions encountered at each gage site. In some cases, NCRFC also accessed the expertise within the USACE and NWS Office of Hydrologic Development to modify rating curves. This new stage-versus-flow information was then relayed to NCRFC to update the curves for NWSRFS. For other cases, NCRFC used the run-time modification feature within the NWSRFS Interactive Forecast Program to modify the rating curve. The “run-time mod” feature, however, does not allow the user to see how the rating curve shift impacts the forecast hydrograph. NCRFC has been developing a local procedure, referred to as rcurve, which allows the user to modify the rating curve and examine the impact of that shift on the resultant forecast hydrograph.

Fact: NCRFC used the expertise of the USGS, USACE, and NWS Office of Hydrologic Development to extend rating curves during the flooding.

Fact: Rating curves were adjusted or redefined as part of the real-time hydrologic modeling process using either measurements or run-time modifications.

Finding 6: NCRFC used the run-time modification feature of NWSRFS to make adjustments to rating curves during the forecast process. This feature does not easily allow the user to examine the impact of the rating curve modification on the forecast crest.

Recommendation 6: The NWS should ensure modeling and modification capabilities within the Community Hydrologic Prediction System (CHPS) architecture include the ability for the user to make adjustments or extensions to the rating curve and be able to examine easily the impacts of these adjustments or extensions on the resultant forecast hydrograph.

4.1.5.2.2 Limited Ability to Account for Levee Failures

The failure or overtopping of river levees had a significant impact to the hydrologic modeling process during this event. More than 50 levees along the Mississippi River and its tributaries failed or were overtopped. Information regarding the time and extent of overtopping or breaching of levees and the storage volume behind breached or overtopped levees often was not immediately available to NCRFC and the impacted WFOs. Upon becoming aware of levee compromises through their field operators, the USACE quickly reported the existence of overtopped and breached levees to NCRFC. In addition, USACE often subsequently provided the extent of the overtoppings and breaches. These information deficiencies made it difficult to account quickly for loss of water due to levee failure or overtopping and then subsequent return of the water to the channel once the newly inundated area was full.

During the event, the National Operational Hydrologic Remote Sensing Center (NOHRSC) became aware of an interagency program using high-resolution satellite imagery to map areas of flood inundation. NOHRSC, with its expertise in geographic information systems and geospatial mapping, was able to work with this interagency group to obtain maps of flood-inundated areas, which they were able to correlate with levee failures or overtoppings. NOHRSC then provided this information to NCRFC. NCRFC was able to estimate a volume of water in the inundated area and, as a result, adjust the river forecasts by removing a certain amount of water from the flow.

Levee failures and overtoppings are not modeled in NWSRFS. They can be modeled using the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS), which will be available in a real-time forecasting mode in the CHPS environment. The amount of water leaving the system and either routed outside the watershed (trans-basin) or returning at a location downstream after routing outside the main channel system is complex, but with appropriate information from field surveys can be modeled. Collaboration with the USACE will be vital in determining river system loss for downstream forecasting. The routing and return to the river system downstream will be more complex and have to be addressed on a case-by-case basis in HEC-RAS.

Finding 7: Information regarding the time and extent of overtopping or breaching of levees and the storage volume behind breached or overtopped levees often was not immediately available to NCRFC and the impacted WFOs.

Recommendation 7: The NWS should develop a real-time process to alert WFOs and RFCs when levees are overtopped or fail.

Finding 8: The USACE is developing a national inventory of all levees in the United States. This inventory will include critical information such as levee alignment and centerline elevations.

Recommendation 8: The NWS should collaborate with the USACE to ensure the national inventory of levees being developed by the USACE is available to WFOs and RFCs.

Finding 9: During the event, NOHRSC worked with an interagency group that included the USGS and the Department of Homeland Security to obtain high-resolution inundation information and provide it to NCRFC. NCRFC was able to correlate inundation areas with specific levee failures and overtoppings, and adjust its forecasts, removing a certain amount of flow based on the areas of inundation.

Recommendation 9: NOHRSC should work with the USGS to assure the NWS is more directly involved in planning activities to obtain high-resolution inundation information for RFCs to use as critical data during floods.

Finding 10: Current modeling capabilities within NWSRFS do not handle the loss of storage and subsequent return of water to the hydrologic system associated with levee failures and overtopping. There are no run-time modifications that can easily account for such effects.

Recommendation 10a: The NWS should leverage the expertise of the USACE and others to investigate the utility of the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) or other hydraulic models that account for the effects of levee failures and overtoppings in real-time flood forecasting.

Recommendation 10b: The NWS should proceed with development and implementation of the Community Hydrologic Prediction System (CHPS) architecture as expeditiously as possible to ensure capabilities such as more advanced modeling of levee failures are available to forecast staff.

4.1.5.2.3 Impacts of Changing Land Use Characteristics

Several emergency managers noted that much of the farm land in central and northern Iowa has had tile drains installed under the fields. These tile drains remove excess water from fields and provide an efficient channel for the water to reach rivers and streams, analogous to urbanization effects on hydrology. As a result, emergency managers have observed that water from heavy rainfall is able to enter rivers and streams faster than in the past. They also noted changes in the way fields have been cultivated and managed over the past few decades are changing the runoff characteristics of some watersheds.

Tile drains can have a pronounced impact on the forecasting process. NCRFC forecasters have observed the effects over a significant number of their forecast locations. Information on such changes in land use is difficult to find. To obtain more accurate river forecasts in these areas the RFC must recalibrate the model, often using a smaller amount of historical data, for example, the last 10 years of data as opposed to the last 40 years.

Fact: Demand for NWS river-forecast services continues to grow as a result of expanding population, increasing value of flood-vulnerable infrastructure, urbanization, and other physical changes in watersheds.

Finding 11a: Changing land-use characteristics, caused by such actions as the installation of tile drains in farm land, result in river model forecasts that can diverge significantly from what is observed.

Finding 11b: NCRFC staff estimated about 50 forecast locations in the NCRFC service area (out of a total of approximately 400 forecast points) need to be recalibrated due to changes in land use.

Recommendation 11: Where significant land-use changes have occurred, RFCs should recalibrate their models to account for these changes.

4.1.5.3 Ensemble River Forecasts

The NWS has been pursuing the delivery of uncertainty information in addition to its traditional, deterministic operational forecasts. Information derived from customer surveys indicates uncertainty information related to forecasts is a high priority.

NCRFC has implemented a set of contingency river stage forecasts based on multiple QPFs provided by HPC. NCRFC has provided the ensemble contingency forecasts to WFOs and some other RFC partners. (See Appendix Section B.2 for details on ensemble contingency forecasting.) The USACE uses the information in its decision-making process for water resource projects. WFO Quad Cities used the information provided in the ensemble contingency forecasts in briefings with local emergency managers and other customers during the event. With this information, WFO staff members were able to answer what-if questions from customers, providing quantitative answers to questions related to potential future rainfall and the resulting impact on river stages. Not all WFOs, however, are aware of or are familiar with the information provided in these ensemble contingency forecasts. Region VII of FEMA did not receive the ensemble contingency forecasts. This created some confusion when FEMA staff saw the official forecasts on AHPS Web pages, but heard about contingency forecasts during conference calls.

The NWS is developing and testing a new system for generating probabilistic QPFs based on HPC QPFs. This new system will provide forecaster-based QPFs with associated probability distribution functions, which indicate the range and uncertainty of QPFs. Output from this system can serve as input into probabilistic river-stage forecast models, such as the eXperimental Ensemble Forecast System (XEFS), which is also being developed. The output from this system will include forecasts of most likely river stages and flows, the range of the stages and flows, and the uncertainty associated with these forecasts.

Fact: About a year and a half before the June 2008 flooding, NCRFC began producing an ensemble suite of river stage forecasts based on maximum and minimum QPFs for 24, 48, and 60 hours for the 95 percent confidence level. NCRFC provided these data to WFOs and the USACE.

Best Practice 3: WFO Quad Cities shared information from the ensemble river forecasts with the local emergency management community for planning and preparation purposes.

Finding 12: Forecast uncertainty information, such as ensemble forecasts of river stage prepared by NCRFC, was very useful to the USACE and others in their contingency planning. The USACE used this information in managing its water resource projects.

Recommendation 12: The NWS should expand its provision of forecast uncertainty information to the USACE and other local and state agencies involved in flood contingency planning.

Finding 13: Not all WFOs have the same level of understanding with respect to information provided in ensemble river forecasts.

Recommendation 13: Training and educational information and materials should be developed for NWS personnel and external users regarding strengths, weaknesses, and utility of ensemble river forecasts.

Finding 14: Information in ensemble river forecasts would benefit a wider audience than currently has access to these data.

Recommendation 14: RFCs producing ensemble river forecasts should include information in Hydrometeorological Discussions highlighting situations when one or more of the ensemble forecasts indicate potential flooding.

Finding 15: A number of users of NWS products would benefit from an expanded suite of probabilistic QPFs, river stages, and river flows.

Recommendation 15: The NWS should make available as expeditiously as possible HPC's experimental probabilistic QPF capability and the eXperimental Ensemble Forecast System (XEFS) for river forecasting.

Finding 16: There is limited linkage between development of HPC's probabilistic QPF capability and development of the XEFS.

Recommendation 16: The NWS should ensure the development of its forecaster-based probabilistic QPF capability is part of the plan for the development of the XEFS.

4.1.5.4 Forecast Dissemination Tool

With the advent of the AHPS Web pages, NWS users are increasingly taking advantage of this dissemination tool to obtain river observations and forecast information. When RFC forecasts are provided to WFOs, data are posted to the WFO database. A process (known as HydroGen) on AWIPS executes at least once an hour to extract river observations and forecasts from the WFO database and pass that information on to regional Web servers, where the data are rendered into AHPS hydrographs. This process executes in the background automatically, without forecaster intervention. Especially during significant events, the WFO may require time to review the RFC forecasts and, if necessary, coordinate modifications to the forecast information with the RFC. In the meantime, the original forecast data are being posted to the AHPS Web pages.

WFO Quad Cities took advantage of a capability within the HydroGen AWIPS software, known as BLESS, to hold off transmission of the forecast data to the AHPS Web page until staff had reviewed the forecast data and coordinated changes with the RFC. This process ensured forecast information was not released to the AHPS Web page until it had been reviewed, compared with current observations, and modified, if necessary.

Best Practice 4: WFO Quad Cities used the AWIPS BLESS function to ensure forecast information was properly reviewed, validated against current observations, and modifications coordinated with NCRFC prior to being posted to the AHPS Web pages.

4.1.6 Collaboration Tools

The emergence of collaboration tools such as chat rooms/instant messaging and Web conferencing (Webinars) has significantly changed the way in which the NWS communicates with partners such as emergency managers and the media. When the need arises, NWS offices are now in constant contact with each other and with critical partners and customers, sharing information regarding significant hydrometeorological events almost instantaneously. In addition, several members of the WFO Des Moines staff have amateur radio licenses and were able to use amateur radio to obtain information about river flooding during this event.

4.1.6.1 IEMChat/NWSChat

IEMChat was an internet-based chat/instant messaging tool facilitating real-time communication of information between operational forecasters and local media and emergency managers at the time of the June 2008 flooding. It was managed and hosted by the Iowa Environmental Mesonet (IEM) and available to WFOs throughout the NWS. WFO Des Moines and WFO Quad Cities hosted their own chat rooms and made extensive use of them in collaborating with local emergency managers and media partners during the floods. These user groups were highly complimentary of the collaboration and the information shared via this chat/instant messaging. NCRFC staff also accessed the chat rooms of WFOs Des Moines and Quad Cities during this event. The NWS, however, did not use this technology to collaborate in real time with the USACE and USGS.

The NWS Service Assessment Report "Tornadoes in Southern Alabama and Georgia, March 1, 2007," released in November 2007, recommended investigating the benefits of using a standard chat/instant messaging system. Based on this recommendation, the NWS developed NWSChat, which was released on November 12, 2008. At the end of an experimental period, the NWS will determine whether NWSChat will become operational in NWS offices.

Fact: Media, emergency management, and water managers described chat/instant messaging as invaluable in rapid dissemination of information throughout the flood.

Finding 17: The NWS did not use chat/instant messaging to collaborate with its Federal partners, such as the USGS and the USACE, during this event.

Recommendation 17: The NWS should investigate using current technologies such as chat/instant messaging to facilitate communication and collaboration with Federal partners, such as the USGS and the USACE, and with other partners during flood events.

Best Practice 5: WFOs Des Moines and Quad Cities used chat/instant messaging to collaborate and coordinate effectively and efficiently with state and local emergency managers and the media during the flood event.

4.1.6.2 12Planet

AWIPS provides the interoffice chat tool 12Planet. WFOs and RFCs use the tool to collaborate on a number of different topics relevant to the forecast process, including quantitative precipitation forecasts.

Fact: NCRFC monitors up to 26 WFOs, in addition to HPC and other national centers, in a 12Planet chat room. This chat room provides information on various topics, including severe weather, flooding, and gridded forecast coordination.

Finding 18: NCRFC had only three 12Planet accounts. During the 2008 flooding, NCRFC had as many as 16 staff members on duty at one time. As a result, bottlenecks developed when using 12Planet chat.

Recommendation 18: NWS should increase the number of 12Planet accounts to accommodate RFC staffing profiles during significant flooding.

4.1.6.3 River Forecast Product (RVF)

RFCs provide operational river forecasts to WFOs in the RVF product. The RVF is a SHEF-encoded message containing the forecast time series for various river forecast points, as well as an appropriate crest forecast. The RVF product is processed by the SHEF decoder at the WFO, and forecast data are posted to the WFO database, where they are available to be viewed and used by the various tools at the WFO. In addition, the SHEF format allows the RFC to include forecaster comments. WFO forecasters are able to view those comments and integrate this information into the forecast process.

Best Practice 6: During this event, NCRFC staff placed extensive, descriptive comments in their RVF products. WFO Quad Cities found these comments to be extremely valuable because they allowed WFO staff to learn quickly of NCRFC forecasters' thoughts and concerns, including forecaster confidence as well as contingencies. These comments helped reduce the amount of follow-up coordination with NCRFC because the comments answered many questions.

4.2 Collaboration among the NWS, USACE, and USGS in the Flood Forecast Process

NWS river forecasting services depend critically on other Federal agencies for providing accurate and timely river data used in the forecast and warning process. The USGS and the USACE are the principal sources of data on river stage and flow.

4.2.1 Agency Roles

Collaboration among agencies is essential during an extreme hydrologic event. The NWS, USACE, and USGS work together to collect and use the most up-to-date hydrologic data. These continuous data of river stage, river flow, and rating revisions are provided to the NWS in real time as they become available. The NWS uses its river models to predict the flow at each forecast service point. The end-to-end flood forecast process and a chart of the NWS river forecast process are provided in Appendix B.

4.2.1.1 USGS

The USGS operates and maintains more than 85 percent of the Nation's streamgaging stations, including almost all of those used for real-time river forecasting. This network comprises more than 7,000 stations, most equipped with earth satellite radios providing real-time communications. The NWS uses data from these stations at forecast-service locations on major rivers and small streams in urban areas. As mentioned above, to be able to make flood forecasts the NWS develops and calibrates complex hydrologic models of how rivers and streams respond to rainfall and snowmelt. Records of river flow must be available so the NWS can calibrate the various components of a hydrologic model. An important hydraulic input to these models is the USGS streamgage stage/flow rating. When heavy rainfall is forecast for the river basin, those amounts are entered into a river model, and the model estimates the resulting river stage and flow. Observed river stages from streamgages and corresponding flows from rating tables are compared in real-time to the model-simulated stage and flow to judge the quality of forecast models.

It is critical for the USGS to send teams to streamgage locations during floods to make flow measurements for verification and possible extension of rating curves. (See **Fig. 18**.) During a major flood, USGS Water Science Centers must make decisions on where to send flood crews to make measurements at the locations on the hydrographs optimizing the measurements' usefulness in defining the stage-discharge ratings. This point typically is at or near peak flows, but not always. An important tool for that decision-making process is NWS river forecasts. During a large flood, USGS personnel consult river forecasts on AHPS to decide where and when to route flood crews. This process results in a greater efficiency than if crews were routed based upon guessing when a peak flow might occur. Efficient use of USGS staff results in a greater number of measurements at or near peak flows obtained during a given period of time.

Fig. 18. USGS staff installing temporary streamgage at 13th Avenue and J Street in Cedar Rapids, Iowa, June 12, 2008. (USGS photograph by Don Becker.)

Fact: The USGS uses NWS forecasts of precipitation and river stage to plan where it will deploy its observational assets during flooding events.

4.2.1.2 USACE

The USACE plays a significant role in the water-level forecasting process for the watersheds and water resource projects for which it has responsibility. Along with the USGS, the USACE is also involved with operating and maintaining water-level, precipitation, air, and other related sensors on many central United States streams. The USACE not only has its own gage maintenance staff, but also funds the USGS to operate and maintain many of the gages the USACE and the NWS rely on to make accurate water-level forecasts.

The USACE data are critical to the forecast process because of the impact of reservoir operations on downstream water levels. In Iowa, the USACE operates three large flood-control reservoirs on the Iowa and Des Moines Rivers. USACE coordinates closely with the NWS when making operational flow changes that affect river levels downstream of its reservoirs. Using the Local Data Manager file transfer software, the USACE communicates all daily operations to the NWS, and incorporates NWS inflow forecasts to prepare 7-day operational outflow forecasts from the reservoirs. The NWS then incorporates those USACE outflow forecasts to make water-level predictions downstream of the reservoirs.

In addition to operating reservoirs, USACE operates 36 navigation locks and dams in the Mississippi basin upstream of St. Louis. Similar to its reservoirs, USACE communicates all daily operational flow changes occurring at Mississippi locks and dams and provides the NWS with any additional information that might help the NWS forecast water levels on the Mississippi and Illinois Rivers. Furthermore, USACE utilizes an unsteady flow model to help predict water levels at the locks and dams. The unsteady flow model relies on inflow forecasts produced by the NWS for the tributaries feeding the Mississippi and Illinois Rivers. The USACE sends the NWS the output of their unsteady flow model, which the NWS takes into consideration when preparing the water-level forecasts. Along with the modeling results, the USACE prepares a 6-day operational flow forecast provided to the NWS. Any significant differences between the USACE and the NWS forecasts are typically resolved before the NWS releases its official water-level forecast.

Fact: River stage forecasts at some locations are made by both the NWS and USACE. Interagency coordination is used to provide consistent forecasts.

4.2.1.3 NWS

The NWS provides daily forecasts on the Nation's rivers. The vast array of users require both low flow forecasts for moving goods and services along rivers and flood forecasts to ensure advance warnings to protect life and property.

River-flood forecasts are prepared by RFCs. WFOs review and adjust the forecasts in consultation with the RFCs. The WFOs issue the public products and provide observed and forecast data for display on the Internet. During periods of flooding, RFCs prepare forecasts for the height of flood crest, the date and time when the river is expected to overflow its banks, and the date and time when the flow in the river is expected to recede to within its banks. These forecasts are updated as new information is acquired. The best stage-flow relationships, together with additional field measurements during extreme high flows, enhance the accuracy and usefulness of NWS river forecast products. During high water, deterministic forecasts are normally run daily, in 6-hour increments out to 54-72 hours, while other special contingency forecasts are made beyond that period to between 3 to 5 days, depending on requests from customers. Probabilistic QPFs can also be made from atmospheric model ensembles. Extended river flow predictions of a week to a month or longer can be made based on a conditional simulation using a long-term historical period.

Besides the complex effects of rainfall runoff, snowmelt, and tidal processes on river stage/flow forecasts, reservoir operations and other man-made activities can significantly alter river conditions and affect river forecasts. NWS forecasts during low, normal, and high flows resulting from large-scale hydrometeorological events will change the USACE reservoir control settings, thus affecting river forecasts. Continual communication between the NWS and USACE assists in providing the best information for accurate forecasts to the NWS users. As mentioned above, USGS streamgage observations are an essential component in NWS river forecasting.

Fact: The NWS relies heavily on both the USACE and USGS for key data in river forecasting.

4.2.2 Interagency Collaboration—Successes and Lessons Learned

The last major flood before 2008 occurred in this region in 1993. Since that historic flood, new technologies have been developed and incorporated into the operations of the NWS, USGS, and USACE that greatly enhanced the amount of information available to staff, emergency managers, and the general public. Two key examples enhancing interagency collaboration are the use of Web applications and access to real-time data.

Fact: Improvements in technology since 1993 have greatly improved communication and data exchange among the NWS, USGS, and USACE.

4.2.2.1 Prior to an Event

There were well-established, positive working relationships among the USGS, USACE, and NCRFC, its associated WFOs, and Central Region Headquarters prior to the 2008 floods. These relationships helped facilitate accessibility of staff for all agencies during the event.

Finding 19: There were occasions when NWS staff members were not aware of certain USGS field activities supporting the flood forecasting process. Likewise, USGS staff at the Iowa Water Science Center and USACE personnel were not acquainted with details of the NWS flood forecast process. Awareness of the NWS, USGS, and USACE staff of these activities might have provided the opportunity for enhanced flood forecasting.

Recommendation 19a: Periodic meetings should be scheduled at least annually between collaborating offices of the NWS, USGS, and USACE to discuss their common data and forecast needs and ensure all points of contact are current.

Recommendation 19b: The NWS, USGS, and USACE should initiate a scientist/engineer exchange program so staff better understand the operations, requirements, and constraints of each organization.

Recommendation 19c: The NWS should pursue the proposed creation of an Interagency Fusion Cell comprising members of NWS, USGS, and USACE to determine what improvements can be made to increase the accuracy of forecasts given the current science, staffing resources, and level of funding.

4.2.2.2 During an Event

The flooding event was historic in both duration and magnitude. Coordination among the three agencies went beyond the normal scope of operations. Staff at all three agencies worked long hours and weekends to ensure the flood forecasts were accurate and timely.

