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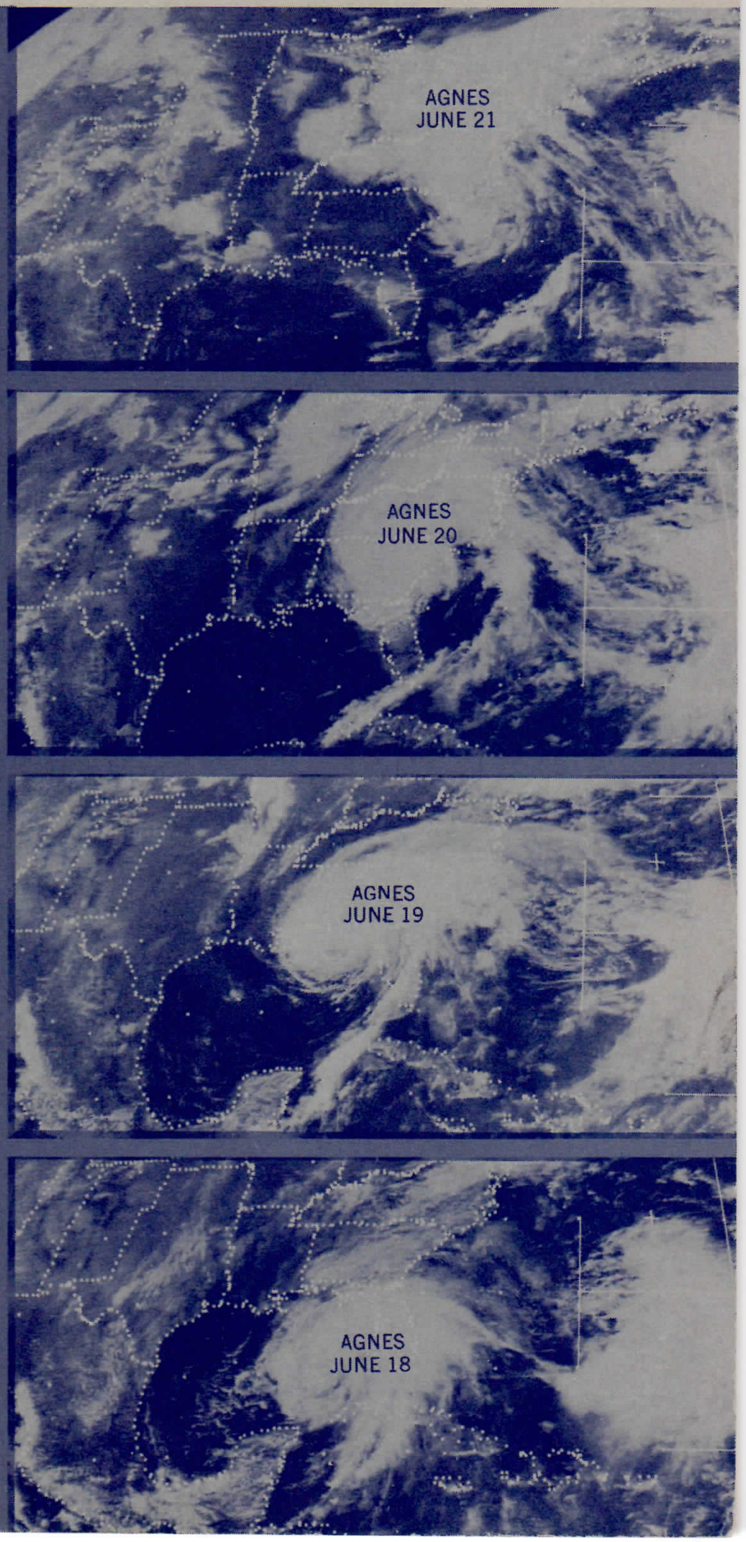
Natural Disaster Survey Report 73-1

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

Final Report of the Disaster Survey Team on the Events of Agnes

A Report to the Administrator



ROCKVILLE, MD.
FEBRUARY 1973

U.S. DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

NATURAL DISASTER SURVEY REPORT 73–1

Final Report of the Disaster Survey Team on the Events of Agnes

A Report to the Administrator

Rockville, Md.
February 1973

FOREWORD

On June 23, 1972, during the widespread floods that accompanied Hurricane Agnes, a disaster survey team was designated by the Administrator of the National Oceanic and Atmospheric Administration to review the effectiveness of NOAA's storm and flood warning services and to gather detailed first-hand information from the communities within the river basins effected by the flood events of Agnes. The field survey was completed by June 30. Since then, several reports concerning the flood disaster have been published, the principal one being *The Agnes Floods—A Post-Audit of the Effectiveness of the Storm and Flood Warnings System of the National Oceanic and Atmospheric Administration*, A Report for the Administrator of NOAA by the National Advisory Committee on Oceans and Atmosphere, November 22, 1972, Washington, D.C. The post-audit report is supported by NOAA's self-examination and self-analysis in this "Final Report of the Disaster Survey Team on the Events of Agnes," which was made available October 1972 in prepublication form and is now published as *NOAA Natural Disaster Survey Report 73–1*.

C. E. Roache
Deputy Associate Administrator for
Environmental Monitoring and Prediction

PREFACE

On June 23, 1972, Robert M. White, Administrator of the Commerce Department's National Oceanic and Atmospheric Administration, designated a Disaster Survey Team to collect and report on the events pertaining to Agnes and the associated floods.

The Disaster Survey Team included the following NOAA personnel:

C. E. Roache, Team Leader
Deputy Associate Administrator for Environmental Monitoring and Prediction

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Meteorologist, Division of Meteorological Services, Headquarters, NOAA

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National Weather Service

Gerald Shak
User Services Representative
Headquarters Eastern Region
National Weather Service

The Disaster Survey Team met initially in the office of the Team Leader on the morning of June 26, to review the task at hand and to develop a plan for the survey. The Eastern Region of the National Weather Service includes nearly all of the area involved. Therefore, the Team, at the request of the Director, Eastern Region, traveled that afternoon to the Region's headquarters at Garden City, N. Y., for a thorough discussion by the Director and his staff of activities related to the flood disaster.

The River Forecast Center (RFC) at Harrisburg, Pa., is responsible for a large portion of the area covered by the storm. The entire team moved to Harrisburg on the morning of June 27 to gather more detailed and first-hand information on the warning activities and on the reactions of State and local officials, the news media, and the public.

At Harrisburg, the Team was divided into four groups of two men each. Each group was assigned specific areas to visit to obtain the facts on the warning services provided, adequacy of facilities, and public response. The groups completed their initial fact-finding missions and returned to their home offices by Friday evening, June 30th.

Major river basins and communities visited were:

1. James-Appomattox
   - Richmond, Va.
   - Lynchburg, Va.
2. Potomac
   - Washington, D.C.
3. Schuylkill
   - Norristown, Pa.
   - Philadelphia, Pa.
   - Reading, Pa.
   - Pottstown, Pa.
4. Susquehanna
   - Lewistown, Pa.
   - Sunbury, Pa.
   - Williamsport, Pa.
   - York-Lancaster, Pa.
   - Wilkes-Barre, Pa.
   - Harrisburg, Pa.
   - Elmira, N.Y.
   - Corning, N.Y.
   - Hornell, N.Y.
   - Binghamton, N.Y.
   - Covington/Mansfield, Pa.
   - Lawrenceville, Pa.
   - Painted Post, N.Y.
5. Genesee
   - Wellsville, N.Y.
   - Rochester, N.Y.
6. Upper Ohio-Allegheny/Monongahela
   - Pittsburgh, Pa.
   - Olean, N.Y.
   - Salamanca, N.Y.
   - Wheeling, W.Va.

After the initial review by the Survey Team, task teams were organized to make more detailed studies of certain of the system's functional areas, to determine as accurately as possible the events that had taken place.

CONTENTS

Foreword ii
Preface iii
Executive Summary 1
Chapter 1. The Hurricane Agnes Floods 3
Chapter 2. System Performance 5
Performance in Individual River Basins 5
Hurricane Forecasts 26
Central Guidance Products 26
Data Collection 27
Satellites 27
Radar 28
River and Rainfall Reporting Networks 28
Flood and Flash Flood Forecasts—
Watches and Warnings 29
Dissemination of Forecasts—Watches and Warnings 30
Public Response 31
Facilities and Staffing 32
Appendixes:
A. The Flood and Flash Flood Warning System 33
B. Winds During Hurricane Agnes 37
C. Precipitation During Hurricane Agnes 45

EXECUTIVE SUMMARY

The Storm

Though Hurricane Agnes, the first Atlantic hurricane of the 1972 season, was not an unusual storm in the beginning, it eventually caused what has been termed the greatest natural disaster ever to befall this Nation. Formed from a depression off the coast of Yucatan on June 15, the storm developed and moved slowly northward, dumping large amounts of rain on western Cuba and spawning tornadoes over the Florida peninsula and Keys. The sustained winds in Agnes never reached more than minimal hurricane intensity, but its circulation and precipitation patterns covered extremely large areas.

