January 2007

Susquehanna River Basin Commission

The Susquehanna River Basin is one of the most flood prone watersheds in the nation and experiences flood-related damages in excess of $150 million on average every year. June 2006 will be remembered by some in the Susquehanna River Basin as producing 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.

While a number of flood control projects are in place to protect the citizens of the basin, studies have determined the best way to further reduce flood damages in the basin is through nonstructural measures such as flood forecast and warning systems. The Susquehanna Flood Forecast and Warning System (SFFWS) – coordinated by the Susquehanna River Basin Commission since 1986 – provides residents of the basin with warning and forecast information in advance of and during flooding events. The program is a cooperative effort involving NOAA's National Weather Service, the U.S. Geological Survey, U.S. Army Corps of Engineers, and the states of New York, Pennsylvania and Maryland.

This report provides a summary of the June 2006 flood and SFFWS performance during that flood for the purpose of developing and implementing recommendations that will improve the system for future flood events.

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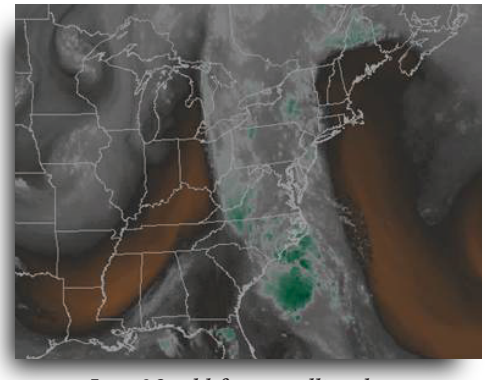
June 2006 Flood

A summary of the flood and performance of the Susquehanna Flood Forecast and Warning System

Prior to June 2006, hydrologic conditions in the basin were dry, and the entire state of Pennsylvania was in "Drought Watch" status. June brought rapid change to the existing conditions as severe thunderstorms occurred during the first part of the month across the basin. On Friday, June 23, a weak surface cold front moved through Pennsylvania scattering strong storms and depositing as much as an inch of rain over parts of the basin, with most of the basin receiving one-quarter to one-half inch of rain.

The weather pattern persisted through the end of June when a stalled front characterized by low pressure centered over the Midwest and high pressure centered off the Atlantic Coast south of New Jersey affected



June 23 cold front satellite photo.

the Northeast for about a week. The opposing rotation of the two pressure systems channeled tropical moisture directly over the Susquehanna River Basin. The National Weather Service (NWS) projected record flooding based on this weather pattern and the rainfall it was expected to produce.

Localized flash flooding began June 25. The heaviest widespread rainfall occurred from June 26 to June 28, and by the time the storm moved out of the basin on June 29, some areas had received 8 to 15 inches or more of rain *(see Figure 1, next page)*.

As a result of widespread heavy rainfall, record flooding occurred in the

Photo: D. Lupardo

Aerial photo of Lourdes Hospital, Broome County, NY.

Upper Susquehanna subbasin, moderate to major flooding occurred in the Middle Susquehanna subbasin, and minor to moderate flooding occurred in the Lower Susquehanna subbasin. The storm's track spared the Chemung, West Branch and Juniata subbasins, resulting in only minor flooding. Low contributions of flow from the western subbasins allowed the middle and lower mainstem Susquehanna River to accommodate excessive flows from the Upper and Middle Susquehanna subbasins without causing major flooding.

The most severe flooding occurred in New York along the Susquehanna and Chenango Rivers, devastating many communities including Binghamton, Conklin, Greene, Oneonta, Owego, Sidney, Unadilla, Union, Vestal, and Waverly. Preliminary results from the U.S. Geological Survey (USGS) indicate that discharges along the Susquehanna River in New York were greater than the 100-year flood and in some locations exceeded the 500-year flood – breaking long-standing records in several locations by as much as 4 feet (*see Table 1*). In Pennsylvania, the gages at Tunkhannock, Bloomsburg, and Hershey reached new record high levels.