Because USACE emergency management teams were deployed in the field to assist local communities during the flood, instances of levees being overtopped and breached were reported to the USACE Water Management offices and then immediately relayed to NCRFC. USACE also provided NCRFC with elevation-volume relationships for storage areas behind levees. This information was critical in determining the impact of overtopped levees on flows, river levels, and forecasts. Further, the USACE provided the NWS with rating curves from the USACE Flow Frequency Study for the main stem Mississippi River. These rating curves were very beneficial since water levels were forecast to exceed previous records at many locations along the Mississippi. During the event, daily conference calls were held between the USACE and NWS to discuss changing river conditions and to be certain water-level forecasts were in agreement.

Fact: Conference calls were held daily among NCRFC, WFOs, USGS, and USACE to coordinate information and collaborate on the resultant forecasts.

Fact: Coordination among WFOs, RFCs, USGS, and USACE was excellent.

Best Practice 7: USACE provided a hydraulic engineer to help NCRFC assess the impacts on river forecasts when levees overtopped. In addition, individual USACE offices provided levee overtopping information to help determine the impact on flow forecasts.

Best Practice 8: USGS provided a hydrologist to NCRFC to supply expertise with flood tools and to serve as a liaison to other USGS Water Science Centers. He worked directly with staff at the Iowa Water Science Center to keep rating curve extension updates current as new measurements were taken. He also worked with rating curve implementation and validation.

4.2.3 Opportunities for Enhanced Collaboration

The central United States flooding of June 2008 presented all three agencies with new challenges and opportunities for enhanced collaboration. Continuing to improve data delivery systems, monitoring systems, and flood forecast models is essential to the mission of each agency.

Finding 20: Many NWS partners voiced the need for more streamgages. These partners would like these new gage sites to be NWS river forecast sites.

Recommendation 20a: The NWS, USGS, and USACE should issue joint news releases to educate the public on how the streamgage network is operated and funded and should work with appropriate county and state officials to ensure they are aware of the options available for procuring additional streamgages.

Recommendation 20b: The NWS, USGS, and USACE need to hold a streamgage optimization summit to determine the optimal network of streamgages to enhance NWS river forecasts.

Finding 21: The NWS depended heavily on the USGS for updated rating curve information when rating curves were exceeded.

Recommendation 21: The NWS, USGS, and USACE need to collaborate to develop rating curve extensions before flood emergencies.

With regard to stage-flow ratings, the USACE and NWS receive updated rating tables automatically each evening from the USGS national repository. The ratings, however, were sometimes truncated and covered only the portion of the rating where recent measurements verified the stage-flow relationship. Having a truncated partial rating available can be problematic when transitioning into a flood event or an extreme low water event where stages exceed the top or bottom of the rating table. The USGS has recognized the problem and developed a process to notify Water Science Centers and partners when a rating has been truncated. This process triggers a response at the applicable Water Science Center to either resend the entire rating or to discuss with its partners the reason the rating was truncated.

4.3 Accuracy and Effectiveness of Service

Accuracy and effectiveness of NWS products and services can be assessed a number of ways. These include both objective and subjective verification of forecasts; anecdotal comments by partners and users on responsiveness, usefulness, and reliability of products and services; and their requests for additional products and services.

4.3.1 Forecast and Warning Accuracy

This section discusses the accuracy of NWS forecasts and warnings for the June 2008 flooding. Quantitative measures of the accuracy of QPFs and flood warnings are provided, as well as the qualitative impressions of NWS partners and customers.

4.3.1.1 Quantitative Precipitation Forecast Verification

As mentioned above, torrential precipitation fell over the central United States in June 2008. **Fig. 19** shows more than 13 inches of rain fell across portions of Indiana, Iowa, Missouri, Oklahoma, and Wisconsin that month. As shown in **Fig. 20 and Fig. 21**, HPC and the RFCs accurately predicted the areas that would receive the heaviest rain and captured the general axes of precipitation. HPC and the RFCs tended to underestimate the maximum precipitation amounts. For example, although both HPC and OHRFC predicted the axis of heaviest precipitation would pass through central Indiana, the magnitude of the maximum was underestimated by nearly a factor of two.

Fig. 22 and Fig. 23 display the mean error and mean absolute error (MAE) for quantitative precipitation forecasts made by HPC forecasters and NCRFC forecasters, respectively, during June 2008. Mean error indicates forecast bias, where positive values denote over forecasting and negative values denote under forecasting. MAE indicates the accuracy of a QPF. The closer the MAE is to zero, the greater the accuracy.

Fact: HPC and RFC forecasts captured much of the precipitation that subsequently fell during June 2008. There was a general tendency to over forecast light amounts and under forecast heavy amounts. Forecast error was greater for heavier amounts of precipitation.

Fig. 24 depicts the forecast accuracy for heavy amounts of precipitation (amounts greater than or equal to 1 inch per 6-hour period) across the NCRFC domain, as predicted by two numerical models, HPC, and NCRFC for the month of June 2008. The two models depicted are the North American Model (NAM) and the Global Forecast System (GFS). Also shown on the graph is the NCRFC's performance for previous Junes starting in June 2001.

Fact: HPC forecasts were considerably more accurate than the numerical model forecasts. The MAE for HPC was 25 percent lower than the MAE for the NAM and 34 percent lower than the GFS. NCRFC further improved the forecasts. NCRFC's forecasts of heavy precipitation for June 2008 were considerably more accurate than those of the previous 7 years.

4.3.1.2 Flood Warning Verification

Probability of detection (POD), false alarm rate (FAR), and critical success index (CSI) statistics were computed to assess flood warning accuracy. Lead time was computed to assess flood warning timeliness. POD is the fraction of river floods correctly warned. The best possible score is one and the worst possible score is zero. FAR is the fraction of all warnings issued for river floods that did not occur. The best possible score is zero and the worst possible score is one. CSI measures the utility of the warnings. CSI is maximized when POD is high and FAR is low. The best possible score is one and the worst is zero. Lead time is the amount of time from when a warning is issued to the time the river reaches flood stage. The larger the lead time the more time people have to take mitigating actions.

Figs. 25-28 provide the POD, FAR, and CSI for flood warnings for WFOs Des Moines and Quad Cities for June 2008 and several preceding years. The verification was limited to those warnings issued for forecast points in Iowa and did not include areal flood warnings or follow-ups to flood warnings for forecast points.

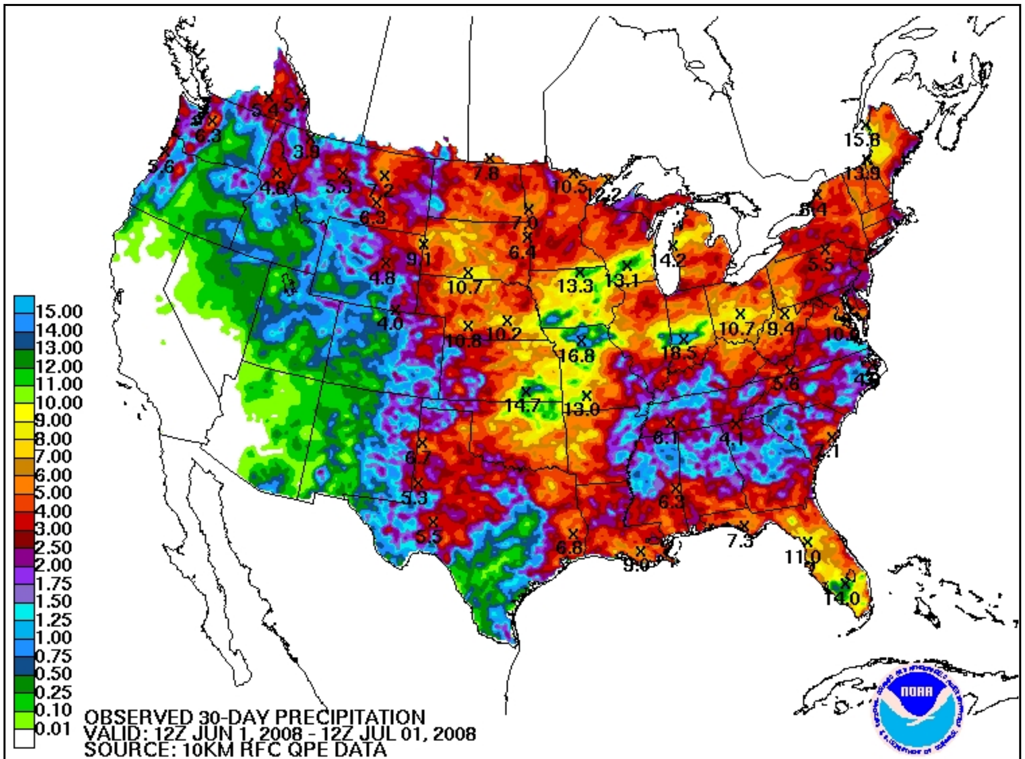

Fig. 19. Observed precipitation during June 2008. Values are in inches. (Figure courtesy of the NOAA/NWS National Precipitation Verification Unit.)

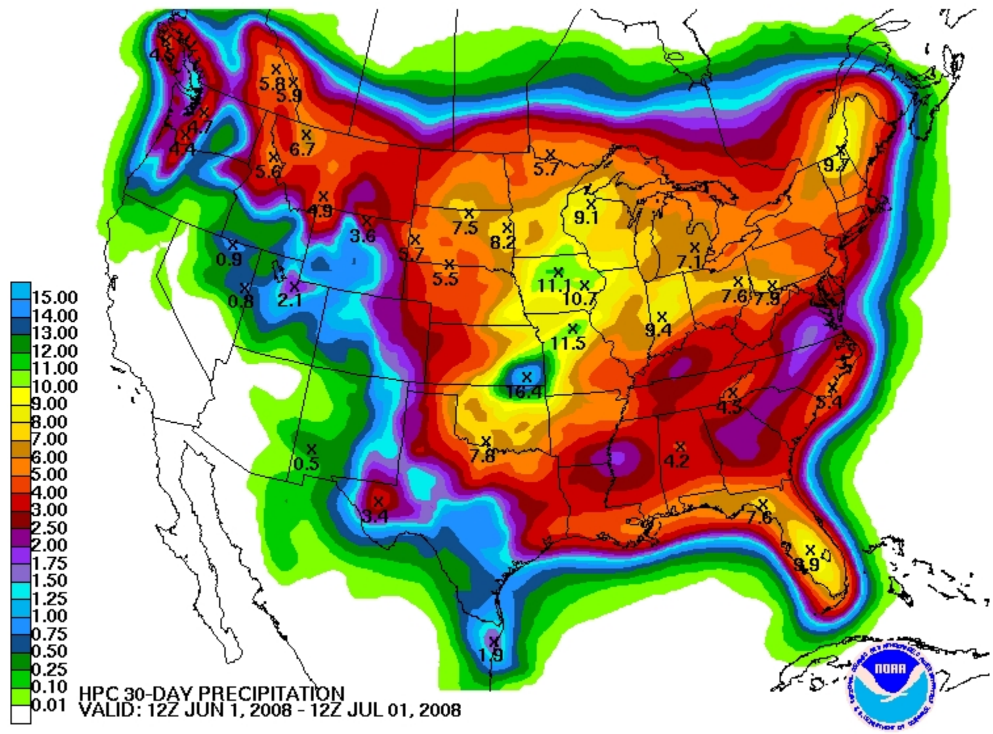

Fig. 20. Sum of the 30 quantitative precipitation forecasts for each of the first 24-hour periods (day 1) by HPC for June 2008. (Figure courtesy of the NOAA/NWS Hydrometeorological Prediction Center.)

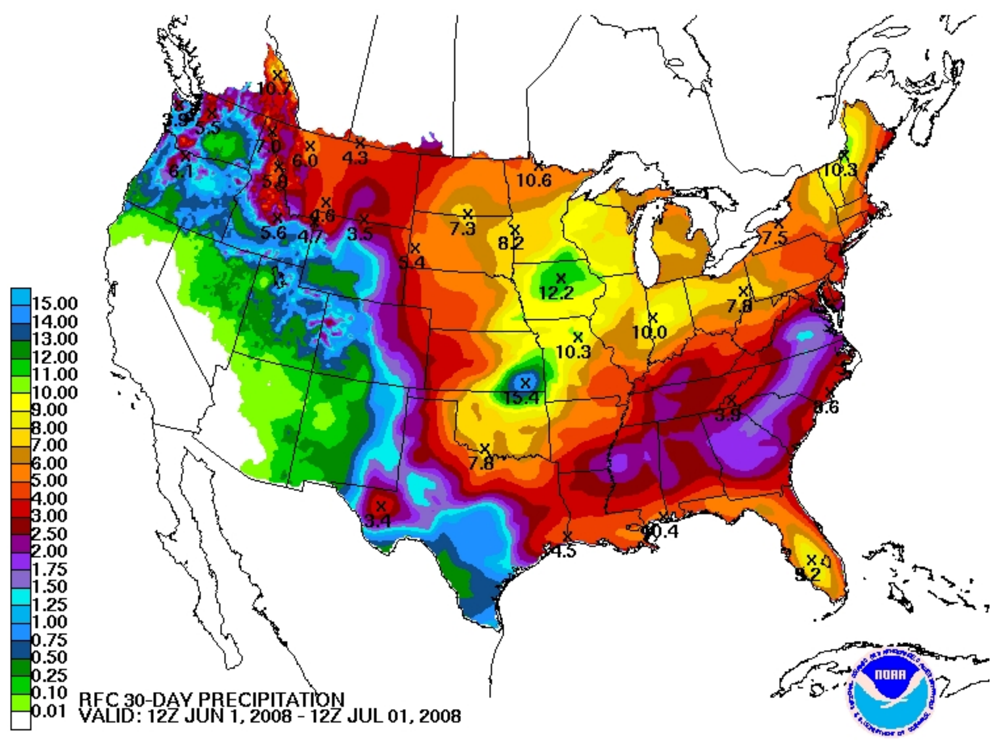

Fig. 21. Sum of the 30 quantitative precipitation forecasts for each of the first 24-hour periods (day 1) by the RFCs of the conterminous United States for June 2008. (Figure courtesy of the NOAA/NWS National Precipitation Verification Unit.)

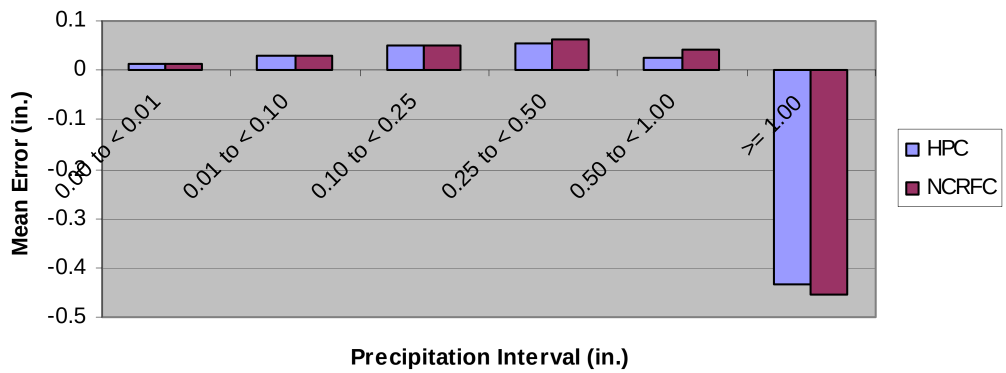

Fig. 22. Mean Error for June 2008 of day 1 QPFs (12 UTC – 12 UTC) by HPC and NCRFC. (Source: https://verification.nws.noaa.gov/npvu/.)

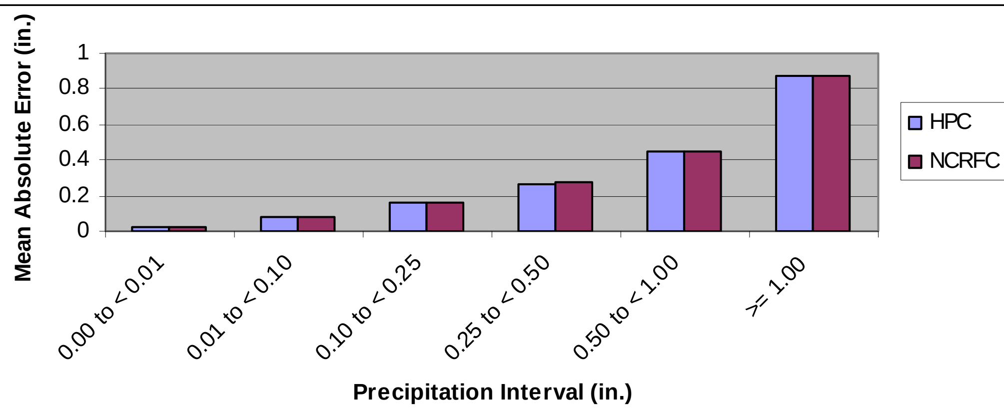

Fig. 23. Mean Absolute Error for June 2008 of day 1 QPFs (12 UTC – 12 UTC) by HPC and NCRFC. (Source: https://verification.nws.noaa.gov/npvu/.)

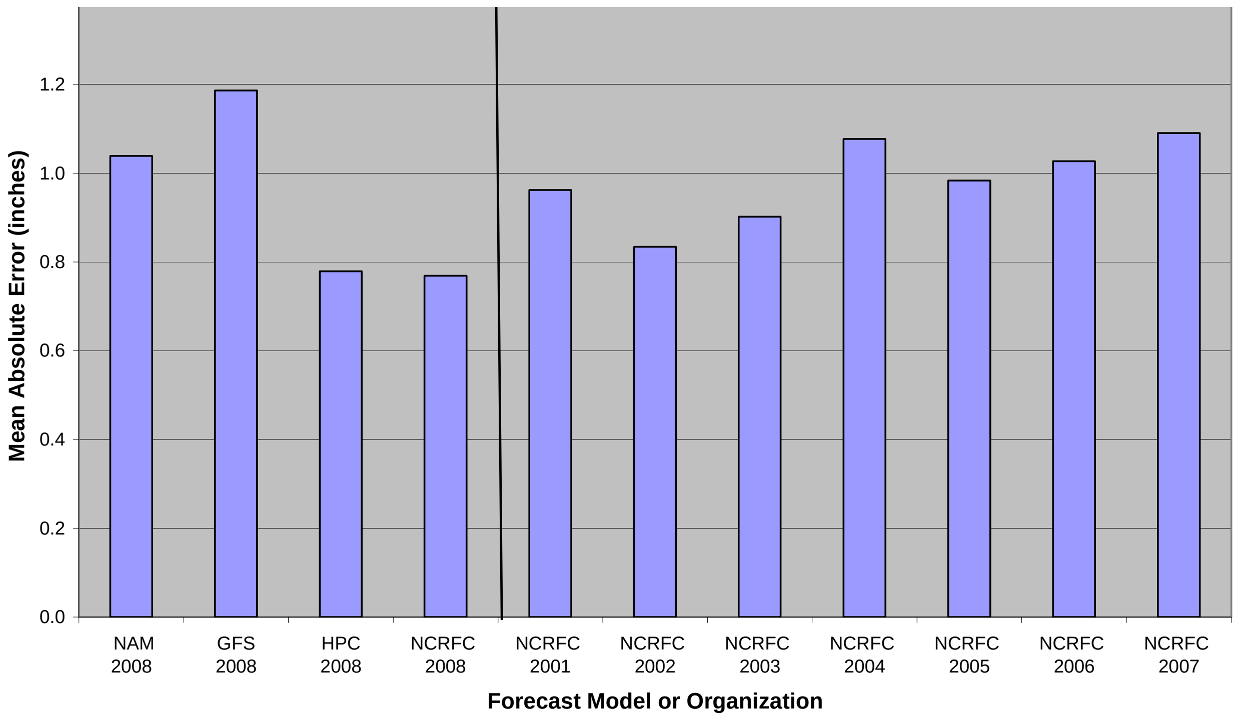

Fig. 24. Mean Absolute Error for precipitation amounts greater than or equal to one inch per 6-hour period by NCRFC in June 2001-2008 and by the NAM, GFS, and HPC in 2008. (Source: NOAA/NWS Service Assessment Team.)

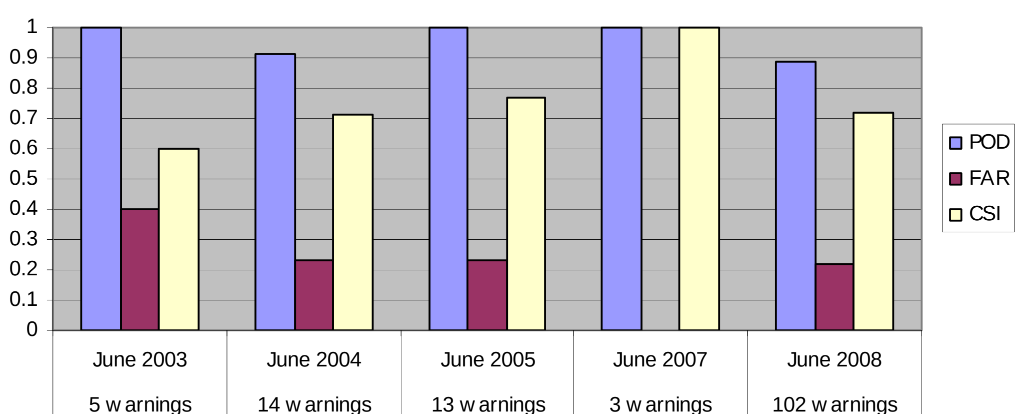

Fig. 25. WFO Des Moines flood warning verification scores for forecast points in Iowa in June 2008 and several previous Junes. (Source: NOAA/NWS Service Assessment Team.)

