Service Assessment

The Missouri/Souris River Floods of May – August 2011

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Kansas City, Missouri and Salt Lake City, Utah

Cover Photographs: Damage to Interstate Highway 680 near Council Bluffs, Iowa. The river crested in nearby Omaha, Nebraska at 36.29 feet on July 2, 2011, which was around 2 feet above the level shown on the photo dated August 16, 2011. (Used with permission ©2011 Iowa Department of Transportation)

Service Assessment

The Missouri/Souris River Floods of May – August 2011

May 2012

National Weather Service Central Region
Lynn P. Maximuk
Regional Director

National Weather Service Western Region
Vickie L. Nadolski
Regional Director

Preface

During the winter and spring of 2010-2011, record to near-record setting snow fell across a large portion of the northern United States Rocky Mountains and eastward into the Northern Plains states. A cool spring held the snowpack in place later than usual, and a fairly rapid melt off of the snow eventually coincided with record-setting rains in May and early June over Montana and western North Dakota. This untimely combination of events caused record river levels and extensive flooding in the Missouri and Souris River basins from June through August. Extensive damage occurred to numerous cities, including Minot, North Dakota, which incurred flood damage to around one-third of its homes. States up and down the Missouri basin – from Montana to Missouri – were also impacted by this flood event.

Due to the magnitude and impact of this event, and its temporal and spatial extent, a bi-regional Service Assessment Team was formed to examine the effectiveness of services provided during this event. Included in this is the decision support services provided to key decision makers and the public, with special attention given to National Weather Service (NWS) coordination of information with other federal, state, and local entities. The recommendations from this assessment, when implemented, will lead to improvements in the quality of NWS products and procedures to enhance decision-making processes associated with flood events. The ultimate goal of this report is to further the NWS mission of protecting lives and property and enhancing the national economy.

Lynn P. Maximuk
Director
NWS Central Region

Vickie L. Nadolski
Director
NWS Western Region

May 2012

Table of Contents

Appendices

List of Figures

Cover Photographs. Receding water reveals damage to Interstate 680 near Council Bluffs, Iowa. Photos dated August 16, 2011.

List of Tables

Service Assessment Team

The following individuals contributed to the service assessment process and subsequent report:

Brian Astifan	Hydraulic Engineer, U.S. Army Corps of Engineers, Water Management Division, Great Lakes and Ohio River Division, Cincinnati, Ohio
Jay Breidenbach	Warning and Coordination Meteorologist, WFO Boise, Idaho
Ed Clark	Flash Flood Program Leader, NWS Headquarters, Office of Climate, Weather and Water Service, Silver Spring, Maryland
Tracy Clark	Hydrologic Services Program Manager, NWS Southern Region Headquarters, Fort Worth, Texas
Joe Intermill	*Co-Team Leader,* Service Coordination Hydrologist, Northwest River Forecast Center, Portland, Oregon
Dan Luna	Meteorologist in Charge, WFO Chanhassen, Minnesota
Glenn Lussky	*Co-Team Leader,* Meteorologist in Charge, WFO La Crosse, Wisconsin
Kevin Werner	Service Coordination Hydrologist, Colorado Basin River Forecast Center, Salt Lake City, Utah
Ray Wolf	Science and Operations Officer, WFO Quad Cities, Iowa

Acknowledgements

The Service Assessment Team would like to thank the many people who made this Service Assessment possible. Valuable contributions were made by the many members of the NWS and its partner agencies at the federal, state and local levels who provided input through the interview process. The time and insights they provided to help enhance the delivery of future flood related services are greatly appreciated.

Executive Summary

The Missouri and Souris River basins experienced widespread record flooding from May through August 2011. This flood event had a major impact on numerous communities and livelihoods along both river basins. Major damage was inflicted on residences, businesses, infrastructure, transportation, and agriculture. Despite the record flooding, some property damage was mitigated and fatalities were limited, due, in part, to the extraordinary and innovative efforts among River Forecast Center (RFC) and Weather Forecast Office (WFO) staff as they provided warning and decision support services.

Major flooding impacted the states of Montana, North Dakota, South Dakota, Iowa, Nebraska, Kansas and Missouri. Appendix A lists the locations that experienced record or major flood levels during this event. Of the 38 National Weather Service (NWS) river forecast locations along the combined 2977 miles of the mainstem Missouri and Souris Rivers, 25 experienced major flooding, while 15 locations experienced record flooding.

The flooding caused over $2 billion dollars in damages and 5 fatalities in the United States, and led the Federal Emergency Management Administration (FEMA), to issue disaster declarations in each state along these rivers. During the event, an estimated 11,000 people were forced to evacuate Minot, North Dakota due to the record high water level of the Souris River, where 4,000 homes were flooded. Numerous levees were breached along the Missouri River, flooding thousands of acres of farmland and damaging transportation infrastructure.

This event encompassed a wide variety of flood situations – from flash flooding along uncontrolled tributaries to extensive mainstem river flooding which continued for months in some locations. The mainstem flooding created unprecedented challenges for reservoir managers and river forecasters. Extreme river levels caused hydraulic conditions which had not been previously observed in the basins. Additional forecast challenges resulted from levee breaches and river levels exceeding existing rating curves.

As a precursor to the event, soils across the northern High Plains were moist following an anomalously wet fall season in 2010. Subsequent record to near-record winter snowfall over the High Plains and northern Rocky Mountains was followed by record-setting precipitation in May. All of these factors contributed to the extreme nature of this event.

The potential for significant and widespread flooding was recognized during the winter season. NWS offices provided critical early information to partners regarding the potential flood threat during the snowmelt season, based on moist antecedent wintertime soil moisture conditions and the deep, extensive snow cover that developed as the winter progressed. The threat for flooding was readily apparent on the NWS Advanced Hydrologic Prediction Service (AHPS) conditional exceedance forecast pages, and this imagery was included as a part of many WFO briefings to partner agencies. Although conditions pointed to a high probability of flooding, the magnitude of the event was less certain. As the spring snowmelt season arrived across the plains, many rivers rose above flood stage, and major flooding occurred at a number of sites. This runoff was sufficient to fill Missouri and Souris River reservoirs to near capacity.

A series of storm systems that brought record-setting rains in the headwaters areas of Montana, North Dakota and southern Canada (and heavy snowfall to the adjacent Rocky Mountains) changed the event dramatically in May and early June. There were four specific periods of heavy rain: May 8-11, May 18-26, May 29-31 and June 6-7. During the May 29-31 event, the United States Army Corps of Engineers (USACE) Missouri River reservoir release projections increased from 60,000 cubic feet per second (cfs) to 150,000 cfs (more than double the previous record flow on the Missouri River). These projections were effectively collaborated with the NWS.

Once the new reservoir release forecasts were disseminated, local, state and federal officials were quickly thrust into making important flood-related public safety decisions. The NWS river and weather forecast information became critical decision-making inputs. Many NWS WFOs provided on-site decision support at Emergency Operation Centers (EOCs) on a daily basis for a number of weeks. The NWS RFCs also provided on-site decision support, a unique situation in the absence of a land-falling hurricane. This extended need for on-site decision support created significant staffing challenges at some of the WFOs and RFCs. Even so, each office indicated they were able to meet mission requirements and partner needs.

Considerable internal and external collaboration occurred on a regular basis, relating to both weather and river forecast information. Daily forecast collaboration between the NWS and USACE regarding river forecasts and reservoir release projections ensured a unified message to the public. This collaboration process was cited among stakeholders as a critical contributor to effective, consistent public service during the event. Additionally, many unique situations demanded new, innovative solutions that were also met through interagency collaboration. External partners praised the NWS offices for their ability to meet those requirements.

The collaboration process had some scientific and communication challenges as well. WFOs were, at times, challenged by specific Decision Support Service (DSS) requirements of on-site EOC partners, and river forecasts that required interpretation or clarification. Similarly, RFCs were challenged by data issues, quantitative precipitation forecast (QPF) impacts on the river forecasts, interagency water management collaboration requirements, and partner needs for special forecasts.

Due to the magnitude and impact of this event, its temporal duration, and spatial extent, a bi-regional 9-member Service Assessment Team was formed to examine the warning, forecast and decision support services provided to key decision makers and the public, with special attention given to NWS collaboration of information with other federal, state, and local entities. Other areas considered by the Service Assessment Team included scientific and technological issues, intra-agency communication and collaboration, and the impact of social media and other emerging technologies.

From August 22 through September 2, 2011, team members interviewed 29 different groups of people, including personnel within NWS offices and a wide variety of NWS partner agencies. Key NWS partners and stakeholders included the USACE, United States Geological Survey (USGS), FEMA, United States Bureau of Reclamation (USBR), state and local emergency management officials, and state, city and county engineers and water managers. Numerous visits were made to EOCs and partner offices.

Interviews with partner groups indicated an exceptional appreciation for NWS services during this event, and a high value placed on NWS interactions. Partners unanimously indicated that recent NWS DSS enhancements, including direct on-site support at EOCs, were an integral part of their decision-making process. This is an activity that is very strongly supported by those responsible for critical public response decisions along the Missouri and Souris Rivers.

Recommendations in this report are aligned with the National Oceanic and Atmospheric Administration (NOAA) and NWS Strategic Plans, which convey a need to continuously identify stakeholder requirements and adjust services accordingly. These recommendations include numerous additions and enhancements in hydrologic and water resource services, such as:

- additional forecast locations
- increased forecast issuance frequency
- expansion of products and information produced
- improved utilization of existing observational networks
- development or enhancement of scientific and technological capabilities (e.g., ensemble forecasts, short-term probabilistic forecasts, QPF, hydraulic modeling, and inundation mapping)
- improvements in the design, support and overall effectiveness of the DSS process

In total, the Service Assessment Team identified 37 facts, 46 findings and 46 recommendations, and 9 best practices. See Appendix B for a summary of the facts, findings, recommendations, and best practices. The definition of these terms is provided in Appendix C.

Service Assessment Report

1. Introduction

1.1. National Weather Service (NWS) Mission

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

These services are delivered through the efforts of staff stationed at 122 Weather Forecast Offices (WFO), 13 River Forecast Centers (RFC), 9 National Centers of the National Centers for Environmental Prediction (NCEP), 21 Center Weather Service Units, the Alaska Aviation Weather Unit, 13 Weather Service Offices, two Tsunami Warning Centers, six Regional Headquarters, and a number of other units. Oversight, policy, and support are provided by NWS Headquarters in Silver Spring, Maryland.

1.2. Purpose of Assessment Report

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

The NWS Central and Western Region Directors chartered this Service Assessment Team on July 20, 2011 as the result of widespread flooding which extended from Montana through the Dakotas, and into Iowa, Nebraska, Kansas and Missouri from May through August 2011. The team reviewed the event across the extensive geographic area affected by the flooding, with a focus on science and services, and a special emphasis on decision support service activities. Assessment of any associated convective severe weather support was not part of the assessment.

The focus areas of this Service Assessment were:

- Decision Support Services: the nature and effectiveness of the support provided and the methods of information management
- Intra-agency services and collaboration, including services of the RFC to the WFO, and collaboration between the RFC, WFO, the National Operational Hydrologic Remote Sensing Center (NOHRSC), and the Hydrometeorological Prediction Center (HPC)

- Services of the RFC to the United States Army Corps of Engineers (USACE)
- Effectiveness of interagency collaboration, including impacts of and responses to forecasts
- Use and effectiveness of social media and emerging technologies
- Scientific and modeling issues, including those related to data, snowmelt, ensemble and contingency forecasting

This assessment is *not* in any way meant to assess the performance of the USACE or United States Bureau of Reclamation (USBR) in relation to their operations of managing river flows. The purpose of this report is to present the facts, findings, recommendations, and best practices identified by the assessment of *NWS performance*, including the collaboration activities with the NWS partner agencies, during the Missouri/Souris River flooding of May through August 2011.

1.3. Methodology

There were nine members on the Service Assessment Team. The team included four members from NWS WFOs, two members from NWS RFCs, one NWS regional headquarters hydrologist, one NWS national headquarters hydrologist, and one member from the USACE.

From August 22 through September 2, 2011, team members interviewed a wide variety of personnel within NWS offices and among NWS partner agencies. Key NWS customers and partners included the USACE, United States Geologic Survey (USGS), Federal Emergency Management Administration (FEMA), USBR, state and local emergency management officials, and state, city and county engineers and water managers. Visits were made to EOCs and partner offices. In the course of the travels, team members also had the opportunity to witness firsthand some of the flood damage that occurred in cities and towns, and visit some of the flood control dams along the Missouri River.

After completing the interviews and reviews, the team spent considerable time discussing and agreeing upon the significant facts, findings, recommendations, and best practices. After internal review, the Service Assessment was approved and signed by the two NWS Regional Directors and issued to the public.

1.4. Use of Terminology in Report

In addition to the many acronyms and abbreviations that exist within the NWS, this report also covers technical aspects of hydrology that utilize numerous acronyms. Within the report, there are also many references to specific software, Information Technology (IT) packages, and other technologies. To simplify the readability of this document, readers may reference Appendices D (for acronyms and abbreviations) and E (for other references to software and technologies utilized by the NWS and partner agencies). In this manner, we avoid these details within the body of the report.

2. Geographical and Climatological Perspective of the Missouri and Souris River Basins

The Missouri River is the longest river in the United States, and its watershed (**Figure 1**) covers the largest land area in the United States as well (around 1/6 of the total area of the lower 48 states). The river itself is 2619 miles long; the source of the headwaters is generally the Rocky Mountains and High Plains portions of Montana and Wyoming. Although it is the longest river and the basin covers the largest area in the United States, the river system also has one of the *lowest* average annual water yields of the major river systems in the United States. This is because much of the basin covers a drainage area which is semi-arid in nature, a large portion of which has annual precipitation totaling less than 20 inches per year (including Montana, Wyoming and most of Nebraska and the Dakotas; **Figure 2**).

Figure 1. Map of Missouri River Watershed.
Image from http://source.sdsu.edu/

Because of the climatologically low water yield in this large basin, years of significant flooding are infrequent. In fact, water scarcity has historically been as significant a concern through the basin as has flooding.

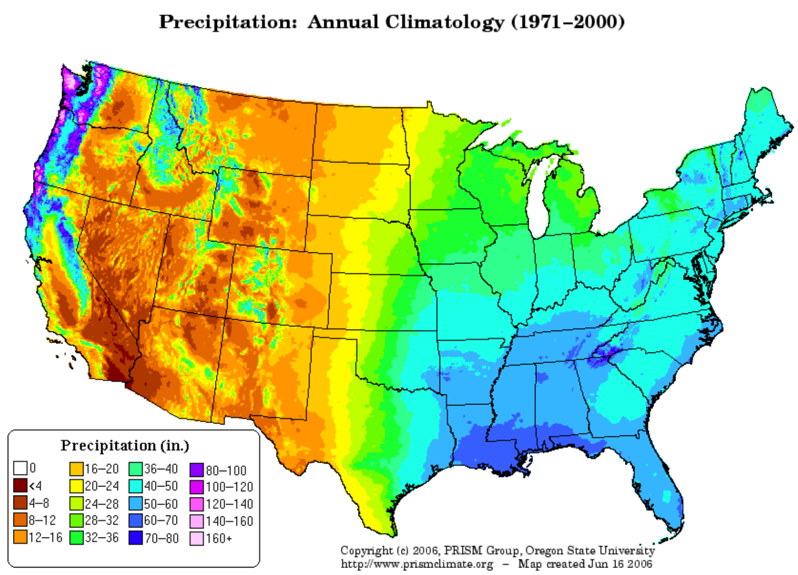

Figure 2. Average precipitation (in inches) across the conterminous United States, as modeled from 1971-2000 NOAA Cooperative Station normals and NRCS SNOTEL data.
Image from http://www.prismclimate.org

The headwaters of the basin, particularly drainages that originate in the higher terrain of the Rocky Mountains, are heavily regulated by projects operated by the USACE and USBR. The Missouri River is largely regulated by a series of dams north and west of Gavins Point Dam in South Dakota (**Figure 3**). Those dams were constructed between 1933 and 1963 to more effectively manage water scarcity and the desire to use it more effectively (e.g., for irrigation), water abundance and the desire to control floods, and navigation from the confluence of the

Missouri River with the Mississippi River in St. Louis, Missouri upstream to Sioux City, Iowa. In addition, they were designed to provide hydroelectric power production and develop recreational areas. Both the USBR and USACE reservoirs are designed to provide water availability for multiple uses, which involves year-round management of reservoir releases.

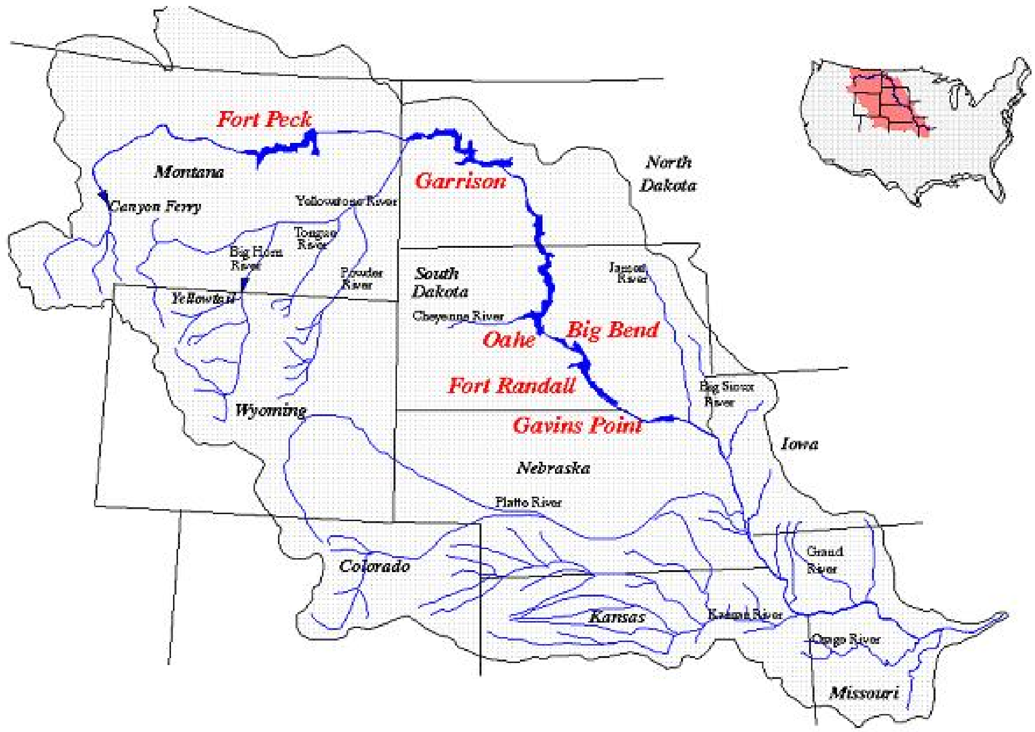

Figure 3. Major USACE dams (in red) along the Missouri River basin. ***Image from: http://www.ksda.gov/includes/images/interstate_water_issues/IWI%20Images/Missouri_River_Basin2161.jpg***

The Souris River Basin (**Figure 4**) originates in southern Saskatchewan, Canada, flows through north central North Dakota, and then flows back into Canada (in southern Manitoba). Like the Missouri River, the Souris emanates from a semi-arid region, in the Yellow Grass Marshes in southern Saskatchewan. It has historically been subject to extreme variations of drought and high water flow. Total length of the Souris River in North Dakota is 358 miles.

Two major water management and flood control projects were completed in Saskatchewan in the 1990s (Rafferty in 1991 and Alameda in 1995; **Figure 5**). An older dam, Boundary Dam (1957), was built on Long Creek, a tributary of the Souris, and is linked to the Rafferty Dam, allowing water to flow between the two reservoirs.

Figure 4. Highlighted area shows the Souris River, beginning in Saskatchewan, extending through northern North Dakota, and ending in Manitoba.

The Rafferty and Alameda Dam Projects were undertaken, in part, to protect Minot, North Dakota from flooding. International agreements exist to manage water in the Souris basin (reference: http://www.ijc.org/conseil_board/souris_river/en/souris_mandate_mandat.htm). An additional dam structure (known as the Lake Darling Dam) is located in North Dakota, about 20 miles upstream from Minot. This dam was built in 1936. Like the dams on the Missouri River, these dams along the Souris River were intended for multiple purposes, including agriculture, recreation, power generation and flood control.

The Saskatchewan Watershed Authority owns the Rafferty and Alameda Dams, and is directly responsible for their operation and maintenance. The Lake Darling Dam is owned and operated by the United States Fish and Wildlife Service (USFWS), but its operation is controlled by the USACE.

Figure 5. The Souris River Basin. Key water management and flood control dams include Rafferty and Alameda (in Canada) and Lake Darling (North Dakota).
Image from: http://www.ijc.org/conseil_board/souris_river/en/souris_home_accueil.htm

3. Event Overview from a Climatological and Historical Perspective

Antecedent Watershed Conditions

Prior to 2011, the most recent significant high water event in the Missouri Basin reservoir system occurred in 1997. At that time, the amount of water stored within the reservoir system was at or near record levels. Since then, generally drier seasons have prevailed. Between 1997 and 2007, reservoir levels at the three primary storage locations on the Missouri River (Ft. Peck, Garrison, and Oahe) dropped 51 feet, 47 feet and 46 feet, respectively, and overall water storage within those three reservoirs dropped by a total of over 36 million acre-feet of water. In essence, they went from record- to near-record levels in 1997 to record- or near-record minimum levels around 2007 (**Figure 6**). There were widespread water availability concerns during this period and flood management procedures were seldom exercised.

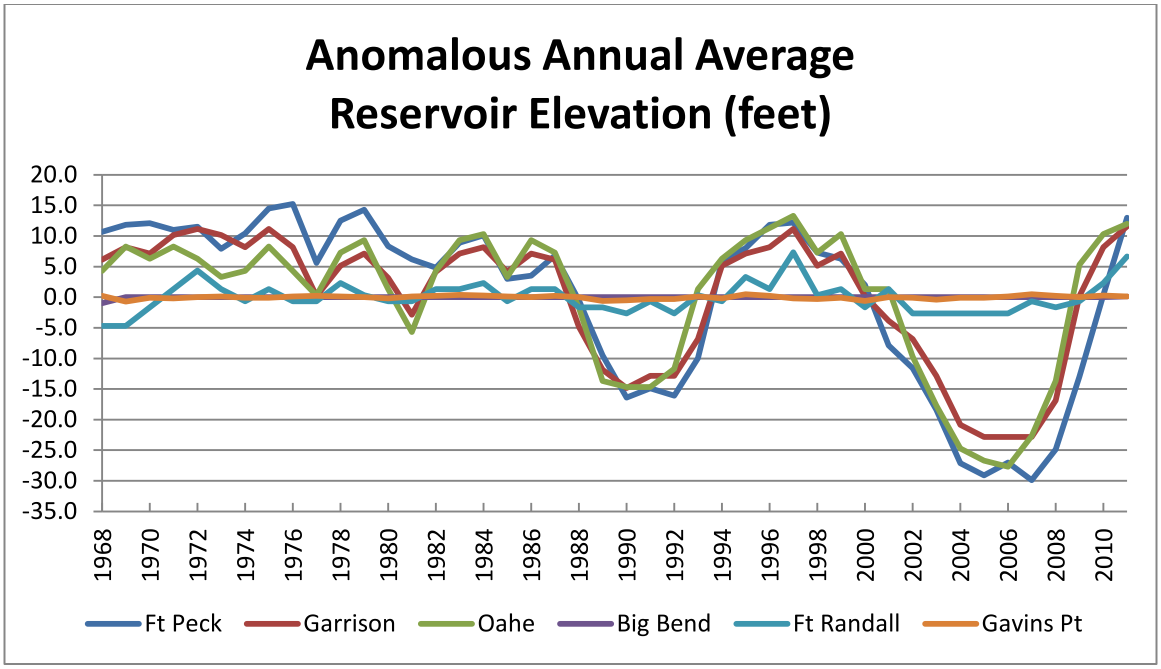

Figure 6. Historical Reservoir Elevation Anomalies within the Missouri River System.
Data from http://www.nwd-mr.usace.army.mil/rcc/information.html

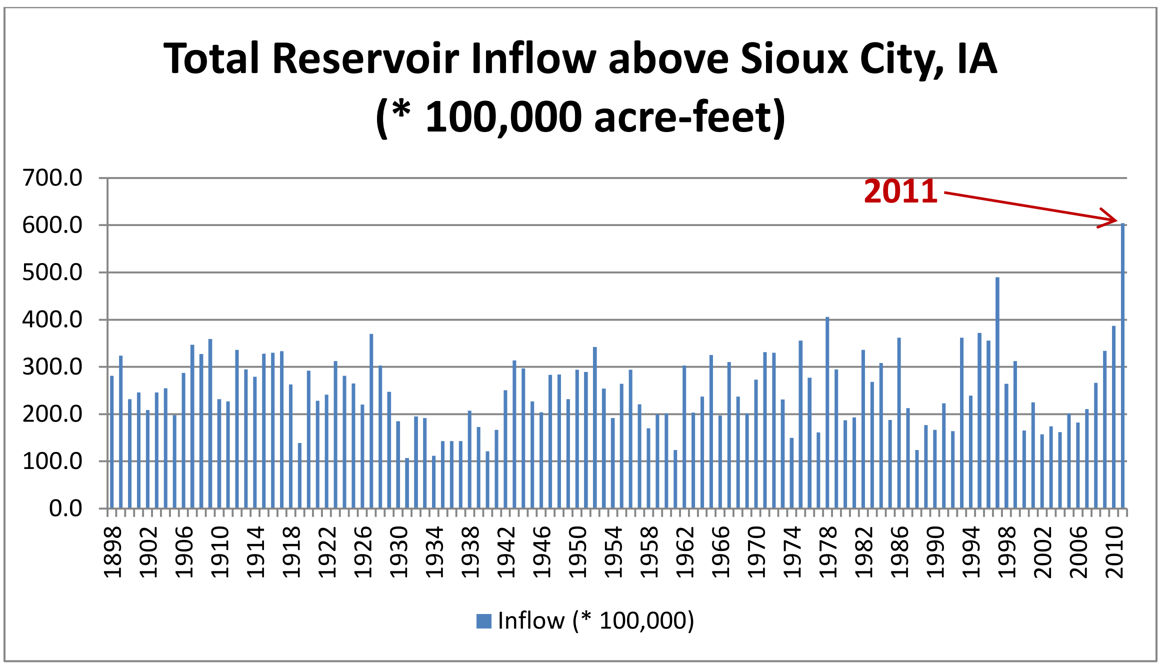

Figure 7. Historical Reservoir Inflow above Sioux City, IA.
Data from http://www.nwd-mr.usace.army.mil/rcc/projdata/system.pdf

Beginning in 2007, wetter conditions in the basin considerably increased water inflow into the mainstem reservoir system (**Figure 7**), which corresponded with increased reservoir storage (**Figure 6**) at the three primary storage reservoirs. Water storage within the entire 6-reservoir system reached normal levels as of August 2010. By the beginning of 2011, total reservoir storage was 4.6 million acre-feet (9.8%) above normal at the three primary storage reservoirs.