The flood impacted 48 of 67 counties within the Susquehanna River Basin; 11 in New York and 37 in Pennsylvania. In each of these counties, a disaster declaration was made at either the state or federal level (*see Figure 2, page 3*),

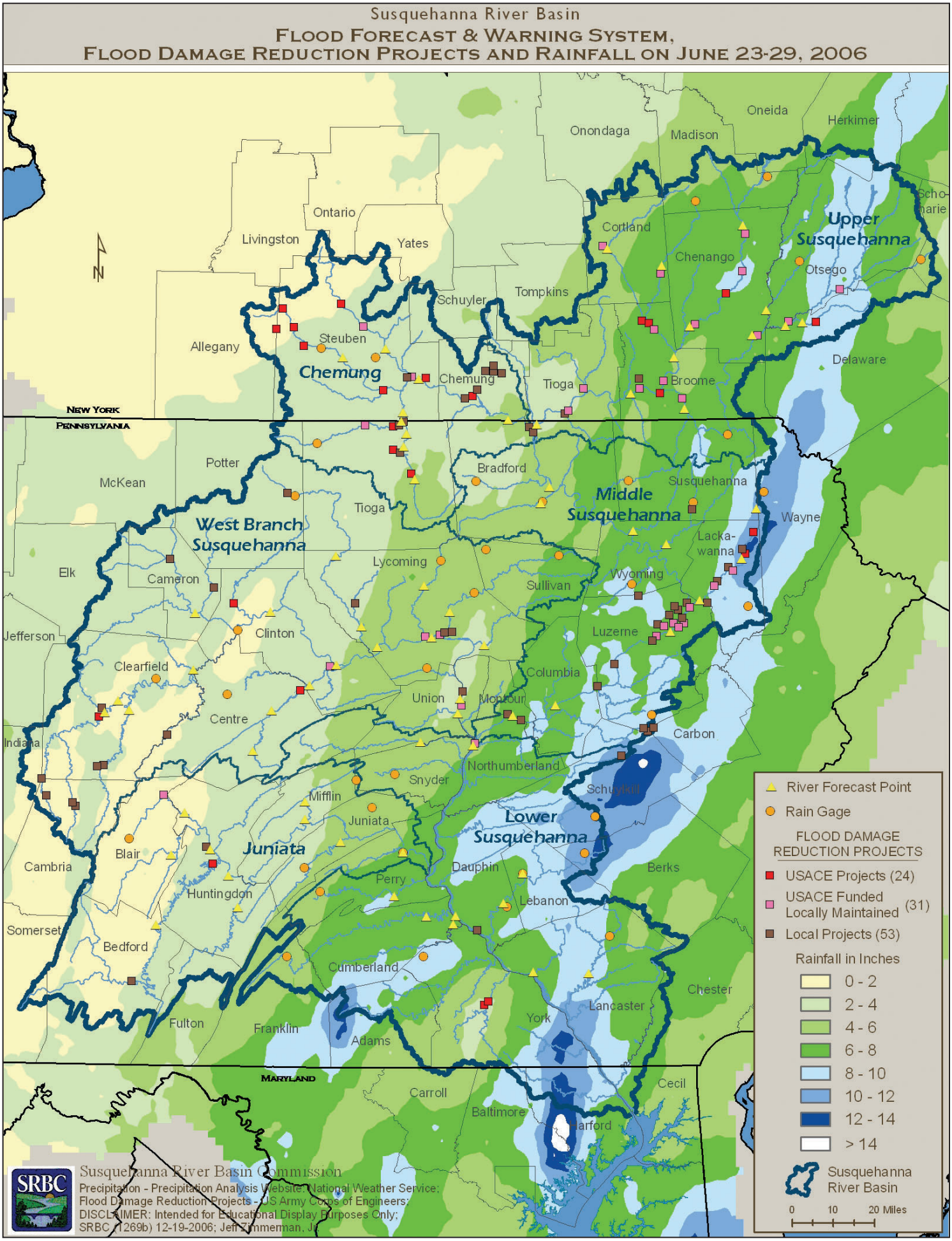

Susquehanna River Basin
FLOOD FORECAST & WARNING SYSTEM,
FLOOD DAMAGE REDUCTION PROJECTS AND RAINFALL ON JUNE 23-29, 2006
N
NEW YORK
PENNSYLVANIA
MARYLAND
Upper Susquehanna
Chemung
West Branch Susquehanna
Middle Susquehanna
Lower Susquehanna
Juniata
Oneida
Herkimer
Onondaga
Madison
Ontario
Livingston
Yates
Cortland
Chenango
Otsego
Schuyler
Tompkins
Steuben
Allegany
Chemung
Tioga
Broome
Delaware
Potter
McKean
Bradford
Susquehanna
Wayne
Tioga
Lycoming
Lacka-wanna
Wyoming
Sullivan
Elk
Cameron
Luzerne
Jefferson
Clinton
Clearfield
Columbia
Union
Montour
Centre
Carbon
Indiana
Northumberland
Snyder
Schuylkill
Mifflin
Juniata
Blair
Cambria
Dauphin
Berks
Perry
Huntingdon
Lebanon
Somerset
Bedford
Cumberland
Chester
Lancaster
Fulton
Franklin
York
Adams
Carroll
Cecil
Baltimore
Harford
River Forecast Point
Rain Gage
FLOOD DAMAGE REDUCTION PROJECTS
USACE Projects (24)
USACE Funded Locally Maintained (31)
Local Projects (53)
Rainfall in Inches
0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12 - 14
> 14
Susquehanna River Basin
0 10 20 Miles
SRBC
Susquehanna River Basin Commission
Precipitation - Precipitation Analysis Website: National Weather Service;
Flood Damage Reduction Projects - US Army Corps of Engineers;
DISCLAIMER: Intended for Educational Display Purposes Only;
SRBC (1269b) 12-19-2006; Jeff Zimmerman, Jr.

Figure 1.