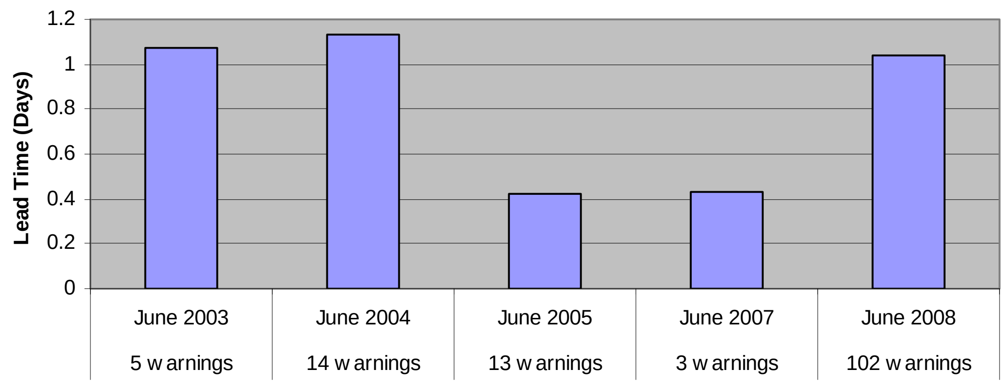

Fig. 26. WFO Des Moines average flood warning lead time for forecast points in Iowa in June 2008 and several previous Junes. (Source: NOAA/NWS Service Assessment Team.)

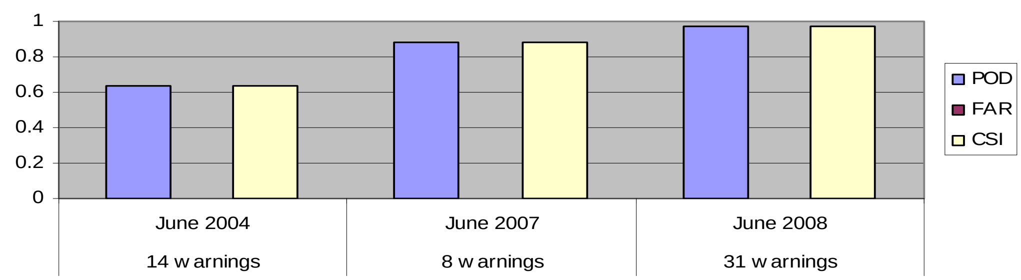

Fig. 27. WFO Quad Cities flood warning verification scores for forecast points in Iowa in June 2008 and two previous Junes. (Source: NOAA/NWS Service Assessment Team.)

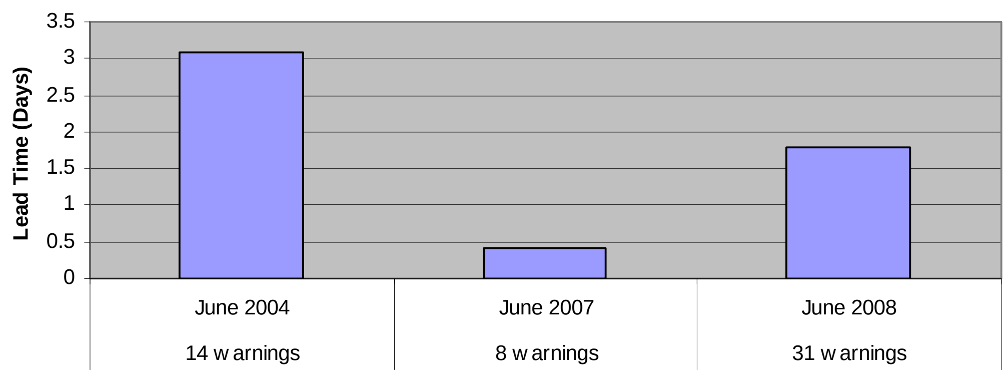

Fig. 28. WFO Quad Cities average flood warning lead time for forecast points in Iowa in June 2008 and two previous Junes. (Source: NOAA/NWS Service Assessment Team.)

Fact: During June 2008, there were 40 different river forecast points above flood stage in the hydrologic service area of WFO Des Moines. The office issued 102 flood warnings for forecast points within Iowa with an average lead time of 25 hours. The WFO's river flood warning probability of detection, false alarm rate, and critical success index for June 2008 were 0.89, 0.22, and 0.72, respectively.

Fact: During June 2008, 25 river forecast points in the Iowa portion of the WFO Quad Cities hydrologic service area were above flood stage. For the 31 flood warnings for forecast points within Iowa, the average lead time was 1 day, 18 hours, 50 minutes. The WFO's river flood warning probability of detection, false alarm rate, and critical success index for June 2008 in Iowa were 0.97, 0.00, and 0.97 respectively.

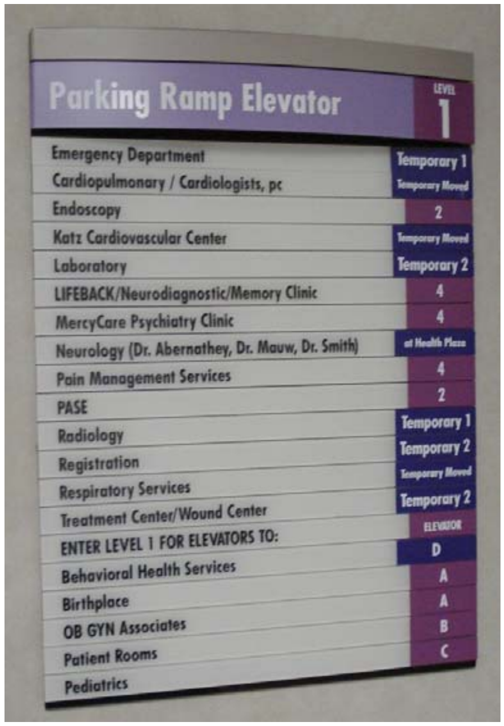

Fig. 29. Departmental directory outside elevator at the Mercy Medical Center in Cedar Rapids, Iowa, taken 10 weeks after the flooding. As indicated by the dark blue overlays in the right column on this directory, many departments were still displaced. (Source: NOAA/ NWS Service Assessment Team)

Fact: WFOs Des Moines and Quad Cities issued accurate and timely flood warnings for river forecast points in Iowa.

4.3.1.3 Qualitative Verification

The NWS received considerable praise from partners and users for its forecast and warning accuracy. Joyce Flinn, Readiness/Response Chief of the Iowa Homeland Security and Emergency Management Division, stated the flooding was not a surprise, thanks to NWS forecasts. Steve Nolan, Deputy Director, Polk County, Iowa, Emergency Management, said the following about the NWS, "It seems like forecast accuracy has increased, especially over the last couple of years." Steve O'Neil, Director of Emergency Management for Cerro Gordo County gave WFO Des Moines a "solid 'A' for performance." The county received plenty of advance warning notification and Mr. O'Neil was very complimentary of the relationship between the county and the WFO. Lori Morrisey, Director of Story County, Iowa, Emergency Management said NWS forecasts were timely and accurate.

Flood fighting activities of some users, including personnel at Mercy Medical Center in Cedar Rapids, were hampered by changing crest forecasts. When the Center staff first learned of a 26-foot flood forecast, officials contracted with a local architectural firm to assess the hospital's vulnerability, resulting in some preventative actions by hospital staff to safeguard lives and property. Had there been more lead time for a higher crest, however, staff could have initiated additional action, such as plugging sewer points to block the back flow.

WFO Des Moines forecasters believed they were constantly "chasing the crest." This was due in part to heavy rainfall continuing almost daily during the first half of June.

Fact: The tendency to underforecast heavy precipitation and using only 24 hours of QPF in preparing the official river forecasts led to river stages not forecast high enough at some locations.

Fact: Despite all the devastation, most emergency managers, other decision makers, and partners contacted during the Service Assessment said they felt NWS forecasts and warnings were as accurate and timely as the science permitted.

4.3.2 NWS Responsiveness

Feedback from users and, in particular emergency managers, on support provided by NWS staffs was decidedly positive. The NWS received significant acclaim for providing on-site support at the Iowa SEOC. Meteorologist-in-Charge Brenda Brock, Warning Coordination Meteorologist Jeff Johnson, and forecasters Jim Lee, Ben Moyer, Kenny Podrazik, and Roger Vachalek from WFO Des Moines and Meteorologist-in-Charge Steve Kuhl from WFO Quad Cities staffed the SEOC from June 8-20, with around-the-clock coverage from June 10-14. They provided briefings every 4 hours and other tailored support, including meetings with the governor, lieutenant governor, and commander of the Iowa National Guard. A comment from Ms. Flinn strongly supports NWS commitment to these activities: "We're fortunate to have an excellent working relationship with the NWS and it became more than a working relationship. It became friends helping each other."

The NWS received praise for its ability to provide timely service and individualized attention. Jessyca Frasher, Watch Officer for FEMA Region VII, stated "We couldn't have asked for better support." She said a great relationship exists between FEMA and the NWS and that this relationship was even better than expected given the size and scope of the flooding event.

A number of contacts stressed the importance of WFOs having a Service Hydrologist to provide expertise and to supervise the hydrology program. These contacts felt offices with Service Hydrologists could be more responsive to the needs of the emergency management community and other partners in flooding situations.

AHPS Web pages provided real-time updates to emergency managers, the media, and others to help guide mitigation efforts. NOAA regional and national Public Affairs Specialists navigated numerous national and foreign media representatives through AHPS Web pages. Media were able to review AHPS Web pages and then consult Public Affairs Specialists about what they had learned. This practice allowed the NWS to serve both the needs of local media to provide critical information to impacted residents in flooded areas and to provide national-level media information to keep the rest of the country informed of conditions.

Server responsiveness for AHPS Web pages was excellent. For example, NWS employees and other SEOC staff relied heavily on the AHPS Web pages and reported that they encountered no problems accessing them. NWS received no reports of AHPS responsiveness problems from partners and customers.

Fact: The NWS received considerable praise for the responsiveness of its staff to user requests. The AHPS Web pages enhanced NWS responsiveness by providing a continuous source of information to meet the needs of various user groups quickly.

4.3.3 Usefulness of Products and Services

Emergency managers and others interviewed said NWS products and services were valuable. Steve Nolan of Polk County said, “The WFO did a great job. There were no surprises during the event. It’s the pre-existing relationships that make it work.” He used NWS forecasts and warnings during the flood to aid in his work as a logistics chief.

Flood warnings and conference calls provided by WFO Des Moines enabled Story County to deploy personnel to the affected areas. Lori Morrisey of Story County commented the NWS issued flood warnings with enough lead time to ensure a nursing home in Ames could be evacuated before flooding began along the Skunk River. Officials from the Iowa Department of Transportation (IDOT) reported information from the NWS was very helpful and was valued by the agency staff. They said service from the NWS was especially good at those times when critical decisions had to be made. Further, although crest forecasts for the Cedar River at Cedar Rapids were lower than what actually occurred, IDOT was still able to protect drivers by closing I-380 about 6 hours before flooding occurred. The University of Iowa staff had this to say: “Kudos to the NWS, USACE, and USGS. Their forecasts were crucial.” Using GoToMeeting (a type of Web-based conference) to connect with Central Region Headquarters, FEMA Region VII staff members were able to maintain situational awareness and to ask such critical questions as the expected length of the flooding and expected impacts. FEMA’s Jessyca Frasher called WFOs Des Moines and Omaha whenever she needed weather and hydrologic forecasts. Information she received from them was critical to making decisions about how to move staff safely from one area to another.

Some users, especially emergency managers from Coralville and Johnson County, Iowa, expressed a desire to have forecast updates available earlier in the day. Earlier updates would have been useful in planning mobilizations for that day.

Finding 22: Many users preferred earlier delivery of products and services. People involved directly with flood fighting preferred morning delivery, the earlier the better.

Recommendation 22: The NWS should address customer requirements for earlier delivery of flood-related products and services.

The NWS received noteworthy commendation for the usefulness and ease of use of its AHPS Web services from emergency managers, the media, and others. Some users of the Web site, however, had difficulty understanding some of the information presented. IDOT officials considered the AHPS Web pages to be an excellent source of information. They stated, “Having AHPS on the workstations in the Iowa State Emergency Operations Center was a tremendous tool.”

Finding 23: Some information on the AHPS Web site is unfamiliar to a number of the site's users, so the full potential of the site is not being achieved.

Recommendation 23: The NWS should post a users guide on the AHPS Web site.

4.3.4 Reliability of Products and Services

There were a few negative comments from users about forecast update availability. During emergency situations such as the June 2008 floods, many users expect forecast updates to appear on the AHPS Web pages at the same time of day as during fair weather. For example, the city of Des Moines Public Works Department relies upon NWS river forecasts for the Des Moines River. Before the June flooding began, the department was accustomed to receiving the river forecast updates at 8:45 a.m. and 3:45 p.m. from the AHPS Web site. Once the flooding began, the department was frustrated these updates were often issued later, sometimes by several hours, and they did not know when to expect receipt of the products. The forecasts were issued later because of the need for additional analysis for levee breaches and exceeded rating curves and increased collaboration among the NWS, USGS, and USACE.

Finding 24: Users have developed a certain expectation of the times of day when products will become available based on their availability during fair weather. During high-impact weather, users expect to receive products about the same time.

Recommendation 24: If it is not possible to meet the fair weather schedule for issuing products during emergency situations such as significant river flooding, a method needs to be developed to manage people's expectations about delayed service delivery.

4.3.5 Enhancements to Products and Services Requested by Partners and Other Users

Users desire a wide range of NWS products and services, including flood impact statements, flood inundation mapping, and communication methods.

4.3.5.1 Flood Impact Statements

Users expressed mostly favorable opinions about flood impact statements (formerly known as E-19 impact statements) included in flood warning products and on the AHPS Web pages. SEOC staff especially liked the impact statements included in the event-based hydrologic products. FEMA's Jessyca Frasher noticed an increase in the amount of impact information disseminated during this event. IDOT officials believed an opportunity exists to work with the NWS to get more IDOT-supplied road-specific information incorporated into flood impact statements. Lori Morrisey of Story County reported that impact statements for one of the streamgages in her county were incorrect. This particular gage was recently upgraded and moved, but the impact statements associated with this gage were not updated to reflect the new location.

Finding 25: The Iowa and Missouri Departments of Transportation have compiled additional information correlating road impacts to specific river stages. An opportunity exists to work with the state departments of transportation and other entities to update and enhance flood impact statements on the AHPS Web pages.

Recommendation 25: WFOs should collaborate with state departments of transportation, emergency managers, city engineers, floodplain managers, and others to develop specific road impacts where appropriate. These impacts should be added to the WFO database to ensure road impacts are available via the AHPS Web pages.

4.3.5.2 Flood Inundation Mapping

Many users expressed a desire for tools to help them visualize the spatial extent and depth of flood waters in the vicinity of NWS river forecast locations. For example, IDOT staff said they would like to have a tool that would assist in determining where flooding will impact roadways, streets, and bridges. Standardized geospatial reference systems for both horizontal and vertical position are necessary to enhance the value of such mapping information. Accuracy of this information and details on its source and basic characteristics are also essential to its usefulness.

Finding 26: Flood inundation mapping will help the public, media, emergency managers, and others visualize the spatial extent and depth of flood waters in the vicinity of NWS river forecast locations.

Recommendation 26: The NWS should expand efforts with state and Federal agencies and other groups to accelerate the implementation of flood inundation mapping across the United States. Such information should use standardized geospatial reference systems and should include indications of its accuracy and derivation.

4.3.5.3 Communication Methods

Technological advances realized in the 15 years between the central United States floods of 1993 and the flooding in 2008 were key elements to both forecast operations and information dissemination. In 2008, the NWS and its partners were able to collect data, update forecasts, and provide new information to users much more efficiently because of advances in computer technology and ancillary programs.

Advances in computer science and communications technology over the years have undoubtedly allowed for a better informed public and more successful mitigation efforts. Many individuals interviewed by the Service Assessment Team noted the greatly improved communications systems. NWS forecasters, emergency managers, media, and other agencies shared instantaneous and widespread communications through chat rooms/instant messaging. Participants also noted advantages of Micron Radio networks and WebEOC. These interactive communications programs eliminated thousands of time-consuming telephone calls. Updated river stage data were available at the click of a mouse around the clock for hundreds of individuals and agencies.

Frequent conference calls and video-teleconferences among government agencies, state and county emergency operations centers, and the media, for example, also improved communications efficiency and accuracy.

Fact: Communication within the NWS and between the NWS and its Federal, state, and local partners occurred at a rapid pace using many different means throughout the flooding.

Fact: Advances in capabilities of the Internet, such as chat rooms/instant messaging and Web conferencing, have reduced the need for time-consuming telephone and radio contact and allow for frequent interactive contacts among large groups of people.

4.4 Societal Perceptions

This section describes how businesses and members of the public reacted to the 2008 flooding. It highlights how the public's decision-making was influenced by its interpretation of the flood messaging and its prior history with the 1993 flood event. In addition, this section addresses the utility of providing information on uncertainty in river stage forecasts. Finally, the section discusses the role behavioral sciences can play in helping the NWS reduce loss of life and property in future flood events.

4.4.1 Communication, Forecast Uncertainty, and the Decision-making Process

Ideally, members of the public and businesses would receive NWS forecasts and then take appropriate actions to prevent loss of life and/or property. Social science literature, however, indicates people do not respond to warnings and weather information in a simple manner (e.g., Sorenson 2000). People bring significant perceptual and behavioral histories to the decision-making process. A whole suite of information—including people's information sources, perceptions, experiences, and emotions relating to weather events—needs to be understood and carefully addressed to maximize the possible benefits of NWS information.

An important step in assessing people's warning response is to determine how they interpreted the information provided. If people misinterpret or do not understand information, they are less likely to take beneficial actions. With respect to this flooding event, the team repeatedly heard that existing flood terminology, such as a 100-year or 500-year flood, was confusing. For example, representatives of the University of Iowa cited members of the public who had cancelled flood insurance after the 1993 flood because they were under the impression they would not experience another 1-in-100-year event in their lifetimes. This sentiment was repeated in discussions with other groups, including in meetings with the Benton County, Iowa, Emergency Management Agency, Linn County, Iowa, Emergency Management Agency, and the Iowa Water Science Center.

Finding 27: The use of 100-year and 500-year flood terminology was confusing to some members of the public.

Recommendation 27: The NWS should further its efforts with the USACE, USGS, other partners, and the public to communicate flood risk more effectively and develop an implementation strategy.

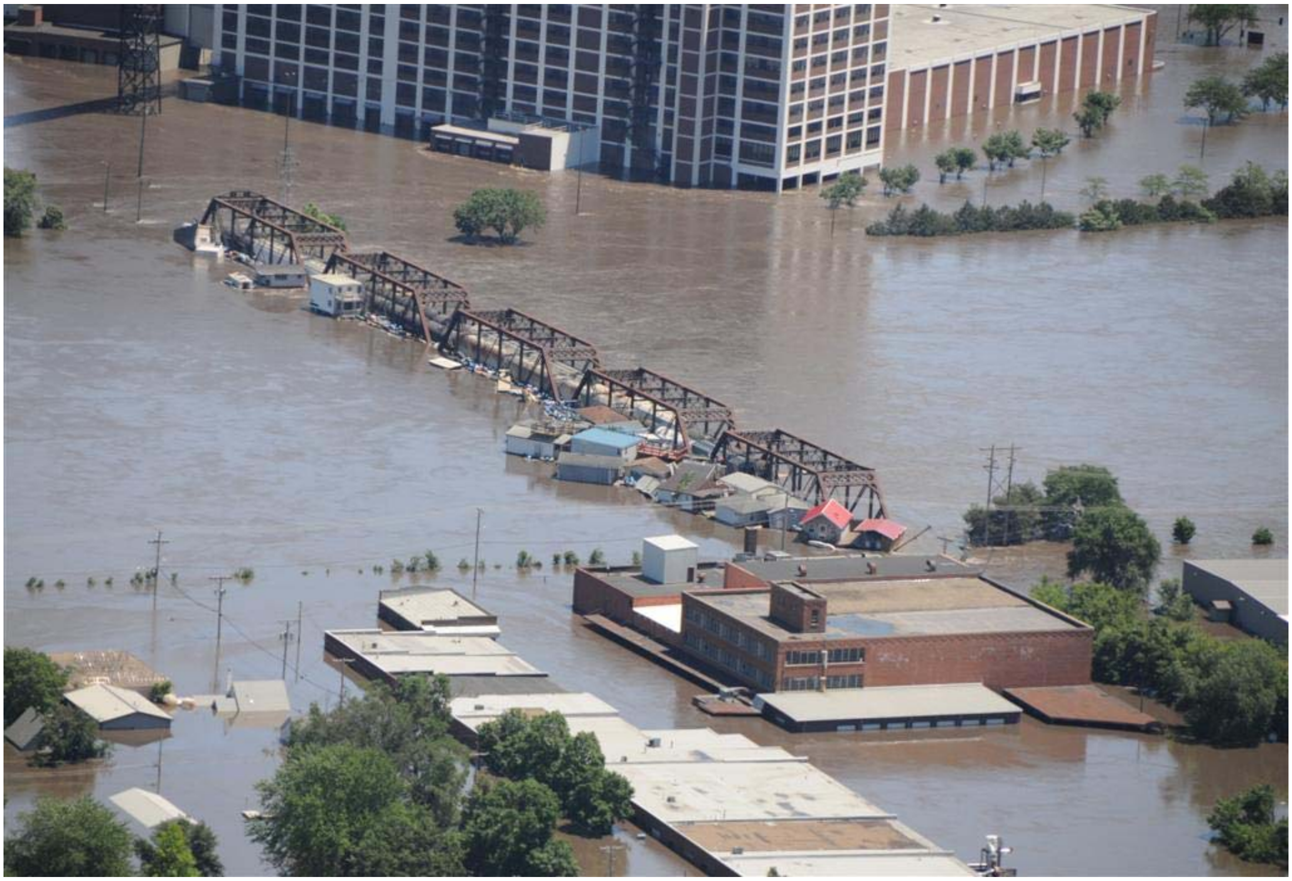

Fig. 30. Houseboats were carried by the Cedar River into the railroad bridge near the Quaker Oats plant in Cedar Rapids, Iowa. (Used with permission. ©2008 Iowa Homeland Security and Emergency Management Division. Photograph by the Civil Air Patrol.)

