FLOOD FORECAST AND WARNING SYSTEM PERFORMANCE DURING JANUARY 1996

Publication 192 *January 1998*

Donald R. Jackson
Staff Hydrologist

Water Management Division
Susquehanna River Basin Commission

This report is prepared in cooperation with the National Oceanic and Atmospheric Administration, under Award No. NA66WDO297

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**Statutory Citations: Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

For additional copies, contact the Susquehanna River Basin Commission, 1721 N. Front Street, Harrisburg, Pa. 17102-2391, (717) 238-0423, FAX (717) 238-2436.

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Flood Forecast and Warning System Performance During January 1996 Flood

Donald R. Jackson
Staff Hydrologist

INTRODUCTION

The Susquehanna River Basin has a long history of flooding, with flood records beginning in 1810. Severe flooding has struck the basin ten times (1810, 1865, 1889, 1935, 1936, 1946, 1955, 1972, 1975, and 1996), and smaller floods have occurred eight times in the same period. On average, the flood stage for the Susquehanna River at Harrisburg, Pa, is exceeded about once every six years. While a number of structural and nonstructural flood control projects have been carried out to protect the citizens of the basin, residual flood damages are estimated as $113 million per year (1993 prices). The U.S. Army Corps of Engineers (US COE) has determined that the best way to further reduce flood damages in the basin is through nonstructural measures such as flood forecast and warning systems.

The Susquehanna River Basin Commission (SRBC) has been coordinating a program of improvements to the Susquehanna Basin Flood Forecast and Warning System since 1986. The original goal of the improvements program was to provide accurate and timely forecasts. In 1995, the state and federal agencies involved in the program adopted the goals shown in Table 1. The program is a cooperative effort involving the

Table 1. Susquehanna Basin Flood Forecast and Warning System Program Goals

1. Improve usefulness of river forecasts to the users.
   a. Improve accuracy and timeliness of river forecasts.
   b. Determine specific needs of flood forecast users.
   c. Improve the reliability of rain gages installed under this program.
   d. Reevaluate the design of the gaging network to ensure accuracy and cost effectiveness. Determine optimal rain gage network configuration for calibration of the WSR-88D precipitation processing algorithm.
   e. Incorporate quantitative precipitation forecasts into river forecasting procedures.
   f. Implement the enhanced hydrometeorological forecasting system.
   g. Incorporate remotely sensed snow-water equivalents into forecasts as appropriate.
   h. Investigate use of new remote sensing and geographic information systems technology to improve forecast/warning and flood management capabilities.
2. Conduct public information and education programs to:
   a. Create greater public awareness of the need and importance for flood warning system enhancements.
   b. Improve capability of users to respond to flood forecasts.
   c. Ensure that all users at all levels are aware of the issuance and dissemination of weather and river forecasts and that they understand how to access and interpret the forecasts.
3. Ensure stable funding at an adequate level to support these goals.
   a. Encourage maximum participation by existing funding sources.
   b. Seek other funding sources.
4. Expand program horizons to other water resource management problems in the Susquehanna basin.

National Weather Service (NWS), U.S. Geological Survey (USGS), US COE, the Commonwealth of Pennsylvania, and the states of New York and Maryland. The NWS is responsible for forecasting stream flows, including floods, on major streams in the Susquehanna basin.

In January 1996, major flooding was experienced throughout the northeastern part of the nation. The Susquehanna basin was particularly impacted, with the loss of many lives and more than $600 million in damages. This flood was the first major test of the improved flood forecast and warning system. The purpose of this report is to evaluate the system's performance during the event, and determine what additional improvements are necessary to achieve the goals established for the improvements program.

THE JANUARY 1996 FLOOD

The January 1996 flood was caused by an unusual combination of meteorological events. By mid-January, most of the basin was covered by 24-36 inches of snow, much of which had fallen during the week of January 7 (Dehoff, 1996; Lazorchick, 1996). Because of below normal temperatures, ice formed on the rivers and tributaries, and there was little opportunity for the snow to melt. The snowpack contained the equivalent of 3.5 to over 5 inches of water (Lazorchick, 1996).