making those counties eligible for disaster relief funding. Some areas in the Maryland portion of the basin did receive heavy rainfall, but no significant flooding occurred. At the time of this report, estimated damages in New York and Pennsylvania are still being compiled. Basinwide, thousands of homes and businesses were severely impacted or destroyed, hundreds of bridges were swept away or left unstable, hundreds of miles of roadways were impacted, and hundreds of millions of dollars in property damage were incurred.

Flood forecasts prompted emergency response in many counties, including activation of evacuation plans, closures of flood levees, and installation of temporary berms and other flood damage reduction measures.

In Pennsylvania, emergency managers reported that seven fatalities occurred in the Susquehanna basin. Three fatalities occurred in the New York portion of the basin; one in Chenango County and two at the collapse of a culvert under Interstate 88 in Delaware County.

RIVER	USGS GAGE NAME	RECORD CREST (YEAR)	JUNE 06 CREST (ft)
Chenango	Sherburne, NY	11.20 (1914)	11.35
Susquehanna	Unadilla, NY	16.60 (1936)	17.73
Susquehanna	Bainbridge, NY	23.10 (1914)	27.03
Susquehanna	Conklin, NY	20.83 (1948)	25.02
Susquehanna	Vestal, NY	30.50 (1936)	33.50
Susquehanna	Waverly, NY	21.40 (1936)	22.52
Tunkhannock Creek	Tunkhannock, PA	19.97 (1996)	20.90
Fishing Creek	Bloomsburg, PA	15.18 (1972)	15.67
Swatara	Hershey, PA	15.36 (1975)	16.12

Table 1. *Record Flood Crests*

Photo: C. Haupt

Washington Street Bridge, Binghamton, N.Y.

"The flood impacted 48 of 67 counties within the Susquehanna River Basin."