When it crossed the Florida coast near Panama City on June 19, Agnes had degenerated to a tropical storm. The storm then moved over Georgia and out into the Atlantic, up the coast to New York, and westward over New York and Pennsylvania (fig. 1). Along the way, Agnes regenerated in strength, produced excessive amounts of precipitation, and caused rivers and streams from the Carolinas to New York to rise to record or near-record stages. A record $3.5 billion in property damage was caused by floods and flash floods, and 118 persons were killed.

Evaluation

The predicted movement of Hurricane Agnes as it approached the Florida coast was excellent. While the winds were over-forecast, the problem was compounded by the news media which emphasized the higher gust figures as the predominant storm wind. This caused some adverse public reaction, but generally public reaction and response were good.

Following are the Disaster Survey Team's evaluations of the warning services provided:

James River Basin (Including the Appomattox River): Both flash flood warnings and forecasts of river crests were timely and allowed effective protective action. The response of local action groups was positive. In some communities, dissemination of information to the public was inadequate, because of the time-consuming nature of telephone dissemination.

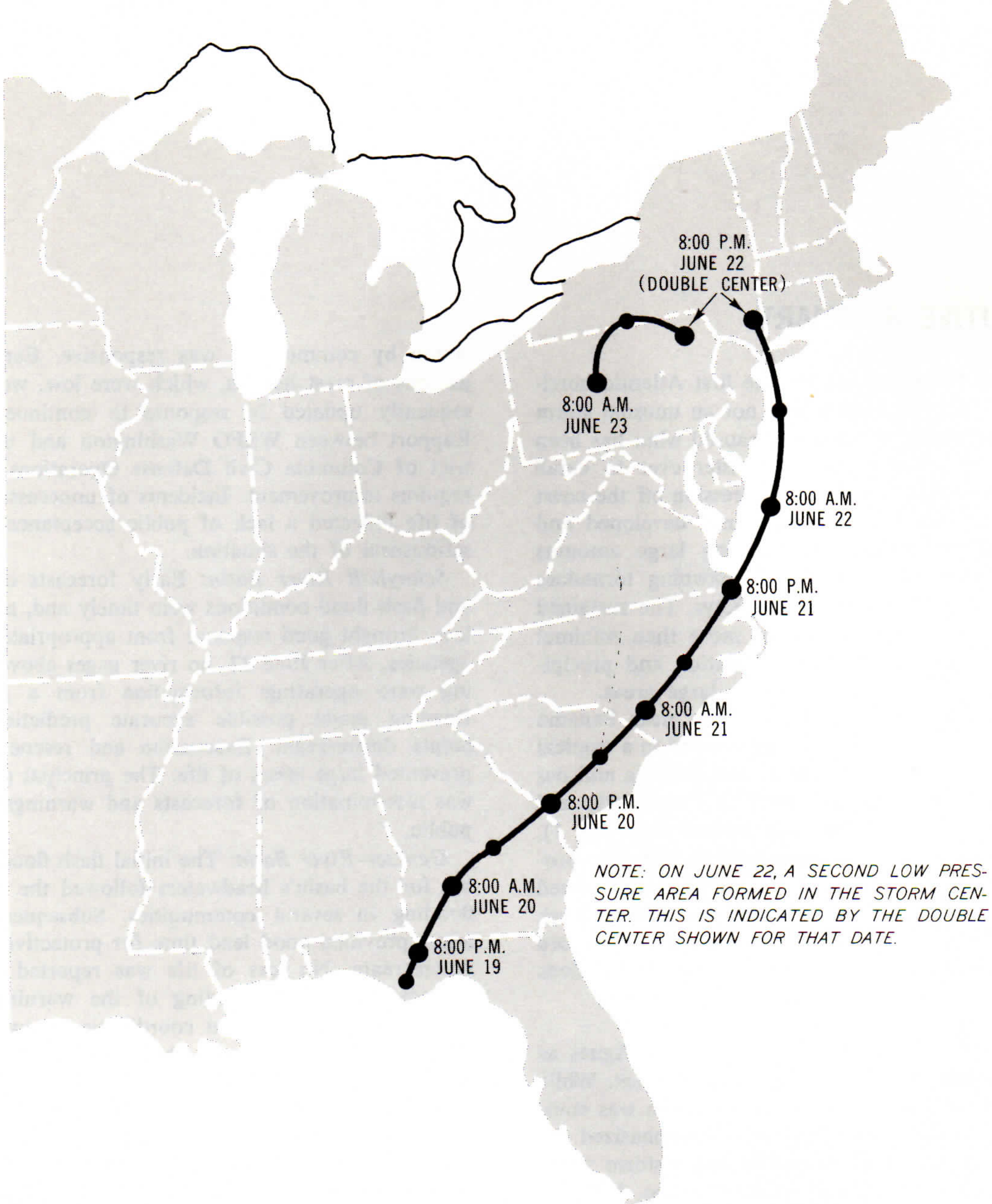
Potomac River Basin: Warnings of flash floods and river crests were adequate. Generally, protective action by communities was responsive. Early projections of crest heights, which were low, were subsequently updated in response to continued rain. Rapport between WSFO Washington and the District of Columbia Civil Defense Operations Center requires improvement. Incidents of unnecessary loss of life reflected a lack of public acceptance of the seriousness of the situation.

Schuylkill River Basin: Early forecasts of flood and flash flood conditions were timely and, although low, brought good response from appropriate action agencies. After June 22, no river gages above Reading were operating; information from a gage at Reading made possible accurate predictions for points downstream. Evacuation and rescue efforts prevented large losses of life. The principal problem was dissemination of forecasts and warnings to the public.

Genesee River Basin: The initial flash flood warning for the basin's headwaters followed the time of flooding in several communities. Subsequent issuances provided good lead time for protective action downstream. No loss of life was reported on the Genesee, and understanding of the warnings was exceptionally good. Good coordination between the Corps of Engineers and the Rochester Weather Service Office averted a potential dam failure.

Susquehanna River Basin: Flood and flash flood warnings for the Susquehanna River Basin ranged from excellent at Wilkes-Barre—where the long lead time permitted evacuation of up to 100,000 persons and prevented major loss of life—to warnings with minimum lead times, as at Harrisburg. Public dissemination of warnings for small towns along the Chemung River was inadequate. Public response varied from excellent to poor. The reason for the great variation in performance of the warning system was the erratic nature of torrential rains, which in some cases brought very rapid river rises. On balance, according to Gov. Milton J. Shapp, the Weather Service has "every reason to be proud" of its performance.

Upper Ohio (Allegheny-Monongahela) Basin: In southwestern New York State, flash flood watches



were issued well in advance of flooding. Local knowledge of flash flood characteristics of the river in this area resulted in prompt community action and timely evacuation of endangered areas. Because of the cooperation of county civil defense and local safety officials, there were no injuries and no loss of life.

At Pittsburgh, flood warnings were generally available with only minimum lead time, because of the suddenness of torrential rains and the fact that they occurred at night, at which time dissemination is most difficult. No lives were lost.

Figure 1.—Path of tropical storm Agnes, June 1972. Note: On June 22 a second low-pressure area formed in the storm center. This is indicated by the double center for that date.

CHAPTER 1

The Hurricane Agnes Floods

The great East Coast flood disaster of June 1972 began with the landfall of Hurricane Agnes near Panama City, Fla., on Monday, June 19. For one full week thereafter, the eastern seaboard was under the continuous assault of torrential rains and floods and flash floods which became progressively worse as the week passed. Hardly a river basin north of Georgia and east of the Appalachians as far north as New York State was unaffected. Many of the basins experienced floods far exceeding the previous record, and near-record levels were reached in others. This storm is unique in the annals of natural disasters in the United States, in that it caused disastrous floods and flash floods almost simultaneously over such a large area.

Agnes, the first Atlantic hurricane of the 1972 season, was not an unusual storm in the beginning. Formed from a depression off the coast of Yucatan on June 15, the storm developed and moved slowly northward, dumping large amounts of rain on western Cuba and spawning tornadoes over the Florida peninsula and Keys. The winds in Agnes never attained more than minimal hurricane intensity, but the area covered by the storm circulation was exceptionally large. Its slow development and movement permitted a large amount of moisture to be transported from the deep Tropics into the storm system. This accounts for the extraordinarily heavy precipitation associated with the storm all the way from Cuba through the eastern tier of States from Florida into New York.

After crossing the U.S. coastline, Agnes weakened to become a tropical storm and, by the time it turned into Georgia on June 20, was classified as a tropical depression. On June 21, as the circulation moved out over the Atlantic, next to the Carolinas, the storm began to regenerate and deepen. It moved north along the coast to New York City on June 22, producing record rains all along the way. North of New York City, Agnes joined forces with a large-scale circulation of colder air, and the combined system turned westward over Pennsylvania and western New York, releasing rains totaling 19 inches in some areas.

The maximum sustained winds over land were 25 to 45 m.p.h. Because Agne's large circulation brought an easterly-southeasterly flow over Florida, winds along the east coast were often as strong or stronger than those along the west coast, closer to the storm. Jacksonville, for example, recorded the highest wind gust in Florida, 56 m.p.h., early on June 19 when Agnes was heading for the panhandle.