Prior to 2011, the Souris Basin in North Dakota experienced an even longer period of flood-free years. Specifically, flood stage for the USGS gage above Minot, ND had not been exceeded since 1979.

Antecedent Soil Moisture

Precipitation during calendar year 2010 across the upper Missouri and Souris River basins was well above normal (**Figures 8 through 10**), with North Dakota recording their wettest year on record from 1895-2010. This above normal precipitation resulted in soil moisture anomalies of 1½ to 4 inches (approximately 20 to 40%) above normal (**Figure 11**). The soils remained saturated throughout the winter freeze and into the spring.

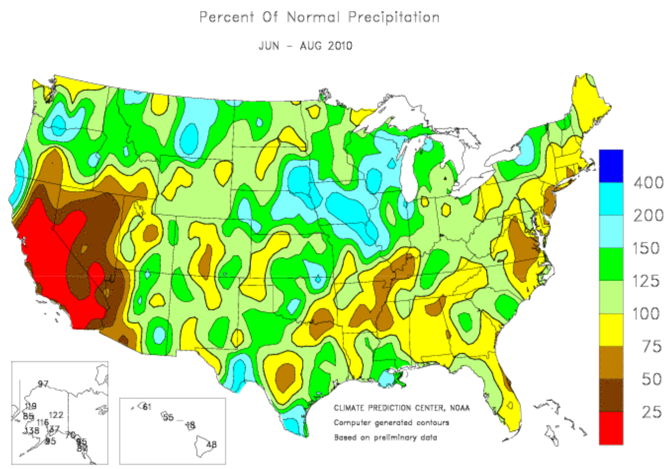

Figure 8. Percent of normal precipitation June-August 2010). ***Map from: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/usa.shtml***

Background Climate Setting

The development of La Niña in late summer and early fall of 2010 set the stage for a potentially active winter storm season (**Figure 12**). La Niña conditions persisted throughout the winter into the spring.

With La Niña in place, the storm track brought frequent snows to the mountain headwaters and plains of the Missouri and Souris River basins. Total precipitation over portions of the northern plains states during the winter and early spring was substantially above normal (**Figure 13**).

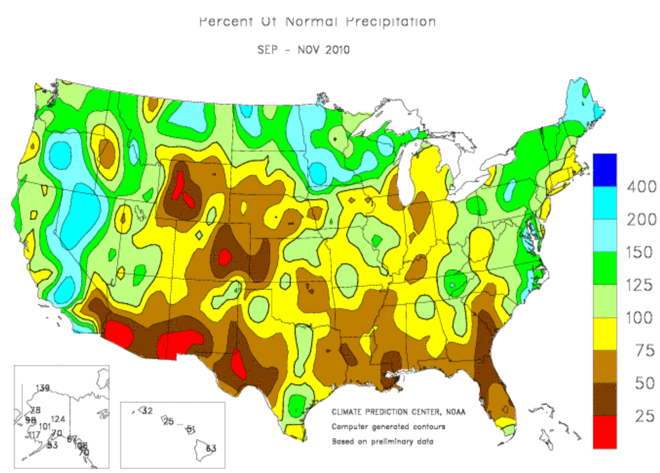

Figure 9. Percent of normal precipitation September-November 2010). ***Map from: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/usa.shtml***

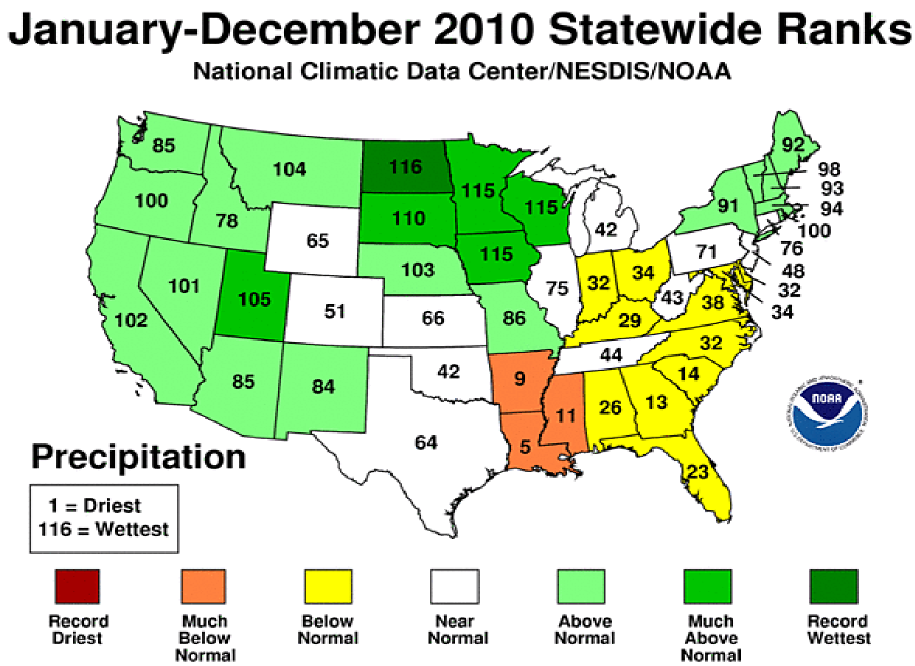

Figure 10. Calendar year 2010 statewide precipitation ranks from 1895-2010.
Data from NOAA/National Climate Data Center.

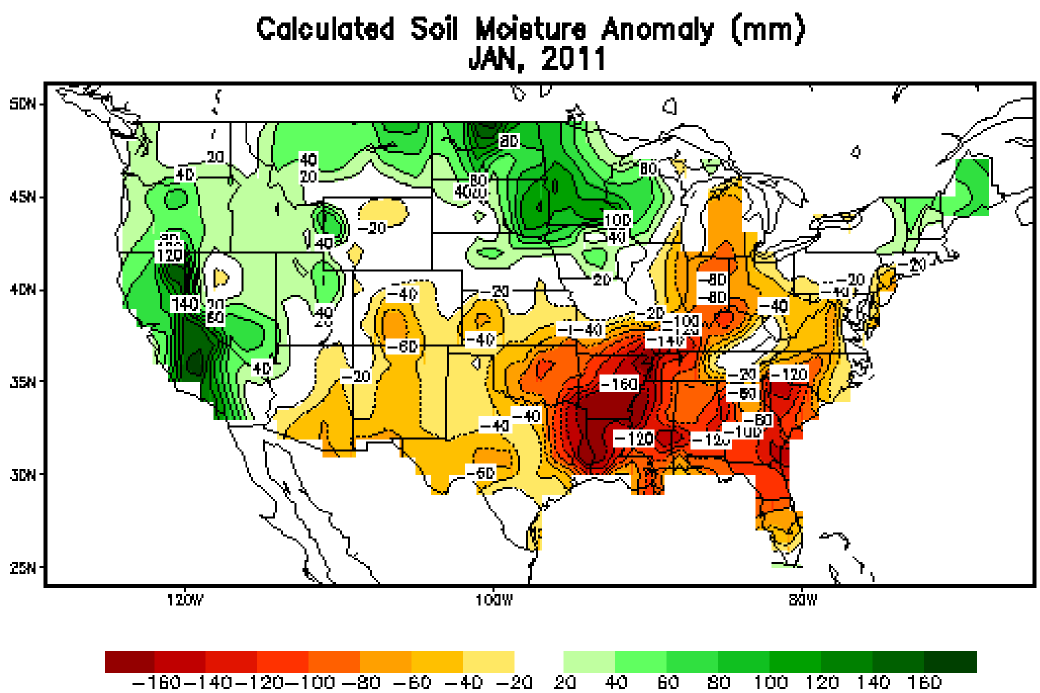

Figure 11. Calculated soil moisture anomaly as of January 2011 (in millimeters).
Data from NOAA at http://www.cpc.ncep.noaa.gov/soilmst/index_jh.html

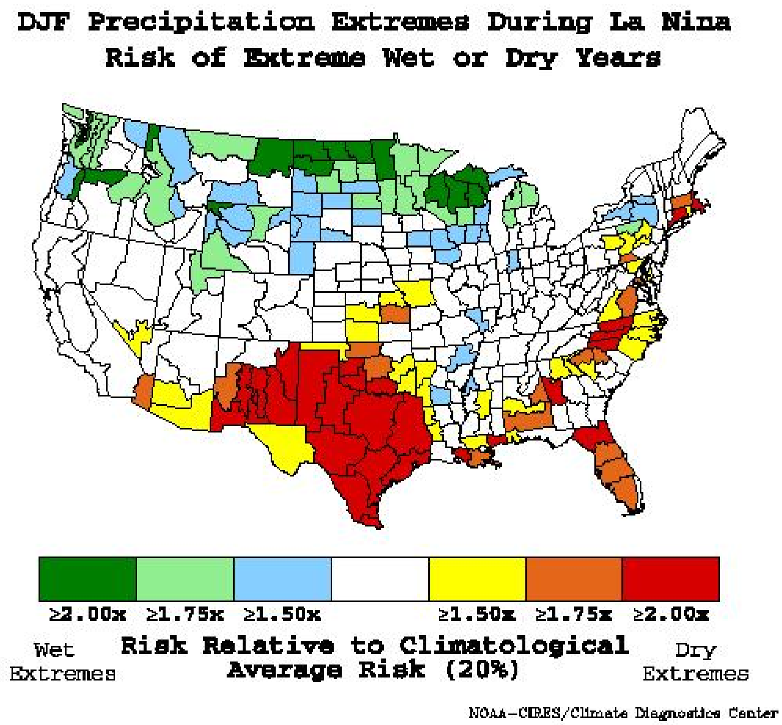

Figure 12. The risk of precipitation extremes during La Niña winter months (December-January-February). ***Image courtesy of NOAA/GSD.***

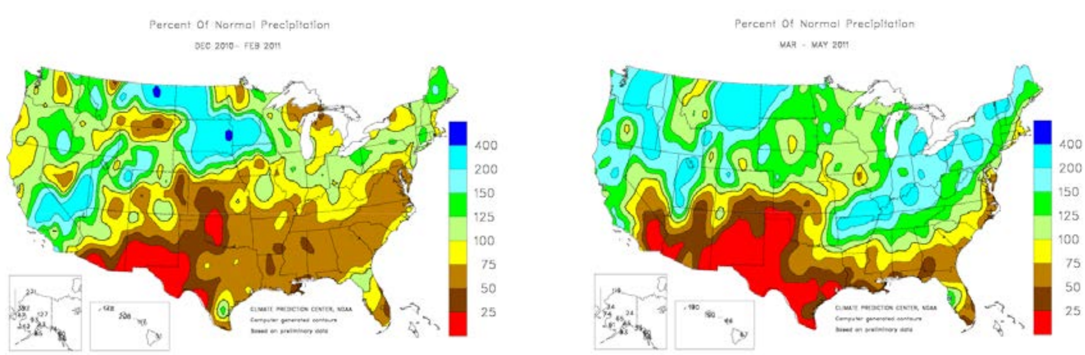

Figure 13. Percent of normal precipitation for the periods December 2010 – February 2011 (left) and March – May 2011 (right). ***Images courtesy of NOAA CPC; available at*****:** ***http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/archive/us/***

By the end of the 2010-11 snow season over the northern plains (late March/early April), total snowfall over the upper Missouri and Souris River basins was well above average. Many cities set new seasonal snowfall records during the season (**Table 1**).

Location	2010-2011 Seasonal Snowfall	Previous Record	Long-Term Average
Lewistown, MT (11ESE)	189.3”	137.9” (2008-09)	134.3”
Hinsdale, MT (4SW)	141.4”	70.8” (1998-99)	40.0”
Beulah, ND (2NW)	108.7”	81.6” (2008-09)	71.3”
Glasgow, MT	108.6”	70.7” (2003-04)	30.4”
Williston, ND	107.2”	94.7” (1895-96)	34.8”
Grassy Butte, ND (2ENE)	105.5”	54.7” (1988-89)	37.5”
Wibaux, MT (2E)	87.7”	67.5” (1981-82)	30.2”
Carter, MT (14W)	80.0”	70.2” (1988-89)	44.6”
Dodson, MT (2WNW)	77.0”	47.0” (1981-82)	17.4”
Sidney, MT	76.9”	75.5” (1978-79)	33.5”
Keene, ND (3S)	75.6”	70.1” (1996-97)	38.5”
Fortuna, ND (1W)	74.5”	65.0” (2008-09)	31.2”
Savage, MT	72.6”	69.5” (1974-75)	32.0”
Nashua, MT	70.5”	55.3” (2003-04)	21.1”
Port of Morgan. MT	61.2”	45.2” (2003-04)	19.3”
Culbertson, MT	54.9”	43.0” (1968-69)	22.2”
Great Falls, MT	108.6”	117.5”	53.9”
Raymond, MT	82.4”	83.5”	21.4”
Stanley, ND (3NNW)	81.4”	81.5”	42.3”
Tioga, ND (1E)	77.5”	80.7”	35.5”

Table 1. Cities with record or near-record snowfall during winter of 2010-2011. Long-term average is based on complete years included in the entire station record (from xmACIS).

Three major predictors typically influence runoff in the Missouri River basin: snowmelt over the plains, snowmelt from the mountain headwaters, and rainfall in the late spring and early summer. Each of these factors is considered separately below.

Plains Snowmelt

The first major component of water to enter the Missouri River each year is the melting snow across the Great Plains. Snowmelt over the plains was delayed due to the cooler than normal spring, but most of the snow had melted by mid-April. Inflow into Ft. Peck reservoir in Montana was 125-150% of normal during the winter season, and elevated inflow continued through April. According to NWS personnel and water management partners, the lower elevation melt resulted in minor to moderate flooding at many locations, and reached major flood levels at a number of sites. On April 20th, concern was raised within the water management community that reservoir levels were nearly full and there was a significant amount of mountain snowpack that had yet to enter the river system.

Mountain Snowpack and Snowmelt

Similar to the plains snowpack, mountain snowpack in the Missouri River headwaters accumulated at above normal rates through the winter and early spring seasons. However, unlike the plains, snow accumulation continued through April and into May.

Typically, mountain snowpack peaks in mid-April. However, in 2011, late April and May were extremely wet and cold, with mountain snowpacks building to record or near-record values. Peak snow water equivalent (SWE) values were observed near the beginning of May for many United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Automated Snowpack Telemetered Network (SNOTEL) sites as the mountain snowpack began to melt. On May 1, 2011, NOHRSC Snow Data Assimilation System (SNODAS) analysis showed snow water equivalent (SWE) averaged between 18 to 30 inches over much of the Missouri Basin mountain headwaters (**Figure 14**). This was corroborated by observations from the SNOTEL network operated by the NRCS that indicated the May 1, 2011 mountain snowpack was greater than 150% of normal in many portions of the northern United States Rocky Mountains (**Figure 15**).

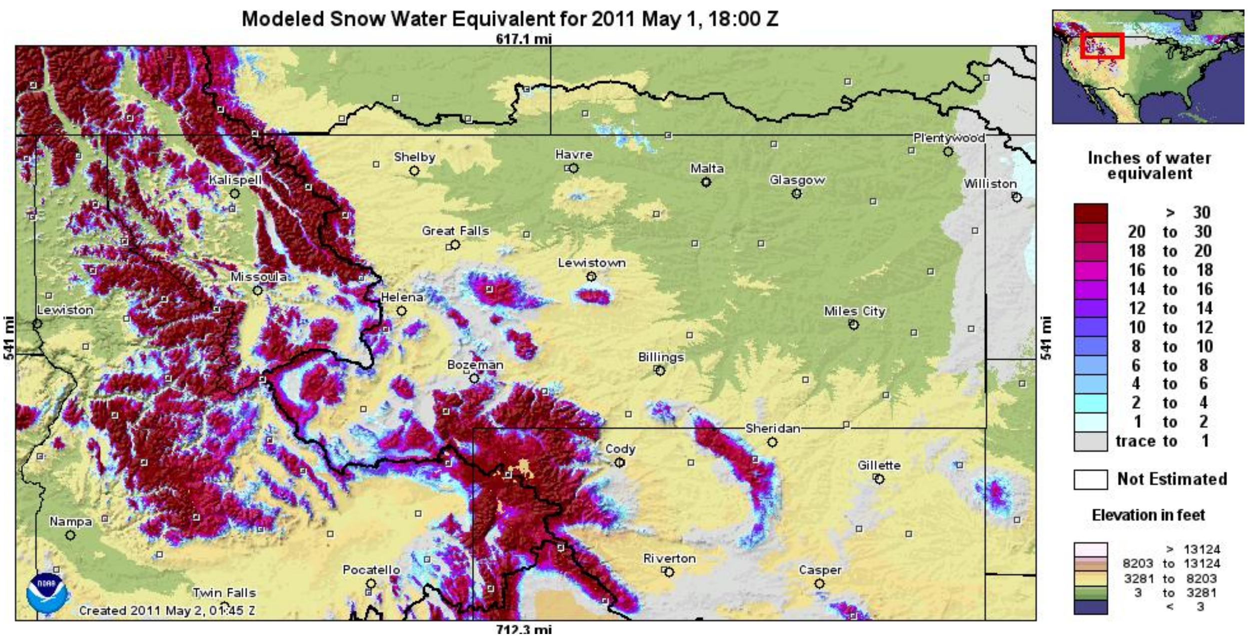

Figure 14. Modeled snow water equivalent for May 1, 2011.
Image courtesy of NOHRSC.

Snowmelt in the mountain headwaters of the Missouri River began in mid-to-late-May and continued through July (**Figure 16**). This was well past the typical "melt out" dates for many SNOTEL sites.

The extreme volume of melt water that emanated from the mountain snowpack caused significant flooding in some headwaters locations. This water was then added to the Missouri River reservoir system that was already near capacity.

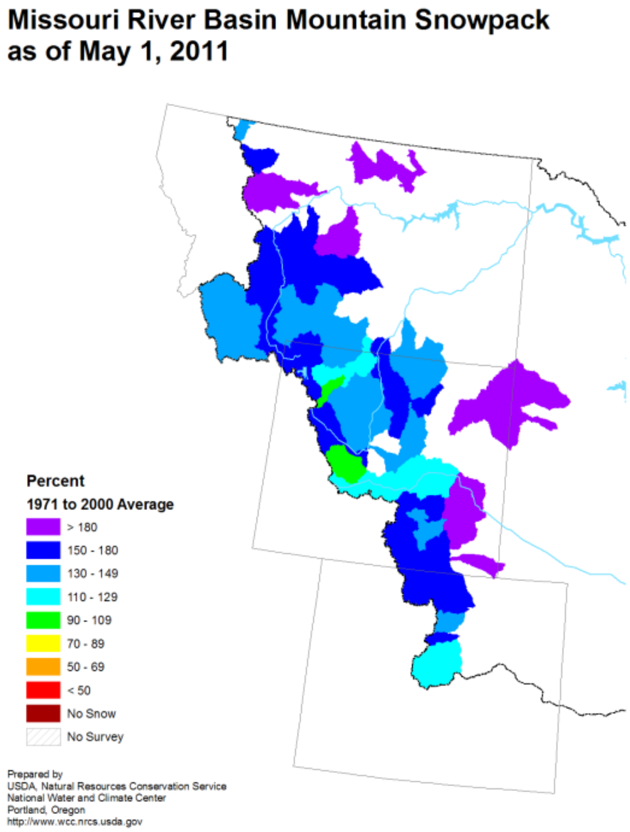

Figure 15. Percent of normal mountain snowpack on May 1, 2011.
Data from the USDA/NRCS National Water and Climate Center.

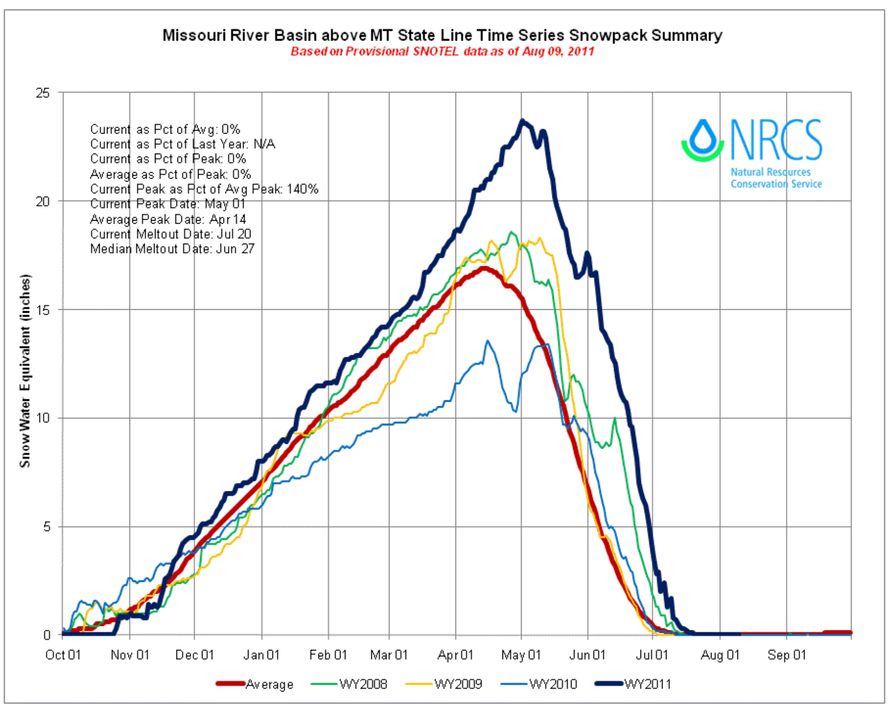

Figure 16. Observed and historical Snow Water Equivalent in the upper Missouri River basin. Heavy red line is the historical average; heavy dark blue line represents water year 2011.
Image courtesy of NRCS.

Spring Rainfall

Record rainfall in Montana, northern Wyoming and the western Dakotas occurred in late May. Combined radar-rain gage rainfall estimates in south central and southeast Montana tallied as high as 15 inches for the month (**Figure 17**), which is nearly 12 inches above normal. Most of eastern Montana received at least 300 percent of normal precipitation for the month of May (**Figure 18**).

The Missouri River headwaters continued to experience heavy rainfall into June (**Figure 19**), with precipitation anomalies of 3 to 8 inches above normal over portions of Montana, the Dakotas and Nebraska (**Figure 20**).

This extensive precipitation in May and June combined with runoff from the record snowpack to produce widespread flooding in eastern Montana. All of this water had to be conveyed through the Missouri River system. In particular, the precipitation events in late May caused the USACE to substantially revise reservoir management plans along the mainstem of the Missouri River in collaboration with the NWS.

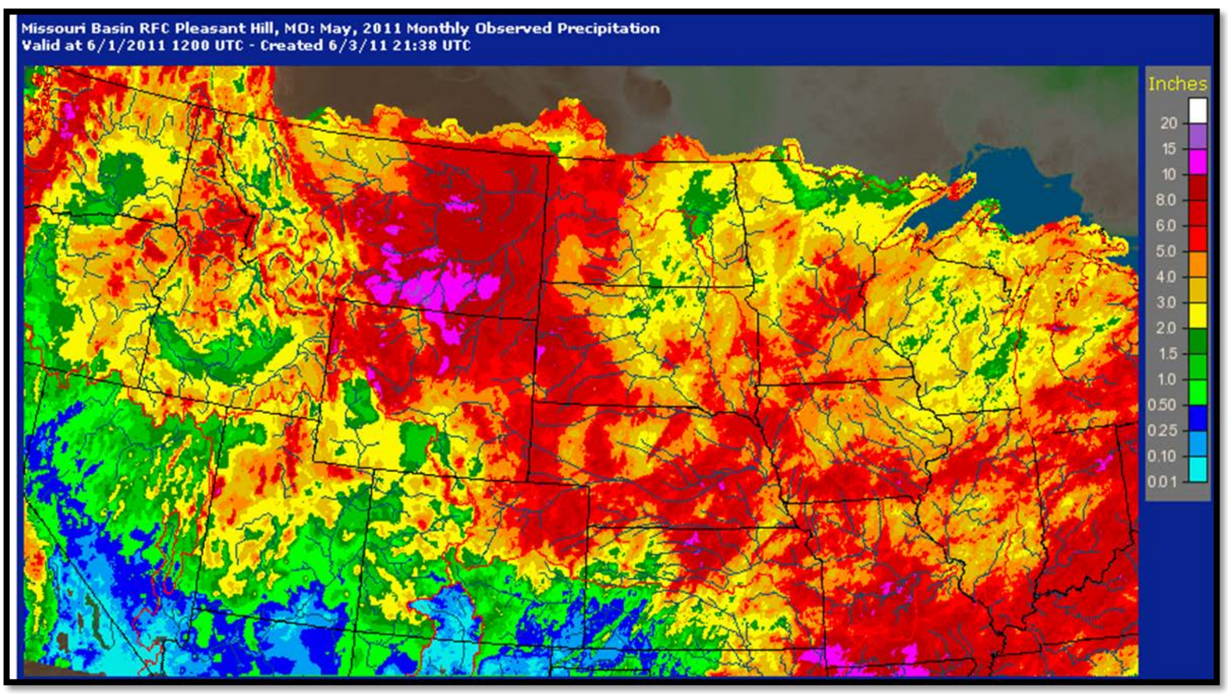

Figure 17. Radar-rain gage rainfall estimates for May 2011.