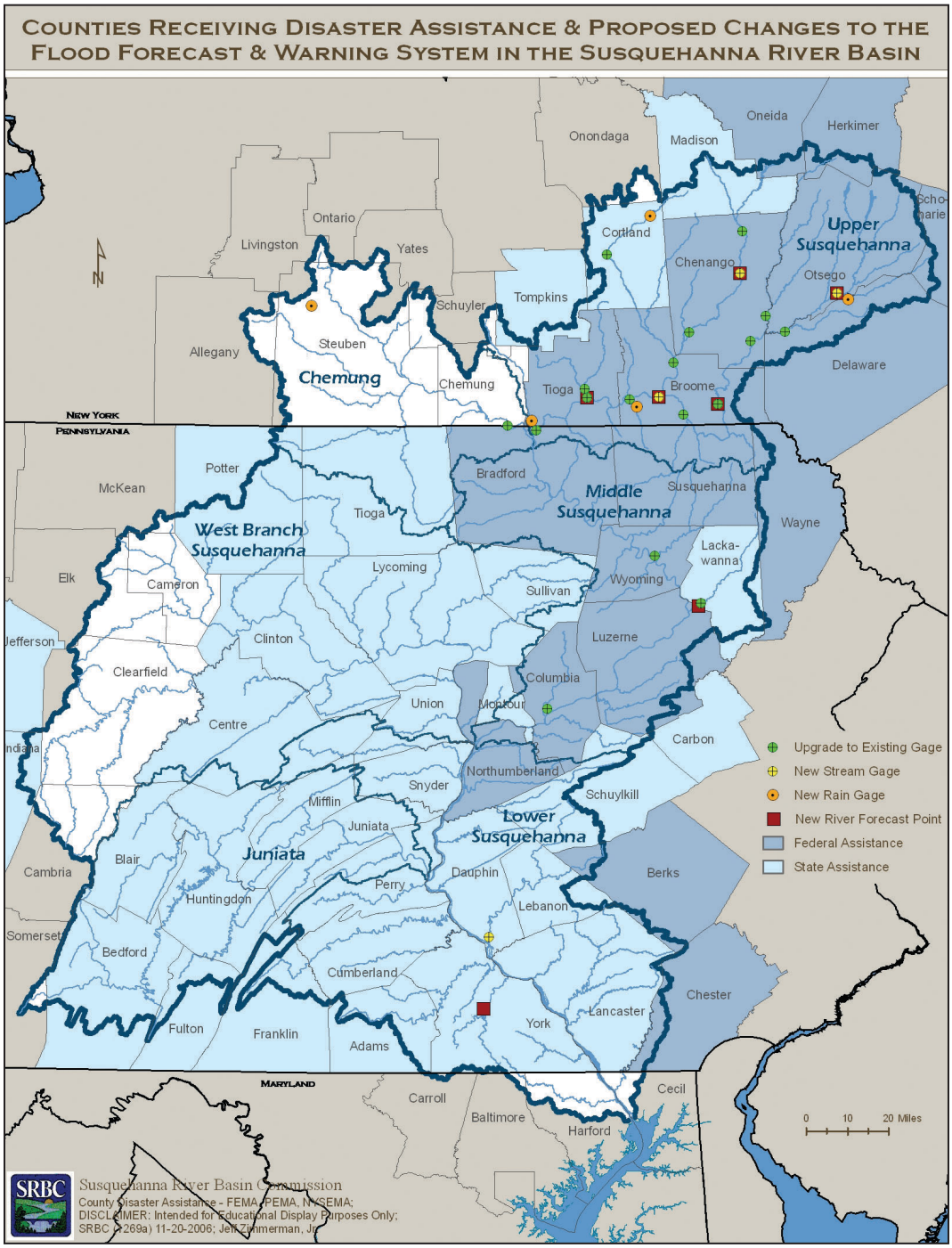


Figure 2.

Susquehanna Flood Fore

Program Goals of the Susquehanna Flood Forecast and Warning System

Develop a sustainable, state-of-the-art observational network
- Develop a gridded observational network
- Incorporate the use of radar-based streamflow velocity measurements

Provide as much lead-time and accuracy in forecasts and warning as practicably possible
- Increase frequency of forecast updates
- Evaluate the need for new forecast points

Evaluate the spatial distribution of flood damages in the basin
- Assess adequacy of existing system for dealing with increased urbanization and flooding in small watersheds

Expand the flood warning system to support water resources management of public water supply, drought, and recreation within the basin
- Develop long-term reservoir inflow and basin outlet forecasts
- Adapt monitoring network for detection of water supply threats

Improve flood warning dissemination through the use of technology
- Develop flood inundation maps for prioritized areas

Increase public awareness, support, and utility of NWS products
- Conduct education and outreach activities to promote loss reduction
- Seek partnerships to leverage resources for warning and dissemination

Develop a mechanism for administration and secure source of funding
- Investigate options for ensuring adequate funding for anticipated needs

The mission of the Susquehanna Flood Forecast and Warning System (SFFWS) is to provide timely and accurate forecasts and warnings to reduce flood damages in the Susquehanna basin.

Daily river stage forecast guidance is issued by the Middle Atlantic River Forecast Center (MARFC), which provides specific estimates of flood crest stages at selected locations on rivers and major tributaries in the Susquehanna basin. The forecast stages are based on model results incorporating large amounts of hydrometeorological data including precipitation measured at a number of gages, precipitation estimates from several weather radars, and quantitative precipitation forecasts (QPF) prepared by support offices of the NWS.

The forecasts generated by MARFC are disseminated to NWS offices in State College, Pa., Binghamton, N.Y., and Mount Holly, N.J. Those offices in turn are responsible for issuing flood and flash flood watches and warnings in the basin. Watches indicate there is potential for flooding, and warnings indicate flooding is imminent.

The NWS forecast offices disseminate the information to state emergency management agencies, other governmental bodies, and the news media. The state emergency management agencies distribute the information to the counties, and the counties then distribute the information to local emergency management officials and others who need the forecasts.

