Service Assessment

Spring 2011 Middle & Lower Mississippi River Valley Floods

U.S. DEPARTMENT OF COMMERCE
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National Weather Service
Silver Spring, Maryland

Cover Photographs courtesy of Weather Forecast Office Jackson, MS

- Yazoo Mississippi Valley railroad station (top left)
- Grain refinery and silos upstream of Natchez, MS (top right)
- North side of Vicksburg, MS (center)
- Intersection of Curry and Robert Streets in Vicksburg, MS (bottom left)
- Harlow's Casino Resort & Hotel in Greenville, MS (bottom right)

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March 2012

National Weather Service

John L. Hayes, Assistant Administrator

Preface

The year 2011 began with extremely wet soil conditions over much of the northern plains in the north central United States. By early March, significant snow had accumulated over the same region resulting in one of the highest snow-water equivalents on record. Snowmelt and spring precipitation caused excessive runoff in much of the Ohio and Upper Mississippi River Basins by late March.

The annual northward migration of warm, moist air from the Gulf Coast region following the retreat of cool, dry winter air is a rite of spring in the central United States. This event typically brings several episodes of severe weather and flooding rains, temporally and spatially, across broad reaches of the Middle Mississippi and Ohio Valleys.

During the spring of 2011, the frontal zone between these two air masses moved little between April 15 and May 5. An active jet stream brought several weather disturbances eastward across the stalled frontal boundary, resulting in numerous episodes of thunderstorms accompanied by deadly tornadoes, hail, high winds, and flooding rains. The hardest hit areas stretched from eastern Oklahoma, northeast across the Middle Mississippi and Ohio River Valleys into northeastern Kentucky.

As water drained into the Ohio and Mississippi Rivers, channels already full from a wet spring were unable to handle the additional runoff. The volume of water moving downstream along the Mississippi River exceeded that experienced during the 1937, 1973, and 2008 floods and caused record flooding at many points from Cairo, IL, to the Gulf of Mexico.

In response to the tragic effects of this event, the National Oceanic and Atmospheric Administration's National Weather Service formed a Service Assessment Team to evaluate the National Weather Service's performance before and during the historic flooding. The findings and recommendations from this assessment will improve the quality of National Weather Service products and services, and enhance awareness of flash and river flooding.

John L. Hayes
Assistant Administrator
for Weather Services

March 2012

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Executive Summary

Widespread flooding occurred across the Lower Ohio and Middle and Lower Mississippi River Valleys from late April into early June 2011 due to a combination of runoff from record snowmelt and unprecedented heavy rainfall in late April and early May. Within a 2-week period, extreme precipitation totals in excess of 20 inches (700-1000 percent above normal) were recorded in some tributary basins.

As water drained into the Ohio and Mississippi Rivers, channels already full from a wet spring were unable to handle the additional water. Record flooding was experienced from the confluence of the Ohio and Mississippi Rivers at Cairo, IL downstream to the Gulf of Mexico.

The volume of water moving downstream along the Middle and Lower Mississippi River exceeded that experienced during the floods of 1937, 1973, and 2008. This 2011 flood was the first time the Birds Point/New Madrid Floodway, Morganza Floodway, and the Bonnet Carre Spillway were operated concurrently.

In the Lower Mississippi River Forecast Center's (LMRFC) hydrologic service area alone, record flood levels were equaled or established at 16 river forecast locations. Some 86 sites experienced at least minor flooding. Many National Weather Service (NWS) Weather Forecast Offices (WFOs) were involved in long-term hydrologic operations, with five offices (Paducah, KY; Memphis, TN; Jackson, MS; Lake Charles, LA; and Slidell, LA) particularly impacted.

One death was directly attributed to the flooding and thousands of homes and businesses were adversely impacted by flood waters. Direct damage to buildings and infrastructure, costs to erect new levees, maintain and fortify existing levees, and impact to commerce was estimated in the billions of dollars.

The extent and magnitude of flooding in the Middle and Lower Mississippi River Basin prompted a major response by the NWS, emergency managers (EM) and other responders, state and local governments, the U.S. Army Corps of Engineers (USACE) and the U.S. Geological Survey (USGS).

The assessment team concluded that long lead times provided by NWS forecasts and warnings and NWS coordination with critical partners such as USACE, USGS, emergency management, and media provided the public with ample opportunity to take mitigative action weeks in advance of the flood. NWS river stage forecasts were accurate in both magnitude and time of occurrence, with river crests at some forecast locations verifying to within 1 foot and 1 day of what was predicted 2 weeks earlier.

Critical partners interviewed by the assessment team complimented the products, services, collaboration, and coordination NWS provided in advance of and throughout the flood event. Many EM directors indicated that "*nothing caught their respective counties by surprise.*" This is one of the long-standing visions of the NWS, taken from the NWS Strategic Plan for

2003-2008, to be America's "*no surprise*" Weather Service that can be trusted when needed the most.

The assessment team, however, did identify areas where changes to NWS products, collaboration, and methodologies could provide an even higher level of services. The following are the key findings and recommendations from this assessment:

Key Findings:

1. The demand for NWS interpretive services by Emergency Operation Centers (EOCs) continues to increase and is consistent with the NWS goal to improve Decision (Support) Services (DSS) for events that threaten lives and livelihoods. The utility of NWS interpretive services is greatest when provided by NWS staff that understand and apply Incident Command System (ICS) principles. Not all NWS operational personnel are prepared to provide the level of interpretive support that is needed.

2. Several NWS offices and county and state-level emergency management (EM) officials expressed concern over differences between Hydrologic Service Area (HSA) and County Warning Area (CWA) boundaries. Not all partners were sure about which NWS office to contact to acquire or provide specific hydrometeorological information. NWS offices incurred increased workload relaying phone-based hydrologic information received by one office to another, and duplicating hydrologic forecasts using differing hydrologic product titles to ensure a single-office source.

3. Current forecast methods did not adequately capture backwater storage areas and the impact of potential levee failures, or provide quality inundation mapping. A Community Model (i.e., advanced 1D and 2D hydraulic models built with new Light Detection and Ranging [LIDAR], Hydrologic Engineering Center River Analysis System [HEC-RAS], and/or others) for the Lower Mississippi and Atchafalaya Rivers and their tributaries would allow the NWS and other partners to provide more precise and well-collaborated river stage and water routing forecasts.

4. For the 2011 Middle and Lower Mississippi River Valley Flood, inundation mapping was widely needed but not readily available. Some EMs created impromptu inundation maps. Interviews with residents in the Memphis area who evacuated their homes indicated they valued having the inundation information.

5. Augmenting LMRFC staff was difficult because of the necessary training and familiarization with LMRFC mainstem Mississippi River forecasting operations using complex hydrologic models.

6. WFO Jackson, MS, (JAN) received reports that major flooding was occurring along the Yazoo River at Yazoo City. Flood categories in effect at the time, as defined in Weather Service (WS) Form E-19, equated to moderate flooding. Because of existing national policy (NWS Directive 10-940), changes could not be made quickly to WFO Hydrologic Forecast System (WHFS) E-19 flood categories to provide a more representative hydrologic category in NWS flood warnings and Advanced Hydrologic Prediction Service (AHPS) Web pages.

7. The Mississippi Emergency Management Agency Director and several media partners stated that acquiring AHPS Website information or more generic Web-based water- and weather-related information was convoluted, cumbersome, and non-intuitive.

Key Recommendations:

1. The NWS, in collaboration with the Federal Emergency Management Agency, should define prototype ICS principles (i.e., engaged partnerships; tiered response; scalable, flexible operational capabilities; unity of effort through unity of command; preparedness; and readiness to act) at one or more NWS operational offices to assess which ICS principles NWS can practically adopt, then develop a training and implementation plan for all operational offices and regional support centers.

2. NWS regions and their respective WFOs should work with critical partners to determine where realignment of disparate CWA and HSA boundaries is both warranted and feasible to limit spatial discontinuity and enhance service-related issues.

3. The NWS should collaborate with USACE to develop a Community Model for the Lower Mississippi River, including the Atchafalaya River and its tributary storage areas.

4. The NWS should create and implement a plan through the Integrated Water Resources Science and Services initiative, which is evaluating flood inundation mapping activities between USACE, USGS, and the NWS, to explore opportunities to partner with other water agencies and accelerate the implementation of inundation mapping nationwide or develop new methods for creating these maps such as dynamically from the community 1-D/2-D hydraulic model.

5. The NWS should develop a more robust cross-training program for RFC staff that identifies unique forecasting and collaborative complexities present during a historic flooding event on controlled waterways, and should develop a comprehensive plan to ensure that RFCs can quickly request deployments of fully-trained and experienced hydrologic forecasters from other offices for forecasting complex mainstem river systems using hydraulic models.

6. NWS Headquarters (NWSH) should streamline the process for modifying E-19 flood categories in the WHFS database to ensure representative hydrologic categories are provided in NWS flood warnings and AHPS Web pages during an ongoing event.

7. The NWS should provide Web services for weather and water information in which users of varying degrees of technical expertise can obtain information compatible with their needs.

Service Assessment Report

1. Introduction

1.1. Purpose of Assessment Report

This report presents findings and recommendations regarding National Weather Service (NWS) performance during the historic river flooding that occurred in the Middle and Lower Mississippi Valley from late April into early June 2011. The areas most impacted were the lower reaches of the Ohio River and associated tributaries and from the confluence of the Mississippi River and Ohio Rivers at Cairo, IL, downstream to the Gulf of Mexico, where a combination of runoff from upstream snowmelt and excessive spring rainfall combined to adversely impact property and commerce over a broad geographic area.

Prolific spring rains and associated runoff from two separate slow-moving weather systems in late April and early May contributed to flash flooding of small streams and creeks, and flooding of major waterways in other areas in the central part of the nation outside of the primary assessment area; however, the nature and scale of these events did not necessitate detailed inclusion in this report.

The objectives of this assessment are to identify effective operations, significant findings and best practices, and to recommend remedial actions to address service deficiencies. This report focuses on the following key areas:

- Timeliness, quality, accuracy, and usefulness of NWS products and services
- Effectiveness of NWS internal and external coordination/collaboration including Decision Support Services (DSS)
- Effectiveness of NWS end-to-end information dissemination
- Efficiency of product delivery
- Effectiveness of NWS office procedures, processes, and staffing levels
- Effectiveness of NWS flood awareness activities
- Degree to which recommendations from the 2010 flood assessment were implemented and, if so, their impact

1.2. Methodology

The NWS formed an assessment team to evaluate the NWS' performance during the spring 2011 Middle and Lower Mississippi River floods. The team interviewed the staff from Weather Forecast Offices (WFOs) and River Forecast Offices (RFCs) in affected area, obtained information from Central Region Headquarters (CRH) and Southern Region Headquarters (SRH) Regional Operations Center (ROC) personnel, visited damaged areas, and interviewed emergency managers (EM), U.S. Army Corps of Engineers (USACE), U.S. Coast Guard (USCG), media, and the public in impacted areas. The team also reviewed products and services from the WFOs, RFCs, and Hydrologic Prediction Center (HPC). Details are provided in Appendix D, Methodology.

2. Hydrometeorological Summary

Widespread flooding occurred across the Lower Ohio Valley and Middle and Lower Mississippi Valley during spring 2011 due to a combination of runoff from record snowmelt and unprecedented heavy rainfall in late April and early May. Twenty-inch (700-1000 percent above normal) precipitation amounts were recorded in some tributary basins within a 2-week period (**Figure 1**).

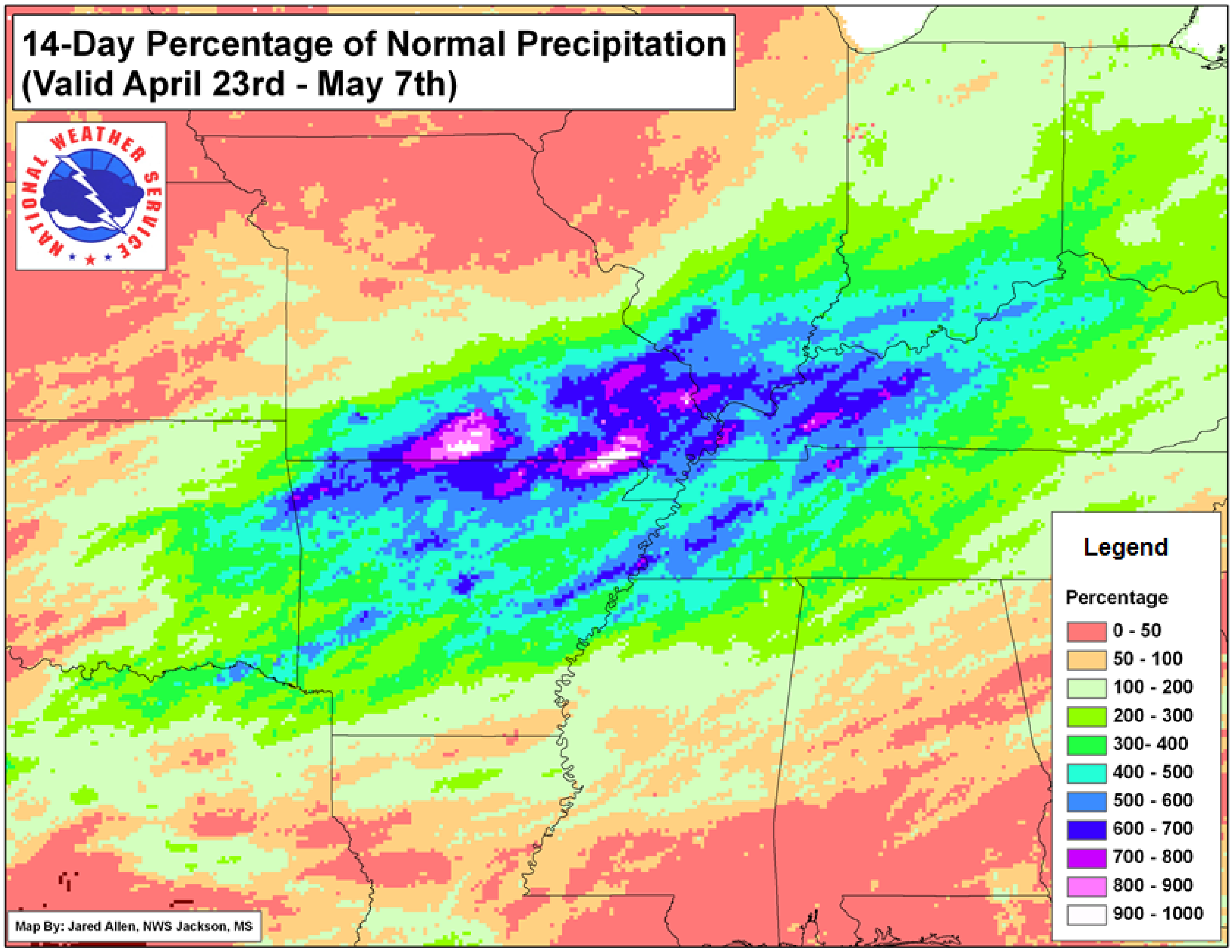


Figure 1: 14-Day Percentage of Normal Precipitation (April 23, 2011 – May 7, 2011)

As water drained into the Ohio and Mississippi Rivers, channels already full from a wet spring were unable to handle the additional flow. The volume of water moving downstream along the Middle and Lower Mississippi River exceeded that experienced during the 1937, 1973, and 2008 floods and caused record flooding at many points from Cairo, IL, to the Gulf of Mexico. This flooding prompted a major response by the NWS, USACE, U.S. Geological Survey (USGS), USCG, Federal Emergency Management Agency (FEMA), EMs, state and local governments, and other first responders.

2.1. Antecedent and Event Conditions

Autumn 2010 brought copious rainfall to the Upper Mississippi River Valley. Rainfall in Minnesota and Wisconsin was 150 to 200 percent of normal, producing record flows on several streams. These moist conditions resulted in a near-record winter flow on the Mississippi above Saint Louis, MO.

Winter precipitation was near normal in the Middle Mississippi and Ohio River Valleys, but was again in the 150 to 200 percent above normal range across the Upper Mississippi River Valley (Minnesota, Wisconsin and Iowa). Melting of the substantial winter snowpack was slow and protracted, and led to very high, sustained river flows on Mississippi River tributaries. This water helped produce late spring peak flows that coincided with heavy rainfall on the Middle Mississippi River and Ohio River Valleys in late April and early May.

In mid-April, the leading edge of a very warm, moist air mass, in the form of a warm front, advanced north into the central United States before becoming stationary near the confluence of the Mississippi and Ohio Rivers. The surface weather map for April 25 (**Figure 2**) reflects the meteorological situation over the region from the latter half of April to early May 2011.

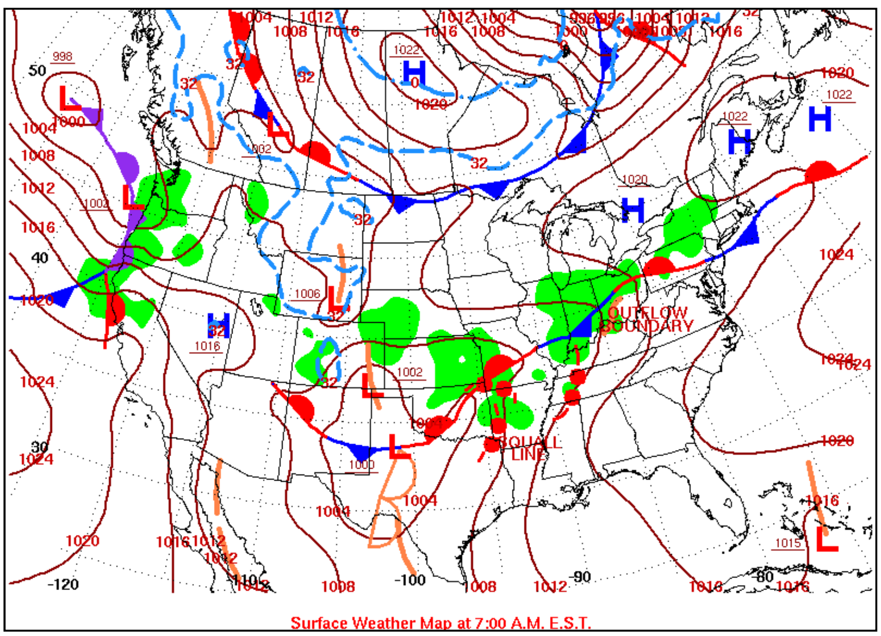


Figure 2: Surface weather map for April 25, 2011

The 500-Millibar height map for the same day (**Figure 3**) reflects a very stable long-wave upper atmospheric pattern. A deep trough was anchored along the eastern flanks of the Rockies, with blocking high pressure ridges off the southeast and southwest coasts. This weather pattern resulted in a persistent southwesterly flow of air aloft over the central and eastern United States. Embedded in this flow was a series of potent, mid-level short waves that interacted with the frontal boundary already in place to produce several periods of intense convective rainfall.

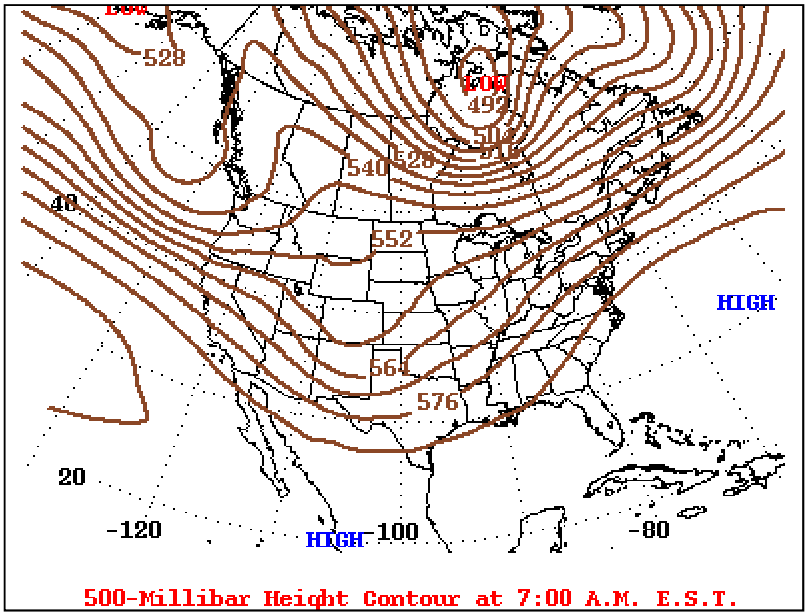


Figure 3: 500-Millibar Height Contour map for April 25, 2011

The map in **Figure 4** illustrates one of several similar 24-hour precipitation events that occurred from late April into early May.

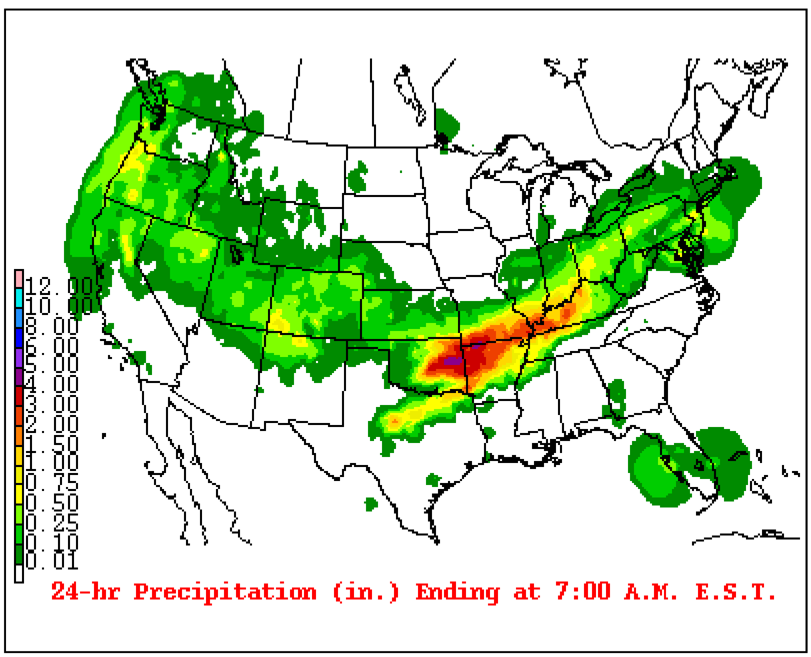


Figure 4: Twenty-Four-hour rainfall for period ending 7 a.m. EST April 25, 2011

Total rainfall for April 15 to May 6 is shown in **Figure 5**. A broad expanse of the central United States from Tulsa OK, to Cincinnati, OH, received 10 inches to more than 20 inches of rain.

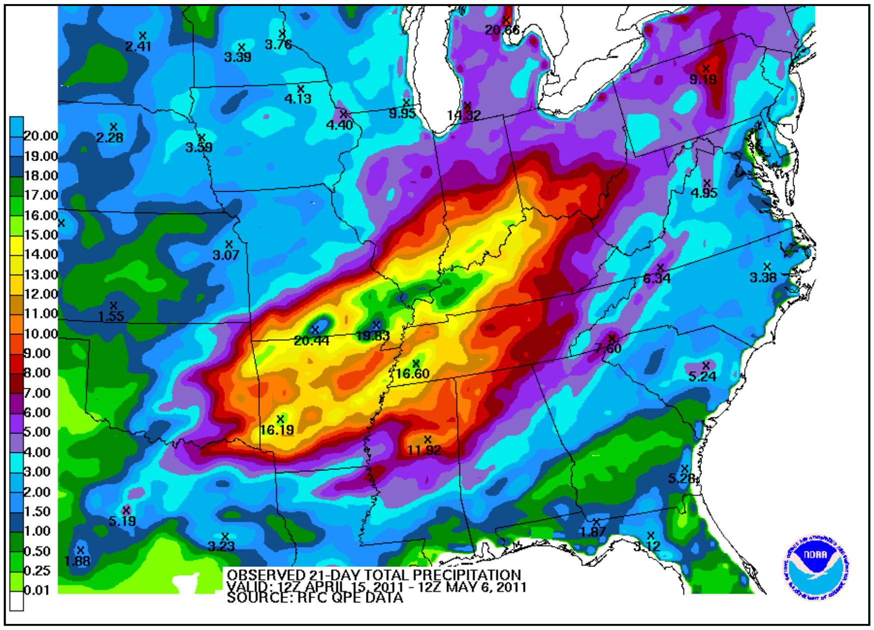


Figure 5: Observed precipitation from April 15 to May 6, 2011. The central focus of rainfall was the Mississippi and Ohio River confluence area near Cairo, IL.