Another key point in effective communication is to assess how to convey uncertainty in river stage and flow forecasts. Within the meteorological enterprise, there is growing recognition of the value of providing uncertainty information (e.g., NRC 2006). Some initial surveys of members of the public show there is a public desire to receive forecast uncertainty information (Morss et al. 2008). Interviews with various public officials and businesses, however, did not provide a clear indication of whether river stage uncertainty would be valuable. In some cases, businesses clearly stated the provision of forecast uncertainty information would better allow them to gauge the potential for various flood crests. A notable example was Alliant Energy in Cedar Rapids, Iowa, where officials might have been more prepared to shut down reactors had they received some probabilistic information.

Another example of the value of forecast uncertainty information was presented by staff at the Davenport Public Works (DPW). DPW has a detailed action plan for various flood stages, with forecasts at transition points being particularly important. These transition points are flood stage forecasts where the DPW enacts varying levels of preventative action. In June 2008, as the deterministic NWS crest forecast at Davenport increased in magnitude over several forecast periods, DPW was left in a reactionary mode; at one point DPW officials took precautions to protect workers as they fortified a previously built levee. DPW officials said ensemble forecasts or some other form of uncertainty information would have enabled them to understand the various possible crests better and to improve decision making.

A final area of forecast uncertainty information that some interviewees felt may be valuable is forecasts on river flow rates. The need for these data were particularly noted in discussions with local and county water control and emergency managers in the Oakville area and with farmers in central Iowa. These users suggested forecasts of flow rates may have helped them make better decisions on how much time they had to act.

On the other hand, there was concern from many public officials that forecast uncertainty information might lead to additional confusion among businesses and members of the public. For instance, one emergency manager was concerned that providing uncertainty information to the public could lead to confusion on what actions to take, and result in longer meetings during emergencies if participants focused specifically on varying uncertainty forecasts.

Finding 28: It is still unclear how useful forecast uncertainty information for river stage and flow is to businesses and the public.

Recommendation 28: The NWS should work with academic partners and others to determine whether businesses and members of the public would benefit from forecast uncertainty information and, if so, what types and formats of flood uncertainty information would be most useful in decision making by businesses and the public.

4.4.2 Experience with the Central United States Flood of 1993

Although it occurred more than a decade earlier, the central United States flood of 1993 had a major influence on business and public response to the 2008 flood. In the majority of cases, businesses and individuals significantly affected by the 1993 flood were more likely to make adequate preparations for the 2008 flood. For example, in 1993 Mercy Medical Center in Cedar Rapids had only five 6-foot long sand points, which are pipes driven into the ground to draw water out of the soil. These sand points reduce the likelihood of seepage through the floor from hydraulic pressure. The five sand points did not have the capacity to remove groundwater quickly enough and, as a result, there was some flooding at the medical center in 1993 due to ground seepage. After that event, an additional 14 sand points were installed to increase water-removing capacity. An engineering assessment indicated the medical center was safe only up to a flood stage of 22 feet. As a result, when hospital personnel learned of the 26-foot forecast crest, they began contacting the local emergency operations center hourly for flood updates to maintain situational awareness. Two days before the crest, hospital staff began checking manholes to monitor water levels. Eventually 205 patients were evacuated.

In other cases, though, 1993 history had a negative impact on response to the 2008 flood. Staff of the University of Iowa pointed out, “90 percent of people felt that we couldn’t beat 1993” in terms of the severity of flooding. This perception led to the loss of a window of opportunity to move furniture, cars, and other goods from vulnerable areas. By the time some people realized the seriousness of their situation, it was too late to take protective action. In Vinton, Iowa, there were reports that some people living on the river did not believe the 2008 forecast. They thought 1993 was as bad as it could get. Those who did not take any protective action suffered preventable loss of property. Officials from the city of Coralville and from Johnson County, Iowa, echoed these sentiments and noted the majority of their constituents felt this event would be similar to 1993, when they were not greatly affected. Thus, they were reluctant to take preventative actions, such as sand-bagging or moving personal property.

Finding 29: Memories of the 1993 flood had a major impact on people's response to the 2008 flood. Businesses and people significantly affected by the 1993 event were more likely to prepare for the 2008 event, whereas those not significantly affected in 1993 were less likely to prepare for the 2008 event.

Recommendation 29: The NWS should work with its partners, businesses, and the public to reduce the chances that people's past experiences with high-impact weather situations do not reduce their likelihood of responding to current or future threats. To do this effectively, research is needed to examine the pros and cons of referring to past events when working with the public and businesses.

4.4.3 Integrating the Behavioral Sciences, Meteorology, and Hydrology

Findings presented in Section 4.3 note that NWS forecasts for this event had a high degree of accuracy in most locations with a fairly long lead time. Nevertheless, the team frequently heard that people suffered preventable losses. This finding confirms property damages are not entirely dependent on the quality of outlooks, watches, and warnings. Rather, people's interpretations, perceptions, and decision-making options also influence the impacts of a given flood. To this end, societal impact research and analysis can provide valuable information to the NWS in developing a better understanding of where people are obtaining information and what they are doing (or not doing) with that information. This type of research can lead to insights on how to communicate flood forecast information more effectively so members of the public and business owners are more likely to take protective action.

Fact: Societal impact research and analysis provide valuable information to the NWS in reducing loss of life and property in future events.

Best Practice 9: The NWS has increased emphasis on and support for research into how people obtain and respond to weather and other environmental information in high-impact and other situations and is assessing ways to integrate the results into its operations.

5. Concluding Remarks

In June 2008, many locations in Illinois, Indiana, Iowa, Missouri, South Dakota, and Wisconsin experienced record and major flooding. Flooding also affected Kansas, Michigan, Minnesota, Nebraska, and Oklahoma. Numerous counties in many states received Disaster Declarations from FEMA. Although the 2008 flooding was overall less severe than that of 1993, a significant portion of the region was hit much harder in 2008. The damage affected the lives and livelihoods of many people in many communities, some places at a catastrophic level. Eleven people in six states died. Reports indicate damages at more than $5 billion.

The Service Assessment identified 26 facts, 30 findings, 33 recommendations, and 9 best practices. Implementation of these will improve NWS products and services. To reiterate:

- Flooding in 2008 was generally less severe than in 1993, but some locations were hit much more severely in 2008.
- Quality of NWS products and services was high.
- The NWS was highly successful coordinating with partners in providing decision support services.
- Collaboration between the NWS, USGS, and USACE was excellent.
- NWS efforts were greatly enhanced by advances in atmospheric modeling, especially in precipitation prediction; implementation of AHPS and information on the AHPS Web site; and exponential growth of communication capabilities.
- Human factors played a major role in the public's responses or lack of response to warnings and other flood information. Additional study needs to be done in this area.
- There is still room for improvement in flood forecasting, communicating forecast information to the public, and getting the public to take action.

Appendix A

Summary of Facts, Findings, Recommendations, and Best Practices

The facts, findings, recommendations, and best practices are compiled below. For cross-referencing purposes they are listed according to the section of the report in which they appeared.

Summary of Facts

4.1 Usefulness of the Tools and Data in the Forecast Process

Fact: The top of the rating curve was exceeded at 17 of 21 forecast locations on the Cedar and Iowa Rivers. The top of the rating curve was exceeded at 37 locations in Illinois, Iowa, and Wisconsin.

Fact: The USGS deployed staff to make real-time river flow measurements at several locations where the observed river stage/river flow exceeded the existing rating curve.

Fact: A WFO's ability to use the graphical time series analysis tool efficiently was hampered by having to scroll through a list of elements to find the observed and forecast river stage information. AWIPS Discrepancy Report 19013 had been opened for this feature, but resources were not available to correct the problem before the June 2008 flooding.

Fact: NCRFC used the expertise of the USGS, USACE, and NWS Office of Hydrologic Development to extend rating curves during the flooding.

Fact: Rating curves were adjusted or redefined as part of the real-time hydrologic modeling process using either measurements or run-time modifications.

Fact: Demand for NWS river-forecast services continues to grow as a result of expanding population, increasing value of flood-vulnerable infrastructure, urbanization, and other physical changes in watersheds.

Fact: About a year and a half before the June 2008 flooding, NCRFC began producing an ensemble suite of river stage forecasts based on maximum and minimum QPFs for 24, 48, and 60 hours for the 95 percent confidence level. NCRFC provided these data to WFOs and the USACE.

Fact: Media, emergency management, and water managers described chat/instant messaging as invaluable in rapid dissemination of information throughout the flood.

Fact: NCRFC monitors up to 26 WFOs, in addition to HPC and other national centers, in a 12Planet chat room. This chat room provides information on various topics, including severe weather, flooding, and gridded forecast coordination.

4.2 Collaboration among the NWS, USACE, and USGS in the Flood Forecast Process

Fact: The USGS uses NWS forecasts of precipitation and river stage to plan where it will deploy its observational assets during flooding events.

Fact: River stage forecasts at some locations are made by both the NWS and USACE. Interagency coordination is used to provide consistent forecasts.

Fact: The NWS relies heavily on both the USACE and USGS for key data in river forecasting.

Fact: Improvements in technology since 1993 have greatly improved communication and data exchange among the NWS, USGS, and USACE.

Fact: Conference calls were held daily among NCRFC, WFOs, USGS, and USACE to coordinate information and collaborate on the resultant forecasts.

Fact: Coordination among WFOs, RFCs, USGS, and USACE was excellent.

4.3 Accuracy and Effectiveness of Service

Fact: HPC and RFC forecasts captured much of the precipitation that subsequently fell during June 2008. There was a general tendency to over forecast light amounts and under forecast heavy amounts. Forecast error was greater for heavier amounts of precipitation.

Fact: HPC forecasts were considerably more accurate than the numerical model forecasts. The MAE for HPC was 25 percent lower than the MAE for the NAM and 34 percent lower than the MAE for the GFS. NCRFC further improved the forecasts. NCRFC's forecasts of heavy precipitation for June 2008 were considerably more accurate than those of the previous 7 years.

Fact: During June 2008, there were 40 different river forecast points above flood stage in the hydrologic service area of WFO Des Moines. The office issued 102 flood warnings for forecast points within Iowa with an average lead time of 25 hours. The WFO's river flood warning probability of detection, false alarm rate, and critical success index for June 2008 were 0.89, 0.22, and 0.72, respectively.

Fact: During June 2008, 25 river forecast points in the Iowa portion of the WFO Quad Cities hydrologic service area were above flood stage. For the 31 flood warnings for forecast points within Iowa, the average lead time was 1 day, 18 hours, 50 minutes. The WFO's river flood warning probability of detection, false alarm rate, and critical success index for June 2008 in Iowa were 0.97, 0.00, and 0.97 respectively.

Fact: WFOs Des Moines and Quad Cities issued accurate and timely flood warnings for river forecast points in Iowa.

Fact: The tendency to underforecast heavy precipitation and using only 24 hours of QPF in preparing the official river forecasts led to river stages not forecast high enough at some locations.

Fact: Despite all the devastation, most emergency managers, other decision makers, and partners contacted during the Service Assessment said they felt NWS forecasts and warnings were as accurate and timely as the science permitted.

Fact: The NWS received considerable praise for the responsiveness of its staff to user requests. The AHPS Web pages enhanced NWS responsiveness by providing a continuous source of information to meet the needs of various user groups quickly.

Fact: Communication within the NWS and between the NWS and its Federal, state, and local partners occurred at a rapid pace using many different means throughout the flooding.

Fact: Advances in capabilities of the Internet, such as chat rooms/instant messaging and Web conferencing, have reduced the need for time-consuming telephone and radio contact and allow for frequent interactive contacts among large groups of people.

4.4 Societal Perceptions

Fact: Societal impact research and analysis provide valuable information to the NWS in reducing loss of life and property in future events.

<u>Summary of Findings and Recommendations</u>

4.1 Usefulness of the Tools and Data in the Forecast Process

Finding 1: State and local officials believed additional rain gages would enhance the ability to anticipate and monitor flooding events.

Recommendation 1: The NWS should work with state and local officials to determine an optimum rain-gage network for Iowa and to investigate options available for installing additional rain gages.

Finding 2: NCRFC personnel believed they were limited by policy to using no more than 24 hours of QPF in their official forecasts. In fact, there is no such limitation in NWS Instruction 10-911, RFC Operations.

Recommendation 2: NWS Regional Headquarters should ensure RFCs are aware of their options regarding the use of extended QPF in generating official river forecasts.

Finding 3: It was difficult to coordinate between WFOs and the NCRFC regarding the amount of QPF to use in some hydrologic forecast updates as a result of differing forecast processes and schedules at the WFOs and RFC.

Recommendation 3: NCRFC and Central Region Headquarters should discuss QPF coordination and collaboration issues with its WFOs and develop procedures to govern input of QPF during forecast updates. Procedures governing input of QPF should be developed at other RFCs and WFOs if they do not already exist.

Finding 4: Sometimes WFOs analyzed additional information during a forecast cycle and decided there was no need to update the QPF grid. In such cases, the grid update times were not modified by the Graphical Forecast Editor because the WFO did not distribute a new grid to the RFC and other users. The RFC could not tell from the grid information whether a WFO had decided not to update a grid or had simply not updated it yet in the cycle.

Recommendation 4: A methodology should be developed within the Intersite Coordination capabilities of the Graphical Forecast Editor to allow a site to modify the update time of the Intersite Coordination grids when the site has analyzed all the relevant data and does not issue a set of modified grids.

Finding 5: Although WFO Des Moines has an ALERT base station in the office, river stage data from several forecast sites are not automatically transferred to AWIPS. As a result, users must manually enter observed river stage information when executing the site-specific application for these locations.

Recommendation 5: WFO Des Moines should ensure the automatic transfer of ALERT data to AWIPS.

Finding 6: NCRFC used the run-time modification feature of NWSRFS to make adjustments to rating curves during the forecast process. This feature does not easily allow the user to examine the impact of the rating curve modification on the forecast crest.

Recommendation 6: The NWS should ensure modeling and modification capabilities within the Community Hydrologic Prediction System (CHPS) architecture include the ability for the user to make adjustments or extensions to the rating curve and be able to examine easily the impacts of these adjustments or extensions on the resultant forecast hydrograph.

Finding 7: Information regarding the time and extent of overtopping or breaching of levees and the storage volume behind breached or overtopped levees often was not immediately available to NCRFC and the impacted WFOs.

Recommendation 7: The NWS should develop a real-time process to alert WFOs and RFCs when levees are overtopped or fail.

Finding 8: The USACE is developing a national inventory of all levees in the United States. This inventory will include critical information such as levee alignment and centerline elevations.

Recommendation 8: The NWS should collaborate with the USACE to ensure the national inventory of levees being developed by the USACE is available to WFOs and RFCs.

Finding 9: During the event, NOHRSC worked with an interagency group that included the USGS and the Department of Homeland Security to obtain high-resolution inundation information and provide it to NCRFC. NCRFC was able to correlate inundation areas with specific levee failures and overtoppings, and adjust its forecasts, removing a certain amount of flow based on the areas of inundation.

Recommendation 9: NOHRSC should work with the USGS to assure the NWS is more directly involved in planning activities to obtain high-resolution inundation information for RFCs to use as critical data during floods.

Finding 10: Current modeling capabilities within NWSRFS do not handle the loss of storage and subsequent return of water to the hydrologic system associated with levee failures and overtopping. There are no run-time modifications that can easily account for such effects.

Recommendation 10a: The NWS should leverage the expertise of the USACE and others to investigate the utility of the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) or other hydraulic models that account for the effects of levee failures and overtoppings in real-time flood forecasting.

Recommendation 10b: The NWS should proceed with development and implementation of the Community Hydrologic Prediction System (CHPS) architecture as expeditiously as possible to ensure capabilities such as more advanced modeling of levee failures are available to forecast staff.

Finding 11a: Changing land-use characteristics, caused by such actions as the installation of tile drains in farm land, result in river model forecasts that can diverge significantly from what is observed.

Finding 11b: NCRFC staff estimated about 50 forecast locations in the NCRFC service area (out of a total of approximately 400 forecast points) need to be recalibrated due to changes in land use.

Recommendation 11: Where significant land-use changes have occurred, RFCs should recalibrate their models to account for these changes.

Finding 12: Forecast uncertainty information, such as ensemble forecasts of river stage prepared by NCRFC, was very useful to the USACE and others in their contingency planning. The USACE used this information in managing its water resource projects.

Recommendation 12: The NWS should expand its provision of forecast uncertainty information to the USACE and other local and state agencies involved in flood contingency planning.

Finding 13: Not all WFOs have the same level of understanding with respect to information provided in ensemble river forecasts.

Recommendation 13: Training and educational information and materials should be developed for NWS personnel and external users regarding strengths, weaknesses, and utility of ensemble river forecasts.

Finding 14: Information in ensemble river forecasts would benefit a wider audience than currently has access to these data.

Recommendation 14: RFCs producing ensemble river forecasts should include information in Hydrometeorological Discussions highlighting situations when one or more of the ensemble forecasts indicate potential flooding.

Finding 15: A number of users of NWS products would benefit from an expanded suite of probabilistic QPFs, river stages, and river flows.

Recommendation 15: The NWS should make available as expeditiously as possible HPC's experimental probabilistic QPF capability and the eXperimental Ensemble Forecast System (XEFS) for river forecasting.

Finding 16: There is limited linkage between development of HPC's probabilistic QPF capability and development of the XEFS.

Recommendation 16: The NWS should ensure the development of its forecaster-based probabilistic QPF capability is part of the plan for the development of the XEFS.

Finding 17: The NWS did not use chat/instant messaging to collaborate with its Federal partners, such as the USGS and the USACE, during this event.

Recommendation 17: The NWS should investigate using current technologies such as chat/instant messaging to facilitate communication and collaboration with Federal partners, such as the USGS and the USACE, and with other partners during flood events.

Finding 18: NCRFC had only three 12Planet accounts. During the 2008 flooding, NCRFC had as many as 16 staff members on duty at one time. As a result, bottlenecks developed when using 12Planet chat.

Recommendation 18: NWS should increase the number of 12Planet accounts to accommodate RFC staffing profiles during significant flooding.

4.2 Collaboration among the NWS, USACE, and USGS in the Flood Forecast Process

Finding 19: There were occasions when NWS staff members were not aware of certain USGS field activities supporting the flood forecasting process. Likewise, USGS staff at the Iowa Water Science Center and USACE personnel were not acquainted with details of the NWS flood forecast process. Awareness of the NWS, USGS, and USACE staff of these activities might have provided the opportunity for enhanced flood forecasting.

Recommendation 19a: Periodic meetings should be scheduled at least annually between collaborating offices of the NWS, USGS, and USACE to discuss their common data and forecast needs and ensure all points of contact are current.

Recommendation 19b: The NWS, USGS, and USACE should initiate a scientist/engineer exchange program so staff better understand the operations, requirements, and constraints of each organization.

Recommendation 19c: The NWS should pursue the proposed creation of an Interagency Fusion Cell comprising members of NWS, USGS, and USACE to determine what improvements can be made to increase the accuracy of forecasts given the current science, staffing resources, and level of funding.

Finding 20: Many NWS partners voiced the need for more streamgages. These partners would like these new gage sites to be NWS river forecast sites.

Recommendation 20a: The NWS, USGS, and USACE should issue joint news releases to educate the public on how the streamgage network is operated and funded and should work with appropriate county and state officials to ensure they are aware of the options available for procuring additional streamgages.

Recommendation 20b: The NWS, USGS, and USACE need to hold a streamgage optimization summit to determine the optimal network of streamgages to enhance NWS river forecasts.

Finding 21: The NWS depended heavily on the USGS for updated rating curve information when rating curves were exceeded.

Recommendation 21: The NWS, USGS, and USACE need to collaborate to develop rating curve extensions before flood emergencies.

4.3 Accuracy and Effectiveness of Service

Finding 22: Many users preferred earlier delivery of products and services. People involved directly with flood fighting preferred morning delivery, the earlier the better.

Recommendation 22: The NWS should address customer requirements for earlier delivery of flood-related products and services.

Finding 23: Some information on the AHPS Web site is unfamiliar to a number of the site's users, so the full potential of the site is not being achieved.

Recommendation 23: The NWS should post a users guide on the AHPS Web site.

Finding 24: Users have developed a certain expectation of the times of day when products will become available based on their availability during fair weather. During high-impact weather, users expect to receive products about the same time.

Recommendation 24: If it is not possible to meet the fair weather schedule for issuing products during emergency situations such as significant river flooding, a method needs to be developed to manage people's expectations about delayed service delivery.

Finding 25: The Iowa and Missouri Departments of Transportation have compiled additional information correlating road impacts to specific river stages. An opportunity exists to work with the state departments of transportation and other entities to update and enhance flood impact statements on the AHPS Web pages.

Recommendation 25: WFOs should collaborate with state departments of transportation, emergency managers, city engineers, floodplain managers, and others to develop specific road impacts where appropriate. These impacts should be added to the WFO database to ensure road impacts are available via the AHPS Web pages.

Finding 26: Flood inundation mapping will help the public, media, emergency managers, and others visualize the spatial extent and depth of flood waters in the vicinity of NWS river forecast locations.

Recommendation 26: The NWS should expand efforts with state and Federal agencies and other groups to accelerate the implementation of flood inundation mapping across the United States. Such information should use standardized geospatial reference systems and should include indications of its accuracy and derivation.

4.4 Societal Perceptions

Finding 27: The use of 100-year and 500-year flood terminology was confusing to some members of the public.