> ***"The successful 20-year effort behind the SFFWS is a model for interagency cooperation and partnership."***

The successful 20-year effort behind the SFFWS is a model for interagency cooperation and partnership. The members of the Interagency Committee are committed to continued improvements to the Susquehanna program through periodic evaluations of the system's performance. Through development of a strategic plan, the committee has identified methodologies and goals to ensure that the program continues to meet the forecasting and warning needs of the Susquehanna River Basin.

Interagency Committee Members

Susquehanna River Basin Commission
National Weather Service
U.S. Geological Survey
U.S. Army Corps of Engineers
NY State Department of Environmental Conservation
NY State Emergency Management Office
Pennsylvania Department of Environmental Protection
Pennsylvania Emergency Management Agency
Pennsylvania Department of Community and Economic Development
Maryland Department of the Environment
Maryland Emergency Management Agency

cast and Warning System

SFFWS Performance

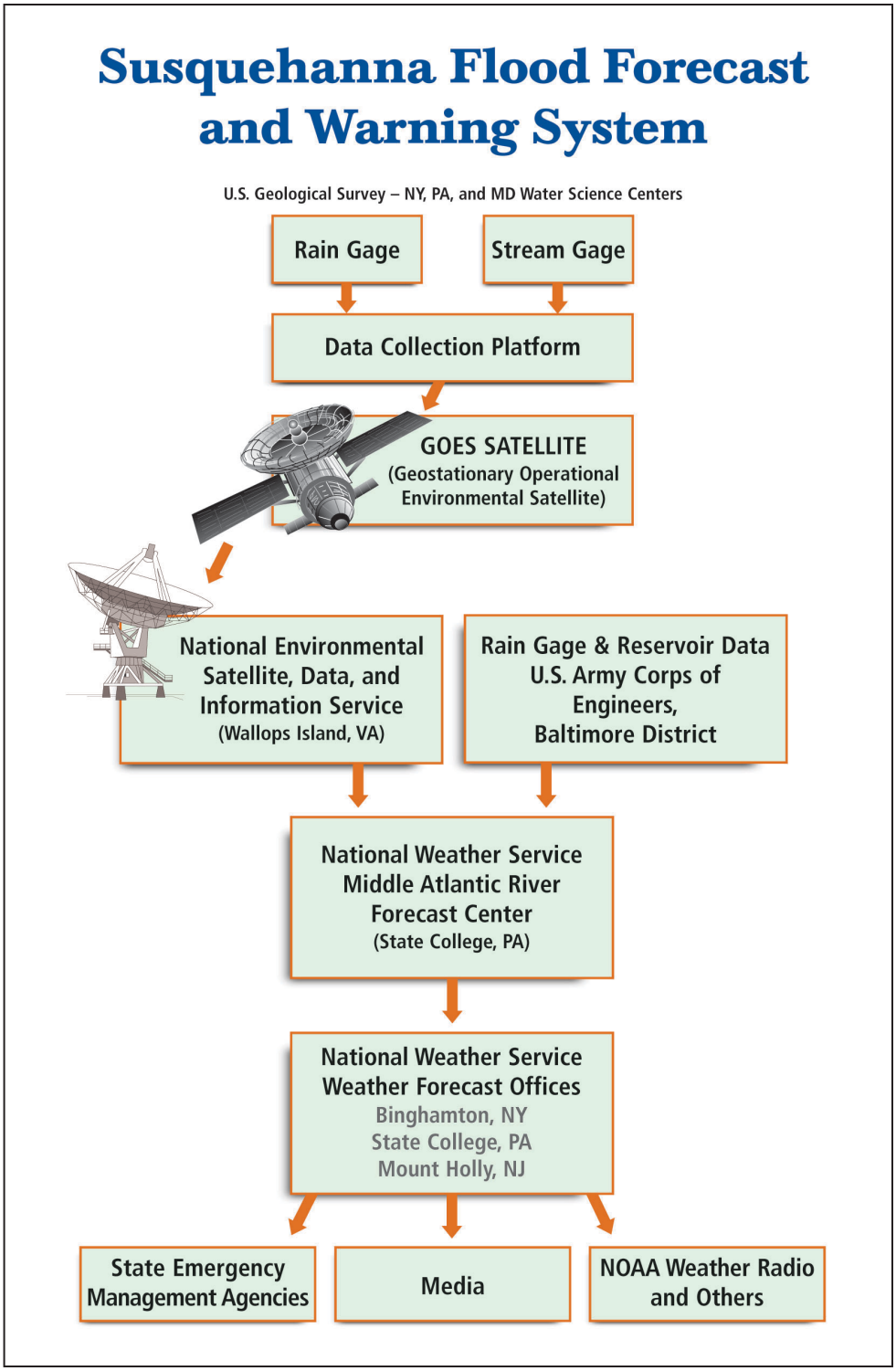
The initial forecast for the June 2006 flood event predicted a storm track that would have concentrated significantly more precipitation in the Susquehanna River Basin. The storm's final track shifted 50 to 75 miles eastward and brought considerably less precipitation and runoff to the basin than initially anticipated. While the shift spared the Western and Lower portions of the basin from major flooding, it caused significant variability in predicted flood levels, particularly on the lower main stem Susquehanna River. Once the storm's track was established, NWS issued accurate forecasts, and the overall performance of the SFFWS was good. Nevertheless, the Interagency Committee conducted an evaluation of all aspects of the SFFWS; the following discussion covers the performance of the SFFWS and any problems encountered during the 2006 flood.