Considering observing stations in the Mississippi Basin with 90 or more years of observations, 49 experienced the wettest April on record. Seven of these stations recorded their wettest month ever (**Table 1**). This extreme rainfall, on top of the already swollen Mississippi and Ohio Rivers, produced record flood crests from Cairo, IL, to the Gulf of Mexico.

Table 1: April precipitation totals for observing stations in the Middle Mississippi River and Ohio River Valleys experiencing their wettest month on record.

Station	April Rainfall (inches)
Poplar Bluff, MO	21.39
Du Quin, IL	16.90
Portsmouth, OH	14.62
Fairfield, OH	14.11
Chester, IL	13.94
Olney, IL	13.31
Farmers, KY	12.53

In the Lower Mississippi River Forecast Center's (LMRFC) Hydrologic Service Area (HSA), record levels were equaled or established at 16 NWS river forecast locations (**Table 2**). There were 86 sites that experienced flooding: major, 28 sites (**Table 3**); moderate, 25 sites; and minor, 33 sites.

Table 2: LMRFC forecast points where existing record flood stages were equaled or exceeded (courtesy of LMRFC)

Site Name	Site River	Crest	Date	Time (UTC)	Major Flood Stage	Flood Stage	Historical Flood Crest	Historical Flood Crest Date	New Record
Sarah	Coldwater River	25.16	04/28/2011	0200	28.0	18.00	25.00	04/20/1973	YES
Brownsboro	Flint River	24.58	04/28/2011	1430	22.0	17.00	23.03	02/06/2004	YES
Lake City	St. Francis River	14.37	05/03/2011	1400	15.0	10.00	14.37	04/02/1979	TIED
Riverdale	Little River	16.24	05/06/2011	1100	15.0	11.00	13.87	02/20/1989	YES
Corning	Black River	18.12	04/28/2011	1600	16.0	15.00	16.92	06/13/1945	YES
Pocahontas	Black River	28.47	04/28/2011	2115	25.0	17.00	27.90	08/04/1915	YES
Georgetown	White River	33.95E	05/06/2011	1200E	28.0	21.00	32.80	02/01/1949	YES
Des Arc	White River	39.43	05/07/2011	0500	30.0	24.00	37.35	02/02/1949	YES
Smithland	Ohio River	54.89	05/06/2011	1245	50.0	40.00	51.44	03/12/1997	YES
Cairo	Ohio River	61.72	05/03/2011	0300	53.0	40.00	59.50	02/03/1937	YES
New Madrid	Mississippi River	48.35	05/06/2011	0700	44.0	34.00	48.00	02/03/1937	YES
Tiptonville	Mississippi River	48.35	05/06/2011	0500	47.0	37.00	47.75	02/06/1937	YES
Caruthersville	Mississippi River	47.61	05/07/2011	1600	43.0	32.00	46.00	02/05/1937	YES
Vicksburg	Mississippi River	57.12	05/19/2011	0300	50.0	43.00	56.20	05/04/1927	YES
Natchez	Mississippi River	61.95	05/19/2011	0200	57.0	48.00	58.04	02/21/1937	YES
Red River Landing	Mississippi River	63.39	05/18/2011	2200	64.0	48.00	61.61	03/24/1997	YES

Table 3: LMRFC forecast points where major flood stages were equaled or exceeded (courtesy of LMRFC)

Site Name	Site River	Crest	Date	Time (UTC)	Major Flood Stage	Flood Stage	Historical Flood Crest	Historical Flood Crest Date
Courtland	Big Nance Creek	22.77	04/29/2011	0330	19.0	14.0	24.97	03/16/1973
Fisk	St. Francis River	27.10	05/04/2001	0200	26.0	16.0	28.00	04/18/1927
Madison	St. Francis River	39.81	05/13/2011	1400	36.0	32.0	41.80	04/21/1912
Palestine	L'Anguille River	36.34	05/13/2011	1700	31.0	15.0	39.70	02/13/1937
Poplar Bluff	Black River	21.41	04/26/2011	0730	21.0	16.0	22.15	03/20/2008
Doniphan	Current River	23.76	04/26/2011	1100	22.0	13.0	26.80	03/01/1904
Ravenden Springs	Eleven Point River	23.58	04/26/2011	0700	20.0	15.0	29.06	12/03/1982
Town Branch/Hardy	Spring River	20.71	04/26/2011	0615	16.0	10.0	29.00	12/03/1982
Imboden	Spring River	29.29	04/26/2011	1115	26.0	18.0	38.12	12/03/1982
Black Rock	Black River	30.45	04/27/2011	0030	28.0	14.0	31.90	08/21/1915
Berryville	Kings River	35.47	04/26/2011	1245	35.0	31.0	38.91	11/19/1985
Batesville	White River	23.58	04/27/2011	1330	22.0	15.0	31.90	02/01/1916
Newport	White River	34.17	05/04/2011	1245	30.0	26.0	35.90	04/17/1945
Augusta	White River	40.80E	05/05/2011	1915E	36.0	26.0	41.04	04/20/1945
Judsonia	Little Red River	36.43	05/03/2011	0145	36.0	30.0	39.25	06/15/1945
Patterson	Cache River	12.87	05/06/2011	0100	12.0	8.0	16.00	04/19/1927
Clarendon	White River	37.54	05/10/2011	1200	32.0	26.0	43.30	04/23/1927
Paducah	Ohio River	55.03	05/05/2011	1745	52.0	39.0	60.60	02/02/1937
Brookport (L&D #52)	Ohio River	57.00	05/06/2011	0500	57.0	37.0	62.30	02/02/1937
Grand Chain (L&D #53)	Ohio River	62.20	05/03/2011	0100	53.0	42.0	64.00	02/02/1937
Cape Girardeau	Mississippi River	46.28	05/03/2011	0130	42.0	32.0	48.49	08/08/1993
Thebes	Mississippi River	45.52	05/03/2011	0600	42.0	33.0	45.91	05/23/1995
Osceola	Mississippi River	47.48	05/08/2011	1200	35.0	28.0	50.90	02/07/1937
Memphis	Mississippi River	48.03	05/10/2011	1200	46.0	34.0	48.70	02/10/1937
Helena	Mississippi River	56.59	05/12/2011	0600	55.0	44.0	60.21	02/12/1937
Arkansas City	Mississippi River	53.14	05/16/2011	2300	44.0	37.0	59.20	04/21/1927
Greenville	Mississippi River	64.24	05/16/2011	1300	57.0	48.0	65.40	04/21/1927
Baton Rouge	Mississippi River	45.01	05/18/2011	1000	40.0	35.0	47.28	05/15/1927

Historic flooding along the lower reaches of the Ohio River, Middle and Lower Mississippi River, and associated tributaries involved significant long-term hydrologic operations at two RFCs (Ohio RFC and LMRFC) and five WFOs: Paducah, KY (PAH); Memphis, TN (MEG); Jackson, MS (JAN); Lake Charles, LA (LCH); and Slidell, LA (LIX).

Many other WFOs, (i.e., Tulsa, OK [TSA]; Little Rock, AR [LZK]; Springfield, MO [SGF]; Saint Louis, MO [LSX]; Central Illinois, IL [ILX]; Indianapolis, IN [IND]; Wilmington, OH [ILN]; Louisville, KY [LMK]; and Nashville, TN [OHX]) also were impacted by flooding of streams, creeks, and major waterways, but the relative magnitude and extent of impact did not warrant detailed inclusion in this report.

The USACE referred to this flood as "*The Great Flood of 2011*" in the fall 2011 edition of its quarterly publication titled "*Our Mississippi*." The event surpassed all floods since the "*Great Flood of 1927*." Following the flood of 1927, a theoretical flood was developed by the Mississippi River Commission with input from the Weather Bureau, now the NWS. The Mississippi River & Tributaries (MR&T) Project Design Flood (**Figure 6**) is based on a hypothetical "*worst-case–maximum probable*" flood scenario of three rain events in the Lower Mississippi River Valley occurring 3 days apart. The USACE used this scenario to design and execute flood protection (e.g., erection of levees, straightening of channels, and creation of backwater areas) in the Mississippi River Valley.

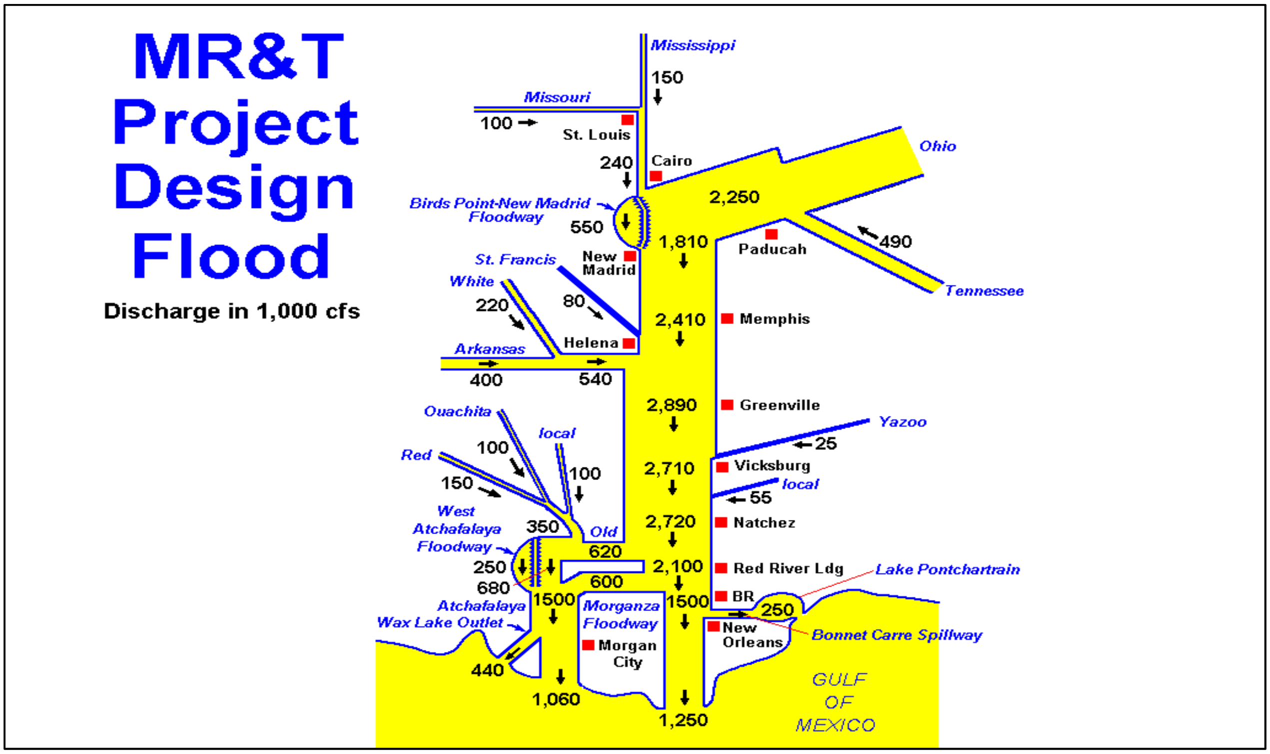


Figure 6: MR&T Project Design Flood

Engineering improvements resulting from the Project Design Flood allowed a greater flow to travel down the river at lower stages. For example, the 2011 flood at Vicksburg, MS, is believed to have had a flow comparable to the 1927 flood (approximately 2.3 million cubic feet per second). It is estimated that the river stage at Vicksburg, MS, would have reached 62.2 feet in 1927 if the levees had not failed; however, in 2011, the stage at Vicksburg, MS, reached only 57.1 feet–a difference of more than 5 feet, and a testimony to USACE flood mitigative efforts undertaken through the years.

Despite the magnitude of the flooding during the spring of 2011, loss of life and damage could have been much more extensive. A severe to extreme drought along the lower reaches of the Mississippi River, mainly in Mississippi and Louisiana, resulted in reduced runoff.

WFOs from Paducah, KY, to the Gulf of Mexico issued hydrologic outlooks over a month before the main flood wave impacted their respective County Warning Areas (CWA). River stage forecasts were also temporally and spatially accurate in forecasting the anticipated flood event, providing the public with long lead times to take appropriate mitigative action.

Table 4: NWS river stage crest forecasts issued on May 2, 2011, for selected forecast points along the Mississippi River versus the actual river stage crest.

	Forecast River Stage (ft.)/ Date of Occurrence		**Actual River Stage (ft.)/ Date of Occurrence**	
Memphis	48.0	May 10	48.0	May 10
Helena	56.0	May 12	56.5	May 13
Arkansas City	53.5	May 14	53.1	May 16
Greenville	64.5	May 15	64.2	May 17
Vicksburg	57.5	May 18	57.1	May 19
Natchez	65.0	May 20	62.0	May 19

2.2. Impacts

2.2.1. Fatalities

One fatality was directly attributed to the flooding along the Mississippi River. A man drowned attempting to cross a field flooded with moving water.

2.2.2. Damage

Flooding resulted in extensive damage to buildings and infrastructure, and impacted commerce. Considerable effort was expended to fortify and repair compromised levees, and erect new ones. Costs were estimated in excess of $2 billion.

President Obama declared the western counties of Kentucky, Tennessee, and Mississippi federal disaster areas. For the first time since 1973, the Morganza Spillway was opened to avert a levee breach and subsequent flooding of Baton Rouge and New Orleans, LA. The opening of this spillway flooded approximately 4,600 square miles of rural Louisiana downstream from the spillway along and near the Atchafalaya River.

<u>Kentucky, Illinois, Missouri, and the Birds Point-New Madrid Floodway</u>

On May 3, 2011, upon direction from the Mississippi River Commission (MRC) President, the USACE executed the water control plan at the Birds Point/New Madrid Floodway, which included opening of the spillway. Operation of the floodway is part of the flood risk management plan for the Lower Mississippi River to reduce flood stages and ease pressure on the entire system during flood events. Opening the levee displaced approximately 200 residents in Mississippi and New Madrid Counties, MO, and flooded approximately 130,000 acres of farmland.

The Farm Bureau estimated damage of approximately $250 million in the New Madrid Floodway, including public infrastructure, private property, crop production, and commerce. River flood damage in McCracken County, KY, and Massac County, IL, immediately upstream from Cairo, IL, was estimated at $10 million.

Tennessee

Public assistance figures used by the Tennessee Emergency Management Agency (TEMA) in its request for a disaster declaration totaled almost 1,500 individuals with $7.1 million damage. According to FEMA, Dyersburg experienced some of the worst flooding in the state with over 600 homes and businesses inundated as the Forked Deer River, a tributary of the Mississippi River, flowed backward into southern areas of the city.

In downtown Memphis, 5,200 residents of the Harbor Town neighborhood were evacuated as the Mississippi River rose to 48.0 feet on May 10. This level was the highest in Memphis since the 1937 flood when the river reached a record 48.7 feet. Subsequent flooding occurred in Millington, as well as suburban areas of Frayser, Bartlett, and East Memphis.

Arkansas

Arkansas Department of Emergency Management (ADEM) and FEMA representatives estimated the cost of restoring facilities and infrastructure to pre-disaster condition in Crittenden, Lee, Mississippi, and Phillips counties at $1.7 million.

Mississippi

In Mississippi, the flood crest moved down the Mississippi River between May 15 and May 21, 2011. Major flood stage levels continued for several days following the crest. Substantial backwater flooding occurred in many of the tributaries, including the Yazoo River.

Forecast points at Vicksburg and Natchez experienced a flood of record, while the Mississippi at Greenville crested 1 foot below the record. Nine casinos on stationary barges in Tunica County were closed during the peak of the flood. On May 15, the Harrah's Tunica reported nearly 6 feet of water inside the hotel. In Wilkinson County, all communities north and west of Highway 24 were inundated and evacuated. Record flooding occurred in the Fort Adams area. Hundreds of properties and several roads were impacted and required evacuation of almost 1,000 people.

Numerous roads along the Mississippi River and in the Mississippi Delta were closed for several days during the flood, including Highway 465 in Warren and Issaquena counties near Vicksburg. Backwater flooding from the Big Black and Yazoo Rivers closed U.S. Highway 61 South between Vicksburg and Port Gibson and North near Redwood, respectively. All four main federal/state highways across the lower Yazoo River Valley were inundated at various locations. The road closures eliminated north-south highway access into Vicksburg.

Temporary levees were erected in and around Vicksburg. South of the city, the Big Black River was closed to boat traffic near its confluence with the Mississippi River due to the river's proximity to high tension power lines. According to the Mississippi Emergency Management Agency (MEMA) and FEMA estimates, more than 2,600 residences, businesses, and other structures were impacted by flood waters. Total damage exceeded $90 million.

Louisiana

According to the Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP), approximately $75.8 million in claims were filed to recover costs for flood response and recovery. This figure did not include the billions of dollars estimated by USACE for the erection and/or reinforcement of levees across the state.

There were significant economic impacts to commerce along the lower reaches of the Mississippi River. Lock closures and loading issues impacted barge traffic. High river levels resulted in low-clearance for ships attempting travel under bridges and power lines, and additional fuel was needed to provide increased power for navigation.

Impacts on parishes (equivalent to counties) included approximately 2,500 evacuations and many road closures. According to a Reuter's news report published on May 9, nine refineries in Louisiana were at risk from flood waters. In St. Martin Parish, a pontoon bridge was closed and the school year ended on May 13—15 days earlier than normal. In St. Mary Parish, there was extensive sandbagging, erection of new levees, placement of barriers, and sinking of barges to restrict river flow. The Intracoastal Waterway was closed west of the Harvey Lock.

3. Facts, Findings, Recommendations, and Best Practices

3.1. NWS Products, Services, Training, and Coordination

A goal of this Service Assessment was to evaluate the degree to which recommendations from the "*Record Floods of Greater Nashville: Including Flooding in Middle Tennessee and Western Kentucky, May 1-4, 2010*" Service Assessment influenced RFC and WFO operations during this event. The 2010 Nashville floods and this 2011 flooding event were similar in that a complex mix of severe convective weather occurred concurrently with mainstem, areal, and flash flooding.

Although the events were similar, the onset of the 2010 Tennessee flooding was significantly faster and with a higher degree of uncertainty in the spatial distribution of extreme rains. In addition, the convective activity that occurred in spring 2011 was much more widespread, allowing a number of affected offices to coordinate their response.

The 2010 Nashville Floods Service Assessment Team found management of WFO operations and staffing did not adequately address the mix of hazards. This fact resulted in the degradation of situational awareness that, in turn, affected warning issuance and decision support. This assessment team did not find such deficiencies in the 2011 event because the WFOs had identified solutions and implemented them based on recommendations from the previous report well before the flooding on the Middle and Lower Mississippi River in 2011. These changes included ensuring a dedicated person covered the hydrologic desk when severe weather and flooding was of concern. Interviews with users and partners during the 2011 flood indicated an extraordinarily high level of service from all NWS offices.

There was a considerable increase in forecaster training resulting from recommendations in the Service Assessments for the 2010 Nashville Floods and "*2009 Southeast United States Floods, September 18-23, 2009*." For example, WFO PAH conducted a Staff Training Day on January 26, 2011, devoted entirely to the Nashville Floods assessment. WFO JAN created an extensive pre-flood training exercise and outreach plan for all operational staff (**Appendix E**). WFO JAN conducted four, 6-hour sessions attended by six to seven forecasters each. The National Centers for Environmental Prediction (NCEP) Advanced Weather Interactive Processing System (N-AWIPS) was used to run four displaced, real-time flood scenarios to review hydrologic principles, methodologies, tools, checklists, hydrologic references and resource guides, procedures and software (i.e., Hydroview and Riverpro). The training session participants were sequestered to ensure they were not distracted by operational demands. In addition, WFO JAN required all staff members to attend an all-day staff meeting on May 4, 2011, to prepare for the event, approximately 1 week prior to the beginning of the flooding.

WFO JAN created a one-stop, ready-reference book. It provides the latest information concerning flood inundation scenarios and operational response procedures in the advent of a levee breach/failure at any point, along with appropriate points of contact and phone numbers.

Other NWS offices developed comparable operational action plans and action items and held management and staff accountable for completion. This aggressive approach to applying lessons learned from past service assessments produced tangible results for operations, interagency coordination, and DSS.

Best Practice: Taking past service assessments very seriously, many WFOs devoted a significant amount of training time to study and implement recommendations cited in the 2010 Nashville Floods and 2009 Southeast United States Floods service assessments. NWS offices impacted by the 2011 Middle and Lower Mississippi River flood conducted operational and all-hands meetings and training sessions well ahead of this event to familiarize or re-familiarize the staff with unique challenges associated with record flooding.

Best Practice: WFOs TSA, PAH, and MEG, which experienced severe weather along with flooding/flash flooding, all maintained a dedicated hydrologic desk for all shifts–even during the peak of the severe weather outbreak to ensure hydrologic threats were efficiently monitored and warned. Other NWS offices farther south and east that experienced flooding as the flood wave moved downstream, but did not experience significant severe weather during the passage of the flood wave, adjusted staffing levels as needed to provide 24/7 hydrologic support.

Another theme from the 2010 Nashville Floods service assessment regarded the need to adopt relevant Incident Command System (ICS) staffing principles into WFO operations. Through extensive interviews with all impacted NWS field offices, it was readily apparent that ICS staffing model principles (e.g., ensuring that the proper number of individuals were available and dedicated to specific operational responsibilities to respond to a weather threat and its associated workload demands) were satisfactorily employed throughout the flood event.

The assessment team did not identify any particular deficiency in the application of ICS principles by the impacted WFOs and RFCs. Critical partners provided a mixed assessment of NWS interpretive services due to some forecasters' unfamiliarity with how Emergency Operation Centers (EOC) operate. For example, the Region 11 Coordinator for the Illinois Emergency Management Agency indicated that he was very pleased with the interpretive services his EOC received from the NWS, but also indicated that "*it would have been beneficial if the NWS had a greater appreciation and knowledge of the ICS system*." He elaborated that "*although NWS forecast support and service was accurate and very much appreciated, NWS meteorologists were not able to hit the ground running because of their unfamiliarity with how an EOC operates*."

In contrast, EOC staff for McCracken County, KY, indicated that an NWS meteorologist provided particularly effective interpretive services because he "*was proficient in ICS and was like one of us.*" These comments were articulated with respect to how seamlessly the transfer of weather and water information moved between the NWS meteorologist and EOC operations. The director of emergency services for McCracken County was asked if the familiarity of the NWS staff member with ICS principles impacted his (the director's) ability to relay weather information to his staff. The director replied: "*Yes, absolutely! He (NWS meteorologist) fit into our operations very well and that helped. It's hard to pinpoint exactly how this made a difference. A person either fits in or they don't. This individual knew who to speak to, how to communicate information, and how he fit into the EOC*."

ICS principles focus on:

- The content and format of provided information, e.g., succinct, specific, detailed, impact-based, commonly understood terminology, level of confidence, deterministic and probabilistic worst- and best-case outcomes;
- How and when to communicate this information, e.g., within the existing ICS command structure, within established protocols; and,
- How the information communicated will influence or impact the unique concerns of the EOC at any particular time.

Staffs from several EOCs indicated they wanted more support from the NWS in the form of interpretive services for their EOCs during significant weather events. The assessment team suggests all NWS operational staff, not a select few, be capable of providing ICS support. Adoption of ICS principles must be ingrained into the NWS culture if the agency is to fully realize its goal to provide enhanced DSS to its partners, especially all federal, state, local, and tribal entities using the ICS system.