On January 18, an unprecedented change in weather conditions began. Temperatures rose from below freezing to above 50° F in 12 to 24 hours, and stayed above freezing for about 48 hours (Lazorchick, 1996). Dew point temperatures also rose into the 50° F range. Strong southerly winds gusting up to 50 miles per hour accompanied these temperatures. These conditions caused the heavy snowpack to become saturated with water, and the saturated snowpack was on frozen ground.

This warming occurred ahead of a cold front, which passed through the basin on January 19. The frontal system dumped an average of about 2.5 inches of rain on the basin, most of it in about 3 hours (Lazorchick, 1996; Dehoff, 1996). With the snowpack already saturated and unable to hold any rain, and the ground still frozen, this combination of events produced 3 to 4 inches of runoff, virtually simultaneously, over most of the Susquehanna basin, causing streams to rise at unprecedented rates. The rise was so rapid that the event could be described as a basinwide flash flood.

The rapid increase in stream flows caused the ice on the rivers and streams to break up. As the ice moved downstream, it formed jams at a number of locations. This caused further rapid rises upstream from the ice jam, until the jam broke and sent a large surge of water downstream.

Generally, the January 1996 flood was the worst flood in the Susquehanna basin since the Agnes flood of 1972 (NWS, 1997). It set new record stages at the following gaged locations (NWS, 1997): Otselic River at Cincinnatus, Cortland County, N.Y. (NWS, 1997); Towanda Creek at Monroeton, Bradford County, Pa.; Tunkhannock Creek near Tunkhannock, Wyoming County, Pa.; Loyalsock Creek at Loyalsockville, Lycoming County, Pa.; Lycoming Creek near Trout Run, Lycoming County, Pa.; Frankstown Branch Juniata River at Williamsburg, Blair County, Pa.; and Aughwick Creek near Three Springs, Huntingdon County, Pa. (Durlin and Schaffstall, 1997). On the Susquehanna River at Wilkes-Barre, the flood crest was second only to the 1972 Agnes flood. The flood crest on the Susquehanna River at Harrisburg was the third highest behind the Agnes flood, and the 1975 Tropical Storm Eloise flood (NWS, 1997). There were 25 deaths resulting from the flood, 14 in the Susquehanna basin in Pennsylvania. There were a total of 10 deaths in New York (NWS, 1997).

FLOOD FORECAST AND WARNING SYSTEM

The mission of the NWS is: "To provide weather and flood warnings, public forecasts and advisories for all the United States, its territories, adjacent waters and ocean areas primarily for the protection of life and property." The Middle

Atlantic River Forecast Center (MARFC) prepares daily river stage forecast guidance for locations in the Susquehanna basin, as well as flash flood and headwater guidance. During periods of flooding or high water, MARFC prepares additional river stage forecast guidance for locations within the Susquehanna River Basin.

NEXRAD Weather Service Forecast Offices (NWSFO) at Albany, N.Y., Pittsburgh, Pa., and Mount Holly, N.J., are responsible for issuing flood watches for counties within the Susquehanna River Basin. The NWSO offices at State College, Pa., and Binghamton, N.Y., are responsible for issuing flood and flash flood warnings in the basin. These offices also provide long-term flood potential statements, daily flow forecasts, and river flood forecasts and warnings to the public. Watches indicate there is a potential for flooding, and warnings indicate flooding is imminent. Watches and warnings provide general statements about flooding in a specified area such as a county or a specified zone, which includes several counties. Stage forecasts provide specific estimates of flood crest stages at selected locations on rivers and major tributaries in the Susquehanna basin.

In addition to the NWS forecast and warning system, county emergency management agencies (EMAs) have meso-data networks for small streams and headwater locations. These meso-data networks are necessary to fulfill data needs above and beyond the data and forecasts routinely issued by the NWS. These networks allow the county EMA to monitor, and, in some cases, prepare forecasts for small flashy streams where the NWS does not routinely monitor hydrologic conditions or prepare forecasts. Based on information from these meso-data networks, county EMAs can request the NWS issue flash flood warnings, as well as invoke emergency action plans and procedures. This report focuses on the performance and problems experienced by the basinwide NWS system. However, the county systems and the data necessary to provide information for warnings on these smaller streams should be recognized.