Data Acquisition

Heavy rainfall intensity in parts of New York caused river levels at some gages to rise to flood levels at a rate greater than the data transmittal window (4 hours) and forecast interval (6 hours). Nevertheless, overall feedback on forecast performance was positive for the region north of Wilkes-Barre.

Radar rainfall algorithms failed to accurately estimate rainfall amounts, necessitating the incorporation of real-time rain gage and satellite data to improve accuracy of rainfall estimates. Overall, radar operation and transmission worked well.

Record high flood elevations caused a number of problems at New York stream gages. River flows at both Conklin and Vestal exceeded the physical measurement capability of the gages, leaving forecasters with no indication of how much water was flowing past those locations. Also, several sites had water inside the gage house above the floor level, and



Visit the SFFWS web site
www.susquehannafloodforecasting.org

flood elevations at several gages exceeded the established rating curves. All gages in the Pennsylvania portion of the basin remained functional during the storm and performed well.

USGS staff in New York made 21 discharge measurements during the event. The measurements are vital for developing and maintaining accurate relationships between water elevation (stage) at the gages and flows in the river. However, USGS staff encountered problems obtaining information and gaining access to closed roads and bridges, which impacted their ability to obtain flow measurements.

Forecasting

On average, the forecast lead-time in the Susquehanna basin ranged from 7 to 17 hours, which met the 6-hour goal of the SFFWS. Nevertheless, the event posed challenges for the NWS in preparing forecasts.

Although the final storm track lessened flooding in the Lower Susquehanna basin, it caused severe flooding in the Delaware and Mohawk River Basins. The simultaneous severe flooding in three river systems posed challenges for MARFC and Binghamton forecast office staff.

Predicting rainfall locations with the June 2006 flood was difficult due to the "mesoscale structure" of the storm and the variability of precipitation amounts within that structure. As a result, rainfall predictions were overestimated in some areas and underestimated in other areas. As river forecast modeling is highly dependent on rainfall input, some river forecasts failed to accurately capture actual runoff and peak flow. Additionally, intense rainfall caused rapid runoff that could not be captured by the 6-hour interval of MARFC forecast models, and some flood crests occurred several hours in advance of predictions.

Dissemination and Communications

NWS Eastern Region's Advanced Hydrologic Prediction Services (AHPS) web server experienced performance and reliability problems due to excessive user demand.

The NWS convened a number of conference calls during the June 2006 flood event with the intent of disseminating weather and flood forecasts. Participants on the calls included SFFWS partners and county emergency managers. The conference calls with county-based emergency managers were especially beneficial.

USACE Baltimore District staff expressed the need for better information about downstream conditions to assist decision making for releases from flood damage reduction projects.

The NWS identified need for better communication about releases from flood damage reduction projects for incorporation into forecast models.

Varying and fluctuating forecasts caused concern among some community officials, particularly in Harrisburg, and served to underscore the need to explain uncertainties inherent in using the quantitative precipitation forecast (QPF). Forecast updates were occasionally difficult to track due to problems with the NWS web server.

Discussions with community emergency managers revealed that there may have been gaps in communications between release of NWS forecasts and their transmittal through the counties to local entities.