At first glance, it would appear that increasing NWS understanding and integrating ICS principles into the NWS culture could be achieved through regimented training and associated drills. In fact, there is an existing model in the Incident Meteorologist (IMET) program where IMETS are trained in ICS; moreover, IMETs also gain practical experience, which reinforces their training through regular IMET deployments. This example should be observed by all NWS operational personnel expected to provide DSS.

The 2010 Nashville Floods service assessment recommended relevant ICS staffing principles be integrated into WFO operations. The adoption of ICS staffing models resulted in improved operational readiness and service to partners during the spring 2011 Middle and Lower Mississippi River Valley flood event. It would therefore be prudent for the NWS to explore other ICS-based principles that further enhance DSS to critical partners.

Fact 1: EOC staff in Illinois indicated a more thorough adoption of ICS principles would have enhanced the efficiency and effectiveness of NWS interpretive services.

Fact 2: EOC staff in Kentucky stated that NWS staff members provided particularly effective interpretive services because they were able to functionally integrate into the EOC and efficiently and effectively communicate in their language.

Fact 3: Staff from several EOCs in multiple states indicated that they desired greater interpretive services from the NWS.

Finding 1: The demand for NWS interpretive services by EOCs continues to increase and is consistent with the NWS goal to improve DSS for events that threaten lives and livelihoods. The utility of NWS interpretive services is greatest when provided by NWS staff that understand and apply ICS principles. Not all NWS operational personnel are prepared to provide the level of interpretive support that is needed.

Recommendation 1: The NWS, in collaboration with FEMA, should define prototype ICS principles (i.e., engaged partnerships; tiered response; scalable, flexible operational capabilities; unity of effort through unity of command; preparedness; and readiness to act) at one or more NWS operational offices to assess which ICS principles NWS can practically adopt, then develop a training and implementation plan for all operational offices and regional support centers.

The assessment team identified ongoing issues related to the disparity between WFO HSA and CWA boundaries. Some of the offices in the Middle Mississippi Valley experienced both short-fused flash flooding and longer-fused river flooding. Inter-office collaboration and intra-office communication were more complex for those offices with overlapping areas of responsibility. The hazard type and valid time for differing hydrologic products had to be carefully collaborated to ensure consistency and seamlessness of service. Partners providing river level observations had to communicate the same hydrologic information to two WFOs, or rely on one WFO to relay critical information to another. In some instances, WFOs had an increased workload because to ensure relevant hydrologic information for all hydrologic interests could be provided by a single WFO, contingency forecasts from one office were reissued as a flood potential outlook at another.

Fact: WFO MEG issues flash flood and areal flood warnings for Randolph, Lawrence, Clay, and Greene Counties, AR, while WFO LZK is responsible for river flood warnings for the same geographic area on the Black River at Corning, Pocahontas, and Black Rock, AR. To be temporally consistent, the WFOs had an increased coordination workload. This extra work was to ensure that when flash flood warnings expired, longer-term areal flood warnings would be issued by WFO MEG for the same time period and geographic area for which WFO LZK issued river flood warnings.

Fact: Several times WFO MEG contacted local authorities for updated information on river levels and levees but was informed the information had been relayed to WFO LZK. Local partners had to deal with two offices for one event.

Fact: WFO LIX has responsibility for issuing long-fused river flood products along the Atchafalaya River while WFO LCH is responsible for issuing short-fused and areal-based hydrologic watches, warnings, and advisories for the same area.

Fact: WFO LIX disseminated contingency forecasts for the lower reaches of the Mississippi and the Atchafalaya Rivers. WFO LCH reissued the information via a Flood Potential Outlook (ESF) product.

Finding 2: Several NWS offices and county and state-level EM officials expressed concern over differences between HSA and CWA boundaries. Not all partners were sure about which NWS office to contact to acquire or provide specific hydrometeorological information. NWS offices incurred increased workload relaying phone-based hydrologic information received by one office to another, and duplicating hydrologic forecasts using differing hydrologic product titles to ensure a single-office source.

Recommendation 2: NWS regions and their respective WFOs should work with critical partners to determine where realignment of disparate CWA and HSA boundaries is both warranted and feasible to limit spatial discontinuity and enhance service-related issues.

3.1.1. Hydrometeorological Prediction Center

The HPC medium-range forecast discussion issued April 14 was the first product that identified a synoptic scale rainfall and flooding event was likely in the coming days. As the event unfolded over the next 3 weeks, accurate HPC forecasts of Day 1 through Day 5 rainfall were critical to the production of river forecasts with significant lead time.

HPC conference call collaboration with internal partners (i.e., WFOs, RFCs, CRH, and SRH) began on April 18 and with external partners (e.g., USACE, FEMA, USGS) on April 21. Over the next 14 days, HPC participated in 29 separate calls with multiple internal and external partners.

HPC management optimized shift coverage and worked with an external partner to adjust one of the recurring daily call times. The only glitch was HPC's inability to access one call when all allocated conference lines were in use. This issue is discussed further in the Interagency Coordination & Collaboration section below.

Collaboration was instrumental in building consensus between the RFCs and HPC on the critical Day 1 Quantitative Precipitation Forecasts (QPF). When the HPC guidance and the RFC operational forecasts are aggregated for the 3-week period (**Figure 7**), there is little areal discrepancy and only a two percent reduction in the maximum rainfall amount. Some collaborative deficiencies existed during the May 2010 Nashville event that was due, at least in part, to uncertainty of the speed, magnitude and spatial distribution of precipitation. This uncertainty resulted in significant discrepancies between HPC guidance and RFC rainfall forecasts.

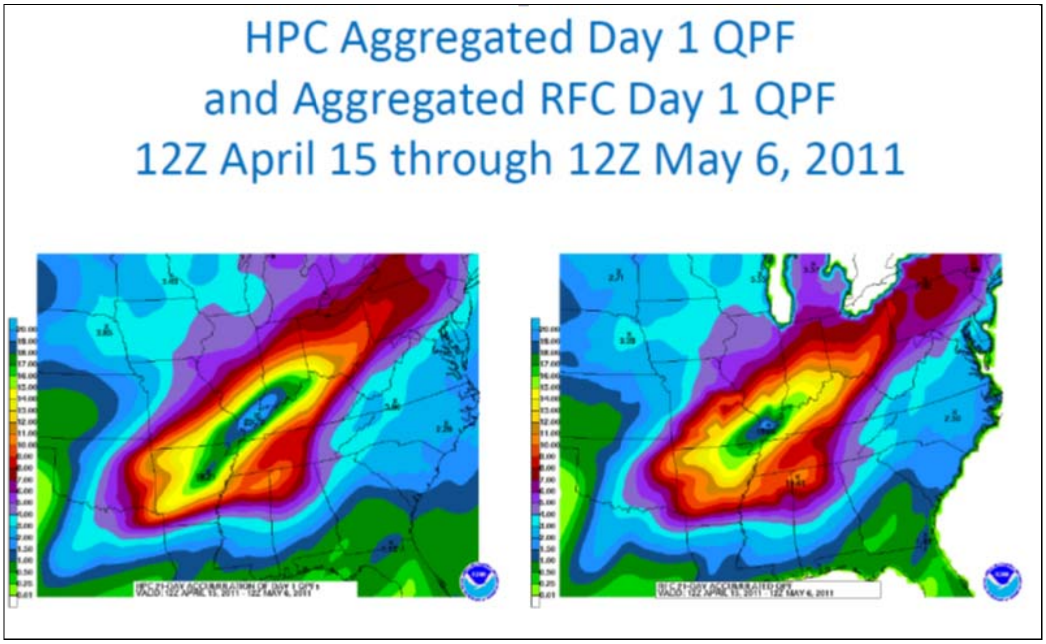


Figure 7: HPC Aggregated Day 1 QPF (left) and Aggregated RFC Day 1 QPF (right) from 12Z April 15 through 12Z May 6, 2011

Best Practice: Collaboration between HPC and the RFCs in the flood area led to consistent product delivery to users and partners.

The continuous engagement of external partners by the NWS was validated in statements made by Major General Michael Walsh, USACE Commander of the Mississippi Valley Division, to the NWS liaison to USACE based in Vicksburg, MS: "*Incredible information from all branches of the National Weather Service. Bending over backwards to provide what the Corps needs.*" The accuracy of HPC forecasts throughout the event was noted by many internal and external partners.

3.1.2. NWS Southern and Central Region Headquarters

The assessment team interviewed the Southern Region Regional Operations Centers (SR ROC) and Central Region Regional Operations Center (CR ROC) via phone. During these phone conversations, four overarching issues were identified at both ROCs: staff resource management, information management, reporting, and regional collaboration. The use of ICS concepts permeated much of the activities at both ROCs.

3.1.2.1. Staff Resource Management

SR and CR personnel coordinated throughout the event to determine regional responsibilities and common methods for event reporting due to the complexity of areas of responsibility within the middle Mississippi River area. The SR ROC identified personnel in field offices not impacted by the event who could be deployed to offices in the event area. Once identified, deployments occurred within 24 hours.

The CR ROC employed a similar approach. In some cases, the additional staff served as decision support specialist (e.g., staffing an EOC). In other cases, the additional staff integrated into the field office's operations.

SR ROC also optimized the use of CRH staff. The SR ROC used an ICS principle that transferred eight people from their normal administrative positions into the ICS structure.

Best Practice: SR and CR ROCs used their headquarters' staff in an innovative manner by applying ICS principles.

3.1.2.2. Information Management

SR and CR ROCs collected information from many sources and presented it to partners in a consistent, standardized, one-stop-shopping format. CR ROC developed a specialized Web page that included information from multiple WFOs and included USACE information not available on the Advanced Hydrologic Prediction Service (AHPS). To support partner response and recovery operations, SR ROC, in collaboration with LMRFC, developed a one-stop shop Web page for short- and extended-range flood forecast and other hydrometeorological information. It is important to note that CR and SR resources were needed to overcome deficiencies in current AHPS Web pages. The need to address NWS Web-based deficiencies is highlighted in Finding and Recommendation 20. SR ROC also developed and regularly updated talking points to ensure consistent messages to NWS partners, regardless of which WFO or RFC was involved.

3.1.2.3. Reporting

Both ROCs issued routine reports for internal and external use. The SR ROC, for example, issued daily Emergency Response Plans (ERP) that were available on SharePoint for WFOs and RFCs to view. These ERPs summarized deployments throughout the region and addressed cross-cutting and tactical issues.

CR issued Event Coordination Plans modeled after Incident Action Plans in ICS, and issued frequent Situation Reports, again modeled after ICS. These plans and reports were used to keep everyone in the NWS informed and, in some cases, for collaboration with key NWS partners.

Consistent with Finding and Recommendation 1, the assessment team suggests regions adopt a standard ICS-based format to facilitate internal and external coordination and communication.

3.1.2.4. Regional Collaboration

Both ROCs expanded collaboration to reduce the burden on the field offices. SR also deployed staff to key partners, such as FEMA, to evaluate the concept of a hydrologic equivalent of the Hurricane Liaison Team. Based on positive feedback from FEMA, the SR ROC is considering expanding this concept to other types of extreme weather events.

Fact: The SR ROC deployed two staff members each to FEMA Regions 4 and 6. Three of these staff deployments involved local travel; the fourth involved travel costs for which SR did not receive reimbursement from FEMA. FEMA was willing to provide reimbursement but there was no mechanism in place to do so in a reasonable timeframe.

Finding 3: Providing staff support to national partners like FEMA during high-impact events is a critical part of the NWS mission and represents the highest level of interpretive services. A formalized reimbursement mechanism between FEMA and the NWS would ensure that the cost of deployment does not factor into the decision to provide this valuable service. A precedent exists in the form of the Interagency Agreement for Meteorological and Other Technical Services between the NWS and the Departments of Agriculture and Interior.

Recommendation 3: NOAA should establish an agreement with FEMA to facilitate reimbursement of costs associated with deploying NWS staff to FEMA operations centers.

3.1.3. Ohio River Forecast Center

OHRFC staff was interviewed via a conference call. Prior to the 2011 flood, OHRFC adequately addressed technical issues cited in the 2010 Nashville Flood Service Assessment. Specifics are provided in the Interagency Coordination & Collaboration section of this assessment.

The staff at OHRFC credit coordination within the NWS and between the NWS and critical partners to the strong relationships it developed prior to this event. This included developing a community model for the Ohio River, including the confluence region of the Mississippi River extending from Chester, IL, to Caruthersville, MO. This includes the critical Birds Point-New Madrid Floodway area along the Mississippi. The Hydrologic Engineering Center River Analysis System (HEC-RAS) community model development occurred during the 4 years before this event. It served to build trust between OHRFC, LMRFC, and the USACE's HEC in Davis, CA, where the HEC-RAS software was developed. These relationships were critical to the successful use of the HEC-RAS model during the analysis of the Birds Point/New Madrid Floodway operation alternatives, and helped to mitigate challenges associated with cumbersome data exchange. This project is referenced in Section 3.2 and captured in a recommendation in the 2010 Nashville Flood Service Assessment.

During a 2-week period, OHRFC staff provided the QPF and inflow data needed by USACE HEC staff for use as input into the HEC-RAS model. Feedback from the HEC lead engineer on the project indicated OHRFC staff members were very helpful throughout the effort. HEC staff independently credited the HEC-RAS project as key in developing strong relationships with OHRFC staff. This relationship was relied upon heavily during the stressful period leading up to the decision to operate the Birds Point-New Madrid Floodway.

Best Practice: Collaborative projects, such as the HEC-RAS-based community model for the Ohio and Upper Mississippi Rivers, advance the technical capabilities of all partners. These projects are also the most productive way to develop and maintain relationships between agencies and optimize the use of resources for complementary missions.

OHRFC used an additional tool to maintain relationships: it developed a 1 to 2 year rotation program that ensures at least one RFC staff member visits with each critical partner.

OHRFC staff visited most of the WFOs in its area of responsibility in the year prior to this event. During interviews, WFO PAH staff was very complimentary of OHRFC support during this event and specifically mentioned there was a significant improvement in responsiveness over prior events. OHRFC participates in Tri-Agency Fusion Team meetings.

OHRFC employed DSS tools such as multimedia briefings, conference calls, weather and hydrologic briefing calls, social media, and self-briefing Web pages. In conjunction with LMRFC, North-Central RFC (NCRFC), and CR ROC, OHRFC conducted multi-regional weather/hydrology briefings to state and local partners prior to Good Friday—recognizing Good Friday would be a holiday for many state and local agencies.

OHRFC staff learned from past hazardous weather-related events that there are measures staff can take prior to an event to reduce the communication burden during the event's most active period. One such action is providing semi-static information to the USGS needed for its own field operations when flooding occurs.

Best Practice: OHRFC shared all NWS-determined critical river levels with USGS before the event so the data could be used as a planning tool. This reduced communication issues during the event.

3.1.4. Lower Mississippi River Forecast Center

The entire assessment team visited the LMRFC to conduct interviews with staff and management. Like OHRFC, LMRFC's area of responsibility is extensive, encompassing all of the Middle and Lower Mississippi River and associated major tributaries (**Figure 8**). Existing collaborative relationships with other agencies, provision of DSS, technical issues, and office staffing were explored by the team.

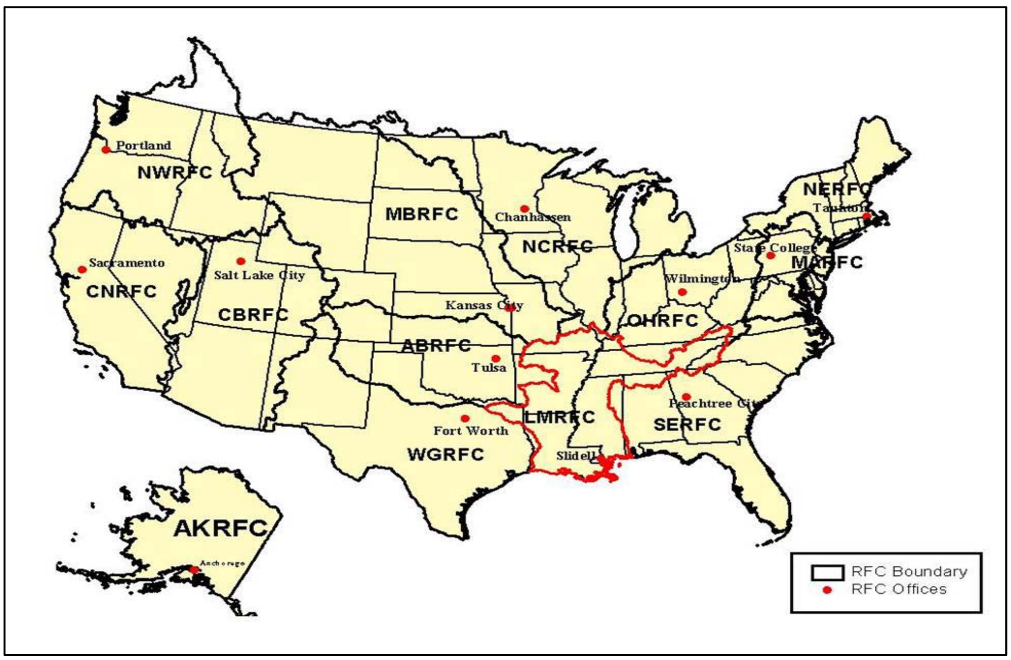


Figure 8: This map depicts the placement of all NWS RFCs and respective areas of hydrologic responsibility, with LMRFC area highlighted in red.

3.1.4.1. Collaboration and Decision Support

LMRFC operated 24/7 for 45 days (April 19 through June 2, 2011) to provide enhanced service to WFOs and partners: 16 forecast points along the Mississippi River equaled or exceeded the flood of record, 28 experienced major flooding, 25 had moderate flooding, and 33, minor flooding.

The RFC used Facebook shortly before the onset of the flood. The site was widely used– quickly reaching 4,000 "*likes.*" The office staff felt that use of this social media tool was helpful as a means of alleviating common questions concerning where and how to acquire hydrologic information and to address misconceptions related to flood stage, inundation, and impact.

An internally developed hydrologic modeling system application was used by LMRFC to produce possible Mississippi and Atchafalaya flow diversion scenarios and impacts in support of DSS for both LMRFC and the USACE New Orleans District.

During the period of continuous operations, more than 175 telephone briefings and conference calls, and in excess of 100 interviews were given to newspapers, radio stations, and TV stations. The staff worked approximately 900 hours of overtime.

Longstanding collaborative relationships exist between LMRFC, USGS, and USACE. For well over a decade, the RFC has actively participated in meetings such as the Mississippi Valley USGS/NWS/COE Annual Tri-Agency meeting. During the past 4 years, LMRFC has aggressively participated on a Tri-Agency Fusion Team to enhance collaboration and improve interagency operations during flood events. These relationships proved invaluable during this event.

LMRFC staff provided enhanced DSS to approximately 45 different stakeholders in the NWS, USACE, USGS Water Science Centers, USCG, FEMA, Tennessee Valley Authority (TVA), Nuclear Regulatory Commission (NRC), local and regional EMs, TEMA, Mississippi Emergency Management Agency (MEMA), and GOHSEP. LMRFC provided non-routine and experimental products and services to enhance DSS to critical partners. These included:

- Creating individual river basin status maps color coded for current river stage magnitude at each forecast point (**Figure 9**)
- Creating Ohio and Mississippi River forecasts integrated into a single product (**Figure 10**)
- Providing Ohio and Mississippi hydrographs on a single page (**Figure 10**)
- Providing selectable display and color-coded status of all river forecast points on a Google-Earth map background (**Figure 11**)
- Issuing 28-day stage forecasts for the Lower Mississippi River two times a week instead of once a week
- Providing contingency forecasts incorporating 5- and 10-day QPF from the Global Forecast System (GFS) model
- Posting a SRH-developed Web viewer incorporating radar imagery, RFC best-estimate rainfall (QPE), and 5-day and 28-day stage forecasts for the Lower Mississippi River and Atchafalaya River

Fact: LMRFC provided 5 days of QPF in operational forecasts based on confidence and collaboration with USACE and WFOs. The QPFs provided a more realistic recession of rivers after the crest.

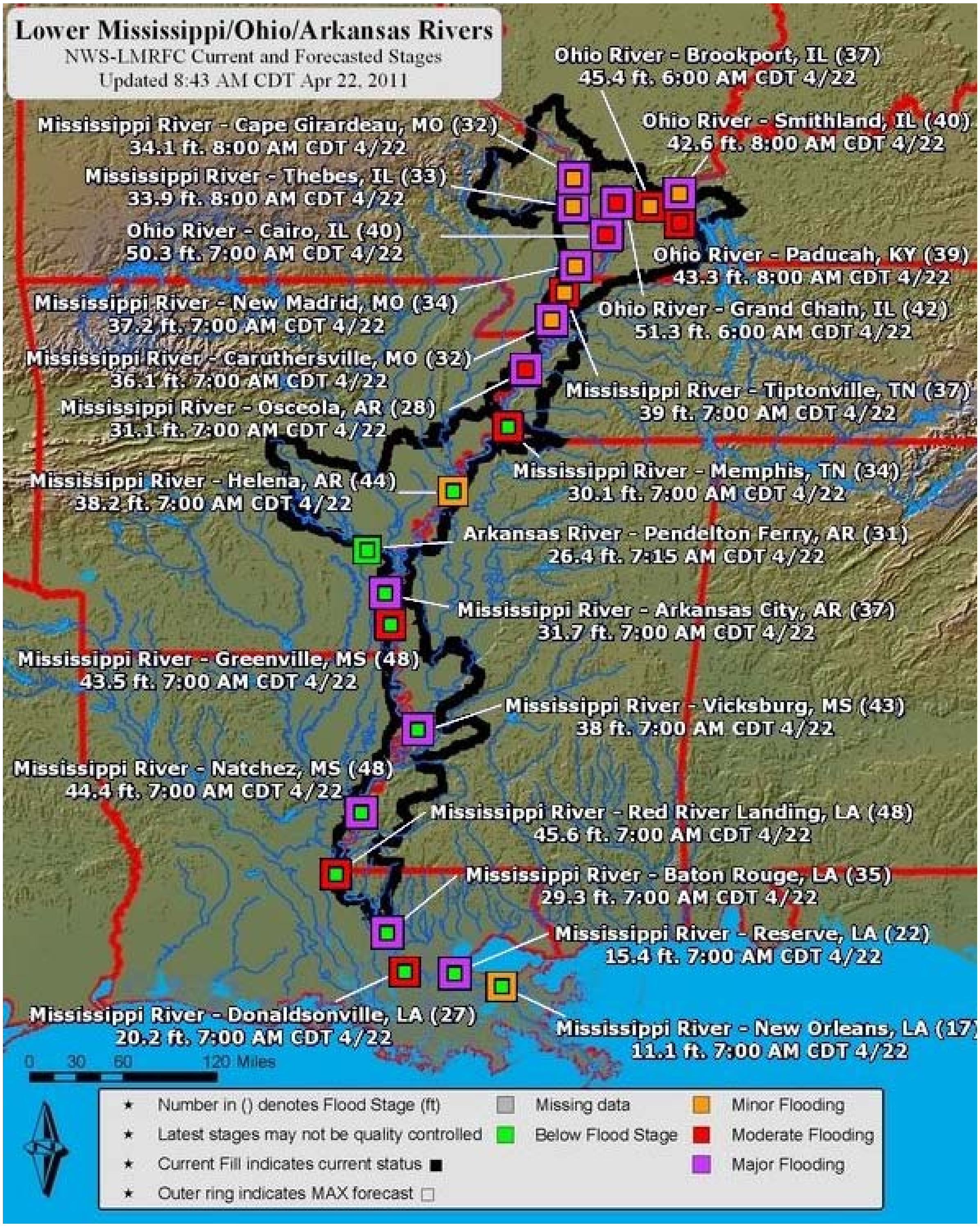


Figure 9: LMRFC individual river basin status maps color coded for magnitude of current stage at each forecast point

Figure 10: Ohio and Mississippi River hydrographs on a single page (left side) and Ohio and Mississippi River forecasts integrated into a single product (right side)

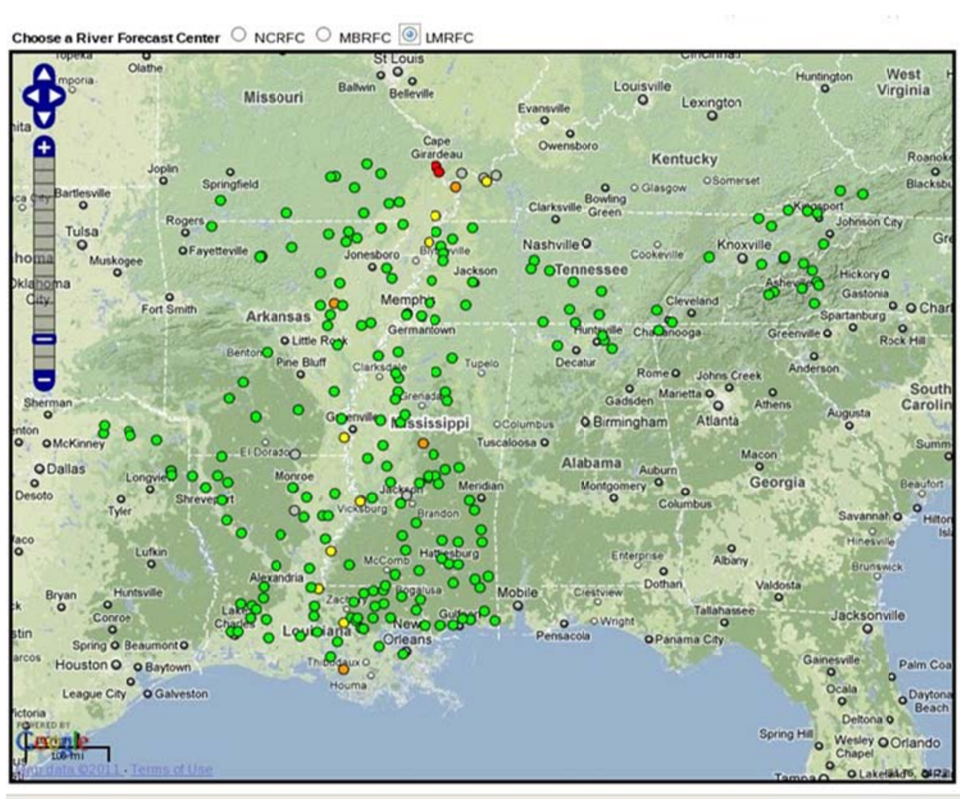


Figure 11: Selectable display and color-coded status of all river forecast points on a Google-Earth map background

Forecast and observation information was distributed through Facebook, onsite briefings, GovDelivery, Internet homepages, Web-based conference calls/briefings, NWSChat, telephone calls, and email. Daily onsite briefings were provided to GOHSEP staff. The RFC used GovDelivery to transmit river forecasts to smartphones. Internet Homepage information, Web-based briefings, and Facebook postings were used by the NRC to remain abreast of forecast river levels at three nuclear power plants along the Mississippi River.