Watches are based on meteorological forecasts and data; warnings are based on the same information and limited streamflow data. River stage forecasts are based on large amounts of hydrometeorological and streamflow data. These data are processed through a computer model that estimates the near-term streamflows and stages at various locations, and the computer results are used to prepare stage forecasts at those locations.

The watches, warnings, and stage forecasts are disseminated over various paths by the forecast offices. The primary dissemination path is from the forecast office to the 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 agencies and others who need the forecasts. Forecasts also are broadcast on the National Weather Radio, the National Warning System (NAWAS), and Emergency Management Weather Information Network (EMWIN).

The hydrometeorological data used to prepare forecasts include precipitation measured at a large number of gages, precipitation estimates from several WSR-88D Doppler Weather Radars, and quantitative precipitation forecasts (QPF) prepared by the forecast offices from meteorological model output provided by the National Center for Environmental Prediction of the NWS. Snow data are collected by NWS observers at certain gage sites, at the US COE's reservoir sites, and by airborne snow surveys conducted by the National Operational Hydrologic Remote Sensing Center of the NWS.

Several precipitation gage networks are used to collect data. Most of the precipitation gages used by MARFC to prepare forecasts are equipped with Data Collection Platforms (DCPs). The DCPs transmit data to the Geostationary Operational Environmental Satellite (GOES), which then transmits data to MARFC through a circuitous path. The satellite stations generally report at a fixed interval of 4 hours, but all the stations in Pennsylvania (R. Durlin, USGS, oral

communication, 7/31/97) and some stations in New York (L.G. Moore, USGS, oral communication, 8/7/97) also have been programmed to report at a random interval whenever the precipitation or stage exceeds a preset threshold. At some locations, volunteers make observations and report those by telephone, generally only once a day. The precipitation gages equipped with DCPs are generally owned and operated by USGS under contract with NWS or US COE.

MARFC also uses data from the Integrated Flood Observing and Warning System (IFLOWS) networks, which are supported by the NWS and operated by Pennsylvania Emergency Management Agency (PEMA) for certain counties. The IFLOWS gages transmit data by radio to county EMAs, where it is collected and transmitted to the state EMA and the NWS. The IFLOWS gages are important because they are frequently located at higher elevations, where the precipitation is the greatest. During this and other events, these local gage networks helped provide rain, snow, and water-equivalent data, which provided advanced warning of flooding. The precipitation data are used to verify radar data and fill gaps in the gage network. However, the IFLOWS gages are generally unheated, and may not be operational during the winter.

Most of the stream gages used to prepare forecasts also are equipped with DCPs. At some stream gages, the current stage also can be obtained by telephone. The stream gage network is supported, operated, and maintained by USGS, in cooperation with the respective states and other parties. Many stream gages are wholly or partly supported by NWS or the US COE.

SYSTEM PERFORMANCE

In general, the flood forecast and warning system performed well during the January 1996 flood. The NWS issued flood potential statements on January 15 and 16, warning the public of the potential for significant flooding. Flood watches were issued the afternoon of January 17 for west-central Pennsylvania; the afternoon of January 18 for central and eastern New York, and southeastern Pennsylvania; and on the morning of January 19 for northeastern Pennsylvania. These watches noted the potential for severe flooding. Flood warnings were issued for the Susquehanna basin beginning early on the morning of January 19 (NWS, 1997).

Flood stage forecasts were issued beginning on the morning of January 19. The initial estimates were too low due to underestimated QPFs and snowmelt. Revised stage forecasts were issued beginning late the same day (NWS, 1997), and were much more accurate.

NWS (1997) found that, based on news reports and personal contacts, users of the forecasts were generally satisfied with the watches, warnings, and stage forecasts. This conclusion is supported by available information (Wynne, 1996; Hutchinson, 1996; Cohick, 1996; J. Siracuse, Luzerne County Emergency Management Agency, oral communication, 7/31/97; L. Gruver, Lycoming County Emergency Management Agency, oral communication, 7/30/97; R. Straw, York County Emergency Management Agency, oral communication, 7/30/97; P. Colvin, Lancaster County Emergency Management Agency, oral communication 8/1/97; D. Lispi, City of Harrisburg, oral communication, 8/1/97; S. Foti, NYSDEC, oral communication, 7/31/97). There were frequent contacts between MARFC and other agencies such as USGS, US COE, and state emergency management agencies. The cities of Harrisburg and Wilkes-Barre received several key briefings during the event. Information provided by forecasters led to evacuations at Wilkes-Barre, Harrisburg, and other critical locations. These agencies confirmed that they had received good support from NWS offices (NWS, 1997).