Flood Damage Reduction Projects

No significant problems were reported at any of the USACE Baltimore District flood damage reduction projects. Preliminary damage prevention estimates total $950 million in the Susquehanna basin ($850M prevented by levees and flood walls; $100M prevented by dams).

Reductions in flood stage were estimated at 2 to 2.5 feet on the Chenango and Upper Susquehanna Rivers, and 1 to 1.5 feet on the Chemung, Lackawanna, and mainstem Susquehanna below the confluence with the Chemung River.

The East Sidney and Aylesworth dams stored record volumes of water; use of the spillway at East Sidney for the first time in the 56-year history of the project prompted erroneous reports of dam failure. The Whitney Point, Aylesworth and Stillwater reservoirs reached 70 to 75 percent of flood storage capacity.

The capacity of the levees in the Vestal-Johnson City-Binghamton area was slightly exceeded and some minor overtopping occurred. The Pennsylvania Department of Environmental Protection reported that seven small low-hazard dams failed in the Pennsylvania portion of the Susquehanna basin. One high-hazard dam (Big Elk dam in Susquehanna County) was overtopped and will require repairs, but did not fail.

Estimated Damages Prevented by Federal Flood Damage Reduction Projects
(provided by the Baltimore District of the U.S. Army Corps of Engineers)

- **$130 million** by the Binghamton levee system in Broome County, N.Y.
- **$230 million** by the Endicott-Johnson City-Vestal levee system in Broome County, N.Y.
- **$460 million** by the Wyoming Valley levee system in Luzerne County, Pa.
- **$2 million** by the Wyoming Valley levee system in Lackawanna County, Pa.
- **$45 million** by East Sidney Lake in Delaware County, N.Y., along the Upper Susquehanna River
- **$35 million** by Whitney Point Lake in Broome County, N.Y., along the Tioughnioga River
- **$13 million** by Stillwater Lake in Susquehanna County, Pa., along the Lackawanna River

Emergency Response

- A temporary floodwall erected in Scranton saved 1,800 homes from flooding.
- The Lackawanna Emergency Management Office evacuated 250 people out of Old Forge, Pa.
- A forecast for flood levels at the top of Binghamton's levee prompted an evacuation of 3,000 people from the city.
- A precautionary decision was made to order the evacuation of 200,000 people in the Wyoming Valley, including the City of Wilkes-Barre. Refined flood forecasts led to the

evacuation order being rescinded. Ultimately, about 60,000 people evacuated the area.
- More than 1,200 people were successfully rescued by emergency responders throughout Pennsylvania.
- 300 people in the Town of Conklin were airlifted.

Community Outreach

Susquehanna River Basin Commission (SRBC) staff tracked forecasts and hydrologic conditions leading up to and during the event, and shared information with the media, basin legislators and community officials as requested. SRBC staff handled an unusually high volume of media inquiries related to flooding effects on water quality. The inquiries were largely in response to failure of a sewage treatment plant in Oneonta, N.Y., and boil water advisories in the Harrisburg area.

SRBC staff and others encountered significant problems trying to obtain up-to-date information about NWS forecasts due to the aforementioned problems with the AHPS web site.

As a follow up to the flood, SRBC convened "Community Dialogue" sessions in Binghamton, N.Y., and Harrisburg, Pa., to garner local perspectives on what worked well and what did not. These sessions gave participants an opportunity to interact with flood management officials and to offer recommendations for improvements to the SFFWS (*see below for more information*).

Recommendations for Improving the SFFWS

Hydrologic Monitoring

Forecast accuracy is limited by performance of data collection networks and accuracy of QPF. By identifying gaps in data coverage and addressing performance shortcomings, the quality and reliability of hydrometeorological data can be improved, thereby improving the accuracy and timeliness of forecasts. Based on the evaluation of the SFFWS performance, recommendations are being made to improve existing gages, provide gage coverage in areas that suffered flooding but lack data, and generally enhance techniques used to collect and interpret hydrometeorological data. The recommendations, to date, include:

- Raise the gagehouse 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: Rockdale, Unadilla, Bainbridge, Conklin, Cortland, Sherburne, Greene, Chenango Forks, Vestal, Owego, Waverly, and Chemung, N.Y.; and Tunkhannock, Old Forge, and Bloomsburg, Pa.
- Install and maintain real-time stream gages at the following sites:
  - o Middletown, Pa. (stage only) (Swatara Creek).
  - o Oneonta, N.Y. (Susquehanna River).
  - o Binghamton, N.Y. (stage only) (Susquehanna River).
- Establish and maintain rating curves at the following stage-only sites:
  - o Sherburne, Norwich and Greene, N.Y. (Chenango River).
  - o Oneonta, Unadilla, Bainbridge, Windsor, Vestal and Owego, N.Y. (Susquehanna River).
  - o Owego, N.Y. (Owego Creek).
- Expand precipitation monitoring network (telemetered gages with temperature sensors) to fill gaps in coverage at or near the following locations:
  - o Vestal, Waverly, Oneonta, Cuyler/Homer area and Haskinville/Cohocton, N.Y., area.
- Reinstate functioning webcam at Conklin, N.Y.; 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.