Recommendation 27: The NWS should further its efforts with the USACE, USGS, other partners, and the public to communicate flood risk more effectively and develop an implementation strategy.

Finding 28: It is still unclear how useful forecast uncertainty information for river stage and flow is to businesses and the public.

Recommendation 28: The NWS should work with academic partners and others to determine whether businesses and members of the public would benefit from forecast uncertainty information and, if so, what types and formats of flood uncertainty information would be most useful in decision making by businesses and the public.

Finding 29: Memories of the 1993 flood had a major impact on people’s response to the 2008 flood. Businesses and people significantly affected by the 1993 event were more likely to prepare for the 2008 event, whereas those not significantly affected in 1993 were less likely to prepare for the 2008 event.

Recommendation 29: The NWS should work with its partners, businesses, and the public to reduce the chances that people’s past experiences with high-impact weather situations do not reduce their likelihood of responding to current or future threats. To do this effectively, research is needed to examine the pros and cons of referring to past events when working with the public and businesses.

Summary of Best Practices

4.1 Usefulness of the Tools and Data in the Forecast Process

Best Practice 1: WFO Des Moines collaborated with Story County, Iowa, to place streamgage data of the Ames ALERT Network on the AHPS Web page.

Best Practice 2: WFO Des Moines generated site-specific forecasts for locations on Walnut Creek and Four Mile Creek at user request. These forecasts assisted local emergency managers in planning and mitigation activities.

Best Practice 3: WFO Quad Cities shared information from the ensemble river forecasts with the local emergency management community for planning and preparation purposes.

Best Practice 4: WFO Quad Cities used the AWIPS BLESS function to ensure forecast information was properly reviewed, validated against current observations, and modifications coordinated with NCRFC prior to being posted to the AHPS Web pages.

Best Practice 5: WFOs Des Moines and Quad Cities used chat/instant messaging to collaborate and coordinate effectively and efficiently with state and local emergency managers and the media during the flood event.

Best Practice 6: During this event, NCRFC staff placed extensive, descriptive comments in their RVF products. WFO Quad Cities found these comments to be extremely valuable because they allowed WFO staff to learn quickly of NCRFC forecasters' thoughts and concerns, including forecaster confidence as well as contingencies. These comments helped reduce the amount of follow-up coordination with NCRFC because the comments answered many questions.

4.2 Collaboration among the NWS, USACE, and USGS in the Flood Forecast Process

Best Practice 7: USACE provided a hydraulic engineer to help NCRFC assess the impacts on river forecasts when levees overtopped. In addition, individual USACE offices provided levee overtopping information to help determine the impact on flow forecasts.

Best Practice 8: USGS provided a hydrologist to NCRFC to supply expertise with flood tools and to serve as a liaison to other USGS Water Science Centers. He worked directly with staff at the Iowa Water Science Center to keep rating curve extension updates current as new measurements were taken. He also worked with rating curve implementation and validation.

4.4 Societal Perceptions

Best Practice 9: The NWS has increased emphasis on and support for research into how people obtain and respond to weather and other environmental information in high-impact and other situations and is assessing ways to integrate the results into its operations.

Appendix B

End-to-End Flood Forecast Process

This appendix describes the general forecast process used by the NWS for major flooding events. The process, summarized in **Fig. B-1**, begins with the atmospheric models, forecast guidance, and observational data, all of which are critical to NWS field offices. Then river modeling and forecasting at RFCs are performed, followed by data analysis and forecasting at WFOs. The forecast process ends with the field office issuing river stage forecasts and flood warnings. Coordination and collaboration activities among the following offices take place throughout the process:

- NWS River Forecast Centers (RFC)
- NWS Weather Forecast Offices (WFO)
- NWS Hydrometeorological Prediction Center (HPC)
- U.S. Geological Survey (USGS)
- U.S. Army Corps of Engineers (USACE)
- Emergency Managers
- Media

The NWS monitors river levels at nearly 4,200 locations and issues river forecasts and warnings for approximately 2,800 of these locations. Most of these observations come from networks supported by government organizations, primarily the USGS and USACE. Although serious flash flooding did occur in conjunction with the 2008 central United States river flooding, this discussion does not address the process associated with flash flood products and services because flash flooding was not part of this assessment.

B.1 Production of Precipitation Forecast Guidance

Various components of the National Centers for Environmental Prediction (NCEP) prepare national and global weather, water, climate, and space weather guidance, forecasts, warnings, and analyses. Several products from these centers are of particular relevance to the flood forecasting process. Working together in Camp Springs, Maryland, the Environmental Modeling Center (EMC) and NCEP Central Operations (NCO) provide the foundational numerical weather forecasts. Using these numerical forecasts as input, HPC forecasters provide key precipitation and temperature guidance forecasts, which are two of the inputs to the river forecasting process. The Climate Prediction Center (CPC) provides forecasts such as 6-10 day, 8-14 day, and 1-month outlooks of probability of precipitation. Their products are not detailed here because this study focuses on the shorter-term flood forecasting process.

B.1.1 NCEP Environmental Modeling Center and Central Operations

Staff members of NCEP's EMC and NCO develop and operate a suite of numerical forecast systems (NFS) covering the global domain and a regional domain centered on North America. The NFS guidance is the primary tool used by forecasters to predict the state of the atmosphere beyond the ensuing 12 hours. Each NFS is composed of a forecast model and an

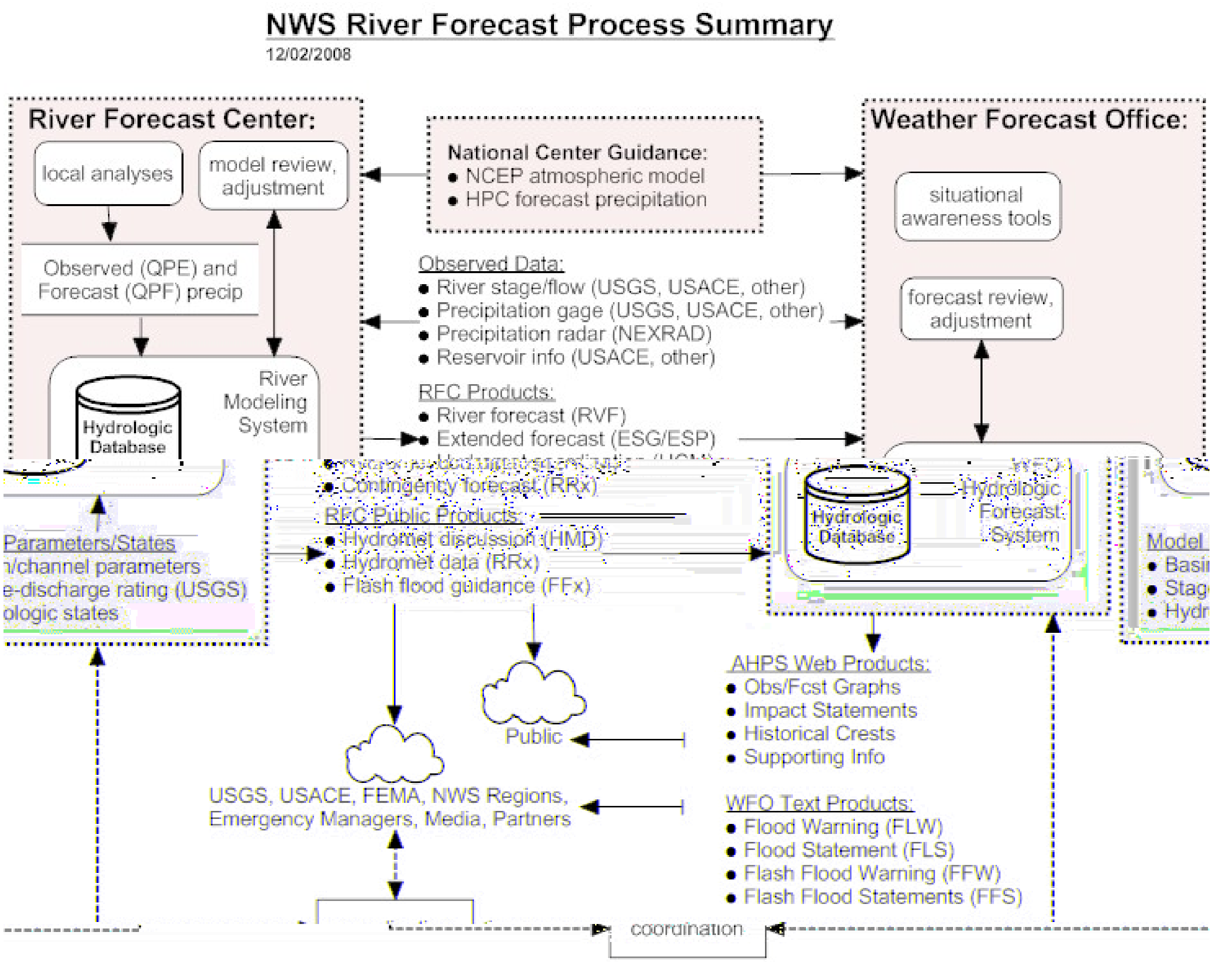

Fig. B-1. NWS river forecast process summary. (Source: NOAA/NWS Service Assessment Team.)

initialization process defining the state of the atmosphere based on the latest observations. Multiple runs, called ensembles, of each NFS are executed with slightly different initial conditions, model physics, and/or model numerics to provide more information on the possible forecast scenarios for any particular initial state.

Atmospheric forecast models are complex representations of the physical processes extending from the earth's surface to 25-35-mile altitude. Forecast models predict wind, temperature, moisture (water vapor, cloud water, and precipitation), surface pressure, and other quantities. From these quantities, forecasters can derive many other meteorological and hydrologic variables, such as atmospheric stability and soil moisture.

Each forecast model must be initialized with an accurate representation of the atmospheric, land surface, and oceanic state through a process called data assimilation. Data assimilation involves combining information from the latest observations and from a previous run of the forecast model. The latter is necessary because the observations are not sufficient to define the atmospheric state completely and information from previous observations can be carried forward in time through the forecast model. Sources of observations include weather balloons, commercial aircraft, surface weather stations, Doppler radar, ocean buoys and ships, and satellites.

Due to the inherent uncertainty in predicting the atmosphere, ensemble-based forecast systems provide more information than a single forecast. Uncertainty can derive from the atmospheric state itself, from the model, and from the observations. The average of all ensemble member forecasts provides a more accurate and reliable forecast. The differences between members are a good indicator of uncertainty. This uncertainty can be conveyed to users, with some users employing ensemble uncertainty information in sophisticated risk-reduction strategies.

B.1.2 Hydrometeorological Prediction Center

The HPC, also located in Camp Springs, Maryland, is responsible for production of a broad suite of products. QPFs are important, primary tools used in the hydrologic forecast process. HPC produces QPFs in 6-hour periods through 120 hours for the conterminous United States. The center generates a complete QPF package twice daily, which it provides to the RFCs for their refinement and use in the river forecast models, as well as to WFOs for use in generating the National Digital Forecast Database (NDFD).

HPC forecasters have access to the predictions of several numerical weather models of NCEP, discussed in the previous section, as well as models of the U.S. Navy, Environment Canada, the European Centre for Medium Range Weather Forecasts, and the Meteorological Office of the United Kingdom. Each model has different strengths, weaknesses, and biases for certain weather regimes. The forecasters also have access to multiple runs (ensembles) of the models.

At HPC, the QPF process starts with the forecasters' assessment of the current, real-time atmospheric conditions. Forecasters compare current conditions with those represented in the various atmospheric forecast models to determine the performance and reliability of the previous model forecasts and to make judgments as to which models should be used as a starting point. Upper-air data such as from radiosondes, satellite imagery, and data from the Weather Surveillance Radar-1988 Doppler (WSR-88D) are key components in this analysis process.

Although numerical models usually forecast areas of precipitation fairly well, models have internal biases and are unable to forecast some mesoscale and convective processes that help initiate and focus significant precipitation areas. HPC forecasters use model forecasts, model biases, pattern recognition, and forecaster knowledge to make adjustments to the model-predicted precipitation forecasts. Accounting for strengths, weaknesses, and biases is a major role of the forecasters in the process. Verification records show HPC forecasters improve on numerical model forecasts of precipitation by about 20 percent. Given the long-term, continuing upward trend in accuracy of precipitation forecasts by both models and forecasters, it will be about 15 years before the accuracy of model forecasts reaches the current accuracy of HPC precipitation forecasters. HPC forecasters also add value to the forecast process by serving as catalysts for collaboration with WFOs and RFCs in arriving at meteorologically sound and

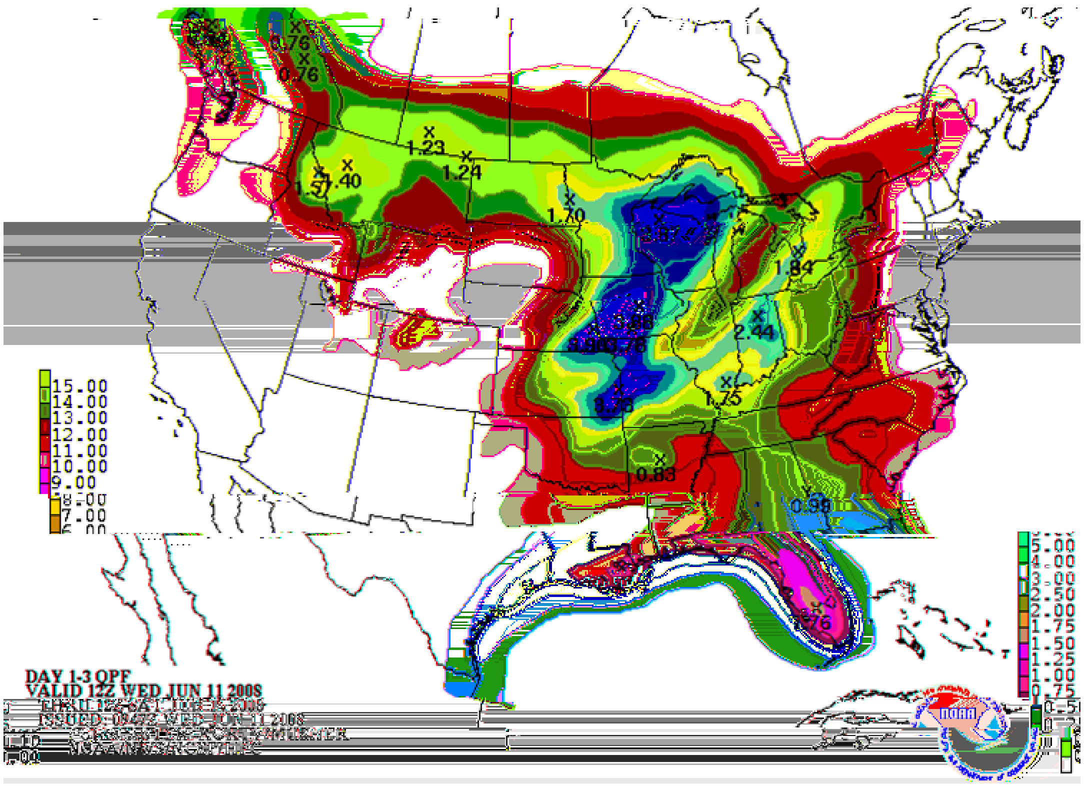

Fig. B-2. Sample HPC QPF graphic for the 72-hour period from 12 UTC June 11 to 12 UTC June 14, 2008. Values are in inches. (Figure courtesy of the NOAA/NWS Hydrometeorological Prediction Center.)

consistent forecasts. This collaboration is done during the forecast process, as the need exists, through the use of Internet-based tools, point-to-point telephone calls, and conference calls.

The resultant forecasts are in the form of isohyets (lines of equal precipitation) on a geographical map of the United States. **Fig. B-2** depicts a 3-day QPF example.

Once a QPF package is complete, these graphical contours are post-processed to create gridded and point forecasts. These forecasts are then made available to the RFCs and WFOs through the communications capabilities of the Advanced Weather Interactive Processing System (AWIPS). The forecasts are also available through the NOAA Family of Services and NOAAPORT, as well as the HPC Web site. A written forecast discussion, known as the QPF Discussion, explains forecaster reasoning and accompanies all graphic QPF products.

B.2 River Forecast Centers

An RFC conducts its operations in accordance with the NWS Hydrologic Services Program, which is formally documented in the NWS Directives System, available at http://www.nws.noaa.gov/directives. NWS Policy Directive 10-9 covers the Hydrologic Services Program, with RFC activities described in NWS Instruction 10-911, RFC Operations.

A specific RFC's operations are further documented in the office's Station Duty Manual, which discusses the different duties performed and products issued at the RFC. These products include river forecast information at specific service locations for the short term (out to 7 days), medium term (7-14 days), and long term (2 weeks out to 3 months or more.)

The focus of the following discussion is on the production of short-term to medium-term flood forecasts, with some brief references to the long-term forecast process.

B.2.1 Observed Data Inputs

The RFCs operate the river forecast models generating river forecasts. These models require observations of river level, precipitation, and temperature, as well as information on reservoir releases and other hydrometeorological inputs. Different sensor types measure different environmental conditions. These sensor systems are operated by an assortment of agencies and provide real-time data to the NWS via a variety of data transmission methods. A summary of the data types, networks, and transmissions follows below.

- Data Types—Streamgage and precipitation gage data constitute the bulk of the required model data. Temperature and sunshine data are required for snowmelt and evaporation estimations made within river models, although these effects are minor for high-flow, non-winter flood events caused by heavy precipitation. For areas of the country where rivers are subject to the influence of dams or other control structures, the models require data about reservoir releases, diversions, or other river flow phenomena that cannot be directly modeled.

- Data Networks—The USGS and USACE operate data networks that provide large volumes of river, precipitation, and other data critically important to the river forecasting function at the RFC. A number of these gages are operated in a cooperative fashion with state, county, and local governments. The NWS also operates and/or supports some data networks, including hydrometeorological observing stations. The NWS manages an extensive cooperative observer network, which includes the collection of precipitation and river stage data. In addition, the NWS uses data from many other data networks operated by local governments and partners.

- Data Transmission—For the many gages with a Data Collection Platform (DCP), the sensor data are collected and transmitted via satellite communications. The NWS Hydrometeorological Automated Data System receives these data and decodes and retransmits them to NWS offices. This system handles data from the approximately 13,000 locations shown in **Fig. B-3**.

The USACE and other operators of river control structures, such as power companies, provide relevant data directly to the NWS, often using the Unidata Program's Local Data Manager, a product of the University Corporation for Atmospheric Research. These data include reservoir and lock and dam outflow information.

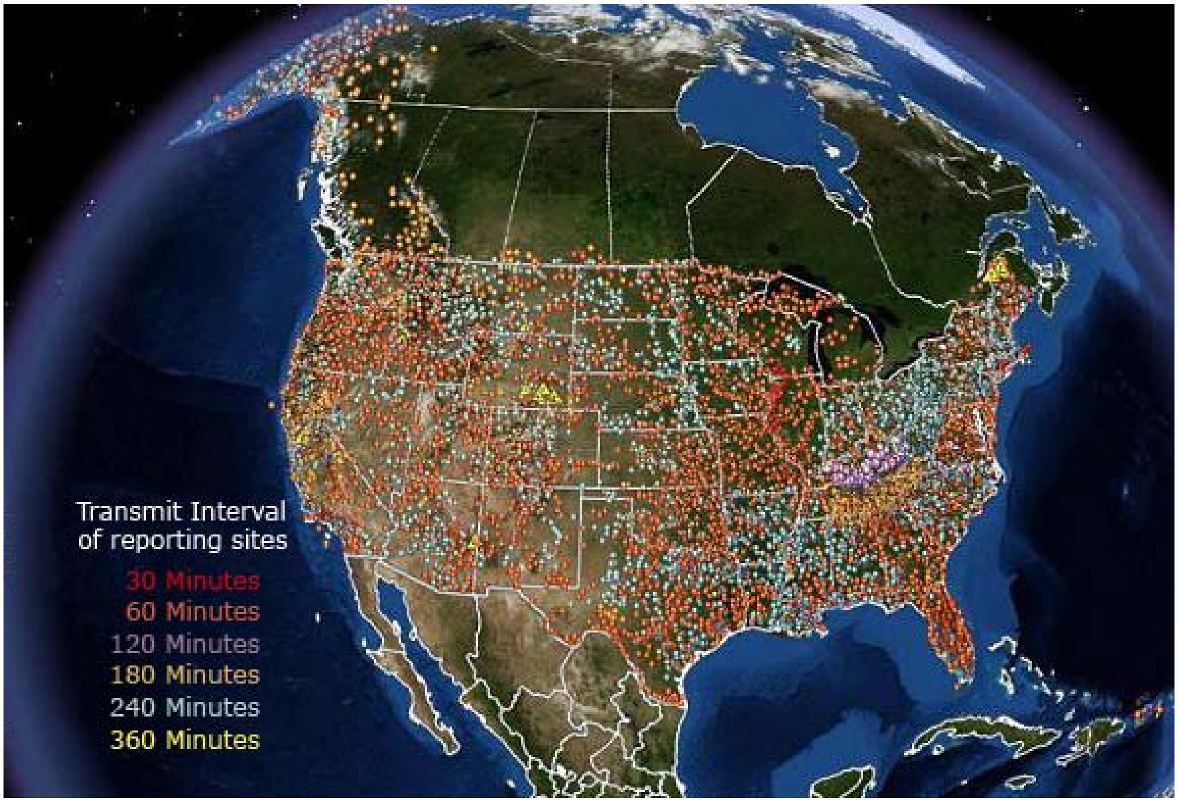

Fig. B-3. Data stations of the Hydrometeorological Automated Data System. (Source: NOAA/NWS, http://www.nws.noaa.gov/oh/hads/.)