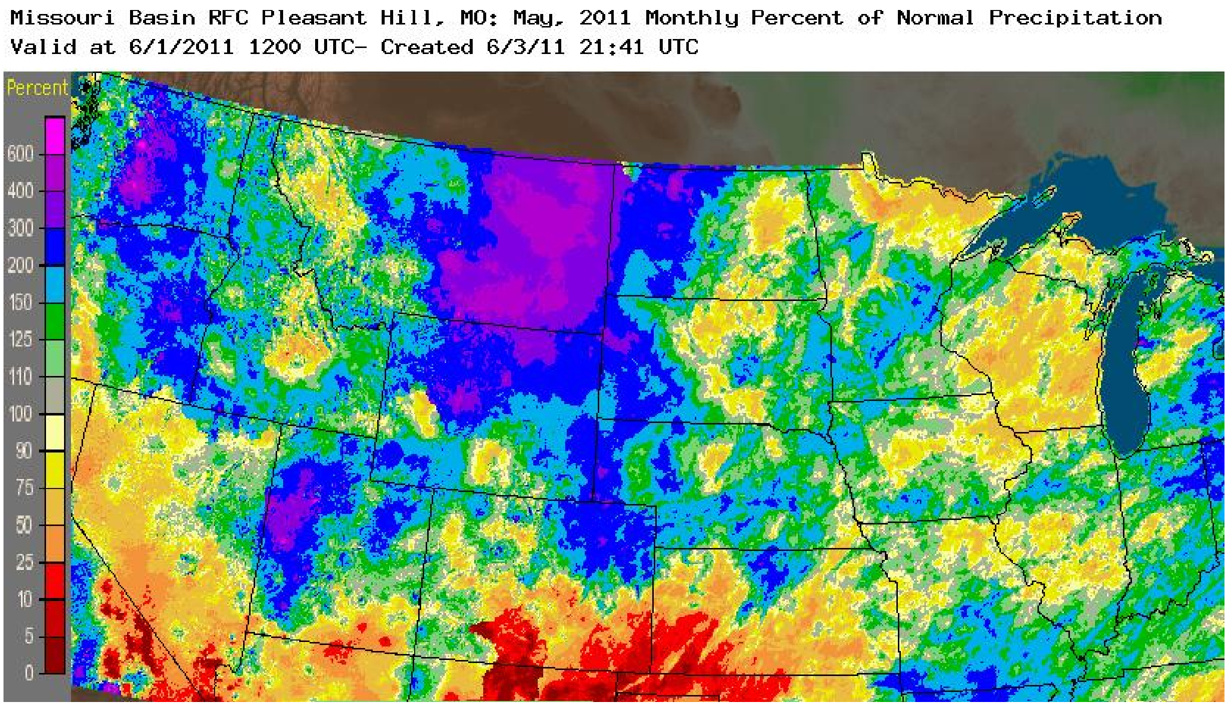

Figure 18. Radar-rain gage estimates of the percent of normal rainfall for May 2011.

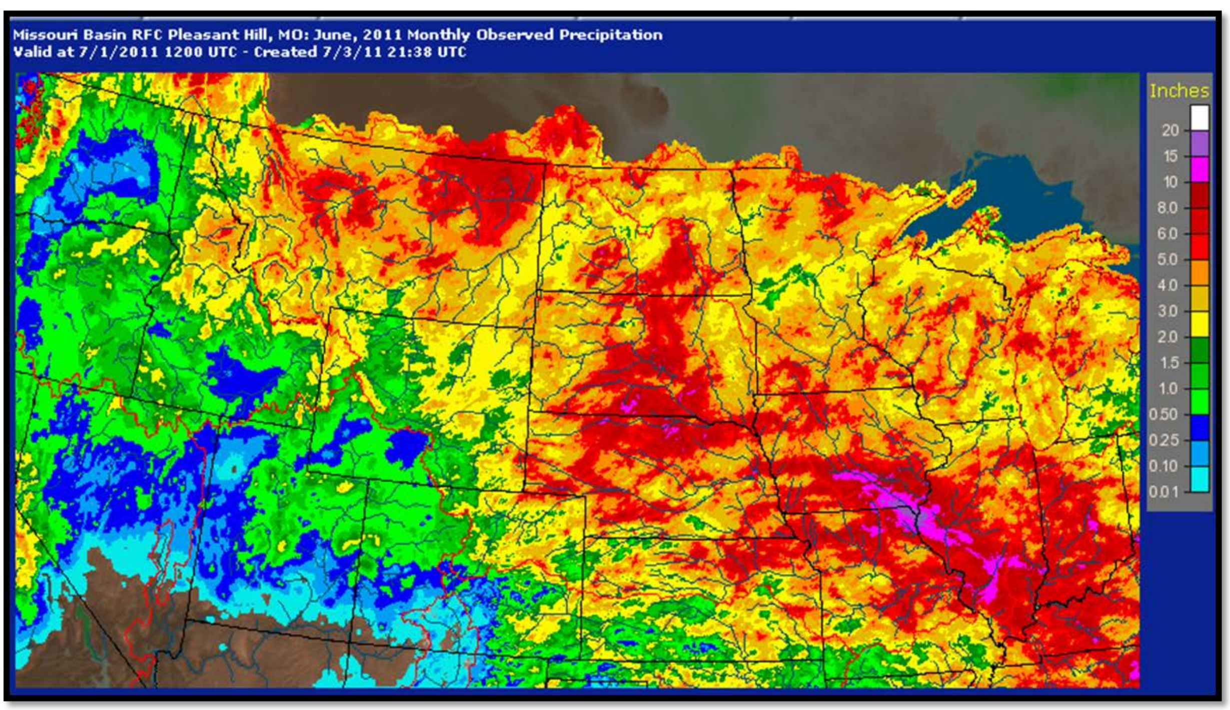

Figure 19. Radar-rain gage rainfall estimates for June 2011.

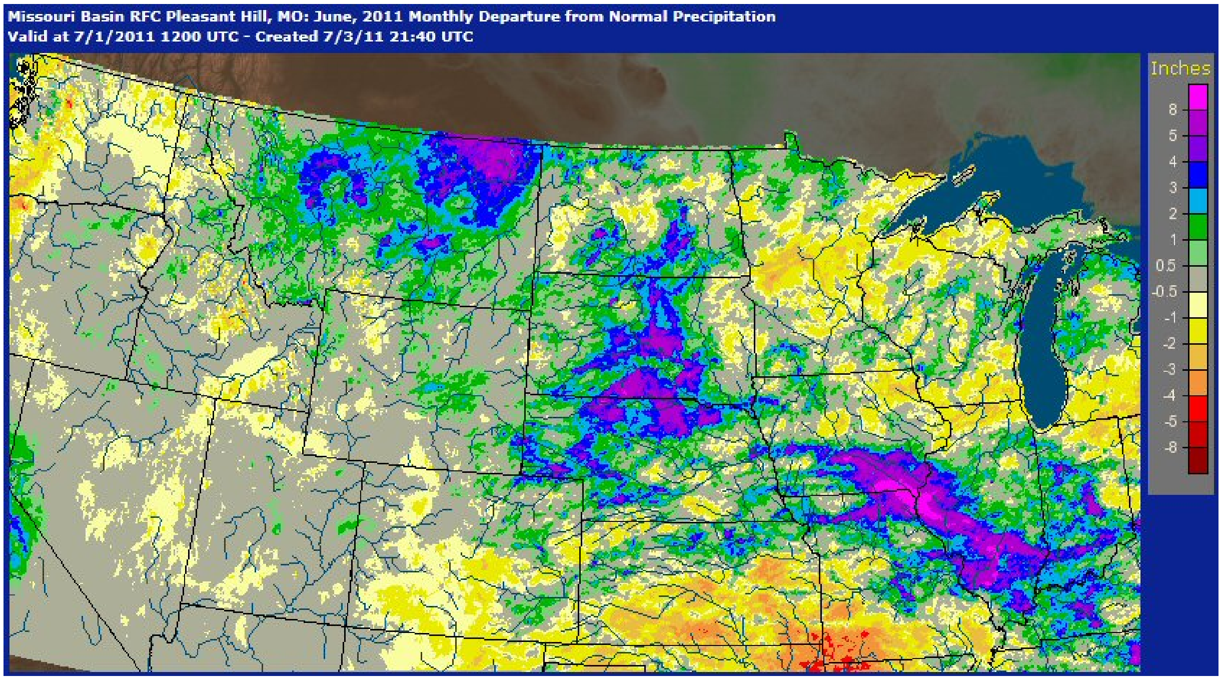

Figure 20. Radar-rain gage estimates of precipitation departures from normal for June 2011.

Summary

The Missouri and Souris watersheds had antecedent wetter-than-normal soils heading into the winter. Significantly above average snowfall over the northern Great Plains, including record-setting amounts across a large area in Montana and North Dakota, generated large amounts of runoff in the lower elevations, filling the reservoirs to near-record levels by the end of April (for that time of year). Mountain snowpack in the headwaters of the Missouri River was also much above average, and the melt was delayed until later in the spring and early summer. Record-setting and significantly above average rainfall fell across a large portion of the Missouri and Souris River basins in late May and into early June.

Runoff from the record snowpack and extreme precipitation events produced an unprecedented volume of water moving through the Missouri River Basin system. (Total inflow of water into the reservoir system for 2011 was estimated to have been 26% above the previous record of 49 million acre-feet, set in 1997). This volume of water overwhelmed the available flood storage in the mainstem reservoir system, resulting in record releases from all Missouri River reservoirs.

The large volume of water also contributed to the extreme duration of the flooding. At Gavins Point (**Figure 21**), releases topped the previous record of 70,000 cfs on May 28, 2011 and remained above that previous record until the end of August. Below Oahe Dam, the Missouri River at Pierre, SD was above flood stage from May 24th through September 7th, 2011.

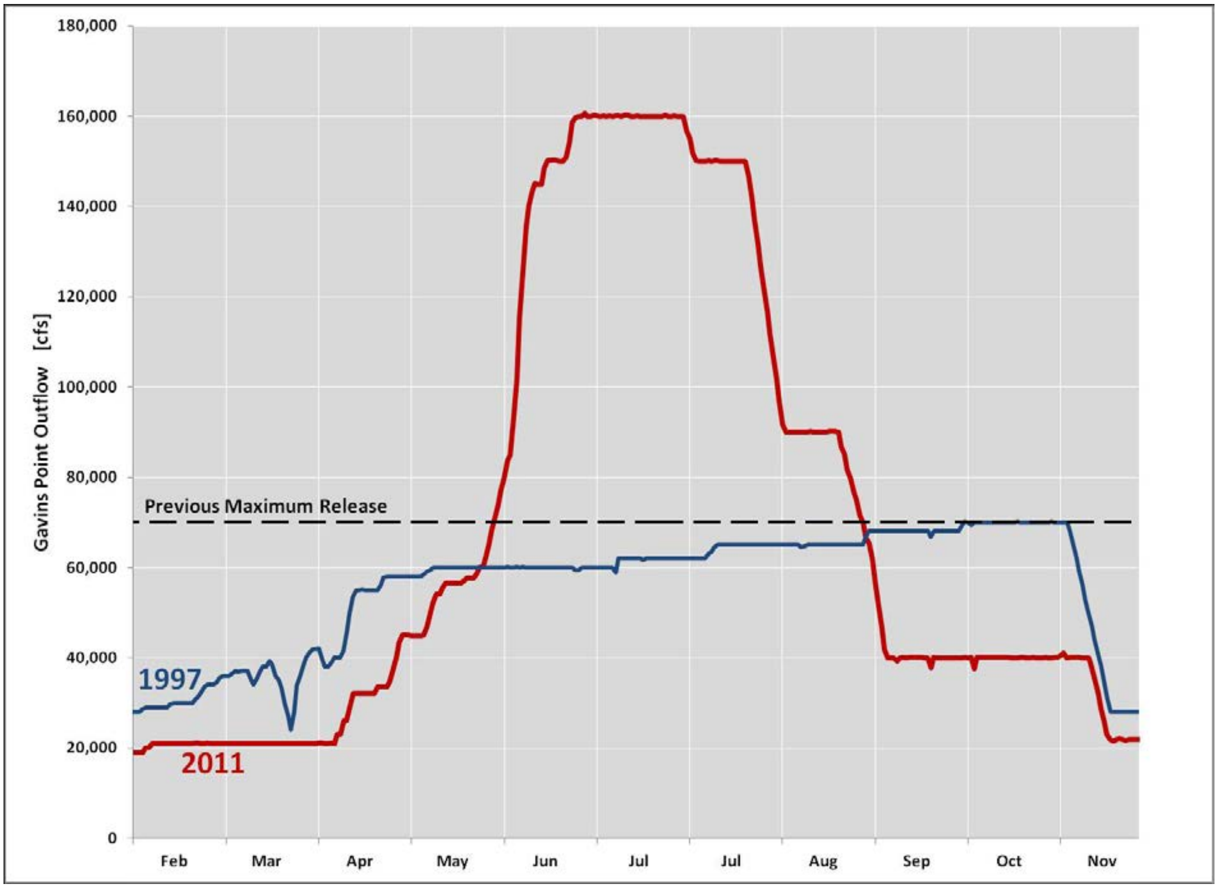

Figure 21. Rate of water release from Gavins Point Dam from May through November 2011 (red, in cubic feet per second). The previous record was 70,000 cfs in October/November 1997 (blue).

Below Gavins Point Dam, the record reservoir releases contributed to major flooding downstream on the Missouri River. The USGS Missouri River gage at Yankton, SD was above flood stage from approximately June 3rd through September 18th, 2011. The extreme amount of water flowing through the system also caused numerous levee breaches along the river. Some of these levees were overtopped completely, causing significant impacts in some areas.

In the Souris River watershed, the extreme precipitation and resulting runoff from already saturated soils produced record flows and devastating flooding. The peak flow of 27,000 cfs at the USGS river gage on the Souris River above Minot, ND was more than double the previous peak flow of 12,000 cfs that occurred in 1904, and nearly 5 times the flow from the flood event that occurred in 1979 (the previous peak flood event during the regulation era).

A timeline summarizing the key elements of the Missouri and Souris River flood events is provided in **Figure 22**.

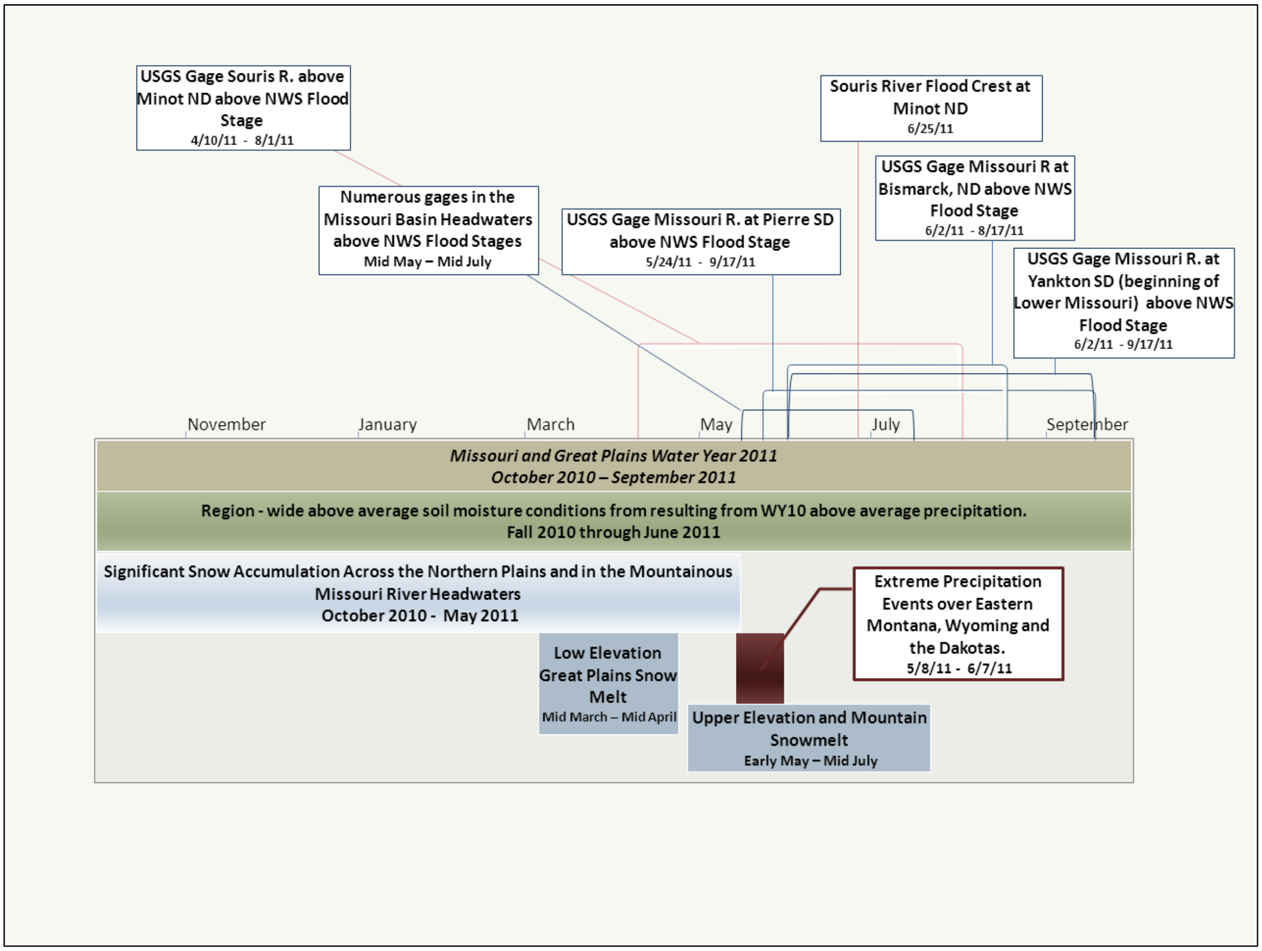

Figure 22. Timeline of key factors associated with the Missouri and Souris River floods.

4. Summary of Event Operations

River forecasting is a complex process involving many different offices, agencies and forecast models. In NWS operations, this process merges a diverse set of data (including observed and forecasted precipitation, temperature, snow cover) with reservoir operations, hydrologic and hydraulic modeling, and forecaster expertise. Considerable interagency efforts are needed to coordinate information on reservoir operations that impact the forecast, river measurements as they relate to the forecast, and to disseminate and describe forecasts to stakeholders.

Once all these complexities are optimally resolved in real time, there still exists the challenge of communicating the information clearly to those with critical interests, including state and local jurisdictions and the media, who help provide the information to the public.

This event impacted a large area of the United States. A majority of the flooding occurred in the Missouri River Basin (see **Figure 3**). River forecasts for this entire basin are supported through operations at the Missouri Basin River Forecast Center (MBRFC) in Pleasant Hill, MO. Official river forecast issuances for this area, including watches and warnings, are ultimately the responsibility of various WFOs throughout the basin.

The greatest concentration of major and record flooding in the MBRFC area of responsibility occurred along the mainstem of the Missouri River and in some of the headwater areas of the Missouri River. WFOs with responsibility for areas which experienced the greatest impacts included Billings, MT; Glasgow, MT; Bismarck, ND; Aberdeen, SD; Sioux Falls, SD; Omaha, NE; and Pleasant Hill, MO.

Additionally, record flooding occurred in the Souris River Basin. River forecasts for this area are supported through operations at the North Central River Forecast Center (NCRFC) in Chanhassen, MN, with official issuance responsibility by WFO Bismarck, ND.

4.1. Internal NWS Operations

Significant flood events create a substantial challenge for those offices with responsibility across the flooded area. This is true not only during the event, but before it as well, when preparedness work with agency partners is significantly increased. When the event is of long duration, lasting literally for months at a time, numerous challenges will arise in association with the additional event-related responsibilities.

This event was extreme in terms of its spatial extent and temporal duration. Supplementary river forecasts were added to the routine suite of hydrologic information. Partner collaboration increased at both WFOs and RFCs, which resulted in increased support activities. Decision Support Service (DSS) activities eventually became extensive and required significant resources at numerous EOCs. Many offices developed comprehensive briefing packages for partners on a daily basis, which required several hours of preparation each day.

Similar to the June 2008 central United States flood event (reference the *NWS Service Assessment* entitled, “Central United States Flooding of June 2008), strained staffing resources led to extensive overtime and personnel fatigue, especially as the duration of the event became prolonged. Some offices were challenged to an extreme level due to staff vacancies in their operational cadre of personnel. Many offices limited their ancillary program development work to focus efforts on ensuring quality services associated with flood event operations.

Within the NWS, extensive coordination and communication was required during this event, primarily between WFOs and RFCs. All offices involved in this event noted that this internal collaboration occurred on a frequent basis. Additional collaboration occurred with NOHRSC, HPC, and the NWS Central and Western Regional Operation Centers (ROC).

4.2. Interagency Operations

Because the Missouri and Souris Rivers are both regulated by partner agencies through their inline reservoir systems, significant collaboration is required between NWS offices and the partner agencies to produce accurate and consistent river forecasts. Relationships between the NWS and these federal and international partner agencies have existed for many years, and forecast collaboration is standard with these partners.

However, the process is more challenging during extreme events, when greater interdependence exists to make appropriate water-release decisions (from the reservoirs) and properly model those releases through the system. In this event, reservoir inflow levels were unprecedented, reservoir releases were more than double those previously experienced on the mainstem Missouri River, and rivers exceeded previously observed stages and associated stage-flow (rating curve) relationships at many gaged locations. Since RFC forecasts rely on rating curves, even greater collaboration was required by partner agencies to update stage-flow relationships beyond the upper limit of the existing rating curves.

Partner agencies are also responsible for levee management. A major flood such as this puts the existing levees at risk and also causes decision-makers to construct temporary levees in an effort to protect low-lying properties and infrastructure. Since the NWS river forecasting system routes water downstream, existing channel characteristics, including levees, are a critical component to the routing process. Changes in levees, including both levee enhancement and levee breaks, during the event create additional significant forecast challenges. Additional interagency collaboration is essential to account for these flow routing changes.

4.3. EOC Operations

NWS forecasts, including both river and weather forecasts, were an important component of local, state, and federal EOC operations during this event. Probabilistic river forecasts provided important information to EOC personnel well before any flooding occurred. This information was available on NWS web sites and was also communicated via webinar or conference calls.

During the event, short-range deterministic forecasts were relied upon by the emergency management community in their decision-making process. These forecasts may have been provided either off-site via conference call or webinar, or on-site via a personal briefing. Additionally, during the event when there were many workers supporting the flood fight on the ground, weather forecasts became critical when thunderstorm activity was expected, to ensure the workers were safe from lightning and other potential severe weather hazards.

EOC decision-making needs varied depending on a variety of factors, including the spatial extent of flooding in the EOC area of responsibility. Most NWS personnel supporting EOC operations developed and provided specially-packaged briefing materials which were specific to the needs of their EOC partners. This required a high degree of close collaboration with the EOC personnel to ensure their specific information needs were met.

4.4. Media Collaboration / Public Information

Media partners played a critical role in communicating flood forecast information to the public during this event. The Missouri and Souris River flooding garnered considerable local, state, national, and even international media interest, as flood waters breached levees, closed interstates, and prompted the evacuation of cities. Some WFOs were a part of live television press conferences on a daily basis. Working with media partners in an organized manner to ensure they had the information they needed to meet public information requirements had an additional workload impact on NWS staff.

Aside from communicating information to the public via the media, Advanced Hydrologic Prediction Service (AHPS) web pages were widely used by the public for access to the latest river forecast information. The availability of this information via the internet was likely a significant benefit to the public, as people were able to get the information they desired without directly contacting the NWS offices (or partner agencies).

4.5. Communication / Collaboration Tools

During this event, many different types of tools and technologies were used to communicate and collaborate with internal and external partners. Some examples of these technologies were webinars, conference calls, NWSChat (internal and external), 12Planet chat (internal NWS only), text messaging, email, and phone calls.

Emerging technological capabilities were used extensively by NWS offices to communicate information to partners, both as a communication conduit (e.g., NWSChat) and as a capability through which information was formally presented (e.g., webinars). Progress made in these areas has clearly improved the amount, quality and coordination of information provided to interagency partners.

Social media capabilities were incorporated into the communication suite as well during this event. Facebook, in particular, was used effectively by a number of offices to post and receive information (data and imagery) from a wide variety of public sources.

5. Components of the River Forecast Process

NWS river forecasts are produced through an interactive process where model results are interpreted and adjusted by RFC forecasters. This process integrates weather observations and forecasts, streamflow observations, water management plans, calibrated parameters, and forecaster expertise into a modeling system which quantitatively simulates and forecasts streamflow. A variety of models may be employed to simulate various processes in the hydrologic cycle. Other "non-natural" processes such as reservoir release schedules and diversions can be included as well. The National Weather Service River Forecast System (NWSRFS) was employed by MBRFC and NCRFC and was the centerpiece of the river forecast process during this event.

Relevant tools and procedures must be available and properly utilized to successfully complete the end-to-end river forecast process. Existence, availability, and utilization of data networks, quality control tools, relevant meteorological and hydrologic/hydraulic models, forecaster expertise, interagency collaboration, intra-agency collaboration, and forecast monitoring/updating are all critical elements of the process.

River forecast requirements vary from basin to basin. In addition, the forecast process itself varies among the River Forecast Centers. The following section is designed to identify key steps in the end-to-end river forecast process employed during the event. Specific details are included when necessary to provide insight or background to the reader. Although many procedural commonalities exist between the various offices, some differences exist. These differences will be highlighted when significant. Facts, findings and recommendations related to each step of the process will be identified, as appropriate.

5.1. Hydrometeorological Observations and Quality Control

Hydrometeorological observations (primarily precipitation and temperature) are critical to the river forecast process. They are foundational inputs to the river forecast models. Observation quality has a direct impact on the quality of the model simulation, the establishment of antecedent conditions (i.e., simulated snow water equivalent, soil moisture and river flow), and the forecast. Apart from the river forecast process, these datasets and graphics generated from them are frequently used for briefing partners. The importance of these data is evidenced by the amount of resources dedicated to accessing relevant networks and quality controlling the observations.

5.1.1. Precipitation

The River Forecast Centers (MBRFC and NCRFC) use the Multi-sensor Precipitation Estimator (MPE) to develop quantitative precipitation estimates (QPE). MPE facilitates the combination of 1-hour precipitation observations from rain gages, radar, and satellite estimates to develop a gridded best-estimate QPE. MPE also includes a technique which was developed to account for orographic enhanced precipitation in mountainous terrain.

Best-Estimate QPE is output in the form of grids and points. These quality controlled gage-based point estimates are passed to the NWSRFS for processing into basin Mean Areal Precipitation (MAP) values used by the hydrologic model (see **Section 5.3.1**).

NCRFC recognized significant gaps in their ability to estimate precipitation over portions of the Souris river basin using their routine MPE methodology, which relies on a combination of gage and radar estimates. Similar challenges were noted in the Missouri River basin as well, where rain gage data and radar coverage were insufficient.

Finding 1: NCRFC and MBRFC both experienced situations where data sources and networks currently used in their precipitation analysis did not sufficiently reflect information received from other available resources.

Recommendation 1: NCRFC and MBRFC should evaluate the potential utility of alternative precipitation sources [such as CoCoRaHS, SNOTEL and Satellite Precipitation Estimates (SPE)] in areas where the current gage-radar networks are insufficient and, where appropriate, adopt techniques to leverage all data sources in the development of observed MAP.