PROBLEMS ENCOUNTERED

Despite the generally satisfactory performance of the system, a number of problems were encountered. These are classified as data problems, forecast preparation problems, and forecast dissemination problems.

Data Problems

1. Initial QPFs issued early on the morning of January 19 were much too low. These were updated later that morning, but were still too low (NWS, 1997).
2. Airborne snow survey data were not available due to the inability to schedule these surveys in the short period between the snowfall the week of January 7 and the onset of the event, about a week later (P. Gabrielsen, NWS, written communication, 8/7/97).
3. Some precipitation gages were not operational, or were providing inaccurate data immediately prior and during the event. Unheated IFLOWS tipping bucket gages were frozen due to prior snow. Some satellite precipitation gages also malfunctioned. NWS observed problems with data for certain gages, which indicated those gages had not been winterized to effectively measure frozen precipitation (NWS, 1997; P. Gabrielsen, NWS, written communication, 8/7/97; J. Ostrowski, NWS, oral communication, 12/9/97).
4. Generally, stream gages functioned well (NWS, 1997). However, the stream gage on Lycoming Creek at Trout Run, Pa., was inundated and could not provide data for part of the event. Also, the stream gage on the Susquehanna River at Marietta, Pa., provided incorrect readings for part of the event, because the float reached the top of its range. Other stream gages also malfunctioned, but were returned to service quickly. One cause of gage failure was loss of power, due to reliance on solar power. The gage on the West Branch Susquehanna River at Milton, Pa., was damaged by ice and gave erroneous readings beginning on the afternoon of January 19. Cold temperatures following the passage of the cold front caused some stream gages to freeze, which resulted in difficulty in forecasting the recession.
5. Very little data were available from observer-read stream gages because observers could not be contacted, or were unable to reach the gage(s) because of the flooding conditions (NWS, 1997).
6. The Doppler Weather Radars generally worked well, and the radar precipitation products were very helpful in preparing river forecasts (NWS, 1997). However, there are continuing problems with detection of low level storms in Lycoming (Curchoe and Walls, 1996), York (R. Straw, oral communication, 7/30/97), and Lancaster (P. Colvin, oral communication, 8/1/97) counties in Pennsylvania. The radar coverage was not a significant problem in this event.
7. Although the weather radars functioned well, MARFC does not have the capability to easily acquire data for radars outside its area, or to easily mosaic the data for multiple radars to produce a complete map of precipitation (NWS, 1997). Also, the county emergency management agencies do not have access to the radar data.
8. DCP data were not available between Saturday evening and Sunday morning, January 20 and 21, because the receiver unit at MARFC failed. This failure was not a major problem in this event because it occurred after the crest (NWS, 1997).
9. Although most of the DCPs in the Susquehanna basin are programmed to report randomly, the random data could not be used by MARFC (NWS, 1997).
10. There were insufficient rain and stream gages in headwater areas in Pennsylvania equipped with data transmission equipment (NWS, 1997; P. Gabrielsen, NWS, written communication, 8/7/97).
11. The current communications system provides data at 4-hour intervals. On average the data are 2 hours old, and can easily be as much as 3.5 hours old. Some of the stream and precipitation gage data could not be used for forecast preparation for an event that occurred in the same time frame in some locations. One example was the stream gage on Loyalsock Creek at Loyalsockville (NWS, 1997; P. Gabrielsen, NWS, written communication, 8/7/97).
12. MARFC was unable to obtain real-time data from the DCP for the gage on Frankstown Branch at Williamsburg, probably due to a data transmission failure (NWS, 1997; J. Ostrowski, NWS, oral communications 12/8/97).

