Regional Service Assessment

Remnants of Tropical Storm Lee and the Susquehanna River Basin Flooding of September 6-10, 2011

U.S. DEPARTMENT OF COMMERCE
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Cover Photograph: Mount Joy, Lancaster County, MD, Air National Guard performed an airlift; WFO State College, PA

Service Assessment

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May 2012

National Weather Service

Mickey Brown
Acting Director, Eastern Region

Preface

Large scale weather patterns allowed tropical moisture from the remnants of Tropical Storm Lee and the Atlantic Ocean to stream northward across the Mid-Atlantic Region, September 6–9, 2011. This pattern allowed continuous rain, very heavy at times, to persist for 48 hours. Because this event occurred only a week and a half after excessive rainfall from Hurricane Irene, the remnants of Tropical Storm Lee produced record flash flooding and river flooding across parts of central New York and central and eastern Pennsylvania.

Given the historical significance of this event, the National Weather Service's Eastern Region chartered a Regional Service Assessment Team to examine warning and forecast services provided by the National Weather Service. This assessment provides additional focus on dissemination, preparedness, and warning response within the community as they relate to these services.

Service Assessments provide a valuable contribution to ongoing efforts by the National Weather Service to improve the quality, timeliness, and value of our products and services. Findings and recommendations from this assessment will improve techniques, products, services, and information provided to our partners and the American public.

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Service Assessment Team

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Executive Summary

During the last part of August 2011, Hurricane Irene passed through the northeast United States producing heavy rain. A week and a half later, the remnants of Tropical Storm Lee produced record setting rain fall over the same area, leading to historic flooding in the Susquehanna River basin. The flooding produced by the rain from Hurricane Agnes in 1972 is the benchmark for flooding in the Susquehanna basin. The flooding associated with heavy rain from the remnants of Tropical Storm Lee is the worst flood of record for the southern tier of New York and portions of northeast Pennsylvania. Twelve river forecast point records were broken.

The Service Assessment Team found that the National Weather Service provided excellent services to their customers. Decision support services and warnings were provided well in advance of the flooding, giving decision makers enough lead time to make evacuation and preparedness decisions. Customers were very satisfied with the National Weather Service's performance before, during and after the flooding.

The Service Assessment Team also found areas where the National Weather Service could improve its customer service and operations. The key findings and recommendations from the assessment were:

Key Findings and Recommendations:

- Turn Around, Don't Drown ™ signs were not installed at some vulnerable locations due to issues with Department of Transportation standards. National Weather Service should work with the Department of Transportation to determine why the national standard for the Turn Around, Don't Drown ™ sign is not uniformly accepted from state to state and develop a sign to fit the standard.

- Eastern Region service backup procedures will be evaluated to ensure paired backup offices are appropriate.

- National Weather Service should develop a robust cross training program for River Forecast Center personnel so staff can be more easily deployed to other River Forecast Centers during large scale, long duration flooding events.

- Impact statements associated with various flood levels at river forecast location should be frequently updated.

- Lack of knowledge regarding the operating limits of the gaging equipment at Wilkes-Barre, Pennsylvania created confusion and uncertainty. National Weather Service needs to work with its partners in the water community to ensure operating limits of stream gaging equipment are known and available.

Service Assessment Report

1. Purpose of Assessment Report

This document presents findings and recommendations regarding National Weather Service (NWS) performance during the Susquehanna River flooding and flash flooding from September 6-10, 2011. Heavy rainfall from the remnants of Tropical Storm **(**TS) Lee produced widespread flash flooding and river flooding in the Susquehanna Valley. Flash flooding was extreme in some locations and many river points came close to or exceeded flooding records set in June 2006 and flooding from Hurricane Agnes in June 1972. Twelve forecast points set new floods of record (Appendix F).

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

- Services provided by the Middle Atlantic River Forecast Center (MARFC) to the Weather Forecast Office (WFO)
- Impact-Based Decision Support Services (IDSS)
- Nature of the support provided by NWS to customers and partners
- Effectiveness of the support provided
- Methods of information management
- Services of the WFO/RFC to various users/partners including United States Geological Survey (USGS), United States Army Corps of Engineers (USACE) , emergency management and river basin commissions
- Effectiveness of the interagency collaboration

The team identified best-case operations, procedures, and practices, and made recommendations to address service deficiencies, new service opportunities, necessary forecaster decision assistance tools, and communications methods to effectively carry out decision support in a high impact event.

2. Methodology

The NWS formed a Service Assessment team on September 28, 2011. Team efforts included the following:

- Completed onsite evaluations from October 11-14, 2011
- Interviewed staff from WFOs in State College, PA, and Binghamton, NY, and the MARFC in State College, PA, the offices with primary responsibility for providing forecasts, warnings, and decision support to the residents and Emergency Managers (EM) of the most affected areas
- Conducted phone interviews with the Meteorologists in Charge (MIC) at WFO Baltimore/Washington, DC, and WFOs Philadelphia and Pittsburgh, PA
- Met with representatives of the Pennsylvania Emergency Management Agency (PEMA), the Susquehanna River Basin Commission (SRBC), the USGS and the Director of the Pennsylvania USGS Water Science Center
- Conducted phone interviews with representatives from USACE, Baltimore District, and USGS Ithaca, NY
- Interviewed EMs, the media, the public, and other government agency representatives
- Conducted assessments of the affected areas
- Interviewed Binghamton Mayor Matt Ryan and several storm water managers
- Evaluated products and services issued by the aforementioned WFOs and RFCs
- Evaluated national guidance issued from the Hydrometeorological Prediction Center (HPC)
- Documented significant findings and recommendations to improve the effectiveness of NWS products and services

3. Event and Hydrometeorological Summary

3.1. Meteorological Overview

Hurricane Irene passed through the northeast United States, making landfall on August 27, 2011 and then again on August 28. **Figure 1** shows storm total rainfall for Hurricane Irene. A week and a half later, heavy rains associated with TS Lee moved up from the Gulf of Mexico and across the northeast United States through Pennsylvania and New York.

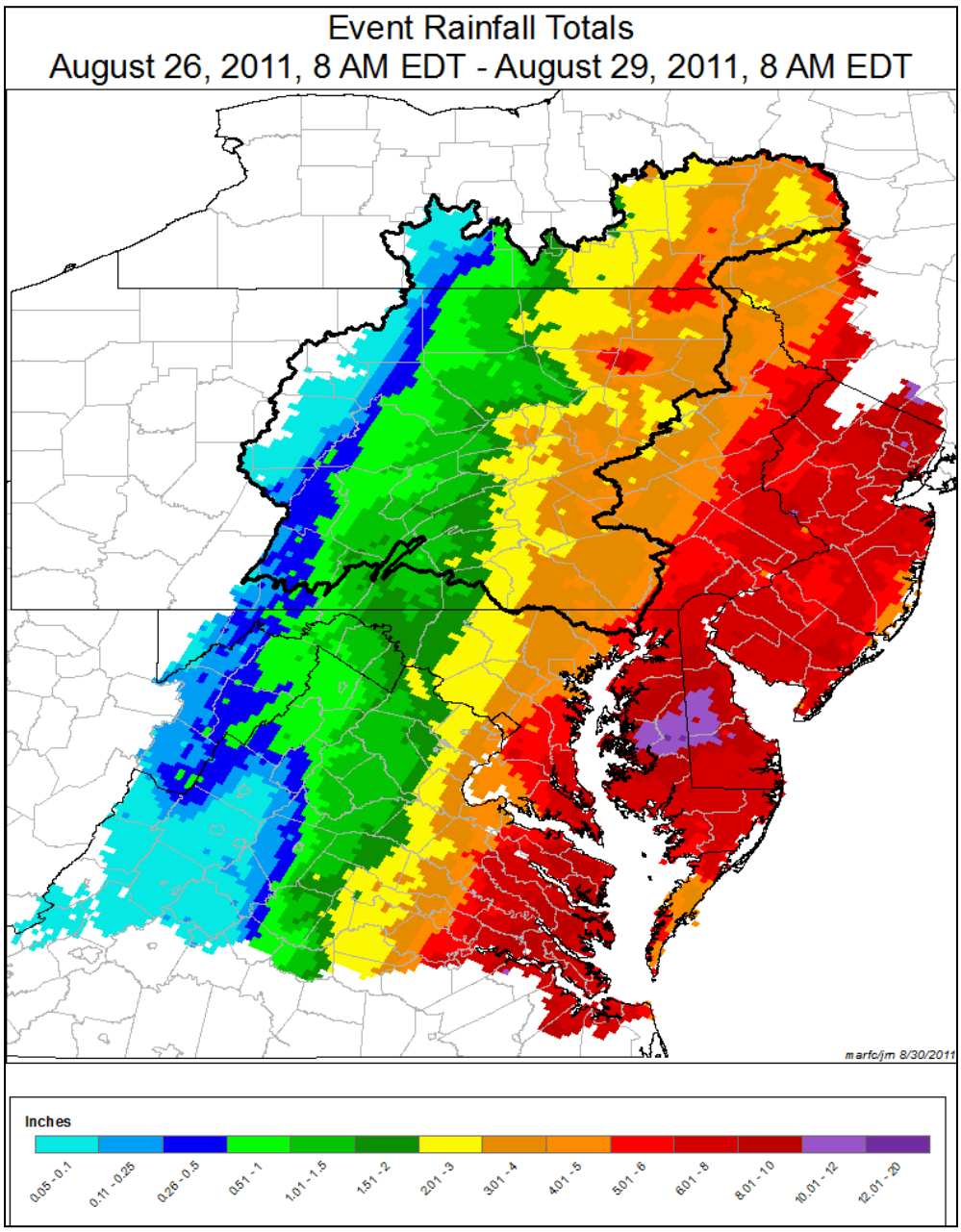

Figure 1: Storm totals for Hurricane Irene over the Susquehanna River Basin outlined in black

Because portions of the Susquehanna River basin were already saturated by Hurricane Irene rainfall, the additional heavy rain associated with the remnants of TS Lee produced widespread flash flooding and river flooding in and to the east of the Susquehanna Valley. Several locations in the Susquehanna basin broke precipitation records set by Hurricane Agnes (June 1972); 12 forecast points set new floods of record (Appendix F). **Figure 2** shows rainfall amounts from the remnants of TS Lee.

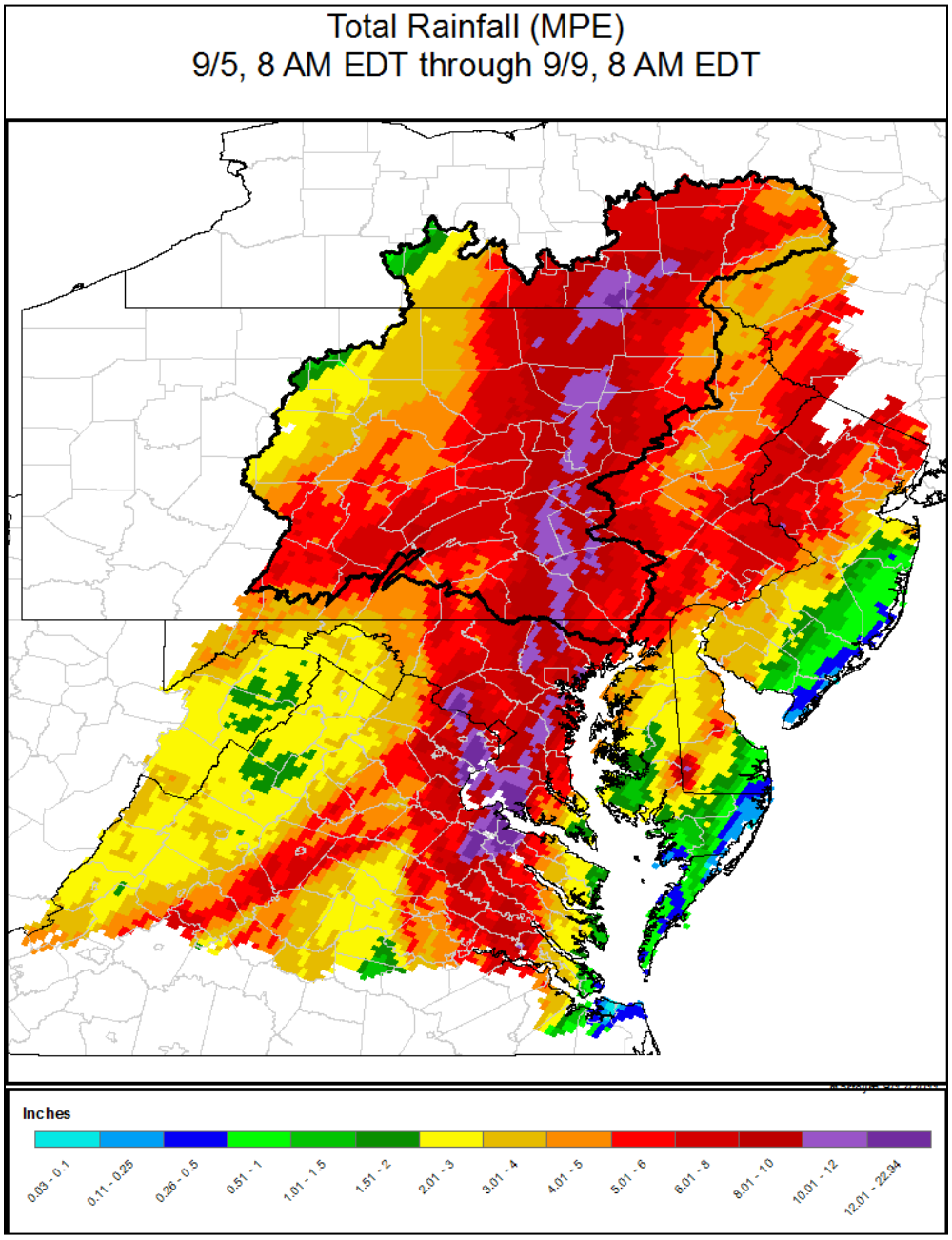

Figure 2: Shown are rainfall totals from remnants of TS Lee. For rainfall amounts at specific locations see Appendix B.

3.2. Synoptic Situation

As TS Lee moved slowly westward along the Gulf Coast, it produced heavy rainfall in Louisiana and Mississippi. A complex combination of interactions between a large scale trough over the Ohio Valley, moisture associated with the remnants of TS Lee, Hurricane Katia in the Atlantic, an upper-level jet streak over Quebec, and a near-stationary lower-to-mid level tropospheric frontal zone over the eastern United States, led to heavy rains moving up through the mid-Atlantic states and historic levels of flooding.

By 8 a.m., September 6, having undergone extra-tropical transition, Lee was located over northern Georgia. The surface low weakened as it moved up the Appalachian Mountain chain. Heavy rain fell on September 7-8 as the strong low-level flow and above normal precipitable water produced an extensive, north-to-south oriented band of heavy rain. Little east-west movement occurred in this band for more than 18 hours as waves of convective rain moved north from Virginia, across Pennsylvania and into New York.

3.3. Hydrologic Overview

Antecedent conditions were very wet across the Susquehanna region. The initial rainfall preceding Lee over the Labor Day weekend was associated with an east-west frontal boundary over the Mid-Atlantic region. The interaction of the stalled frontal boundary with a strong northern stream short wave, a persistent jet entrance region, and the surge of deep tropical moisture, resulted in a multi-day, heavy rainfall event (Appendix B). Significant precipitation fell from the early morning hours of September 6 through the morning of September 9, with large amounts of rain along the main rainfall axis falling in less than 18 hours. This rain fell over portions of the basin that had received rainfall from the earlier passage of Hurricane Irene.