Although NWSChat was an effective tool in relaying information, the use of one-on-one and conference calls was more beneficial. Email was the least effective communication method based on existing staffing and workload.

Fact: LMRFC used GovDelivery to transmit river forecasts to smartphones. Those opting for the service received a text message and were able to view forecasts on smartphones every time a forecast was updated.

3.1.4.2. Technical Issues

Output from a community-based hydraulic model (e.g., discharge, model flow) was successfully used for river stage forecasting along the Ohio and upper Mississippi Rivers as described in Section 3.1.3. This model was developed in collaboration with NWS and USACE. The model does not yet exist for the Lower Mississippi River.

LMRFC uses the Dynamic Wave Routing Model (DWOPER) to forecast Mississippi River stages from Cape Girardeau to New Orleans. The model can be used on a single river or system of rivers where storage routing methods are inadequate due to the effects of backwater, tides, and mild channel bottom slopes. Over 100 USACE scenarios for diverting floodwaters from the Mississippi River through floodway structures were developed using DWOPER. The HEC-RAS also was used and was especially helpful during the operation of the Birds Point/New Madrid floodway.

Fact: LMRFC used DWOPER to generate 100+ model run scenarios to assist USACE with floodway water-routing decisions. LMRFC forecasts, and a separate set of contingency forecasts, were then issued based on a "*most likely*" operation of USACE-controlled floodways.

The channel characteristics (e.g., slope, depth) have changed since the last flood of record in 1973 (**Figure 12**). This change is due to sedimentation and channel resistance (slowing) that occurred because of riparian growth (vegetation). This change resulted in a challenging river forecast because the river flows and stages exceeded 1973 levels the models were calibrated against. The "*loop-rating*" effect was notable (**Figure 13**). A rating curve shows higher values of discharge (flow) for a certain stage when the river is rising and lower values when the river is falling. This effect is due to the slope of the water surface causing flow to accelerate with the rising level and decelerate when falling.

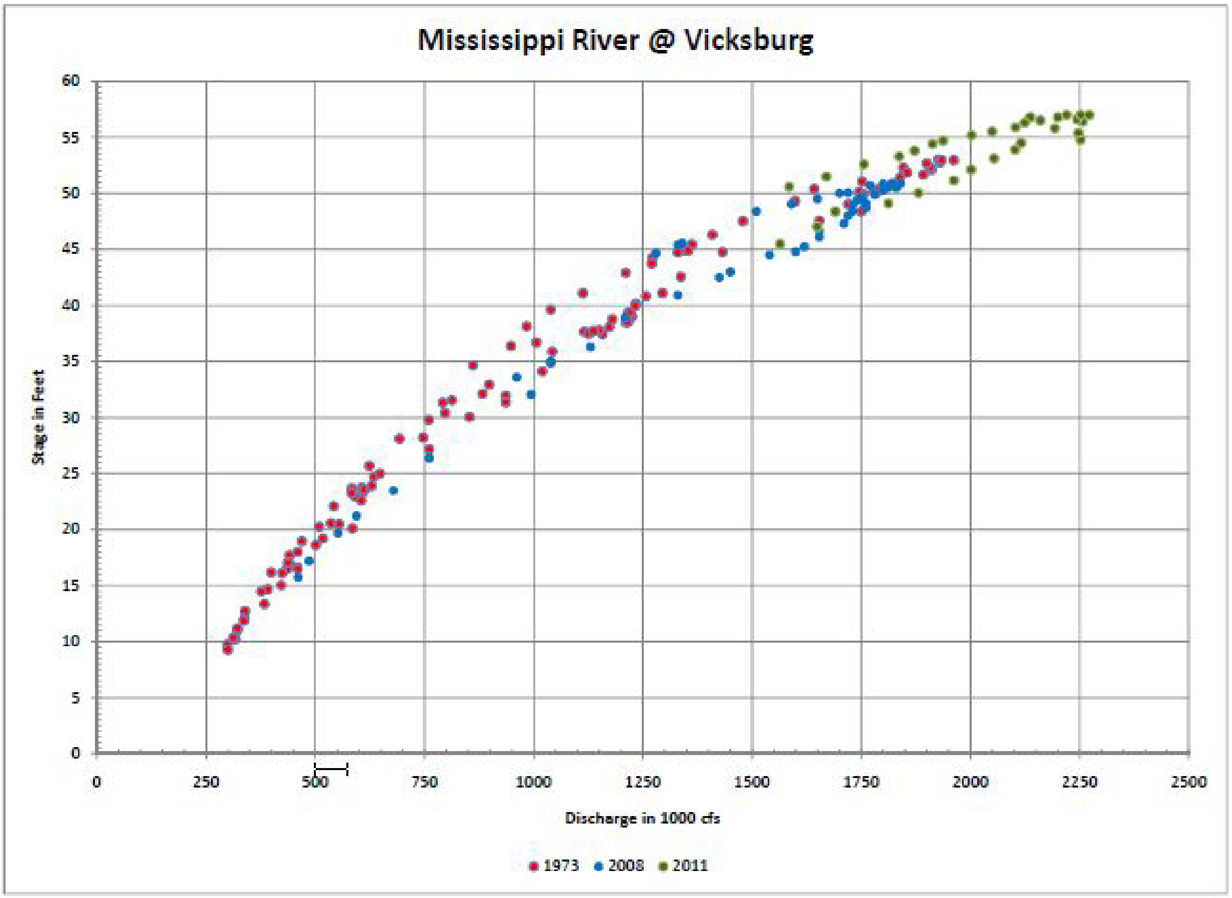


Figure 12: Stage versus discharge on the Mississippi River at Vicksburg, MS, depicting the loop-rating effect that occurred at this location during floods in 1973, 2008, and 2011 (2011 data are preliminary). Source**:** LMRFC.

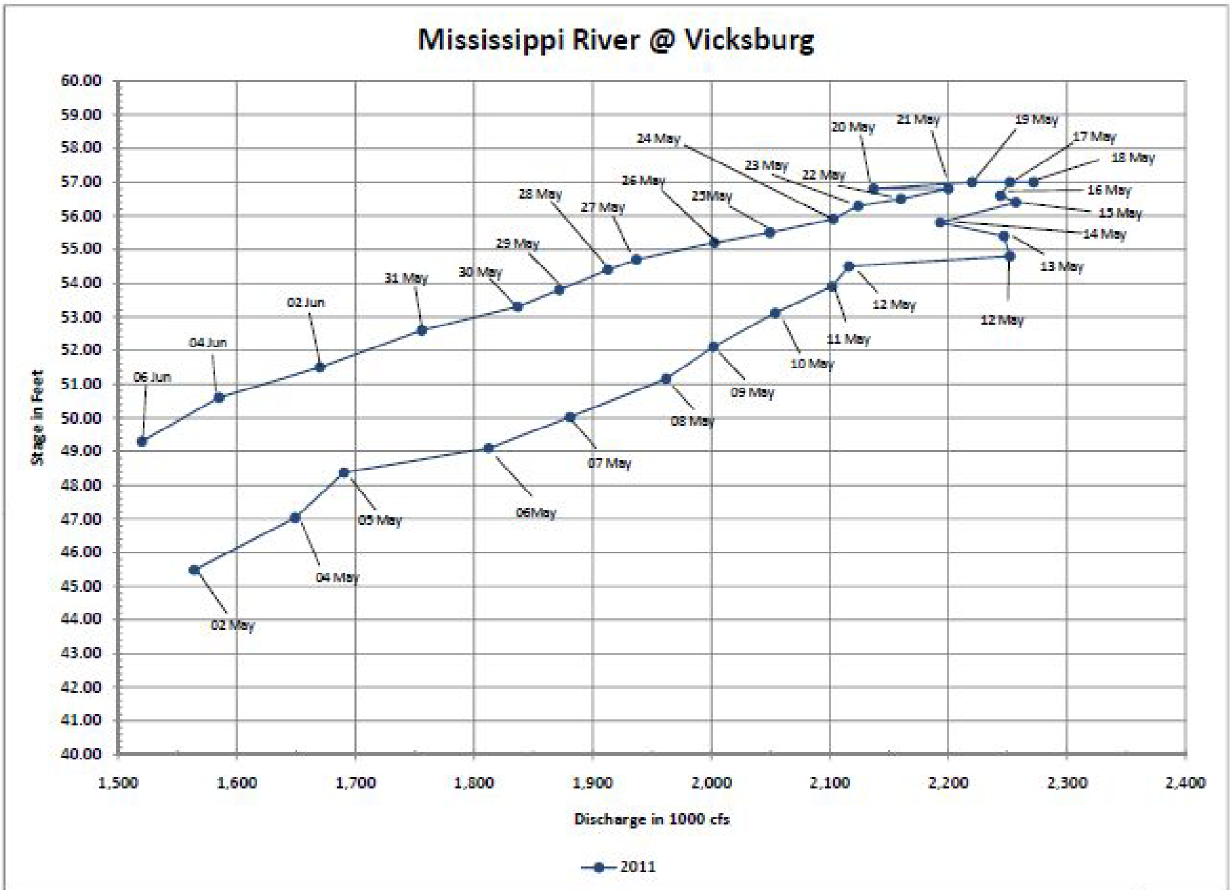


Figure 13: This graph contains the stage versus discharge on the Mississippi River at Vicksburg, MS, showing a pronounced loop-rating effect during the 2011 Mississippi River Valley Flood (2011 data are preliminary). Source: LMRFC.

Fact: As a result of the looped nature of the rating curve evident at most forecast points along the Lower Mississippi, LMRFC model flows were too high when the river was forecast to rise and too low when the river was forecast to fall. USACE and LMRFC coordinated extensively to ensure that peak LMRFC stage forecasts were consistent with USACE modeling. This coordination yielded very accurate and consistent river stage forecasts at most Mississippi River forecast points throughout the event.

LMRFC worked with the Hydrologic Services Division, Hydrologic Support Team on multiple occasions during the Spring 2011 Middle and Lower Mississippi Valley flood event to remove unrepresentative tabular flow data from AHPS Web pages. This process was typically accomplished in 1-2 hours from the time of request.

Finding 4: The dynamic nature of the Lower Mississippi River is not compatible with the single value rating curve depicted on AHPS Web pages. AHPS graphics are limited to defining a specific stage on the left Y-axis to a specific flow/discharge on the right Y-axis. When looped rating curves are present, reference to a specific flow/discharge with respect to stage becomes increasingly problematic since two differing flows may yield the same stage at different times during the hydrologic event. During such instances, the forecast stage becomes the only standard that remains viable on the Y-axis.

Recommendation 4: The NWS should work with the USACE and USGS to realize system interoperability and data synchronization for rating curves on dynamically changing waterways. In the interim, WFOs should receive training on how to directly change data within the AHPS Content Management System (CMS) to remove flow/discharge labels on the right Y-axis of AHPS Web pages whenever loop rating curves are anticipated or in effect. WFOs should work with the Hydrologic Support Branch to remove tabular listing of flow data on the AHPS Web page when needed.

There were several problems forecasting for the Atchafalaya River. LMRFC uses hydrologic routing techniques in the NWSRFS to produce forecasts. The lack of an NWS Community 2-D hydraulic model for the Atchafalaya River added to the uncertainty in the forecast crests. Older mapping and Light Detection and Ranging (LIDAR) systems were insufficient to provide reliable inundation mapping in portions of the Atchafalaya Basin.

Finding 5: Current forecast methods did not adequately capture backwater storage areas or the impact of potential levee failures, nor provide quality inundation mapping. A Community Model (i.e., advanced 1D and 2D hydraulic models built with new LIDAR, HEC-RAS, and/or others) for the Lower Mississippi and Atchafalaya Rivers and its tributaries would allow the NWS and other partners to provide more precise and well-collaborated river stage and water routing forecasts.

Recommendation 5: The NWS should collaborate with USACE to develop a Community Model for the Lower Mississippi River, including the Atchafalaya River and its tributary storage areas.

During the flood, the Morganza Spillway was operated for the first time since 1973. The opening of this spillway had a significant impact on downstream areas along the Atchafalaya River. Both the USACE and the NWS were surprised at the slow response to inundation downstream. This fact was most evident at Butte La Rose, LA.

The initial LMRFC stage forecast at Butte La Rose, LA, was 27.0 feet with a contingency forecast of 29.0 feet. The contingency forecast equated to about 1 foot of water in the highest part of town. During a town hall meeting in Butte La Rose, a couple of weeks before the expected flooding, references were made to inundation maps by USACE personnel. Public confusion resulted from how to interpret official NWS stage forecasts with respect to USACE inundation maps.

Finding 6: Lack of information on how to relate NWS stage forecasts to USACE inundation maps resulted in confusion and anxiety among the residents of Butte La Rose, LA.

Recommendation 6: The NWS should work within the Tri-Agency Fusion Team to ensure a consistent and understandable message to partners. The NWS also should advocate use of a vertical datum (i.e., North American Vertical Datum of 1988-NAVD88) referenced to gravity measured at Father Point in Canada for flood forecasting and inundation mapping. All modern elevation data are based on a gravitational model of the Earth.

USACE uses a Water Control Plan (WCP) that governs how water will be released and routed through various control points. LMRFC had questions about how to best incorporate WCP data into RFC model projections when flow/stage relationships became suspect.

Finding 7: Due to lack of community and 2-D models to provide a more precise river stage and water routing forecast and uncertainty concerning how much flow would be diverted through the Morganza spillway, LMRFC adopted a conservative approach and did not lower the forecast at Butte La Rose, despite downward adjustments to forecast points further upstream. Downward adjustments were made at Butte La Rose a couple of days later.

Recommendation 7: To ensure optimal coordinated river stage forecasts in highly controlled waterways, RFCs should incorporate USACE Water Control Plans into forecast models when applicable.

Flooding in the greater Nashville area in 2010 exceeded levels that had been experienced in most peoples' lifetimes. Information on what areas would flood at certain river stages was not available. The ability to inform the public of flood impacts above record river levels or at levels higher than observed in the past 50 years is difficult without inundation maps.

In the 2 years prior to the 2011 Middle and Lower Mississippi River Valley Flood, inundation maps were developed for only a few areas along the river. These maps were critical flood fighting tools when coupled with the NWS long-range crest predictions.

Fact: Flood inundation and other GIS-based products were heavily used by the public. According to the management team at WFO JAN, flood inundation mapping was the number one requested service that users and partners would like to have the next time flooding occurs.

Fact: The NWS has a plan for implementing inundation maps and has successfully implemented over 60 map libraries across the United States.

Finding 8: For the 2011 Middle and Lower Mississippi River Valley Flood, inundation mapping was widely needed but not readily available. Some EMs created impromptu inundation maps. Interviews with residents in the Memphis area who evacuated their homes indicated they valued having the inundation information.

Recommendation 8: The NWS should create and implement a plan through the Integrated Water Recourses Science and Services (IWRSS) initiative, which is evaluating flood inundation mapping activities between USACE, USGS, and the NWS, to explore opportunities to partner with other water agencies and accelerate the implementation of inundation mapping nationwide or develop new methods for creating these maps such as dynamically from the community 1-D/2-D hydraulic model.

Although much of the Middle Mississippi Valley experienced well above normal precipitation from the fall of 2010 through the spring of 2011, the Lower Mississippi Valley received scant rainfall. Many areas in the lower portion of the basin, west into the southern plains, experienced severe to extreme drought during the same period. The abundance of water moving downstream along the Mississippi was in stark contrast to the parched land surrounding it.

Finding 9: Only small areas of each county/parish immediately near the river were impacted by flood waters. Some EMs perceived an inconsistency between areal flood warnings released for large geographic areas to the impact that was often restricted to areas close to the waterway.

Recommendation 9: Modify areal flood warning templates and software to establish predefined flood warning polygons that more specifically identify areas along a waterway most likely to flood.

Several of the Findings and Recommendations in this service assessment highlight the need to develop a Community Model for the Middle and Lower Mississippi, incorporating USACE Water Control Plans, and incorporating flow, fetches, and tides to improve river forecasts. This assessment supports the larger goal of the multi-agency IWRSS to advance model development. The assessment team thinks that multi-agency system interoperability and data synchronization, and a multi-disciplinary summit-to-sea water modeling capability (e.g., water movement from headwater areas all the way to the ocean) will support the needed common operating picture among federal water agencies. System interoperability and data synchronization, summit-to-sea modeling, and common operating picture are foundations of the Services Roadmap and the NWS Strategic Plan.

3.1.4.3. Staffing Issues

Unlike 24/7 staffing at WFOs, RFCs support a smaller base staffing configuration, averaging around 15 personnel who are routinely configured to a 16 hour operation. Whenever a significant flood threat exists, RFCs operate 24/7 to support WFOs and other hydrologic interests; however, the extension of normal operational hours, smaller number of operational staff, and prolonged period where operations are required to support a long-lived flood event often results in a significant accrual of overtime or compensatory time.

The staff at the LMRFC accrued approximately 900 hours of overtime/compensatory time to support a 45-day, 24/7 extended operation. Only a few staff members had the necessary experience to forecast the complexities of the Lower Mississippi River under such an extreme event. The pool of former LMRFC staff, who work for the NWS at other offices or in other capacities, was also limited. This presented some unique staffing challenges.

Fact: Given the unique nature of RFC operations, the pool of potential staff that could be deployed to LMRFC with minimal training was limited.

Fact: The complex nature of forecasting on the mainstem of the Mississippi River coupled with the amount of coordination needed with USACE resulted in a limited number of available forecasters responsible for the bulk of the Mississippi River.

Fact: To help ease staffing and workload concerns, the LMRFC Management Team worked more than 50 percent of the total overtime and compensation time accrued during the event.

Fact: Three additional NWS personnel (two with prior LMRFC experience) were detailed to LMRFC for short periods during the height of the flood to provide staff relief.

Finding 10: Despite the extra resources made available to the LMRFC (i.e., support of the management team and persons deployed on a temporary duty assignment), many staff members worked long and consecutive daytime and evening/midnight shifts to respond to the operational and decision-support demands.

Recommendation 10: Well in advance of significant long-term hydrologic events where extended 24/7 operations are anticipated, RFCs should devise a "*phantom/hybrid*" long-term planning schedule to ensure (additional) staff coverage will be made available in as fair and equitable a fashion as possible for overnight shifts. This process may involve using creative scheduling practices (e.g., temporary compressed/alternative work schedules) to ensure that staff has at least one day off a week despite high workload demands and a shortage of staffing.

Finding 11: There was difficulty finding personnel to augment LMRFC staffing given the level of training and familiarization necessary on LMRFC mainstem Mississippi River forecasting operations using complex hydrologic models.

Recommendation 11a: The NWS should develop a more robust cross-training program for RFC staff that identifies unique forecasting and collaborative complexities present during an historic flooding event on controlled waterways.

Recommendation 11b: The NWS should develop a comprehensive plan to ensure that RFCs can quickly request deployment of fully trained and experienced hydrologic forecasters from other offices for forecasting complex mainstem river systems using hydraulic models.

Recommendation 11c: Deployed personnel to the RFC should work the less complex river systems allowing local hydrologists to train/shadow operations on the more complex river systems. This system will allow additional local staff members to be trained on the complex river systems, providing more staffing options and less dependence on long overtime hours for a few select members of the existing staff.

3.1.5. WFO Paducah, KY

Following the 2010 Nashville flood event, WFO PAH carefully reviewed both the NWS service assessment and the USACE After-Action Report to identify potential areas for operational changes. A staff training day was held on January 26, 2011, to ensure all issues were addressed.

Interviews with WFO PAH partners indicated the WFO performed exceptionally during the 2011 flood. The degree to which the WFO PAH staff and management modified operations is captured by the Best Practices below.

Area Forecast Discussions from WFO PAH advertised the potential for a significant flood event as early as April 12, 2011. On April 24, during a live press conference for more than 100 EMs and media reps, WFO PAH used language such as, "*historic flooding*" and "*this will be an event of decades…this has the potential to be a flood of historical nature*." This was only the third press conference ever held by WFO PAH. As the flooding worsened, the term "*catastrophic flooding*" was used in statements. The Butler County, MO EMA Director stated he "*…had never seen those terms used before in a briefing from WFO PAH*." Fire and law enforcement agencies in Butler County and the city of Poplar Bluff altered their operating schedules to be better prepared for potential flooding.

Fact: WFO PAH conducted only the third press conference it had ever held on April 24, 2011.

Best Practice: The judicious use of press conferences by WFO PAH reinforced the need to prepare for this high-impact, weather-related event.

Best Practice: Rare use of the terms "*catastrophic*" and "*historical*" to define the forecast extreme flooding helped emphasize the severity of the threat to local communities.

Best Practice: "*Do not drive*" and/or "*Do not drive at night*" was used in warnings and statements from WFO PAH as behavior modification statements. They were used in place of "*Turn Around, Don't Drown*" (TADD) to discourage travel altogether during the worst of the flooding.

WFO PAH was proactive in providing staffing for the Unified Command EOC at Marion, IL, and the lower Ohio Unified Command EOC at Paducah, KY, by offering services before assistance was formally requested. This action elicited quotes from several EMs such as the following from the Deputy EOC Director for McCracken County, KY: "*From now on, for any kind of weather emergency, we are going to have a spot for the NWS at our EOC.*" According to a McCracken County Judge and Executive, "*We have new respect for the NWS thanks to support to the EOC through this event. The NWS is an asset to our community that we have not used enough in the past.*" To provide this service to EOCs, CRH arranged for a lead forecaster/hydrologic program leader from WFO Topeka, KS, and a Service Hydrologist (SH) from WFO Lincoln, IL, to supplement the WFO PAH staff.