During a high-flow event, data can also be collected from nonstandard sources. For example, estimated observations may be called in by on-site spotters using references to surrounding landmarks, such as water levels under bridges. The information is especially valuable when gages become inoperable due to very high flows, which may submerge the equipment.

B.2.2 RFC River Model Concepts

At the RFC, observational data are input into river forecast models, which have been calibrated based on past observations of elements such as rainfall and streamflow. An RFC forecaster reviews the generated forecast and may adjust it to match river conditions or to reflect other criteria. After review, a river forecast product (RVF) is encoded and distributed for use at WFOs and by selected partners.

The river models used to generate the core forecast information are complex models integrated within a large-scale modeling system. These models must be configured ahead of time to define the river network being modeled and the data network providing the observational and forecast data. Also, the hydrologic characteristics (for example, the rainfall-runoff relationship) and the hydraulic characteristics (such as river reach properties and dynamic flow effects) must be carefully studied and represented in an accurately calibrated set of model parameters to ensure model accuracy.

A simplified description of the model process is given below. To forecast the amount of water flowing past a certain point along a river, the model breaks the flow down into three components: baseflow, runoff, and routed flow.

1) Baseflow—the amount of water coming from groundwater. During a large flood event, the proportionate contribution of baseflow to the total flow is very low. Therefore, baseflow is not important during a flood event; it is relevant for low-flow conditions.

2) Runoff—the amount of water traveling over the land surface. Runoff generally comes from rainfall and snowmelt. The model estimates runoff for each type based on characteristics of the weather and the river basin. Snowmelt calculations depend in part on air temperature and amount of sunshine. Other adjustments are possible to incorporate the effects of wind and high dewpoints on the runoff from the snowpack. The rainfall/runoff relationship is based on slope of the land, amount of urbanization, soil types, nature of prior precipitation, and amount of evaporation occurring over the basin.

   When rain begins to fall, it generally either enters the soil or runs off directly into the channel. The latter condition occurs especially when the ground is saturated, which can quickly occur during heavy or prolonged rain events. Models of conceptual soil moisture accounting (SMA) distribute available moisture through the soil zones with assumed percolation characteristics. The water capacity of the zones and percolation characteristics between zones are determined by calibrated parameters. The amounts of water simulated to exist in the various zones at a given time are known as soil moisture variable states.

   Runoff takes time to flow into the river, with the amount of time depending in part on where in the basin the rain fell. Any graph of water flow versus time is called a hydrograph. A special pre-calibrated hydrograph, called the unit hydrograph, is based on the basin receiving enough rain to produce 1 inch of runoff for a given duration. Each basin has a unique unit hydrograph. Each time the model is executed, the unit hydrograph is used to determine flow at the basin outlet based on model-calculated basin runoff. The duration used is normally 6 hours, meaning the models generate forecasts of river levels at every 6 hours over some period in the future, typically 7 days.

   If snowmelt is discounted, observed and forecast rainfall entered into the rainfall-runoff model determines the basin runoff. This runoff is then translated into flow at the basin outlet through use of the unit hydrograph.

3) Routed flow—the water moved downstream from the upstream gage point(s). Different methods of routing are used, but all rely on the principle that water passing through the upstream point must eventually pass through the downstream point, barring such things as human intervention and levee failure. Routing makes use of various factors such as riverbed slope and cross section, viscosity of water, channel roughness, and distance between gaging points.

The predefined network of tributaries moves the water downstream, adding the routed flows with the local runoff flows, to determine a total flow at each point. This overall process is repeated for each river network within the RFC area. **Fig. B-4** shows the NCRFC river network, forecast basins, and forecast locations.

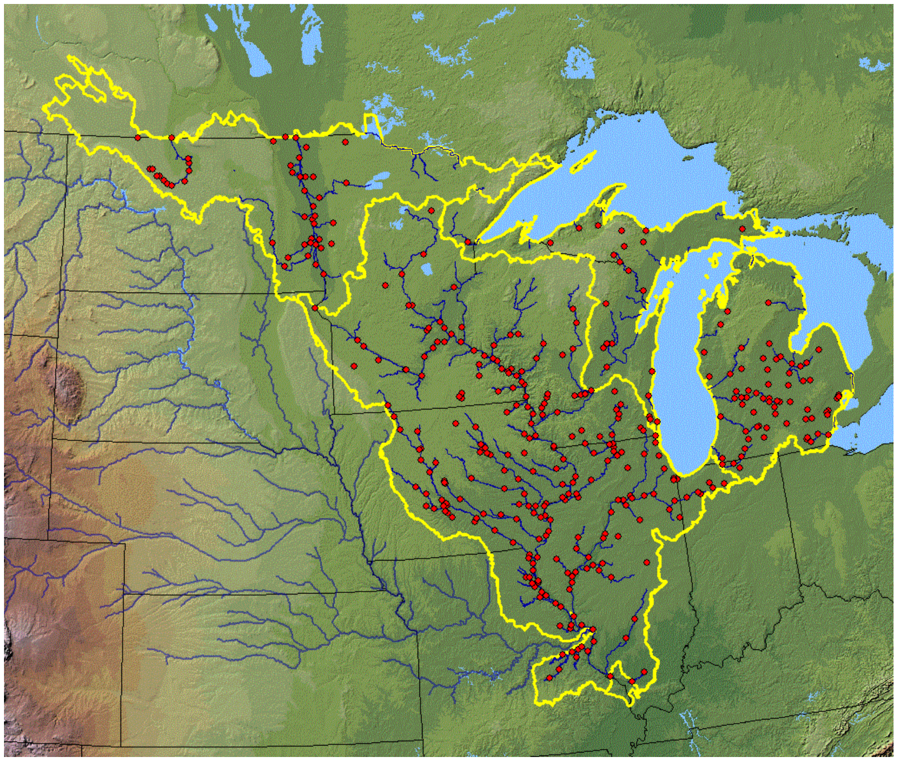

Fig. B-4. NCRFC River Model Network. Yellow lines designate the extent of the Upper Mississippi and Great Lakes basins and portions of the Lake Winnipeg basin. Red dots indicate NWS river forecast points. (Figure courtesy of the NOAA/NWS North Central RFC.)

Physical modeling is done using river flow data, not river stage data, because models work with volumes of water. Stage is dependent on channel cross-section geometry, which varies upstream and downstream and from river to river. River flow is the volume of water per unit time passing a specific span of the river. Throughout the forecast process, river stage values and flow values must be converted from one to the other. An empirical relationship referred to as a rating curve (or rating table) is used to relate river stage (also known as water level) and river flow (also known as discharge.) (See **Fig. B-5**.) These rating curves are provided primarily by the USGS and USACE and are essential to the river modeling process.

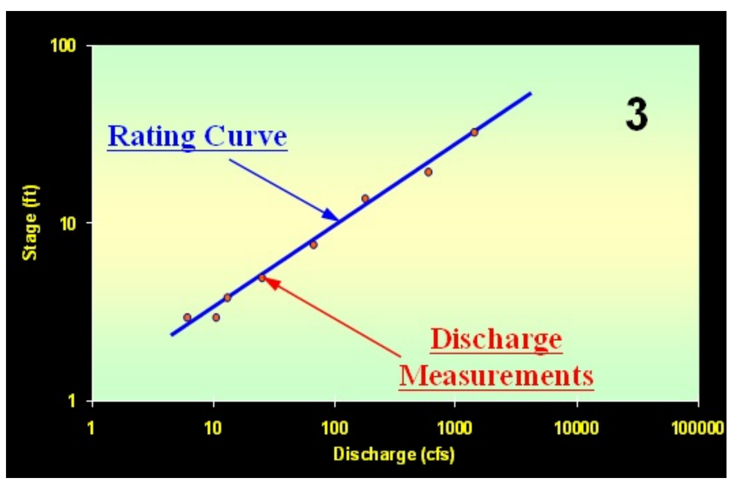

Fig. B-5. Sample USGS rating curve, which relates river discharge and river stage. (Figure courtesy of the USGS.)

The accuracy of estimated rainfall, calibrated rainfall-runoff parameters, and calibrated unit hydrograph parameters all play critical roles in forecast accuracy. Estimated rainfall includes both observed precipitation (quantitative precipitation estimates–QPE) and quantitative precipitation forecasts (QPF). If one assumes accurate observed precipitation estimates and proper calibration of the hydrologic model, there is still a major source of uncertainty in the river models introduced by the future precipitation, which is often difficult to forecast. The timing, amount, and location of precipitation directly impact the river flow forecast. Therefore, accurate forecasts of precipitation are critical to river forecast accuracy.

QPFs generated by atmospheric models and forecasters are vital in providing a forecast range for the maximum and minimum stages of the river. In addition, executing the hydrologic model with contingency what-if scenarios can be beneficial. These contingency forecasts may include various amounts of QPF over particular time periods. RFCs may generate this ensemble of contingency river forecasts and make them available to WFOs and others.

B.2.3 Steps in the RFC Forecast Generation Process

This section lists the general steps taken to produce an operational river flood forecast. Assumed is that the necessary data have been ingested and posted and the models fully calibrated and configured. RFC staff members typically perform the following steps:

1) Quality Controlling River and Other Data—The forecaster manually reviews observational data, which have already undergone some automated quality control. River data will be checked along with other data, such as temperatures, which are input into the models. Corrections are made as necessary.

2) Defining QPE—Forecasters analyze and adjust multisensor precipitation estimates for use as input to hydrologic models. This involves extensive quality control of precipitation data, because both gage reports and radar estimates can have serious errors. After the precipitation quality control process is complete, QPE software is used to generate the best estimate QPE for use in the model runs.

3) Defining QPF—Forecasters analyze EMC model output, HPC QPF, WFO QPF, and other guidance to generate QPF used as input to hydrologic models. RFC staff members adjust the HPC and WFO QPF, collaborating with those offices if necessary. QPF is often generated for multiple periods starting at the next model run time. These periods can include 12, 24, 48, 60, and 72 hours into the future.

4) Coordinating Supplemental Data—In certain areas of the country, USACE and other operators of water control structures exchange specialized information with the RFC. For example, inflow forecasts for a reservoir may be transferred to the USACE, which then uses these forecasts as input to its models to generate an outflow forecast from the reservoir. The forecast is then provided to the RFC for use in its models.

5) Running the Models—Calibrated river models with real-time modifications to update hydrologic states are executed. The models are automated using the previously reviewed and processed observed and forecast data, previously defined model parameters, and

model states based on previous model runs. The execution of the models is initiated and managed interactively as part of forecaster review of a given river system.

6) Reviewing Model Output—Forecasters must review the model output and in some cases the model is adjusted, based on forecaster judgment. Adjustments may be made to the model parameters and soil moisture variable states to match the current event, because the model parameters are generally calibrated to a limited set of events, which may not match the current event characteristics. For certain locations, forecasters may collaborate with partners, such as the USACE, to ensure consistent forecasts.

7) Creating Forecast Products—Once the model output is accepted by the forecaster, it can be used to generate a series of forecast products, most important of which is the RVF. The river forecast is a time series of values usually 6 hours apart and given for designated forecast points along a river. The official time series is generally only for one QPF scenario (for one duration, such as 24 hours, and from one source, such as the HPC/RFC QPF) although ensemble forecasts may be generated based on alternate QPF. Forecasters also create other products, such as forecast discussion or coordination messages.

8) Disseminating Products—Generated products are distributed. Most are sent to public outlets for external use, while some are made available only to other NWS offices or governmental partners. These internal products usually are experimental.

   Normally, an RFC is open 16 hours per day, but during a flood event, the office may initiate 24-hour operations. The forecast products are generated and shared on a defined cycle, which varies by RFC, but usually includes two or more cycles per day. In addition, non-routine updates to river forecasts may also be provided.

The forecast process is a dynamic process often involving extensive coordination with other NWS offices, USGS, USACE, local government offices, media outlets, and others. This coordination depends heavily on previously established relationships with these other entities. During large, complex flood events, coordination is vital.

The USGS may provide real-time guidance to the NWS on the usage of rating curves, especially if any rating curves are exceeded and need to be extended. This can occur during record flood events. The USACE may provide custom support and guidance to the NWS to coordinate water control structure operations and activities. Furthermore, if there are levee breaks or other unexpected events impacting river behavior, coordination with USACE or levee districts is vital because these breaks greatly complicate the river model approach.

B.2.4 RFC Products

The suite of products issued by an RFC is detailed in NWS Instruction 10-912, River Forecast Center Products Specification, and NWS Manual 10-913, River Forecast Center Product Examples. The RVF is the core product, but other products are also relevant to the flood forecast process, including the Hydrometeorological Discussion (HMD), the Hydrometeorological Coordination Message (HCM), and the Hydrometeorological Data

Products (RRx). Each of these products is described below. Extended-range forecasts and flash flooding products are not discussed here.

B.2.4.1 River Forecast (RVF) Product

This short-term hydrologic forecast product provides routine and event-driven hydrologic forecasts. The information is usually encoded in the Standard Hydrologic Exchange Format (SHEF), a machine- and human-readable text format. An example RVF excerpt is given in **Fig. B-6**. This product is available to the public on the Internet.

An RFC can embed comments in RVFs. These comments can provide detailed supporting information to complement the forecast information. Comments may discuss QPF, reservoir releases, and rating curve usage, for example. Information on QPF associated with a given forecast is necessary for the proper interpretation of the forecast. An example RVF comment block is shown in **Fig. B-7**.

B.2.4.2 Hydrometeorological Discussion (HMD) Product

HMDs provide hydrology-oriented overviews of current and expected hydrometeorological situations across the RFC area. This product is available to the public on the Internet.

The HMD enhances WFO understanding of the meteorological basis for the forecast, including discussion of the observed and forecast precipitation. The HMD also can provide details on hydrologic conditions in the basins, such as saturated soil, rising or falling trends of rivers, and possible reservoir operation considerations. This written public discussion complements verbal coordination among offices and helps maintain situational awareness.

B.2.4.3 Hydrometeorological Coordination Message (HCM) Product

HCMs, issued by both RFCs and WFOs, communicate internal forecast/support-oriented information among RFCs, associated WFOs, and NCEP using the NWS Wide Area Network. This product is not made public, but may be made available through secured channels to partners.

During flood events, both RFCs and WFOs generate and use HCM products extensively, as HCM products are an invaluable component of coordination efforts. Furthermore, HCMs help document the event.

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RIVER FORECAST
NWS ARKANSAS BASIN RIVER FORECAST CENTER TULSA OK
838 AM CDT FRI JUN 14 2002
:
:THIS IS A NWS GUIDANCE PRODUCT FROM THE RIVER FORECAST CENTER.
:OFFICIAL FORECASTS/WARNINGS ARE ISSUED ONLY BY VARIOUS LOCAL NWS OFFICES.
:BELOW ARE 6-HOURLY FORECASTS.
:FORECAST GROUP IS HAV_ARKANSAS_FLOOD
:
:****************************************************************
:ARKANSAS RIVER AT ARKANSAS CITY 1W
:FLOOD STAGE 17.0
:
:REMAIN NEAR FLOOD STAGE NEXT 12 HOURS..THEN FALL.
:
:LATEST STAGE 16.89 FT AT 745 AM CDT ON 0614
.ER ARCK1 0614 C DC200206140838/DH13/HGIFF/DIH6
:QPF FORECAST 7AM 1PM 7PM 1AM
.E1 :0614: / 17.0/ 17.0/ 16.7/ 16.5
.E2 :0615: / 16.2/ 15.6/ 14.9/ 14.2
.E3 :0616: / 13.6/ 13.1/ 12.7/ 12.3
.E4 :0617: / 11.9/ 11.6/ 11.3/ 11.1
.E5 :0618: / 10.9/
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Fig. B-6. Sample RVF Excerpt. (Figure courtesy of the NOAA/NWS Arkansas-Red Basin RFC.)