13. Ice jam and flow observations by state and local agencies did not reach MARFC (NWS, 1997).

Forecast Preparation Problems

One of the major problems in this event resulted from the formation and breakup of ice jams, particularly along the lower Susquehanna River south of the Juniata River. The present technology does not allow forecasts of ice jam formation or breakup.

The computer model initially underestimated the amount of runoff, due to underestimation of snowmelt and precipitation, and the procedures used by MARFC to estimate antecedent moisture conditions. Snowmelt was underestimated due to limitations of the existing snowmelt model. Precipitation was underestimated because the procedure used to estimate mean areal precipitation does not consider differences in elevation, and because there are no procedures yet available for visualizing variations of precipitation with elevation. Also, the antecedent conditions used in the model are single-event based, rather than continuously modeling rainfall-runoff processes.

Mean areal precipitation may have been underestimated because of missing precipitation data from frozen gages. Those gages are frequently at higher elevations where precipitation is greatest. The effects of elevation on precipitation were more pronounced during this event than normal.

Dissemination and Communications Problems

The counties and municipalities did not have access to USGS stream gage data in real-time (L. Gruver, Lycoming County Emergency Management Agency, oral communications, 7/30/97; J. Siracuse, Luzerne County Emergency Management Agency, oral communication, 8/1/97).

The media, emergency managers, and the public were frustrated by frequent forecast updates (NWS, 1997).

Watches, warnings, and forecasts were not received by Conowingo Dam and the Town of Port Deposit, Cecil County, Md. This caused significant problems with the operation of the dam, which caused serious problems in the Town of Port Deposit. There was a lapse in coverage for this area (Dehoff, 1996), which may have been caused by one or more of several factors:

- MARFC does not prepare stage forecasts for the Susquehanna River downstream from Marietta;
- This is the only part of the Susquehanna where the Mount Holly office issues flood warnings (NWS, 1997);
- There have been reports that the national weather radio transmissions cannot be received in the Town of Port Deposit, due to the terrain.

During the event, some state and county communications systems did not relay complete hydrologic information to local officials and the public (NWS, 1997). In some cases, it may be a major task for the county to provide complete data (L. Gruver, Lycoming County Emergency Management Agency, oral communication, 7/29/97).

The PEMA forecast dissemination system is very sophisticated. However, it distributes products to all counties according to type of product, rather than targeting each county (NWS, 1997). As a result, the counties receive irrelevant material, which causes delays in forecast dissemination.

Various NWS offices received a large number of phone calls from the media, county and local agencies, and others during the flood event. The calls generally asked about the latest observations and forecasts (NWS, 1997). The counties requested additional detail targeted to their area.

The counties and municipalities want to have this personal contact with the forecasters (L. Gruver, Lycoming County Emergency Management Agency, oral communication, 7/31/97; D. Lispi, City of Harrisburg, oral communication, 8/1/97). Most calls were handled by the service hydrologists, but the sheer volume of calls required assistance from the meteorologist-in-charge, the warning coordination meteorologist, and the lead forecaster at the same time those people were preparing forecasts (NWS, 1997). There is a continuing conflict at the forecast offices between the need to prepare forecasts and the important public briefings.

SRBC also received a large number of inquiries regarding the flood, and responded to the inquiries to the extent possible. The information available to SRBC was not adequate for its purposes, or for responding to inquiries from others.

The users seem to want additional information regarding relationships of the current event to historical events. This information was apparently not readily available during this flood.