The flooding associated with heavy rain from the remnants of TS Lee during September 2011 is the worst flood of record for the southern tier of New York and portions of northeast Pennsylvania. Twelve river forecast point records were broken. NWS's Flood Frequency Analysis ranks this event at the fourth largest flood of record in the Mid-Atlantic behind Hurricane Agnes in 1972, the winter flood of 1996, and the flood of March 1936.

4. Impacts

4.1. Pennsylvania

The remnants of TS Lee left significant amounts of water over almost all of central and eastern Pennsylvania, affecting the Susquehanna River basin. Nearly every municipality along the Susquehanna River experienced flooding including Towanda, Wilkes-Barre, Bloomsburg, Danville, Sunbury, Harrisburg, and Marietta.

More than 2,000 people were evacuated and 3,000 homes and businesses were flooded in Bradford County. Over half of these homes had major damage or were uninhabitable. Athens and other small communities were particularly hard hit. Almost every road in the county had flood damage. So many roads were damaged in the county that more than 10 days later water and food had to be transported by air to reach stranded residents. Record flooding almost completely destroyed the town of Monroeton and destroyed the flood levee built to protect the

community. While many rural farms in Bradford County were wiped out, farmers had time to move and protect livestock; however, there was about $7 million in crop damage.

Tunkhannock in Wyoming County was trying to recover from flood damages caused by Irene and rains over Labor Day Weekend when the remnants of Lee hit. In Luzerne County, more than 100,000 people were ordered to evacuate with about 60,000 people in Wilkes-Barre heeding the call. While the Wilkes-Barre levee system held to the new record river crest, towns like West Pittston saw water rise several feet higher than it did during Hurricane Agnes (June 1972) and other communities like Shickshinny were under water as the river spread across the valley. Had the Wilkes-Barre levee failed, several billion dollars in additional damage would have occurred according to local officials.

Due to the aftermath of the historic flooding, the Bloomsburg State Fair, scheduled to run from September 24 to October 1, was cancelled for the first time since 1855. Some parts of the fairgrounds were covered in 10-12 feet of water.

Ten deaths in Pennsylvania have been attributed to the storm and thousands of people were evacuated (Appendix C). Many counties opened shelters in high schools or churches. Preliminary estimates show at least 23,780 structures (businesses, mobile homes, single family, and multi-family homes) affected, with 1,050 structures destroyed and 7,975 reported to have had major damage. The Department of Agriculture reported wide spread crop damage, much of which was uninsured.

PEMA, state, county, and municipal agencies were fully engaged for this event. State and local incident management teams and response personnel from across the state were deployed to the impacted areas. Successful evacuations of hospitals, nursing homes, and residences occurred throughout the state, along with critical rescues during the height of the flooding. On September 8, President Obama declared a State of Emergency for Pennsylvania. This initial State of Emergency declaration enabled funds to be sent for emergency measures only. On September 12, the President signed a major disaster declaration for Pennsylvania. This declaration made federal aid available to the state and ordered federal aid to supplement state and local recovery efforts in the area affected by TS Lee. To date in Pennsylvania, total damage (debris removal, emergency protective measures, road and bridge repair, water control facilities, buildings, utilities, and parks) is estimated to be $200 million.

4.2. New York

Historic flooding occurred along the Susquehanna River and surrounding basins in New York as the remnants of TS Lee moved northward into the northeast United States. Extreme flash flooding destroyed homes that had not seen flooding before. The rivers rapidly swelled and eventually topped levees and broke flood records. In Binghamton, NY, the flood waters spilled over a levee that had protected the city since the 1940s. The flooding inundated 25,000 homes and businesses along the Susquehanna and its tributaries in the state. There were 30,000 people evacuated; hundreds of roads and bridges were flooded and dozens destroyed. The NWS's close communication with local officials led to them posting "States of Emergency" and "Mandatory Evacuation" orders before flooding became serious. These actions helped get people out of harm's way. There were no flood related fatalities in New York. States of Emergency were in

effect for counties along the Susquehanna River in the southern tier of New York. All major interstates, including Routes 17, 81, and 88, in New York were closed during the height of the flooding. Most of the severe flooding occurred in Broome and Tioga Counties, which, combined, totaled more than $900 million in damages. A FEMA representative stated the flooding and impacts from Lee and Irene combined to be the worst natural disaster in New York State history.

On September 13, President Obama declared a major disaster for New York. There was no initial State of Emergency declaration for emergency spending similar to the one issued for Pennsylvania; however, emergency operations centers (EOCs) were fully activated prior to the floods and the state deployed over 130 National Guard to Broome County in advance of the river flood to aid mandatory evacuations. New York State eventually brought in rescue and medevac helicopters, over 40 high-axle trucks and Humvees, special boats, and over 1,000 guardsmen to aid with rescues and response. To date, the estimated damage is nearing $1 billion in New York.

4.3. Fatalities

There were 10 confirmed flood-related fatalities during the event. All 10 fatalities occurred in Pennsylvania. There was one fatality in Bradford County, four in Dauphin County, three in Lancaster County, one in Lebanon County, and one in the city of Philadelphia. Four of the fatalities were female; six were male (Appendix C).

There were no flood related fatalities reported in New York despite the historic flooding. This statistic is notable because the flooding in New York was similar to what occurred during Hurricane Agnes in 1972, during which over 30 people were killed. Local EMs and officials attribute at least part of the credit for the lack of fatalities to the level of decision support services NWS provided.

Robin Smith, Athens, Pennsylvania Township Supervisor commented, "…*we really could have had loss of life on this one, and you [NWS] made us see that we needed to move, and move fast. Loss of things has never been an importance at a time like this—but loss of life can never be replaced.*"

A Flood Watch was issued Monday night (September 5) which provided 30 hours lead time before significant flash flooding and 40 hours before significant river flooding. The Watch mentioned the possibility for "dangerous major flooding." Flash Flood Warning lead times averaged 145 minutes. Flash Flood Emergency language was inserted into some of the Flash Flood Warnings during the height of the heaviest rainfall. County EMs in the upper watershed stated, *"Thanks to the critical information NWS Binghamton provided to us and what we did with that information, WE SAVED LIVES."*

Finding 1a*:* Of the 10 storm-related fatalities, five occurred as a result of automobiles engulfed by rushing floodwaters near swollen stream channels.

Finding 1b: Turn Around, Don't Drown ™ signs were not installed at some vulnerable locations in New York and Pennsylvania prior to the flooding as a result of issues with Department of Transportation (DOT) standards.

State DOT representatives said the United States DOT's Federal Highway Administration Manual on Uniform Traffic Control Devices does not contain the Turn Around, Don't Drown ™ sign. Therefore, some state and local municipalities will not allow the signs to be installed on roadways. These signs promote flooding safety and are a valuable tool that can be easily recognized at vulnerable locations along roadways.

Recommendation 1: The NWS Office of Climate, Water, and Weather Services (OCWWS) Hydrologic Service Division should work with the DOT to determine why the national standard for the Turn Around, Don't Drown ™ sign is not uniformly accepted from state to state and develop a sign to fit the DOT standard.

5. Warning Services Performance

In 2007, the NWS introduced storm-based warnings for flash floods. These warnings are more geographically specific for short-duration weather events. Storm-based warnings show the specific meteorological or hydrological threat area and are not restricted to geopolitical boundaries. Prior to that, such warnings were issued countywide. To compare statistics from 2011 to flooding in prior years, both verifications statistics are provided.

5.1. Storm-based Flash Flood Warning Verification

There were 53 polygon Flash Flood Warnings issued by WFOs State College and Binghamton for the event. The probability of detection (POD) was 95 percent and the false alarm rate (FAR) was 13 percent. The average lead time was 125 minutes. The Government Performance and Results Act metric in 2011 for accuracy (POD) was 72 percent and for Storm-Based Flash Flood Warning lead time was 38 minutes.

5.2. County-based Flash Flood Warning Verification

WFOs State College and Binghamton issued a total of 236 county-based Flash Flood Warnings for the event. The POD was 100 percent and the FAR was 45 percent. The average lead time was 168 minutes. NWS issued Flash Flood Emergency Warnings prior to the worst flooding. Details of storm-based and county-based Flash Flood Warning verification statistics are available in Appendix D.

5.3. River Point Warning Verification

WFOs State College and Binghamton issued a total of 57 point-based flood warnings for the event. The average lead time was 7.5 hours. The POD was 90 percent and the FAR was 16 percent. In some cases, rainfall rates were so high, flooding along larger rivers was more akin to a flash flood and reached above major flood stage in record time.

5.4. Flash Flood Warning Performance Comparison

Prior to this event, the last historic flash flood event to impact the Susquehanna River Valley occurred in June 2006. Comparison of performance statistics from June 2006 to September 2011 reveals a significant improvement in average lead time. This report used county-based Flash Flood Warning statistics for comparison because storm-based statistics were not computed in 2006. The average warning lead time during the June 2006 flash floods was 98 minutes compared to 168 minutes during this event. That statistic reflects an increase of 70 minutes. POD was 98 percent for the 2006 event, 100 percent for 2011.

	2011 National Goal Accuracy	2011 Eastern Region Goal Accuracy	TS Lee Event Actual Accuracy
Flash Flood	**72%**	**72%**	**95%**
River Flood	**N/A**	**83%**	**90%**

Table 1: Detection accuracy for the TS Lee event in comparison to national and regional performance metrics

	2011 National Goal Lead Time	2011 Eastern Region Goal Lead Time	TS Lee Event Actual Lead Time
Flash Flood	**38 min.**	**38 min.**	**125 min.**
River Flood	**N/A**	**N/A**	**7.52 Hours**

Table 2: Lead time for the TS Lee event in comparison to national and regional performance metrics

5.5. WFO State College, PA, Performance

WFO State College, PA, initially began to highlight the potential for heavy rainfall with the Hazardous Weather Outlook (HWO) issued at 6:01 a.m., Friday, September 2, 2011. The HWO mentioned *"locally heavy rain in excess of 2 inches is possible from training heavy showers and thunderstorms later Sunday through Labor Day."*

Thunderstorms and heavy rain showers brought 1-3 inches of rainfall in short periods from Sunday afternoon, September 4, through the night. Flash Flood Watches for this event were posted on Sunday, September 4, with Flash Flood Warnings following late in the evening. Gaged rivers in the area measured nearly three-quarters bank full on Monday, September 5. These soaking rains set the stage for the flooding rains that started on Tuesday night, September 6.

A Flood Watch was issued for the entire county warning area (CWA) on Monday evening, September 5, through Thursday evening, September 8, due to anticipated heavy rain. Forecasters coordinated with staff at WFOs Pittsburgh and Baltimore/Washington on the Watch issuance as well as with their Senior Service Hydrologist (SSH) and the Warning Coordination Meteorologist (WCM) regarding potential for serious flooding Tuesday night through Thursday. This Watch was the first to be issued in Pennsylvania in anticipation of the heavy rains with the remnants of TS Lee.

In addition, WFO State College began to include non-routine hydrology sections in its Area Forecast Discussions issued at 10:16 p.m., Monday, September 5. This section was updated throughout the flood event. The hydrology sections discussed the flood potential, specific areas to be impacted, quantitative precipitation forecasts (QPF), and antecedent conditions to convey effectively the WFO's hydrometeorological thinking and potential impacts throughout the event.

The WFO issued Areal Flood Warnings beginning Tuesday, September 6, at noon for their southwestern CWA then Tuesday evening for much of the remainder of its CWA. The warnings were extended and reissued for much of Wednesday, Thursday and Friday when flash flooding occurred. The WFO first issued Flash Flood Warnings at 9:30 a.m., Wednesday, September 7, in the lower Susquehanna and 10:20 a.m. for the middle and upper Susquehanna Valley counties. The warnings were extended throughout the day and night into Thursday. A second round of Flash Flood Warnings was issued on Friday, September 9, for much of the lower and middle portion of the CWA.

The WFO issued River Flood Warnings for mostly moderate flooding of the tributaries to the Juniata River and main stem Susquehanna on Tuesday morning, September 6, for Wednesday flooding. River Flood Warnings for major flooding on the Susquehanna River were issued by late morning of Wednesday, September 7, for flooding on Thursday and cresting on Friday and Saturday.

On Thursday, September 8, the Upper Boon Lake Dam in Shrewsbury Township, about 1.5 miles west of Muncy Valley in Sullivan County, had the spillway blocked by debris. Officials feared the dam giving way. WFO State College was alerted to a potential flash flood situation. Three homes downstream of the dam were evacuated as a precaution.

Also on Thursday, due to excessive water over the spillway, officials were watching the Dehart Dam in Dauphin County, a water supply reservoir for Harrisburg. Evacuations were a possibility. The county was asked to contact the NWS if it needed a Flash Flood Warning for evacuations.

5.6. WFO Binghamton

WFO Binghamton began to highlight the potential for heavy rainfall with the HWO issued at 3:43 a.m., Friday, September 2. This product stated tropical moisture interacting with a front could produce heavy rainfall from Sunday night into Tuesday. A subsequent HWO issued at 5:06 a.m., Monday, September 5, stated the remnants of Lee combined with the stalled front could lead to additional heavy rainfall. The WFO issued a Flash Flood Watch for the entire CWA at 4:34 a.m., Tuesday, September 6, as it became evident significant moisture from the remnants of Lee would be impacting the service area. The Flash Flood Watch stated, *"There would be a potential for dangerous moderate to major flooding on some rivers by Thursday night and Friday."* At 11:19 a.m., Wednesday, September 7, WFO Binghamton updated the watch emphasizing major flash flooding and river flooding would take place.

In addition, Area Forecast Discussions issued by WFO Binghamton began to include the non-routine hydrology sections with the 4:59 a.m., Tuesday, September 6, issuance. This section was updated multiple times and carried throughout the flood event. The hydrology sections

discussed the flood potential, specific areas to be impacted, QPF, and antecedent conditions to convey effectively the WFO's hydrometeorological thinking and potential impacts throughout the event.

Late Tuesday evening, September 6, WFO Binghamton transmitted initial Flash Flood Warnings across northeast Pennsylvania at 11:04 p.m. The issuances of Flash Flood Warnings spread north and expanded across the upper Susquehanna basin into the New York counties Wednesday morning. As flood conditions worsened, these warnings were continually reissued throughout Wednesday afternoon and into Thursday. At 11:33 a.m., Wednesday, forecasters issued the new and enhanced Flash Flood Emergency product for portions of Broome and Tioga Counties in New York, and Bradford and Susquehanna Counties of northeast Pennsylvania. This product was used to illustrate the incredible rainfall rates falling over the area and the devastating impact flash flooding would have to this relatively urban corridor along the Susquehanna River. WFO Binghamton issued a total of seven Flash Flood Emergency products during the event.

The WFO issued River Flood Warnings for major to record flooding on the headwaters and upper main stem of the Susquehanna River during the late morning and afternoon hours of Wednesday, September 7, for flooding to exceed the major flood stages on Thursday with crests on Friday. Along the river downstream in northeast Pennsylvania, warnings were issued by late afternoon for major to record flooding expected Thursday, with crests late Friday night into Saturday.

The products issued by WFO Binghamton were timely and accurately depicted impacts. Luzerne County EM Director Stephen Bekanich stated, *"The office did a great job incorporating Emergency Manager feedback and specific locations in the warnings and statements."*

5.7. Staff Impacts

WFO Binghamton employees and their families dealt with the escalating impacts of the event including flooded basements, mandatory evacuations, loss of power, and closed roads limiting access, all the while maintaining operations. Power was out in some areas for days, some key roads remained under water, and boil water advisories were in place. WFO Binghamton was also short staffed during the event.