WFO PAH maintained outstanding coordination and communication with OHRFC and USACE throughout the event. WFO PAH reported that OHRFC was consistently willing to answer all questions.

The WFO PAH SH and the OHRFC Service Coordination Hydrologist (SCH) ensured WFO PAH was included in coordination calls with partners. The SCH facilitated discussions between the WFO and critical hydrologic partners, a recommendation in Section 3.2 (Interagency Coordination & Collaboration).

WFO PAH had to discontinue its multi-media briefings because its computer bandwidth was not adequate to support this dissemination method. This issue is addressed by a recommendation in Section 3.3.

3.1.6. WFO Memphis, TN

Unlike NWS offices further south, WFO MEG was busy with severe weather and flash flooding at the time flooding began along the Lower Mississippi River and its tributaries. Despite this fact, and based on interviews conducted with critical partners, the WFO MEG staff maintained hydrologic situational awareness. As needed, the office used a hydrologic forecaster or hydrometeorological technician (HMT) to issue river forecasts and long-fused river flood warnings, up to two separate severe weather teams to focus on severe weather warnings, and a separate forecaster to address short-term hydrologic warnings and services.

Beginning in the first week of April 2011, WFO MEG staff members contacted every EM along the Mississippi River in the WFO MEG HSA. They provided personal forecasts and DSS to local communities in advance of the flood. This service included providing a range of potential flood crests that allowed local communities to prepare for various scenarios.

This direct contact with partners was cited in interviews as being valuable in helping understand the significance of the event. According to the Operations Major for the Tunica County Sheriff's Office, "*Without this personal service, the county would have been more reactive than proactive*."

WFO MEG provided contingency forecasts for a flood crest of 48 feet at Memphis, TN, and 60 feet at Cairo, IL, as April 24, 2011. These contingency crests were used extensively by the director of the TEMA and other partners throughout the event. All partners interviewed used superlatives in describing how critical this early notification was to their respective missions.

On April 29, 2011, WFO MEG staff requested that LMRFC begin including 5-day QPF in its river forecast models so contingency forecasts could be provided to critical partners. This addition allowed WFO MEG to provide partners with value-added information.

WFO MEG provided comprehensive DSS throughout the event. There were twice daily "*in person*" briefings, some with live news conferences, and daily conference calls for Memphis/Shelby County and TEMA. Clay County, AR, was briefed daily about the possible failure of Wappapello Dam. WFO MEG's decision support activities elicited the following comment from TEMA Assistant Director: "*One of the biggest floods I have experienced, but also one of the best coordinated.*"

WFO MEG and LMRFC established a basin-standard operating protocol in which contingency QPF is included in future forecasts. WFO MEG also led a multi-agency, inundation mapping effort that included the USACE and local EMs. The SH conducted extensive ground surveys prior to and during the spring 2011 flood. Inundation maps were posted to the Internet prior to the flood for the forecast point at Osceola, AR, on the Mississippi River. The SH also produced inundation maps for other areas along the Mississippi River in Tunica, MS, and Shelby County, TN. These maps were used as briefing tools with local emergency management during the flood, and to produce new impact statements.

WFO MEG inundation mapping effort and forecast prediction for the Osceola, AR, area was a significant DSS according to the EM Director for Lauderdale County, TN (across the

Mississippi River for the forecast point at Osceola, AR):

"*The information you gathered and sent to me was very helpful. I want to thank you for the mapping effort concerning where, when, and the roads and homes involved. Lauderdale County had 305 homes involved in the Historical Flood. The prediction was very accurate. This accuracy was useful in alerting homeowners that have never been flooded before. This flood was a very bad flood not to have a loss of life. The Osceola gage information was outstanding. All this information was very informative and was added to Lauderdale County Hazard Mitigation plan for FEMA.*"

3.1.7. WFO Jackson, MS

WFO JAN has responsibility for four river forecast points along the Mississippi River: Vicksburg and Natchez set new record flood stages, Arkansas City and Greenville exceeded major flood stage. Areal flood warnings were issued for parts of Issaquena, Warren, and Claiborne counties due to backwater flooding.

The office provided at least four daily Web-based briefings during the height of the event and provided daily informational packets containing projected stage, anticipated rainfall, and previous rainfall estimates. These packets were sent electronically before the briefings. All partners were able to access real-time NWS Website information (e.g., AHPS pages).

WFO JAN conducted daily statewide conference calls with MEMA and affected Mississippi counties. WFO JAN participated in conference calls every other day with GOHSEP and impacted parishes and provided extensive DSS via the Web:

- One-stop Web page with interactive, extended stream flow forecasts
- Mississippi River Graphicast updated four times daily **(Figure 14)**
- Backwater flooding Graphicast updated daily **(Figure 15)**

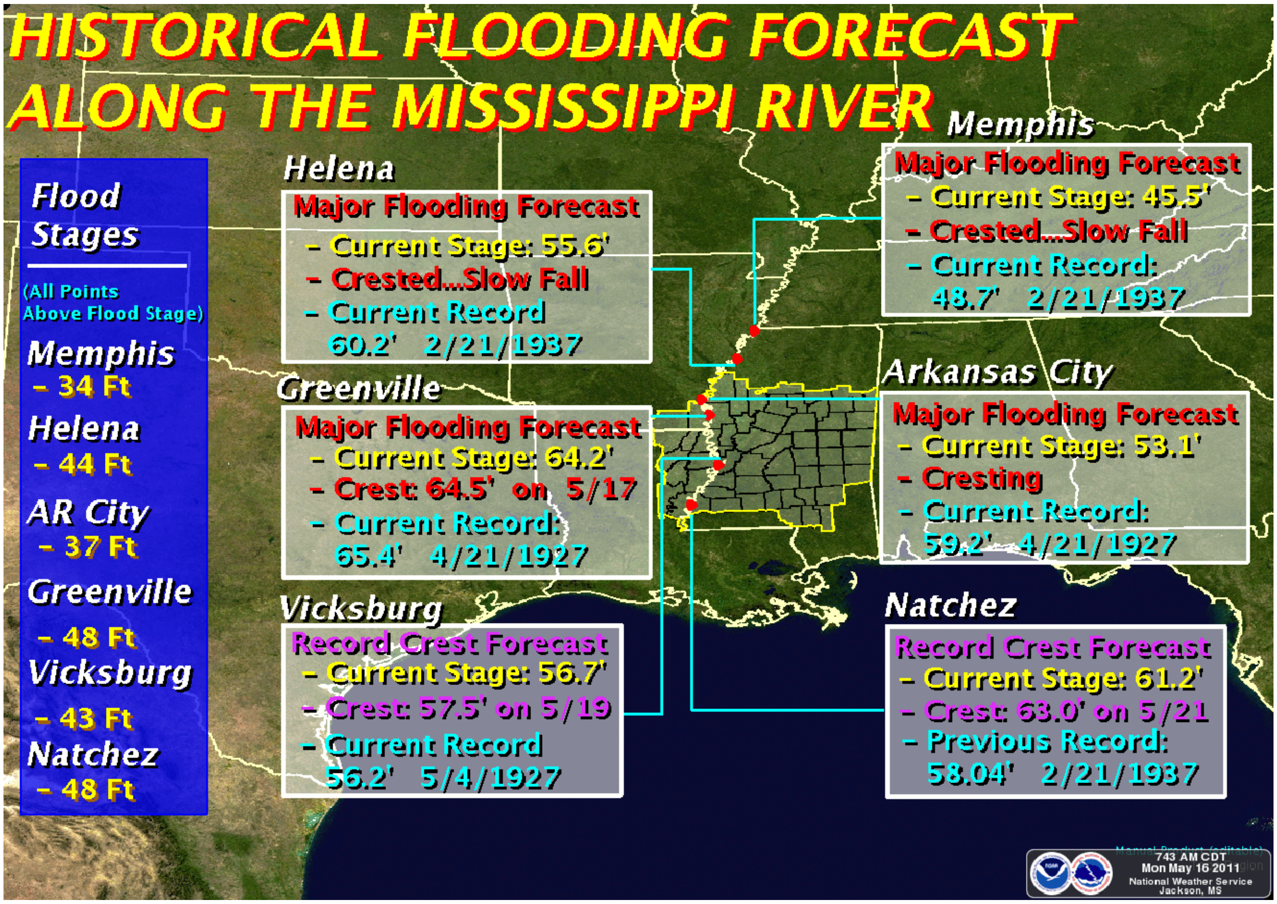


Figure 14: This figure shows the WFO JAN Graphicast for Mississippi River Forecast Points issued at 7:43 a.m. CDT on Monday, May 16, 2011.

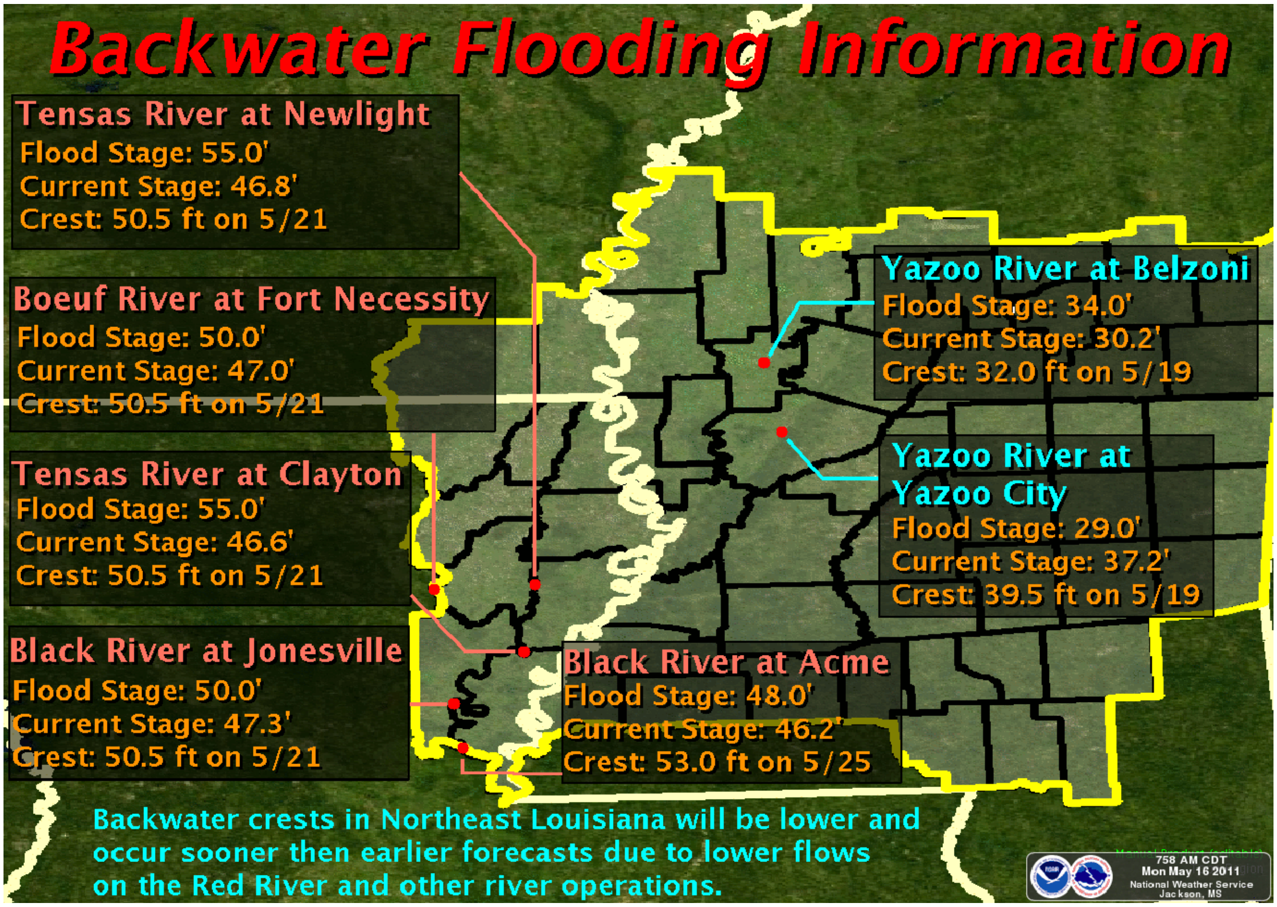


Figure 15: This figure shows the WFO JAN Graphicast for Mississippi River Backwater Forecast Points issued at 7:58 a.m. CDT, on Monday, May 16, 2011.

MEMA and USACE referred the public to the WFO JAN Web page. The MEMA director said he thought the Web page, and specifically the inundation mapping, was "*the best information regarding the flood available to the public at the time*."

Although WFO JAN created an interactive extended stream flow forecast for the Mississippi River for all four forecast points in the WFO JAN HSA, SRH independently created a static graphical display for much of the Mississippi River. Both displays were valuable, but time could have been saved, and the best aspects of both programs could have been integrated, if better coordination existed during the developmental phase of either program. It is advisable that NWS regional and/or national headquarters initiate coordination with WFOs prior to any large-scale weather event to ensure data, regardless of their point of origin, are provided efficiently and consistently. Similarly, WFOs should coordinate significant service enhancements through regional headquarters, which, in turn, should coordinate between field offices and adjacent regions.

WFO JAN helped the USACE Vicksburg District create Flood Inundation Maps placed on WFO JAN's Web page (**Figure 16**). This included an interactive map using Google Earth. Another map was created later by USACE depicting contingency inundation in the event of a Yazoo River backwater levee breach.

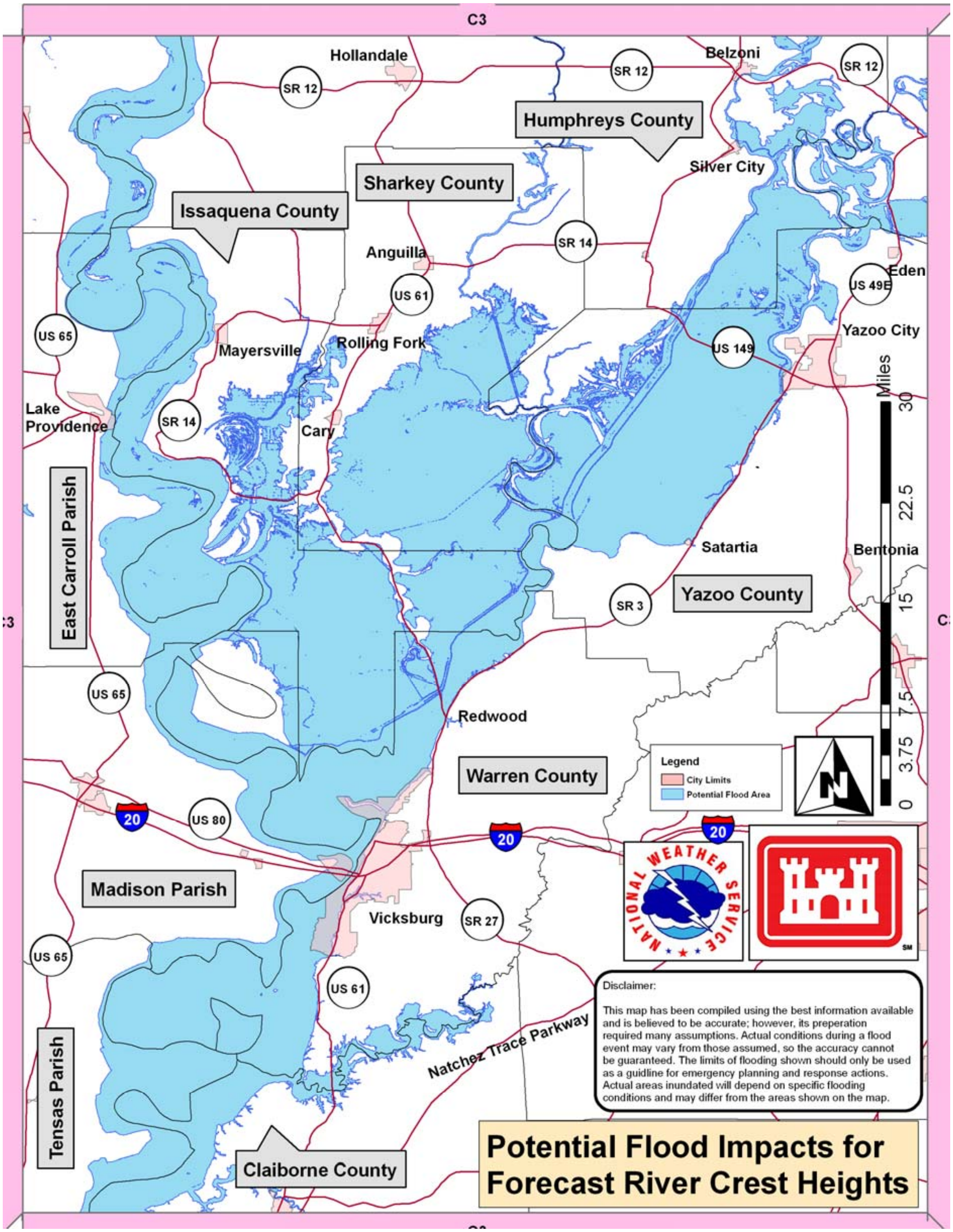


Figure 16: Flood inundation map created by USACE Vicksburg District representing potential flood impacts for NWS forecasted river crests along the Mississippi River

WFO JAN effectively used its Facebook page reflected by more than 4,000 "*likes*" since its activation shortly before a tornadic outbreak on April 27, 2011. According to staff, keeping up with comments and questions slightly increased workload.

WFO JAN conducted extensive outreach with local and state EM officials to ensure that all entities were prepared for the level of coordination and collaboration needed in the advent of a levee breach. The SH handled most of the interaction with the media, including contacts with national organizations such as Reuters and Associated Press, and numerous interviews with regional and local news outlets.

At least one EM in Mississippi expressed interest in MEMA or NWS sponsoring a training session on creating and disseminating Civil Emergency Messages (CEMs) on NOAA Weather Radio All Hazards (NWR). Since this need may exist in other places, NWS state liaison offices should consider working with MEMA to sponsor training sessions.

Best Practice: As the main flood wave moved downstream along the Mississippi within the WFO JAN HSA, the office conducted ground surveys using a cell phone with geo-tagging capability to establish high water benchmarks (**Figure 17**). Making full use of new and emerging Geographic Information System (GIS)-based technologies will help the NWS better capture impact-based detail in the WFO Hydrologic Forecast System (WHFS) for future flooding applications.

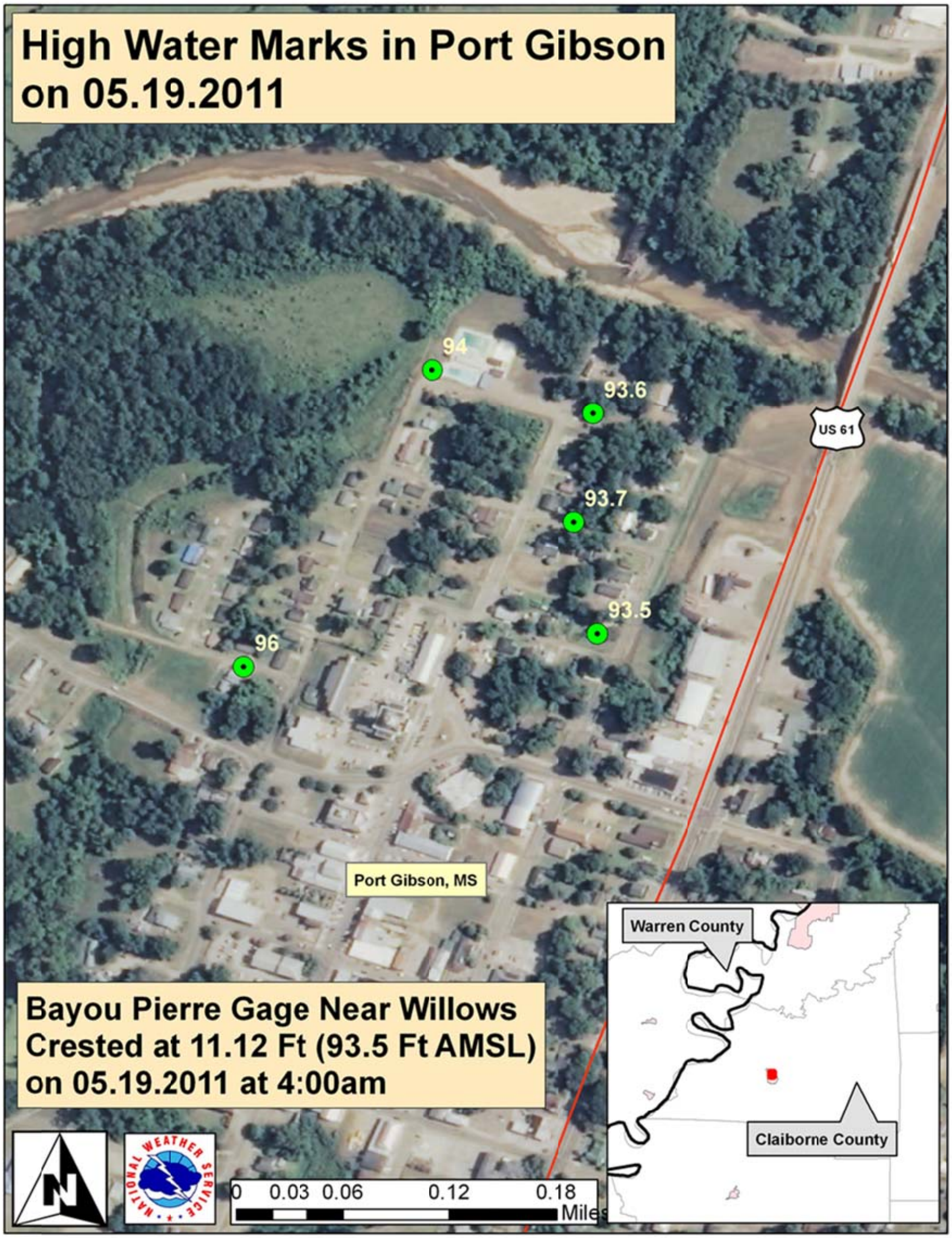


Figure 17: High water marks in Port Gibson, MS, on May 19, 2011

Fact: The flood event was well advertised months in advance. Flood advisory products were first issued on March 1, 2011, for anticipated significant rises above bankfull but below Flood Stage. Hydrologic Outlooks also were issued in early March calling for an above normal chance of spring flooding along the Lower Mississippi River based on longer term Ensemble

Streamflow Prediction (ESP) forecasts issued by LMRFC. Products could not indicate a potential flood situation since official NWS river stage forecasts were not available that far in advance; however, the products did alert users to a likely high water event many weeks in advance.

Finding 12: WFO JAN issued flood advisories before stage forecasts became available. The advisories indicated river levels above bankfull, but below Flood Stage. Flood advisory terminology confused some users, since an actual flood was not being forecast at that time.

Recommendation 12: The NWS should coordinate with critical partners and social scientists to devise ways to reduce the number of hydrologic products, simplify their titles, and ensure consistent use to minimize confusion.

Fact: The NWS liaison to the USACE Division Office in Vicksburg (a dedicated, full-time position) greatly reduced WFO JAN workload.

Finding 13: A format specifier within RiverPro software displays the day of the week, not the date, of a forecast river crest. If, for example, a crest forecast is made for "*Saturday,*" the user does not know if it is this Saturday or next Saturday.

Recommendation 13: Modify the format specifier within RiverPro to display date, as well as day of the week, of forecast river crests.

Finding 14: WFO JAN received reports that major flooding was occurring along the Yazoo River at Yazoo City. Flood categories in effect at the time, as defined in WS Form E-19, equated to moderate flooding. Because of existing national policy (NWS Directive 10-940), changes could not be made quickly to WHFS E-19 flood categories to provide a more representative hydrologic category in NWS flood warnings and AHPS Web pages.