Even at its peak, Agnes was a minimal hurricane. Over the open Gulf, maximum sustained surface winds reached 85 m.p.h. on June 18, and surface pressure fell to 978 mb on the 19th. Neither the eye nor the wall cloud ever became fully developed. By the afternoon of the 18th, two things were obvious: Agnes would cross the coast along the Florida panhandle; and the most destructive blow would be storm tides along the west coast.

These tides hit the west coast on the morning of June 19. At Fort Myers, tides rose 3 feet above normal. A short time later, they were 4 to 5 feet above normal in the Tampa-St. Petersburg area. In the afternoon, Cedar Key recorded a tide 7 feet above normal. As the storm neared the coast, Apalachicola recorded a tide 6.4 feet above normal. Agnes moved ashore as a tropical storm near Panama City late in the afternoon of the 19th. Sustained winds were 40 to 45 m.p.h., and gusts close to the center reached 45 to 55 m.p.h.

Precipitation produced by Agnes caused rivers and streams from the Carolinas to New York to rise to record or near-record stages. The most recent floods in this area approaching the same magnitude were the 1936 Pennsylvania floods and the 1969 Hurricane Camille floods in Virginia. In the wake of Agnes, previous record stages were exceeded by as much as 12 feet on the Chemung River at Corning, N.Y. (previous record 24.4 feet in 1946; Agnes, 36 feet). On the Schuylkill River at Reading, Pa., the record flood of 1850 (26 feet) was exceeded by 5½ feet. Flood protection works, designed to provide protection against floods of the magnitude of the previous record, were overtopped. River gaging stations that were located to accommodate all reasonable stages were covered by water and washed away.

According to preliminary estimates, Agnes and the subsequent floods caused property damage of more than three billion dollars, and killed 118 persons in the United States. An unknown number of those killed were fully aware of the existence of the general flooding, nevertheless they waded in rain-swollen streams, tried to drive through flooded areas, ignored warnings, or attempted to save others.

Considering the scope of the disaster—which the President has called the greatest in the history of this country—loss of life was remarkably low.

Major flooding occurred in the James, Potomac, Schuylkill, Genesee, Susquehanna, and Upper Ohio River basins. Numerous flood and flash flood watches and warnings were issued to the public by the National Weather Service (NWS)—a component of the National Oceanic and Atmospheric Administration (NOAA). Appendix A describes the flood and flash flood warning system and its various products—bulletins, forecasts, watches, and warnings.

Agnes was so large in areal extent and affected so many communities for several days, that all supporting statistics are not included in this report. Details of the storm, precipitation, and floods are published in *NOAA Technical Memorandum EDS NCC-1,* Preliminary Climatic Data Report Hurricane Agnes June 14-23, 1972, August 1972, issued by the National Climatic Center, Environmental Data Service; and in *Preliminary Reports on Hurricanes and Tropical Storms, Hurricane Agnes June 14-23, 1972,* September 1972, issued by the Office of Meteorological Operations, National Weather Service, which lists all bulletins issued by NOAA units during the storm period.

CHAPTER 2
System Performance

PERFORMANCE IN INDIVIDUAL RIVER BASINS

The major flooding—except for that on the upper Ohio River—occurred in the area served by the Harrisburg River Forecast Center. River District Offices most directly involved were: WSO Richmond for the James and Appomattox; WSFO Washington for the Potomac and Rappahannock; WSO Trenton for the Schuylkill and Brandywine; RFC (RDO) Harrisburg for the Susquehanna in Pennsylvania; WSO Binghamton for the Upper Susquehanna; and WSO Rochester for the Genesee. The upper Ohio, including the Allegheny and the Monongahela, is served by the RFC Cincinnati and the WSFO (RDO) Pittsburgh.

The floods generated by Agnes demanded the maximum participation by NWS staff throughout the operational forecast system. All systems—including communications, data acquisition, data processing, and community-action programs—were strained and in some cases failed during this record catastrophe.

Performance of the system in each river basin is described in the following summaries. Various operational problems associated with flood detection and forecasting, and with alerting processes for communities, are presented in the descriptions for key locations within each river basin.

James River Basin (Including the Appomattox and Roanoke River Basins)

Both flash flood warnings and forecasts of river crests were timely and allowed effective protective action. The response of local action groups was positive. In some communities, dissemination of information to the public was inadequate, because of the time-consuming nature of personal telephone communication.

Weather forecasts for the James and Appomattox River Basins are prepared at WSFO Washington. WSO Richmond serves as the River District Office. River stage forecasts are prepared by RFC Harrisburg. Local weather summaries and flash flood watches and warnings are issued by WSFO Washington and WSOs Richmond and Lynchburg, when warranted.

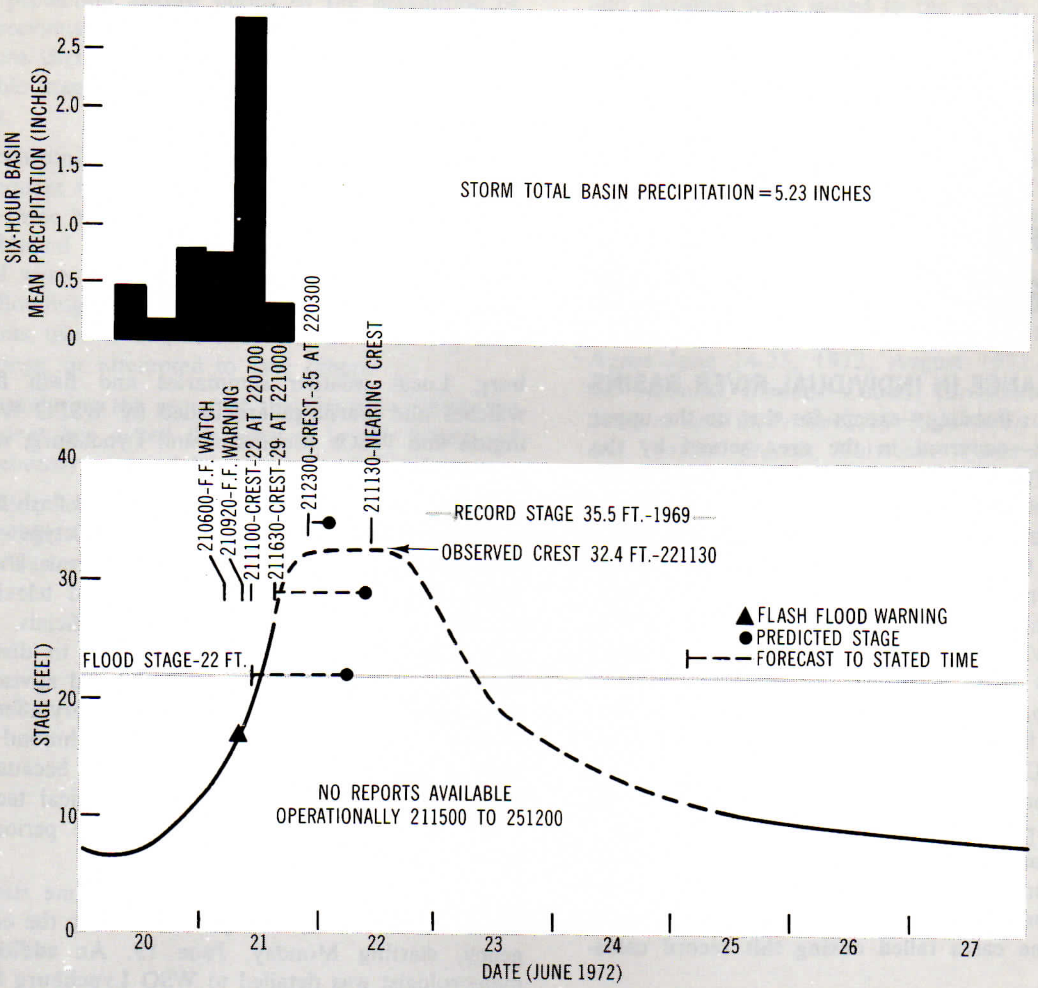
WSO Richmond disseminated flood and flash flood warnings by means of local weather teletypewriter loop and telephone to the Associated Press, United Press International, Richmond radio and television stations, and civil defense and city officials. The local teletypewriter loop also was used to disseminate civil defense and City of Richmond advisories to the news media. This procedure was very effective in informing the public. The staff at Richmond was two people short during this emergency because of vacancies, but an additional meteorological technician was detailed to Richmond for the period of June 22 to 25.

WSO Lynchburg is normally a part-time station, but it went into 24-hour operation during the emergency, starting Monday, June 19. An additional meteorologist was detailed to WSO Lynchburg from WSFO Washington. To disseminate flood warnings, the Lynchburg office must place telephone calls to about 30 city, civil defense, and industry officials. The staff had great difficulty in completing these calls, and in some cases the issuance of warnings was delayed an hour or more.

The first forecast for "showers and some locally heavy thunderstorms," for the night of June 19 and all day on June 20, was issued by WSO Richmond at 5:45 p.m., June 18. Moderately heavy rains began during the evening of June 19, and rain was heavy through the afternoon and evening of June 20.