Eastern Region senior management discussed the operational and personnel status of the office on Wednesday, September 7, with the MIC when the event was beginning to escalate. Management decided to deploy a forecaster from WFO Buffalo to WFO Binghamton to support operations. WFO Binghamton coordinated with the forecaster and had him travel to Binghamton from the north, one of a few paths left opened. The forecaster was advised there were no hotel rooms and few open restaurants or stores. The quick decision to deploy the forecaster allowed him to get to the office before roads were cut off and to ensure he came prepared for various contingencies.

Best Practice 1: Early consideration and deployment of a forecaster from a neighboring un-impacted WFO allowed WFO Binghamton to continue to meet its mission and provide a high level of service.

5.7.1. WFO Binghamton Facility

During the event, the subfloor in the WFO facility flooded. The office Electronics Systems Analyst (ESA) looked under the floor panels and discovered standing water. Water sensors installed in the subfloor were not operating. The water had entered the building through the conduit that connects the Advanced Weather Interactive Processing System (AWIPS) antenna with the communications room. If the ESA had not discovered the flooding, a potentially dangerous and destructive shorting out of the WFO's electrical system could have occurred, resulting in a lengthy service backup. The water was pumped outside over a period of 24 hours.

The potential for WFO Binghamton to invoke service backup for a lengthy time during this event might have been problematic. WFO State College, the primary backup office for WFO Binghamton, was already heavily impacted by the event. The ongoing critical warning operations at WFO State College required full use of all available AWIPS work stations at the office, and the need to realign one or more work stations to support WFO Binghamton operations would have stressed WFO State College's ability to support the NWS mission. WFO Binghamton's secondary backup office, WFO Albany, was also in full storm warning mode without additional work stations available to support backup operations for WFO Binghamton. The MICs at all three offices developed a contingency plan to share operational duties in the event WFO Binghamton had to shift operational services to its backup offices.

Finding 2: WFO Binghamton had the potential to invoke service backup for an unknown and perhaps lengthy period during the event due to water in the sub-floor of the office. As the primary backup office for WFO Binghamton, WFO State College would have had significant challenges providing service backup at the height of the storm on Wednesday, September 7, due to the lack of additional work stations. The secondary backup office, WFO Albany, was also in full storm mode without additional work stations available.

Recommendation 2: Eastern Region should evaluate backup procedures and backup pairings to ensure appropriate resources and equipment, such as an appropriate number of AWIPS work stations, are available to support the operations of WFOs when backup offices are also in high impact events.

5.7.2. Post Storm and During-Storm Surveys

After this historic flood event, the WFO Binghamton SSH conducted surveys of the hardest hit areas along the Susquehanna River. Staff documented impacts related to stream height and conducted high water mark surveys at some USGS gage locations. The region was photographed to support historical documentation and research. The WCM and other staff members also visited sites and interviewed local officials and community members to capture information about the event as it occurred and obtain a glimpse into the social impact of the event.

Eastern Region senior management supported the deployment of the WFO Albany SSH to help WFO Binghamton conduct flood surveys. MARFC hydrologists were also deployed into the Wilkes-Barre area to tour the levee system and support the WFO hydrologists in their efforts to document what happened.

Best Practice 2: WFO Service Hydrologists should conduct post flood storm surveys for moderate to major record flood events to assess the impacts of these events, capture time sensitive field data, and interact with community members and officials. Support from neighboring WFO or RFC hydrologists should be used as needed. Information gathered should be used to update impact statements and review or re-evaluate minor, moderate, and major flood categories at specific forecast points.

5.8. Middle Atlantic River Forecast Center

MARFC initiated 24-hour operations on Sunday, September 4, and continued 24-hour operations for 7 days. Additional staffing was added to the normal evening shift staff beginning on Sunday, September 4. At the MARFC, the Senior Duty Forecaster on shift has authority assumes operational shift leadership, including the authority to initiate 24-hour staffing and bring in extra staff. From Tuesday morning until Friday, the MARFC had a member of its management team fill the position of Flood Coordinator to assist the Senior Duty Forecaster with staffing arrangements, briefings, conference calls, coordination, and media interviews. This event consisted of widespread major to record flooding across two MARFC river systems, the Susquehanna and Passaic/Raritan, with moderate and isolated major flooding in a third system. The remainder of the MARFC service area saw isolated minor to moderate flooding, due to drier antecedent conditions.

RFCs have unique characteristics and many have developed unique procedures and policies to best handle forecasting needs in their specific area, which can create challenges in bringing in additional staffing from neighboring RFCs, should the need arise.

Finding 3: The MARFC staffing was sufficient to handle this major to historical flood; however, there was a two-day period when nearly all forecast staff were required for flood operations. Had the area of significant flooding included additional large river systems, available resources could have been stressed.

Recommendation 3: NWS should develop a robust cross training program for RFC staff so personnel can more easily be deployed to neighboring RFCs during large-scale flood events. NWS should also increase the consistency in operational software tools, modeling techniques, and RFC procedures to facilitate the ability to deploy staff to neighboring RFCs.

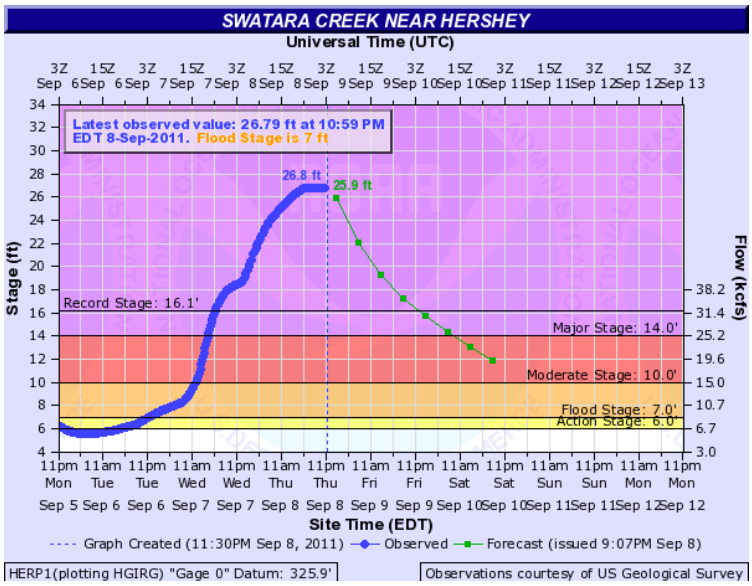

Figure 3: Hydrograph for Swatara Creek near Hershey, PA, September 10, 2011

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On Saturday, September 3, *"Moderate to potentially heavy rain"* was first mentioned in the MARFC Hydrometeorological Discussion (HMD) for Monday night through Wednesday when the remnants of Lee were expected to interact with a cold front moving through the region. The potential for renewed river rises (rivers in the area were in recession from Hurricane Irene's rainfall) was headlined in the MARFC HMD. The RFC issued the first forecast for a rise to near flood stage for Swatara Creek near Hershey, PA, on Sunday (**Figure 3**). By Monday, the RFC dramatically increased forecast rainfall amounts from a maximum of 4-6 inches in the morning QPF to a maximum of 10 inches in the evening QPF. There was much uncertainty in the QPF, but after extensive coordination with WFOs, MARFC issued river forecasts with 72 hours of QPF beginning the morning of Monday, September 5. QPF verification statistics for September showed that MARFC forecasters improved upon national guidance by 32 percent in the first 6-hour period and 10 percent in Day 1 for areas with forecasts greater than 1 inch. By Monday evening, MARFC forecasts indicated moderate to major flooding for the Susquehanna River for Wednesday through Friday.

One of the more critical decisions made by MARFC forecasters was to raise the crest forecast for Wilkes-Barre by more than seven feet, from 30.9 feet to 38.0 feet, during Wednesday afternoon. (For a more detailed discussion, see Section 6.0).

Based on how rain bands were developing, the RFC updated its Wednesday evening forecasts for the Susquehanna River to have crests higher than the 2006 floods. MARFC staff notified WFOs and PEMA of this update. After close coordination with WFO Binghamton, MARFC updated the forecast at the Susquehanna River at Binghamton to 26 feet, one foot over the 2006 record crest and above the top of flood wall. This forecast, made before all the heavy rain had fallen, provided 18 hours of lead time prior to levee overtopping and facilitated an orderly evacuation of about 20,000 residents.

The MARFC provided forecast inflows and discharges from Conowingo Dam to Maryland EMA and local counties in Maryland on Wednesday. The discharge forecast was for 700,000 cubic feet per second (cfs), which was referenced against the 950,000 cfs flow observed during Hurricane Agnes in 1972. On Thursday, the Conowingo Dam discharge forecast was raised to 1,000,000 cfs, cresting on Saturday morning based on latest rainfall estimates and forecasts and routing of upstream forecast crests. Actual releases from the dam are controlled by the utility company operating the Conowingo hydroelectric plant.

Two flood-vulnerable communities lie on either side of the river below Conowingo Dam: The first, Port Deposit, MD, is a historic town, extending for approximately one mile along the east bank of the Susquehanna River. The second community, Havre de Grace, MD, is further down river on the west bank at the mouth of the river on the Chesapeake Bay.

WFO Baltimore/Washington is responsible for Harford County, the west bank of the Susquehanna River. WFO Philadelphia is responsible for Cecil County, the east bank of Susquehanna River, as well as hydrologic forecast and warning responsibility for Conowingo Dam. WFO Philadelphia issued the first flood warning for the Susquehanna River below Conowingo Dam on Wednesday, September 7, at 4:40 p.m. Flood stage at Conowingo Dam is 23.5 feet. Major flooding was forecast with a rise to 31.4 feet by Saturday morning. The impact statement contained in the Flood Warning read, "*...At 31.0 feet...Notification level 9 with 43-53 gates open at Conowingo Dam. Mandatory evacuations initiated in Port Deposit.*" RiverPro automatically generated the impact statement in the Flood Warning. The same impact statement appeared on the Advanced Hydrologic Prediction System (AHPS) page at Conowingo Dam.

Language in the impact statement referencing mandatory evacuations was not well received by Cecil and Hanford County EMs. County 911 Dispatch Centers were inundated with panicked phone calls immediately following the issuance of the initial Flood Warning. EMs requested reference to mandatory evacuations be stricken from the warning.

WFO Philadelphia issued a follow-up flood statement for the Susquehanna River below Conowingo Dam 10 minutes later at 4:50 p.m. The updated information included a revised forecast for the river to rise above flood stage much sooner, Wednesday night versus Thursday evening. In addition, the impact statement was modified to read, *"Notification level 9 with 43 to 53 gates open at Conowingo Dam."* Reference to mandatory evacuations was eliminated.

Finding 4: NWS crafted impact statements for Conowingo Dam many years ago. They were widely vetted and approved by the downstream communities before being adopted. Until the Lee event, they were rarely used. Through the years, many of the people involved in adopting the impacts statements retired or moved to new positions.

Recommendation 4: Impact statements associated with various flood levels at a river forecast location should be frequently updated to reflect changing conditions as stated in NWS Instruction 10-924 Weather Forecast Office Hydrologic Reporting. Updates should be reviewed and approved by the entire river community before adoption.

On Thursday, September 8, the forecast crest was lowered slightly on the lower main stem Susquehanna River due to a rapid decrease in discharges on the West Branch Susquehanna River. The heaviest rainfall materialized over the eastern portions of the basin. As a result, there was a slight downward revision in forecasts, although major flooding was still forecast. The Conowingo Dam forecast was lowered Thursday evening to 875,000 cfs based on latest rainfall analysis and revision of upstream forecasts.

On Friday, the lower Susquehanna River forecasts were revised slightly downward again based on continued dramatic recession of flows on the West Branch, although major flooding was still forecast. The Conowingo Dam forecast was revised to slightly lower the forecast again to 800,000 cfs based on upstream trends. The RFC had previously forecast a second higher crest for Saturday that was no longer expected. The MARFC advised partners the current flow around 750,000 cfs would be the highest flows experienced in the event. This final downward revision was based on the continued lowering of crest forecasts at upstream locations.

Best Practice 3: RFC staff had spent considerable time developing an archive of previous heavy rain and flood events in its basin. RFC staff could access this archive to see how rivers might respond. During this flood event, some hydrologic model runs generated unrealistic results in which RFC staff had very low confidence. In these instances, the staff referred to analog events from the flood archive to refine forecasts. References to analog events also helped staff convey the seriousness of the forecasted flood during briefings.

5.8.1. Experimental Meteorological Model-Based Ensemble Forecast System (MMEFS)

MMEFS runs are available 2-4 times a day, dependent on the model suite. The RFC has promoted MMEFS as an experimental self-briefing tool for the past two years. The system was reviewed by Eastern Region WFOs and RFC Customer Advisory Boards for a year before becoming available on a routine basis. This vetting process resulted in significant improvements in the format and display of the information. The RFC conducted multiple training seminars and presentations for WFOs and partners and offered an online learning module. In this event, the RFC first used MMEFS output in a briefing on Monday, September 6. MMEFS was a valuable tool and should be used as a planning tool in the 3-7 day window only. Since RFC forecasters regularly uses 48 hours of QPF in their forecasts, the staff advises partners and customers to use official forecasts in the 1-2 day window leading into an event. During this flood event, some MMEFS runs showed extreme outcomes, and there was some considerable variability from run to run. This variability was due to the extreme variability of model QPF in the days prior to the actual flood event.

There is still some lack of understanding from partners and customers on what information is conveyed in the MMEFS output. An example of this was relayed by Julie Fritz, Director of Water Control for the USACE Baltimore District, who acknowledged that she was unsure of what the difference was between the three models used to generate output.

There is also ongoing debate about how decision makers and the general public would react to the probabilistic forecast provided by MMEFS. Susan Obleski, Director of Communications for the SRBC, felt people might only look at the lowest trace with a false sense of security that flooding might not be as bad as forecast. On the other end of the spectrum, several EMs in

Pennsylvania felt that people might only look at the highest trace and make decisions based on a very small chance of outcome. According to Charles Ross, SSH at WFO State College, *"MMEFS is a good briefing tool, but it is not a replacement for the expertise of hydrologists at Middle Atlantic RFC."*

Finding 5: MMEFS provided a useful tool to show the potential range of flooding during this event, but some extreme values and some issues with run-to-run consistency may have limited its usefulness. NWS offices participating in the experiment have provided extensive training and outreach on the science in MMEFS and how to read and understand MMEFS output; however, there remains some significant lack of understanding.

Recommendation 5: NWS offices participating in the experiment need to continue working with partners and customers to improve understanding of MMEFS and to refine the way MMEFS output is displayed to provide maximum benefit.

6. Wilkes-Barre Stream Gage

The Wilkes-Barre levee project, constructed in 1936, is located on the Susquehanna River in the vicinity of Wilkes-Barre in Luzerne County, PA. In 1972, Hurricane Agnes overtopped the project causing over $1 billion in damage. In 2003, approximately 15 miles of levee and floodwalls were modified by 3-5 feet to an effective flood protection level of 41 feet at Wilkes-Barre, which was engineered to just above the Agnes peak flood stage. At 41 feet, the impact statement at Wilkes-Barre, found on the AHPS Website stated, *"Maximum effective design of levee protection for the city of Wilkes-Barre. Levee height above this level may not provide protection."* This statement was the result of a collaborative effort between emergency management officials and the NWS.