5.1.2. Temperature

Quantitative Temperature Estimates (QTE), in the form of instantaneous, maximum, and minimum temperature observations, are quality controlled by the RFCs. These data originate from multiple sources (ASOS, AWOS, COOP, SNOTEL, RAWS, etc.).

MBRFC and NCRFC quality control procedures for these data are much less "hands-on" than the precipitation analysis. These temperature observations are passed through automated range checking algorithms and manual evaluations which identify potentially erroneous data and remove it from the analysis. Values which pass the quality control criteria are forwarded to the NWSRFS to create Mean Areal Temperature (MAT) values (see **Section 5.3.1**).

5.1.3. River Stage and Stage-Flow Relationships

Observations of river stage and flow are reviewed and quality controlled using a combination of automated and manual processes. The data is first passed through a series of automated range checks. Other tools are used to manually review stage and flow observations. Erroneous data is removed from the forecast process.

The USGS is the primary provider of river gage ratings for MBRFC and NCRFC. The rating curves represent a singular stage-flow relationship used to translate stage observations into flow. The rating curve is also used to translate the simulated flow values from the hydrologic model into a local river stage forecast.

During this event, significant changes to rating curves were observed, increasing the uncertainty in stage predictions. Excessive sediment loads moving downstream in the main channel caused continual changes to the river bottom profile between the banks, while numerous overtopped and breached levee systems led to significant uncertainty in overbank areas. To account for these changes in stage-flow relationships, rating curves were frequently updated and made available by the USGS.

Both MBRFC and NCRFC run automated scripts nightly which download updated ratings from the USGS. Forecasters then review the updated rating curves and, if deemed valid, manually implement them into the operational system. In several instances, this forecaster review and implementation process took weeks or longer at MBRFC.

As a result of these delays, there were times when the updated USGS rating curves were not consistent with those depicted on the NWS AHPS web site. This caused confusion among WFO personnel and their stakeholders.

Fact: The timetable for review and implementation of USGS rating curve updates is left to the discretion of individual forecasters at MBRFC.

Finding 2: At times, the review (and implementation, as appropriate) of updated USGS rating curves was not completed at MBRFC for weeks. This led to inconsistencies between published NWS and USGS stage-flow relationships, which created confusion among some partners.

Recommendation 2: MBRFC should adjust their rating curve update procedures to expedite the review (and implementation, as appropriate) process.

The record flooding levels along the Missouri River presented a number of additional challenges to the typical rating curve process. During this event, uncertainty in the forecast increased at numerous locations when the river level exceeded the maximum value depicted on the rating curve.

Fact: Rating curve extensions were provided by the USGS; however, they contained a considerable level of uncertainty.

Fact: Confidence in river forecasts decreased as the stage-flow relationships became dependent on the extended ratings provided by the USGS.

Water surface elevations, as measured by the stage height near the confluence of rivers, can be significantly impacted by the streamflow of adjoining rivers. Hydrologists often refer to this phenomenon as backwater-effects.

Accurately forecasting water surface elevation or stage at sites which experience backwater effects is a challenge. While hydrologic models are used to simulate flow at these points, the standard stage-flow relationships are not valid in backwater-affected flow regimes. Forecasters must augment the hydrologic models with other techniques (e.g., backwater curves) when river conditions include changes to stage that are not necessarily related to changes in flow.

Fact: MBRFC forecasters indicated that use of backwater curves often requires significant manual interaction in the forecast process to produce reasonable results. They also indicated that many of the curves need to be updated.

Although backwater curves can be quite useful and accurate at times, hydraulic modeling would employ a more dynamically robust approach.

Finding 3: The hydrologic modeling techniques currently employed by MBRFC do not adequately simulate backwater affected river stages.

Recommendation 3a: MBRFC should consider implementation of a hydraulic model, such as the Hydrologic Engineering Center River Analysis System (HEC-RAS), for portions of their area of responsibility where backwater effects adversely impact the quality of the river forecast.

Recommendation 3b: MBRFC should augment current hydrologic modeling procedures by updating or developing backwater curves for affected sites. This would serve as an interim solution until hydraulic modeling can be implemented.

5.1.4. Snow Water Equivalent

One of the important parameters used to determine whether an area will experience significant flooding (major to record) is the amount of water contained in the snow pack. This is also one of the more difficult parameters to quantify (measure and/or estimate).

SWE observations are widely used as quantitative and qualitative indices for hydrologic response. In the absence of rainfall, the volume of snow within a basin is the most influential factor for determining the volume of runoff. Snow observations, therefore, serve as critical "ground truth" for simulated SWE comparisons within hydrologic models.

At critical times, SWE estimates within a basin can be reasonable indicators of expected spring runoff volume and peak flow. Because relationships can be developed using just SWE, volume, and peak flow, water resource managers regularly use SWE in their planning processes.

The primary sources for SWE information during this event were SNOTEL, COOP, and independent observations, NOHRSC gamma flight line surveys, and SNODAS simulated SWE. The observational data is sparse in some areas and not always representative of basin-wide conditions. SNODAS information was used extensively to fill in data gaps in many locations.

Fact: In general, WFOs, RFCs and their partners valued the NOHRSC SWE information.

Finding 4: Simulated SWE information was present in the RFC hydrologic modeling systems, but was not routinely available for use by WFOs and their partners.

Recommendation 4: MBRFC and NCRFC should consider providing simulated SWE information with their river forecasts for use by all stakeholders.

5.2. Meteorological Forecasts for Hydrologic Models

Precipitation, particularly during late May 2011, was an extremely important driver for the flooding that occurred on the Missouri River. Water management strategies were greatly impacted by the extreme precipitation that fell across the northern High Plains. The predictability of synoptic-scale storms, in general, and this event, in particular, presented an opportunity for the NWS to engage with water management stakeholders to more effectively use QPF and QPF-based streamflow forecasts to inform decision making before, rather than after, the precipitation event.

Temperature forecasts can have a dramatic impact on the timing and peak of hydrologic model simulations. These forcings are key factors in driving the ripeness of simulated snowpack and the resulting runoff. Temperature also determines precipitation type (snow vs. rain), which can also have a great impact on forecasted flows.

The following sections describe these meteorological forecasts and how they are provided to the hydrologic modeling system.

5.2.1. Quantitative Precipitation Forecasts (QPF)

There were three primary sources of QPF available within the NWS for this event: HPC, WFO, RFC. These gridded forecast products can be independent, but are often developed from one another.

HPC generates QPF at various temporal and spatial scales, and in both deterministic and probabilistic formats. For the purposes of this assessment, we will limit discussion to those forecasts that are most relevant to this event. Day 1-5 HPC QPF is produced at 6-hour time steps, and is available both graphically and in gridded format. The products are created on spatial scales that extend throughout the contiguous United States and into bordering areas of Canada and Mexico. These forecasts are often used by WFOs and RFCs to produce more detailed, downscaled QPF. Another specific HPC forecast used by MBRFC and NCRFC is the 95% and 5% probabilistic maximum/minimum QPF for 24, 48, and 60 hours.

WFOs generate 72 hours of QPF at 6-hour time intervals as part of their routine gridded forecast package. These forecasts are combined into a national mosaic in the National Digital Forecast Database (NDFD). These forecasts are used extensively (and often, explicitly) by the RFCs as input to their hydrologic models.

MBRFC and NCRFC use various combinations of WFO and HPC QPF to produce forecast precipitation input for their hydrologic models. Depending on the staff profile of a particular shift (e.g., when a Hydrometeorological Analysis and Support (HAS) forecaster is present), the RFC may make modifications to the WFO and HPC forecasts. The RFC QPF is also available to the public via the internet.

Due to the antecedent conditions in the basin during this event, the hydrologic models were very sensitive to QPF. Stakeholders, including USACE, FEMA, and state emergency management personnel, understood the significance of these forecasts. Therefore, QPF was the subject of many discussions and was routinely incorporated into the DSS briefing process. At various times, all three QPF products (i.e., HPC, WFO and RFC) were used to brief stakeholders. Each of these products had a limitation (spatial extent, temporal extent, or relevance to the official hydrologic forecast) which necessitated the use of an alternative QPF presentation.

The stakeholders desired a continuous 5-day product that spatially spanned the entire basin, and was used in the hydrologic model. None of the three QPF sources consistently satisfied all of these briefing requirements. HPC QPF was limited due to its coarse resolution and inconsistent use in the hydrologic models. WFO QPF was limited in its spatial and temporal extent, visual QPF differences between adjacent WFOs, and the uncertainty as to whether it was explicitly used in the hydrologic models. RFC QPF was limited by the inconsistent availability of a 5-day QPF product.

Fact: Recommendation 8 from the NWS Service Assessment for the Nashville, TN flood event (2010) noted that "RFCs should communicate in detail their use of QPF and QPE in generating river forecasts to…critical partners."

Finding 5: Individually, the three available QPF products (i.e., HPC, WFO and RFC) did not consistently meet partner DSS needs with regard to spatial/temporal extent and relevance to the official river forecast. Consequently, NWS personnel used multiple QPF sources within their DSS briefings, which resulted in some confusion among the stakeholders.

Recommendation 5: NWS DSS personnel should utilize a QPF briefing product which independently meets all the spatial, temporal and relevance criteria needed by the stakeholders.

Nearly all stakeholders had strong opinions regarding the skill of QPF, but virtually none had seen or conducted any formal verification of these forecasts. The NWS has extensive QPF verification capabilities throughout the agency (e.g., HPC, the National Precipitation Verification Unit (NPVU), RFCs, WFOs, etc.).

Finding 6: Most stakeholders had opinions – often strong and negative – about QPF skill, although their conclusions were not based on quantitative scientific evidence. To improve partner confidence in the use of QPF and maximize its benefit in the hydrologic forecast process, there is a need to educate stakeholders regarding its strengths and limitations.

Recommendation 6: The NWS (WFOs, RFCs and HPC) should include QPF verification as part of its routine stakeholder outreach and engagement activities.

5.2.2. Temperature Forecasts

Temperature forecasts arrive at the RFCs in the form of WFO grids. Seven days of maximum and minimum temperature forecast grids are sampled at specific points in the hydrologic calibration process and transferred to NWSRFS for additional processing. MBRFC and NCRFC can view and adjust these temperature forecasts, when appropriate.

Interaction with these grids by MBRFC or NCRFC forecasters is rare. RFC personnel noted that adjustment of these grids by RFC forecasters was not deemed necessary during this event.

5.3. Hydrologic Modeling / Analysis

At the time of the event, the Community Hydrologic Prediction System (CHPS) was not operational at MBRFC and NCRFC. Although certain functions of CHPS were implemented and available for testing at these RFCs, they both utilized NWSRFS to produce their official river forecast information.

5.3.1. Forcings – Areal Analysis (MAP/FMAP, MAT/FMAT)

The hydrologic models used by MBRFC and NCRFC require meteorological forcings (precipitation and temperature) in the form of mean areal time series over the basins and elevation zones modeled by the RFC (MAP, FMAP, MAT, FMAT; see Appendix C for definitions). The observed and forecast precipitation and temperature data (points and grids) are used to produce the mean areal values. These time series are required inputs for the observed and forecast period of the model simulation. The precipitation time series controls the moisture input to the modeling system while the temperature time series influences precipitation type and the rate at which snow melts. These time series represent an areal averaged value for an entire basin or sub-basin area at six hour time steps. NWSRFS includes pre-processing software (MAP, MAT) which is designed to produce these time series and link them to the appropriate basins.

5.3.2. Model State Review / Adjustments

Certain activities in the production of hydrologic forecast information do not require a vast amount of direct forecaster interaction. For these activities, review of inputs and the final output are often adequate to produce the desired result. Other activities require intermediate forecaster review and intervention at various steps in the process. This forecaster interaction is a critical activity.

The proper simulation of SWE in the model was a critical process during this event. It not only impacts short-term forecasts, it is also the primary model state driving long-term ensemble and volume forecasts. MBRFC and NCRFC have established local snow updating procedures which evaluate model simulated SWE.

At MBRFC, the simulated SWE is routinely compared on a weekly basis to an alternative computation of SWE which utilizes point snow observations (primarily from SNOTEL networks) with a calibrated weighting scheme. Comparative procedures which utilize snow depth observations and estimated densities were used as well. Deviations between simulated SWE and the alternative estimates were investigated by the forecasters. Modeled SWE values were adjusted accordingly, if deemed appropriate. NCRFC employs a similar process. NOHRSC simulated SWE grids were also used qualitatively by both RFCs to corroborate or adjust snow model states, when required.

5.3.3. Other Hydrologic Modeling Issues

Model input is often derived from real-time data networks which are inconsistent regarding quality and availability. Even well calibrated hydrologic models require modifications to simulated states when these data are utilized. This extreme event has exposed some hydrologic modeling issues that extend beyond the requirement for minor real-time adjustments to hydrologic simulations. The next three sections will detail some of these issues.

5.3.3.1. Calibration

MBRFC and NCRFC reported several modeling challenges regarding the simulation of snowmelt, river routing, and rainfall runoff. The onset and rate of snowmelt at many forecast points were not simulated reasonably and required significant adjustments by MBRFC forecasters to produce acceptable results. Diurnal fluctuations in streamflow due to natural snowmelt processes, particularly in high elevation basins, were not simulated adequately by the snow and soil moisture models. In addition, river routing techniques at several sites did not produce accurate simulations at downstream forecast points.

The routing model parameters for the Milk River (northeast Montana) were found to be invalid for high flows and had to be adjusted by MBRFC forecasters during the event. Changing calibrated routing parameters during an event is a rare activity, but was required in this situation.

Routings on the Souris River were based on historical records and proved to be in error at the peak flow. A dramatic departure from observed travel times (with observed speeds that were approximately twice that produced by the model) occurred once the valley storage was filled.

Aerial reconnaissance by the USACE indicated that the entire floodplain had been inundated and the normal channel sinuosity was gone, thereby allowing water to flow linearly through the valley at a much greater rate than any event in the observed record. Once this physical phenomenon was identified, forecast crest timing at Minot was revised accordingly.

Finding 7: MBRFC and NCRFC did not have adequate tools to anticipate and account for the shortened flow path of the Milk and Souris River channels, respectively, as their natural sinuosity became submerged.

Recommendation 7: MBRFC and NCRFC should investigate additional routing techniques (including hydraulic models) to account for situations where the river channel flow path is shortened as its natural sinuosity is submerged.

Runoff resulting from rainfall events was quite difficult to predict in the western plains basins of MBRFC and NCRFC. Model calibrations for these forecast points were developed using historical precipitation networks that are much too sparse to adequately represent basin rainfall. The lack of significant historical rainfall events also made it difficult to develop reasonable soil moisture model parameters during the calibration process.

Finding 8: The extreme nature of this event produced hydrologic conditions that were not previously observed at several sites and, therefore, were not part of the historical datasets used in the hydrologic model calibration process. Consequently, some of the hydrologic model configurations contain calibrated parameters that were not valid during this event.

Recommendation 8: MBRFC and NCRFC should use observations from this event to evaluate the validity of their current hydrologic model parameters and configurations. Simulations which perform unacceptably should be recalibrated, as appropriate.

5.3.3.2. Reservoir Operations

The presence of reservoirs adds uncertainty and complexity to the river forecast process. These impacts are directly related to the reservoir capacity, purpose, location, predictability of operating plans, and the effectiveness of the real-time communications regarding regulation strategies between the operating agency and the RFC.

There are hundreds of small, mainly privately-owned, reservoirs within the Missouri River basin which have very limited impact on the flow at downstream forecast points. These reservoirs are not included in the river modeling configuration.

Larger reservoirs can have a significant impact on the flow at downstream forecast points. This is particularly true if the operators store and release water in a way that deviates markedly from natural hydrologic responses. Most of these projects are operated by large utility companies or government agencies such as the USACE or USBR. Many of these reservoirs are included in the MBRFC modeling configurations.

MBRFC has established collaborative relationships with the USACE and USBR regarding the exchange of reservoir inflow forecasts and projected releases. These relationships and processes will be detailed in **Section 5.5.2** (Interagency Collaboration). The inclusion of these projected releases in the generation of downstream forecasts added value and was critical during this event.

Operator-provided real-time release projections were not available for all significant reservoirs during this event. MBRFC has an ongoing project in which they are attempting to “calibrate” reservoir operating rules based on historical events (referred to as regulation modeling). The calibration results are reasonable for years where hydrologic conditions are near normal. However, water management strategies are much less predictable (i.e., difficult to calibrate) in extreme years (wet or dry). RFC forecaster intervention was frequently required to produce more reasonable results at points downstream of these reservoirs during this event.

The lack of regulation modeling in the Upper Missouri and its tributaries created challenges for river forecasters as they were forced to estimate future reservoir releases with little guidance. Forecast quality at points downstream of these reservoirs often suffered as a result of these estimates.

Reservoir operations can also impact the validity of long-range probabilistic forecasts (described in **Section 5.4.3**). The exclusion of reservoir modeling in the Upper Missouri and Bighorns, and the non-representative regulation modeling in the North Platte created unrealistic probabilistic forecasts during this event. Due to poor forecast quality, MBRFC chose not to release this information during the event.

NCRFC has configured complex reservoir operations to model the system upstream of key forecast points on the Souris River. Operational rule curves have been developed and implemented through collaboration with Canadian and USACE representatives. These configurations were used effectively for short-term deterministic and long-term probabilistic forecasts during the event.

Finding 9: MBRFC has several forecast points which are affected by upstream reservoirs that are not modeled adequately.

Recommendation 9: MBRFC should add reservoir models, as needed, at sites affected by upstream reservoirs, and investigate options for establishing better projected release schedules. This includes collaboration with the reservoir operators and reservoir modeling for short-term deterministic and long-range probabilistic forecasts.

5.3.3.3. Levee Failures

Nearly all overbank areas downstream of Omaha, Nebraska on the mainstem Missouri River are protected from high water by an extensive network of levees. There are numerous federal and private levees through this stretch of the river, with federal levees typically producing a higher degree of protection (e.g., the one percent exceedance probability flood) than non-federal levees. During the 2011 flood event, every non-federal levee from Rulo, Nebraska to Kansas City, Missouri (approximately 90 miles downstream from Rulo) was either overtopped or breached, diverting water out of the main river channel and presenting a significant forecast challenge for MBRFC.

MBRFC uses hydrologic routing to compute future flow time series at forecast points on the mainstem Missouri River. These flows are then converted to stages using rating curves at each location. However, this method has no means of explicitly modeling or accounting for water diverted out of the river channel (or, when the river is subsiding, releasing water back into the channel) when a levee is overtopped or breached.

Forecasters at MBRFC, with no modeling tool available, used forecaster judgment to account for the significant flow diversions caused by levee failures. One primary method attempted to correlate the drop in stage to a corresponding decrease in river flow using the rating curves extrapolated for that location. However, this tended to significantly overestimate the impact of the levee breach. Since the flow reductions caused by the levee breach were manually derived, their impact also had to be manually propagated downstream. On average, the forecasts again overestimated the impact of the levee failure at forecast points downstream. The result of these manual estimations was frequent updates to forecasts during a levee breach, with significant changes.

Finding 10: MBRFC is in the process of cooperatively developing a HEC-RAS model for the lower Missouri River with the Kansas City District of the USACE. This unsteady, fully dynamic model has the capability of modeling the impact of levee overtopping and breaches.

Recommendation 10: The mainstem Missouri River HEC-RAS model, currently being developed by MBRFC in cooperation with the USACE, should be completed and configured to run operationally in the CHPS environment. Forecasters should be trained how to modify and interpret the model results to account for levee breaches.

5.4. River Forecast Information Suite

NWS RFCs produce a suite of river forecast products ranging from hours to seasons into the future based on the forecast system described above. River forecasts are typically made at forecast points established in the forecast system. Forecast updates are typically made according to stakeholder requirements. These range from forecasts issued daily to forecasts issued seasonally to forecasts issued only when flooding is occurring or forecast to occur. In addition to routine forecasts, RFCs sometimes issue special forecasts in response to specific stakeholder requests. This section describes the river forecast information available for this flooding event.

5.4.1. Deterministic Forecasts (Official, Contingency)

Both RFCs involved in this event issued many official and contingency deterministic forecasts. These forecasts represent the full hydrograph typically out to five or more days in the future. The most common vehicle for disseminating the official forecasts externally was the NWS AHPS web site.

MBRFC and NCRFC official streamflow forecasts normally run 5 and 7 days into the future, respectively. These forecasts are typically produced using 24 hours of QPF followed by zero QPF during the remainder of the forecast period. During this event, forecasters occasionally deviated from this standard practice to include non-zero QPF beyond 24 hours in their official streamflow forecasts, when requested by a WFO and supported by a high confidence QPF at longer lead times. However, more typical was the practice of providing *contingency forecasts*, where the RFC would issue additional streamflow forecasts that included varying days of QPF into the future. These forecasts were provided to partners, but were not available to the general public. Many of these partners found contingency forecasts to be helpful as a planning tool.

Other contingency river forecasts which used the 5% and 95% HPC QPF percentile accumulation forecasts were made available to partners during this event. More detailed information describing these probabilistic QPF forecasts is available at *http://www.hpc.ncep.noaa.gov/pqpf/about_pqpf_products.shtml*.

Fact: Partners were aware of the river forecasts based on the HPC 5% and 95% contingency precipitation forecasts, but generally did not find them useful because the results were too extreme and there was little probability that either of the results would occur.

During this event, there was extensive confusion regarding the amount of QPF which was included in the official hydrologic forecast model runs. Some of this confusion arose as NWS offices provided briefings noting non-zero QPF beyond 24 hours, while the official river forecasts only included 24 hours of non-zero QPF. Therefore, 5-day river forecasts based on 24 hours of non-zero QPF and an additional 96 hours of zero QPF were inconsistent with the 5-day QPF presented at the briefings.

Partners expressed varying opinions regarding the appropriate temporal extent of analyzed (zero or non-zero) QPF that should be included in the forecast process. Some stakeholders supported the concept of using only 24 hours of non-zero QPF in the official RFC river forecasts. One perceived that the first day of QPF was "relatively accurate," whereas day 2 and beyond were not reliable. Other partners preferred forecasts which included analyzed (and potentially non-zero) QPF for the entire river forecast period (hence, the significant interest in contingency forecasts provided by the RFC). Official river forecasts with only 24 hours of analyzed, non-zero QPF do not meet these partner needs when forecast precipitation beyond day 1 is not included in the hydrologic model. It is important to note that all of these partner preferences were based on past experience, with limited qualitative or quantitative analysis (i.e., their opinions were not based on formal QPF verification).

A common theme among the partners was a desire for the most accurate river forecast. It is reasonable to assume that the most accurate river forecast would include the best possible precipitation forcing (QPF). A standard practice of using only 24 hours of non-zero QPF limits the benefit of scientific QPF analysis to the river forecast beyond that 24 hour period.

The NWS has various capabilities and technologies available to provide analyzed, confidence-based QPF through the entire river forecast period (and beyond). HPC, WFOs, and the RFC all have this capability. Additionally, HPC provides analyzed QPF data through 120 hours (and beyond, in certain circumstances). Clearly, the capability exists to produce QPF forecasts through 120 hours which are based on forecaster analysis and the use of the latest science and technology.

Finding 11: Current integration of QPF into the official MBRFC and NCRFC river forecasts does not utilize the full capability of the science and has resulted in confusion among partners.

Recommendation 11: RFCs should consider utilizing QPF which is consistent with the temporal duration of the river forecast. This QPF should be based on meteorological analysis, and could include confidence-based adjustments.

5.4.2. Short-Term Ensemble Forecasts

Stakeholders interviewed by the team expressed interest in a wide range of hydrologic information beyond that which is available on the AHPS hydrographs or within the WFO Flood Warning products. Much of this interest stemmed from their recognition that the deterministic forecast does not express the uncertainty in hydrologic predictions, especially during extreme events.

Numerous comments were provided from partners which suggested the need for a broader array of potential river forecast outcomes. A selection of these comments included:

- “it would be helpful to see a range of possible crest forecasts”
- “it would have been nice to see ‘worst case’ scenario information”
- “there was a huge gap in communicating the uncertainty of the 5-day river forecast”
- “there were no confidence level (probabilistic) forecasts”
- “the 5/95 forecasts were too extreme and there was little probability that either of the results would occur”

Additionally, the varying opinions regarding QPF in the river forecast and the extensive interest in contingency forecasts also point to the need for an ensemble approach to short-term hydrologic forecasting.

Fact: Finding 12 from the NWS Service Assessment for the Central United States flood event (2008) noted that “forecast uncertainty information, such as ensemble forecasts of river stage…, was very useful to the USACE and others in their contingency planning.” The associated Recommendation stated that “the NWS should expand its provision of forecast uncertainty information to the USACE and other local and state agencies involved in flood contingency planning.”

Consistent with these needs, the NWS has made significant progress towards developing new methods of quantifying and communicating uncertainty in the hydrologic forecasting process as part of the Hydrologic Ensemble Forecast Service (HEFS). Since HEFS is still in development, these processes were not operational at MBRFC or NCRFC during this event.

Finding 12a: The singular deterministic official river forecast does not satisfy all customer needs.

F**inding 12b**: Many partners wanted to see short-term ensemble and probabilistic river forecasts which would have provided a more complete array of potential outcomes.

Recommendation 12: The NWS should expedite implementation of HEFS to satisfy partner needs for short-term ensemble and probabilistic river forecast information.

5.4.3. Long-Term Ensemble (Exceedance Probability) Forecasts

MBRFC and NCRFC generate long-term ensemble forecasts (ESP) to support the AHPS long-lead exceedance probability forecasts. These forecasts represent a probability distribution for maximum streamflow over the ensuing three-month period, as well as for each week during that same period. These forecasts are typically updated once per month by both MBRFC and NCRFC.

Reactions to these forecast products varied considerably between stakeholders. Many reported that they either did not understand them, did not use them, or both. By contrast, some stakeholders viewed these forecasts frequently, even though they had difficulty interpreting the plots. One USACE staff member reported that they heard “a hundred different explanations” of the AHPS probabilistic charts. A few WFOs reported that these forecast products were very important to their early season DSS efforts, calling the long-lead products "game changing," "huge," and that they "helped rev-up the DSS webinars in March/April" (see **Figure 23**). In addition, North Dakota EOC personnel noted these forecasts "helped with resource procurement and the staging of people and equipment."