The first flood warning bulletin for the James River was issued by WSO Richmond at 10:00 a.m. on June 21. This bulletin, indicating the James River would be 2 to 3 feet above flood stage at 7:00 p.m. on June 23, was a 57-hour prediction. It was changed at 11:15 a.m. the same day to reflect a crest of 23 feet (11 feet above flood stage) on the 23d at 7:00 a.m.—serious flooding compared with that caused by Hurricane Camille in 1969. These

JAMES RIVER AT HOLCOMBS ROCK, VA.



bulletins were revised periodically through June 22, finally reflecting a crest of 28 feet at 3:00 a.m. on June 23. The river crested at 28.6 feet on June 23 at 10:00 a.m.

Of nine river gages in the James River, seven became inoperative between 7:00 p.m. and midnight on June 21, well in advance of cresting. Flooding in downtown Richmond knocked out longline teletypewriter, local teletypewriter, and facsimile circuits for a 16½-hour period beginning at 10:30 a.m. on June 23.

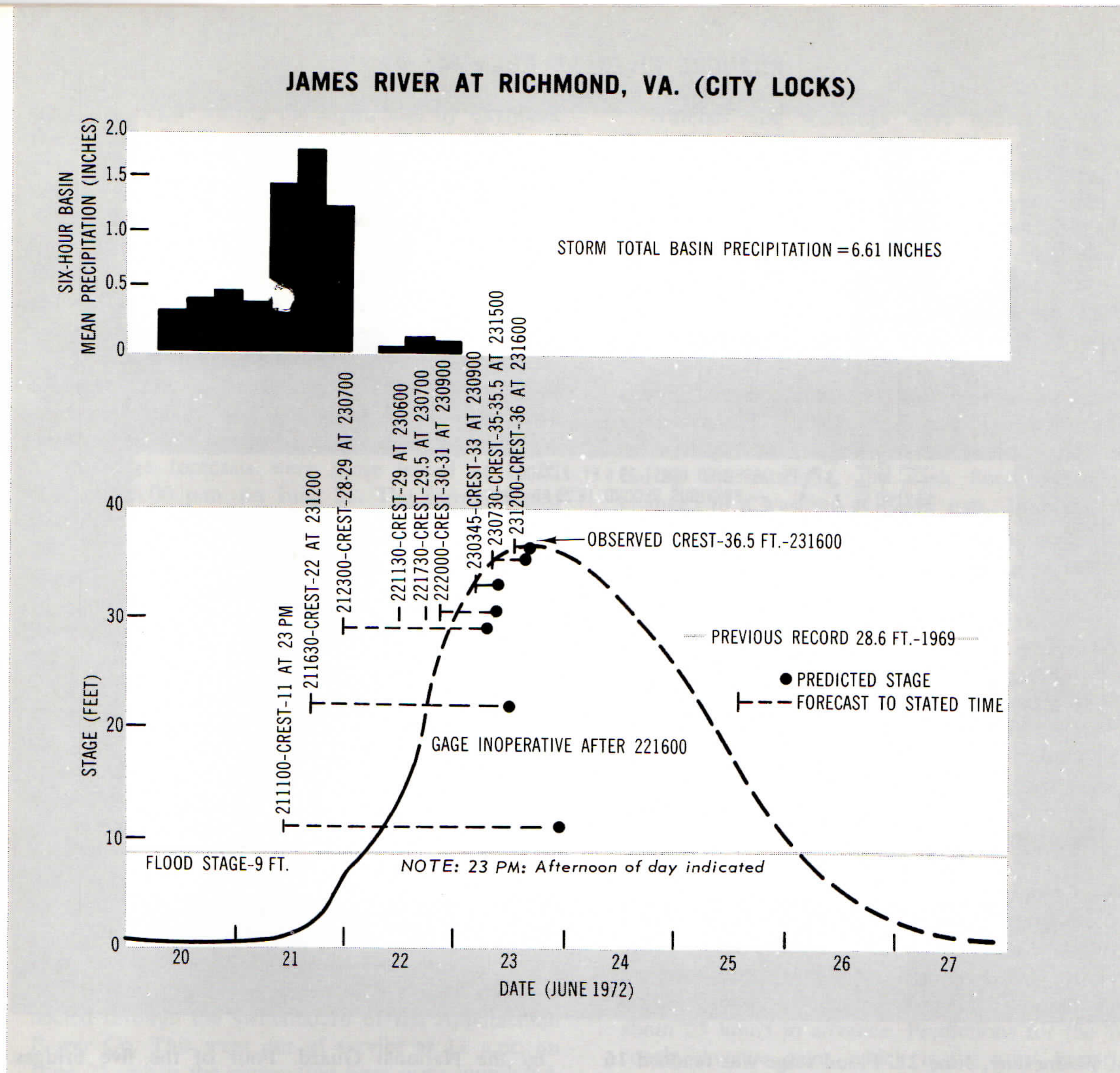
In the Appomattox River Basin, no previous flood-stage base was available for determining flood impact at Petersburg. The one and only river gage ceased operating at 8:00 p.m. on June 22.

Virginia State Police reported five flood fatalities along the James River, including one person who had deliberately passed a police barricade.

Civil defense, State, and city governments acted quickly and in the best interests of protection of life and property. Public understanding of warnings was especially good, probably as a result of experience in the 1969 Camille floods.

James River at Holcombs Rock, Va.

Holcombs Rock is located several miles upstream from the city of Lynchburg and below the 3,250-square-mile drainage comprising the upper James River Basin. Rain began in the upper basin on the morning of Tuesday, June 20, and continued at a moderate rate for 24 hours. During the morning of Wednesday, June 21, 2.8 inches fell in a 6-hour period, adding to the 2 inches already on the ground. The river began to rise rapidly. By midnight, it had risen 22 feet in 24 hours and was within one-half foot of the crest which occurred 12 hours later at 11:30 a.m. on Thursday, June 22. The area had



been placed under a flood watch at 6 a.m. on June 21, and the first warning was issued at 9:20 a.m. that day. At this time, the stage was still 4 feet below flood.

Protective measures were only partially effective. Some warning recipients took effective action, and others did not. A plant operated by Libby-Owens-Ford reported $1 million damage. Damage to commercial interests and permanent and mobile homes was fairly heavy.

The river gage survived the flood, but telephone lines were submerged at 3 p.m. on Wednesday, June 21. This was 20 hours before and 6 feet below the crest. No readings were available during the next 4 days.

The power loss to the RFC computer at Harrisburg did not affect the preparation of forecasts for this point.

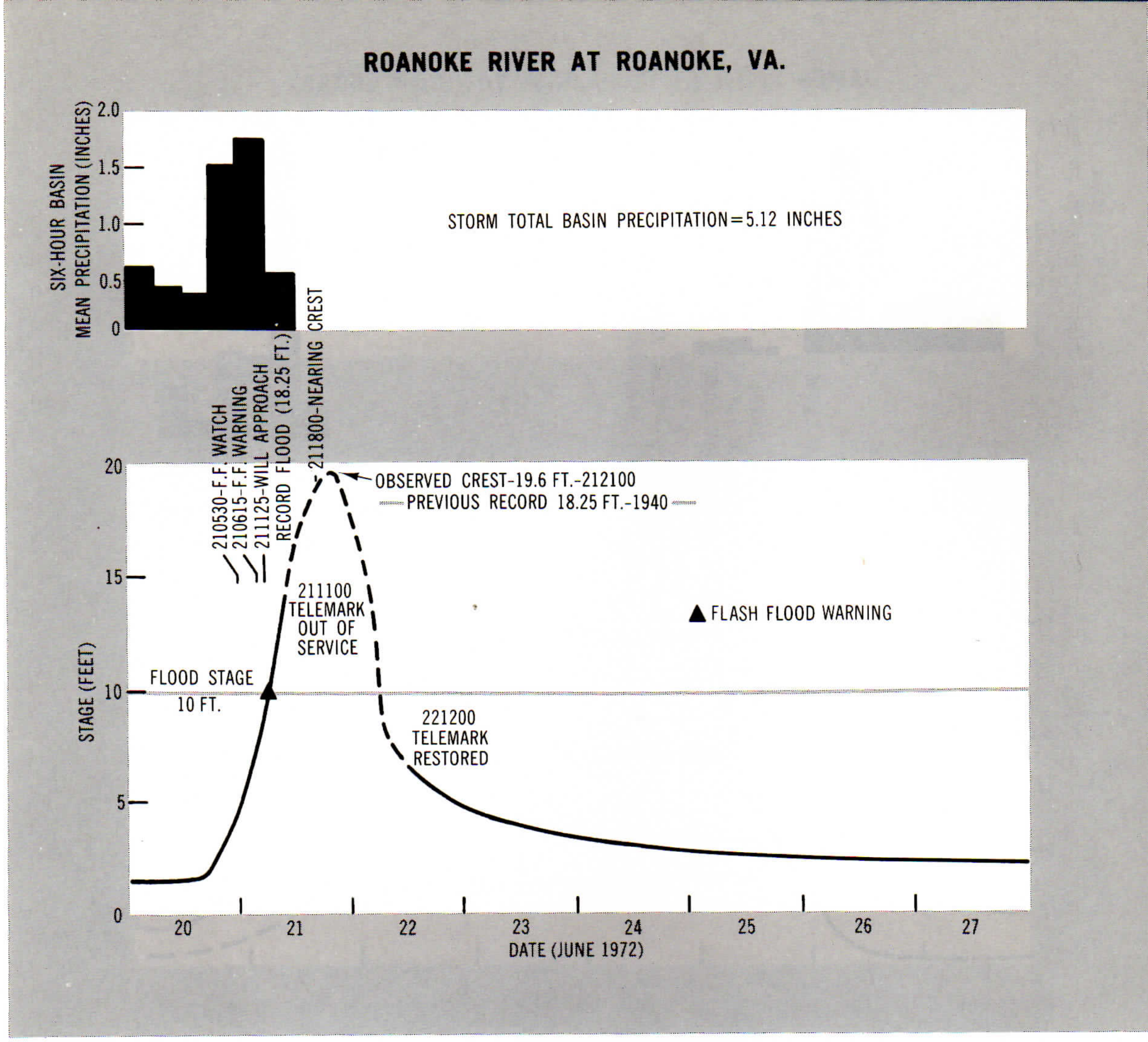
Governor Holton of Virginia praised NWS in his several radio and television appearances.