On Wednesday, September 7, MARFC began forecasting dangerously high levels on the Susquehanna River. At 4:03 p.m., WFO Binghamton issued the initial river flood warning at Wilkes-Barre predicting major flooding (38 feet) to occur Friday morning. During the overnight period, WFO Binghamton issued a flood statement update based on MARFC updates at 10:21 p.m. and 3:49 a.m., Thursday, increasing the crest to near 39.6 feet, resulting in a precautionary evacuation of 60,000–70,000 Wilkes-Barre residents by Thursday.

At 9:00 a.m., Thursday, the RFC increased the crest forecast to 40.7 feet, within 0.3 feet of the effective levee protection level of 41 feet. WFO Binghamton's 10:19 a.m., Thursday River Flood Statement indicated a river observation of 32.7 feet and a forecast to rise to around 41 feet late that night.

Figure 4: Comparison of Hurricane Agnes in June 1972 and flooding on the Market Street Bridge in Wilkes-Barre, PA, on September 8, 2011 (Courtesy of Tim Bender)

At 2:30 p.m., Thursday, the MARFC increased the crest forecast slightly to 40.8 feet; 0.2 feet below the effective levee protection level of 41 feet. WFO Binghamton's 3:15 p.m., River Flood Statement indicated a river observation of 37.0 feet and a forecast to rise to near 40.8 feet by midnight Friday. At 5:00 p.m., Thursday, the gage appeared to level off near 38 feet. The USGS confirmed the gage functioned properly until 5:00 p.m., Thursday, when the pressure transducer reached its operational limit at a river stage of about 38.5 feet (**Figure 4**). Around this time, the USGS was told to evacuate the area because it was unsafe to continue manual observations. The instrument continued to transmit this stage for about three hours until the electronic equipment was inundated by the flood waters at 8:00 p.m., Thursday. WFO Binghamton's 9:21 p.m., Thursday River Flood Statement indicated a river observation of 38.8 feet and forecasted the river to continue rising to near 40.8 feet by Friday morning and then begin falling.

At 10:00 p.m., Thursday the RFC issued a forecast update, keeping the crest forecast at 40.8 feet, almost three feet higher than the gage was currently reading. The RFC issued a river forecast containing the following statement: *"It is possible that gage readings at Waverly, Towanda, and Wilkes-Barre are clipping the actual hydrograph."* "Clipping the actual hydrograph" refers to a gage malfunction where the gage reaches its maximum observing level and stops rising while the actual river levels continue to rise. Although the flood levee system successfully held and protected much of Wilkes-Barre from a catastrophic disaster, hundreds of city homes and businesses not protected by the system were severely flooded. Early warnings for the fast developing and severe flood event were credited with giving residents and business time to prepare, protecting lives and minimizing property losses.

At 3:22 a.m., Friday, the RFC determined in Luzerne County the river had crested and was falling. The RFC issued a river forecast containing the following statement: *"Apparent gage malfunction around crest; however, likely receding at this time."* WFO Binghamton 3:44 a.m., Friday, River Flood Statement indicated the river observation was missing; the river had crested and was forecasted to continue to slowly fall.

Onsite post analysis on Friday morning, September 9, conducted by the USGS at the gage indicated the actual crest was 42.66 feet, a new record crest for Wilkes-Barre. The previous record crest, 40.91 feet, occurred during Hurricane Agnes in 1972. Flood stage is 22 feet.

Despite the Wilkes-Barre gage observations flat lining near 38.8 feet Thursday evening (**Figure 5**), experienced RFC forecasters held fast to the river model projections of 41 feet during the Thursday night forecast cycle, a correct choice.

Finding 6: Ground observers on the levee system in Wilkes-Barre, PA, assigned to monitor the situation for structural failures and safety concerns failed to report back to Luzerne County EOC and the Flood Protection Authority that the river continued to rise throughout the night. This lack of communication occurred despite gage observations indicating an apparent crest at 38.50 feet.

Recommendation 6: The NWS should continue to build, foster, and train on-the-ground river-observer contact networks to supplement real-time gage observations and use during emergencies, such as high-flow events and equipment outages.

The following information was provided to the White House National Security Staff from the USGS Pennsylvania Water Science Center:

> *"The gage at Wilkes-Barre functioned properly until 5 p.m., Thursday, Sep 8, when the pressure transducer reached its operational limit at a river stage of about 38.50 feet. The instrument continued to transmit this stage (+/-) for about 3 hours until the electronic equipment were inundated by the flood waters at 8 p.m. on Sep 8. The gauge was inaccessible due to flooded roads and inundation of the structure from late afternoon on Thursday, Sep 8, until early Saturday morning. On Friday, Sep 9, USGS technicians were able to gain access to the auxiliary wire-weight gauge located on the bridge. At 9:33 a.m., the river stage was measured using the wire-weight gage at 41.73 feet (+/- 0.05 feet) and a*

high-water mark located near the wire-weight gauge indicated the peak stream stage had occurred at 42.66 feet (+/- 0.05 feet). This peak was confirmed the next day at the gage location from additional high-water marks. A streamflow measurement was made at the Wilkes-Barre location later that morning. The next day (Saturday) data-collection and transmission equipment were replaced and transmissions were restarted at 3:30 p.m. at a stage of 31.15 feet. During the period of missing record, five manual measurements (including the high-water mark estimate) were made to assist with filling in the record. Each of these measurements was relayed to the NWS Middle Atlantic RFC, the USACE-Baltimore District, and the Luzerne County EM."

Figure 5: Flooding along Market Street Bridge in Wilkes-Barre, PA, September 8, 2011 (Courtesy of Deirdre Mollahan)

The elevation of the existing gage was based on previous flood experience. As a part of the storm recovery effort, USGS positioned a new, elevated gage structure to allow the accurate recording and transmission of stream stage and streamflow data to an elevation of approximately two feet above the top-of-levee elevation at the gage structure. The levee top elevation at the gage has been reported to USGS by USACE as 46.44 feet. This level required an elevation of the existing structure of about 10 feet. The gage structure was repositioned closer to the Pierce

Street Bridge near the elevation of the road surface to provide necessary access so it can be serviced during a flood. The repositioning took place in less than 30 days following the record flooding.

The USGS recognized the need to make data users aware of stream gage operating limits and gage heights of importance. The events at Wilkes-Barre have prompted a national action by the USGS to post the information on each individual real-time Web page and provide a state-by-state summary to selected cooperators such as NWS. USGS has completed the task for Wilkes-Barre by adding, "The Gage Heights of Importance" section to their Web service and notifying data users (**Figure 6**).

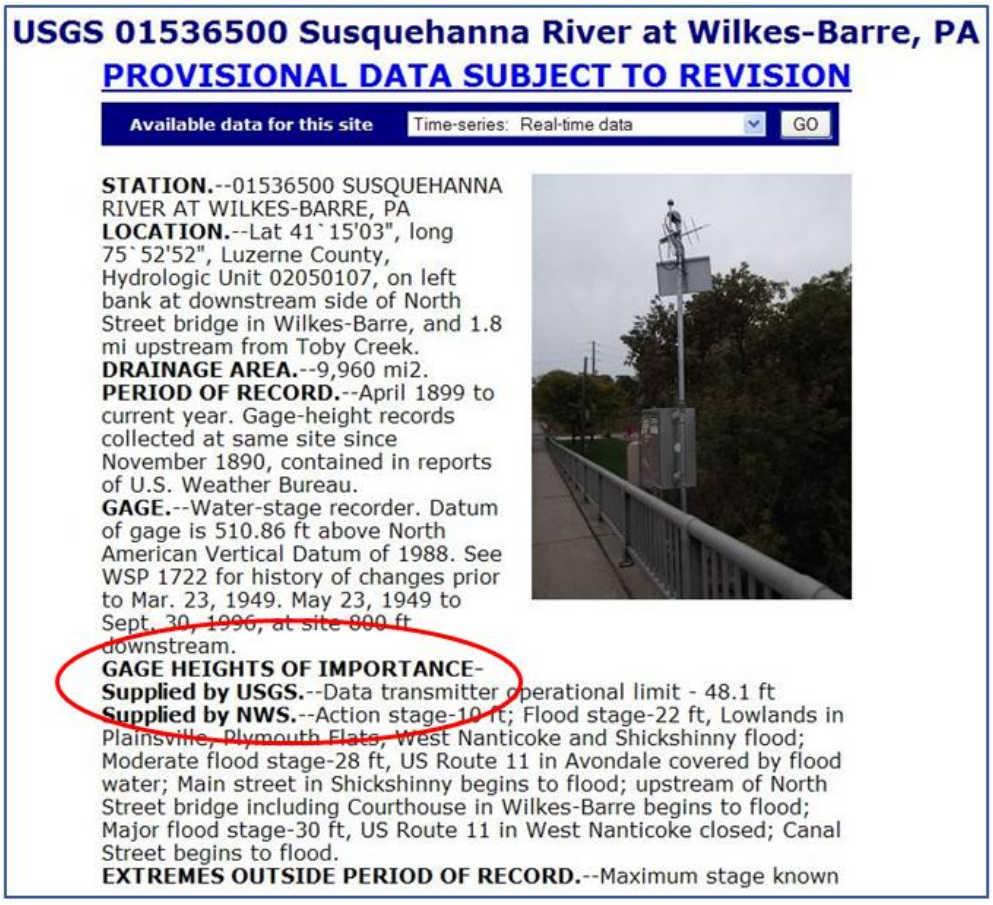


Figure 6: Gage Heights of Importance section of USGS Website for Wilke-Barre, PA

Finding 7: Lack of knowledge regarding the operating limits of the gaging equipment at Wilkes-Barre (WBRP1) created a substantial amount of confusion and uncertainty when the gage began reporting suspect stage heights just prior to cresting.

Recommendation 7: The NWS needs to work with the USGS and other partners to ensure that the operating limits of stream gaging equipment are known and available. The events that occurred at Wilkes-Barre, PA, have prompted a national action by the USGS to post the

information on each individual real-time Web page and provide a state-by-state document to selected cooperators such as NWS. The NWS should publish the data on corresponding AHPS Web pages to reduce confusion.

On Thursday evening, September 8, during the height of the event, Luzerne County officials were hard pressed to explain to residents of Wilkes-Barre and to the media why the AHPS graphic at Wilkes-Barre (WBRP1) (**Figure 7**) was indicating the river had crested and yet the forecast was still calling for the river to possibly overtop the levee the next morning.

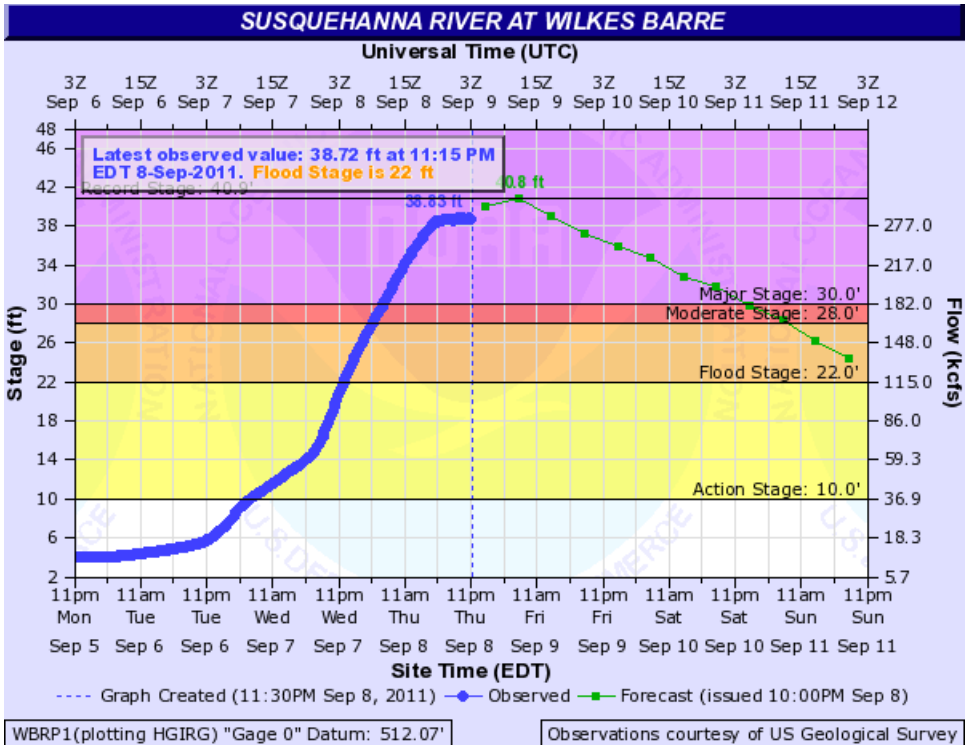


Figure 7: AHPS Hydrograph (stage flow) for Susquehanna River at Wilkes-Barre on September 8, 2011

Finding 8: The AHPS Web page continued to publish suspect data for WBRP1 even after the USGS had removed the data from its Web pages.

Recommendation 8: The NWS should ensure that erroneous data can be easily removed from NWS systems, most notably the AHPS Web pages.

7. Impact Based Decision Support Services (IDSS)

7.1. WFO State College IDSS

Early notification and the communication of frequent forecast updates played a key role in WFO State College's enhanced IDSS throughout the event. PEMA State Emergency Operations Center (SEOC) was formally notified of the potential for flooding on Friday, September 2, when the WFO forecast cold frontal storms for Sunday, September 4, and rain on Monday, leading into the influence of the remnants of TS Lee from Tuesday through Thursday. The HWO WFO State College issued at 5 a.m. on Saturday indicated the potential for moderate to heavy rain across central Pennsylvania from Tuesday into Thursday.

Formal state level briefings with the PEMA SEOC, state agencies and the USACE began on Monday, September 5, at 11:00 a.m. Thirteen briefings with these partners, as well as the SRBC, USGS, and the Delaware River Basin Commission continued throughout the week. The briefings were conducted mainly by the same NWS personnel during the event.

PEMA Director Glenn M. Cannon told WFO State College WCM Pete Jung, "*Peter…you're doing a great job on the weather briefings. It's great how you and your office produce briefings that cover the whole Commonwealth. They are extremely helpful, and you are a valuable asset to us.*" PEMA Deputy Director, Robert Full stated to Pete, "*Pete…you do a great job on the weather briefings…You're one of the best.*"

WFOs Binghamton, Philadelphia, and MARFC contributed on most of the state-level calls with participation by the Ohio RFC and WFO Pittsburgh early in the event. All Webinar slides were provided to the Webinar participants.

WFO State College county emergency management briefings were conducted once on Tuesday, September 6, at 2 p.m., and Wednesday, September 7 at 1 p.m. Decision support information continuously flowed to these parties throughout the week. Pete Jung was the primary speaker on the WFO State College county conference calls.

PEMA Central Area Director Fred Boylstein stated, "*I've received feedback from many of the counties that you guys [NWS State College] serve, and they all say you're doing a great job. They really love the briefings you distribute and the support they are getting from your office.*" Lycoming County Director of Public Safety John Yingling said, "*Your briefings and support are invaluable to us.*" Blair County EM Director Dan Boyles also said, "*You provide great weather support. Thanks!*"

PEMA SEOC went to Level III status at 8 p.m., Tuesday, September 6, and Level II status at 8 p.m., Wednesday. PEMA then went to Level I (highest, status-full staffing) at 4 p.m., Thursday, and returned to Level II at 8 p.m., Friday.

While the state level conference calls served a valuable purpose during the event, an issue concerning the calls was noted. EMs from several counties expressed the feeling that the state level and PEMA regional calls were a waste of their time and felt direct coordination with the NWS served them better. Although facilitating the PEMA calls are not a direct function of the

NWS offices that serve Pennsylvania, NWS involvement has been reviewed. In contrast, in New York the WFOs coordinate conference calls and New York State Office of Emergency Management is tasked with participating on multiple calls for briefings. The local, county EMs prefer WFO led calls in lieu of the state conference calls with PEMA.