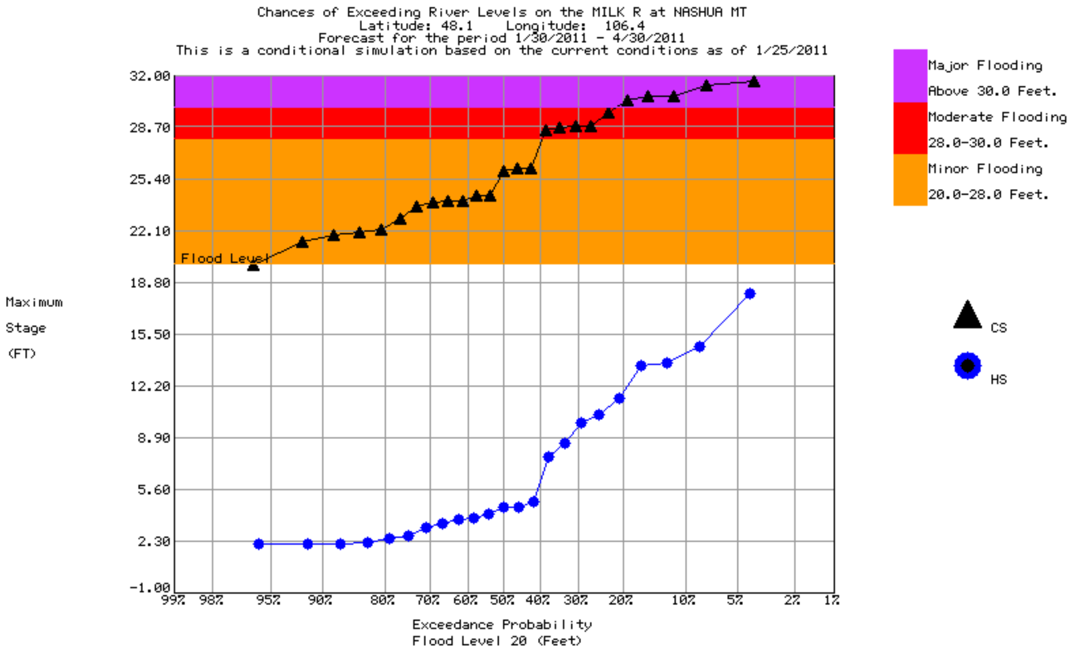

Figure 23. Example of 90-day exceedance plot for the Milk River at Nashau, MT for the period January 30 – April 30, 2011.

Fact: NWS AHPS long-lead forecasts are difficult for many users to properly interpret and apply. Many stakeholders were unaware of these forecast products. Others found them to be very helpful, when explained effectively.

Finding 13: Most stakeholders reported some level of confusion with the long-lead probabilistic river forecast products on the AHPS web pages.

Recommendation 13: The NWS should evaluate the effectiveness of existing methods for presenting and explaining long-lead probabilistic river forecasts to its partners, including the "About this graph" feature on the AHPS web pages.

Some partners expressed a need for more frequent issuance of these probabilistic forecasts as basin conditions changed rapidly (e.g., snowpack increased, heavy rain fell, etc.) during the event. Although MBRFC increased issuance frequency to 2-week intervals, some partners would have preferred weekly updates.

Finding 14: The 30-day and bi-weekly issuance schedules for long-lead probabilistic river forecasts did not always meet the needs of all partners.

Recommendation 14: The NWS should work with partners to identify optimal update schedules for their long-lead probabilistic river forecasts.

Fact: There are many forecast points throughout the Missouri River basin for which probabilistic long-lead forecasts are not produced. The existence of upstream reservoirs at many of these points makes it more difficult to directly incorporate realistic reservoir operations into ensemble results.

Finding 15: Some partners indicated access to long-lead probabilistic river forecast information at additional sites in the Missouri River basin would have been beneficial.

Recommendation 15: MBRFC should work with partners to identify locations throughout the Missouri River basin where long-lead probabilistic river forecasts need to be implemented.

5.4.4. Volumetric Forecasts

Water resources information is a critical element of the NWS Weather Ready Nation Strategic Goal. Expanding hydrologic services to better encompass water resource information is also an overarching principle of the Integrated Water Resources Science and Service (IWRSS) initiative. RFCs develop long-lead volumetric seasonal water supply forecasts in regions where mountain snowpack is a vital component to water supply. These forecasts are an example of hydrologic services that have roots in both flood protection and water resources management.

At MBRFC, volumetric water supply forecasts are developed using a combination of Ensemble Streamflow Prediction (ESP) and statistical methods. These forecasts are routinely issued once a month during periods of snow accumulation and predict the volume of water anticipated to pass a forecast point during a specific period (e.g., the April through July runoff period).

Other federal partners (i.e., USACE, USBR and NRCS) also produce seasonal volumetric forecasts for sites within the Missouri River Basin. The USACE and USBR coordinate volumetric forecasts for USBR projects in the upper basin. These forecasts are not routinely coordinated with NRCS or MBRFC. The USACE did not typically integrate MBRFC volumetric forecasts into their planning process; however, they did request some forecasts from MBRFC, which they found useful in planning the management of their reservoir systems.

Fact: Volumetric water supply forecasts are routinely identified as high value water resource products by stakeholders at the federal, state and local level.

Finding 16: MBRFC did not produce volumetric forecasts at a number of locations where partners indicated they would have been useful. Partners also indicated a desire for more frequent volumetric forecast updates to assist in long range planning and situational awareness.

Recommendation 16: Consistent with the overarching IWRSS goals, MBRFC should coordinate with the USACE, USBR, and other partners to develop a volumetric forecast information suite which meets water resource management agency requirements.

5.4.5. Streamflow Forecast Accuracy

Similar to QPF, the Service Assessment Team heard many opinions about the accuracy of streamflow forecasts, ranging from very good to very poor. Very few of these opinions were substantiated by quantitative forecast verification.

Streamflow forecast verification capabilities are increasingly available online and at RFCs. Even so, verification results and activities have largely not been shared with stakeholders at any level.

Finding 17: Formal streamflow forecast verification information was generally unavailable during this event. Partners were not able to assess the historical accuracy of the streamflow forecasts.

Recommendation 17a: The NWS, in general, and RFCs, in particular, should produce timely and meaningful verification to share with stakeholder agencies as part of their regular engagement with those agencies.

Recommendation 17b: The NWS should consider including online forecast verification as part of its forecast distribution system (e.g., the AHPS pages).

5.4.6. Streamflow Forecast Service Requirements

Stakeholders noted that MBRFC forecast locations, information, and timing and frequency of issuances were not always optimal for supporting their decision-making process. The following subsections contain examples of service deficiencies in each of these categories.

Forecast Locations

The mainstem Missouri River has no official forecast points from the headwaters of the river through the controlled portion of the river to Gavins Point in southeastern South Dakota. This had an impact on the information available to partners as they prepared for potential flooding in the spring. At Bismarck, ND, a state-level official noted that “this event was a 500-year flood along the Missouri River, and there was no forecast service available.”

Forecast Information

No long-term probabilistic information is available along the mainstem Missouri River. MBRFC indicated that implementation of this capability was impacted by existence of upstream reservoirs as described in **Section 5.4.3**. Additionally, many tributary forecast points across the Missouri basin did not include long-term probabilistic information. This made it difficult for stakeholders to understand the potential for flooding at these points prior to the event.

Forecast Timing

The routine deterministic forecast issuance times, which included full assimilation of new observed and forecast hydrometeorological conditions, were not always optimal for the EOC decision-making process. Partner agencies often have morning planning briefings where a wide variety of critical decisions are made prior to the issuance of the new river forecasts.

Partner agencies acknowledged that their forecast and briefing needs don't necessarily correspond well with NWS data access and forecast processes. Most EOCs expressed that they could normally work around the times of the routine NWS river forecast issuances.

Fact: All EOC personnel desired to have the latest information before their critical decision-making times, but most recognized that NWS data management and forecast processes were not able to meet all of those needs with the latest model-run forecasts. Even so, they did desire the best, most representative river forecast information that was available *at that time*.

Forecast Frequency

Section 5.4.3 identified an example where long-term probabilistic forecasts were no longer representative of current conditions and required updating. In these cases, the standard monthly forecast release frequency was not sufficient to satisfy partner requirements.

Finding 18a: There were a number of instances where the existing river forecast service suite did not adequately support stakeholder decision-making processes. A variety of opportunities were identified to expand the frequency, timing, content, and location of river forecast services to meet stakeholder requirements.

Finding 18b: Many stakeholders were unaware of the full suite of MBRFC forecast capabilities that would have enhanced planning and facilitated more effective DSS. Specifically, they did not know the RFC could produce non-standard probabilistic information. Examples of this information include inflow and tailwater forecasts on reservoir controlled rivers, the probability that a river will fall below a certain level at a specific time, and the probability of a reservoir reaching a certain level.

Recommendation 18: MBRFC should perform a comprehensive services evaluation, in collaboration with their internal and external partners, to assess the need for new river forecast points, evaluate the issuance schedules of routine river forecasts and products, and provide additional services and information which meet partner needs. This evaluation process should be performed on a regular basis.

5.5. Collaboration of Forecasts and Other Information

This section covers topics related to internal and external collaboration activities throughout the Missouri and Souris River flood events.

5.5.1. Internal Collaboration

The NWS has two primary groups of offices who interact closely during high-water events: the WFOs and the RFCs. Other groups interact to some extent as well, including the National Operational Hydrologic Remote Sensing Center (NOHRSC) and the Hydrometeorological Prediction Center (HPC). This section will look most closely at the internal collaboration between WFO and RFC, and the WFO and RFC with NOHRSC and HPC.

5.5.1.1. WFO/RFC Collaboration

The WFO/RFC collaboration relationship is crucial to ensure accurate and timely river forecast information is provided to partners and the public. In this regard, WFOs and RFCs are very inter-dependent in their mutual mission of providing the best river forecast service possible. RFCs utilize WFO temperature forecasts, QPF, precipitation observations, and other information for their hydrologic models. WFOs depend on the river forecasts, including routine forecasts, contingency forecasts, probabilistic information, special model runs, and non-model-based RFC updates to provide the most accurate information possible to partners and local decision-makers.

During critical hydrologic events, both WFOs and RFCs need to manage staffing levels to meet additional hydrologic workload. This includes working overtime and shifting schedules to meet internal and external partner needs. This process can change on a day-to-day basis as an event unfolds. In this particular event, extensive overtime and schedule management was required to meet customer needs and maximize timely collaboration between WFOs and RFCs.

Input from both WFOs and RFCs noted there was frequent interaction between the WFOs and RFCs relating to the river forecasts. At the request of the WFOs, the RFCs provided many contingency forecasts to help highlight the potential impact of additional expected rainfall beyond the ensuing 24 hour period. In this difficult event, where flows exceeded previous records, there was considerable adaptation required to rapidly changing river situations, and various WFOs noted that RFC efforts to support their DSS processes were important and helpful. These offices appreciated the time and effort made to support their needs.

Nevertheless, there were numerous challenges associated with this collaboration process. Among these challenges were a lack of consensus between MBRFC and WFOs, at times, relating to collaboration of scientific and forecast service issues.

The scientific issues were generally related to hydrologic modeling processes, including data inputs and model state conditions that required forecaster interpretation and interaction. During this event, there were a number of occasions where WFOs raised concerns regarding the hydrologic model inputs when the river forecasts didn't match their expectations. Specific examples of these concerns were observed precipitation analysis and SWE model conditions. Ensuing real-time discussions with MBRFC did not always result in consensus resolution or understanding of the issue. At times, WFOs left these discussions with the perception that MBRFC was not consistently incorporating optimal data resources into their modeling processes.

Finding 19: Scientific collaboration between MBRFC and the WFOs during the event did not always create a shared perspective regarding hydrologic modeling processes and the resulting official river forecast.

Recommendation 19: MBRFC and the WFOs should engage in periodic scientific collaboration meetings to increase mutual understanding of hydrometeorological data needs and hydrologic modeling processes.

The RFCs have a clear service role to both the external partners and the WFOs. While the USACE and FEMA were extremely pleased with the support provided by MBRFC, there were times the WFOs and their state and local-level partners were less satisfied. Although most WFO requests were honored, many WFOs noted their requests were met with resistance, at times. Specific examples of requests which met resistance included extending a standard weekday product through the weekend, producing additional contingency forecast runs, and updating poorly tracking forecasts during a rain event.

As the event unfolded, many WFOs attempted to contact USACE in Omaha directly to gather reservoir release projections and other information. Because the USACE could not support this additional direct communication with all WFOs in their jurisdiction, they requested a single point of contact with the NWS (MBRFC). Under this arrangement, WFOs were to contact MBRFC regarding their questions, and MBRFC was to forward relevant information from USACE to the affected WFOs.

From the WFOs' perspective, the resulting communication did not always meet their needs. At times, the WFOs did not receive information that would have been useful when briefing their state and local-level partners and answering public inquiries. Ultimately, it appeared to some state and local partners that there was lack a communication between the USACE and some of the WFOs. In reality, the communication challenges existed between MBRFC and the WFOs.

Fact: To provide the best service during an event of this magnitude, WFOs and RFCs need a solid pre-existing inter-office relationship and a clear commitment to communicate information within the agency.

Finding 20: The relationships between MBRFC and its WFOs were not sufficient to adeptly work through some of the more challenging aspects of this event. Although there was considerable communication between MBRFC and its WFOs, and much of it was effective, there were also situations where this communication could have been improved.

Recommendation 20: MBRFC should work with its WFOs (and vice versa) to strengthen the WFO/RFC partnership. An understanding of each office's requirements should be enhanced, with a unified mission perspective reinforced by WFO and MBRFC management.

5.5.1.2. WFO/RFC Collaboration with NOHRSC

The NOHRSC provides a unique set of snow observation and modeling information that is well suited for operational hydrologic forecasting processes. General response of internal and external partners regarding NOHRSC data was fairly positive, though comments regarding the perceived accuracy of the data were mixed.

Collaboration between WFOs, RFCs and NOHRSC was primarily achieved via conference calls. NOHRSC personnel held weekly conference calls with both NCRFC and MBRFC prior to and during this event. They also joined in on conference calls coordinated by WFOs Glasgow and Great Falls as well.

NOHRSC stated they are trying to expand this type of support to WFOs, but it is a challenge to have weekly conference calls with each office due to their limited staff. They have organized multi-office calls across the NWS Eastern Region (with whom they started doing calls during previous winters), and will need to organize joint calls across other portions of the country, if they are to more broadly serve those WFOs in an effective manner.

Finding 21: NOHRSC participated in numerous SWE collaboration calls with various WFOs and RFCs. This frequently resulted in a duplication of effort and created workload challenges for NOHRSC personnel.

Recommendation 21: As needed, the NWS Central Region and Western Region should facilitate multi-WFO/RFC calls with NOHRSC to maximize collaboration and more effectively utilize NOHRSC time resources.

WFOs noted that support by NOHRSC on the conference calls was "spectacular", and had a big impact on the information and service they provided to their DSS partners. The information provided by NOHRSC was also useful for RFCs to corroborate their modeled SWE.

Fact: In support of the NOHRSC SWE modeling efforts, a number of WFOs provided real-time snow core observations. NOHRSC indicated these observations were essential inputs for their data assimilation process, thus improving the accuracy of information available from the NOHRSC snow model.

Best Practice 1: Where staffing allows, a positive WFO response to NOHRSC field snow core requests can enhance the quality of information provided by the NOHRSC model and can also enhance the collaboration process between WFO and NOHRSC.

5.5.1.3. WFO/RFC Collaboration with HPC

WFO and RFC forecasters indicated that HPC QPFs were generally of high enough quality that little collaboration was needed to make them useful for their operational and DSS needs. RFC collaboration with HPC forecasters primarily focused on HPC *confidence* in their QPF forecasts, whereas WFO collaboration also included QPF amounts. In both cases, offices indicated that the required collaboration, although limited, was effective.

Specific comments from WFOs regarding HPC QPFs included:

- “HPC 3-5 day QPFs were good, and seemed to drive the contingency forecasts well,”
- “The forecasts were a very good resource; we used them in our briefings,” and
- “HPC extended period QPFs were really good when we called on them.”

Both NCRFC and MBRFC reported that the HPC QPFs were of sufficient quality to use in their contingency river forecasts.

5.5.2. Interagency Collaboration (with USACE, USGS, USBR, and others)

Prior service assessments have repeatedly indicated that a well-coordinated forecast, with a consistent message from each agency, is vital for public confidence in the forecast and to ensure proper actions and preparations are taken. Due to the numerous water management structures operated within the Missouri River Valley by the USACE and USBR, successful forecasts downstream of these projects requires close collaboration with these agencies. Ongoing collaboration with the USGS during flood events regarding stage-flow relationships, in the form of rating curves, is also critical. In the Souris River Basin, which originates in Canada, effective forecasts require information and collaboration with international partner agencies. This section provides a brief overview of the interagency collaborations which took place between MBRFC, NCRFC, WFOs, and their federal and international partners.

Critical interagency collaboration often occurs *prior to* events as well. This collaboration process ensures an interagency understanding of ongoing activities and responsibilities in the basin, and identifies opportunities for agencies to work together more effectively.

Fact: The USACE in both Omaha and Kansas City reported that their collaboration with MBRFC was superb. This success emanated from a long history of close collaboration and an increased focus on face-to-face meetings in recent years. Both agencies stated that without these meetings, their ability to react to unique situations during this event would have been much more difficult.

Best Practice 2: MBRFC participated in a meeting with its critical partners (USACE, USBR, and USGS) in November 2010 to enhance interagency communication and information exchange.

Collaboration between the agencies took many forms during this event, from passive data exchange via automated methods to detailed discussions via telephone. Additional information regarding methods of collaboration is included in **Section 5.5.3**. The most effective collaboration was characterized by frequent communication, a clear sense of what both the NWS and the partner agency required, and an understanding that all federal agencies needed to be “on the same page”, providing consistent information to state, local and public stakeholders.

Routine collaboration during an event is a standard practice between USACE, USBR, and the RFCs. This typically consists of exchanging reservoir release strategies and schedules. During this event, the range of communication with Federal agencies expanded to include:

- discussions on uncertainties in forecast flows and stages due to snowmelt and precipitation,
- requests for additional products or services to assist with regulation decisions, and
- coordination with the USGS regarding real time flow measurements and the resultant shift or extension of rating curves.

At most headwater projects regulated by the Omaha and Kansas City USACE Districts during periods of flooding (including USBR projects), reservoir release schedules are transferred to MBRFC via automated methods. The Kansas City District receives forecast flow inputs to their reservoirs from the RFC which are used to generate release schedules. Deviations from the release schedule are typically communicated to the RFC.

Routine coordination calls between interagency partners were heavily used at both MBRFC and NCRFC during this event. The timing and frequency of calls evolved with the event, as the need for increased and consistent coordination became apparent.

Best Practice 3: NCRFC, MBRFC and WFO Bismarck actively participated in daily coordination calls for their respective events with the USGS and USACE to develop a unified message regarding river forecasts and reservoir releases prior to public dissemination.

All parties, including the emergency management partners, lauded this practice for its effectiveness in providing consistent information to the public.

Collaboration with the USGS was also exceptional during this event. There were *many* cases on both river systems where flows exceeded previous records by a substantial amount, and new stage-flow relationships were required quickly to assist emergency management partners in their decision-making processes. Both the NWS and USGS partners noted that the associated interactions allowed them to effectively prioritize locations where updated ratings were needed and communicate the subsequent rating changes.

The exceptional nature of this flood event required numerous unique interagency collaboration activities. Two examples are listed below.

Missouri River Gavins Point Release Forecast

As the magnitude of the precipitation events in May became more apparent at the end of the month, MBRFC and USACE began to realize their inflow forecasts for the major Missouri River reservoirs were too low. As a result, the operations plans for the reservoirs needed to be revised to accommodate significantly more inflow.

Once the decision to move to 150,000 cfs at Gavins Point had been made, representatives from MBRFC and USACE realized that record flows would last for a majority of the summer. It was agreed that a consistent message regarding the most likely peak river stages would be needed. The MBRFC, the Omaha District office, the USACE Kansas City District office, and the USACE Omaha Division office held a conference call to establish, point by point, a consensus forecast regarding the most likely range of peak stages at each location along the mainstem

Missouri from Gavins Point to Hermann, MO. Due to time constraints and limited probabilistic forecast resources along this reach of the river, the analysis was highly subjective. However, the coordination was able to leverage the experience of each office to arrive at a consensus that was later affirmed by a more technical analysis of tributary flow probabilities.

Ultimately, the Gavins Point releases were set at 160,000 cfs in late June. This release would more than double the previous record (70,000 cfs in 1997). For both the 150,000 cfs and 160,000 cfs releases, MBRFC coordinated closely with USACE to provide a product which was used heavily as a planning tool for communities and levee districts, as well as a concise resource for the media during the flood event. **Table 2** shows an example of this forecast for the 160,000 cfs release.

The forecast tables were placed on the USACE Omaha Division website. NWS web sites contained direct links to that table, which ensured a consistent message and reduced the likelihood of miscommunication with the public and the media.

This highly unusual forecast was widely cited by many stakeholders, particularly those external to the NWS, as very useful and a great example of interagency collaboration.

International Collaboration

During periods of flooding on the Souris River, NCRFC relies on communication and collaboration with Saskatchewan Water, the Canadian agency responsible for forecasting and regulating flood control reservoirs upstream of the United States' portion of the river. This collaboration was restricted during this flood event by the inability to contact Saskatchewan Water staff via telephone, when necessary. Email was the most effective means of contact; however, both the NWS and Saskatchewan Water experienced an extended email outage during the height of the flood event at Minot.

This communication limitation made it very difficult for NCRFC to obtain current snowpack, precipitation and reservoir release information in real time from our Canadian partners. On several occasions, reservoir releases were changed without notice. Forecasts issued by NCRFC along the Souris were negatively impacted by the incomplete data, and situational awareness at both the RFC and WFO was similarly restricted.

Finding 22: Communication with Saskatchewan Water was deficient during the Souris River flood event. NCRFC experienced critical information gaps regarding conditions upstream of Minot in the Souris Basin.

Recommendation 22: NCRFC and WFO Bismarck should work directly with their Canadian partners to enhance real-time communication capabilities and improve the exchange of information related to Souris River forecasting.

Gavins Point Release of 160 kcfs

This forecast was issued on: **24-Jun-2011**

The information below is being reviewed continuously and will be updated as conditions dictate. Projected stages are based on current flow-stage relationships. Many reaches of the river have not experienced flows this high since the dams were constructed; therefore, these flow-stage relationships may need to be refined as events unfold. Additionally, levee breaches may have a significant impact on eventual stages. It should be noted that this is a "likely" range of flows and stages and actual flows and stages could be higher or lower than those specified.

Lower range of flows and stages represents approximately a 50% chance of being exceeded during the months of June, July and August.

Higher range of flows and stages represents approximately a 10% chance of being exceeded during the months of June, July and August.

Missouri River @	Flood Stage	Gage Datum *	w/ Incremental Flows **	
		ft NGVD 29	Likely Range of Flows and Stages	
Sioux City	30	1056.98	170 kcfs	200 kcfs
	Stage		35	37
Decatur	35	1010.00	170 kcfs	200 kcfs
	Stage		40	42
Blair	26.5	977.60	175 kcfs	210 kcfs
	Stage		32	34
Omaha	29	948.24	180 kcfs	215 kcfs
	Stage		34	36
Nebraska City	18	905.36	200 kcfs	260 kcfs
	Stage		27	above 28 ***
Brownville	33	860.00	205 kcfs	280 kcfs
	Stage		43	above 44 ***
Rulo	17	837.23	220 kcfs	300 kcfs
	Stage		27	above 27 ***
St. Joseph	17	788.19	225 kcfs	330 kcfs
	Stage		28	32.5
Atchison	22	762.20	225 kcfs	330 kcfs
	Stage		30	34

Table 2: Coordinated USACE/MBRFC special forecast for 160,000 cfs Gavins Point releases

5.5.3. Collaboration Methods

A variety of communication methods were used effectively, depending on the situation, the technologies available, the required working process, and the collaborators involved. Email, phone, texting and NWSChat were all considered to be important communication methods during this event.

Telephone

The importance of telephone communication cannot be overstated. The USACE, in particular, noted that telephone conversations between both Division and District offices and MBRFC were critical in their management of the event. While many of the newer communication technologies were utilized by various partners, many of the partners relied on telephone access to NWS offices and/or teleconferences to clarify forecasts and coordinate with the NWS.

NWSChat

NWSChat was useful in the collaboration process between WFOs and RFCs, where it was utilized to review the preliminary forecast prior to its official release. Several of the USGS State Water Centers used NWSChat to post streamflow measurements and rating curve adjustments. Many other partners, including emergency management personnel, also used NWSChat to coordinate with the NWS.

There were some situations where NWSChat was not effective; examples are noted below.

- NWSChat is only effective when personnel with whom you are collaborating are at their computer, are logged in to NWSChat, and are monitoring it. This wasn't always the case during this event.
- Each NWS office has its own NWSChat room. In a widespread event which impacts many NWS offices, each office will have a separate chat room open for discussion with their partners. Any office or partner wishing to monitor multiple chat rooms found that process challenging. At times, it was difficult for them to effectively monitor and communicate in each of the rooms.
- Some partners did not have an IT structure which allowed them to utilize NWSChat. This was true for rural emergency management personnel who used their pickup truck as their office. (Note: Smart phone applications are available which provide remote chat capability via NWSChat).

Fact: NWSChat can be ineffective when multiple NWSChat rooms are used to communicate with a single partner during an event.

GoToMeeting

GoToMeeting was very effective for communication and collaboration between the NWS offices and the state and local partners. This technology was used extensively for DSS activities, both prior to and during the event.

Email

Email was used effectively to broadcast messages to multiple recipients. Some offices found that sending out a mass email was an excellent way to share and receive information with partners. One office found this method was very effective at getting additional observations as well.

Text Messaging

Some situations demanded use of text messaging and, in fact, some DSS personnel noted that text messaging was the *most* effective way to communicate quickly.

Fact: NWS personnel were unsure if they were authorized to use text messaging capabilities on their government-issued cell phones for DSS-related activities.

Finding 23: Some NWS personnel used personal phones to ensure text messaging capability was available to them for their DSS-related activities. This required them to carry and communicate using both their personal and government-issued phones.

Recommendation 23: The NWS should clarify policy regarding utilization of government-issued phones for SMS, MMS and internet-based (e.g., email) processes. In addition, the NWS should ensure government-issued phones have sufficient capability to fully support immediate communication needs, including texting plans and email access.

800 MHz Radio

Some states have implemented 800 MHz radio systems through their Emergency Management (EM) structure. Where available, statewide 800 MHz radios were helpful in reaching a broad partner base in the EM community.

5.6. Communicating River Forecast Information

The NWS provides river and flood forecast information via products (e.g., warnings and statements) and web-based information. This section identifies a number of findings related to methods used to generate and communicate this information.