At Lynchburg, Central Virginia Industries, an association of manufacturers and industry, expressed concern about poor and late dissemination of forecasts and warnings.

James River at Richmond, Va. (City Locks)

The storm began slowly in the James Basin about noon on Tuesday, June 20. After 24 hours of light-to-moderate rain, the intensity increased and in the last 18 hours of Wednesday, June 21, the 6,757-square-mile basin received 4.6 inches, contributing to the storm total of 6.6 inches. The heaviest amounts were in the center of the basin near Scottsville.

Flood stage at Richmond is 9 feet. The first flood warning consisted of a forecast for an 11-foot crest prepared and issued by Richmond RDO at 11 a.m.



on Wednesday, June 21. Flood stage was reached 16 hours later, at 3 a.m. on Thursday, June 22.

The rise began at noon on Wednesday, June 21, and the level rose steadily for 54 hours, cresting at 4 p.m. on Friday, June 23. The level rose 36 feet and reached a maximum of 36.5 feet. This was 27.5 feet above flood stage and 8 feet above the previous flood of record set in August 1969.

Precautionary measures in Richmond were extensive and extremely well executed. An NWS bulletin issued at 11:00 p.m. on Wednesday, June 21, and calling for a 28- to 29-foot stage resulted in the city and State emergency centers being manned. Warnings were disseminated through the City Harbormaster's office. Evacuations began on the morning of Thursday, June 22, as the river—then slightly above flood stage—rose one-half foot per hour. Residents of the low-lying areas were officially served a legal order to vacate. Closures were made in the dikes early that morning. As the water rose higher, portions of the city were cordoned off by the National Guard. Four of the five bridges across the James River were closed. During the rise, the water purification plant was inundated, and Virginia Electric Power Company lost one electric power generation station and its dispatch center. By Friday, June 23, all of downtown Richmond had ceased to operate, being without electric power, drinking water, or communications.

The City Lock's river gage was inundated but not severely damaged. The telephone telemetering device (telemark) ceased to function at 4 p.m. on June 22. After that time, a leveling party from the Richmon Bureau of Survey made half-hourly readings, relating bench marks to the water surface and producing an excellent stage record.

Roanoke River at Roanoke, Va.

Rain started in the basin on the afternoon of June 19 and was fairly light until late in the evening of June 20. Within a period of about 10 hours, ending at 7 a.m. on June 21, the basin received 3.2 inches of the 5.23-inch storm total. An extremely sharp river rise began during the night, and by daybreak the 10-foot flood stage was reached with the level increasing at the rate of 1 foot per hour. A flash flood watch was issued by Washington WSFO at 5:30 a.m. on June 21 and a warning 45 minutes later. The level rose rapidly through the day, cresting at 9 p.m. at a stage of 19.6 feet. This is 9.6 feet above flood and exceeds the previous record set in 1940 by 1.4 feet.

The actual forecast operation, conducted by WSO Roanoke and RDO Raleigh, N.C., consisted of issuing warnings and advisories of a descriptive nature. The only statements that might be considered actual stage forecasts were those issued at 11:25 a.m. and 6:00 p.m. on June 21. The former stated that this flood would approach the record of 18.25 feet. At the time of issuance, however, the stage was already 15.5 feet, and the river was rising 1 foot per hour. The 6 p.m. statement declared that the river was near crest, and it was within 0.6 feet and 3 hours of it. The foregoing is not to be construed as a criticism of the operation. This RDO is not served by an RFC and must prepare its own forecasts by means of a rudimentary procedure. Cooperation by radio and TV stations is said to have been excellent. As a result of their broadcasts—and of the efforts of the local civil defense organization, and a limited number of calls by NWS personnel—the warning was spread very quickly. It was received with apathy by some people who did not believe the water could rise high enough to bother them. Others, however, took action to reduce property damage.

The river gage is equipped with a telemark connected through the switchboard of the Appalachian Power Co. This went out of service at 11 a.m. on June 21, when the connecting lines were inundated. Service was restored 25 hours later. In the interim, power company employees supplied slope-gage readings.

Potomac River Basin

Warnings of flash floods and river crests were adequate. Generally, protective action by communities was timely and responsive. Early projections of crest heights, which were low, were subsequently updated in response to continued rain. Communications between WSFO Washington and the District of Columbia Civil Defense Operations Center require improvement. Incidents of unnecessary loss of life reflected a lack of public acceptance of the seriousness of the situation.

Weather forecasts and flash flood watches and warnings for the Potomac River Basin are prepared by RFC Harrisburg and disseminated through WSFO (RDO) Washington.

Watches and warnings were issued by WSFO Washington to Associated Press, United Press International, local radio and television, Red Cross, and civil defense, by means of a local teletypewriter loop and VHF-FM radio. Other offices were notified by telephone. The office's telephone warning list requires 44 calls.

A flash flood watch was issued for northern Virginia, to include the counties immediately west of Washington, D.C., at 6:00 p.m. on June 20. A forecast for "heavy rain at times" was issued at 9:40 a.m., June 21. This forecast was for the immediate forecast period (today). When heavy rain began during the morning, the flash flood watch was changed to a warning at 12:45 p.m., June 21.

A flash flood warning for the Washington area was issued Wednesday, June 21, at 4:45 p.m. At 6:13 p.m., based on a radar report, the civil defense and police of Alexandria were notified by telephone of impending heavy rain, and evacuation of Four-Mile Run was recommended. A few hours later, Four-Mile Run had risen to record flood level. At 6:00 p.m. on June 21, WSFO Washington, in its capacity as a Hurricane Warning Office, issued a bulletin on tropical storm Agnes, indicating that large stream flooding was expected to be near record-high level throughout the Carolinas and Virginia that night and farther northeast Thursday.

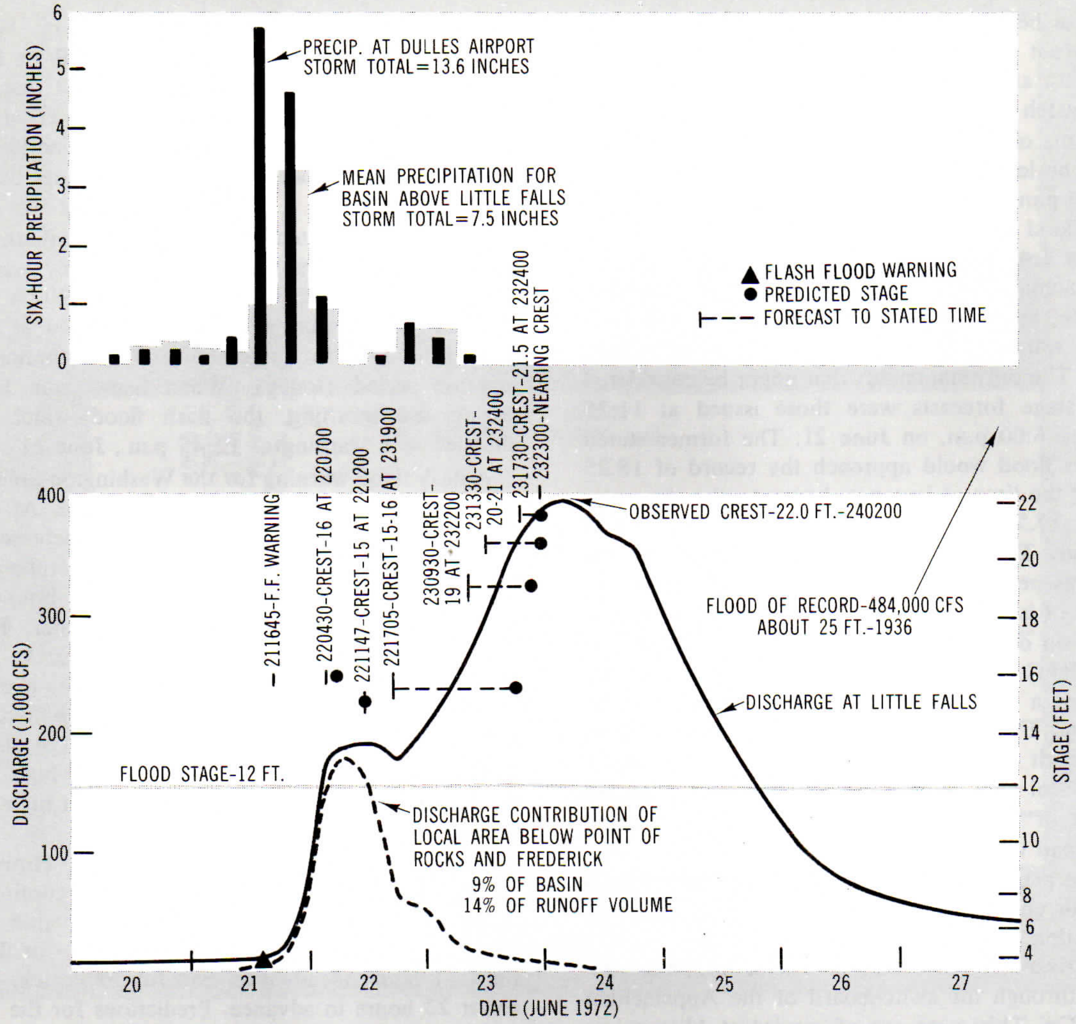
Initial flood crest forecasts were low. However, subsequent predictions, reflecting the continuous heavy rains, repeatedly raised the crest value until the final crest was accurately predicted for Little Falls 11 hours in advance, and for Frederick, Md., about 23 hours in advance. Predictions for the Wisconsin Avenue gage, which is the most important gage for Washington, were complicated by the loss of readings from the gaging site, substitution of readings from a previously unused gage at Key Bridge, and the loss of communications with RFC Harrisburg.