RECOMMENDATIONS

Data Collection Network

1. The federal, state, and regional agencies participating in the program should continue to stress the importance of adequate funding for precipitation and stream gages used in preparing flood forecasts, including funding to restore gages that have been discontinued.
2. NWS forecast offices should evaluate the need for additional precipitation and stream gages within the headwaters of their hydrologic service areas. Evaluations should be coordinated with the MARFC.
3. Telephone or radio data transmission equipment should be installed at critical gage locations to ensure that data are available.
4. Cooperative observers still are necessary for backup in case the automated equipment fails. Efforts should be made to recruit observers at critical locations (NWS, 1997).
5. New precipitation gages should be all-weather gages that can be used with data transmission equipment. Modification or replacement of existing IFLOWS gages that are not winterized should be encouraged and supported, subject to funding constraints.
6. An ice observation and reporting network should be established to provide necessary data on ice conditions, including jam formation and breakup.
7. State and federal agencies should encourage and support the development of local gage networks such as IFLOWS.
8. Procedures should be developed to facilitate coordination of maintenance and repair of field observation equipment before and during floods to keep the equipment operational. Equipment restoration plans should be developed for all sites (NWS, 1997). Dual power systems should be installed at sites used for flood forecasting, if reliance on solar power has been unsatisfactory, and if economically justified.
9. The stream gage on the Susquehanna River at Marietta should be modified to read higher stages than that observed in this event. The need to elevate the stream gage on Lycoming Creek at Trout Run should be evaluated.

Data Acquisition

1. The Advanced Weather Interactive Processor (AWIPS) communications system should be installed as soon as possible, and the capability to quickly compute forecasts for headwater locations should be added as soon as possible (NWS, 1997).
2. To minimize problems caused by DCP data that are too old for forecast preparation, the feasibility of transmitting data at more frequent intervals should be investigated.
3. The satellite data receiver at MARFC should be replaced, or a redundant receiver installed, to minimize the risk of failure during future events.
4. Procedures should be developed to allow forecasters to easily acquire data for other radars outside their area of coverage and to mosaic the various radar images (NWS, 1997).

5. Procedures should be established to ensure that data collected by local government agencies or by the private sector are furnished to MARFC (NWS, 1997).
6. Although the radar coverage was not a factor in this event, the coverage in Lycoming, York, and Lancaster Counties in Pennsylvania should be improved.
7. The procedures for scheduling airborne snow surveys should be reevaluated to allow flexibility and shorter lead-times, based on current flood potential.

Enhancements to Flood Forecasting Model

1. The river forecasting computer model needs to be modified to allow for higher snowmelt rates than currently estimated by the model (NWS, 1997).
2. The current calibration of the snowmelt model should be refined so that parameter values will provide reasonably accurate simulation of snow accumulation and melting processes (NWS, 1997).
3. The river forecasting model should be modified to include: (a.) additional displays that allow forecasters to visualize how precipitation varies with elevation for the current event and compare this variation to isohyetal analysis, based on historical data; and (b.) displays to show what is happening inside the models (NWS, 1997).

Data Processing and Forecast Preparation Procedures

1. Considering the uncertainty associated with the routine QPFs, those precipitation forecasts should be updated by the responsible office promptly whenever the current forecast is under- or over-estimating basin average precipitation (NWS, 1997).
2. Each field office should conduct local hydrologic studies to determine how best to evaluate radar precipitation values, considering storm type, beam blockage, and other factors (NWS, 1997).
3. Procedures for estimating mean areal precipitation should be modified to incorporate effects of elevation (NWS, 1997).
4. Procedures for estimating snow-water equivalent should be improved, and used to adjust snow-water equivalent estimated by the snowmelt model. The procedures should use additional meteorological variables besides air temperature to estimate snowmelt, especially during periods of abnormal melt rates (NWS, 1997).
5. MARFC should convert to continuous water balance modeling to estimate changes in soil moisture between precipitation events (NWS, 1997).

Dissemination and Communications

1. Forecast dissemination and communication should provide SRBC, state, county, and local emergency management agencies, the media, and the public with a variety of well-coordinated hydrologic information, including probabilities of different levels of flooding, in a timely fashion (NWS, 1997). To accomplish this goal:

   - Forms that show flood stages and flood history (Form E-19) for each forecast point should be updated after every significant flooding event, and made available to appropriate users (NWS, 1997).
   - Stream gage, rain gage, and radar data should be provided to the forecast offices, SRBC, state, county, and local emergency management agencies, and the public, and these data should be updated as frequently as possible.

2. Procedures should be developed to ensure that watches, warnings, and stage forecasts are available to all interested parties through multiple data paths. This may require the purchase of weather radio receivers, expansion of the NAWAS or EMWIN systems, use of the Internet, or development of new technology to allow counties to reformat and transmit targeted data to municipalities and the public.