Recommendation 14: NWSH should streamline the process for modifying E-19 flood categories in the WHFS database to ensure representative hydrologic categories are provided in NWS flood warnings and AHPS Web pages during an ongoing event.

Even if a WFO could modify flood categories in real time, basic optical-leveling equipment used by many WFOs, including WFO JAN, does not allow the surveyor to conduct surveys as accurately or efficiently as laser-based tools.

Finding 15: Enhanced laser-based survey and leveling tools would provide field offices with a more accurate and efficient means to update flood categories and impact statements.

Recommendation 15: The NWS should provide modernized surveying and leveling equipment at all WFOs—including those without leveling equipment and WFOs with leveling equipment should receive a technology upgrade.

Finding 16: WFO JAN issued areal flood warnings for backwater areas. Baseline WarnGEN software used to generate areal flood warnings allows a maximum expiration time of 48 hours, insufficient in many instances.

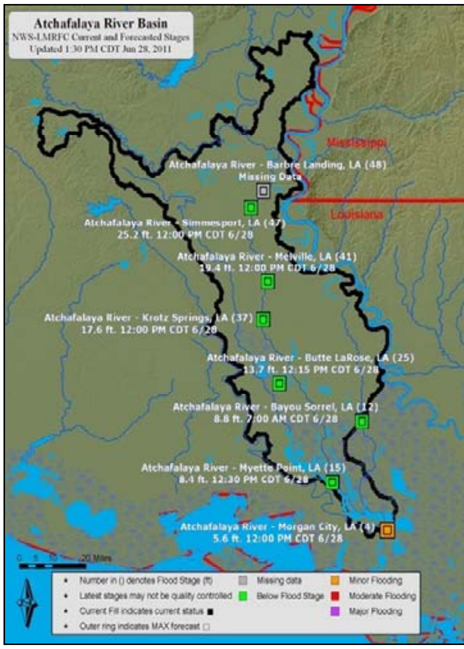
Recommendation 16: Ensure all WFOs understand NWS WarnGen warning software is configurable to allow expiration times beyond 48 hours for areal flood warnings.

3.1.8. WFO Lake Charles, LA

WFO LCH provided decision support for interests along the Atchafalaya River by participating in public meetings and providing briefings for EMs, media, elected officials, and local communities along the river (i.e., Butte La Rose, Patterson, and Stephenville). Office staff also attended Parish board meetings with elected officials in St. Landry Parish to discuss backwater flooding impacts. Daily conference calls were provided to GOHSEP. The office used Graphicasts, multimedia briefings, Facebook, and weekly Webinars to communicate information as the event enfolded.

WFO LCH conducted extensive flood assessments prior to and during the flood along the Atchafalaya River from Marksville to Morgan City. The SH placed a staff gage at the fire station in Butte La Rose to educate the community about the relationship between stage forecasts and water depth.

As indicated in Section 3.1, CWA and HSA discontinuities exist between WFOs LCH and LIX. WFO LCH issues short-fused and areal-based hydrologic watches, warnings, and advisories for parishes along the Atchafalaya River, but WFO LIX also issues long-fused river flood products for forecast points on the river (**Figure 18**); however, the Graphical Forecast Editor (GFE) used by all WFOs (including WFO LIX) to compose, generate, and transmit many NWS products and forecasts does not have the capability to issue products containing Federal Information Processing Standard (FIPS) codes for WFO LCH parishes. WFO LCH, therefore, cut and pasted information internally received from WFO LIX and used RiverPro software to generate the Flood Potential Outlooks.



Atchafalaya River Responsibilities

All Hydrologic Services are provided by NWS Slidell (LIX)

Forecast Points within the LIX CWA:
- Bayou Sorrel (Iberville)

Forecast Points within the LCH CWA (forecasts provided by LIX):

-Simmesport (Avoyelles)
-Melville (St. Landry)
-Krotz Springs (St. Landry)
-Butte Larose (St, Martin)
-Myette Point (St. Mary)
-Morgan City (St. Mary)

Figure 18: This figure shows the disparity of forecast responsibility between WFO LIX and WFO LCH for the same geographic area on the Atchafalaya River.

Finding 17: GFE software does not allow one WFO to include FIPS codes for another WFO's counties/parishes in flood potential outlooks.

Recommendation 17: Configure GFE software to provide the capability to enable one WFO to include counties/parishes not in its CWA, but in its HSA to generate flood potential outlooks.

In some areas along the Atchafalaya River, flooding impacts occurred at levels below official flood stage. WFO LCH issued areal flood warnings to notify EMs, other first responders, media, and the general public of the impending flood threat and helped WFO LIX assess impacts at points along the river within the WFO LCH CWA. Based on this event, WFO LCH recommended that flood stages at several forecast points be lowered. WFO LIX is submitting official paperwork and updating E-19s to implement these changes.

Finding 18: On the Atchafalaya River, flood impacts occurred at levels other than the established official flood stage.

Recommendation 18: WFOs should aggressively survey flood areas during and immediately following a significant flood event to ensure that existing flood stages and categories are representative of impact.

3.1.9. WFO Slidell, LA

WFO LIX began coordinating with partners concerning potential significant flooding 4-6 weeks before its occurrence. From late April 2011 through early June 2011, the office participated in 20 state-level briefings at GOHSEP, provided 17 Webinars, and initiated more than 40 telephone contacts or in-person meetings with partners. WFO LIX issued 18 flood potential outlooks, 13 flood warnings, and 147 flood statements. The Office's Facebook users increased from approximately 200 to 600 followers.

The office used Web page graphics to make information more understandable than tabular formats (**Figures 19 and 20**). To minimize workload, all graphics and PowerPoint presentations used for daily briefings were stored in a central repository, easily accessible to the entire staff.

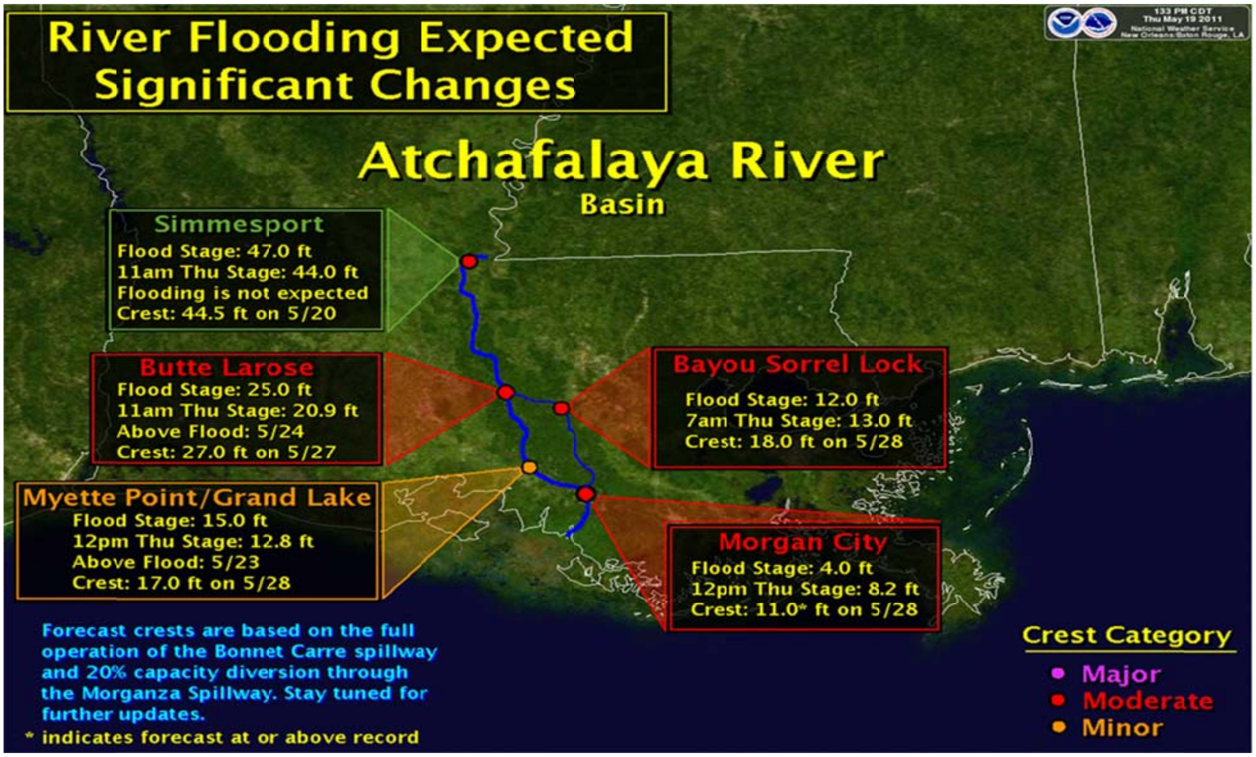


Figure 19: This figure shows the flood potential outlook for expected flooding along the Atchafalaya River, issued at 1:33 p.m. CDT on Thursday, May 19, 2011.

GIS-based inundation contingency graphics from USACE were heavily utilized by critical decision makers. While providing this type of information was beneficial to users, there was a downside. Interpretative differences between a probabilistic USACE contingency map and a deterministic NWS river stage forecast resulted in some public confusion. At a point when workload was heaviest, WFO LIX staff spent almost as much time answering public questions as providing accurate NWS forecast products, data, and services.

About half of WFO LIX's staff members were interviewed by the assessment team. All stated there was a big advantage to being co-located with an RFC. They suggested that employees at non-collocated sites visit a collocated site. Without exception, WFO LIX and LMRFC staff complemented each other. During the event, the two areas occupied by these offices, in effect, became one large work space for continuous collaboration and general discussion.

Figure 20: LIX flood potential outlook along the Lower Mississippi River issued at 1:21 p.m. CDT on Thursday, May 19, 2011

The WFO LIX staff was appreciative of the management team's participation in state- and county-level briefings. This interaction enabled operational personnel to focus better on shift demands, support local EM needs, and support other DSS projects. Forecasters complimented office Meteorologist Interns and Hydrometeorological Technicians who were largely responsible for issuing flood statements. The assessment team noted that workload seemed to be distributed equally among operational personnel.

Fact: All WFO LIX operations staff members were able to issue products on hydrologic software because they had been thoroughly trained using job sheets and one-on-one teaching. Staff was expected to share equally in these responsibilities.

The need for extensive coordination between the NWS and USACE increased as the flooding event progressed. Accurate upstream flow and stage measurements became increasingly essential to ensure the highest quality stage forecast possible. The time invested, however, in obtaining data needed for a well collaborated river stage forecast resulted in an increasing delay in the issuance of river stage forecasts from a scheduled release time of about 11:00 a.m. to late afternoon in some instances. Delayed product release times resulted in an increase in overtime hours at WFO LIX. In addition, since the actual time of product release could not be anticipated from day to day, news media that relied on receipt of updated river stage forecasts prior to news deadlines became increasingly frustrated when they were not available. This is discussed further in Section 3.2.8.3.

3.2. Interagency Coordination and Collaboration

3.2.1. Relationship to Previous Service Assessments

The Nashville flood of 2010 exposed weaknesses in relationships between the NWS and its hydrologic partners. These weaknesses resulted in a loss of time, miscommunication, and poor river crest forecasts. The assessment attributed the problem to the lack of direct interaction via meetings and inter-agency exercises in preceding years. One goal of this assessment is to determine the degree to which recommendations from the 2010 assessment have been implemented.

The team found significant improvement in interagency collaboration and communication. NWS offices interviewed stated they now meet with key partners on a scheduled basis. WFOs proactively reached out to partners to ensure inclusion on call lists used during significant events. The WFOs had set up long-term joint projects such as the previously mentioned inundation mapping and unified HEC-RAS model for the Ohio River and its major tributaries. Despite software challenges, the strong relationship between the agencies and individuals involved enabled the joint model operation to function smoothly.

Despite the successes mentioned above, additional action is needed. Specifically, WFOs and USACE district offices continue to have misunderstandings regarding dam releases and their impacts on downstream populations. In addition, there were a few instances where communication breakdowns or a lack of information from areas that were prone to flooding impaired the ability of the WFOs to issue timely flood warnings. There were also cases where technology was a barrier to effective communication. The team encourages continued outreach to partners to address these types of shortcomings.

Fact: WFO PAH and USACE Saint Louis, MO, had difficulty communicating the potential impacts of Lake Wappapello releases on downstream communities.

In comparing the services provided for the 2010 Nashville Flood to the 2011 Middle and Lower Mississippi River Valley Flood, it is important to note the events differed in how NWS offices functioned and performed. The 2010 Nashville Flood evolved quickly with few antecedent storms to encourage pre-event collaboration. The 2011 Middle and Lower Mississippi River Valley Flood was affected by a well-advertised snow pack and an early flood event that served as a warm-up for the major flooding that followed.

Because conditions did not rapidly deteriorate during the 2011 Middle and Lower Mississippi River Valley Flood, the conclusion that collaboration and communication improved must be tempered by the fact that these skills were not put to a test comparable to the 2010 event. Furthermore, the 2010 event and service assessment spurred affected NWS offices to correct cited problems in time for the 2011 event. In situations where a long period of time elapses between floods, close relationships need to be maintained to ensure all are ready for the next event.

Creation of the SCH position at RFCs was a critical step in increasing and enhancing coordination with critical hydrologic stakeholders and was cited by multiple NWS and USACE offices as critical to the development and maintenance of relationships; however, responsibility for maintaining strong inter-agency relationships should not rest exclusively with the WFO or RFC management team. WFO MEG assigned the WCM and SH to cover operational shifts so other staff could attend coordination meetings. This more inclusive bridge-building approach ensures that relationships between agencies do not suffer when one or more persons leave the WFO.

There are additional agency-wide activities that can provide the technology necessary to support long-term relationship building and maintenance. The Inter-Regional Integrated Services (IRIS) database is an example that will ensure partner contact information resides in a centralized location. IRIS is a database designed to manage many types of NWS data, including customer contact information, criteria and thresholds, spotter information, and communication logs. Use of this kind of technology ensures that customer contact information is available to anyone in an office. It also supports the maintenance of relationships and logical notifications of key partners during real-time events.

3.2.2. U.S. Army Corps of Engineers

Members of the assessment team visited USACE offices in Mississippi (Vicksburg) and in Louisiana (New Orleans). A research facility of the USACE in Davis, CA, was also visited because of its vital role in the hydraulic analysis of the Birds Point/New Madrid Floodway.

The USACE is responsible for water releases and water routing along the Mississippi River. The NWS uses information provided by USACE to estimate water flow and resulting stages at forecast points. Six different USACE districts exist along the length of the Mississippi, which require significant collaboration between USACE and NWS offices (**Figure 21**).

Fifteen years of tri-agency meetings resulted in a solid understanding of each agency's mission during the 2011 flood event. Fusion team meetings of modelers and forecasters also resulted in successful collaboration. Coordination assisted senior USACE leaders in providing weather and hydrologic information for water control operations at the Birds Point/New Madrid Floodway and the operation of the Bonnet Carre and Morganza Floodways.

As mentioned in Sections 3.1.1 and 3.1.7, the presence of a dedicated NWS liaison at the USACE Division Office in Vicksburg, MS, proved valuable for flood support. NWS presented daily weather and water briefings verbally to USACE command. The support of the NWS SCH position from LMRFC as a single point of contact was described by USACE representatives as "*very beneficial*" throughout the flood coordination period.

LMRFC forecasts and services, most notably issuing 28-day stage forecasts twice-weekly, instead of once weekly, and processing the 5-10 day QPF into the models, were much appreciated by USACE. USACE staff noted the Mississippi and Louisiana USACE offices would have found *probabilistic* stage forecasts helpful for planning purposes. The assessment team suggests the RFC continue twice weekly, 28-day Atchafalaya River stage forecasts and that the RFC implement probabilistic stage forecasts for the Lower Mississippi River as soon as possible. Probabilistic stage forecasts cannot be implemented for the Lower Mississippi River until all rivers upstream have probabilistic procedures implemented. The Missouri River is next to have probabilistic procedures implemented, followed by the Lower Mississippi River.

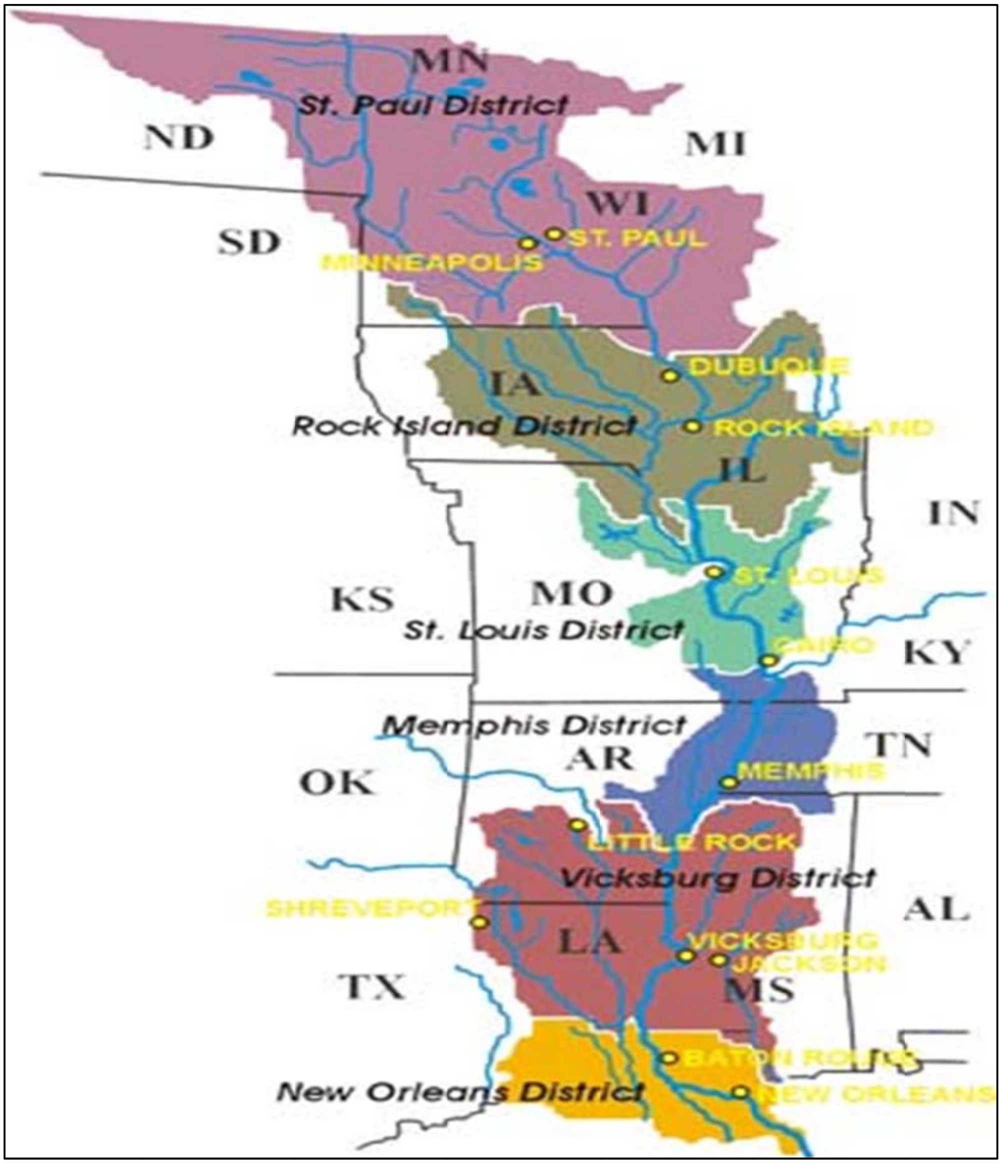


Figure 21: USACE districts along the Mississippi River

Finding 19: While 28-day stage forecasts provided by the LMRFC for the Lower Mississippi and Atchafalaya Rivers were useful, USACE also would have found probabilistic stage forecasts helpful. Communicating uncertainty provides enhanced DSS to critical partners.

Recommendation 19: LMRFC's deterministic model forecasts should be complemented by probabilistic stage forecast such as the NWS Hydrologic Ensemble Forecast System (HEFS) and Ensemble Streamflow Prediction (ESP). Efforts to move in that direction should be accelerated.

3.2.3. Mississippi Emergency Management Agency

The assessment team interviewed three members of MEMA upper management: The Director, the Director of Office of Response, and the State Officer to Executive Director at the Joint Field Office in Pearl, MS. State EMAs and FEMA in Mississippi assembled a team to prepare for the event. Governor Barbour became involved in the process due to his strong professional and personal interest in flooding.

Four WFOs serve Mississippi: MEG, JAN, LIX, and MOB, as well as the LMRFC. Daily briefings to MEMA, and occasionally to Governor Barbour, began 7-10 days before significant rises in river levels occurred and approximately 3 weeks before the actual flood crest in the Tunica area in northwestern Mississippi. The briefings continued from early May until high water cleared the state in mid-June. Briefings focused on current and projected stages but also reviewed worst-case scenarios and contingencies should levee failures occur.

The NWS and USACE collaborated on model output to determine stage and contingency forecasts based on anticipated control/routing of water–resulting in accurate and reliable official forecasts from LMRFC. MEMA was *"most appreciative and proud*" of this collaboration.

MEMA routinely coordinated with all four WFOs noted above and requested separate briefings to cover the state. According to MEMA upper management, "*All NWS offices were always supportive in scheduling briefings that would not overlap with one another so that all critical MEMA players could be present for each briefing.*" The director was "*thoroughly pleased with the support and service provided by all four NWS office –including LMRFC.*"

Fact: The MEMA director was proud of the strong partnership that exists between MEMA and the NWS.

Best Practice: WFO JAN provided a user-friendly packet of weather information for partners, e.g., media and emergency responders.

The MEMA director did not recommend any local improvement to NWS products, service, or collaboration. In his words, "*If it isn't broken, do not try to fix it.*" He did, however, indicate that the national provision of weather and water data via Web pages needed improvement. He feels these Web pages are not intuitive and have to be "*repackaged*" to make them understandable. Similar observations were noted by other partners, including the media.

For example, many EMs were not comfortable accessing AHPS Web pages to obtain stage and forecast information for specific points within their area of responsibility, nor were they comfortable using the Web pages to navigate upstream and downstream along a waterway or to switch to forecast points on another river. This process often involved multiple key strokes or mouse clicks. As a result, MEMA created an internal Website and established file folders for each EM displaying AHPS Website information for only the forecast points of interest for each EM–regardless of the EM's location on a particular river or backwater area. This one-stop-shopping approach enabled the EMs to acquire the information needed with a single mouse click.

Other issues related to confusion over the type of response required where the Action Stage and Flood Stage were similar at one location, but differed by several feet at other locations. An Action Stage was originally for internal NWS use only and used as a means in Hydroview to alert WFO staff of a high water situation that warranted the NWS to take some type of mitigation action (e.g., issuance of a River Statement) to advise partners to prepare for possible significant hydrologic activity. Action Stages are established with a variety of local criteria which are not universally applicable. Therefore, the difference between the Action Stage level and Flood Stage level at a river forecast point often differs from one site to another—even those that are in close proximity and on the same river. When the NWS created the AHPS Website, Action Stage alert levels became available to the public. However, public confusion ensued because an explanation of Action Stage or why the Action Stage and Flood Stage can be similar at one location and different at another was never fully provided.

Finding 20: The MEMA Director and several media partners stated acquiring AHPS Website information or more generic Web-based water- and weather-related information was convoluted, cumbersome, and non-intuitive.

Recommendation 20: The NWS should provide Web services for weather and water information in which users of varying degrees of technical expertise can obtain information compatible with their needs.

Finding 21: Some EMs were confused about the amount of mitigative action they needed to take when a river forecast point had the same Action Stage and Flood Stage versus differing Action and Flood Stages.

Recommendation 21: Establish a nationally consistent methodology for defining an Action Stage at all river forecast points, e.g., 80 percent flood flow or 90 percent bankfull.