5.6.1. Flood Warnings

The NWS has a variety of flood-related products (e.g., FLW, FLS, FFW, FFA, etc.). By design, each of these products provides information related to specific hydrologic conditions. Some of the partners expressed confusion regarding the array of flood-related products issued by the NWS. To address this issue, the NWS Hydrologic Services program has conducted several customer satisfaction surveys to evaluate the potential for hydrologic product simplification.

The NWS provided flood warnings (FLW) for areas that are protected by permanent levees. This raised unnecessary confusion and alarm in areas where there were no imminent threats. (Note: FLWs are not issued for New Orleans and Devils Lake, ND despite a prolonged threat to both communities by local bodies of water where normal surface elevation exceeds that of the populated area. Portions of both communities are protected by permanent levees.)

Finding 24: FLWs were issued for areas that were protected by permanent levees. With the levees intact, there were no imminent flood threats in these areas.

Recommendation 24: WFOs should work with local communities to determine appropriate flood warning issuance levels in areas that are protected by permanent levees or similar structures.

5.6.2. RiverPro

The Advanced Weather Interactive Processing System (AWIPS) RiverPro software was utilized by the WFO staff to disseminate river flood warnings and forecasts. Many WFO forecasters indicated that the RiverPro software is not intuitive and can be cumbersome to use. Manual editing of the warning/forecast was often needed before public dissemination. This manual intervention can significantly add time to the process of preparing the warnings/forecasts, especially when flooding is occurring over a wide area.

WFOs noted that improved templates and local training did not adequately reduce workload inefficiencies related to the use of RiverPro. Work is ongoing at the NWS national level to develop a more intuitive flood warning tool.

5.6.3. AHPS and the NWS Web

NWS Web pages, including AHPS, provide users an easy way to access a wide variety of hydrologic data, forecasts, and warnings provided by the NWS, and were widely used by NWS partners and the public during this event. Many partners offered very positive reviews of the information provided by the NWS via the AHPS pages. The USACE Omaha District remarked that the AHPS pages were "fantastic". FEMA representatives stated that the AHPS river forecast information was very useful, with the impact information used extensively by FEMA personnel. In general, there was a great deal of praise for the extent and usefulness of the information provided on NWS AHPS pages.

Although the overall tone was quite positive, a number of issues related to web page performance and functionality were noted.

Web Infrastructure and Stability

The NWS Internet Dissemination System (NIDS) was implemented during this event. This change in infrastructure and policies resulted in the AHPS Configuration Management System (CMS) restricting access to computers inside the OPSnet or through an assigned Virtual Private Network (VPN) account. A number of offices within the NWS Central

Region were not correctly identified as being within the OPSnet. These offices also lacked a VPN account. This resulted in disruption of access to the CMS by WFO staff for a number of days at two significant occasions during the flood event. These internet service interruptions also prevented DSS personnel from accessing important briefing material.

Fact: NWS web services, including AHPS pages, were very important tools for NWS DSS personnel and the partners served at the various EOCs.

Finding 25: NWS web service and disruption in access to the AHPS CMS negatively impacted DSS and reduced the credibility and usefulness of NWS web services to key partners and customers.

Recommendation 25: The NWS should institute IT policy which ensures safeguards are in place to prevent web service downtime and disruption in access to interfaces through which NWS staff provide web page updates. This is especially critical during high-impact events.

Web Content and Update Frequency

The USGS made numerous river measurements throughout the event to provide updated stage-flow relationships, or rating curves. This updated information was posted on the USGS web pages and made available to the NWS. NWS web processes only update rating curve information on the AHPS pages once per day. Therefore, there was no mechanism for the NWS to update this information in real-time. This delay led to inconsistent rating curve information on the AHPS and USGS web sites, at times. These rating curve differences occasionally caused partners to question the validity of the NWS forecast information.

Finding 26: The daily NWS transfer of rating curve updates during this event was not sufficiently frequent to avoid inconsistencies with USGS information.

Recommendation 26: The NWS should identify a solution to allow for more timely and effective updates to static information, such as rating curves, used by AHPS web pages.

AHPS Display of Non-Standard Forecast Information

As noted in **Section 5.5.2**, collaborating agencies recognized that, for locations downstream of Gavins Point, a single value crest forecast would not be sufficient to represent the uncertainty for this event. A unique forecast table was developed to provide a range of crest values for each forecast location.

Typically, NWS AHPS pages are the conduit for official river forecast dissemination. However, in this specific case, the NWS AHPS pages could not accommodate the unique forecast information (i.e., a range of crest values).

Finding 27: NWS AHPS pages could not provide the flexibility to accommodate the unique requirements of non-standard forecasts, such as the “likely crest range forecasts” based on the Gavins Point projected reservoir releases.

Recommendation 27: The NWS should examine potential opportunities to provide non-standard information within the AHPS suite of products to meet current and future DSS needs.

AHPS Display of Hydrologic Model Information

Fact: AHPS web pages do not accommodate the display of additional hydrologic modeling information alongside the river forecasts.

Finding 28: Stakeholders expressed interest in viewing the temperature and precipitation forcings used in the hydrologic models alongside the AHPS hydrographs.

Recommendation 28: The NWS should consider adding AHPS web display functionality that facilitates visualization of additional hydrologic modeling information related to the forecasts, such as observed/forecast temperature and precipitation and river forecast verification.

Flood Impact Statement Information and Accuracy

NWS partners indicated flood impact statements provided on the AHPS web pages were extremely useful, though some deficiencies were noted. These included:

- They were not always current.
- There was a need to define the level and reach of levee protection.
- There was a need to distinguish between impacts that occur below permanent levee protection and those which occur above the level of levee protection.
- There was a need to include potential impacts above previously observed flood of records.

Finding 29: Partners find AHPS flood impact statements useful, and identified ways to improve the content.

Recommendation 29: NWS Service Hydrologists should ensure AHPS flood impact statements are current, include information relating to levee control, and, if possible, include potential impacts at river levels exceeding previous record floods, especially for critical infrastructure.

Hydrologic Product Displays on the Watch/Warning/Advisory (WWA) Map

Flood warnings for official river forecast locations issued using RiverPro software highlight the warning for the entire county on the WWA map, even though the only threat area is along the river. This caused some confusion among emergency managers, since areal flood warnings and flash flood warnings use a different, forecaster-specified polygon for the warning area.

Fact: The differences between the way county-based and polygon-based flood warnings are displayed on the WWA map caused confusion regarding the areal coverage of the flood threat.

Fact: WFO Hydrologic Forecast System developers, along with some NWS Central Region offices, have established a method to incorporate polygon warning information within RiverPro.

Fact: Recommendation 4 from the NWS Service Assessments for the Southeast U.S. flood event (2009) noted that "warnings should not encompass an entire county if only a portion of the county will be impacted."

Finding 30: County-based RiverPro warnings do not accurately represent the true areal coverage of the flood threat.

Recommendation 30: The NWS should update operational warning software to consistently reflect a more realistic true areal coverage of the flood threat.

DSS Web Services

Many state EOCs and other federal agencies use NWS web pages as part of a situational awareness display. Several of these partners noted that NWS web pages, including the AHPS web pages, do not auto-update, which causes situational awareness information to become stale without manual intervention.

Fact: NWS Web pages do not auto-update.

Finding 31: NWS partners requested auto-update capability for NWS web pages.

Recommendation 31: The NWS should add auto-update capability to NWS web pages.

Fact: Throughout the event, NWS offices received many requests to implement additional web services in support of DSS activities.

Finding 32: Current NWS web infrastructure does not permit rapid development and deployment of customer-based web services. The negative impact resulting from this lack of flexibility increases during high-impact events.

Recommendation 32: The NWS should investigate the potential to accommodate flexible, real-time web service modifications to meet the needs of partners.

5.7. Quality Control, Monitoring and Updating of River Forecasts

Monitoring and updating river forecasts are critical RFC activities which need to take place routinely to meet internal and external stakeholder needs. MBRFC and NCRFC have local policies which are designed to ensure river forecasts maintain near-term accuracy and an appropriate trend. RFC personnel are responsible for reviewing forecasts immediately upon release to ensure there are no immediate issues with the forecast information.

There are additional policies in place which define WFO and RFC roles and responsibilities for the provision of unscheduled river forecast updates. In general, the RFC has responsibility for providing unscheduled updates as required. However, these policies have provisions which authorize WFO personnel to make short-term “cosmetic” changes to river forecasts, as long as the crests remain unchanged. Changes to the crest can be made by the WFOs as well, though these changes need to be collaborated with the RFC. If these policies are executed effectively, the river forecast should reasonably represent current and expected conditions at all times.

During this event, there were times when the cosmetic change process was not effective, and the WFO/RFC collaboration process did not result in a representative forecast update. Clear concerns were expressed by internal and external stakeholders that the river forecast quality control, monitoring, and update processes did not adequately meet their expectations. Inconsistencies between observations and forecasts created operational challenges for external partners (USBR and EMs). Internal partners (WFOs) noted that when forecasts were clearly not representative with current conditions, or were not representative of reasonable short-term trends, partner confidence in the forecasts diminished and WFO personnel were required to “apply their own interpretation” of the forecast information. These situations had a particularly notable impact during DSS activities, and were evident in many locations of the Missouri River basin as well as along the Souris River.

This scenario was not unique to this event. A similar situation was noted in the NWS Service Assessment entitled, *“Southeast United States Floods, September 18-23, 2009”* (reference, Finding and Recommendation 8).

Finding 33: Initial quality control, monitoring, and updating of the official river forecasts by MBRFC and NCRFC did not consistently meet internal and external stakeholder needs.

Recommendation 33: MBRFC/NCRFC and their associated WFOs should collaboratively discuss their capabilities and customer-based expectations regarding forecast monitoring and updating activities. The result of this discussion should be an agreement which details a collaborated WFO/RFC policy regarding river forecast monitoring and updates. The details of this agreement should be clearly communicated and implemented at the RFCs and WFOs.

6. Weather and Climate Outlooks (Long-Lead Preparedness)

One of the major challenges during this event was anticipating the occurrence of the very heavy rains that fell in late May in the Upper Missouri River basin. This section considers the utility of weather and climate precipitation outlooks (week 2 to seasonal forecasts) from the partners’ perspective.

The NWS Climate Prediction Center (CPC) issues monthly and seasonal forecasts every month, and 8-14 day forecasts every day. All monthly and seasonal forecasts from September 2010 through April 2011 (except February 2011) suggested higher than normal probabilities of above normal precipitation over at least some portion of the Missouri and Souris River basins. Therefore, in general, these CPC forecasts provided a reasonable outlook for above normal precipitation 1 to 3 months into the future in this area.

The USACE and other partners noted that CPC monthly and seasonal outlooks are not routinely relied upon to provide useful information for their water management decisions. They indicated that the very nature of the monthly and seasonal forecasts (i.e., probabilities of above and below normal) did not render them overly useful for flood planning. There was no inherent indication in the CPC forecasts that the late spring period would have such extreme precipitation (both rainfall and mountain snowfall) which would significantly impact the river systems. This was the information that would have been most useful to the partner agencies.

Fact: In general, partners do not currently use CPC extended forecasts, even though they are widely disseminated through NWS briefings.

Finding 34: Partners indicated the probability information in the CPC forecasts was not useful for flood planning. Alternatively, they expressed a need for climate forecasts which identify potential for extreme events, such as the spring 2011 Missouri River basin precipitation.

Recommendation 34: The NWS should collaborate with its DSS partners to identify what seasonal, monthly and other forecast information would be most beneficial to them in their decision-making processes, and work to provide that information in their forecast product suite.

7. Decision Support Service

The extended duration and high impact nature of the Missouri and Souris River floods provided an opportunity to exercise NWS decision support capabilities beyond the normal provision of river and weather forecasts and warnings. NWS DSS activities were generally provided at state EOCs and for regional/local emergency managers.

Every state affected by the flood, including Montana, North Dakota, South Dakota, Iowa, Nebraska, Missouri and Kansas, requested “on-site” decision support from the NWS at their respective state EOC. These requests were received by the corresponding NWS state liaison offices. In each case, the support provided to state level partners was for a long duration and generally fit into the Incident Command System (ICS) structure. The extended nature of the event, and requests for additional decision support services, required assistance from other WFOs, RFCs and Regional Headquarters in order meet all internal staffing requirements and external customer requests.

In addition, every WFO and RFC surveyed engaged in significant “off-site” support where additional information and briefings were provided by staff that remained at the forecast office. Off-site support involved various formats and communication methods, including recorded presentations, interactive webinars, email disseminations, NWSChat, multimedia web briefings, and phone conference calls.

After the peak of the flood, NWS field offices also worked with state officials and FEMA to provide data and event summaries to help facilitate FEMA disaster declaration requests.

7.1. Value and Effectiveness of Decision Support Service

Unanimous and highly favorable responses from partner groups indicate that NWS DSS activities were essential and provided valuable information for the partners' decision-making processes during the flood fight. As stated by Mark Gruener of the Northeast Montana Disaster and Emergency Services (DES), "Never has so much been owed to one agency - that's the case here." It was clear from all partner groups that the NWS DSS activities were exactly the kind of service the partners wanted from the NWS. This sentiment was captured well by Earl Imler of the Nebraska Emergency Management Agency when he stated, "We were extremely pleased and very grateful for the NWS support."

The DSS process started early, with the NWS conducting pre-season briefings and outreach highlighting La Nina impacts, excessive snow cover, and spring flood outlooks. These pre-season efforts helped build relationships with the partners prior to the onset of flooding.
As the event unfolded, all WFOs, RFCs, HPC, and NOHRSC were highly engaged in the process of providing unique DSS information that was valuable and tailored to their partner needs.

Best Practice 4: Webinars were frequently used to provide information during the winter season, including CPC outlooks and AHPS graphics. These webinars were noted as being very useful by partners.

Best Practice 5: GoToMeeting, email briefing summaries, web page summaries, and other processes were used effectively to disseminate information to all levels of partners; this enabled transmission of high-level briefings to county and local levels as well and allowed the information to reach the largest audience possible.

While much of the feedback on the effectiveness of NWS DSS was positive, some partner comments indicated that consistency in products and services varied across NWS office boundaries and from one DSS briefing to the next. Partners indicated the NWS should also provide products and maps based on the customer's geographical area (e.g., state or regional area) as opposed to WFO/RFC forecast boundaries.

Finding 35: NWS graphical briefing packages did not always conform adequately to the geographic scales desired by partners.

Recommendation 35: The NWS should identify methods to produce products and graphics on varying geographic scales to support information needs of DSS partners.

During this event, partners often had specific information needs which were not well supported by "standard" NWS graphical or text products, or were not consolidated well for ease of use. Many WFOs developed specialized local formats for presenting information to partners on a daily basis to better meet their needs. This was, in some cases, a time-consuming endeavor, but one which the NWS staff felt was necessary to meet partner needs.

Best Practice 6: All NWS offices interviewed developed specialized methods of providing information to their partners. These were all examples of how the NWS adjusted services at each DSS location to meet unique partner needs.

7.2. On-Site vs. Off-Site Decision Support Service

The NWS used a variety of methods to provide decision support service to partners prior to and during this event. These methods can be categorized as "on-site", where the NWS provided in-person support at the partner/customer location, or "off-site", where NWS personnel remained at their office and used various remote communication technologies.

There were various perspectives offered by NWS and partner personnel when asked whether it was sufficient to provide DSS remotely, or whether on-site DSS was essential. While nearly all responses indicated that off-site decision support *can* work (and was very beneficial when used), the consensus of responses indicated that on-site support was much better, and in some cases essential*, for more significant events*.

Specific situations in this event demonstrated that the need for on-site support may, at times, also be driven by the level of partner knowledge regarding certain aspects of the information being provided by the NWS offices. A partner with considerable background knowledge/experience with hydrology or meteorology may find off-site support sufficient, whereas a partner with rudimentary understanding may require a greater level of support.

Best Practice 7: The NWS and USACE collaboratively determined that the USACE required on-site meteorological support and off-site hydrological support during this event. The USACE was comfortable with hydrological issues, but needed a higher level of support regarding meteorological interpretation.

Partners identified the following considerations as those which impacted the need for on-site support:

- When briefings are needed on a sub-daily timescale to make timely and/or critical decisions
- When media attention starts to increase considerably
- When a larger number of people/businesses will be impacted by the event
- When the impact of the event is high and the temporal duration becomes prolonged
- When the frequency of weather-related questions increases considerably between briefings
- When the partner is uncomfortable with the topical information being provided
- When the "human moment" makes a difference

NWS personnel and partners felt that on-site interpretive service was critical during this event, both from a supporting agency perspective (at state and federal EOCs) and from a tactical decision-making perspective (at local EOCs). It was stated numerous times that having all of the important players in the same room was critical because it allowed everyone to ask questions and interact in a way that simply would not happen otherwise. Quotes which exemplify this sentiment include: “In the heat of the battle, on-site support was irreplaceable” (North Dakota EOC) and “On scene support dictated more of our decisions than not” (Montana EOC).

The Minot EOC initially received remote support via daily calls from WFO Bismarck and NCRFC. Once it became obvious there could be significant societal impacts within the city, the WFO and RFC supplied personnel to provide on-site decision support for the city of Minot.

The Minot EOC officials felt off-site support was sufficient until it became clear this could become a much larger event, with critical decisions and actions, and much more media and public interest. When this occurred, the on-site support was valuable for decision-making, press conferences, and even public relations needs with the city officials. It was noted that one of the big benefits of having on-site support was the immediate availability of someone to clarify or reiterate weather and hydrologic information as the officials were making critical decisions. Similar sentiments were provided in Glasgow, MT, where they noted the NWS personnel were able to break down the scientific issues to a level of understanding for the EOC officials.

Best Practice 8: Off-site support was utilized effectively until the event support requirements escalated to a level where on-site support was needed. This strategy was endorsed by EOC personnel in various locations.

7.3. Requirements for Effective On-Site Decision Support Service

Effective on-site DSS requires technological tools, procedural knowledge, interpersonal skills, and pre-existing collaborative working relationships. Most of the on-site DSS during the flood event was provided at EOCs, collaborating with personnel from multiple agencies.

Pre-Existing Collaborative Working Relationships

Interviews with NWS staff and EOC managers all indicated that success in decision support service was often based on having built relationships with EOC personnel *prior to the event* through contact and visits by NWS staff. Joyce Flinn, of the Iowa EOC, said “Emergency Managers don’t want to meet you in a disaster; I want to meet you ahead of time.” Kristi Turman, of the South Dakota EOC, said, “Our relationship with the NWS has always been strong, but preparation for spring flooding has strengthened our relationship with the Corps (USACE) and the media”. She added, “Because we had met ahead of time, everyone knew what to expect, who was doing what, what was probably going to happen, and what we needed to do to keep people and property safe. The public knew that when you have the NWS, the Department of Public Safety, and the governor’s office speaking together, it’s time to listen”.

Skill Set Required of DSS Personnel

Effective collaborative and interpersonal skills are also essential for effective on-site DSS. Major General Sprynczynatyk, of the North Dakota EOC, noted that “ego and attitude absolutely have to be checked at the door”. Others noted the need for “top notch communication skills," "the ability to interact with high level leadership," and "an understanding of the Incident Command System (ICS) structure." While these weren't identified as concerns during this event, the comments are important for the NWS to heed. The DSS position is not for everyone. It is important for DSS support personnel to demonstrate a positive, supportive, and helpful attitude. This is particularly true during high-stress situations, which is typically the case when on-site support is required.

Partner agencies recommended that the NWS consider the overall skill set of its DSS personnel prior to assigning them to support an EOC. In addition to interpersonal skills, briefing skills and conference call management skills are needed to streamline the communication of important information. Although many NWS personnel possess these skills, training may be needed to expand the pool of effective DSS providers.

Finding 36: Partners noted that specific technical and interpersonal skills were essential to work effectively in the DSS environment.

Recommendation 36: NWS managers should ensure that all personnel who perform the on-site DSS role have the technical and interpersonal skill sets required to work effectively with agency partners. Training should be available to potential DSS providers, as needed.

Information Technology

Ensuring availability of operative information technology is another important requirement for effective on-site DSS. NWS personnel at EOCs must be able to establish communication with their home office via phone, internet and email. They also need adequate access to PCs and printers at the DSS location. All of these IT-related functionalities posed challenges during this event.

WFO comments included:

- "IT security was overbearing and EOC staffers generally used their own laptops",
- "WiFi access was up and down at the DSS site and an AirCard was needed for web access",
- "VPN access to the regional intranet was slow to the point of being useless, resulting in no access to Sharepoint from the EOC",
- "We couldn't use the on-site printer", and
- "It would be nice to have real-time AWIPS analysis and graphics generation capabilities to on-site DSS personnel".

WFO Bismarck personnel summed it up succinctly, stating, "IT support for DSS was a major challenge."

Fact: Properly functioning IT capabilities are an essential component of effective DSS.

Finding 37: During this event, NWS DSS personnel were required to spend valuable time addressing IT issues rather than DSS-related activities.

Recommendation 37: The NWS should identify and deploy a variety of technological solutions to facilitate effective on-site DSS.

7.4. Overhead/Cost of Decision Support Services

There are a wide variety of costs to the NWS which are associated with providing DSS support, including travel and lodging costs, labor and overtime expenses, staff shortages at supporting offices, and the impact on personnel when deployed for an extended period of time.

Travel and Lodging

Travel and lodging costs were significant for those offices that provided on-site DSS at "remote" locations. In some cases, lodging at remote locations was required for weeks.

From a fiscal perspective, these costs must be repurposed from other program areas within the NWS budget. This has an impact on the NWS ability to financially support other programs or initiatives.

Overtime

On-site DSS often incurs significant overtime for the supporting staff member. Execution of routine DSS activities could routinely extend a number of hours beyond a normal 8-hour workday. In addition, where extended travel was required, these extra commuting hours would further extend the workday.

There are also times when the local office will incur additional overtime due to the absence of the on-site DSS provider.

Human Resources

The performance of on-site DSS had an impact on the availability of human resources for other important activities at local NWS offices. DSS personnel were unavailable to contribute to routine operations, program development and other activities.

Because of that, other staff members were required to cover the routine operations, and were unable to perform their own ancillary program responsibilities. All offices indicated they were able to prioritize work to meet the DSS needs. At one office, this re-prioritization led to the cancellation of SkyWarn training throughout their county warning area.

DSS staffing, ongoing workload with local flood issues and, in some cases, short-staffing at the WFO, created significant challenges at most offices. To address these staffing issues, several NWS offices requested personnel from other offices to assist them with their routine forecast duties.

Impact on Personnel

Personnel providing on-site DSS, who work long hours many consecutive days, can become mentally and physically fatigued. NWS forecasters are accustomed to working additional hours of overtime during significant events on an occasional basis. However, the DSS personnel worked long hours over an extended period of time, with little opportunity to recharge mentally and physically. This can also impact the quality of service provided.

Fact: It is usually possible for NWS offices to rotate personnel through the on-site DSS assignments.

Fact: Partners clearly stated they prefer continuity with the personnel providing them support.

The NWS will have to strike a balance between maintaining this continuity and providing for the needs of its personnel.

There is additional DSS overhead (including both time and funding) which is required to ensure readiness for future events. This includes the need to enhance outreach efforts with partners, complete required training, and ensure IT resources meet DSS needs.

The Service Assessment Team identified a number of aspects related to provision of DSS that should be reviewed from the policy and budget perspectives. Some of these items are listed below:

- What are the costs of DSS?
    - What are the monetary costs associated with on-site vs. off-site DSS?
    - What are the human resource costs associated with on-site vs. off-site DSS?
    - What are the technological costs (e.g., hardware, software, development, etc.) associated with on-site vs. off-site DSS?
- How will on-site DSS be funded?
    - Should there be Memorandums of Understanding with partner agencies to offset the cost of DSS?
- Do current staffing profiles satisfy expectations of future DSS requirements?
    - Will expansion of DSS activities have an impact on resources allocated to other current and future programs?
- Should there be an approval process for on-site DSS requests?
    - When should a local office decline a request, if ever?
    - To what level should DSS providers create “special services”? How specialized and extensive should this support be? (e.g., writing talking points for a mayor, facilitating FEMA disaster declaration requests, etc.)

Finding 38: NWS personnel noted a number of issues related to the provision of DSS that have not been fully addressed through policy.

Recommendation 38: The NWS should establish policy and provide guidance to enable the effective execution of DSS. This should include allocation of funding and personnel resources to support DSS activities, and the identification of activities that are appropriate for DSS.

7.5. Regional Operations Center (ROC) Contributions to Decision Support Services

The Regional Operations Centers at the NWS Central and Western Region Headquarters provided overarching coordination of event operations throughout their respective regions. They provided assistance to local offices by coordinating regional information, as needed, for national reporting requirements. Field forecast offices indicated this was useful, and likely reduced the time required to address questions regarding this nationally significant event. The ROCs also assisted in the coordination of additional staffing, as needed, to support DSS activities.

Even so, most field offices felt they were providing more support to the ROC than the ROC was providing to them. Part of this sentiment was related to duplicative requests for media contacts and impact summaries, some of which were already reported through other required processes. Field offices noted that the ROCs were not able to effectively assist them by coordinating information between the offices, states, agencies, and other entities.

Note: The addition of regional DSS support personnel in late 2011 should provide focus and clarity to regional activities which support the DSS process.

7.6. Public Affairs Strategies for Decision Support Service

High impact events, such as the Missouri and Souris River floods, typically garner significant media attention. Much of this media attention is drawn to the decision-making centers such as the EOCs.

The NWS deployed DSS personnel to the EOCs with the idea they would handle both the scientific and public affairs activities related to the event. At some of the more high profile locations, the extent of scientific support activities did not allow adequate time to effectively coordinate with the media. In Minot, ND, with intense local, national and international media interest, it became very evident that additional Public Affairs support was required. The NWS Central Region Headquarters deployed a Public Affairs specialist to Minot to assist with media collaboration.

At the onset of event, several partner agencies (e.g., USACE and USGS) immediately deployed Public Affairs personnel along with their on-site technical experts to the EOC. These Public Affairs personnel communicated with the media and helped advertise their agency contributions to the flood fight. They were also well-versed in utilizing Social Media, which was an additional, effective method to promote the support efforts provided by their agency personnel.

Fact: The USACE and USGS ensured public affairs specialists were deployed concurrently with their technical experts at the EOCs.

Fact: Overall, the NWS did not provide adequate Public Affairs support during this event. This support was not as well organized as that provided by other agencies. Additionally, when support was provided, it was later in the process and limited due to a lack of equipment (i.e., camera) and the ability to utilize Social Media.

Finding 39: In many situations, DSS specialists do not have the time or expertise to perform effective public affairs activities.