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›  BASED ON QPF. . . 2 INCHES + IN THE NEXT 24 HOURS . . . MOST OF WHICH IS
   EXPECTED TO FALL IN THE 6 HOUR PERIOD ENDING AT 12Z
›  FORECAST RELEASES FROM THE CORPS ARE EXPECTED TO EXCEED 32K CFS . . .
   RATING AT IOWI4 TOPS OUT AT 29.5 FEET.
›  CREST 32 - 34 FEET . . . WE HAVE 2 DIFFERENT RATING EXTENSIONS AT THIS
   LOCATION AND WE WILL BE LOOKING AT THE RATING EXTENSIONS  LATER THIS
   MORNING . . . UPDATES WILL BE ISSUED AS NECESSARY
```

Fig. B-7. Sample RVF Comments. (Figure courtesy of the NOAA/NWS North Central RFC.)

B.2.4.4 Hydrometeorological Data (RRx) Products

These products, identified as RR1 through RR9 and RRA, are for regionally or locally designated purposes. They are usually publically available.

One noteworthy specific usage of this product series is the RR9 product used by the five RFCs providing forecasts within the Mississippi River Basin. This product is not public and contains contingency river forecasts based on different QPFs, as listed in **Table B-1,** along with the SHEF type code.

The RR9 product is used to encode SHEF-format information for each forecast point. These products provide essential insight into how QPF affects the forecasts by providing what-if scenarios. These products also indicate the inherent uncertainty in the forecasts and give a range of forecast values. If the QPF associated with the official forecast does not occur, then these

Table B-1. RFC contingency QPF-based forecast types. (Source: NOAA/NWS.)

SHEF Code	*Description*
CA	HPC/RFC QPF through 12 hours
CB	HPC/RFC QPF through 24 hours
CC	HPC/RFC QPF through 48 hours
CD	HPC/RFC QPF through 72 hours
CL	Minimum QPF at 95% Confidence Level through 60 hours
CM	Minimum QPF at 95% Confidence Level through 48 hours
CN	Minimum QPF at 95% Confidence Level through 24 hours
CO	Minimum QPF at 95% Confidence Level through 12 hours
CV	Maximum QPF at 95% Confidence Level through 60 hours
CW	Maximum QPF at 95% Confidence Level through 48 hours
CX	Maximum QPF at 95% Confidence Level through 24 hours
CY	Maximum QPF at 95% Confidence Level through 12 hours
CZ	zero QPF

contingency forecasts provide initial, ready-to-go guidance on the adjusted forecast. A graphical example of these forecasts is given in **Fig. B-8** in the section on WFO operations.

B.2.4.5 RFC Internet Information

RFCs often include detailed river forecast information on Web pages. Some of these pages are accessible to the public, while others are accessible only to WFO staff or other authorized users.

Information displayed on the Web pages usually includes observed precipitation, QPE, presented for hourly intervals on a gridded basis. This QPE is used within the river models and can provide valuable insight into the forecast.

The RVF forecast products provided by RFCs are sent to the WFOs, which review the data and post them to AHPS Web pages, the primary public source of NWS river forecast information. This is discussed in later sections.

B.3 Weather Forecast Offices

Each WFO provides its services in accordance with NWS Instruction 10-921, Weather Forecast Office Hydrologic Operations. The shared mission of WFOs and RFCs is to provide timely and accurate hydrologic forecasts and warnings. This requires collaborative operations and effective two-way communication.

The RFC provides the internal forecast information for official forecast points. The WFO reviews and may adjust the forecast in consultation with the RFC. In the event the RFC and WFO cannot reach consensus on a forecast, the RFC forecast takes precedence. The WFO then issues a public product called Daily River Forecasts (RVD) and also provides observed and forecast data for the Internet-based graphical forecast.

B.3.1 WFO Observed Data Inputs

The WFO ingests a large amount of hydrometeorological data. For the purposes of the flood warning program, these data are essentially identical to the data collected by the RFC discussed earlier. Data include streamgage and precipitation information. In many cases, WFOs collect data from local mesonets or other data networks and share the data with RFCs and other WFOs.

B.3.2 WFO Operational Duties

WFO forecasters maintain a continuous hydrologic watch over river and stream locations within their hydrologic service area. The WFO provides a full set of hydrologic services for official RFC forecast locations. In addition, the WFO provides some products, such as a Flood Watch, for areas and occasionally for specific locations along a river. The WFO may run a local forecasting procedure for small headwater river basins. Regardless of the model source, forecasts are provided for locations where a user requirement has been identified for point-based information and sufficient real-time data, rating tables, and other required resources are available.

To support these services for river locations and areas, at a basic level, the WFO role during an active river flood event includes the following duties:

1) Maintaining situational awareness—Meteorological and hydrologic conditions are monitored by scrutinizing observations and other information that may indicate ongoing or imminent flooding. This step may also involve communication with other offices involved in the flood event, such as the USACE, USGS, and local entities.

2) Reviewing observed data—Forecasters review timeliness and quality of these reports, particularly since the observed river data will be graphically displayed on public Web pages. This review is done using editing tools available within the situational awareness tools. When necessary, supplemental rainfall and streamgage data, flood information, and spotter reports are sought to validate and assist in the flood warning and verification processes.

3) Collaborating QPF with neighboring WFOs—After HPC's QPF is reviewed, the WFO coordinates with RFC(s)[5] regarding significant departures between WFO and HPC QPFs. Further coordination with the RFC(s) and HPC is done if necessary. These data are vital for severe flood events.

4) Reviewing all RFC products—Products are reviewed for accuracy and timeliness. Each WFO collaborates with other WFOs and the servicing RFC(s) regarding flood potential, accuracy of estimated precipitation and flood guidance, and the need for additional river

[5] Note the hydrologic service area of some WFOs is in the service area of more than one RFC.

model runs or extended hours of RFC operation. RFC forecasts are adjusted by the WFO, as necessary, after consultation with the RFC.

5) Issuing flood products—Official watch, warning, advisory, and statement flood products are formatted, reviewed, and issued, as needed.

6) Ensuring public Web pages are properly updated—WFO staff members ensure observed and forecast river information is available on the Web and that other staff members are knowledgeable about this information, which is often used during coordination activities.

7) Supporting public awareness of flood event—By coordinating and communicating with local officials, media, partners, and others, WFO staff members ensure public awareness of and response to flood conditions.

This list of duties does not account for flash flooding or other coincident severe weather that must be simultaneously managed.

The way forecast staff duties are divided varies from office to office. Some offices dedicate a shift forecaster or several forecasters to perform only hydrologic duties. When multiple forecasters are involved, as is the case in widespread events, the geographic area may be divided up among forecasters. Other offices may have a forecaster split duties between hydrologic and non-hydrologic activities. The roles assigned among forecasters are determined carefully, with consideration given to the types of active weather, staff availability, and other factors. In some cases of severe and/or widespread events, additional support may be provided by forecasters temporarily assigned to the office from either a nearby WFO or RFC.

B.3.3 Forecast Monitoring

Various software applications support the WFO forecaster in these operational duties. For situational awareness and data review, the forecaster will display the data in assorted geographic, tabular, and time series forms.

A sample time series display of forecast hydrographs for a single location is shown in **Fig. B-8**. This example also demonstrates contingency forecasts using different QPF scenarios.

Longer QPF durations provide more opportunity for river forecasts to be affected by forecast rainfall and can lead to higher peak stages. In addition to the zero-QPF line shown in red, the remaining three forecast lines are for different QPF amounts. These amounts correspond to the QPF confidence-level runs given in **Table B-1**. Forecasters can use this information and their knowledge of the local river location and river model characteristics to assess the range of flooding that might occur based on different QPFs.

Customized predefined or ad hoc displays of hydrologic data on a geographic display are also available. The user can view the latest river observations and forecasts, station or gridded precipitation, and other relevant data sets. These displays automatically update the map, allowing the display to be shown continuously and revealing the latest observed and forecast river levels.

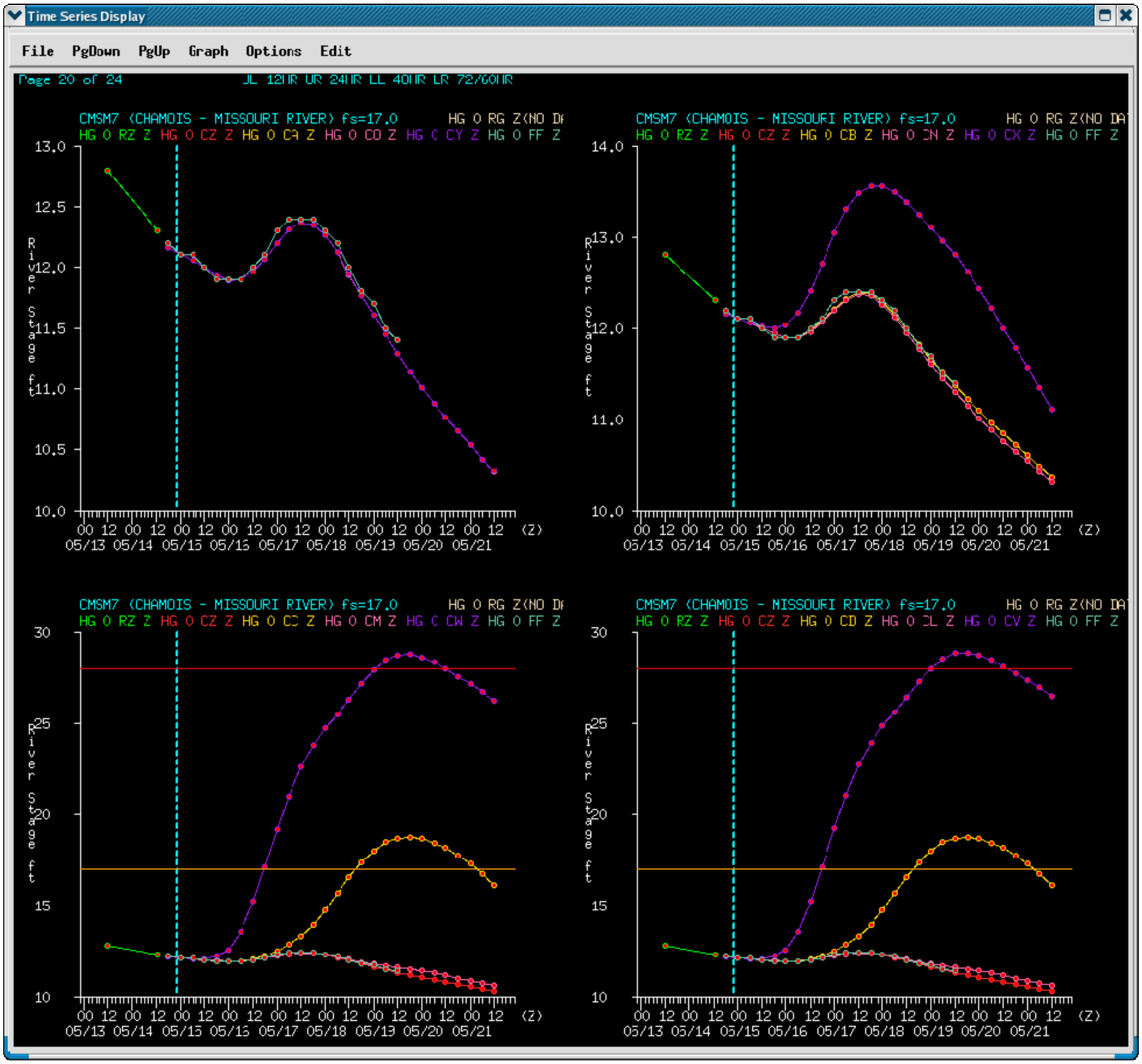

Fig. B-8 Time series plots of contingency river stage forecasts for various QPFs. Each graph quadrant is for a different QPF duration in hours: first 12 hours (upper left), first 24 hours (upper right), first 48 hours (lower left), and first 60/72 hours (lower right). Current time is indicated by the vertical blue line. Observed river stage is indicated in green. For each QPF duration used in the river forecast model, there are four forecasts of river stage. These four ensemble forecasts are 1) no QPF during the period (red), 2) minimum QPF at the 95 percent confidence level (pink), 3) HPC/RFC QPF (orange/yellow), and 4) maximum QPF at the 95 percent confidence level (violet/purple). Note the maximum values of the y-axes, which indicate river stage in feet, differ among several of the quadrants. (Figure courtesy of NOAA/NWS Missouri Basin RFC.)

B.3.4 Coordination of Forecast Process Activities

This section summarizes various types of WFO coordination in the overall forecast process. This coordination is essential for the effective management of flood services. In general, there are three basic coordination types:

1) Among NWS Offices—WFOs and RFCs coordinating with other WFOs and RFCs, HPC, and NWS regional and national headquarters staff. This coordination can include sharing detailed RFC ensemble information, agreed upon QPF and other model input data, rating curve usage, product issuances, and adequate staffing.

2) Among NWS, USGS, and USACE—As discussed in more detail in Section 4.2, the USGS and USACE play a critical role in the NWS river forecast process. For example, the USGS provides the majority of the river observations, as well as the rating curves and support for rating curve extensions during high flows. The USACE monitors and controls outflow from its reservoirs and flows on parts of certain navigable waterways like the Mississippi River.

3) Among NWS and Other Groups—This category includes county, state, and local emergency managers, media, and business interests, among others. Typically this coordination involves detailed discussion of the river forecasts and any uncertainty they may have.

Historically, this coordination was performed almost exclusively via one-on-one phone contacts, but now this communication is conducted through multiple media, including the following:

- Telephone or video conference calls
- Web-based chat rooms/instant messaging, conferences, Webinars, and bulletin boards
- Internal Web pages (Intranet)
- Amateur radio
- Specialized emergency manager Web connections
- NWS HCM and HMD product displays
- Locally provided aerial photographs or image displays

B.3.5 WFO Public Products

After WFO forecasters have reviewed and accepted all observed and forecast information, it is disseminated via formatted text products and Web-based images and graphs. Official text products are generated in accordance with NWS Instruction 10-922, Weather Forecast Office Hydrologic Products Specification. The WFO generates the following location-specific (that is, non-areal) river flood products:

- Hydrologic Outlook (ESF)
- Flood Watch (FFA)
- Flood Warning (FLW)

- Flood Statement (FLS)—follow-up to Flood Warning
- Flood Advisory (FLS)

The Flood Warning and its associated Flood Statement are the predominant products during a major flood event. An excerpt from a Flood Warning product is provided in **Fig. B-9**.

```
WGUS43 KDVN 140415
FLWDVN

BULLETIN - IMMEDIATE BROADCAST REQUESTED
FLOOD WARNING
NATIONAL WEATHER SERVICE QUAD CITIES IA IL
1115 PM CDT FRI JUN 13 2008

...FORECAST FLOODING CHANGED FROM MAJOR TO RECORD SEVERITY FOR THE
FOLLOWING RIVERS IN IOWA...ILLINOIS...

  MISSISSIPPI RIVER AT GLADSTONE LD18 AFFECTING DES MOINES AND
  HENDERSON COUNTIES
  MISSISSIPPI RIVER AT BURLINGTON AFFECTING DES MOINES...LEE...
  HANCOCK AND HENDERSON COUNTIES

.RECORD FLOODING IS NOW EXPECTED ON THE MISSISSIPPI RIVER AT
GLADSTONE LD18...AND BURLINGTON.

RIVER FORECASTS TAKE INTO ACCOUNT PAST PRECIPITATION...AS WELL AS
PRECIPITATION AMOUNTS EXPECTED 24 HOURS INTO THE FUTURE FROM THE
FORECAST ISSUANCE TIME.

SAFETY MESSAGE...IF YOU ENCOUNTER A FLOODED ROADWAY...TURN AROUND
AND FIND AN ALTERNATE ROUTE. TURN AROUND...DON/T DROWN.

ADDITIONAL RIVER AND WEATHER INFORMATION IS AVAILABLE AT...
HTTP://WWW.WEATHER.GOV/QUADCITIES .

IAC057-ILC071-141615-
/O.CON.KDVN.FL.W.0130.000000T0000Z-000000T0000Z/
/GLDI2.3.ER.080604T0526Z.080618T1800Z.000000T0000Z.NR/
1115 PM CDT FRI JUN 13 2008

THE FLOOD WARNING CONTINUES FOR
  THE MISSISSIPPI RIVER AT GLADSTONE LD18.
* UNTIL FURTHER NOTICE.
* AT  8:00 PM FRIDAY THE STAGE WAS 17.4 FEET...AND UNKNOWN.
* MAJOR FLOODING IS OCCURRING AND RECORD FLOODING IS FORECAST.
* FLOOD STAGE IS  10 FEET.
* FORECAST...RISE TO 22.4 FEET WEDNESDAY...THEN BEGIN FALLING.
* THE PRESENT RECORD CREST IS 21.5 FEET SET IN 1993.