3.2.4. Louisiana Governor's Office of Homeland Security and Emergency Preparedness

Staff of the Louisiana Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP) was pleased with the service provided by the management teams of WFO LIX and LMRFC. The LMRFC Hydrologist in Charge (HIC) and WFO LIX MIC participated in person in daily briefings at the EOC for several weeks. Weather-related briefings were thorough and informative. Partners found it "*extremely helpful*" to have experts onsite who could explain technical information and address "*what does it mean to me*" concerns.

GOHSEP personnel said of the four WFOs and RFC that they "*…felt very comfortable being able to pick up the phone and ask questions at any time of the day or night…were on a first-name basis with most individuals… and never felt rushed.*" The Senior Planner for the Infrastructure Branch stated, "*All NWS offices provided full support and service throughout the event despite other distractions associated with shorter-fused weather concerns. We feel like they serve us exclusively, even though we know that they serve everyone else as well. The culture of the NWS has become that of service. Weather is the event, or affects the event of everything we do! Despite the type of weather event, the process of the event remains the same.*"

Fact: GOHSEP upper-management noted NWS has corrected the disparity of forecast service and support between NWS offices that existed in the past. For the past several years, products, services, and support have been consistent and seamless.

Best Practice: WFO LIX created a standardized briefing format for GOHSEP that eliminated extraneous hydrometeorological information, integrated input from four NWS offices serving Louisiana, and focused on weather-related impacts critical to decision makers.

3.2.5. Local Emergency Management (WFO JAN CWA/HSA)

EMs for Jones, Warren, Adams, Washington, and Yazoo Counties, MS, and for Tensas Parish, LA, were interviewed by the assessment team. All EMs had positive, supportive comments about the quality and consistency of the service provided by WFO JAN.

A recurring theme was that while EMs used information provided during conference calls and from Web-related products, each director relied strongly on personal relationships with SHs, meteorologists, and LMRFC staff to provide answers to specific questions. The SH at WFO JAN made it a point to contact all affected EMs every couple of days and visited each one at least once. Calls were initiated to provide updates of river stage forecasts ahead of each regional conference call. This personalized service gave EMs the confidence to advise residents, business owners, government personnel, and school administrators when to take mitigative actions to safeguard their interests.

No manager interviewed complained about the level of service NWS provided. All EMs trusted the WFO JAN staff. There were no complaints and no suggestions for improvement.

One director found it remarkable that the NWS could predict the river stage at his location to within four tenths of a foot and a river crest to within 1 day of its actual occurrence 16 days in advance. In 15 years working with WFOs JAN, SHV, and LIX, this EM could not recall a time when his needs were not fully satisfied. Four of five directors independently said, "*Nothing caught my county by surprise*." This is one of the long-standing visions of the NWS, taken from the NWS Strategic Plan for 2003-2008, to be America's "*no surprise*" Weather Service that can be trusted when needed the most. Other remarks included, "*I'm one satisfied customer*," "*The NWS maintained 100 percent communication –perfect and extremely timely and accurate,*" "*event handled very, very well*," "*information timely and informative*," "*It helps to have a source* [NWS] *that folks trust enough to validate the information and its accuracy*."

3.2.6. Local Emergency Management (WFO LIX CWA/HSA)

The Directors of Pointe Coupee and West Feliciana Parishes participated in daily briefings provided by WFO LIX. One director indicated the daily briefings were "*always professional and highly accurate, just as we have learned to expect from the NWS,*" and "*…had observed a huge increase in NWS accuracy during the past 20 years along with significant attention given to personalized customer service.*" Another EM said he had worked with the NWS for 37 years in various positions and capacities and observed a marked improvement in service. He is on a first-name basis with all forecasters, often picks up the phone when he has questions, and his calls are handled professionally and responsively. This person uses Web services and still prefers personal contact to obtain information. In his words, "*The computer will never replace the benefit of two people talking—a government agency can never afford to isolate itself from the public.*"

Additional quotes received underscored the uniform level of satisfaction and appreciation for NWS services, "*No data was lacking at any time from the NWS,*" "*I want to commend the forecasters for their level of service provided to me throughout the event,*" and "*It is a breath of fresh air working with the NWS.*" There were no suggestions for service improvement.

3.2.7. U.S. Coast Guard

A USCG officer interviewed by an assessment team member said the NWS always provided a superb "*no surprise*" service. He also remarked the MIC and SH at WFO LIX provided proactive service for surge and river height predictions and possible impacts on USCG operations.

This officer partnered with the NWS on the Governor's Unified Command Group to conduct briefings, and indicated that "*superb data was always provided by the NWS in an acceptable format.*" Websites and Webinars were used to acquire needed data 3-4 times daily. LMRFC 28-day stage forecasts (that increased in issuance frequency from once per week to twice weekly) "*…provided no surprises and were at the expected level of excellence based on previous history with the agency*."

3.2.8. Media

More than a dozen broadcast meteorologists were interviewed. They all noted that their stations relied heavily on the NWS. Interviews focused on communications, products and services, and suggested areas of improvement.

3.2.8.1. NWS Communications

Media representatives expressed universal approval of the responsiveness and quality of communications with WFOs and LMRFC. In addition to verbal contacts, most made extensive use of online information and NWS Chat. Specific comments included:

"*The quality of information and the speed with which we received it was excellent*." KKLR-Radio, Popular Bluff, MO.

"*The WCM provides excellent weather training and I pass this training to all radio staff.*" Production Manager, KKLR-Radio, Poplar Bluff, MO.

"*I'm very impressed with the fact that they respond so well to you*." Chief Meteorologist, WBDB-TV, Jackson, MS.

"*I think NWSChat has been a Godsend to connect with the Weather Service, local officials, EMs and the media*." Chief Meteorologist, WJTV, Jackson, MS.

"*The accessibility of the MIC, HIC and all the forecasters was very important. I was very pleased with the way both offices provided information and the willingness to allow me access when I had questions*." Chief Meteorologist, WAFB-TV, Baton Rouge, LA.

"*We had a media day with the NWS in April 2011. They do it every year to get the broadcasters and the NWS guys together to see what they like and don't like, what works and what doesn't. We have a great relationship with them*." Meteorologist, WBRZ-TV, Baton Rouge, LA.

"*If we ever had any questions, we would just call and they would help us out. We never had any problems with that*." Meteorologist, WDSU-TV, New Orleans, LA.

3.2.8.2. NWS Products and Services

Most responded favorably to online products provided. Products were described as helpful, accurate, detailed, and easy to use as underscored by the following comments:

"*The flood forecast was unbelievably accurate*." Meteorologist, WREG-TV, Memphis, TN.

"*Thanks to the maps and graphics, we could show where the water was going to be at a certain point, and that was great because people could see when and where their homes could be affected*." Meteorologist, WAPT-TV, Jackson, MS.

When asked about possible improvements to NWS service, the Chief Meteorologist for WBDB-TV in Jackson, MS said, "*In this event, the answer is 'No'! We were able to get good information and great maps. I really think the flooding was handled perfectly for us. I think the accuracy was fantastic! They came within inches of the flood totals. That was an amazing feat – right off the bat.*"

"*The user interface was very easy to use. All the information was at my fingertips as one stop shopping and that's fantastic!"* Chief Meteorologist, WJTV, Jackson, MS.

"*I never had an issue finding or interpreting the information. I thought it was all very clear*." Chief Meteorologist, KLFY-TV, Lafayette, LA.

"*The best stuff was what they put out on the Internet. I could put those links out to my viewers and they could easily get the information*." Meteorologist, WBRZ-TV, Baton Rouge, LA.

"*We used just about everything that was available to us from both NWS offices*." Chief Meteorologist, WWL-TV, New Orleans, LA.

On a final note, interviewees reported the LMRFC 28-day Extended River Stage Forecast for the mainstem of the Lower Mississippi River was the most valuable and frequently used tool in the NWS product mix. While there was some concern the general public would perceive the extended forecasts as "*absolutes*" (Section 3.2.8.3), the prevailing view was most would understand forecast crest levels were subject to change. This was underscored by the following comments:

"*I told my viewers they [long range crest levels] were just predictions, but they were pretty accurate. I tracked them, and later compared them with what actually happened and they were pretty good*." Chief Meteorologist, WXVT-TV, Greenville, MS.

"*Your river crest forecast page was great, especially when you upgraded and did a long term*." Meteorologist, WAPT-TV, Jackson, MS.

"*I definitely utilized that. What we would do is tell the viewers 'Here's where the river is right now,' 'Here's where it's going to crest and when,' and 'Here's how long it's going to be before it goes below flood stage*.'" Chief Meteorologist, WBDB-TV, Jackson, MS.

"*The long term forecasts were very useful. Along with the day-to-day forecasts, that was probably the hottest tool*!" Chief Meteorologist, WAFB-TV, Baton Rouge, LA.

Best Practice: For the past several years, LMRFC has issued a 28-day Extended River Stage Forecast for the mainstem of the Lower Mississippi River.

The USACE opened the Bonnet Carre Spillway on May 11, 2011, and the Morganza Floodway a few days later. LMRFC modified its river forecasts accordingly and added contingency forecasts. One TV meteorologist summarized his appreciation for this additional service as follows: "*They [LMRFC] also compared what the stage would be if the spillway was open and what it would be if the spillway remained closed. Down here, that's a significant difference*." Meteorologist, WBRZ-TV, Baton Rouge, LA.

Best Practice: In advance of floodway/spillway operation, and when floodway/spillway operations began, LMRFC issued contingency river forecasts and updated official river forecasts.

3.2.8.3. NWS Areas for Improvement

TV meteorologists had a few areas of concern. First, river forecasts project an air of certainty that led the public, and even some news reporters, to view them as "*absolutes*" instead of forecasts that could change day to day. Second is the desire for NWS forecasters to speak directly to the public. One media meteorologist believed the 28-day river stage forecasts were great for EMs and other response personnel who could use a long-range forecast for their operations. However, he believed that explaining the numbers and accounting for variables was risky when dealing with the general public, but this was a minority view.

"*I told my newsroom specifically not to use those numbers. We always gave ourselves some leeway because, God forbid, 6 or 7 inches of rain could be deposited upstream, the numbers would have to be re-adjusted, and the public just doesn't understand that*." Chief Meteorologist, WJTV-TV, Jackson, MS.

"*I found the WFOs and LMRFC did a good job. But maybe the only thing that would have been nice to add was just how much water was flowing –you know—cubic feet per second*." Meteorologist, WAPT-TV, Jackson, MS.

"*It's one thing for us to go on the air and talk about the variables, but it's more important that people hear forecasters from the RFC or NWS office explain the variables and the effects they could have on the forecasts*." Chief Meteorologist, KLFY-TV, Lafayette, LA.

"*What I would like to see in a similar event in the future are some news conferences with WFO staff and RFC hydrologists, where we can hear directly from them about some of the variables in play*." Chief Meteorologist, KLFY-TV, Lafayette, LA.

"*Probably the more important thing the NWS can do with another big water event is to make sure they contact the news departments to transmit the gravity of the threat better to the people that are shaping the newscasts*." Chief Meteorologist, KATC-TV, Lafayette, LA.

"*I think there were times when the public might have perceived a degree of certainty to the RFC forecasts. I knew better, but perhaps the audience didn't*." Chief Meteorologist, WAFB-TV, Baton Rouge, LA.

"*I think there were a few newspeople who complained about the numbers and we had to explain to them it's impossible to know exactly what height the river is going to be in the future. A little bit of explanation was needed, but nothing major*." Meteorologist, WDSU-TV, New Orleans, LA.

"*I know people wanted to know the cubic feet per second (cfs) number because it was a trigger point for opening the Morganza Spillway. People along the Atchafalaya were quite concerned*." Chief Meteorologist, WWL-TV, New Orleans, LA.

TV meteorologists were critical of the display of river stage forecasts and other graphics. "*We had no problem with the flood warnings and flood level updates, but the NWS online graphics needed to be presented in a higher resolution, and with greater clarity in distinguishing between the current observed river level and the forecast level. The observed value should be given greater prominence" (paraphrased)* Meteorologist, WREG-TV, Memphis, TN.

"*The river outlook often seemed a little crowded. There were so many boxes that were sometimes hard to read. That was really the only problem I had*." Meteorologist, WDSU-TV, New Orleans, LA.

The final concern expressed by TV meteorologists centered on the need for more timely release of hydrologic forecasts. A few meteorologists expressed the concern that certain products would have been more helpful if they were available sooner. Lack of common data format and security restrictions at NWS and USACE slowed data transfer and model output, increased collaborative challenges, and resulted in the lost time in the forecast development process.

"*Sometimes the updates were a little later than we would have liked and we would have to wait for an update on your Web page*." Meteorologist, WDSU-TV, New Orleans, LA.

Finding 22: The need for extensive coordination between the NWS and USACE increased as the flooding event progressed in order to share the latest and most accurate upstream flow and stage measurements. This coordination was necessary to ensure the highest quality stage forecast possible but resulted in progressively delayed release of stage forecasts (approximately 11:00 a.m. local time in the beginning of the event to late afternoon, on occasion, during the peak of the event). News media, who relied on updated forecasts being available for noon newscasts, did not always have them available, nor did they know when to expect them from one day to another.

Recommendation 22: To address product availability, timeliness, and reliability issues, enhanced data synchronization and forecast system operability (e.g., establishment of common data formats and transfer protocols) is needed between the NWS and other federal partners, including USACE. The NWS must begin to document requirements and develop an implementation plan to meet this goal.

In conclusion, media representatives were convinced that the public was well warned and well served by both the NWS and the EM community. They indicated numerous lives were probably saved thanks to early warnings.

"*I think the Weather Service did a good job of underscoring the seriousness of this flood. The EMs also did a good job of getting the word out so people could evacuate before the roads got flooded*." WJDX Radio, Jackson, MS.

"*In all honesty, I would give the NWS a grade of 'A' in dealing with this flood. I really would*." Chief Meteorologist, WBDB-TV, Jackson, MS.

3.3. Multi-Office Decision Support

As mentioned in Section 3.1.5, WFO PAH suspended multimedia briefings at the peak of the flood event due to limited bandwidth issues. WFO MEG used a Web page in coordination with conference calls (as opposed to using GoToMeeting, WebEx, or other electronic conferencing software) to provide briefings of flood threats and forecasts. These steps were taken because the office felt that this was the most efficient means to communicate critical weather and water information.

Finding 23: Inadequate bandwidth and limited use of large-scale conferencing resources restricted WFO use of technology for briefings to partners.

Recommendation 23: The NWS should identify and catalogue licenses and resources needed to address bandwidth and conferencing deficiencies.

AHPS Web pages display a range of data including rating curves and stage forecasts; however, AHPS River Forecasts data display (http://water.weather.gov/ahps/forecasts.php) is limited to the first 48 hours of forecasts. AHPS pages had forecast points shaded green (no flooding) because the flooding was forecast to begin beyond the software's 48-hour capability. This confused partners, the media, and the public.

Finding 24: The response times on large rivers is often longer than 48 hours. In these instances, an AHPS Web-based, 48-hour display is insufficient to convey flood threats and timing.

Recommendation 24: Provide an AHPS Web-page feature to display NWS river forecast information beyond 48 hours in a nationally consistent way.

Appendix A: Acronyms

ADEM	Arkansas Department of Emergency Management
AHPS	Advanced Hydrologic Prediction Service
AWIPS	Advanced Weather Interactive Processing System
cfs	Cubic Feet per Second
CEMs	Civil Emergency Messages
CDT	Central Daylight Time
CMS	Content Management System
CR	Central Region
CRH	Central Region Headquarters
CWA	County Warning Area
DOT	Department of Transportation
DSS	Decision Support Service
DWOPER	Dynamic Wave Flood Routing Model
EM	Emergency Management/Manager
EMA	Emergency Management Agency
EOC	Emergency Operation Center
ERP	Emergency Response Plan
ESF	Flood Potential Outlook
ESP	Ensemble Streamflow Prediction
FEMA	Federal Emergency Management Agency
FFS	Flash Flood Statement
FFW	Flash Flood Warning
FIPS	Federal Information Processing Standard
FLS	River Flood Statement
FLW	Flood Warning
GFE	Graphical Forecast Editor
GFS	Global Forecast System
GIS	Geographic Information System
GOHSEP	Governor's Office of Homeland Security and Emergency Preparedness
HEC	USACE Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center River Analysis System
HEFS	NWS Hydrologic Ensemble Forecast System
HIC	Hydrologist in Charge at the River Forecast Centers
HPC	Hydrometeorological Prediction Center
HSA	Hydrologic Service Area
HMT	Hydrometeorological Technician
ICS	Incident Command System
ILN	Station Identifier for Weather Forecast Office Wilmington, OH
ILX	Station Identifier for Weather Forecast Office Central Illinois
IMET	Incident Meteorologist
IND	Station Identifier for Weather Forecast Office Indianapolis, IL
IRIS	Inter-Regional Integrated Services
IWRSS	Integrated Water Resources Science and Services
JAN	Station Identifier for Weather Forecast Office Jackson, MS

LCH	Station Identifier for Weather Forecast Office Lake Charles, LA
LIDAR	Light Detection and Ranging
LIX	Station Identifier for Weather Forecast Office New Orleans/Baton Rouge, LA
LMK	Station Identifier for Weather Forecast Office Louisville, KY
LMRFC	Lower Mississippi River Forecast Center
LSX	Station Identifier for Weather Forecast Office Saint Louis, MO
LZK	Station Identifier for Weather Forecast Office Little Rock, AR
mb	Millibar
MEG	Station Identifier for Weather Forecast Office Memphis, TN
MEMA	Mississippi Emergency Management Agency
MIC	Meteorologist in Charge at an NWS Weather Forecast Office
MRC	Mississippi River Commission
MR&T	Mississippi River & Tributaries
NAVD88	North American Vertical Datum of 1988
N-AWIPS	National Centers for Environmental Prediction Advanced Weather Interactive Processing System
NCEP	National Centers for Environmental Prediction
NCRFC	North Central River Forecast Center
NHC	National Hurricane Center (Tropical Prediction Center)
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NWR	NOAA Weather Radio All Hazards
NWS	National Weather Service
NWSRFS	NWS River Forecast System
NWSChat	Internet-based chat software
OCWWS	Office of Climate, Water and Weather Services
OHRFC	Ohio River Forecast Center
OHX	Station Identifier for Weather Forecast Office Nashville, TN
PAH	Station Identifier for Weather Forecast Office Paducah, KY
QPE	Quantitative Precipitation Estimation
QPF	Quantitative Precipitation Forecast
RAS	USACE River Analysis System
RFC	River Forecast Center
ROC	Regional Operations Center
SCH	Service Coordination Hydrologist at an NWS River Forecast Center
SGF	Station Identifier for Weather Forecast Office Springfield, MO
SH	Service Hydrologist
SHV	Station Identifier for Weather Forecast Office Shreveport, LA
SOO	Science Operations Officer at an NWS Weather Forecast Office
SR	Southern Region
SRH	Southern Region Headquarters
TADD	Turn Around, Don't Drown™
TEMA	Tennessee Emergency Management Agency
TSA	Station Identifier for Weather Forecast Office Tulsa, OK
TVA	Tennessee Valley Authority
USCG	United States Coast Guard
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

WCM	Warning Coordination Meteorologist
WCP	Water Control Plan
WFO	Weather Forecast Office
WHFS	WFO Hydrologic Forecast System
Z	Coordinated Universal Time (UTC)

Appendix B: Definitions

Advanced Hydrologic Prediction Service (AHPS): AHPS provides Hydrologic information and products provided through the infusion of new science and technology. This service improves flood warnings and water resource forecasts to meet diverse and changing customer needs.

Advanced Weather Interactive Processing System (AWIPS): A technologically-advanced processing, display, and telecommunications system serving as the cornerstone of NWS operations.

Content Management System: Program used to manage and organize data and/or data display within software programs or output from those programs, e.g., Web pages.

Contingency Forecast: **N**on-publicly disseminated forecasts developed at RFCs in coordination with internal entities (e.g., WFO) or external partners (e.g., USACE). Contingency river forecasts are developed to provide a range of potential outcomes based on variations in QPF or reservoir operations coordinated with the requesting partner. Contingency river forecasts are not disseminated publicly. They are designed to be a planning tool for decision makers.

Dynamic Wave Flood Routing Model (DWOPER): Routing system for inflow hydrograph to a point downstream. The model can be used for a single river or system of rivers for which storage routing methods are inadequate due to backwater, tides and mild channel bottom slopes.

E-19: NWS form used to provide detailed station and flood history information for a river gage station. This information is an invaluable hydrologic resource used in many capacities, especially during active hydrologic situations.

Federal Information Processing Standard (FIPS): Publicly announced standard developed by the federal government for use in computer systems by all non-military government agencies and by government contractors.

Fusion Team: NWS, USACE, and USGS tri-agency consortium formed in response to the 2008 upper Mississippi River flood. The team's mission is "*to improve accuracy and utility of river/rainfall observations and river forecasts with an emphasis on collaboration, interoperability, and a common operating picture.*" The Fusion Team's mission was extended to address collaboration issues uncovered during the Kentucky and Tennessee floods of May 1-2, 2010. Fusion Team successes have been underscored in this Service Assessment.

Hydrologic Engineering Center River Analysis System (HEC-RAS): USACE computer program that models the hydraulics of water flow through natural rivers and other channels.

Hydrometeorological Prediction Center (HPC): NWS office providing forecasts, guidance, and analysis products and services to support the 24x7 public forecasting activities of the NWS and other HPC customers. HPC develops and distributes daily QPFs to all continental U.S. NWS offices and posts them online for public use. QPFs are evaluated and used by the RFCs to prepare river stage forecasts.

Hydroview: Software package used by the NWS to monitor river and stream levels and other hydrometeorological data relevant to specific forecast points along established waterways.

Incident Meteorologists (IMET): NWS staff dispatched to remote locations in support of wildfires and other hazardous situations. When incidents require localized weather information, IMETs are quickly deployed to an incident command site anywhere in the country. Once onsite, IMETs become key members of the incident command teams and provide continuous meteorological support for the duration of the incident. IMETs help incident specialists from federal, state and local agencies by interpreting weather information, assessing its impact, and helping responders develop strategies to best address the incident, while keeping responders and the general public safe.

Light Detection and Ranging (LIDAR): Optical remote sensing technology that can measure the distance to, or other properties of, a target by illuminating the target with light, often using pulses from a laser.

NWSChat: Instant Messaging program used by NWS operational personnel to share critical warning decision expertise and other types of significant weather information. This information is exchanged in real-time with the media and emergency response community, who, in turn, play a key role in communicating the NWS' hazardous weather messages to the public.

NWS River Forecast System (NWSRFS): NWS river and hydrologic forecast system that includes all the necessary hydrologic and routing models as well as data handling and presentation systems. NWSRFS has been in operation for over 20 years and is constantly refined and improved.

River Forecast Centers (RFC): Offices across the United States, which provide hydrologic forecasting. RFCs also provide a range of hydrometeorological data, including river stage forecasts for over 4,400 locations. Each RFC provides river forecasts to local WFOs within the RFC's service area. The Ohio RFC, in Wilmington, OH, is responsible for forecasts along the Ohio River and its tributaries, including the lower Cumberland River Basin. Cumberland River forecasts from the RFC are provided to the Nashville Forecast Office for evaluation and public dissemination.

RiverPro: Software used by the NWS to issue long-fuse river flood watches, warnings, statements, and advisories for River Forecast Points.

WarnGEN: Software used by forecasters to prepare and issue short-fused severe weather and hydrologic warnings and statements quickly and efficiently based on observed or forecast storm motion and trends.

Weather Forecast Office (WFO): NWS local offices that, among many functions, receive river forecasts and guidance from the 13 RFCs. After reviewing the river forecasts for accuracy, WFO forecasters use this guidance to compose river flood watches, warnings, and advisories for public dissemination.

WFO Hydrologic Forecast System (WHFS): Software application program used by WFO forecasters and service hydrologists to manage hydrometeorological data, communicate with RFCs, model hydrologic conditions within the HSA, and generate and communicate hydrologic and hydrometeorological products for the user community.