The river forecasts for the Potomac and Monocacy Rivers are normally prepared by RFC Harrisburg and disseminated by WSFO Washington. Because of communications outages between the two offices, WSFO Washington prepared the later forecasts.

There was not optimum coordination between the WSFO Washington and the District of Columbia Civil Defense Operations Center. The Center, which includes the mayor's emergency command post, did not have the information needed to equate crest heights with the potential flooding impact.

The public's primary source of information was radio and television. Surrounding communities reacted well, but there were some minor problems. For the most part, public understanding and reaction

POTOMAC RIVER AT LITTLE FALLS NEAR WASHINGTON, D.C.

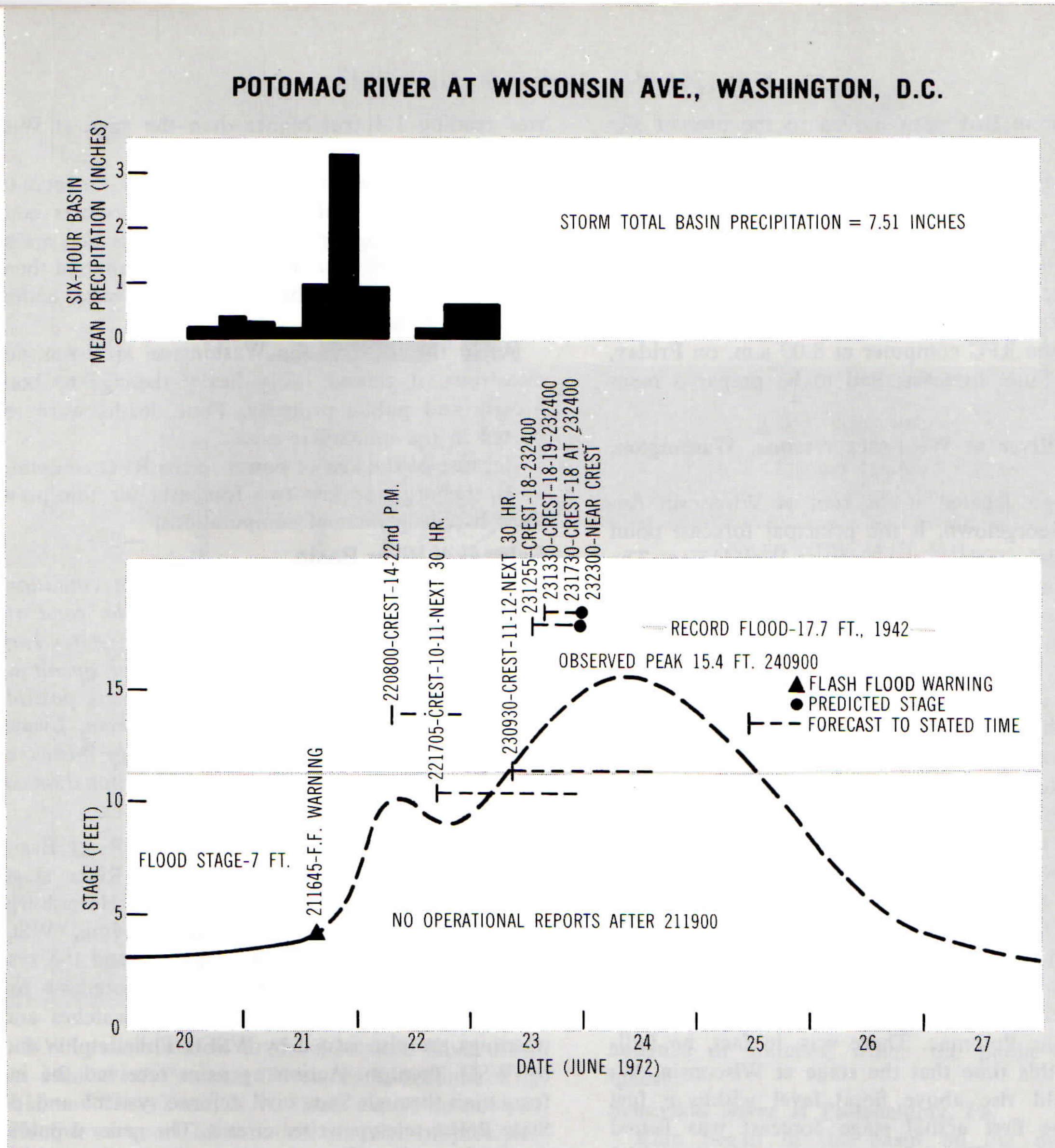


was slow, perhaps bordering on disbelief. Two lives were lost in the District of Columbia when a family went wading in Rock Creek and the two children were swept away from their parents. The Red Cross reports 21 lives lost at unspecified locations in Maryland.

Potomac River at Little Falls Near Washington, D.C.

Little Falls is the last station on the main stem of the Potomac above tidewater. Stages at this gage do not directly relate to flood problems in the Washington, D.C., metropolitan area, but discharge forecasts for Little Falls are used to produce the stage forecasts for the Wisconsin Avenue gage located in the tidal reach.

Rain began in the basin about noon on Tuesday, June 20, and continued at a light-to-moderate rate for 24 hours. During the afternoon and evening of Wednesday, June 21, it became heavy in the basin with the greatest concentration in the local area immediately above Little Falls. Dulles Airport, which is in this area, recorded 5.74 inches in one 6-hour perod and 11.88 inches in the 24-hour period ending at 7 a.m. on Thursday, June 22. The heavy rains caused an almost immediate rise of the river. Flood stage of 12 feet, caused solely by rainfall in the local area, was reached 10 hours after the rise began. An initial peak of 13.5 feet occurred at 2 p.m. on Thursday, June 22. This was followed by a slight drop as the local area runoff receded. Then, as the water from the main portion of the basin moved in, a secondary rise began and continued for 32 hours. The crest of 22 feet was reached on Saturday, June 24, at 2 a.m. This was 10 feet above flood stage but about 3 feet below the record flood of March 1936.



The Washington area had been under a flash flood watch since 9:25 p.m. on Tuesday, June 20, and a flash flood warning was issued at 4:45 p.m. on Wednesday, June 21, at about the time the heavy rain began. The continuing rain required frequent updating of stage forecasts issued during the rise.

There is not much property subject to flooding in the vicinity of the Little Falls gage. Those persons on the warning list were notified, and the forecasts were further publicized through civil defense and local radio and TV stations. Because of the short lead time, precautions were minimal and damage was heavy. Numerous homes in the Seneca area were badly damaged, as were recreational facilities along the river.

The forecast operation was extremely difficult both for RFC Harrisburg and for RDO Washington. A number of factors contributed to this. The initial rise to flood stage was caused by extremely heavy rain in the local area. The reporting network has very few gages in that area, and the intense rains were not adequately sampled.

While observed rainfall is the quantity used to forecast the initial response at this gaging station, prediction of the main flood wave is based primarily on observed discharge at upstream points. The final forecast for Little Falls is a function of the observed hydrographs at Point of Rocks on the main stem and Frederick on the Monocacy River, the principal tributary to the lower Potomac. RDO lost contact with the river-gaging stations at Frederick and Point of Rocks 37 hours and 19 hours, respectively, before the crest was reached at Little Falls.

Another complicating factor was the fact that, while this was not a record flood for this reach of the Potomac, it was the highest since the gaging and forecast point had been moved to the present site in 1965. Consequently, the stage-discharge relation for Little Falls was an extension above the previous maximum experienced at this site. This extension has been found to be in error by 1.8 feet.

The Little Falls gage remained operative throughout the event.

The forecast operation was affected by loss of power to the RFC computer at 8:00 a.m. on Friday, June 23. Final forecasts had to be prepared manually.

Potomac River at Wisconsin Avenue, Washington, D.C.