Finding 9: Some county-level EMs indicated that state led conference calls in Pennsylvania were ineffective as a coordination tool between the state, county-level EMs, and the NWS.

Recommendation 9: WFO State College, as State Liaison Office, should work with PEMA to optimize conference calls to address the concerns of local EMs.

It was also noted by the assessment team that compiling a briefing package for distribution to the emergency management community and participating in the state and regional calls required an extra full-time person on hand. Many of the graphics used in the briefing packages were products already accessible via the Internet. Additional efforts and resources were used to pull together and repackage WFO-centric and RFC-centric information into state-centric products and images. While the compilation of specific information is needed and greatly appreciated by customers, it requires significant time to produce these packages. The concern also was expressed that paper briefings quickly become dated. New information will become available before another briefing package becomes available but partners may continue to use an outdated briefing package.

WFO State College has developed, and locally generates, experimental state-centric graphics for precipitation periods, 12, 24 hours, etc. These graphics import and sum surrounding WFOs gridded data. These experimental state-centric graphics give an event-based overview, both spatially and temporally, and can be an effective briefing tool for PEMA and state partners. More work needs to be done to improve these experimental products, including collaboration with surrounding WFOs with responsibility in the state to ensure consistency across CWA boundaries and ensure the data meets collaboration thresholds.

Finding 10: Workload to compile graphics for briefing packages, PDF files, and PowerPoint presentations may become excessive and requires extra staff. WFO-centric or RFC-centric products may need to be altered or regenerated to produce state level graphics. Many products used for briefings already exist and redundancy of work during a significant event strains staff and resources.

Recommendation 10: Eastern Region should develop a consistent, efficient approach (methodology, software, procedure and state-centric products) to streamline PowerPoint briefings and graphic development, preferably using existing products. These products would be disseminated to the emergency management community for briefing purposes and should allow updated graphics to be immediately available to users.

7.1.1. PEMA Onsite Support

Eastern Region Headquarters was proactive in ensuring adequate staffing at WFOs and meeting the needs of the local offices. The Eastern Region Acting Director assigned the MIC from WFO Pittsburgh, Richard Kane, to provide onsite NWS support at PEMA Headquarters in

Harrisburg for the latter portion of the event. Kane provided two days of interaction with PEMA and the state administration staff, including the Governor. PEMA was very appreciative of his onsite support at its headquarters during such a critical time.

Kane had several observations on his participation onsite: *"Our partners are extremely appreciative of our onsite assistance. It provides them expertise, information, and resources that are just not available via phone. In addition, it provides them with the ability to provide weather briefing information to high level officials (Governor, Congress, Commissioner) and it gives the NWS very high visibility."*

When Kane first arrived at PEMA, a weather brief had just started with more than 30 people crammed into a small conference room and people crowding the doorway to hear the weather briefing from the NWS. Many of these people were section or program leaders and were taking notes. Kane commented on how the attendees were listening intently to what the NWS had to say on these calls and that it was vital to them.

Kane also stated there were information technology (IT) issues with NWS mobile capability. Adequate briefing abilities require proper software and data availability/accessibility. Kane has GR2 Analyst, FX-net, and the Internet available; however, he needed access to flash flood monitoring and prediction software across the state to help brief on potential flash flooding because there were swift water rescue teams deployed, along with numerous other teams in recovery mode, scattered across the area. Kane had significant difficulty, most likely with the servers, with FX-net. At one time, he was trying to provide weather information for a pilot doing over-flights of the flooded area and could not get a visible satellite image. It was also important to brief on cloud-to-ground lightning, only available through FX-net, and at times the data flow was intermittent. Onsite NWS presence at the PEMA SEOC in Harrisburg during the latter stage of the event ensured smooth communication was an effective liaison with one of our most important partners. The NWS should coordinate with all SEOCs to ensure the ability of an onsite NWS representative to access data and software applications.

Best Practice 4: WFO Pittsburgh's MIC served as liaison to PEMA during the event. Establishing a liaison at the state level from a WFO outside of the weather and hydrologic impact areas was very effective in coordinating a multitude of warnings, statements, expected regional impacts, and handling briefings.

7.2. WFO Binghamton IDSS

WFO Binghamton provided critical decision support services to state, local, and other key river partners well in advance of the flood event. Early identification of the flood threat and constant flow of critical information to decision makers prior to and during the event was crucial to emergency management operations; pre-storm mitigation lessened flood impacts. EMs served by WFO Binghamton were first notified of the event at 2:17 p.m., Friday, September 2, through a blast email aimed to arrive before Labor Day weekend. The email provided notice about the formation of TS Lee and potential for flooding during the following week. In addition to the email messages, the first briefing package was sent to EMs at 4:58 p.m., Saturday, highlighting the potential for heavy rainfall with information supported by national center guidance.

WFO Binghamton participated on multiple state-level briefings with PEMA during the week before the event. In addition, the WFO led multiple formal conference calls and Webinars with its partners. WCM Dave Nicosia and SSH Jim Brewster developed most of the briefings and facilitated the conference calls and Webinars. The WFO also sent the slides used during the Webinars to all participants in PDF format.

On Monday, September 5, at 5:09 p.m., WFO Binghamton conducted a Webinar with an associated PowerPoint briefing. The briefing specifically mentioned the potential for a "major river flood disaster" in the WFO Binghamton service area. It was too early to tell which area would see a potential disaster so the information was provided to the EMs only.

On Wednesday at 10 a.m., WFO Binghamton led a Webinar that emphasized uncertainties but zeroed in on the likelihood for "catastrophic" flash flooding and disastrous river flooding in the Binghamton CWA.

By Wednesday afternoon, WFO Binghamton was able to zero in on where the major river and flash flood disaster would occur: the North Branch of the Susquehanna River in New York State and the entire Susquehanna River Basin in northeast Pennsylvania. WFO Binghamton stated on the Webinar that major to record breaking flooding would occur along the Susquehanna River from Oneonta south through Bainbridge, Conklin, Binghamton, Vestal, Owego, Waverly/Sayre/Athens, Towanda, Meshoppen, Tunckhannock and Wilkes-Barre. This briefing was coordinated with MARFC.

During Wednesday evening, September 7, a Webinar was conducted to inform EMs of the likelihood of record breaking historic river flooding. Catastrophic flash flooding was ongoing across much of the Upper Susquehanna Basin in New York and northeast Pennsylvania. The rivers were rising faster than many people had ever experienced. The official MARFC river forecast numbers were forecast to be close to the 2006 flood of record in the North Branch of the Susquehanna River in New York and come within a few feet of the Hurricane Agnes crests in 1972 in northeast Pennsylvania.

As a result of Wednesday briefings, evacuations were being rushed to completion and EOCs fully activated. The WFO impressed upon EMs that record and devastating flooding was either happening in the North Branch Susquehanna or expected to occur in the upper main stem Susquehanna in northeast Pennsylvania. The tone of the briefing was geared around a high confidence forecast of catastrophic flooding.

Multiple EMs and river partners served by WFO Binghamton commended the high level of work and commitment by the office to ensure decision makers and planners had all the information needed to keep people out of harm's way. In particular, partners praised the WFO briefings as extremely valuable in conveying this information. Charlene Moser, EM from Susquehanna County, NY stated, *"The pre-event planning and briefings were extremely helpful, the depth of information provided was very good, and the WFO provided very good open communications."*

WFO Binghamton provided many other key briefings throughout the event. On Thursday, September 8, the SSH briefed New York State Division of Homeland Security and Emergency Services and U.S. Senator Charles Schumer about the crest expectations at Binghamton. The SSH stated the forecasted crest would top the flood walls in the city. During a call with PEMA, which included Tom Corbett, Governor of Pennsylvania, the office provided a full briefing on expected weather, river levels, and projected crest heights and times.

Best Practice 5: WFO Binghamton's close relationship with its partners and customers, and outreach and preparedness activities conducted by the WFOs, ensured when words like "catastrophic," and "major flood disaster" were used, partners understood the severity of the situation and that this event was not a typical flood event.

In addition to the numerous briefings, WFO Binghamton offered key river level and flow information directly to customers. Really Simple Syndication (RSS) alerts allow river gages to provide NWS partners with critical river level and flood information. This tool would be especially useful to EMs in the field or at the EOCs during an event because the alerts are received by email. The alerts contain stage information, the latest observations, forecast water levels, and a link to the AHPS Web page to access hydrographs.

Finding 11: Some EMs and river partners were not aware of the RSS alert subscriptions for river gages data via the AHPS program, likely since the option is not easily visible on AHPS.

Recommendation 11: WFOs should demonstrate the AHPS RSS capability to all relevant partners so that they are aware of this program.

7.3. Middle Atlantic RFC IDSS

MARFC has developed a strong connection with its partners through active participation in the Susquehanna, Potomac, and Delaware River Basin Commissions, Silver Jacket (in cooperation with the USACE) State Teams, Floodplain Manager's Associations, Northeast Federal Water Agencies Annual Meetings, and the MARFC Customer Advisory Board. The MARFC Customer Advisory Board was founded in 2009 and meets bi-monthly, giving the RFC a clear understanding of its partner's requirements and establishing a strong base of communication

The RFC began IDSS briefings to nearly 100 partners on September 6 to help them prepare for TS Lee. The RFC also participated in conference calls led by PEMA providing updates on river forecasts, and in conference calls with the Maryland EMA coordinating forecasts for the Conowingo Dam.

Coordination with SRBC

MARFC has collaborated with SRBC and USGS since 1986 on the Susquehanna Flood Forecast and Warning System (SFFWS). This close collaboration has led to enhancements in stream gage networks, rain gage networks, forecasting systems, inundation mapping, and extensive flood outreach and education throughout the basin. SFFWS contributes to improved forecast accuracy and warning lead time, reducing loss of life and property during flood events.

The RFC participates in annual multi-agency coordination meetings with SRBC, and federal and state partners. In addition, the WFOs and RFC collaborates with SRBC on a Volunteer Ice Observer Program in the Susquehanna Basin. Free training on ice observation and ice jam reporting is offered to local communities. SRBC has partnered with NWS to install 55 Turn Around. Don't Drown ™ signs across the basin to promote flash flood safety and awareness.

Best Practice 6: The longstanding relationship between the MARFC and the SRBC aided in collaboration during the 2011 Susquehanna floods and promoted trust among NWS and its partners and customers.

During the peak of the flood event, SRBC was forced to evacuate its headquarters in Harrisburg due to rising flood waters. In addition, on Thursday, September 8, SRBC notified the RFC that AHPS pages were down and they could not access forecasts. The RFC used NWSChat to disseminate its latest river forecasts, allowing SRBC staff to receive forecast information from remote locations. In spite of these hardships, the relationship been cultivated over the years instilled confidence in the information SRBC was receiving form the RFC.

Best Practice 7: The RFC educated partners how to use NWSChat to receive the text version of SHEF formatted river forecasts during an AHPS outage.

After a significant and destructive flood event in 2006, the SFFWS Interagency Coordination Committee developed a plan to improve event operations and performance (Appendix G). A part of this plan was to develop flood inundation mapping at many locations on the Susquehanna River. At some locations, mapping was developed from return-period profiles, while at others a full hydraulic analysis was used to develop mapping. The RFC referred to the inundation mapping developed by SRBC in briefing materials it provided during the event; however, the RFC does not provide a link from its Website to the SRBC inundation mapping, nor is there any link from the AHPS pages for those locations that have mapping.

The SRBC inundation maps, which are available on the WFO Binghamton Web page, were a critical part of the Broome County EOC operations and evacuations. The maps were used exclusively for reverse 911 calls, NY alerts, and other municipal evacuation orders.

Finding 12: Although the SRBC inundation mapping may not be developed to NWS standards at all locations, inundation mapping has proved a useful risk communication and planning tool for local communities in advance of flood events.

Recommendation 12: Eastern Region should collaborate with partner members of the SFFWS Interagency Coordinating Committee to increase public awareness of inundation mapping resources in the Susquehanna River Basin for use as risk awareness and planning tools.

According to Susan Obleski, Director of Communications for the SRBC, MARFC provided outstanding support in this event. The briefings provided by the RFC were "*excellent*" and "*unmatched.*"

7.3.1. Coordination with USACE Baltimore District

MARFC has used automated data exchange with the Baltimore District for over five years. Staff from the USACE Baltimore District visited the RFC in the spring of 2011 to observe operations and to develop collaborative projects between the agencies. The RFC is currently running a pilot project with the Baltimore District at Raystown Reservoir. The RFC provides reservoir inflow forecasts that USACE ingests into its modeling. USACE then sends projected discharges from the reservoir to the RFC for use in developing downstream forecasts. The information the RFC provides is developed by a batch run process. Although this information is beneficial to operations, the USACE states there would be more benefit if the RFC also could provide official, quality-controlled forecasts. During this flood event, the RFC staff used frequent phone coordination with the USACE Baltimore District to discuss forecast river flows and potential impacts of reservoir operations on the Susquehanna River basin. Based on this coordination, USACE personnel determined the appropriate timing of reservoir releases to minimize ongoing flooding. Julie Fritz, Director of Water Control for the USACE Baltimore District, stated, "*Every decision made during the Tropical Storm Lee flood event was based on data from the NWS.*"

7.3.2. Coordination with USGS

MMEFS output used in briefings by MARFC and WFO Binghamton 2-3 days prior to the onset of the flood event helped staff at the USGS office in Ithaca, NY, prioritize resources and request additional staffing from the USGS office in Troy, NY. These actions proved extremely beneficial to the USGS in Ithaca during the height of the flood event. According to Carolyn Szabo, Hydrologist, with the USGS in Ithaca, "*We could not have orchestrated this [event] or gotten the measurements we did without the NWS data and services we received*."

Best Practice 8: During this flood event, USGS field technicians took photos during site visits. These photos were uploaded in near real time to a USGS Website where NWS personnel could access them for visual confirmation of the extent and severity of flooding.

River flooding drills have been an adjunct to larger exercises in Pennsylvania and New York but there have been no specific drills or exercises designed to test emergency management, river partner, and NWS capabilities specifically for large-scale river flooding. WFO Binghamton conducted the Hurricane David exercise, which brought massive flooding within the Chemung basin, a sub-basin of the Susquehanna Basin. The MARFC was involved in river forecast modeling and attended the tabletop exercise. WFO Binghamton conducted a hurricane and flood tabletop drill with the NY State Department of Homeland Security covering portions of the Susquehanna Basin and has led multiple NWS/FEMA Hazardous Weather and Flooding Preparedness Courses in the Upper Susquehanna Basin in New York and Pennsylvania.

Exercises highlight potential coordination issues between the agencies, what-if scenarios and consequences, e.g., levee overtopping. In addition, exercises enable the NWS to showcase the full spectrum of its decision support services.

Finding 13: Although exercises and drills have been conducted for portions of the Susquehanna, there have been no specific drills or exercises for large-scale river flooding on the Susquehanna River.

Recommendation 13: NWS offices with areas of responsibilities along the Susquehanna River should partner with each other, EMs, and other river-related constituency to design an exercise to tests all facets of river flood operations and response.

8. Advanced Hydrologic Prediction Service Web Outage

The slowdown in obtaining AHPS data hampered the flow of critical information to EMs, especially during times when the water level was dangerously high and potentially overtopping levees along the river.