   - To maximize usefulness of NWS products, PEMA should consider modifying its statewide dissemination system so as to

target information to particular counties, rather than targeting by type of product (NWS, 1997).

- NWS should check whether national weather radio transmissions can be received in the Town of Port Deposit, Md.

3. Alternative procedures for handling questions from state, county, and local emergency management, the media, and the public during a flood should be considered to minimize the effect of such inquiries on forecast preparation. More systematic and uniform ways of providing this type of information such as the Advanced Hydrologic Prediction System should be developed. These procedures may include additional involvement by SRBC in responding to questions from users. The commission's role in information dissemination needs to be defined, and appropriate institutional and technical arrangements developed.
4. Alternative or enhanced procedures for disseminating watches, warnings, and forecasts to municipalities and businesses should be investigated. These procedures may require purchase of appropriate hardware, or include additional information, or development of new technology to facilitate dissemination of forecasts by the counties.

Public Information and Education

1. The NWS and SRBC should expand public information and education programs. Such programs should (NWS, 1997):

   - Ensure that people understand flood hazards, and recognize the need to evacuate flood-prone areas when instructed by emergency management;
   - Foster increased awareness and understanding of the forecasting process, and understanding of the reasons for forecast updates; and
   - Make counties aware of the ways they can obtain the forecasts and encourage procurement of appropriate equipment.

ACTIONS TAKEN

In response to the ice jam problem, NWS has established an ice monitoring observer network in the Susquehanna basin. Presently, the network includes 13 primary locations, shown in Table 2. This network is designed to provide information on ice jam formation and breakup for emergency response and short-term forecasting. USGS has prepared a list of locations in Pennsylvania that were affected by ice-jam flooding in the 1996 flood, which is shown in Table 3. These locations

Table 2. Susquehanna Basin Ice Observation Network
(Source: P. Gabrielsen, NWS, written communication, 8/7/97)

River	Location
Susquehanna	Oneonta, N.Y., and vicinity
Chenango	Chenango Forks, N.Y.
Susquehanna	Binghamton/Vestal, N.Y., and vicinity
Chemung	Corning/Elmira, N.Y., and vicinity
Susquehanna	Towanda, Pa., and vicinity
Susquehanna	Wilkes-Barre, Pa., and vicinity
Susquehanna	Sunbury, Pa., and vicinity
West Branch Susquehanna	Lock Haven, Pa.
West Branch Susquehanna	Williamsport, Pa., and vicinity
West Branch Susquehanna	Lewisburg, Pa., and vicinity
Susquehanna	Dauphin, Pa.
Susquehanna	Harrisburg, Pa., and vicinity
Susquehanna	Safe Harbor Dam, Pa.

Table 3. Partial List of Communities Damaged by Ice-Jam Flooding, January 1996 Flood
(Source: Compiled by U.S. Geological Survey from newspaper reports)

Avoca, Luzerne County, Pa.	Milton, Northumberland County, Pa.
Berwick, Columbia County, Pa.	New Cumberland, Cumberland County, Pa.
Bloomsburg, Columbia County, Pa.	Scranton, Luzerne County, Pa.
Camp Hill, Cumberland County, Pa.	Sunbury, Northumberland County, Pa.
Dauphin, Dauphin County, Pa.	Washington Boro, Lancaster County, Pa.
Elizabethville, Dauphin County, Pa.	West Pittston, Luzerne County, Pa.
Harrisburg, Dauphin County, Pa.	Wilkes-Barre, Luzerne County, Pa.
Highspire, Dauphin County, Pa.	Williamsport, Lycoming County, Pa.
Huntingdon, Huntingdon County, Pa.	Wormleysburg, Cumberland County, Pa.
Long Level, York County, Pa.	Wrightsville, York County, Pa.
Millersburg, Dauphin County, Pa.	

were identified from newspaper articles and other sources, and the list is probably incomplete. Present plans include a study by the Cold Regions Research and Engineering Laboratory of the US COE to determine a complete list of locations in the Susquehanna basin that are prone to ice-jam formation. Additional data that could improve forecasting of ice-jam formation and breakup also may be useful (White and Zufelt, 1994).