This gage, located at the foot of Wisconsin Avenue in Georgetown, is the principal forecast point for the tidal reach of the river at Washington. The response of the river at this point to rainfall in the basin occurs about 2 hours later than at Little Falls. Consequently, when the intense storm occurred on the evening of Wednesday, June 21, the level rose sharply, and passed the 7-foot flood stage at midnight. An initial peak of just over 10 feet occurred late in the morning of Thursday, June 22. This was followed by a brief fall. Then, as the main flood wave moved in, the level again began to rise to a crest of 15.4 feet at 9 a.m. on Saturday, June 24. This was 8 feet above flood stage, but 2.3 feet below the record flood of 1942.

A flash flood warning was issued at 4:45 p.m. on Wednesday, June 21. Normally, a warning of this type would be considered applicable to small streams in the area but not to lands adjacent to the tidal reach of the Potomac. There was, in fact, no indication at this time that the stage at Wisconsin Avenue would rise above flood level within a few hours. The first actual stage forecast was issued Thursday, June 22, at 8 a.m. at the time the initial 10-foot peak occurred. It called for a continued rise to 14 feet later in the day. When the level began to drop a short time later, this was revised to 10 to 11 feet. When the secondary rise began, forecasts were steadily increased, and shortly after noon on Friday, June 23, called for a crest of 18 to 19 feet, which would have been an all-time record had it occurred.

Many aspects of this forecast and warning operation must be considered unsatisfactory. All of the technical problems that complicated the Little Falls forecast also affected the forecast for Wisconsin Avenue. In addition, the telemetering device at Wisconsin Avenue failed at 7 p.m. on Wednesday, June 21, when the rise had barely begun. RDO Washington was able to obtain stage reports from a city employee who was reading a staff gage at Key Bridge, ½-mile upstream from the Wisconsin Avenue gage. At the time of the peak, the staff gage was reading 1.4 feet higher than the gage at Wisconsin Avenue.

NWS was criticized—not because of the quality of the forecasts—but because those forecasts consisted only of anticipated stages. The critics maintained that NWS personnel should have advised them what land areas would be inundated and what action should be taken.

While the flood in the Washington area was not disastrous, it caused fairly heavy damage to both private and public property. Four deaths were reported in the immediate area.

Because of the loss of power to the RFC computer at Harrisburg, the last two forecasts for this point were based on manual computations.

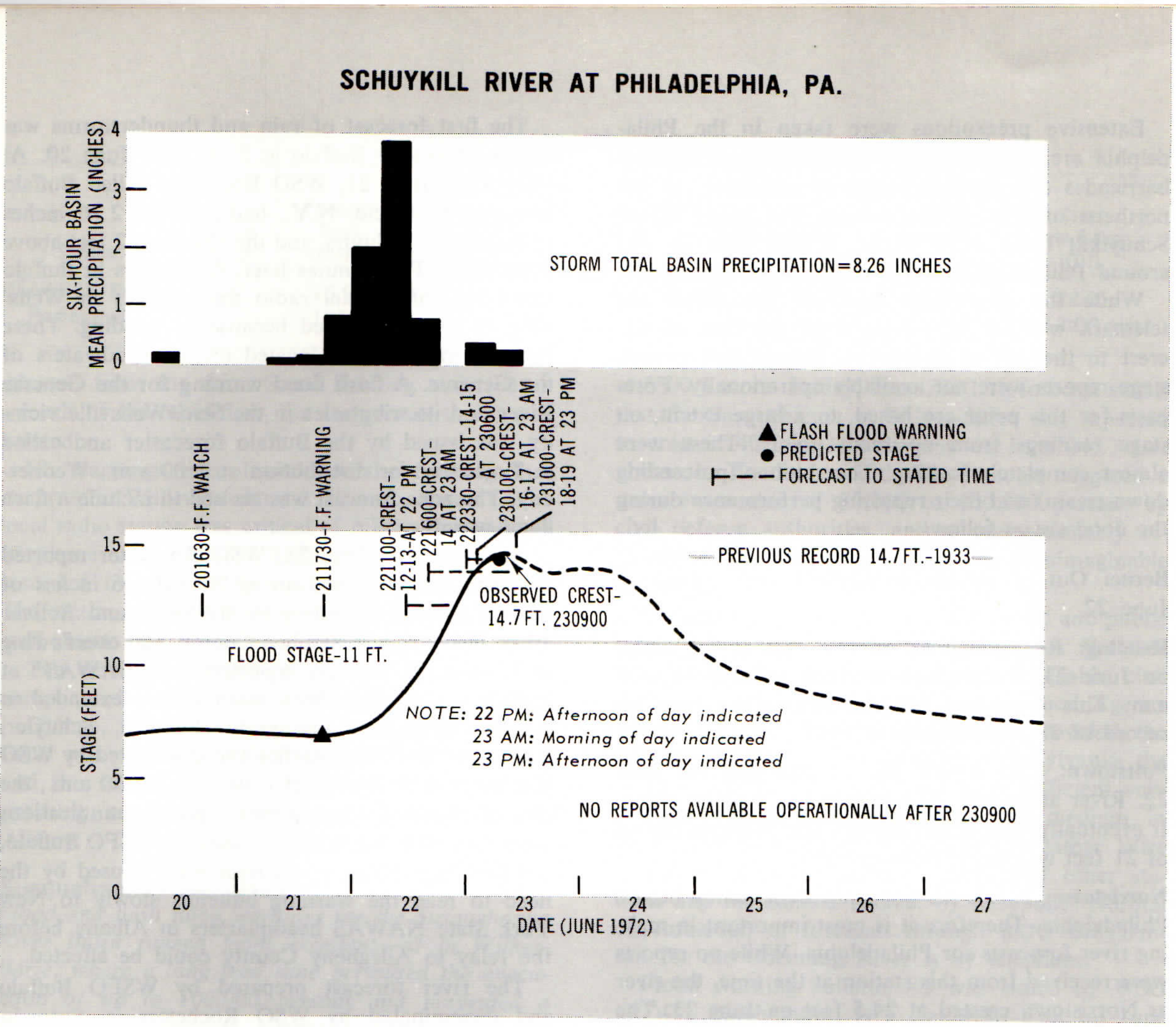
Schuylkill River Basin

Early forecasts of flood and flash flood conditions were timely and, although low, brought good response from appropriate action agencies. After June 22 river gages above Reading were not operating; observations from a gage in Reading made possible accurate predictions for points downstream. Evacuation and rescue efforts prevented large losses of life. The principal problem was dissemination of forecasts and warnings to the public.

Weather forecasts for the Schuylkill River Basin are prepared at WSFO Philadelphia. River stage forecasts are normally prepared by RFC Harrisburg. However, during the widespread flooding, WSO Trenton, using previous RFC guidance and the system's forecast procedure, issued river forecasts for the Schuylkill River. Area flash flood watches and warnings are also issued by WSFO Philadelphia and by WSO Trenton. Action agencies received the information through State civil defense systems and/or State Police teletypewriter circuit. The general public received warnings through radio and television, which were serviced by Associated Press or United Press International. (In this area, there are very few subscribers to the NOAA Weather Wire Service.) The news wire services gave bulletin status to all weather warnings. However, from 30 minutes to an hour sometimes elapsed between the issuance of a warning and its receipt by the radio/television studio.

The first forecast of heavy rain was issued by WSFO Philadelphia at 5:00 p.m. on June 20, indicating heavy rain that night. A flash flood statement was issued by WSO Trenton at 7:30 a.m., June 22, for the upper Schuylkill.

All river gages in the Schuylkill basin except the power company staff gage at Reading became inoperative during the afternoon of June 22. The result was a total lack of information on river stages above Reading, but forecasts for points below Reading were good.



NWS radars closest to the Schuylkill River Basin are located at Patuxent River, Md., Atlantic City, N.J., and New York, N.Y. These radars do not provide the adequate information on rates of precipitation over the basin that is needed for flood and flash flood warning services.

An additional man was temporarily detailed by Eastern Region Headquarters to the WSO staff at Trenton, N.J., on June 21. The Meteorologist-in-Charge, WSFO Philadelphia, was not on duty, but the office had sufficient personnel available during the emergency.

Although some action agencies were unable to relate the river stage forecasts to probable flooding, civil defense and other action agencies responded extremely well and can be credited with keeping loss of life to a minimum. Two lives were lost. Generally, people apparently did not appreciate the severity of the flood. NWS received compliments from the mayor, borough manager, and newspaper editor from Pottstown.

Newsmen in the area felt that the lack of public response may have been due to a too frequent issuance of watches, which the public comes to ignore.

Schuylkill River at Philadelphia, Pa.

Rain began in the basin on the morning of Wednesday, June 21. The intensity was light during the afternoon and early evening, but became heavy during the night. The area had been under a flash flood watch since 4:30 p.m. on Tuesday, the 20th, and the first warning was issued at 5:30 p.m., Wednesday, in anticipation of the heavy rain. By daybreak on Thursday the 22d, the river was beginning to rise and at 5:30 p.m. the 11-foot flood stage was reached. The rain began to taper off during the afternoon. The river continued to rise through the night, cresting at 9 a.m., Friday, June 23. The maximum stage was 14.7 feet, equal to the flood in 1933 but 3 feet below the record of 17 feet set in October 1869.