AHPS Web service is routinely operated on two independent Web farms in Kansas City, MO, and Silver Spring, MD. Each Web farm at the time was configured with two front end servers to handle user requests. Since the flood event, and as part of a previously scheduled sustainment project, each Web farm is now configured with a dozen front end servers. The NWS Internet Dissemination System (NIDS) manages performance of the Web farms, which includes load balancing and user request functions. During anticipated periods of high usage, NWS has contracts with a commercial vendor to share AHPS loads.

Finding 14: NWS has contracts with a commercial vendor to share AHPS loads during high usage events. The commercial vendor, however, did not spin-up operations until an AHPS outage already had occurred. The result was a lapse in the availability of river forecasts for partners and customers.

Recommendation 14: NWS should review its contracts with commercial vendors to establish load sharing of AHPS pages at the beginning of a high-usage event rather than at the failure of NWS AHPS Web pages.

On Friday, September 2, at 3:30 a.m., the Maryland site suffered the loss of a core switch which impacted AHPS at that site. The Missouri site switched to 100 percent at that time. The NIDS team worked with Operational Systems Network (OPSNet) and the Telecommunications Operations Center (TOC) personnel but could not get the site functioning. NIDS personnel were sent to Silver Spring, but due to scheduling conflicts did not have anyone on site until Friday, September 9. From Friday, September 2, to Friday, September 9, AHPS was not available at the Maryland site.

Finding 15: During the failure of the Maryland site, the NIDS manager used OPSNet technicians to fix the problem. This attempt failed and due to scheduling conflicts a technician was unable to travel again until Friday, September 9.

Recommendation 15: Staffing should be based on anticipated significant load demands due to high-usage events so there is no delay in sending NIDS technicians to remote sites.

Beginning the evening of Wednesday, September 7, and continuing through Friday,

September 9, problems with the timeliness of forecasts on the AHPS Web pages and the general accessibility of the AHPS pages became recurrent issues. Eastern Region Headquarters, MARFC, and WFOs all made inquiries with the TOC during this period concerning AHPS stability. On Thursday morning, September 8, SRBC informed MARFC no Susquehanna River forecasts were available on the AHPS Web pages. During the morning hours of Thursday, September 8, water.weather.gov Web service suffered five service outages ranging from 3 minutes to 25 minutes. These outages meant users could not receive products from the AHPS service. The service was apparently impacted by extremely high traffic exacerbated by the fact that the NIDS site at Silver Spring was unavailable.

On Thursday, September 8, unsuccessful changes were made to the NIDS load balancing switch and the Web server configuration files to try to eliminate the error. These changes increased the number of connections the Web servers would receive from the public. The load on the AHPS Web servers was too high to respond efficiently to the number of queries being made against them. NIDS stabilized AHPS at the Missouri site on Thursday, September 8. Further details of the AHPS Web service outage are documented in Appendix E.

9. WFO State College and MARFC Bandwidth Issues

The collocated MARFC/WFO State College facility does not have the same communications infrastructure as two separate stand-alone WFOs. This setup is the standard configuration across the NWS for collocated sites. During this event Internet access and Web briefing capabilities were severely impacted due to the lack of bandwidth to support such functions across both offices. The current bandwidth availability at the collocated WFO/RFCs in Eastern Region is a carryover from an early 1990s legacy spoke and hub communications design. Due to the role of the RFCs in the legacy system design, these collocated sites have half the band width available for administrative and non-AWIPS applications that a standalone WFO has access to.

The limited bandwidth results in slow Internet response during high demand events. During TS Lee, both the RFC and WFO staff members were using personal computers at home and smartphones at the office to download work related data files and graphics due to their inability to access Web pages on office equipment. The continuous slowdown of data had operational impacts on the RFC/WFO ability to provide service to customers. The following instances of slow Internet access were documented by WFO State College and MARFC:

- **Wednesday and Thursday, Sep. 7-8:** Slow access to connect into PEMA hosted WebEx briefings
- **Wednesday, Sep. 7:** Inability to access AHPS pages for media interviews resulted in AHPS graphics loaded via employee's smartphone (As the requests for information increased, operations personnel began briefing using the AWIPS Hydroview application because the Web became nearly unusable.)
- **Wednesday, September 7:** Internet prevented downloading and inclusion of several graphics in preparation of PEMA briefing attended by the Governor. AHPS page was not loadable from a NWS desktop computer. WCM gave portions of the briefing verbally from AHPS pages loaded on his personal IPad using 3G-Network.

Staff members of the WFO and RFC stressed their concern with the inability to provide information to the media, EMs, and the general public as a result of the bandwidth issues.

Eastern Region Systems Operations Division is aware of this problem and is implementing a short-term solution to provide additional bandwidth to the offices through the use of commercial Internet connections. This connection will be incorporated into the office network and have the necessary security firewalls. NWS Headquarters is deploying a new design to alleviate the congestion offices are noticing when accessing the Internet. This deployment will occur during late FY12. Along with this design solution, Eastern Region has optimized the grid sizes the offices are pushing through the Internet pipe and has worked with the NWS Gateway to get key model data on the Satellite Broadcast Network flowing into AWIPS. While these solutions will not satisfy the ever increasing demand for more bandwidth, it should free up bandwidth to improve Internet access.

Finding 16: NWS communications infrastructure for collocated offices cannot handle the volume of data being distributed and received during a large-scale, high-profile severe weather or flood event.

Recommendation 16: NWS should improve bandwidth availability at field offices, particularly collocated facilities.

10. Summary of Findings, Recommendations, and Best Practices

10.1. Findings and Recommendations

Finding 1a*:* Of the 10 storm-related fatalities, five occurred as a result of automobiles engulfed by rushing floodwaters near swollen stream channels.

Finding 1b: Turn Around, Don't Drown ™ signs were not installed at some vulnerable locations in New York and Pennsylvania prior to the flooding as a result of issues with Department of Transportation (DOT) standards.

Recommendation 1: The NWS Office of Climate, Water, and Weather Services (OCWWS) Hydrologic Service Division should work with the DOT to determine why the national standard for the Turn Around, Don't Drown ™ sign is not uniformly accepted from state to state and develop a sign to fit the standard.

Finding 2: WFO Binghamton had the potential to invoke service backup for an unknown and perhaps lengthy period during the event as they had water in the sub-floor of the office. As the primary backup office for WFO Binghamton, WFO State College would have had significant challenges providing service backup at the height of the storm on Wednesday (September 7) due to the lack of additional work stations. The secondary backup office, WFO Albany, was also in full storm mode without additional work stations available.

Recommendation 2: Eastern Region should evaluate backup procedures, including analyzing backup pairings and ensuring that appropriate resources and equipment, including an appropriate number of AWIPS work stations, are available to support the operations of WFOs when backup offices are also in high impact events.

Finding 3: The MARFC staffing was sufficient to handle this major to historical flood; however, there was a two-day period when nearly all forecast staff were required for flood operations. Had the area of significant flooding included additional large river systems, available resources could have been stressed.

Recommendation 3: NWS should develop a robust cross training program for RFC staffs so personnel can more easily be deployed to neighboring RFCs during large scale flood events. NWS should also increase the consistency in operational software tools, modeling techniques and RFC procedures to facilitate the ability to deploy staff to neighboring RFCs.

Finding 4: NWS crafted impact statements for Conowingo Dam many years ago. They were widely vetted and approved by the downstream communities before being adopted. Until the Lee event, they had gotten little use. Through the years, many of the people involved in adopting the impacts statements retired or moved to new positions.

Recommendation 4: Impact statements associated with various flood levels at a river forecast location should be frequently updated to reflect changing conditions as stated in NWS

Instruction 10-924 Weather Forecast Office Hydrologic Reporting. Updates should be diligently reviewed and approved by the entire river community before adoption. Periodic review of impact statements with community EMs is essential.

Finding 5: MMEFS provided a useful tool to show the potential range of flooding during this event, but some extreme values and some issues with run-to-run consistency may have limited its usefulness. NWS offices participating in the experiment has provided extensive training and outreach on the science in MMEFS and how to read and understand MMEFS output, however, there remains some significant lack of understanding.

Recommendation 5: NWS offices participating in the experiment need to continue working with partners and customers to improve understanding of MMEFS and to refine the way MMEFS output is displayed to provide maximum benefit.

Finding 6: Persons on the ground on the levee system in Wilkes-Barre, PA, assigned to monitor the situation for structural failures and safety concerns failed to report back to Luzerne County EOC and the Flood Protection Authority that the river continued to rise throughout the night despite gage observations indicating an apparent crest at 38.50 feet.

Recommendation 6: The NWS should continue to build, foster and train on-the-ground river observer contact networks to supplement real-time gage observations and use during emergencies, such as high-flow events and equipment outages.

Finding 7: Lack of knowledge regarding the operating limits of the gaging equipment at Wilkes-Barre (WBRP1) created a substantial amount of confusion and uncertainty when the gage began reporting suspect stage heights just prior to cresting.

Recommendation 7: The NWS needs to work with the USGS and other partners to ensure that the operating limits of stream gaging equipment are known and available. The events that occurred at Wilkes-Barre, PA, have prompted a national action by the USGS to post the information on each individual real-time web page and provide a state-by-state document to selected cooperators such as NWS. The NWS should publish this data on corresponding AHPS Web pages to reduce confusion.

Finding 8: The AHPS Web page continued to publish suspect data for WBRP1 even after the USGS had removed the data from its Web pages.

Recommendation 8: The NWS should ensure that erroneous data can be easily removed from NWS systems, most notably the AHPS Web pages.

Finding 9: Some county-level EMs indicated that state led conference calls in Pennsylvania were ineffective as a coordination tool between the state, county-level EMs, and the NWS.

Recommendation 9: WFO State College, as State Liaison Office, should work with PEMA to optimize conference calls to address the concerns of local EMs.

Finding 10: Workload to compile graphics for briefing packages, PDF files and PowerPoint presentations may become excessive and requires extra resources to compile. WFO-centric or RFC-centric products may need to be altered or re-generated to produce state level graphics. Many products used for briefings already exist and redundancy of work during a significant event strains staff and resources.

Recommendation 10: Eastern Region should develop a consistent, efficient approach (methodology, software, procedure and state-centric products) to streamline PowerPoint briefings and graphic development, preferably using existing products. These products would be disseminated to the emergency management community for briefing purposes and should allow updated graphics to be immediately available to users.

Finding 11: Some EMs and river partners were not aware of the RSS alert subscriptions for river gages data via the AHPS program, likely since the option is not easily visible on AHPS.

Recommendation 11: WFOs should demonstrate the AHPS RSS capability to all relevant partners so that they are aware of this program.

Finding 12: Although the SRBC inundation mapping may not be developed to NWS standards at all locations, inundation mapping has proved a useful risk communication and planning tool for local communities in advance of flood events.

Recommendation 12: Eastern Region should collaborate with partner members of the SFFWS Interagency Coordinating Committee to increase public awareness of inundation mapping resources in the Susquehanna River Basin for use as risk awareness and planning tools.

Finding 13: Although exercises and drills have been conducted for portions of the Susquehanna, there have been no specific drills or exercises for large scale river flooding on the Susquehanna River have occurred.

Recommendation 13: NWS offices with areas of responsibilities along the Susquehanna River should partner with each other, EMs and other river related constituency to design an exercise to tests all facets of river flood operations and response.

Finding 14: NWS has contracts with a commercial vendor to share AHPS loads during high usage events. The commercial vendor, however, did not spin-up operations until an AHPS outage already had occurred. The result was a lapse in the availability of river forecasts for partners and customers.

Recommendation 14: NWS should review its contracts with commercial vendors to establish load sharing of AHPS pages at the beginning of a high usage event rather than at the failure of NWS AHPS Web pages.

Finding 15: During the failure of the Maryland site, the NIDS manager used OPSNet technicians to fix the problem. This attempt failed and due to scheduling conflicts a technician was unable to travel again until Friday, September 9.

Recommendation 15: In the future, staffing should be based on anticipated significant load demands due to high usage events so there is no delay in sending NIDS technicians to remote sites.

Finding 16: NWS communications infrastructure for collocated offices cannot handle the volume of data being distributed and received during a large-scale, high-profile severe weather or flood event.

Recommendation 16: NWS should improve bandwidth availability at field offices, particularly collocated facilities.

10.2. Best Practices

Best Practice 1: Early consideration and deployment of a forecaster from a neighboring un-impacted WFO allowed WFO Binghamton to continue to meet its mission and provide a high level of service.

Best Practice 2: WFO Service Hydrologists should conduct post flood storm surveys for moderate to major record flood events to assess the impacts of these events, capture time sensitive field data and talk to community members and officials in an effort to assess the overall forecast and hydrologic warning services. Support from neighboring WFO or RFC hydrologists should be used as needed. Information gathered should be used to update impact statements and review or re-evaluate minor, moderate, and major flood categories at specific forecast points.

Best Practice 3: RFC staff had spent considerable time developing an archive of previous heavy rain and flood events in its basin. RFC staff could access this archive to see how rivers might respond. During this flood event, some hydrologic model runs generated unrealistic results that RFC staff had very low confidence in. In these instances, the staff would refer to analog events from the developed flood archive to refine forecasts. References to analog events also helped staff convey the seriousness of the forecasted flood during briefings.

Best Practice 4: WFO Pittsburgh's MIC served as liaison to PEMA during the event. Establishing a liaison at the state level from a WFO outside of the weather and hydrologic impact areas was very effective in coordinating a multitude of warnings, statements, expected regional impacts and handling briefings.

Best Practice 5: WFO Binghamton's close relationship with its partners and customers, and outreach and preparedness activities conducted by the WFOs, ensured when words like "catastrophic," and "major flood disaster" were used, partners understood the severity of the situation and that this event was not a typical flood event.

Best Practice 6: The longstanding relationship between the MARFC and the SRBC aided in collaboration during the 2011 Susquehanna floods and promoted trust among NWS and its partners and customers.

Best Practice 7: The RFC educated partners how to use NWSChat to receive the text version of SHEF formatted river forecasts during an AHPS outage.

Best Practice 8: During this flood event, USGS field technicians took photos during site visits. These photos were uploaded in near real time to a USGS Website where NWS personnel could access them for visual confirmation of the extent and severity of flooding.