USGS has established Internet sites that include data for all stream gages having DCPs. The Pennsylvania data are updated every two hours, and the New York data are updated every four hours. MARFC also has established an Internet site that provides stage data only for selected sites. The MARFC site also provides linkage to the USGS sites, which provide more detailed information. The Internet addresses for these sites are:

PA USGS: http://wwwpah2o.er.usgs.gov
NY USGS: http://ny.usgs.gov
MARFC: http://marfcws1.met.psu.edu

The frequency of updating data may not meet all needs. Lycoming County needs the data at least every hour (L. Gruver, Lycoming County Emergency Management Agency, oral communication, 7/31/97). The frequency of updating may be unsatisfactory for response to small stream flooding, but satisfactory for response to main stream flooding. It is not feasible at this time to update the web site every hour (G. Paulachok, USGS written communication, 10/15/97).

Procedures have been developed for monitoring ice jams on the lower Susquehanna River, beginning at the Safe Harbor hydroelectric project. The procedure includes issuing warnings of ice-jam formation and breakup for downstream interests, including the Town of Port Deposit, Md. NWS will furnish categorical river forecasts for the Town of Port Deposit. The forecasts will be prepared by MARFC and issued through the Mount Holly, N.J., office

Increased communication between NWS and USGS has been established and should minimize problems caused by failure of gages or DCPs.

Forms (E-19) that describe flood history for each location have been updated and provided to PEMA, and are available at the forecast office home pages on the Internet.

The AWIPS communications system is scheduled to be deployed at the State College office in February 1998. The schedule for deployment at other offices in the vicinity of the basin is uncertain (P. Gabrielsen, NWS, written communication, 8/7/97). The system will initially

include only limited capabilities for hydrologic forecasting, but eventually satellite precipitation and streamflow data will be available through AWIPS (J. Ostrowski, NWS, oral communication, 12/8/97).

MARFC has developed procedures for obtaining satellite data through the US COE via the Internet in case the NWS data transmission channel malfunctions (J. Ostrowski, NWS, oral communication, 12/9/97). USGS has installed redundant satellite data receivers at the Harrisburg office. MARFC could obtain data directly from the USGS, via the Internet, if necessary. Telephone lines have been installed at several gages (G. Paulachok, USGS, written communication, 10/15/97). These system redundancies should minimize problems with lack of data due to transmission failure, provided the GOES satellite is operational.

NWS and USGS are jointly conducting a pilot study to determine feasibility of transmitting satellite data every hour instead of every four hours. More frequent data reports should minimize problems with data that are too old to use in forecast preparation.

The satellite data receiver at MARFC has been replaced by new equipment, which should eliminate the data reception problem (P. Gabrielsen, written communication, 8/7/97).

The State College office now has a direct connection to the Baltimore-Washington radar, which should improve the capability to provide watches and warnings for York and Lancaster counties in Pennsylvania (P. Gabrielsen, written communication, 8/7/97). WGAL-TV in Lancaster, Pa., has installed a Doppler radar in Hellam Township, York County. It is not known whether the radar data will be made available to NWS or the county emergency management agencies, and under what terms.

NWS is investigating options for improved communication and coordination with local emergency managers.

Plans are underway to increase the elevation of the gage on the Susquehanna River at Marietta (G. Paulachok, USGS, written communication, 10/15/97).

USGS has installed dual (solar and commercial) power at about half of the stream gages used for flood forecasting, but has no plans to install commercial power at the remaining gages (G. Paulachok, USGS, written communication 10/15/97).

SUMMARY AND CONCLUSIONS

The Susquehanna Basin Flood Forecast and Warning System performed well during the January 1996 flood. This event was the first major test of the improvements made over the last ten years to the system. The users of the forecasts were generally satisfied with the accuracy and timeliness of the watches, warnings, and stage forecasts issued by NWS.

Despite the overall satisfactory performance, some problems were experienced during the event. These problems may be classified as data availability and collection problems, forecast preparation problems, and communications and dissemination problems. Recommendations for additional improvements to the system are proposed and are necessary to meet the goals of the Susquehanna Basin Flood Forecast and Warning System Program. Some of these improvements are already underway or have been completed, and some are programmed for the future. Other improvements will be made as funds become available.

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