Recommendation 39a: The NWS should consider strategies which include simultaneous deployment of Public Affairs experts alongside DSS specialists, particularly in high profile events.

Recommendation 39b: The NWS should ensure its Public Affairs experts possess the proper tools and skills (including social media) to effectively provide internal and external media-related support and public relations outreach.

8. Use and Effectiveness of Social Media

NWS deployment of local office Facebook pages occurred during the spring of 2011. Many of the impacted offices implemented their Facebook page during the course of the event.

WFO and RFC personnel stressed that use of social media helped them in many ways. Facebook enabled NWS forecasters to obtain additional data from non-standard methods (e.g., non-COOP reports), which assisted greatly in traditionally data-sparse areas. WFO Billings, MT felt they "may have received more information via Facebook than through normal channels and that the information received was reliable." WFO Glasgow, MT noted that they received many aerial photos of flooding via their account, and stated, "Facebook was huge." NWS offices were also able to relay important flood-related information, including event impacts, imagery, and safety material. Public feedback on the Facebook pages helped NWS personnel gain a more complete understanding of the scope and magnitude of the event.

Best Practice 9: Social Media mechanisms were utilized to effectively obtain additional precipitation reports from data sparse areas.

NWS Facebook pages were also used by the Emergency Management community to maintain situational awareness of the event and obtain NWS information. The Montana EOC personnel stated "The NWS needs to continue with social media – it was essential." The North Dakota EOC felt it had a "huge value" for them.

Fact: NWS personnel, and many partners, noted that Facebook had significant value in terms of public outreach and information sharing.

9. Opportunities for Improved Services

9.1. Integration of Social Science into the Forecast Process

High impact and extreme flooding events often require NWS offices to alter their forecast process to meet specific partner needs. These modified procedures are often executed in close collaboration with, and at the request of, event collaboration partners.

While these special procedures can be examples of the flexibility required to meet partner needs in today's DSS environment, they can also underscore the need to understand and apply principles of social science to the end-to-end forecast process. Aspects such as the kind of information provided, methods of communication used, and timing of information provided are all issues that can be impacted by social science considerations. At times, these issues can involve political sensitivities, attentiveness to interagency needs, and the overall management of information flow to the public.

During this event, there were a number of circumstances where social responses became critical considerations during the forecast process. These social concerns impacted generation of the forecast itself, degree to which pre-coordination forecast information was shared with partners, and timing of the forecast release.

Societal Response to River Forecasts

One scenario evolved in which the NWS was asked to maintain a constant crest in its updated river forecasts. This request was made to influence societal response, even though objective scientific analysis suggested a different forecast solution would be more accurate. The social objectives were to maintain a consistent flood-fighting target for the temporary levee system, which would create a persistent public perception of the threat.

In light of the uncertainty surrounding this record forecast, this case demonstrates a legitimate, but very non-standard, forecast perspective, one which met the perceived socio-political need of forecast consistency to obtain a desired public response. This social science perspective deviates from typical NWS goals of providing the latest science-based information at all times. It also places the WFO and RFC in a challenging position of publishing a forecast they don't necessarily believe is accurate.

Finding 40: As social science considerations have increased, NWS operational personnel have been faced with situations which require striking an uncomfortable balance between social science needs and objective science-based processes.

Recommendation 40: The NWS should develop river forecast solutions which meet both social science interests and scientific principles. Short-term probabilistic forecasts are one potential solution to this challenge.

Pre-Coordination Information Sharing/Management

This section addresses societal needs for information sharing prior to release of the official river forecast. A number of situations occurred where various partners had an interest in the upcoming river forecast values, and desired access to that information prior to official public release.

The rationale for these requests generally included one of the following stated requirements:

1) the need to prepare a tactical response to the information contained in the river forecast prior to its release (important for planning appropriate flood mitigation activities), or
2) the need to prepare public information prior to release of the forecast (important to both internal and external partners who had public leadership or communication responsibilities).

As a result of these tactical planning and communication needs, there were requests to delay the official river forecast release for up to four hours after pre-release communication of the forecast with the partners. This process tends to conflict with the typical NWS practice of communicating new forecast information *as soon as it is available*.

Fact: There were inconsistent responses from NWS offices regarding the appropriateness of delaying the issuance of updated river forecasts.

If the NWS were to formally embrace the concept of routine pre-release forecast communication with partners, evidence from this event suggests there are a number of questions that may need to be addressed through policy.

1) In what situations would it be appropriate to delay river forecast issuance to achieve pre-release communication (major flooding, any flooding, any time, etc.)?
2) Who should (or should not) be included in this pre-release sharing of information? Should this group vary based on the situation?
3) How much of a delay in the forecast release is acceptable? Could the answer to this question vary based on the situation as well?

Finding 41: During this event, there were situations where partners requested access to river forecast information prior to their official public release. NWS field offices were unclear if, when, for whom, and for how long it would be appropriate to delay forecast issuance to support partner needs.

Recommendation 41: The NWS should develop policy regarding appropriate service-based responses to partner requests for pre-release sharing of river forecast information.

The NWS response to these situations during this event could be considered 'best practices', as they met partner needs, even though the required actions conflicted, in part, with established NWS practice. When standard procedures do not meet stakeholder needs, it is important for the NWS to adjust services accordingly. For this to be successful, the NWS must have service flexibility and associated policy which includes social science considerations.

9.2. Inundation Mapping

Since 2007, the NWS has implemented over 66 flood inundation mapping (FIM) libraries across the country, each of which are tied to NWS forecast points. Each library consists of geospatial representations (maps) of flood inundation at various flows and stages, using robust hydrologic analysis and hydraulic models. Where available, these maps are provided on the NWS AHPS web site for each forecast location. Many of these FIM libraries were developed with funds that originated outside of NWS base appropriations and were often made available by FEMA or other agencies following significant flood events.

Fact: During the 2011 flood event, the NWS had no flood inundation map libraries implemented within the Missouri or Souris River basins.

To assist emergency managers during this event, the USACE developed flood inundation maps for affected reaches at critical discharge levels. There were also state and local efforts to develop flood delineation maps. (A distinction should be made between a flood delineation map and a flood inundation map. The former may utilize GIS techniques as opposed to the rigorous data and modeling standards of a FIM). While some stakeholders identified minor discrepancies between these maps and observations during the event, there was an overwhelming sentiment that this information was critical in the flood response decision making process. A representative from the Nebraska DNR noted that, “An inundation map is worth 1000 impact statements.” Earl Imler of the Nebraska Emergency Management Agency stated, “I can’t see how inundation maps would not be a part of improved services in the future”.

Fact: During this event, some flood delineation and inundation information was developed by government agencies and the private sector to communicate the extent of flooding within the affected basins.

Fact: The NWS continues to support development of flood inundation mapping via a multiagency approach facilitated by the IWRSS consortium.

Fact: Recommendations from the NWS Service Assessments for the Central United States (2008; recommendation 26) and Nashville, TN (2010; recommendation 4) flood events noted the need to “accelerate” and “expedite” the implementation of flood inundation mapping.

Finding 42a: Partners and stakeholders expressed a need for additional flood inundation mapping libraries.

Finding 42b: Existing FIM methodologies have been an expensive and time-consuming process, which has slowed widespread development and implementation of inundations maps on AHPS web pages.

Recommendation 42: In addition to the current FIM library development process, the NWS, in collaboration with other agencies, where appropriate, should identify and support alternative cost-effective approaches to developing geospatial flood information that depicts the areal extent and depth of flood flows.

9.3. Hydrologic Service Evolution

Existing NOAA and NWS Strategic Plans highlight the importance of delivering “a broad suite of improved water forecasting services to support management of the Nation’s water supply.” The objective is to develop cross-government integrated water resource services, including expanded services such as water flow forecasts, water temperature, water quality, water oxygen content, and soil moisture conditions. This also includes the development and delivery of DSS products and tools.

This section considers overarching perspectives from this event which relate to the goals and objectives of the NOAA and NWS Strategic Plans.

Expanding and Enhancing Services

Within this document, numerous additions and enhancements in hydrologic and water resource services have been recommended. These include, but are not limited to, additional forecast locations, increased forecast issuance frequency, expansion of products and information produced, improved utilization of existing observational networks, and development of new scientific and technological capabilities, such as ensemble forecasts, short-term probabilistic forecasts, and inundation mapping.

DSS activities are noted in this report as critical inputs to partner decision-making processes. Stakeholders praised the overall NWS DSS efforts. As the DSS process becomes more fully developed in conjunction with the summit-to-sea water resources data and information plan, demand for this support will likely increase with time.

Incorporating New Technologies

NWS technological capabilities continue to evolve. AWIPS II, scheduled for implementation in 2012, will provide capabilities to share data and information more readily within the NWS and to partners as well. CHPS, which was implemented nationwide as of late 2011, will help integrate NOAA’s water research and development enterprise and operational service delivery infrastructure with other federal water agency activities, academia, and the private sector.

These new technologies will create opportunities to enhance interagency and partner collaboration activities with NWS offices. They will also offer opportunities to improve WFO/RFC river forecast modeling, collaboration, and real-time data sharing.

Some of the challenges during this event related to forecast collaboration and information sharing. As AWIPS II and CHPS are implemented, a new opportunity will exist to assess whether current collaboration and information sharing processes effectively utilize improvements and developments in this technology.

Improving the Hydrologic Service Delivery Structural Model

The NWS has existing policies and procedures which establish the collaborative river forecast process between the RFC and WFO. This unique WFO/RFC structure, where the WFO is responsible for issuing forecasts produced by the RFC, requires a close and strongly collaborative working relationship. If executed properly, the existing policies and procedures should minimize collaboration challenges between the offices. When procedures are not executed at an optimal level, challenges may arise.

The Service Assessment Team documented numerous instances during this event where there were collaboration challenges between MBRFC and WFOs. This led to occasional inconsistencies in the information presented to partners. Most of these challenges would likely have been avoided through strengthened WFO/RFC partnerships (**Section 5.5.1.1**) and improved execution of the river forecast update process (**Section 5.7**).

Although it appears these issues could have been avoided through skillful execution of existing policies and procedures, it may be unrealistic to assume these policies and procedures can, indeed, be executed flawlessly. It may be beneficial to consider whether some of these challenges could be inherent to the structure itself.

Human Resource Allocation Strategies

The NOAA and NWS Strategic Plans provide a framework which emphasizes agency responsiveness to stakeholder requirements. Along with the identification of these requirements, there is a fundamental need to ensure service-related activities match the requirements. An important component of this process is the evaluation and allocation of resources to support those requirements-based activities.

To effectively apply the Strategic Plan in this regard, the service, technological and structural considerations noted in this section will require an agile agency human resource allocation strategy. This would enhance flexibility in support of short-term and long-term hydrologic service delivery requirements by creating staffing profiles which allocate resources where and when they are needed.

Fact: NWS Headquarters continuously evaluates stakeholder needs, new capabilities, service delivery, and the basic organization and resource allocation of the agency hydrology program. Recent initiatives, such as IWRSS, are aimed at enhancing water resources science and services based on stakeholder input. These activities are at the core of the agency's collective science and service improvement efforts.

Finding 43: Numerous topics discussed in this assessment report, including developments in science and technology, stakeholder needs, and human resource allocation strategies, are relevant to the NWS hydrology program evaluation process.

Recommendation 43: The ongoing evaluation of NWS hydrologic services should consider specific details identified in this document related to effective utilization of improvements in science and technology, and challenges associated with the existing hydrologic service delivery structure and strategies. This evaluation should consider the implementation of ensemble and probabilistic forecast services and inundation mapping, the need for additional forecast information (locations, frequency, etc.), the impact of CHPS and other technologies as inter- and intra-agency forecast and collaboration tools, the evolution of DSS with agency partners, the role of WFOs and RFCs, and the incorporation of agile human resource allocation strategies to support these science and service advancements.

10. Summary

Record flooding on the Missouri and Souris Rivers, which occurred during the late spring and summer months of 2011, caused significant damage to infrastructure and the economic well-being over a very large geographical area. The flooding was caused by a combination of pre-existing wet soil conditions, record-setting snow pack over the northern High Plains and northern Rocky Mountains and very heavy rain which fell across large areas of these river basins.

During the event, an estimated 11,000 people were forced to evacuate Minot, North Dakota due to the record high water level of the Souris River, where 4,000 homes were flooded. Numerous levees were breached along the Missouri River, flooding thousands of acres of farmland and damaging transportation infrastructure. The flooding caused over $2 billion dollars in damages in the United States, and led FEMA to issue disaster declarations in each state along these rivers. There were 5 fatalities associated with flooding on the Missouri and Souris Rivers and their tributaries.

Decision support activities began in the winter and early spring when it appeared that heavy snowpack would lead to large volumes of runoff in these river basins. These services increased significantly in late May and persisted through June, when it became apparent river levels would be much higher than previously forecast. Numerous federal, state and local EOCs requested on-site support from NWS meteorologists and hydrologists so they could effectively manage flood fight activities and keep emergency flood responders safe. The need for daily on-site support, which extended for weeks at some locations, seriously impacted staffing at some of the WFOs and RFCs.

Interviews with partner groups indicated an exceptional level of appreciation for NWS services during this event, and a high value placed on NWS interactions in the DSS process. Response was unanimous that recent NWS effort to enhance its DSS activities, including direct on-site support at EOCs, was a critical component of effective decision-making by the partner agencies during this event. While there are some recommendations to further enhance the benefit and utility of the DSS process, this is an activity that is very strongly supported by those responsible for critical public response decisions along the Missouri and Souris Rivers. Despite the record flooding and major damage inflicted along these rivers, some property damage was mitigated and fatalities limited, due, in part, to the extraordinary and innovative efforts among RFC and WFO staff as they provided warning and decision support services.

Considerable internal and external collaboration occurred on a regular basis, relating to both weather and river forecast information. Many unique situations demanded new, innovative solutions that were met through interagency collaboration. External partners praised the NWS offices for their ability to meet those requirements. The collaboration process had some scientific and communication challenges as well. WFOs were, at times, challenged by specific DSS requirements of on-site EOC partners, and river forecasts that required interpretation or clarification. Similarly, RFCs were challenged by data issues, QPF impacts on the river forecasts, interagency water management collaboration requirements, and partner needs for special forecasts.

The NOAA and NWS Strategic Plans convey a need to continuously identify stakeholder requirements and adjust services accordingly. To effectively apply the Strategic Plan in this regard, numerous additions and enhancements in hydrologic and water resource services have been recommended by the Service Assessment Team. These include additional forecast locations, increased forecast issuance frequency, expansion of products and information produced, improved utilization of existing observational networks, and development or enhancement of scientific and technological capabilities, such as ensemble forecasts, short-term probabilistic forecasts, QPF, hydraulic modeling, and inundation mapping.

In total, the Service Assessment Team identified 37 facts, 46 findings, 46 recommendations, and 9 best practices. See Appendix B for a summary of the facts, findings recommendations, and best practices. The definition of these terms is provided in Appendix C.

The recommendations from this assessment, when implemented, will lead to improvements in the quality of NWS products and procedures to enhance decision-making processes associated with flood events. The ultimate goal of this report is to further the NWS mission of protecting lives and property and enhancing the national economy.

Appendix A

Locations that Experienced Record or Major Flooding

WFO	River/Creek	Site	Crest Stage (in feet)*	Comments	Date	Major FS (in feet)
Aberdeen, SD (ABR)						
ABR	Elm River	Westport	23.38	3rd Highest	2/27/2011	19.0
ABR	James River	Columbia	19.80	2nd Highest	7/16/2011	18.0
ABR	James River	Stratford	20.43	Record	4/30/2011	18.5
ABR	James River	Ashton	24.40	3rd Highest	4/29/2011	15.0
ABR	James River	Redfield	28.09	3rd Highest	4/27/2011	24.0
ABR	Turtle Creek	Redfield	15.50	4th Highest	3/23/2011	15.0
Bismarck, ND (BIS)						
BIS	Des Lacs River	Foxholm	20.57	3rd Highest	6/1/2011	19.0
BIS	James River	Grace City	> 17.37	2nd Highest	4/11/2011	15.0
BIS	Long Creek	Noonan †	19.55	Record	6/21/2011	n/a
BIS	Missouri River	Williston	30.61	Record	6/21/2011	26.0
BIS	Missouri River	Bismarck ‡	19.25	Highest since	7/1/2011	19.0
BIS	Pipestem Creek	Pingree	12.29	2nd Highest	7/9/2011	13.0
BIS	Souris River	Sherwood	28.16	Record	6/23/2011	25.0
BIS	Souris River	Lake Darling inflow	29,700 cfs	Record flow	6/23/2011	n/a
BIS	Souris River	Foxholm	22.44	Record	6/25/2011	15.0
BIS	Souris River	Minot 4NW	24.37	Record #	6/25/2011	22.0
BIS	Souris River	Minot Broadway	1561.65	Record	6/26/2011	1555.0
BIS	Souris River	Logan	37.54	2nd Highest	6/23/2011	38.0
BIS	Souris River	Sawyer	29.28	Record	6/26/2011	26.0
BIS	Souris River	Velva	1512.00	Record	6/30/2011	1515.0
BIS	Souris River	Verendrye †	18.53	Record	6/26/2011	n/a
BIS	Souris River	Towner	58.73	Record	6/28/2011	56.0
BIS	Souris River	Bantry	16.90	Record	6/28/2011	14.0
BIS	Souris River	Westhope	22.66	Record	7/2/2011	16.0
BIS	Willow Creek	Willow City	15.24	7th Highest	6/22/2011	16.0

Billings, MT (BYZ)						
BYZ	Big Horn River	near Big Horn ‡	10.85	Record	5/23/2011	14.0
BYZ	Little Big Horn River	near Hardin	12.32	Record	5/23/2011	11.8
BYZ	Musselshell River	Harlowton ‡	10.25	Record	5/25/2011	8.0
BYZ	Musselshell River	Shamut ‡	9.27	Record	5/26/2011	7.5
BYZ	Musselshell River	Lavina ‡	14.04	Record	5/25/2011	10.5
BYZ	Musselshell River	Roundup ‡	14.78	Record	5/26/2011	11.0
BYZ	Musselshell River	Musselshell ‡	13.23	Record	5/27/2011	12.0
BYZ	Powder River	near Locate ‡	11.70	3rd Highest	5/21/2011	13.5
BYZ	Pumpkin Creek	near Miles City ‡	13.98	Record	5/21/2011	14.0
BYZ	Rock Creek	Red Lodge	7.82	Record	6/30/2011	8.5
BYZ	Tongue River	Decker ‡	9.83	4th Highest	5/23/2011	14.0
BYZ	Tongue River	Birney Day School	7.30	Record	6/12/2011	8.0
BYZ	Tongue River	Miles City	13.99	Record	5/21/2011	15.0
BYZ	Yellowstone River	Livingston	10.15	2nd Highest	6/30/2011	10.0
BYZ	Yellowstone River	Billings	13.95	3rd Highest	7/2/2011	15.5
BYZ	Yellowstone River	Forsyth	12.35	3rd Highest	5/24/2011	12.0
BYZ	Yellowstone River	Miles City	16.51	2nd Highest	2/15/2011	21.0
BYZ	Yellowstone River	Miles City	14.54	4th Highest	5/24/2011	21.0
Cheyenne, WY (CYS)						
CYS	North Platte River	Saratoga	10.49	Record	6/9/2011	10.5
CYS	North Platte River	Sinclair	11.46	2nd Highest	6/9/2011	11.0
CYS	North Platte River	Mitchell	9.70	2nd Highest	6/20/2011	9.5
CYS	North Platte River	Minatare	7.84	5th Highest	6/17/2011	9.5
CYS	North Platte River	Bridgeport	8.86	Record	6/18/2011	12.0
Pleasant Hill, MO (EAX)						
EAX	Missouri River	St. Joseph	29.97	2nd Highest	6/28/2011	27.0
EAX	Missouri River	Atchison	31.00	2nd Highest	6/29/2011	30.0
EAX	Missouri River	Leavenworth	30.80	2nd Highest	6/30/2011	30.0
EAX	Missouri River	Sibley	31.10	5th Highest	7/7/2011	31.0
EAX	Missouri River	Napoleon	27.60	2nd Highest	7/10/2011	30.0
EAX	Missouri River	Waverly	30.75	2nd Highest	7/9/2011	31.0
EAX	Missouri River	Miami	28.80	4th Highest	7/10/2011	29.0

Sioux Falls, SD (FSD)						
FSD	Big Sioux River	Bruce †	11.56	Record	3/29/2011	11.5
FSD	Big Sioux River	Brookings	13.41	5th Highest	3/24/2011	12.0
FSD	Big Sioux River	Dell Rapids	15.62	4th Highest	3/24/2011	15.0
FSD	Big Sioux River	Sioux City - Hwy 77	102.20	5th Highest	6/27/2011	108.0
FSD	James River	Huron	20.16	2nd Highest	3/26/2011	15.0
FSD	James River	Forestburg	20.26	2nd Highest	3/25/2011	16.0
FSD	James River	Mitchell	25.14	2nd Highest	3/26/2011	22.0
FSD	James River	Scotland	19.48	6th Highest	3/27/2011	16.0
FSD	James River	Yankton	22.22	3rd Highest	3/28/2011	16.0
FSD	Missouri River	Chamberlain †	75.10	Record	7/10/2011	70.0
FSD	Missouri River	Greenwood †	38.90	Record	7/12/2011	32.0
FSD	Missouri River	Verdal †	29.20	Record	6/30/2011	26.0
FSD	Missouri River	Niobrara †	26.80	Record	6/27/2011	24.0
FSD	Missouri River	Springfield †	14.80	Record	6/22/2011	14.0
FSD	Missouri River	Gayville †	57.10	Record	6/29/2011	60.0
FSD	Vermillion River	Wakonda	17.30	4th Highest	3/20/2011	17.0
Glascow, MT (GGW)						
GGW	Milk River	Tampico	27.96	Record	4/15/2011	27.0
GGW	Milk River	Glasgow	34.08	Record	6/9/2011	32.8
GGW	Musselshell River	Mosby ‡	16.00	2nd Highest	5/23/2011	14.0
GGW	Missouri River	Wolf Point ‡	14.77	4th Highest	6/14/2011	17.5
GGW	Missouri River	Culbertson ‡	17.23	6th Highest	6/21/2011	25.0
GGW	Yellowstone River	Sidney	22.08	2nd Highest	3/19/2001	21.7
GGW	Yellowstone River	Sidney	21.92	3rd Highest	5/25/2011	21.7
North Platte, NE (LBF)						
LBF	North Platte River	Lewellen	8.65	Record-tie	5/21/2011	9.5
LBF	North Platte River	North Platte	7.69	Record	6/3/2011	6.4

Omaha, NE (OMA)						
OMA	Missouri River	Maskell †	31.90	Record	6/29/2011	34.0
OMA	Missouri River	Blair	32.73	2nd Highest	6/29/2011	33.0
OMA	Missouri River	Omaha	36.29	2nd Highest	7/2/2011	40.0
OMA	Missouri River	Plattsmouth	36.73	Record	6/30/2011	35.0
OMA	Missouri River	Nebraska City	28.27	Record	6/28/2011	27.0
OMA	Missouri River	Brownville	44.79	Record	6/23/2011	43.0
OMA	Missouri River	Rulo	27.26	Record	6/27/2011	25.6
Riverton, WY (RIW)						
RIW	Big Horn River	Basin	10.80	Record	6/11/2011	13.0
RIW	North Platte River	Casper	8.34	2nd Highest	6/20/2011	10.0
RIW	Wind River	Kinnear	9.36	Record	7/8/2011	11.0
RIW	Wind River	Riverton	11.80	Record	7/2/2011	12.0
Rapid City, SD (UNR)						
UNR	Little Missouri River	Camp Crook	19.27	Record	5/24/2011	19.0
UNR	White River	White River	18.16	Record	3/15/2011	17.0

Table 3. Locations that experienced record or major flooding.

* Preliminary - USGS stage data is provisional as of publication date
‡ Special request forecast points
† Not an RFC forecast point; information available on WFO webpage
# Modern record; 1881 estimates indicate stage may have been higher at that time

Appendix B

Summary of Facts, Findings and Recommendations, and Best Practices

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

Summary of Facts

5.1.3 River Stage and Stage-Flow Relationship

Fact: The timetable for review and implementation of USGS rating curve updates is left to the discretion of individual forecasters at MBRFC.

Fact: Rating curve extensions were provided by the USGS; however, they contained a considerable level of uncertainty.

Fact: Confidence in river forecasts decreased as the stage-flow relationships became dependent on the extended ratings provided by the USGS.

Fact: MBRFC forecasters indicated that use of backwater curves often requires significant manual interaction in the forecast process to produce reasonable results. They also indicated that many of the curves need to be updated.

5.1.4 Snow Water Equivalent

Fact: In general, WFOs and partners valued the NOHRSC SWE information.

5.2.1 Quantitative Precipitation Forecasts (QPF)

Fact: Recommendation 8 from the NWS Service Assessment for the Nashville, TN flood event (2010) noted that "RFCs should communicate in detail their use of QPF and QPE in generating river forecasts to…critical partners."

5.4.1 Deterministic Forecasts (Official, Contingency)

Fact: Partners were aware of the river forecasts based on the HPC 5% and 95% contingency precipitation forecasts, but generally did not find them useful because the results were too extreme and there was little probability that either of the results would occur.

5.4.2 Short-Term Ensemble Forecasts

Fact: Finding 12 from the NWS Service Assessment for the Central United States flood event (2008) noted that "forecast uncertainty information, such as ensemble forecasts of river stage…, was very useful to the USACE and others in their contingency planning." The associated Recommendation stated that "the NWS should expand its provision of forecast uncertainty information to the USACE and other local and state agencies involved in flood contingency planning."

5.4.3 Long-Term Ensemble (Exceedance Probability) Forecasts

Fact: NWS AHPS long-lead forecasts are difficult for many users to properly interpret and apply. Many stakeholders were unaware of these forecast products. Others found them to be very helpful, when explained effectively.

Fact: There are many forecast points throughout the Missouri River basin for which probabilistic long-lead forecasts are not produced.

5.4.4 Volumetric Forecasts

Fact: Volumetric water supply forecasts are routinely identified as high value water resource products by stakeholders at the federal, state and local level.

5.4.6 Streamflow Forecast Service Requirements

Fact: All EOC personnel desired to have the latest information before their critical decision-making times, but most recognized that NWS data management and forecast processes were not able to meet all of those needs with the latest model-run forecasts. Even so, they did desire the best, most representative river forecast information that was available *at that time*.