Appendix A: Acronyms

AHPS	Advanced Hydrologic Prediction Service
AWIPS	Advanced Weather Interactive Processing System
CDT	Central Daylight Time
cfs	Cubic Feet per Second
CWA	County Warning Area
DOT	Department of Transportation
EM	Emergency Management/Manager
EOC	Emergency Operations Center
FAR	False Alarm Rate
FEMA	Federal Emergency Management Agency
HMD	Hydrometeorological Discussion
HPC	Hydrometeorological Prediction Center
HWO	Hazardous Weather Outlook
IDSS	Impact-Based Decision Support Services
ISSO	Information Systems Security Officer
IT	Information Technology
MARFC	Middle Atlantic River Forecast Center
MEMA	Maryland Emergency Management Agency
MIC	Meteorologist-in-Charge
MMEFS	Meteorological Model-Based Ensemble Forecast System
NWS	National Weather Service
NIDS	NWS Internet Dissemination System
NWSChat	Internet-based chat software
OCWWS	Office of Climate, Water and Weather Services
OPSNet	Operational Systems Network
PEMA	Pennsylvania Emergency Management Agency
POD	Probability of Detection
QPF	Quantitative Precipitation Forecast
RSS	Really Simple Syndication
SEOC	State Emergency Operations Center
SFFWS	Susquehanna Flood Forecast and Warning System
SRBC	Susquehanna River Basin Commission
SSH	Senior Service Hydrologist
TOC	Telecommunications Operations Center
TS	Tropical Storm
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office

Appendix B: Storm Rainfall Totals

County	State	Location	Total Rainfall (ins)
Broome	NY	Vestal Center	9.92
		Binghamton Regional Airport	9.19
		1NW Park Terrace	8.47
		1SE Kattellville	7.74
		Deposit	4.55
Chemung	NY	Van Etten	5.79
		1SW Rosstown	5.61
		1ESE Elmira	5.49
		1W Big Flats	3.37
Chenango	NY	Coventry	8.46
		Chenango Lake	5.77
		2W Preston	5.68
		Upperville	4.91
Cortland	NY	1NW Hunt’s Corner	6.40
		Marathon	6.04
		2SSW Willet	5.95
Delaware	NY	Arkville	4.02
		1NW Walton	3.87
		3SE DeLancey	3.46
Madison	NY	2NNW Earlville	4.33
		2SW Munnsville	3.74
		1NNE Oneida	3.14
Oneida	NY	1S New Hartford	3.71
		Vernon	3.60
		Dix	3.54
		2E Marcy	3.46
Onondaga	NY	Tully Lake Park	3.95
		Dewitt	3.19
		2E Marcellus	2.88
		Syracuse Hancock Airport	2.65
Otsego	NY	2N Unadilla	6.06
		1NE Oneonta	5.13
		1N Cooperstown	3.70
Schuyler	NY	1W Alpine Junction	4.84
		2NE Catharine	4.77
		4ESE Cayuta	4.70
		Burdett	4.43
County	**State**	**Location**	**Total Rainfall**

			(ins)
Steuben	NY	1WNW Caton	4.14
		1SSW Corning	3.51
		Sonora	3.17
		Bath	2.27
Tioga	NY	Tioga Terrace	11.24
		1ENE Valley Mobile	10.31
		2NW Berkshire	6.62
Tompkins	NY	2WNW Caroline Center	5.24
		2SSE Slaterville	5.17
		Red Mills	4.81
		1NNE North Lansing	3.98
Yates	NY	Penn Yan Regional Airport	1.34
Adams	PA	2N Abbottstown	9.36
		1SE York Springs	8.33
		Hanover	7.57
		Biglerville	5.89
Bedford	PA	Everett	6.37
		Wolfsburg	5.93
		9SSE Rainsburg	4.99
Blair	PA	Wolfsburg	5.93
		Altoona Airport	5.06
Bradford	PA	Alba	9.02
		South Towanda	7.21
		1WNW Covert	6.75
Cambria	PA	Johnstown Airport	5.62
		1W Westmont	3.98
Centre	PA	6E Port Matilda	6.84
		State College	4.90
		2S Phillipsburg	4.37
Clinton	PA	Renovo	3.28
Cumberland	PA	5NE Mechanicsburg	9.31
		1NNW Mechanicsburg	8.10
		3W Enola	7.70
		Pine Grove Furnace	6.98
Dauphin	PA	Dehart Dam	13.54
		2E Paxtonia	13.51
		Harrisburg Airport	13.30

County	State	Location	Total Rainfall (ins)
Dauphin	PA	Hershey	12.18
Franklin	PA	South Mountain	5.61
Huntingdon	PA	Huntingdon	5.77
Lackawanna	PA	1N Ransom	3.68
		1ESE Glenburn	3.24
		Montdale	2.88
Lancaster	PA	1NNE Elizabethtown	15.20
		3W Lancaster	12.56
		Lancaster Airport	9.92
		Millersville	7.83
Luzerne	PA	1NE Koonsville	6.01
		1NNE Cranberry	5.55
		Yatesville	4.90
		Hazelton	4.64
		Wilkes-Barre/Scranton Airport	4.52
Lycoming	PA	Williamsport Airport	8.98
		Williamsport	7.89
Northumberland	PA	Bear Gap	12.04
		Sunbury	11.82
Schuylkill	PA	Pine Grove	14.70
		1WSW Pottsville	9.44
		Mahanoy City	7.56
Snyder	PA	Selinsgrove	9.26
		Selinsgrove Airport	7.30
Somerset	PA	Laurel Summit	4.92
		Meyersdale	4.90
		Somerset	4.83
Susquehanna	PA	Montrose	7.97
		2ENE Choconut	7.39
		Stanfordville	7.18
		1WNW Heart Lake	6.28
Tioga	PA	Tioga-Hammond	6.36
		Wellsboro	4.30
Union	PA	Lewisburg	10.19
Wayne	PA	1NNW Seelyville	5.71
Wayne	PA	Bethel	4.79
		Starrucca	4.46
Wyoming	PA	1S Mehoopany	9.14
York	PA	York Airport	10.82

Appendix C: Confirmed Flood Fatalities

COUNTY	DATE/TIME	AGE/GENDER	CIRCUMSTANCES
Bradford, PA	9/10/11 11:30 PM	92-YEAR OLD FEMALE	An elderly woman in Towanda refusing to evacuate her home, was exposed to flood waters and died from hypothermia.
Dauphin, PA	9/7/11 8:57PM	70-YEAR OLD MALE	A Derry Township resident was bailing out water from his flooded basement when a wall collapsed on him.
Dauphin, PA	9/9/11 1:15PM	81-YEAR OLD MALE	An elderly man drove through standing water and was swept into Clarks Creek in Middle Paxton Township. His body was found inside the submerged car.
Dauphin, PA	9/13/11 1:54PM	87-YEAR OLD MALE	A mud-covered body was found in an automobile caught in the floodwaters of Swatara Creek in Swatara Township.
Lancaster, PA	9/8/11 2:11AM	62-YEAR OLD FEMALE	A woman drowned when her car ended up in a small creek at the intersection of US 322 and Pumping Station Road near Brickersville in Elizabeth Township.
Lancaster, PA	9/8/11 5:42AM	40-50 YEAR OLD MALE	A man was discovered ½ mile downstream from where he was swept away by Chickies Creek while returning home from helping neighbors in Penn Township.
Lancaster, PA	9/8/11 2:00PM	8-YEAR OLD MALE	A young boy drowned after getting caught up in a storm-water drain in East Cocalico Township.
Lebanon, PA	9/10/11 4:45AM	55-YEAR OLD MALE	A Lebanon County man, departing his stalled vehicle, fell in rushing waters and was swept away into Swatara Creek while attempting to cross Route 72 on foot. Good Samaritans tried to pull the man to safety but were unsuccessful. The body was discovered more than a month later 3 miles downstream some 60 yards from the creek.
Philadelphia, PA	9/7/11 NA	27-YEAR OLD FEMALE	A young woman, driving home late Wednesday night, got caught in floodwaters and drowned in the East Germantown section of Philadelphia. Police, responding to a missing persons report, found her body in the back seat of her SUV after the vehicle was towed.
Dauphin, PA	9/9/11 NA	54-YEAR OLD FEMALE	A woman was presumed swept away in flood waters along Swatara Creek while walking; body not discovered until January 3, 2012

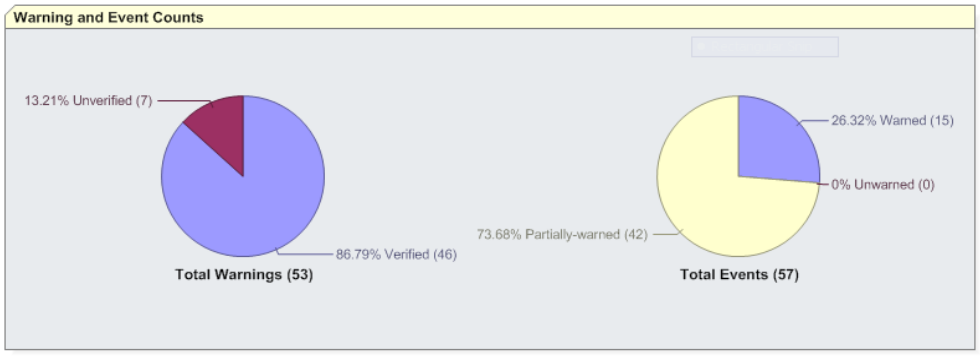
Appendix D: Verification

Storm-based Flash Flood Warning Verification

Dates	09/06/2011 - 09/10/2011
Areas	WFO - BGM, CTP
Match Type	Flash Flood Only (Polygon)
Group Type	National, Region, WFO
Groups Found	BGM, CTP
Download Data	Summary [1KB csv file]

Summary Statistics

Group	Counts							Statistics									
	Warnings			Events				Scores			Lead Time (min)		Warning Area (sq. mi)			Event Area (sq. mi)	
	Total	Verif	NOT Verif	Total	Fully Warned	Partially Warned	NOT Warned	POD	FAR	CSI	Area Weighted	Max Event	Total	Average	County Reduction	Total	Average
BGM	35	31	4	43	5	38	0	0.955	0.114	0.851	144.90	173.58	70571.41	2016.33	0.69	776.74	18.06
CTP	18	15	3	14	10	4	0	0.918	0.167	0.775	65.09	92.64	34917.20	1939.84	0.70	1252.94	89.50
Total	53	46	7	57	15	42	0	0.946	0.132	0.827	125.30	153.70	105488.61	1990.35	0.69	2029.68	35.61



Storm-based Flash Flood Warning verification statistics for September 6-10, 2011

County-based Flash Flood Warning Verification

Dates	09/06/2011 - 09/10/2011
Areas	WFO - BGM, CTP
Match Type	Flash Flood Only (county-based)
Group Type	National, Region, State, WFO, County
Groups Found	BGM, CTP
Download Data	Summary [1KB csv file]

Summary Statistics

Group	Counts						Statistics				
	Warnings			Events			Scores			Lead Time	
	Total	Verif	NOT Verif	Total	Warned	NOT Warned	POD	FAR	CSI	Mean (min)	% > 0
BGM	140	97	43	45	45	0	1.000	0.307	0.693	185.69	0.96
CTP	96	32	64	14	14	0	1.000	0.667	0.333	110.43	1.00
Total	236	129	107	59	59	0	1.000	0.453	0.547	167.83	0.97

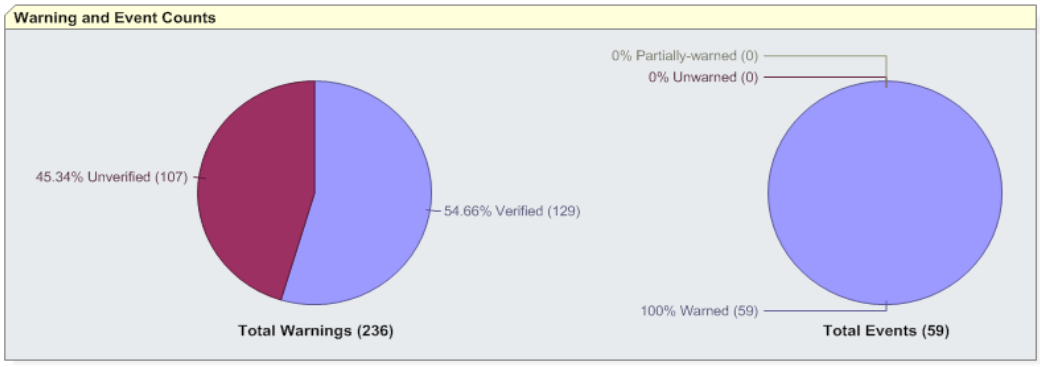
County-based Flash Flood Warning Verification

Dates	09/06/2011 - 09/10/2011
Areas	WFO - BGM, CTP
Match Type	Flash Flood Only (county-based)
Group Type	National, Region, State, WFO, County
Groups Found	NY, PA
Download Data	Summary [1KB csv file]

Summary Statistics

Group	Counts						Statistics				
	Warnings			Events			Scores			Lead Time	
	Total	Verif	NOT Verif	Total	Warned	NOT Warned	POD	FAR	CSI	Mean (min)	% > 0
NY	91	61	30	34	34	0	1.000	0.330	0.670	184.06	1.00
PA	145	68	77	25	25	0	1.000	0.531	0.469	145.76	0.92
Total	236	129	107	59	59	0	1.000	0.453	0.547	167.83	0.97

County-based Flash Flood Warning Verification Statistics for September 6-10, 2011



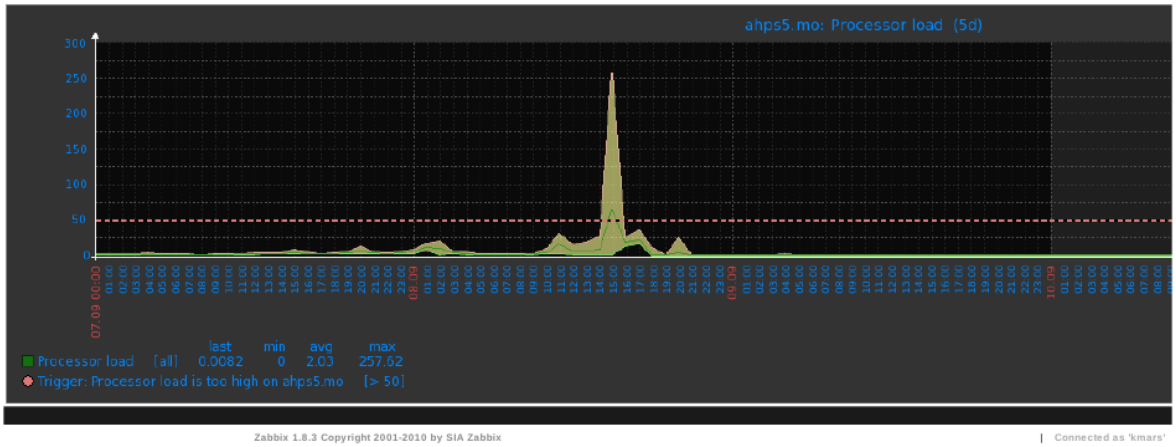
Appendix E: AHPS Web Service Outage

During the morning hours of Thursday, September 8, water.weather.gov Web service suffered five service outages ranging from 3 minutes to 25 minutes. These outages meant that users of the service, both public and internal, received no products from the AHPS service.

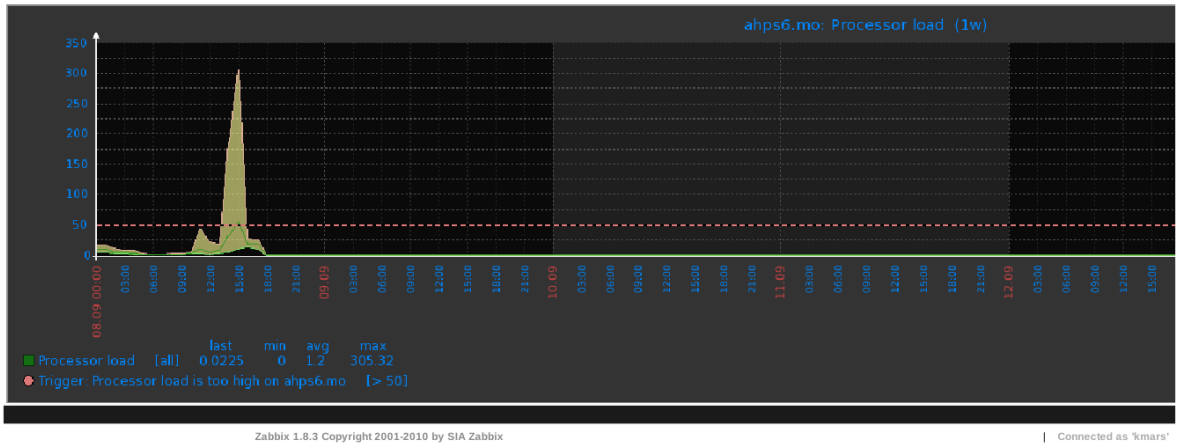
The order of outages was as follows:

6:41 a.m. CDT: 7 minutes
7:26 a.m. CDT: 7 minutes
7:41 a.m. CDT: 25 minutes
8:11 a.m. CDT: 3 minutes
8:56 a.m. CDT: 25 minutes

The service was apparently impacted by extremely high traffic exacerbated by the fact that the NIDS Silver Spring was unavailable.