$$
```

Fig. B-9. Sample River Flood Warning Product. (Figure courtesy of the NOAA/NWS WFO Quad Cities.)

The Hydrologic Outlook often provides details on possible flooding in the next several days. This product is issued when forecaster confidence is at least 30 percent that flooding will occur.

The WFO is also responsible for transmitting observed and forecast data for each river forecast location to the AHPS Web server, used to generate the NWS Web pages. These data are accessible via the "Water" tab on the NWS home page: www.weather.gov. Clicking on a specific area of the national map displays a more localized map of the area, from which an individual forecast point can be selected. The Web page then displays a time series graph and other information for the forecast point. In addition to the time series graph (sample shown in **Fig. B-10**), the site offers supporting information for the location. This information includes a list of historical crests, flood impact descriptions, and station reference information. The flood impact information is valuable in describing possible damage or effects likely at the river levels depicted in the graph.

These Web pages are extremely important to NWS customers and are extensively used. They represent the end of an extensive process that begins with observations of the atmosphere, rivers, and other elements of the environment, and proceeds with the generation of NCEP model guidance, forecaster guidance from HPC, and river forecasts produced at the RFC and finalized at the WFO. The resultant products are then issued to decision makers and the many other people heavily dependent on accurate river forecasts.

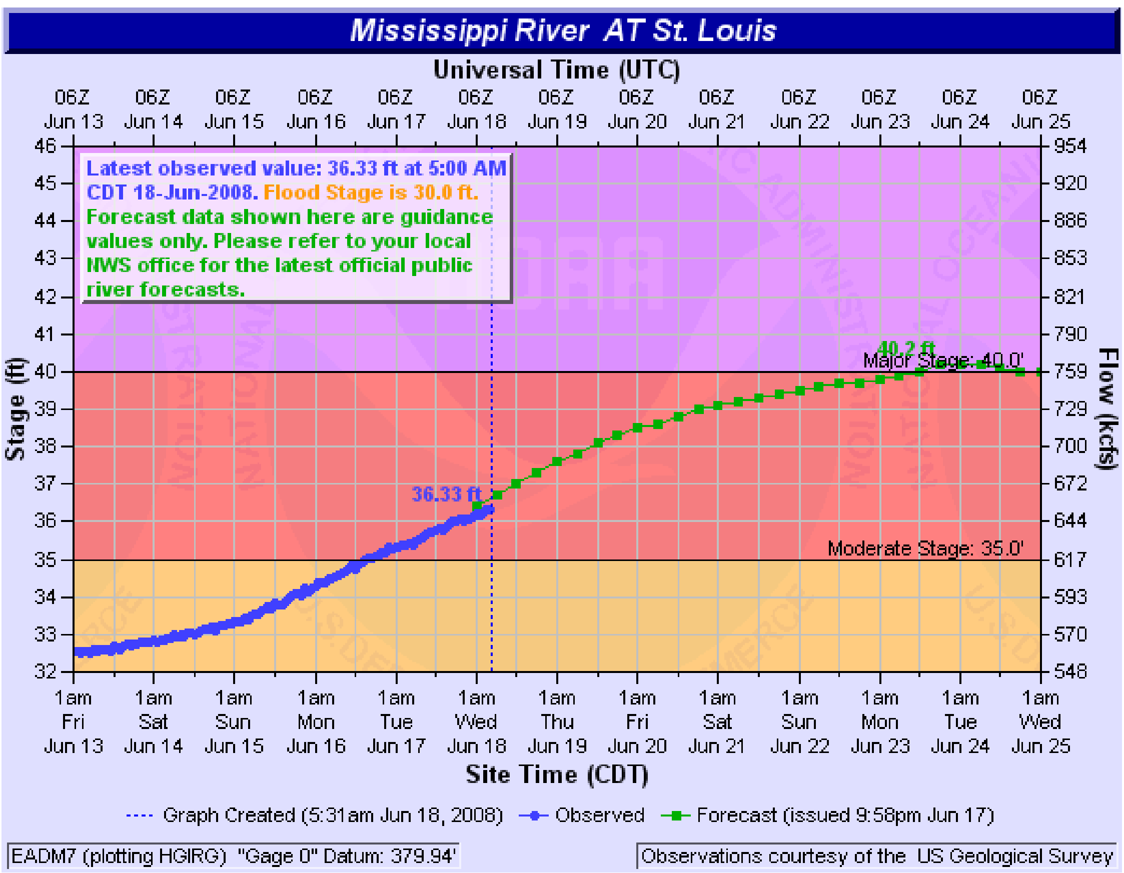

Fig. B-10. Sample NWS web-based hydrograph.
(Source: NOAA/NWS, http://www.weather.gov/ahps/.)

Appendix C

NWS Definitions

Fact, Finding, Recommendation, and Best Practice

Fact—A verifiable statement describing something important learned from the assessment for which no action is necessary. Facts are not numbered, but often lead to recommendations.

Finding—A statement describing something important learned from the assessment for which an action may be necessary. Findings are numbered in ascending order and are associated with a specific recommendation or action.

Recommendation—A specific course of action, based on an associated finding that should improve NWS operations and services. Not all recommendations may be achievable, but they are important to document. If the affected office(s) and the Office of Climate, Water, and Weather Services determine a recommendation will improve NWS operations and/or services, and it is achievable, the recommendation will likely become an action. Recommendations should be clear, specific, and measurable.

Best Practice—An activity or procedure producing outstanding results during a particular situation that could be used to improve effectiveness and/or efficiency throughout the organization in similar situations. No action is required.

Flood Severity Levels

The NWS specifies the following definitions of flood categories in NWS Manual 10-950, Definitions and General Terminology:

Minor Flooding—Minimal or no property damage, but possibly some public threat.

Moderate Flooding—Some inundation of structures and roads near stream. Some evacuations of people and/or transfer of property to higher elevations.

Major Flooding—Extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.

Record Flooding—Flooding which equals or exceeds the highest stage or discharge observed at a given site during the record-keeping period. The highest stage on record is not necessarily above the other three categories. It may be within any of them or even less than the lowest.

Appendix D

Acronyms

AHPS	Advanced Hydrologic Prediction Service
ALERT	Automatic Local Evaluation in Real Time
AWIPS	Advanced Weather Interactive Processing System
CHPS	Community Hydrologic Prediction System
CPC	Climate Prediction Center, NCEP, NWS
CSI	critical success index
DCP	Data Collection Platform
DPW	Davenport Public Works, Davenport, Iowa
EOC	Emergency Operations Center
EMC	Environmental Modeling Center, NCEP, NWS
ESF	Hydrologic Outlook product
FAR	false alarm rate
FEMA	Federal Emergency Management Agency
FFA	Flood Watch product
FLS	Flood Statement product, Flood Advisory product
FLW	Flood Warning product
GFS	Global Forecast System
GOES	Geostationary Operational Environmental Satellite
HCM	Hydrometeorological Coordination Message product
HEC-RAS	Hydrologic Engineering Center's River Analysis System, USACE
HMD	Hydrometeorological Discussion product
HPC	Hydrometeorological Prediction Center, NCEP, NWS
IDOT	Iowa Department of Transportation
IEM	Iowa Environmental Mesonet
MAE	mean absolute error
MBRFC	Missouri Basin River Forecast Center, NWS
MPE	Multi-sensor Precipitation Estimator
NAM	North American Model
NCEP	National Centers for Environmental Prediction, NWS
NCO	NCEP Central Operations, NCEP, NWS
NCRFC	North Central River Forecast Center, NWS
NDFD	National Digital Forecast Database
NFS	numerical forecast systems
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center, NWS
NWS	National Weather Service, NOAA
NWSRFS	NWS River Forecast System
OHRFC	Ohio River Forecast Center, NWS
PE	Physical Element code
POD	probability of detection
QPE	quantitative precipitation estimate
QPF	quantitative precipitation forecast

RFC	River Forecast Center
RRx	Hydrometeorological Data products
RVD	Daily River Forecast product
RVF	River Forecast product
SEOC	State Emergency Operations Center
SHEF	Standard Hydrologic Exchange Format
SMA	soil moisture accounting
WFO	Weather Forecast Office
WSR-88D	Weather Surveillance Radar-1988 Doppler
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
UTC	Universal Time Coordinated
XEFS	eXperimental Ensemble Forecast

Appendix E

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Appendix F

Locations with Record or Major Flooding

Table F-1. Locations in Iowa with either major or record (shaded) flooding.

Stream	Location	State	Major Flood	Flood of Record		2008 Crest		NWS ID
			Stage (ft)	Stage (ft)	Date	Stage (ft)	Date	
Beaver Creek	New Hartford	IA	14.0	13.50	6/13/1947	15.43	6/9/2008	nhri4
Big Sioux River	Akron	IA	20.0	23.38	4/26/2001	20.20	6/8/2008	akri4
Boone River	Webster City	IA	17.0	19.10	6/10/1918	17.28	6/8/2008	wbci4
Cedar River	Cedar Falls	IA	93.0	96.20	7/23/1999	102.13	6/11/2008	cedi4
Cedar River	Cedar Rapids	IA	16.0	20.00	3/18/1929	31.12	6/13/2008	cidi4
Cedar River	Charles City	IA	18.0	22.81	7/21/1999	25.55	6/9/2008	ccyi4
Cedar River	Conesville	IA	16.5	17.11	4/6/1993	23.40	6/15/2008	cnei4
Cedar River	Janesville	IA	15.0	17.15	7/22/1999	19.68	6/8/2008	jani4
Cedar River	Vinton	IA	19.0	19.30	3/30/1961	24.60	6/12/2008	vini4
Cedar River	Waterloo	IA	19.0	21.86	3/29/1961	25.39	6/11/2008	aloi4
Des Moines River	Des Moines 2nd Ave	IA	27.0	31.71	7/11/1993	31.57	6/13/2008	dmoi4
Des Moines River	Des Moines SE 6th	IA	30.0	34.29	7/11/1993	35.27	6/13/2008	desi4
Des Moines River	Fort Dodge	IA	14.0	19.62	6/23/1947	15.73	6/8/2008	fodi4
Des Moines River	Keosauqua	IA	27.0	32.66	7/13/1993	30.49	6/16/2008	keqi4
Des Moines River	Ottumwa	IA	15.0	22.15	7/12/1993	20.59	6/17/2008	otmi4
Des Moines River	Stratford	IA	22.0	25.68	4/2/1993	27.32	6/9/2008	stri4
Des Moines River	Tracy	IA	23.0	26.50	6/14/1947	23.70	6/14/2008	trci4
Iowa River	Columbus Jct	IA	23.0	28.30	7/7/1993	32.49	6/16/2008	cjti4
Iowa River	Decorah	IA	14.0	15.20	5/29/1941	17.90	6/9/2008	dehi4
Iowa River	Dorchester	IA	19.0	22.20	2/28/1948	22.46	6/9/2008	dchi4
Iowa River	Iowa City	IA	25.0	28.52	8/10/1993	31.53	6/15/2008	iowi4
Iowa River	Lone Tree	IA	18.0	22.94	7/7/1993	23.15	6/15/2008	lnti4
Iowa River	Marengo	IA	18.5	20.31	7/19/1993	21.38	6/12/2008	mroi4
Iowa River	Marshalltown	IA	21.0	20.77	8/17/1993	21.79	6/13/2008	miwi4
Iowa River	Wapello	IA	25.0	29.53	7/7/1993	32.15	6/14/2008	wapi4
Maquoketa River	Maquoketa	IA	28.5	34.09	6/5/2002	31.64	6/14/2008	maqi4
Mississippi River	Burlington	IA	18.0	25.10	7/10/1993	25.73	6/17/2008	brli4
Mississippi River	Camanche	IA	20.5	24.65	4/28/1965	21.16	6/15/2008	cmmi4
Mississippi River	Keokuk	IA	19.0	27.58	7/10/1993	26.95	6/17/2008	eoki4
Mississippi River	LeClaire	IA	13.5	17.75	4/28/1965	14.84	6/16/2008	leci4
Mississippi River	Muscatine	IA	20.0	25.61	7/9/1993	24.42	6/17/2008	musi4
Nodaway River	Clarinda	IA	25.0	30.30	6/13/1947	26.61	6/5/2008	icli4
North Fk Raccoon R.	Perry	IA	20.0	23.00	7/10/1993	21.67	6/10/2008	proi4
Raccoon River	Des Moines Fleur Drive	IA	20.0	26.70	7/11/1993	24.66	6/13/2008	demi4
Raccoon River	Des Moines Highway 28	IA	39.5	41.31	6/13/2008	41.31	6/13/2008	dmwi4
Raccoon River	Van Meter	IA	21.0	26.34	7/10/1993	22.67	6/13/2008	vnmi4
Shell Rock River	Shell Rock	IA	15.0	17.70	04/01/1856	20.00	6/10/2008	shri4
Skunk River	Augusta	IA	20.0	27.05	4/23/1973	22.85	6/16/2008	agsi4
South Skunk River	Ames	IA	16.0	15.89	7/17/1996	16.93	6/9/2008	amei4
South Skunk River	Oskaloosa	IA	24.0	25.80	5/1/1944	24.60	6/13/2008	ooai4
Turkey River	El Dorado	IA	17.0	22.11	6/9/2008	22.11	6/9/2008	edri4
Turkey River	Elkader	IA	20.0	27.33	6/15/1991	30.90	6/10/2008	ekdi4
Turkey River	Garber	IA	23.0	32.80	5/23/2004	29.13	6/10/2008	grbi4
Wapsipinicon River	Anamosa	IA	19.0	22.73	5/26/2004	26.18	6/13/2008	ansi4
Wapsipinicon River	DeWitt	IA	12.5	14.19	6/17/1990	14.13	6/16/2008	dewi4
Wapsipinicon River	Independence	IA	15.0	22.35	5/18/1999	18.86	6/11/2008	idpi4
West Fk Cedar River	Finchford	IA	16.0	18.45	7/29/1990	20.82	6/10/2008	fnhi4
Winnebago River	Mason City	IA	14.0	15.70	3/30/1933	18.74	6/9/2008	mcwi4

Table F-2. Locations in Illinois with either major or record (shaded) flooding.

Stream	Location	State	Major Flood	Flood of Record		2008 Crest		NWS ID
			Stage (ft)	Stage (ft)	Date	Stage (ft)	Date	
Embarras River	Lawrenceville	IL	41.0	41.34	5/16/2002	42.32	6/10/2008	lawi2
Embarras River	Ste Marie	IL	27.0	26.54	6/30/1957	28.01	6/8/2008	stmi2
Mississippi River	Chester	IL	38.0	49.74	8/7/1993	39.46	7/1/2008	chsi2
Mississippi River	Gladstone	IL	14.0	21.54	7/10/1993	22.46	6/17/2008	gldi2
Mississippi River	Grafton	IL	29.0	38.15	8/1/1993	30.80	6/29/2008	grfi2
Mississippi River	Illinois City	IL	18.0	24.10	7/9/1993	22.96	6/17/2008	ilni2
Mississippi River	Keithsburg	IL	17.0	24.15	7/9/1993	24.49	6/17/2008	khbi2
Mississippi River	New Boston	IL	18.5	25.90	7/9/1993	25.20	6/17/2008	nboi2
Mississippi River	Quincy	IL	22.5	32.13	7/13/1993	30.80	6/18/2008	uini2
Mississippi River	Quincy Lock	IL	22.0	31.30	7/13/1993	29.59	6/18/2008	qldi2
Mississippi River	Rock Island	IL	18.0	22.63	7/9/1993	21.49	6/16/2008	rcki2
North Fk Embarras R.	Oblong	IL	(not defined)	24.38	1/4/1950	26.26	6/7/2008	obli3
Rock River	Joslin	IL	16.5	19.24	6/7/2002	16.54	6/21/2008	josi2
Rock River	Latham Park	IL	14.0	6.28	5/16/2003	14.23	6/18/2008	lati2
Rock River	Moline	IL	14.0	16.15	4/26/1973	14.91	6/17/2008	mlii2
Rock River	Rockton	IL	14.0	15.54	3/25/1975	14.72	6/17/2008	roki2
Wabash River	Hutsonville	IL	28.0	29.80	3/30/1913	28.40	6/10/2008	huti2
Wabash River	Mount Carmel	IL	32.0	33.95	1/13/2005	33.24	6/14/2008	mcri2

Table F-3. Locations in Indiana with either major or record (shaded) flooding.

Stream	Location	State	Major Flood	Flood of Record		2008 Crest		NWS ID
			Stage (ft)	Stage (ft)	Date	Stage (ft)	Date	
Clifty Creek	Columbus	IN	21.0	16.72	1/14/2007	22.17	6/7/2008	ccci3
Clifty Creek	Hartsville	IN	13.0	25.10	3/27/1913	17.83	6/7/2008	cchi3
East Fk White River	Columbus	IN	16.0	17.90	3/27/1913	18.61	6/8/2008	baki3
East Fk White River	Seymour	IN	19.0	21.00	3/26/1913	20.92	6/8/2008	seri3
Eel River	Bowling Green	IN	23.0	30.00	8/01/1875	23.48	6/7/2008	boli3
Flatrock River	North Columbus	IN	15.0	16.45	3/27/1913	19.83	6/7/2008	flci3
Flatrock River	St. Paul	IN	12.0	20.50	3/27/1913	12.82	6/7/2008	stpi3
Lick Creek	Beech Grove (Indianap.)	IN	11.0	9.61	6/25/1978	9.84	6/7/2008	lcii3
Little Buck Creek	Indianapolis	IN	10.0	11.21	11/14/1993	13.01	6/7/2008	lbci3
Mill Creek	Cataract	IN	22.0	23.00	12/30/1990	22.62	6/7/2008	cati3
Plum Creek	Bainbridge	IN	6.0	6.50	9/14/1989	7.15	6/4/2008	pcbi3
Sugar Creek	Edinburgh	IN	17.0	18.38	5/29/1956	19.23	6/7/2008	edni3
Wabash River	Riverton	IN	24.0	29.36	5/21/1943	26.56	6/10/2008	rvti3
White River	Centerton	IN	19.0	21.90	3/26/1913	19.87	6/7/2008	cnti3
White River	Eagle Valley Pwr Plant	IN	610.0	613.50	3/25/1913	612.20	6/7/2008	ceni3
White River	Edwardsport	IN	25.0	27.65	1/9/2005	29.40	6/10/2008	frei3
White River	Elliston	IN	29.0	33.50	8/01/1875	32.95	6/9/2008	elli3
White River	Hazleton	IN	28.0	31.70	1/22/1937	29.70	6/12/2008	hazi3
White River	Newberry	IN	24.0	31.50	8/03/1875	28.67	6/9/2008	nwbi3
White River	Petersburg	IN	26.0	29.50	3/29/1913	26.96	6/12/2008	ptri3
White River	Petersburg	IN	27.0	29.30	1/10/2005	28.02	6/12/2008	peti3
White River	Spencer	IN	24.0	28.50	3/26/1913	26.93	6/8/2008	spni3
Youngs Creek	Amity	IN	12.5	13.40	1/27/1952	15.67	6/7/2008	amti3

Table F-4. Locations in Minnesota with major flooding. There were no observation points with record flooding.

Stream	Location	State	Major Flood	Flood of Record		2008 Crest		NWS ID
			Stage (ft)	Stage (ft)	Date	Stage (ft)	Date	
Cedar River	Austin	MN	20.0	25.00	9/16/2004	22.40	6/12/2008	astm5

Table F-5. Locations in Missouri with major flooding. There were no observation points with record flooding.

Stream	Location	State	Major Flood	Flood of Record		2008 Crest		NWS ID
			Stage (ft)	Stage (ft)	Date	Stage (ft)	Date	
Chariton River	Prairie Hill	MO	21.0	23.27	7/27/2008	22.84	6/26/2008	prim7
Des Moines River	St. Francisville	MO	25.0	32.02	7/15/1993	28.21	6/17/2008	sflm7
Grand River	Chillicothe	MO	35.0	39.60	7/25/1993	35.32	6/26/2008	chzm7
Grand River	Sumner	MO	40.0	42.52	7/10/1993	40.02	6/28/2008	snzm7
Mississippi River	Canton	MO	25.0	27.88	7/9/1993	27.73	6/18/2008	canm7
Mississippi River	Clarksville	MO	33.0	37.50	7/29/1993	36.70	6/24/2008	clkm7
Mississippi River	Gregory Landing	MO	25.0	28.49	7/9/1993	27.60	6/18/2008	ggym7
Mississippi River	Hannibal	MO	22.0	31.80	7/15/1993	29.54	6/18/2008	hnnm7
Mississippi River	Louisiana	MO	25.0	28.40	7/28/1993	26.96	6/23/2008	lusm7
Mississippi River	Saverton Lock	MO	22.0	29.58	7/25/1993	28.00	6/18/2008	svrm7
Mississippi River	Winfield Lock	MO	34.0	39.62	8/1/1993	37.08	6/27/2008	cagm7
Tarkio River	Fairfax	MO	25.0	28.90	5/7/2007	26.29	6/6/2008	ffxm7

Table F-6. Locations in South Dakota with either major or record (shaded) flooding.

Stream	Location	State	Major Flood	Flood of Record		2008 Crest		NWS ID
			Stage (ft)	Stage (ft)	Date	Stage (ft)	Date	
Belle Fourche River	Sturgis	SD	19.0	19.10	5/21/1982	20.10	6/6/2008	sbfs2
Cheyenne River	Plainview	SD	19.0	22.10	5/28/1996	22.63	6/7/2008	plns2
James River	Scotland	SD	16.0	20.45	6/23/1984	18.00	6/8/2008	scos2
Little Vermillion River	Salem	SD	9.0	11.95	7/4/1993	9.20	6/7/2008	lvss2
Moreau River	Faith	SD	21.0	21.90	4/9/1944	21.50	6/8/2008	fths2
Moreau River	Whitehorse	SD	25.0	26.93	3/23/1997	25.40	6/8/2008	whis2
Vermillion River	Parker	SD	11.0	13.14	5/8/1993	11.70	6/7/2008	pkrs2
Vermillion River	Wakonda	SD	17.0	17.62	6/23/1984	17.00	6/10/2008	wkas2

Table F-7. Locations in Wisconsin with either major or record (shaded) flooding.

Stream	Location	State	Major Flood	Flood of Record		2008 Crest		NWS ID
			Stage (ft)	Stage (ft)	Date	Stage (ft)	Date	
Baraboo River	Baraboo	WI	23.1	25.10	3/26/1917	27.48	6/13/2008	babw3
Baraboo River	La Valle	WI	19.0	14.00	3/15/2007	23.23	6/10/2008	lavw3
Baraboo River	Rock Springs	WI	23.0	21.71	6/2/2000	28.73	6/11/2008	rspw3
Baraboo River	West Baraboo	WI	12.5	7.57	8/21/2007	13.69	6/13/2008	bbow3
Bark River	Rome	WI	5.0	2.56	4/20/1993	4.59	6/9/2008	romw3
Beaverdam River	Beaver Dam	WI	846.0	843.10	6/14/2004	845.52	6/16/2008	beaw3
Crawfish River	Milford	WI	10.0	11.15	4/6/1959	13.59	6/16/2008	milw3
Fox River	Burlington	WI	14.0	12.50	8/21/2007	13.54	6/15/2008	brgw3
Fox River	New Munster	WI	14.0	14.98	8/24/2007	15.18	6/15/2008	nmsw3
Fox River	Waukesha	WI	10.0	8.00	4/1/1960	8.85	6/9/2008	wkew3
Grant River	Burton	WI	22.0	24.83	7/16/1950	23.99	6/13/2008	btnw3
Kickapoo River	Gays Mills	WI	17.0	19.80	7/2/1978	20.44	6/9/2008	gmiw3
Kickapoo River	La Farge	WI	14.0	14.92	7/1/1978	15.88	6/9/2008	lafw3
Kickapoo River	Ontario	WI	20.0	18.85	3/14/2007	21.96	6/8/2008	ontw3
Kickapoo River	Readstown	WI	17.0	19.08	7/21/1951	19.65	6/9/2008	reaw3
Kickapoo River	Soldiers Grove	WI	19.0	21.63	7/22/1951	21.21	6/9/2008	sogw3
Kickapoo River	Steuben	WI	15.0	18.00	7/3/1978	19.15	6/10/2008	stew3
Kickapoo River	Viola	WI	20.0	21.00	7/1/1978	21.25	6/9/2008	viow3
Milwaukee River	Cedarburg	WI	14.0	13.19	5/24/2004	13.97	6/13/2008	cedw3
Oak Creek	South Milwaukee	WI	11.0	9.88	8/6/1986	11.46	6/8/2008	oakw3
Rock River	Afton	WI	12.2	13.05	2/5/1916	13.51	6/21/2008	aftw3
Rock River	Fort Atkinson	WI	8.0	7.29	6/5/2004	10.85	6/22/2008	fatw3
Rock River	Horicon	WI	11.0	10.00	4/9/1998	10.29	6/17/2008	hcnw3
Rock River	Indianford Dam	WI	17.0	16.23	4/5/1979	18.33	6/21/2008	infw3
Rock River	Jefferson	WI	13.0	12.84	4/2/1979	15.64	6/18/2008	jffw3
Rock River	Newville	WI	11.5	12.23	4/25/1993	15.12	6/21/2008	nvlw3
Rock River	Watertown	WI	6.5	6.96	1/17/1997	7.81	6/13/2008	watw3
Rock River	Waupun	WI	10.0	8.20	6/11/2004	10.07	6/13/2008	wpnw3
Root River	Franklin	WI	12.0	9.57	3/30/1960	12.13	6/9/2008	frkw3
Root River	Racine	WI	8.0	8.54	3/5/1974	11.29	6/9/2008	racw3
Root River Canal	Raymond	WI	12.0	11.66	8/21/2007	12.13	6/9/2008	rayw3
South Br Baraboo R.	Hillsboro	WI	15.0	15.60	6/29/1990	16.17	6/9/2008	hilw3
Spring Creek	Lodi	WI	7.5	7.70	8/19/2007	8.40	6/9/2008	lodw3

Table F-8. Locations on the Mississippi River with either major or record (shaded) flooding. (Note: these locations are also included in other tables of this appendix.)

Stream	Location	State	Major Flood	Flood of Record		2008 Crest		NWS ID
			Stage (ft)	Stage (ft)	Date	Stage (ft)	Date	
Mississippi River	Burlington	IA	18.0	25.10	7/10/1993	25.73	6/17/2008	brli4
Mississippi River	Camanche	IA	20.5	24.65	4/28/1965	21.16	6/15/2008	cmmi4
Mississippi River	Keokuk	IA	19.0	27.58	7/10/1993	26.95	6/17/2008	eoki4
Mississippi River	LeClaire	IA	13.5	17.75	4/28/1965	14.84	6/16/2008	leci4
Mississippi River	Muscatine	IA	20.0	25.61	7/9/1993	24.42	6/17/2008	musi4
Mississippi River	Chester	IL	38.0	49.74	8/7/1993	39.46	7/1/2008	chsi2
Mississippi River	Gladstone	IL	14.0	21.54	7/10/1993	22.46	6/17/2008	gldi2
Mississippi River	Grafton	IL	29.0	38.15	8/1/1993	30.80	6/29/2008	grfi2
Mississippi River	Illinois City	IL	18.0	24.10	7/9/1993	22.96	6/17/2008	ilni2
Mississippi River	Keithsburg	IL	17.0	24.15	7/9/1993	24.49	6/17/2008	khbi2
Mississippi River	New Boston	IL	18.5	25.90	7/9/1993	25.20	6/17/2008	nboi2
Mississippi River	Quincy	IL	22.5	32.13	7/13/1993	30.80	6/18/2008	uini2
Mississippi River	Quincy Lock	IL	22.0	31.30	7/13/1993	29.59	6/18/2008	qldi2
Mississippi River	Rock Island	IL	18.0	22.63	7/9/1993	21.49	6/16/2008	rcki2
Mississippi River	Canton	MO	25.0	27.88	7/9/1993	27.73	6/18/2008	canm7
Mississippi River	Clarksville	MO	33.0	37.50	7/29/1993	36.70	6/24/2008	clkm7
Mississippi River	Gregory Landing	MO	25.0	28.49	7/9/1993	27.60	6/18/2008	ggym7
Mississippi River	Hannibal	MO	22.0	31.80	7/15/1993	29.54	6/18/2008	hnnm7
Mississippi River	Louisiana	MO	25.0	28.40	7/28/1993	26.96	6/23/2008	lusm7
Mississippi River	Saverton Lock	MO	22.0	29.58	7/25/1993	28.00	6/18/2008	svrm7
Mississippi River	Winfield Lock	MO	34.0	39.62	8/1/1993	37.08	6/27/2008	cagm7

Appendix G

FEMA Disaster Declarations

The map below depicts counties for which there were FEMA Disaster Declarations as a result of flooding and severe weather. FEMA does not partition the impacts of flooding from severe weather. Therefore, not all areas shown in these maps are associated with the central United States flooding of June 2008.

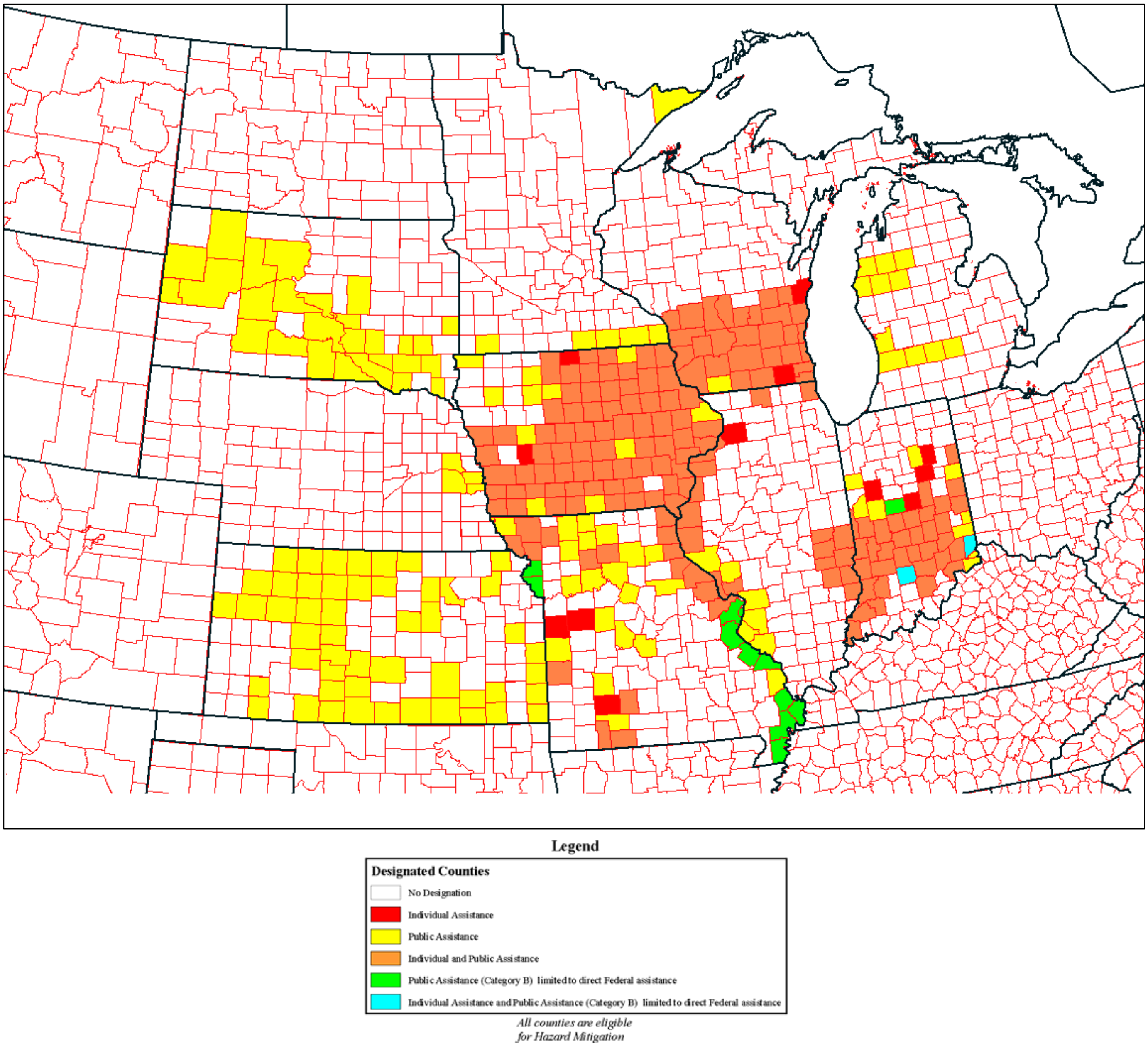

Fig. G-1. FEMA Disaster Declarations by county. The declarations were the result of disasters occurring before July 9-August 12, 2008, depending on the state. (Data from the FEMA Mapping and Analysis Center.)