Appendix C: Findings, Recommendations, & Best Practices

Definitions

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

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

Finding – A statement that describes 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, which should improve NWS operations and services, based on an associated finding. Not all recommendations may be achievable but they are important to document. If the affected office(s) and OCWWS determine a recommendation will likely improve NWS operations and services, and it is achievable, the recommendation will likely become an action. Recommendations should be clear, specific, and measurable.

Findings and Recommendations

Finding 1: The demand for NWS interpretive services by EOCs continues to increase and is consistent with the NWS goal to improve DSS for events that threaten lives and livelihoods. The utility of NWS interpretive services is greatest when provided by NWS staff that understand and apply ICS principles. Not all NWS operational personnel are prepared to provide the level of interpretive support that is needed.

Recommendation 1: The NWS, in collaboration with FEMA, should define prototype ICS principles (i.e., engaged partnerships; tiered response; scalable, flexible operational capabilities; unity of effort through unity of command; preparedness; and readiness to act) at one or more NWS operational offices to assess which ICS principles NWS can practically adopt, then develop a training and implementation plan for all operational offices and regional support centers.

Finding 2: Several NWS offices and county and state-level emergency management (EM) officials expressed concern over differences between HSA and CWA boundaries. Not all partners were sure about which NWS office to contact to acquire or provide specific hydrometeorological information. NWS offices incurred increased workload relaying phone-based hydrologic information received by one office to another, and duplicating hydrologic forecasts using differing hydrologic product titles to ensure a single-office source.

Recommendation 2: NWS regions and their respective WFOs should work with critical partners to determine where realignment of disparate CWA and HSA boundaries is both warranted and feasible to limit spatial discontinuity and enhance service-related issues.

Finding 3: Providing staff support to national partners like FEMA during high impact events is a critical part of the NWS mission and represents the highest level of interpretive services. A formalized reimbursement mechanism between FEMA and the NWS would ensure that the cost of deployment does not factor into the decision to provide this valuable service. A precedent exists in the form of the Interagency Agreement for Meteorological and Other Technical Services between the NWS and the Departments of Agriculture and Interior.

Recommendation 3: NOAA should establish an agreement with FEMA to facilitate reimbursement of costs associated with deploying NWS staff to FEMA operations centers.

Finding 4: The dynamic nature of the Lower Mississippi River is not compatible with the single value rating curve depicted on AHPS Web pages. AHPS graphics are limited to defining a specific stage on the left Y-axis to a specific flow/discharge on the right Y-axis. When looped rating curves are present, reference to a specific flow/discharge with respect to stage becomes increasingly problematic since two differing flows may yield the same stage at different times during the hydrologic event. During such instances, the forecast stage becomes the only standard that remains viable on the Y-axis.

Recommendation 4: The NWS should work with the USACE and USGS to realize system interoperability and data synchronization for rating curves on dynamically changing waterways. In the interim, WFOs should receive training on how to directly change the AHPS Content Management System (CMS) to remove flow/discharge labels on the right Y-axis of AHPS Web pages whenever loop rating curves are anticipated or in effect. WFOs should work with the Hydrologic Support Branch to remove tabular listing of flow data on the AHPS Web page when needed.

Finding 5: Current forecast methods did not adequately capture backwater storage areas or the impact of potential levee failures, nor provide quality inundation mapping. A Community Model (i.e., advanced 1D and 2D hydraulic models built with new LIDAR, HEC-RAS, and/or others) for the Lower Mississippi and Atchafalaya Rivers and its tributaries would allow the NWS and other partners to provide more precise and well-collaborated river stage and water routing forecasts.

Recommendation 5: The NWS should collaborate with USACE to develop a Community Model for the Lower Mississippi River, including the Atchafalaya River and its tributary storage areas.

Finding 6: Lack of information on how to relate NWS stage forecasts to USACE inundation maps resulted in confusion and anxiety among the residents of Butte La Rose, LA.

Recommendation 6: The NWS should work within the Tri-Agency Fusion Team to ensure a consistent and understandable message to partners. The NWS also should advocate use of a vertical datum (i.e., North American Vertical Datum of 1988-NAVD88) referenced to gravity measured at Father Point in Canada for flood forecasting and inundation mapping. All modern elevation data are based on a gravitational model of the Earth.

Finding 7: Due to lack of community and 2-D models to provide a more precise river stage and water routing forecast and uncertainty concerning how much flow would be diverted through the Morganza spillway, LMRFC adopted a conservative approach and did not lower the forecast at Butte La Rose, despite downward adjustments to forecast points further upstream. Downward adjustments were made at Butte La Rose a couple of days later.

Recommendation 7: To ensure optimal coordinated river stage forecasts in highly controlled waterways, RFCs should incorporate USACE Water Control Plans into forecast models when applicable.

Finding 8: For the 2011 Middle and Lower Mississippi River Valley Flood, inundation mapping was widely needed but not readily available. Some EMs created impromptu inundation maps. Interviews with residents in the Memphis area who evacuated their homes indicated they valued having the inundation information.

Recommendation 8: The NWS should create and implement a plan through the Integrated Water Recourses Science and Services (IWRSS) initiative, which is evaluating flood inundation mapping activities between USACE, USGS, and the NWS, to explore opportunities to partner with other water agencies and accelerate the implementation of inundation mapping nationwide or develop new methods for creating these maps such as dynamically from the community 1-D/2-D hydraulic model.

Finding 9: Only small areas of each county/parish immediately near the river were impacted by flood waters. Some EMs perceived an inconsistency between areal flood warnings released for large geographic areas to the impact that was often restricted to areas close to the waterway.

Recommendation 9: Modify areal flood warning templates and software to establish predefined flood warning polygons that more specifically identify areas along a waterway most likely to flood.

Finding 10: Despite the extra resources made available to the LMRFC (i.e., support of the management team and persons deployed on a temporary duty assignment), many staff members worked long and consecutive daytime and evening/midnight shifts to respond to the operational and decision-support demands.

Recommendation 10: Well in advance of significant long-term hydrologic events where extended 24/7 operations are anticipated, RFCs should devise a "*phantom/hybrid*" long-term planning schedule to ensure (additional) staff coverage will be made available in as fair and equitable a fashion as possible for overnight shifts. This process may involve using creative scheduling practices (e.g., temporary compressed/alternative work schedules) to ensure that staff has at least 1 day off a week despite high workload demands and a shortage of staffing.

Finding 11: There was difficulty finding personnel to augment LMRFC staffing given the level of training and familiarization necessary on LMRFC mainstem Mississippi River forecasting operations using complex hydrologic models.

Recommendation 11a: The NWS should develop a more robust cross-training program for RFC staff that identifies unique forecasting and collaborative complexities present during an historic flooding event on controlled waterways.

Recommendation 11b: The NWS should develop a comprehensive plan to ensure that RFCs can quickly request deployment of fully trained and experienced hydrologic forecasters from other offices for forecasting complex mainstem river systems using hydraulic models.

Recommendation 11c: Deployed personnel to the RFC should work the less complex river systems allowing local hydrologists to train/shadow operations on the more complex river systems. This system will allow additional local staff members to be trained on the complex river systems, providing more staffing options and less dependence on long overtime hours for a few select members of the existing staff.

Finding 12: WFO JAN issued flood advisories before stage forecasts became available. The advisories indicated river levels above bankfull, but below Flood Stage. Flood advisory terminology confused some users, since an actual flood was not being forecast at that time.

Recommendation 12: The NWS should coordinate with critical partners and social scientists to devise ways to reduce the number of hydrologic products, simplify their titles, and ensure consistent use to minimize confusion.

Finding 13: A format specifier within RiverPro software displays the day of the week, not the date, of a forecast river crest. If, for example, a crest forecast is made for "*Saturday,*" the user does not know if it is this Saturday or next Saturday.

Recommendation 13: Modify the format specifier within RiverPro to display date, as well as day of the week, of forecast river crests.

Finding 14: WFO JAN received reports that major flooding was occurring along the Yazoo River at Yazoo City. Flood categories in effect at the time, as defined in WS Form E-19, equated to moderate flooding. Because of existing national policy (NWS Directive 10-940), changes could not be made quickly to WHFS E-19 flood categories to provide a more representative hydrologic category in NWS flood warnings and AHPS Web pages.

Recommendation 14: NWSH should streamline the process for modifying E-19 flood categories in the WHFS database to ensure representative hydrologic categories are provided in NWS flood warnings and AHPS Web pages during an ongoing event.

Finding 15: Enhanced laser-based survey and leveling tools would provide field offices with a more accurate and efficient means to update flood categories and impact statements.

Recommendation 15: The NWS should provide modernized surveying and leveling equipment at all WFOs—including those without leveling equipment and WFOs with leveling equipment should receive a technology upgrade.

Finding 16: WFO JAN issued areal flood warnings for backwater areas. Baseline WarnGEN software used to generate areal flood warnings allows a maximum expiration time of 48 hours, insufficient in many instances.

Recommendation 16: Ensure all WFOs understand NWS WarnGen warning software is configurable to allow expiration times beyond 48 hours for areal flood warnings.

Finding 17: GFE software does not allow one WFO to include FIPS codes for another WFO's counties/parishes in flood potential outlooks.

Recommendation 17: Configure GFE software to provide the capability to enable one WFO to include counties/parishes not in its CWA, but in its HSA to generate flood potential outlooks.

Finding 18: On the Atchafalaya River, flood impacts occurred at levels other than the established official flood stage.

Recommendation 18: WFOs should aggressively survey flood areas during and immediately following a significant flood event to ensure that existing flood stages and categories are representative of impact.

Finding 19: While 28-day stage forecasts provided by the LMRFC for the Lower Mississippi and Atchafalaya Rivers were useful, USACE also would have found probabilistic stage forecasts helpful. Communicating uncertainty provides enhanced DSS to critical partners.

Recommendation 19: LMRFC's deterministic model forecasts should be complemented by probabilistic stage forecast such as the NWS Hydrologic Ensemble Forecast System (HEFS) and Ensemble Streamflow Prediction (ESP). Efforts to move in that direction should be accelerated.

Finding 20: The MEMA Director and several media partners stated acquiring AHPS Website information or more generic Web-based water- and weather-related information was convoluted, cumbersome, and non-intuitive.

Recommendation 20: The NWS should provide Web services for weather and water information in which users of varying degrees of technical expertise can obtain information compatible with their needs.

Finding 21: Some EMs were confused about the amount of mitigative action they needed to take when a river forecast point had the same Action Stage and Flood Stage versus differing Action and Flood Stages.

Recommendation 21: Establish a nationally consistent methodology for defining an Action Stage at all river forecast points, e.g., 80 percent flood flow or 90 percent bankfull.

Finding 22: The need for extensive coordination between the NWS and USACE increased as the flooding event progressed in order to share the latest and most accurate upstream flow and stage measurements. This coordination was necessary to ensure the highest quality stage forecast possible but resulted in progressively delayed release of stage forecasts (approximately 11:00 a.m. local time in the beginning of the event to late afternoon, on occasion, during the peak of the event). News media, who relied on updated forecasts being available for noon newscasts, did not always have them available, nor did they know when to expect them from one day to another.

Recommendation 22: To address product availability, timeliness, and reliability issues, enhanced data synchronization and forecast system operability (e.g., establishment of common data formats and transfer protocols) is needed between the NWS and other federal partners, including USACE. The NWS must begin to document requirements and develop an implementation plan to meet this goal.

Finding 23: Inadequate bandwidth and limited use of large-scale conferencing resources restricted WFO use of technology for briefings to partners.

Recommendation 23: The NWS should identify and catalogue licenses and resources needed to address bandwidth and conferencing deficiencies.

Finding 24: The response times on large rivers is often longer than 48 hours. In these instances, an AHPS Web-based, 48-hour display is insufficient to convey flood threats and timing.

Recommendation 24: Provide an AHPS Web-page feature to display NWS river forecast information beyond 48 hours in a nationally consistent way.

Best Practices

Best Practice: Taking past service assessments very seriously, many WFOs devoted a significant amount of training time to study and implement recommendations cited in the 2010 Nashville Floods and 2009 Southeast United States Floods service assessments. NWS offices impacted by the 2011 Middle and Lower Mississippi River flood conducted operational and all-hands meetings and training sessions well ahead of this event to familiarize or re-familiarize the staff with unique challenges associated with record flooding.

Best Practice: WFOs TSA, PAH, and MEG, which experienced severe weather along with flooding/flash flooding, all maintained a dedicated hydrologic desk for all shifts–even during the peak of the severe weather outbreak to ensure hydrologic threats were efficiently monitored and warned. Other NWS offices farther south and east that experienced flooding as the flood wave moved downstream, but did not experience significant severe weather during the passage of the flood wave, adjusted staffing levels as needed to provide 24/7 hydrologic support.

Best Practice: Collaboration between HPC and the RFCs in the flood area led to consistent product delivery to users and partners.

Best Practice: SR and CR ROCs used their headquarters' staff in an innovative manner by applying ICS principles.

Best Practice: Collaborative projects, such as the HEC-RAS-based community model for the Ohio and Upper Mississippi Rivers, advance the technical capabilities of all partners. These projects are also the most productive way to develop and maintain relationships between agencies and optimize the use of resources for complementary missions.

Best Practice: OHRFC shared all NWS-determined critical river levels with USGS before the event so the data could be used as a planning tool. This reduced communication issues during the event.

Best Practice: The judicious use of press conferences by WFO PAH reinforced the need to prepare for this high-impact, weather-related event.

Best Practice: Rare use of the terms "*catastrophic*" and "*historical*" to define the forecast extreme flooding helped emphasize the severity of the threat to local communities.

Best Practice: "*Do not drive*" and/or "*Do not drive at night*" was used in warnings and statements from WFO PAH as behavior modification statements. They were used in place of "*Turn Around Don't Drown*" (TADD) to discourage travel altogether during the worst of the flooding.

Best Practice: As the main flood wave moved downstream along the Mississippi within the JAN HSA, the office conducted ground surveys using a cell phone with geo-tagging capability to establish high water benchmarks (**Figure 17**). Making full use of new and emerging Geographic Information System (GIS)-based technologies will help the NWS better capture impact-based detail in the WFO Hydrologic Forecast System (WHFS) for future flooding applications.

Best Practice: WFO JAN provided a user-friendly packet of weather information for partners, e.g., media and emergency responders.

Best Practice: WFO LIX created a standardized briefing format for GOHSEP that eliminated extraneous hydrometeorological information, integrated input from four NWS offices serving Louisiana, and focused on weather-related impacts critical to decision makers.

Best Practice: For the past several years, LMRFC has issued a 28-day Extended River Stage Forecast for the mainstem of the Lower Mississippi River.

Best Practice: In advance of floodway/spillway operation, and when floodway/spillway operations began, LMRFC issued contingency river forecasts and updated official river forecasts.

Appendix D: Methodology

The NWS formed an assessment team on June 23, 2011. Team efforts included the following:

- Conducted separate conference calls with staffs from the Ohio River Forecast Center , WFO Tulsa, OK and WFO Little Rock, AR.
- Conducted in-person interviews of staff and management at WFO Paducah , KY; Memphis , TN; Jackson , MS; and the collocated WFO New Orleans and Lower Mississippi RFC in Slidell, LA. These NWS offices had primary responsibility for providing forecasts, warnings, and decision support to critical partners and the general public for the most impacted areas.
- Conducted in-person and telephone interviews with the Meteorologist in Charge, Warning Coordination Meteorologist, Science Operations Officer, and Senior Service Hydrologist at WFO Lake Charles, LA, which is responsible for areas impacted along the Atchafalaya River.
- Conducted in-person and telephone interviews with the NWS liaison to the USACE Mississippi Valley Division Office.
- Met with representatives from the USACE Memphis District Office, Mississippi Valley Division Office and Vicksburg District Office in Vicksburg, MS, and the New Orleans District Office in New Orleans, LA. Additional phone interviews were also conducted with representatives from the New Orleans office.
- Conducted in-person interviews with upper-management officials of the Mississippi Emergency Management Agency in Jackson, MS, and the Governor's Office of Homeland Security and Emergency Preparedness in Baton Rouge, LA.
- Conducted telephone interviews with representatives from FEMA Regions 4, 6 and 7.
- Conducted in-person interviews with representatives from the USACE Hydrologic Engineering Center.
- Conducted phone interviews with county- and parish-level emergency management directors and regional coordinators.
- Conducted telephone interviews with Department of Transportation representatives in Mississippi and Louisiana.
- Conducted telephone interviews with representatives from the U.S. Coast Guard in Louisiana.
- Conducted telephone interviews with representatives from the United States Geological Survey in Mississippi and Louisiana.
- Initiated numerous telephone interviews with various print and news media interests.
- Conducted telephone interviews with representatives from the NWS Southern Region Headquarters and Central Region Headquarters Regional Operations Centers.
- Evaluated NWS products and services and national guidance provided by the Hydrometeorological Prediction Center.
- Developed significant findings and recommendations to improve the effectiveness of NWS products and services.

Appendix E: WFO JAN Flood Exercise & Outreach Plan

NWS Jackson, MS, Flood Exercise

- **Rationale: Flooding in Atlanta area, Little Rock area, especially Nashville showed the need for more preparation and planning. Widespread flooding has the most potential to hammer this WFO**
- **The format allows pauses for discussions, training and the demonstration of new tools**
- **Process reflects training is a work in progress and allows for sharing more information after this exercise**

1. Scenario

A spring storm system dumps heavy rainfall across the County Warning Area, with the heaviest rain occurring north of Interstate 20. A maximum of 10 to 15 inches of rain falls across the Pearl River Basin from Madison and Rankin Counties northeast into Winston County. This rainfall occurs in a period of 12 to 18 hours and is accompanied by some severe weather; however, the main issue is flooding.

2. Exercise

This scenario will be conducted twice, which should allow the entire staff to participate. Scheduling will be arranged so that everyone can participate. Dates for this exercise are scheduled to be 10/25/10 and 11/8/10. A dry run to test equipment and coordination will be conducted 10/22/10 at 10 am.

Graphics that need to be shown for this section: 1. Last 7 days of rainfall 2. Day 1 QPF indicating nearly 6 inches of rain across central Mississippi

A. Prestorm – This event is well anticipated as a risk of both severe weather and flash flooding. Staffing plans should be discussed and put into place. This event will occur on a Saturday to force the staff to think about each position and who to call in as opposed to just relying on X shifts already at the office.

***Action item to stress: The staff should use the newly developed flooding staffing plan.
***Action Item to Stress: SH will discuss the guidelines for flood operations

It needs to be stressed that often major flooding events are not well forecast and that staff should maintain situational awareness to notice when a severe weather event is transitioning into a major flood or when rain is much heavier than expected.

***Action Item to Stress: SH will go over the new list of flashy creeks in the CWA

Graphics that need to be shown for section B: 1. Observed rainfall 18z Saturday-00z Sunday and 2. Observed rainfall 03z-09z Sunday.

An AWIPS machine will be set up in the conference room for this exercise. The computer will need the capability of displaying Warngen, DamCat, RiverPro, Hydro Time Series, Hydroview, and River Monitor.

B. Flash Flooding/Flash Flood Emergency – The heavy rainfall is occurring over already moist ground and flash flooding begins quickly. Initial Flash Flood warnings are issued.

*** Action item to stress: The Flash Flood warnings should include local flooding information provided in the Warngen templates, where available.

A brief break in the heavy rain (3 hours) occurs when the flooding is at its worst, but soon a second batch of heavy rain develops. What products (Flash Flood vs. Areal Flood Warning) should be issued as the warnings expire and need to be reissued? Discussion

Once the heavy rainfall returns, reliable reports indicate that water rescues are occurring and that water is flooding numerous homes.

*** Action item to stress: At this point, a Flash Flood Emergency(s) is issued to highlight the extreme life threatening nature of the event.

We will soon update templates to include the Flash Flood Emergency Statement in follow-up Flash Flood Warnings. Stress making numerous phone calls to keep up with the rapidly changing nature of the event and logging them in the Coordination Log, which is now located in the Shift Log. Also, stress the media, through NWSChat, how significant the flood event is becoming.

Pause for SH to go over how to check the river stages and rainfall amounts through Hydro Time Series, Hydroview, and River Monitor. Also talk about software guides.

C. Dam break/Initial Pearl River Flooding –A call comes in from the media that water is overtopping Kenneth Lowe dam in Attala County and dam failure is imminent. How do we verify the dam break? We need to make sure the information is from a reliable source, so we need to call the Attala County EM to confirm the report. Once it is confirmed, immediately issue a Flash Flood Warning for the dam break using the templates in Warngen. Then, go through the procedures to look up the dam in DamCat and provide additional information in a Flash Flood statement for the dam.

With this much heavy rain falling in the Pearl River Basin, be sure to keep an eye on the discharge readings from the Ross Barnett Reservoir. These readings are available from the JANRR2JAN product or by calling the reservoir. When discharges are forecast to reach 15,000-20,000 cfs, notify LeFleur's Bluff State Park, which floods at a stage of 26-27 feet.

Show total rainfall for the event

The heavy rain has now ended. As a result of the heavy rain that fell across the Pearl River Basin and a projection that the Ross Barnett Reservoir discharge will equal or exceed 30,000 cfs, a conference call will be scheduled among the Pearl River Valley Water Supply District (PRVWSD), the Army Corps of Engineers, the United States Geological Survey, the Lower Mississippi River Forecast Center, and WFO JAN to discuss the potential impact. This will most likely be handled by SH. This conference call will help coordinate releases into the lower Pearl River.

D. <u>Moderate to Major Pearl River Flooding</u> - The heavy rain is draining into the Ross Barnett Reservoir and water releases are increasing rapidly. We need to ask the PRVWSD to call us whenever the releases change; however, we do not need to wait for their calls and should monitor the JANRR2JAN product and place a call to the PRVWSD every 30 minutes if we do not have release information within the last 30 minutes.

***Action item to stress: SH will go over the discharge-stage relationship for the Pearl River at Jackson

The PRVWSD has increased its release to 40,000 cfs. NWS JAN can use the discharge-stage relationship to determine if the Jackson stage will reach a value around 34 feet. What type of product should be issued? Areal Flood with Tone Alert?) This information is also being sent to the Lower Mississippi River Forecast Center, but it will take at least an hour for them to produce a new river forecast reading. Thus, the citizens of Hinds and Rankin County will not have much time to react.

*** Action item to stress: Graphicasts are being developed for each 2 foot increment from 28 to 46 feet in the Jackson area.

SH will introduce these Graphicasts. Graphics are being developed using the 1979 and 1983 flood information and GIS mapping, but do not represent a hydrologic study. The graphics will have an associated disclaimer that will be coordinated with the Rankin and Hinds County EMs. Thus, the graphics will represent an approximation, but not an exact representation of what will occur; however, this information can be used as a best guess for rapid evacuation of parts of Hinds and Rankin Counties along the river.

The graphics will be stored on AWIPs in the X directory and should be posted to the Web (1.gif) as soon as its determined a major flood is expected. Immediate calls should be made to the Hinds and Rankin County EMs and the information placed on NWSChat for the media to give wide dissemination.

The PRVWSD has increased its release to 60,000 cfs. NWS JAN can use the discharge-stage relationship to determine that the Jackson stage will reach a value around 37 feet. Issue the appropriate Graphicast, place calls to the Hinds and Rankin County EMs, and place the information on NWSChat for the media to give wide dissemination.

The PRVWSD has increased its release to 100,000 cfs. NWS JAN can use the discharge-stage relationship to determine the Jackson stage will reach a value around 41 feet. Issue the appropriate Graphicast, place calls to the Hinds and Rankin County EMs, and place the information on NWSChat for the media to give wide dissemination.

Other rivers are reaching flood stage.

***Action item to stress: SH will discuss other rivers in the HSA and where the most significant flooding occurs. Eventually, we hope to have an alarm/alert feature appear on AWIPs when a river is observed or forecast to reach a predetermined critical stage. The message will indicate the need to notify an EM.

In each case, collaboration should be made with the Lower Mississippi River Forecast Center.

Open Discussion