The image above shows ahps5.mo webserver processor load during the time of the outage



The image above shows the ahps6.mo webserver processor load during the outage

NIDS staff took the following actions on Thursday, September 8,) to resolve the issue:

- At approximately 9:30 a.m. CDT, AHPS service was moved to a commercial vendor under contract for content delivery.
- NIDS contacted its Information System Security Officer (ISSO) and gave credentials on ahps5, and ahps6 and NIDS switches and firewall for forensic analysis.
- Over the course of the day, AHPS services were moved from ahps5.mo and ahps6.mo to the core NIDS Webservers. The switchover occurred at approximately 5:00 p.m. CDT and increased total capacity of the application by a factor of 42.

These actions stabilized AHPS at the Kansas City site.

On Friday, September 9, NIDS personnel arrived on site at Silver Spring and repaired the AHPS system there.

NIDS ISSO worked with the NOAA Computer Incident Response Team to investigate the possibility of a denial of service attack causing the increase, but could not find evidence to confirm an IT security incident. One reason for the lack of determination is that the commercial vendor is unable to provide adequate Web logs to identify a denial of service attack.

Appendix F: River Flood Summary

USGS station number	USGS station name	Drain. area [mi^2]	NWS flood stage [ft]	No. of days above flood stage	Highest peak from 2011-09-03 to 2011-09-12				Historical Peaks	
					Date	Stage [ft]	Stream flow [ft^3/s]	Rank	No. of years	Max Stage (year) [ft]
01505000	Chenango River at Sherburne, NY	263	8.5	TBD	2011-09-08	11.64	TBD	1	73	11.35 (2006)
01507000	Chenango River at Greene, NY	593	13	TBD	2011-09-08	21.09	TBD	3	74	22.00 (1935)
01512500	Chenango River near Chenango Forks, NY	1483	10	TBD	2011-09-08	14.93	TBD	4	98	20.30 (1935)
01502500	Unadilla River at Rockdale, NY	520	11	TBD	2011-09-08	14.22	TBD	1	81	13.96 (2006)
01500500	Susquehanna River at Unadilla, NY	982	11	TBD	2011-09-09	16.34	TBD	3	76	17.27 (2006)
01502731	Susquehanna River at Windsor, NY	1820	17	4	2011-09-08	24.21	55400	2	23	24.27 (2006)
01503000	Susquehanna River at Conklin, NY	2232	12	6	2011-09-08	23.94	72100	2	98	25.02 (2006)
01503500	Susquehanna River at Binghamton, NY	2291	14	5	2011-09-08	25.71	NA	1	100	25.00 (2006)
01513500	Susquehanna River at Vestal, NY	3941	18	6	2011-09-08	35.26	129000	1	76	33.66 (2006)
01513831	Susquehanna River at Owego, NY	4216	30	1	2011-09-07	39.62	159000	1	22	35.90 (2006)
01515000	Susquehanna River near Waverly, NY	4773	11	6	2011-09-08	26.67	167000	1	75	22.52 (2006)
01516350	Tioga River near Mansfield, PA	153	12	1	2011-09-08	13.08	15600	11	40	20.13 (1972)
01531500	Susquehanna River at Towanda, PA	7797	16	4	2011-09-08	30.52	250000	2	118	33.42 (1972)
01532000	Towanda Creek near Monroeton, PA	215	15.5	2	2011-09-08	20.97	64200	1	69	20.86 (1996)
01533400	Susquehanna River at Meshoppen, PA	8720	27	5	2011-09-08	44.42	362000	1	34	43.51 (1972)
01534000	Tunkhannock Creek near Tunkhannock, PA	383	11	1	2011-09-08	13.72	19900	9	97	20.90 (2006)
01536500	Susquehanna River at Wilkes-Barre, PA	9960	22	4	2011-09-09	42.66	TBD	1	112	40.91 (1972)

USGS station number	USGS station name	Drain. area [mi^2]	NWS flood stage [ft]	No. of days above flood stage	Highest peak from 2011-09-03 to 2011-09-12				Historical Peaks	
					Date	Stage [ft]	Stream flow [ft^3/s]	Rank	No. of years	Max Stage (year) [ft]
01538700	Susquehanna River at Bloomsburg, PA	10560	19	4	2011-09-09	32.75	342000	1	18	32.70 (1904)
01540500	Susquehanna River at Danville, PA	11220	20	4	2011-09-09	31.55	311000	2	112	32.32 (1972)
01548005	Bald Eagle Creek near Beech Creek Station, PA	562	11	1	2011-09-07	11.66	5340	13	99	15.94 (2004)
01552000	Loyalsock Creek at Loyalsockville, PA	435	12	1	2011-09-07	19.78	69100	1	84	17.93 (1996)
01553240	W Br Susquehanna River at West Milton, PA	6825	19	3	2011-09-08	26.60	NA	10	NA	34.55 (1972)
01553500	West Branch Susquehanna River at Lewisburg, PA	6847.00	18	3	2011-09-08	25.91	168000	11	77	34.23 (1972)
01554000	Susquehanna River at Sunbury, PA	18300	24	3	2011-09-08	31.66	463000	3	95	35.80 (1972)
01555000	Penns Creek at Penns Creek, PA	301	8	2	2011-09-08	8.88	7000	35	81	14.85 (1972)
01556000	Frankstown Br Juniata River at Williamsburg, PA	291	12	3	2011-09-07	14.03	9810	14	95	19.46 (2004)
01564512	Aughwick Creek near Shirleysburg, PA	301	10	3	2011-09-07	14.8	15800	5	21	19.46 (1996)
01568000	Sherman Creek at Shermans Dale, PA	207	9	3	2011-09-07	11.04	11400	25	82	20.34 (1927)
01570000	Conodoguinet Creek near Hogestown, PA	470	8	3	2011-09-08	10.53	10600	10	78	17.01 (1972)
01570500	Susquehanna River at Harrisburg, PA	24100	17	4	2011-09-09	25.17	590000	5	125	32.57 (1972)
01571500	Yellow Breeches Creek near Camp Hill, PA	213	7	3	2011-09-08	9.60	4310	10	67	18.77 (1975)
01573000	Swatara Creek at Harper Tavern, PA	337	9	3	2011-09-08	24.60	70400	2	93	25.60 (1889)
01573560	Swatara Creek near Hershey, PA	483	7	5	2011-09-08	26.80	72500	1	36	16.12 (2006)
01576000	Susquehanna River at Marietta, PA	25990	49	5	2011-09-09	58.16	665000	4	80	64.54 (1972)

USGS station number	USGS station name	Drain. area [mi^2]	NWS flood stage [ft]	No. of days above flood stage	Highest peak from 2011-09-03 to 2011-09-12				Historical Peaks	
					Date	Stage [ft]	Stream flow [ft^3/s]	Rank	No. of years	Max Stage (year) [ft]
01576500	Conestoga River at Lancaster, PA	324	11	1	2011-09-08	21.30	28500	2	82	27.90 (1972)
01578310	Susquehanna River at Conowingo, MD	27100	23.5	6	2011-09-09	32.41	778000	3	43	36.83 (1972)
NA	West Branch Susquehanna R near Muncy	6332	20	3	2011-09-08	26.7	NA	10	75	37.45 (1972)
NA	West Branch Susquehanna R at Montgomery	6426	20	3	2011-09-08	26.7	NA	12	146	37.5 (1972)
NA	West Branch Susquehanna R at Watsontown	6573	23	3	2011-09-08	26.7	NA	8	75	37.5 (1972)
NA	Swatara Creek at Middletown	569	11	NA	2011-09-09	23.23	NA	2	39	28.45 (1972)

Appendix G: Actions Taken as a Result of 2006 Susquehanna Flood

June 2006 Flood

The Susquehanna River Basin is one of the most flood prone watersheds in the nation and experiences flood-related damages, on average, in excess of $150 million every year. The June 2006 flooding is remembered by some in the Susquehanna River Basin as producing some of the worst flooding in recorded history. The most severe flooding in the basin occurred in the southern tier of New York along the Susquehanna and Chenango Rivers and the eastern and central areas of Pennsylvania.

As a result of the 2006 flood, it was determined that the best method to mitigate flood damages in the basin was through nonstructural measures such as flood forecast and warning systems. NWS, in collaboration with the SRBC, the USGS, the USACE and the states of New York, Pennsylvania and Maryland developed and implemented improvements to the Susquehanna Flood Forecast and Warning System for future events. After the June 2006 flood, NWS developed and implemented recommendations to improve the system for future flood events. The Susquehanna Basin flooding of 2011 provided an opportunity to evaluate how the implementation of these recommendations improved hydrologic monitoring, forecast and warning product generation, warning dissemination, interagency communications and operations and public information and education.

Hydrologic Monitoring

The following recommendations were developed to improve hydrologic monitoring after the June 2006 flood:

- Raise the gage house floors and flood-proof the Rockdale, Unadilla, Vestal, and Conklin stream gages
- Evaluate performance and implement enhancements to reduce radar limitations in tracking observed rainfall
- Extend the rating curves at all river forecast points to 125 percent above the record flow as time and funding allow. Priority locations identified to date:
    - Unadilla River at Rockdale
    - Susquehanna River at Unadilla
    - Susquehanna River at Bainbridge
    - Susquehanna River at Conklin
    - Tioughnioga River at Cortland
    - Chenanago River at Sherburne
    - Chenango River at Greene
    - Chenango River at Chenango Forks
    - Susquehanna River at Vestal
    - Susquehanna River at Owego
    - Susquehanna River at Waverly
    - Susquehanna River at Chemung

    - Tunkhannock Creek at Tunkhannock
    - Lackawanna River at Old Forge
    - Lackawanna River at Bloomsburg
- Investigate need for a full-time gage and/or forecast point at Binghamton
- Install and maintain real-time stream gages at the following sites:
    - Swatara Creek at Middletown, Pa. (stage only)
    - Susquehanna River at Oneonta
    - Susquehanna River at Binghamton, N.Y. (stage only)
- Establish and maintain rating curves at the following stage-only sites:
    - Norwich
    - Greene
    - Oneonta
    - Unadilla
    - Bainbridge
    - Windsor
    - Vestal
    - Owego, NY(Susquehanna River)
    - Owego, NY (Owego Creek).
- Expand precipitation monitoring network (telemetered gages with temperature sensors) to fill gaps in coverage at or near the following locations:
    - Vestal
    - Waverly
    - Oneonta
    - Cuyler/Homer area
    - Haskinville/Cohocton, N.Y., area
- Reinstate functioning Webcam at Conklin, NY; evaluate expansion of Webcam network
- Provide more site-specific monitoring and forecasting for smaller watersheds with shorter response time
- Have agencies evaluate data management problems associated with inadequate or too frequent data transmissions from gages
- Make available real-time information on road and bridge closures to facilitate USGS operations and measurements during flood events

The report made 11 recommendations to improve available flood forecast and warning infrastructure. Ten of the recommendations have been implemented or are underway. Improvement highlights include the expansion of the rain gage and stream gage network by adding four rain and three stream gages and flood proofing four existing gages to levels above the June 2006 flood. The MARFC implemented the use of a quality controlled Multisensor Precipitation Estimator, a combination of weather radar precipitation estimates and rain gage data, as model input. MARFC also incorporated daily precipitation observations from hundreds of volunteer observers participating in the CoCoRaHS network. The only recommendation not adopted is establishing a system-wide Webcam network.

Forecast and Warning Product Generation

The following recommendations were developed to improve forecast and warning product generation after the June 2006 flood:

- Evaluate modeling time steps and forecasting intervals and assess need to provide more frequent updates of river stages and flood forecasts
- Develop modeled forecast points at Oneonta, Windsor and Owego on the Susquehanna River
- Develop crest-crest relationships for forecasts at Norwich, NY (Chenango River), and Binghamton, NY (Susquehanna River)
- Provide more forecast information on the Lower Lackawanna River in the area of the flood damage reduction project; evaluate reliability of local gages
- Provide forecast information on the Codorus Creek in the York, PA, area; evaluate need for improvements to the gage, including relocation of the gage off private property and development and maintenance of a rating curve
- Modify graphical forecast products to display the range of probability for river forecasts at each site, instead of one discrete forecasted stage
- Refine and enhance techniques for monitoring and forecasting flash flooding

A total of seven recommendations were made to improve forecast and warning products to allow enhanced computer modeling and improved forecasts. Most of the recommendations in this category are currently underway or complete. Improvement highlights include:

- Establishing a new forecast point on the Susquehanna at Windsor and Owego
- Converting most flood-only forecast points to daily forecast points
- Converting several crest-only forecast points to full time-series forecast points
- Experimental implementing a 0-7 day Met Model Ensemble River Forecasts (MMEFS)
- Modeling to improve flash flood monitoring and forecasting

Warning Dissemination

The following recommendations were developed to improve warning dissemination after the June 2006 flood:

- Increase and enhance AHPS Web server capacity
- Develop Geographic Information System layers depicting areas of flood inundation to provide EMs a functional tool to facilitate emergency response
- Increase public and agency understanding of the QPF and its use in forecasts
- Encourage NWS and local county partnership efforts to improve communication, mitigation and response through participation in the NWS StormReady® community program and county emergency planning and mitigation meetings

Four recommendations were made to improve the dissemination of flood forecasts to the general public to reduce property loss and save lives. Three of the four are ongoing and one is complete. The completed recommendation increased and enhanced Web server capacity of the NWS Advanced Hydrologic Prediction Service. SRBC also produced draft flood inundation maps and

demonstrated them to county and community leaders and EMs in New York. Flood inundation maps for Jersey Shore, PA, were posted on AHPS.

Interagency Communications and Operations

The following recommendations were developed to improve Interagency Communications and Operations after the June 2006 flood:

- Establish direct and reliable communication routes for forecasts to the SFFWS partners
- Continue using conference calls with county emergency management agencies (EMAs) and FEMA
- Include PEMA, USGS, and SRBC in the conference calls held between NWS and the county EMAs
- Enhance communications with USACE regarding reservoir releases
- Investigate the coordination of reservoir releases with MARFC; improve the accessibility of release data to MARFC
- Develop an internal emergency action plan at SRBC to identify roles, responsibilities, and contacts for use during floods

Six recommendations were made to improve communications among the partners in the SFFWS. Of the six recommendations, two are complete and four are ongoing. Highlights include the implementation of NWSChat software that lets external partners interact with each other and with RFC forecasters, receives notices when forecast updates are issued, and receive forecasts as a back-up through chat software. MARFC also set-up automated system to provide UACE Baltimore District with preliminary model inflows and downstream flow forecasts to assist with management of its reservoirs.

Public Information and Education

The following recommendations were developed to improve public information and education after the June 2006 flood:

- Improve understanding of NWS predicted flood characterization: minor, moderate, major.
- Emphasize that river forecasts generally cover a range of 2 to 3 feet, and emphasize the inherent uncertainty of forecasts using QPFs

Two recommendations were made to improve public information and education regarding the understanding and application of forecast information. Efforts supporting both recommendations are ongoing and include improved media communication and flood stage forecast mapping, which provides a graphical representation of a forecast flood.