5.5.1.1 WFO/RFC Collaboration

Fact: To provide the best service during an event of this magnitude, WFOs and RFCs need a solid pre-existing inter-office relationship and a clear commitment to communicate information within the agency.

5.5.1.2 WFO/RFC Collaboration with NOHRSC

Fact: In support of the NOHRSC SWE modeling efforts, a number of WFOs provided real-time snow core observations. NOHRSC indicated these observations were essential inputs for their data assimilation process, thus improving the accuracy of information available from the NOHRSC snow model.

5.5.2 Interagency Collaboration (with USACE, USGS, USBR, and others)

Fact: The USACE in both Omaha and Kansas City reported that their collaboration with MBRFC was superb. This success emanated from a long history of close collaboration and an increased focus on face-to-face meetings in recent years. Both agencies stated that without these meetings, their ability to react to unique situations during this event would have been much more difficult.

5.5.3 Collaboration Methods

Fact: NWSChat can be ineffective when multiple NWSChat rooms are used to communicate with a single partner during an event.

Fact: NWS personnel were unsure if they were authorized to use text messaging capabilities on their government-issued cell phones for DSS-related activities.

5.6.3 AHPS and the NWS Web

Fact: NWS web services, including AHPS pages, were very important tools for NWS DSS personnel and the partners served at the various EOCs.

Fact: AHPS web pages do not accommodate the display of additional hydrologic modeling information alongside the river forecasts.

Fact: The differences between the way county-based and polygon-based flood warnings are displayed on the WWA map caused confusion regarding the areal coverage of the flood threat.

Fact: WFO Hydrologic Forecast System developers, along with some NWS Central Region offices, have established a method to incorporate polygon warning information within RiverPro.

Fact: Recommendation 4 from the NWS Service Assessments for the Southeast U.S. flood event (2009) noted that "warnings should not encompass an entire county if only a portion of the county will be impacted."

Fact: NWS Web pages do not auto-update.

Fact: Throughout the event, NWS offices received many requests to implement additional web services in support of DSS activities.

6 Weather and Climate Outlooks (long-lead preparedness)

Fact: In general, partners do not currently use CPC extended forecasts, even though they are widely disseminated through NWS briefings.

7.3 Requirements for an Effective On-Site DSS

Fact: Properly functioning IT capabilities are an essential component of effective DSS.

7.4 Overhead/Cost of Decision Support Services

Fact: It is usually possible for NWS offices to rotate personnel through the on-site DSS assignments.

Fact: Partners clearly stated they prefer continuity with the personnel providing them support.

7.5 Public Affairs

Fact: The USACE and USGS ensured public affairs specialists were deployed concurrently with their technical experts at the EOCs.

Fact: Overall, the NWS did not provide adequate Public Affairs support during this event. This support was not as well organized as that provided by other agencies. Additionally, when support was provided, it was later in the process and limited due to a lack of equipment (i.e., camera) and the ability to utilize Social Media.

8 Use and Effectiveness of Social Media

Fact: NWS personnel, and many partners, noted that Facebook had significant value in terms of public outreach and information sharing.

9.1 Integration of Social Science into the Forecast Process

Fact: There were inconsistent responses from NWS offices regarding the appropriateness of delaying the issuance of updated forecasts.

9.2 Inundation Mapping

Fact: During the 2011 flood event, the NWS had no flood inundation map libraries implemented within the Missouri or Souris River basins.

Fact: During this event, some flood delineation and inundation information was developed by government agencies and the private sector to communicate the extent of flooding within the affected basins.

Fact: The NWS continues to support development of flood inundation mapping via a multiagency approach facilitated by the IWRSS consortium.

Fact: Recommendations from the NWS Service Assessments for the Central United States (2008; recommendation 26) and Nashville, TN (2010; recommendation 4) flood events noted the need to “accelerate” and “expedite” the implementation of flood inundation mapping.

9.3 Hydrologic Service Evolution

Fact: NWS Headquarters continuously evaluates stakeholder needs, new capabilities, service delivery, and the basic organization and resource allocation of the agency hydrology program. Recent initiatives, such as IWRSS, are aimed at enhancing water resources science and services based on stakeholder input. These activities are at the core of the agency's collective science and service improvement efforts.

Summary of Findings and Recommendations

5.1.1 Precipitation

Finding 1: NCRFC and MBRFC both experienced situations where data sources and networks currently used in their precipitation analysis did not sufficiently reflect information received from other available resources.

Recommendation 1: NCRFC and MBRFC should evaluate the potential utility of alternative precipitation sources [such as CoCoRaHS, SNOTEL and Satellite Precipitation Estimates (SPE)] in areas where the current gage-radar networks are insufficient and, where appropriate, adopt techniques to leverage all data sources in the development of observed MAP.

5.1.3 River Stage and Stage-Flow Relationships

Finding 2: At times, the review (and implementation, as appropriate) of updated USGS rating curves was not completed at MBRFC for weeks. This led to inconsistencies between published NWS and USGS stage-flow relationships, which created confusion among some partners.

Recommendation 2: MBRFC should adjust their rating curve update procedures to expedite the review (and implementation, as appropriate) process.

Finding 3: The hydrologic modeling techniques currently employed by MBRFC do not adequately simulate backwater affected river stages.

Recommendation 3a: MBRFC should consider implementation of a hydraulic model, such as the Hydrologic Engineering Center River Analysis System (HEC-RAS), for portions of their area of responsibility where backwater effects adversely impact the quality of the river forecast.

Recommendation 3b: MBRFC should augment current hydrologic modeling procedures by updating or developing backwater curves for affected sites. This would serve as an interim solution until hydraulic modeling can be implemented.

5.1.4 Snow Water Equivalent

Finding 4: Simulated SWE information was present in the RFC hydrologic modeling systems, but was not routinely available for use by WFOs and their partners.

Recommendation 4: MBRFC and NCRFC should consider providing simulated SWE information with their river forecasts for use by all stakeholders.

5.2.1 Quantitative Precipitation Forecasts (QPF)

Finding 5: Individually, the three available QPF products (i.e., HPC, WFO and RFC) did not consistently meet partner DSS needs with regard to spatial/temporal extent and relevance to the official river forecast. Consequently, NWS personnel used multiple QPF sources within their DSS briefings, which resulted in some confusion among the stakeholders.

Recommendation 5: NWS DSS personnel should utilize a QPF briefing product which independently meets all the spatial, temporal and relevance criteria needed by the stakeholders.

Finding 6: Most stakeholders had opinions – often strong and negative – about QPF skill, although their conclusions were not based on quantitative scientific evidence. To improve partner confidence in the use of QPF and maximize its benefit in the hydrologic forecast process, there is a need to educate stakeholders regarding its strengths and limitations.

Recommendation 6: The NWS (WFOs, RFCs and HPC) should include QPF verification as part of its routine stakeholder outreach and engagement activities.

5.3.3.1 Calibration

Finding 7: MBRFC and NCRFC did not have adequate tools to anticipate and account for the shortened flow path of the Milk and Souris River channels, respectively, as their natural sinuosity became submerged.

Recommendation 7: MBRFC and NCRFC should investigate additional routing techniques (including hydraulic models) to account for situations where the river channel flow path is shortened as its natural sinuosity is submerged.

Finding 8: The extreme nature of this event produced hydrologic conditions that were not previously observed at several sites and, therefore, were not part of the historical datasets used in the hydrologic model calibration process. Consequently, some of the hydrologic model configurations contain calibrated parameters that were not valid during this event.

Recommendation 8: MBRFC and NCRFC should use observations from this event to evaluate the validity of their current hydrologic model parameters and configurations. Simulations which perform unacceptably should be recalibrated, as appropriate.

5.3.3.2 Reservoir Operations

Finding 9: MBRFC has several forecast points which are affected by upstream reservoirs that are not modeled adequately.

Recommendation 9: MBRFC should add reservoir models, as needed, at sites affected by upstream reservoirs, and investigate options for establishing better projected release schedules. This includes collaboration with the reservoir operators and reservoir modeling for short-term deterministic and long-range probabilistic forecasts.

5.3.3.3 Levee Failures

Finding 10: MBRFC is in the process of cooperatively developing a HEC-RAS model for the lower Missouri River with the Kansas City District of the USACE. This unsteady, fully dynamic model has the capability of modeling the impact of levee overtopping and breaches.

Recommendation 10: The mainstem Missouri River HEC-RAS model, currently being developed by MBRFC in cooperation with the USACE, should be completed and configured to run operationally in the CHPS environment. Forecasters should be trained how to modify and interpret the model results to account for levee breaches.

5.4.1 Deterministic Forecasts (Official, Contingency)

Finding 11: Current integration of QPF into the official MBRFC and NCRFC river forecasts does not utilize the full capability of the science and has resulted in confusion among partners.

Recommendation 11: RFCs should consider utilizing QPF which is consistent with the temporal duration of the river forecast. This QPF should be based on meteorological analysis, and could include confidence-based adjustments.

5.4.2 Short-Term Ensemble Forecasts

Finding 12a: The singular deterministic official river forecast does not satisfy all customer needs.

Finding 12b: Many partners wanted to see short-term ensemble and probabilistic river forecasts which would have provided a more complete array of potential outcomes.

Recommendation 12: The NWS should expedite implementation of HEFS to satisfy partner needs for short-term ensemble and probabilistic river forecast information.

5.4.3 Long-Term Ensemble (Exceedance Probability) Forecasts

Finding 13: Most stakeholders reported some level of confusion with the long-lead probabilistic river forecast products on the AHPS web pages.

Recommendation 13: The NWS should evaluate the effectiveness of existing methods for presenting and explaining long-lead probabilistic river forecasts to its partners, including the "About this graph" feature on the AHPS web pages.

Finding 14: The 30-day (or bi-weekly) issuance schedule for long-lead probabilistic river forecasts did not always meet the needs of all partners.

Recommendation 14: The NWS should work with partners to identify optimal update schedules for their long-lead probabilistic river forecasts.

Finding 15: Some partners indicated access to long-lead probabilistic river forecast information at additional sites in the Missouri River basin would have been beneficial.

Recommendation 15: MBRFC should work with partners to identify locations throughout the Missouri River basin where long-lead probabilistic river forecasts need to be implemented.

5.4.4 Volumetric Forecasts

Finding 16: MBRFC did not produce volumetric forecasts at a number of locations where partners indicated they would have been useful. Partners also indicated a desire for more frequent volumetric forecast updates to assist in long range planning and situational awareness.

Recommendation 16: Consistent with the overarching IWRSS goals, MBRFC should coordinate with the USACE, USBR, and other partners to develop a volumetric forecast information suite which meets water resource management agency requirements.

5.4.5 Streamflow Forecast Accuracy

Finding 17: Formal streamflow forecast verification information was generally unavailable during this event. Partners were not able to assess the historical accuracy of the streamflow forecasts.

Recommendation 17a: The NWS, in general, and RFCs, in particular, should produce timely and meaningful verification to share with stakeholder agencies as part of their regular engagement with those agencies.

Recommendation 17b: The NWS should consider including online forecast verification as part of its forecast distribution system (e.g., the AHPS pages).

5.4.6 Streamflow Forecast Service Requirements

Finding 18a: There were a number of instances where the existing river forecast service suite did not adequately support stakeholder decision-making processes. A variety of opportunities were identified to expand the frequency, timing, content, and location of river forecast services to meet stakeholder requirements.

Finding 18b: Many stakeholders were unaware of the full suite of MBRFC forecast capabilities that would have enhanced planning and facilitated more effective DSS. Specifically, they did not know the RFC could produce non-standard probabilistic information. Examples of this information include inflow and tailwater forecasts on reservoir controlled rivers, the probability that a river will fall below a certain level at a specific time, and the probability of a reservoir reaching a certain level.

Recommendation 18: MBRFC should perform a comprehensive services evaluation, in collaboration with their internal and external partners, to assess the need for new river forecast points, evaluate the issuance schedules of routine river forecasts and products, and provide additional services and information which meet partner needs. This evaluation process should be performed on a regular basis.

5.5.1.1 WFO/RFC Collaboration

Finding 19: Scientific collaboration between MBRFC and the WFOs during the event did not always create a shared perspective regarding hydrologic modeling processes and the resulting official river forecast.

Recommendation 19: MBRFC and the WFOs should engage in periodic scientific collaboration meetings to increase mutual understanding of hydrometeorological data needs and hydrologic modeling processes.

Finding 20: The relationships between MBRFC and its WFOs were not sufficient to adeptly work through some of the more challenging aspects of this event. Although there was considerable communication between MBRFC and its WFOs, and much of it was effective, there were also situations where this communication could have been improved.

Recommendation 20: MBRFC should work with its WFOs (and vice versa) to strengthen the WFO/RFC partnership. An understanding of each office's requirements should be enhanced, with a unified mission perspective reinforced by WFO and MBRFC management.

5.5.1.2 WFO/RFC Collaboration with NOHRSC

Finding 21: NOHRSC participated in numerous SWE collaboration calls with various WFOs and RFCs. This frequently resulted in a duplication of effort and created workload challenges for NOHRSC personnel.

Recommendation 21: As needed, the NWS Central Region and Western Region should facilitate multi-WFO/RFC calls with NOHRSC to maximize collaboration and more effectively utilize NOHRSC time resources.

5.5.2 Interagency Collaboration (with USACE, USGS, USBR, and others)

Finding 22: Communication with Saskatchewan Water was deficient during the Souris River flood event. NCRFC experienced critical information gaps regarding conditions upstream of Minot in the Souris Basin.

Recommendation 22: NCRFC and WFO Bismarck should work directly with their Canadian partners to enhance real-time communication capabilities and improve the exchange of information related to Souris River forecasting.

5.5.3 Collaboration Methods

Finding 23: Some NWS personnel used personal phones to ensure text messaging capability was available to them for their DSS-related activities. This required them to carry and communicate using both their personal and government-issued phones.

Recommendation 23: The NWS should clarify policy regarding utilization of government-issued phones for SMS, MMS and internet-based (e.g., email) processes. In addition, the NWS should ensure government-issued phones have sufficient capability to fully support immediate communication needs, including texting plans and email access.

5.6.1 Flood Warnings

Finding 24: FLWs were issued for areas that were protected by permanent levees. With the levees intact, there were no imminent flood threats in these areas.

Recommendation 24: WFOs should work with local communities to determine appropriate flood warning issuance levels in areas that are protected by permanent levees or similar structures.

5.6.3 AHPS and the NWS Web

Finding 25: NWS web service and disruption in access to the AHPS CMS negatively impacted DSS and reduced the credibility and usefulness of NWS web services to key partners and customers.

Recommendation 25: The NWS should institute IT policy which ensures safeguards are in place to prevent web service downtime and disruption in access to interfaces through which NWS staff provide web page updates. This is especially critical during high-impact events.

Finding 26: The daily NWS transfer of rating curve updates during this event was not sufficiently frequent to avoid inconsistencies with USGS information.

Recommendation 26: The NWS should identify a solution to allow for more timely and effective updates to static information, such as rating curves, used by AHPS web pages.

Finding 27: NWS AHPS pages could not provide the flexibility to accommodate the unique requirements of non-standard forecasts, such as the “likely crest range forecasts” based on the Gavins Point projected reservoir releases.

Recommendation 27: The NWS should examine potential opportunities to provide non-standard information within the AHPS suite of products to meet current and future DSS needs.

Finding 28: Stakeholders expressed interest in viewing the temperature and precipitation forcings used in the hydrologic models alongside the AHPS hydrographs.

Recommendation 28: The NWS should consider adding AHPS web display functionality that facilitates visualization of additional hydrologic modeling information related to the forecasts, such as observed/forecast temperature and precipitation and river forecast verification.

Finding 29: Partners find AHPS flood impact statements useful, and identified ways to improve the content.

Recommendation 29: NWS Service Hydrologists should ensure AHPS flood impact statements are current, include information relating to levee control, and, if possible, include potential impacts at river levels exceeding previous record floods, especially for critical infrastructure.

Finding 30: County-based RiverPro warnings do not accurately represent the true areal coverage of the flood threat.

Recommendation 30: The NWS should update operational warning software to consistently reflect a more realistic true areal coverage of the flood threat.

Finding 31: NWS partners requested auto-update capability for NWS web pages.

Recommendation 31: The NWS should add auto-update capability to NWS web pages.

Finding 32: Current NWS web infrastructure does not permit rapid development and deployment of customer-based web services. The negative impact resulting from this lack of flexibility increases during high-impact events.

Recommendation 32: The NWS should investigate the potential to accommodate flexible, real-time web service modifications to meet the needs of partners.

5.7 Quality Control, Monitoring and Updating of River Forecasts

Finding 33: Initial quality control, monitoring, and updating of the official river forecasts by MBRFC and NCRFC did not consistently meet internal and external stakeholder needs.

Recommendation 33: MBRFC/NCRFC and their associated WFOs should collaboratively discuss their capabilities and customer-based expectations regarding forecast monitoring and updating activities. The result of this discussion should be an agreement which details a collaborated WFO/RFC policy regarding river forecast monitoring and updates. The details of this agreement should be clearly communicated and implemented at the RFCs and WFOs.

6 Weather and Climate Outlooks (long-lead preparedness)

Finding 34: Partners indicated the probability information in the CPC forecasts was not useful for flood planning. Alternatively, they expressed a need for climate forecasts which identify potential for extreme events, such as the Spring 2011 Missouri River basin precipitation.

Recommendation 34: The NWS should collaborate with its DSS partners to identify what seasonal, monthly and other forecast information would be most beneficial to them in their decision-making processes, and work to provide that information in their forecast product suite.

7.1 Value and Effectiveness of Decision Support Service

Finding 35: NWS graphical briefing packages did not always conform adequately to the geographic scales desired by partners.

Recommendation 35: The NWS should identify methods to produce products and graphics on varying geographic scales to support information needs of DSS partners.

7.3 Requirements for Effective On-Site Decision Support Service

Finding 36: Partners noted that specific technical and interpersonal skills were essential to work effectively in the DSS environment.

Recommendation 36: NWS managers should ensure that all personnel who perform the on-site DSS role have the technical and interpersonal skill sets required to work effectively with agency partners. Training should be available to potential DSS providers, as needed.

Finding 37: During this event, NWS DSS personnel were required to spend valuable time addressing IT issues rather than DSS-related activities.

Recommendation 37: The NWS should identify and deploy a variety of technological solutions to facilitate effective on-site DSS.

7.4 Overhead/Cost of Decision Support Services

Finding 38: NWS personnel noted a number of issues related to the provision of DSS that have not been fully addressed through policy.

Recommendation 38: The NWS should establish policy and provide guidance to enable the effective execution of DSS. This should include allocation of funding and personnel resources to support DSS activities, and the identification of activities that are appropriate for DSS.

7.6 Public Affairs Support of Decision Support Services

Finding 39: In many situations, DSS specialists do not have the time or expertise to perform effective public affairs activities.

Recommendation 39a: The NWS should consider strategies which include simultaneous deployment of Public Affairs experts alongside DSS specialists, particularly in high profile events.

Recommendation 39b: The NWS should ensure its Public Affairs experts possess the proper tools and skills (including social media) to effectively provide internal and external media-related support and public relations outreach.

9.1 Integration of Social Science into the Forecast Process

Finding 40: As social science considerations have increased, NWS operational personnel have been faced with situations which require striking an uncomfortable balance between social science needs and scientific integrity.

Recommendation 40: The NWS should develop river forecast solutions which meet both social science interests and scientific principles. Short-term probabilistic forecasts are one potential solution to this challenge.

Finding 41: During this event, there were situations where partners requested access to river forecast information prior to their official public release. NWS field offices were unclear if, when, for whom, and for how long it would be appropriate to delay forecast issuance to support partner needs.

Recommendation 41: The NWS should develop policy regarding appropriate service-based responses to partner requests for pre-release sharing of river forecast information.

9.2 Inundation Mapping

Finding 42a: Partners and stakeholders expressed a need for additional flood inundation mapping libraries.

Finding 42b: Existing FIM methodologies have been an expensive and time-consuming process, which has slowed widespread development and implementation of inundations maps on AHPS web pages.

Recommendation 42: In addition to the current FIM library development process, the NWS, in collaboration with other agencies, where appropriate, should identify and support alternative cost-effective approaches to developing geospatial flood information that depicts the areal extent and depth of flood flows.

9.3 Hydrologic Service Evolution

Finding 43: Numerous topics discussed in this assessment report, including developments in science and technology, stakeholder needs, and human resource allocation strategies, are relevant to the NWS hydrology program evaluation process.

Recommendation 43: The ongoing evaluation of NWS hydrologic services should consider specific details identified in this document related to effective utilization of improvements in science and technology, and challenges associated with the existing hydrologic service delivery structure and strategies. This evaluation should consider the implementation of ensemble and probabilistic forecast services and inundation mapping, the need for additional forecast information (locations, frequency, etc.), the impact of CHPS and other technologies as inter- and intra-agency forecast and collaboration tools, the evolution of DSS with agency partners, the role of WFOs and RFCs, and the incorporation of agile human resource allocation strategies to support these science and service advancements.

Summary of Best Practices

5.5.1.2 WFO/RFC Collaboration with NOHRSC

Best Practice 1: Where staffing allows, a positive WFO response to NOHRSC field snow core requests can enhance the quality of information provided by the NOHRSC model and can also enhance the collaboration process between WFO and NOHRSC.

5.5.2 Interagency Collaboration (with USACE, USGS, USBR, and others)

Best Practice 2: MBRFC participated in a meeting with its critical partners (USACE, USBR, and USGS) in November 2010 to enhance interagency communication and information exchange.

Best Practice 3: NCRFC, MBRFC and WFO Bismarck actively participated in daily coordination calls for their respective events with the USGS and USACE to develop a unified message regarding river forecasts and reservoir releases prior to public dissemination.

7.1 Value and Effectiveness of Decision Support Service

Best Practice 4: Webinars were frequently used to provide information during the winter season, including CPC outlooks and AHPS graphics. These webinars were noted as being very useful by partners.

Best Practice 5: GoToMeeting, email briefing summaries, web page summaries, and other processes were used effectively to disseminate information to all levels of partners; this enabled transmission of high-level briefings to county and local levels as well and allowed the information to reach the largest audience possible.

Best Practice 6: All NWS offices interviewed developed specialized methods of providing information to their partners. These were all examples of how the NWS adjusted services at each DSS location to meet unique partner needs.

7.2 On-Site vs. Off-Site Decision Support Services

Best Practice 7: The NWS and USACE collaboratively determined that the USACE required on-site meteorological support and off-site hydrological support during this event. The USACE was comfortable with hydrological issues, but needed a higher level of support regarding meteorological interpretation.

Best Practice 8: Off-site support was utilized effectively until the event support requirements escalated to a level where on-site support was needed. This strategy was endorsed by EOC personnel in various locations.

8 Use and Effectiveness of Social Media

Best Practice 9: Social Media mechanisms were utilized to effectively obtain additional precipitation reports from data sparse areas.

Appendix C

NWS Definitions

Best Practice – An activity or procedure that has produced outstanding results during a particular situation which could be used to improve effectiveness and/or efficiency 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 improve NWS operations and/or services, and it is achievable, the recommendation will likely become an action. Recommendations should be clear, specific, and measurable.

Flood Severity Levels

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

Minor Flooding – Minimal or no property damage, but possible some public threat.

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

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

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

Appendix D

Acronyms and Abbreviations

AHPS	Advanced Hydrologic Prediction Service
ASOS	Automated Surface Observing System
AWIPS	Advanced Weather Interactive Processing System
AWIPS II	Advanced Weather Interactive Processing System II
AWOS	Automated Weather Observing System
cfs	Cubic Feet Per Second
CHPS	Community Hydrologic Prediction System (replacement for NWSRFS)
CMS	AHPS Configuration Management System
CoCoRaHS	Community Collaborative Rain, Hail and Snow Network
COOP	Cooperative Observer Program (NWS)
CPC	Climate Prediction Center (NCEP)
DJF	December through February
DSS	Decision Support Service
EM	Emergency Manager
EOC	Emergency Operations Center
ESP	Ensemble Streamflow Prediction
FEMA	Federal Emergency Management Agency
FIM	Flood Inundation Mapping
FMAP	Future Mean Areal Precipitation
FMAT	Future Mean Areal Temperature
GSD	Global Systems Division (NOAA Earth System Research Laboratory)
HAS	Hydrometeorological Analysis and Support Forecaster (RFC)
HEC-RAS	Hydrologic Engineering Center River Analysis System
HEFS	Hydrologic Ensemble Forecast Service
HPC	Hydrometeorological Prediction Center (NCEP)
IA	Iowa
ICS	Incident Command System
IT	Information Technology
IWRSS	Integrated Water Resources Science and Service
KS	Kansas
MAP	Mean Areal Precipitation
MAT	Mean Areal Temperature
MBRFC	Missouri Basin River Forecast Center (Pleasant Hill, MO)
MMS	Multimedia Messaging Service
MN	Minnesota
MO	Missouri
MPE	Multisensor Precipitation Estimator
MT	Montana
NCEP	National Centers for Environmental Prediction (NWS)
NCRFC	North Central River Forecast Center (Chanhassen, MN)
ND	North Dakota

NDFD	National Digital Forecast Database (NWS)
NE	Nebraska
NIDS	NWS Internet Dissemination System
NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center (Chanhassen, MN)
NPVU	National Precipitation Verification Unit (NWS)
NRCS	Natural Resources Conservation Service (USDA)
NWS	National Weather Service
NWSRFS	NWS River Forecast System
QPE	Quantitative Precipitation Estimates
QPF	Quantitative Precipitation Forecast
RAWS	Remote Automated Weather Stations
RFC	River Forecast Center (NWS)
ROC	Regional Operations Center (NWS)
SD	South Dakota
SMS	Short Message Service
SNODAS	Snow Data Assimilation System (NOHRSC)
SNOTEL	Automated Snowpack Telemetered Network (NRCS)
SPE	Satellite Precipitation Estimates
SWE	Snow Water Equivalent
TN	Tennessee
UTC	Coordinated Universal Time
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WFO	Weather Forecast Office (NWS)
WWA	Watch/Warning/Advisory

Appendix E

Software, IT, and Other Information

12Planet	NWS internal collaboration software package
AirCard	A wireless broadband device used for connecting to the internet over 3G or 4G networks
FFA	NWS code for Flash Flood Watch
FFW	NWS code for Flash Flood Warning
FLS	NWS code for Flood Statement
FLW	NWS code for Flood Warning
NWSChat	NWS external collaboration software package
RiverPro	NWS software used for creating river flood watches, warnings and statements
VPN	Virtual Private Network – can be used to provide remote access to a central organizational network
WiFi	A mechanism for wirelessly connecting electronic devices, such as computers and communication systems
xmACIS	A custom applied climate information system used by NWS offices