Forecast and Warning Products Generation

Gathering hydrometeorological data is the first step in flood forecasting. Computer modeling, updating of forecasts and presentation of the forecast and warning information are all vital to the generation of forecast and warning products. Lessons learned during the June 2006 flood should allow improvements to the generation of these products if

DIALOGUE SESSIONS WITH IMPACTED COMMUNITIES

On August 15 and 16, SRBC convened sessions in Binghamton, N.Y., and Harrisburg, Pa., respectively, to assess the performance of the SFFWS and the basin's flood damage reduction projects. The sessions gave community officials and others impacted by the flooding an opportunity to: (1) hear from agency officials responsible for flood forecasting and emergency response; and (2) share their local perspectives on what worked well and what did not.

These sessions also gave participants an opportunity to offer comments and recommendations for improvements to flood forecasting, flood protection, communications, and other areas of concern such as flood mapping and protection of water quality against failure of wastewater treatment plants.

Recommendations coming out of the two community dialogue sessions included:

- Designate a local contact in each municipality to receive forecasts.
- Evaluate implemention of a reverse 911 call system.
- Undertake a basinwide "detention study" to assess efficacy of stormwater retention to reduce flood elevations.
- Secure funding for mitigation planning, as well as funding for pumps and hoses for municipalities.

Recommendations for Improving the SFFWS (continued)

the following recommendations are implemented:

- 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 the following locations:
  - o Oneonta, Windsor and Owego, N.Y. (Susquehanna River).
- Develop crest-crest relationships for forecasts at the following locations:
  - o Norwich, N.Y. (Chenango River).
  - o Binghamton, N.Y. (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.

Warning Dissemination

The forecasts and warnings are only as good as their distribution. The warnings need to reach the appropriate audiences through timely, reliable, and convenient means. Successful dissemination of warnings requires clear communication of the forecast details and reliable transmission of the forecast through various media. Shortcomings encountered during the June 2006 flood can be addressed through the following recommendations:

- Increase and enhance AHPS web server capacity.
- Develop GIS layers depicting areas of flood inundation to provide emergency managers 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.

Interagency Communications and Operations

The interaction between SFFWS partners is critical, particularly during a flooding event. It is important that information flow between partners is seamless. Challenges encountered during the June 2006 flood present an opportunity to improve the flow of information between agencies, through the following recommendations:

- Establish direct and reliable communication routes for forecasts to the SFFWS partners.
- Continue the use of 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.

Public Information and Education

A major component of successful flood forecasting and warning is proper understanding and application of the forecast information by the public. Reactions to forecasts during the June 2006 flooding indicate that general understanding of the meaning, limitations, and applicability of forecasts can be improved. The better informed the audience is, the more useful and successful the products will be in aiding the public to react to potential flood events. The following recommendations are designed to improve the value of the forecast by raising the general public's understanding of the information they offer:

- 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.

Water Quality

Water quality concerns associated with flooding are typically short term in duration and mostly the result of failed sewage treatment plants, oil spills, and combined sewer overflows. The following recommendations could provide valuable data in the interest of public health and safety and assessing environmental impacts of flood events:

- Perform bacteriological monitoring at select locations during and after flood events to assess water quality impacts to recreational uses.
- Report nutrient and sediment load data routinely gathered during each individual flood event.

PROGRESS REPORT

- USGS is currently working with the Borough of Middletown, Pa., to complete initial installation for the new Swatara Creek stage-only gage at Middletown. Full installation should be complete in early 2007.
- NWS has addressed AHPS performance and reliability problems by increasing web server capacity.
- SRBC, in partnership with USGS and NWS, is developing flood inundation GIS layers.
- SRBC, in conjunction with SFFWS partners, identified specific locations for precipitation and stream gages in New York and is currently finalizing installation logistics.