Crest forecasts were issued throughout the period of the rise. Those issued shortly before and at the time of the crest called for a secondary rise, 3 to 4 feet higher than the first crest. A secondary crest did occur, but it was lower than the first.

Extensive precautions were taken in the Philadelphia area, consisting of the placing of highway barricades and the evacuation of residences in the northern suburbs. While damage was heavy in the Schuylkill basin as a whole, it was light in and around Philadelphia. Three deaths were reported.

While the river gage survived the flood, the telemark was out of service from the time of the crest to the end of the event. During that period, stage reports were not available operationally. Forecasts for this point are based, to a large extent, on stage readings from upstream points. These were almost completely lacking. The stations (proceeding downstream) and their reporting performance during the flood are as follows:

Berne: Out of service permanently at 1 p.m. on June 22.

Reading: Reported crest of 31.5 feet at 4:30 a.m. on June 23. Report was received at RFC at 9:00 a.m. This crest was 9.5 feet above the previous record of 22 feet set in May 1942.

Pottstown: Last report was at midnight on June 22. River stage was 20.9 feet and said to be rising. It eventually went 9 feet higher. The previous record of 21 feet was set in February 1902.

Norristown: This is the last main stem station before Philadelphia. Therefore it is most important in making river forecasts for Philadelphia. While no reports were received from this station at the time, the river at Norristown crested at 24.5 feet on June 23. The previous record of 21 feet was set in August 1933.

Genesee River Basin

The initial flash flood warning for the basin's headwaters was issued after flooding had occurred in several communities. Subsequent issuances provided good lead time for protective action downstream. There was no loss of life reported on the Genesee, and understanding of the warnings was exceptionally good. A potential dam failure was averted by good coordination between the Corps of Engineers and WSO Rochester.

WSFO Buffalo prepares zone weather forecasts for upper New York State, including the Genesee River Basin. This basin is outside the jurisdiction of a River Forecast Center. River stage forecasts are prepared by RDO Rochester. Flash flood watches and warnings for the Genesee are issued through WSFO Buffalo and transmitted to WSO Rochester by telephone and RAWARC* for distribution. Dissemination is made through news wire services, local teletypewriter loop, VHF-FM, and a telephone warning list. There is no NOAA Weather Wire Service in New York State.

The first forecast of rain and thunderstorms was issued by WSFO Buffalo at 5:00 a.m., June 20. At 6:20 a.m., June 21, WSO Rochester called Buffalo to report that Scio, N.Y., had received 2.76 inches of rainfall in 12 hours, and the river was 2 feet above flood stage. Ten minutes later, forecasters in Buffalo heard on commercial radio that schools in Wellsville, N.Y., were closed because of flooding. These two communities are located on the headwaters of the Genesee. A flash flood warning for the Genesee River and its tributaries in the Scio/Wellsville vicinity was issued by the Buffalo forecaster and called to Rochester for distribution at 7:00 a.m., Wednesday. The zone forecast was revised to include a flash flood warning.

At 7:35 a.m., June 21, WSO Rochester reported that Scio had received an additional 1.6 inches of rain in 1 hour. Flooding in Wellsville and Bolivar areas, heavy rain in Steuben County, and overflowing in Hornell, N.Y., were reported over NAWAS* at 7:40 a.m. The flash flood warning was extended to include Allegheny, Livingston, Steuben, Schuyler, Yates, and Ontario Counties and distributed by WSO Rochester at 8:30 a.m. that day. At 10:30 a.m., the city of Wellsville lost power, and communications were disrupted. NAWAS was used by WSFO Buffalo, but time lags of up to an hour were caused by the need to read the warning bulletins slowly to New York State NAWAS headquarters in Albany before the relay to Allegheny County could be effected.

The river forecast prepared by WSFO Buffalo and disseminated by WSO Rochester is given in table 1.

The lower Genesee River Basin was subjected to the successive rains of two large weather systems on June 21 and 22, which produced two separate but cumulative flash floods in the Genessee headwaters on these days.

Flooding along the main stem of the Genesee did not take place until Friday, June 23. River statements and warnings were issued well in advance of flood occurrence. On June 24, the flood control dam at Mt. Morris, N.Y.—which is normally empty—became filled to capacity and threatened to cause a major disaster if it were to collapse. The Corps of Engineers contacted WSO Rochester to advise them of the need to relieve pressure on the structure. Personnel at RFC Hartford responded to WSO Rochester's request to calculate a safe flow level and advised that a flow level not to exceed 15,000 cubic feet per second would be required to prevent disastrous flooding downstream. Residents who would be affected by the flow were given 5 hours' notice (by the Corps) to evacuate before the water was

*NAWAS—National Warning System, primarily a conference telephone system operated by Civil Defense.

Table 1.—River forecast for Genesee River

Station	Flood stage	Previous flood record	River Stage Forecast: Date & time issued (EDT)	River Stage Forecast: Forecast stage	River Stage Forecast: Effective date & time (EDT)	Date & time (EDT) river first reached flood stage	Crest, date & time (EDT)
GENESEE RIVER Portageville	17′	28.9′ 1956	21/10:45 p.m.	21.0′		Unknown	22.0′ 23/12:00 noon

released from the dam. Some flooding occurred as a result of the relief flow, but the greater threat was averted.

No warnings were issued for the flooding that occurred at Wellsville about 2:30 a.m., June 21. The local radio station was critical of NWS. The station's telephone call to WSFO Buffalo was answered by a recorded message of general weather information. The station is on WSO Rochester's call list, but its staff asserts that no call was received.

The emergency situation in WSO Rochester was complicated by the retirement of the Meteorologist-in-Charge, who was absent on terminal leave. The slack was taken up effectively by WSFO Buffalo, and the vacant position was filled quickly by dispatching an acting Meteorologist-in-Charge from Albany.

Susquehanna River Basin

Flood and flash flood warnings for the Susquehanna River Basin ranged from excellent—as in Wilkes-Barre, where a long lead time permitted the evacuation of up to 100,000 persons and prevented a major loss of life—to warnings with a minimum lead time, as in Harrisburg. Public dissemination of warnings for many small towns along the Chemung River was inadequate. Public response varied from excellent to poor. The reason for the great variation in performance of the warning system was the erratic nature of torrential rains, which in some cases brought very rapid river rises. On balance, according to Gov. Milton J. Shapp, NWS has "every reason to be proud" of its performance.

Weather forecast responsibility for the Susquehanna Basin is divided between the Pittsburgh, Philadelphia, Albany, and Buffalo WSFOs. All river forecasts are prepared by RFC Harrisburg.

A flash flood watch was issued at 11:00 a.m. on the morning of June 21 by RFC (RDO) Harrisburg for much of the Susquenhanna Basin. A flash flood warning issued at 3:00 p.m. that day, as extremely heavy precipitation began, assured excellent lead time before critical stages could develop on smaller streams.

Perhaps the most outstanding issuance of the whole disaster was a flood forecast sent by RFC Harrisburg to the civil defense office in Wilkes-Barre at 3:00 a.m. on Friday, June 23. This forecast stated that the Susquehanna at Wilkes-Barre was expected to crest at 40 feet, at 8:00 a.m. on June 24, 7 feet above the flood of record. The forecast triggered a mass evacuation of 80,000 to 100,000 persons by civil defense authorities, and is unquestionably responsible for preventing a disaster of unimaginable magnitude.

Forecasts were distributed to the public and public safety officials by means of the NOAA Weather Wire, the news wire services, and available civil defense and State Environmental Protection Agency systems. Personal telephone contact provided the only warnings for many areas. In Pennsylvania, the NOAA Weather Wire did not have sufficient subscribers to make it an adequate warning medium. In New York State, where the NOAA Weather Wire is not installed, broadcasters monitored other stations and maintained contact by telephone. Normal dissemination of forecasts through RDO Binghamton for the Chemung River is by telephone.

Flood warning bulletin #1 was issued by WSO (RDO) Binghamton, N.Y., at 9:30 a.m. on June 21, for Steuben, Chenango, and Tioga Counties, which encompass the cities of Hornell, Painted Post, Corning, and Elmira. This bulletin, advising "all interests to take maximum protective action immediately," was distributed by telephone to a calling list which included Elmira and Corning radio and TV stations. At 10:15 a.m., the flood warning bulletin was extended to include additional counties, and, at 11:00 a.m., the extended warning was telephoned to area radio and TV stations as part of the local forecast. At 4:00 p.m., June 21, flash flood warning bulletin #2 was issued for Steuben, Chemung, Tioga, Broome, Chenango, Cortland, and Otsego Counties. Although the bulletins were repeatedly broadcast, there was a consensus that "there was no recollection of warnings."

Crest forecasts issued during the progress of the storm required frequent upward revisions to reflect the continuous heavy rainfall. This situation was prevalent throughout the river basin. The performance of the local radio and television stations was exemplary. In general, they were the principal means of warning citizens and, in some cases, they were the only avenue of warning, remaining on the air for

80 to 90 hours until the emergency was over. Most stations exercised good judgment in filtering rumors and avoiding sensationalism, refusing to broadcast reports of broken dams, for example, until the information could be verified. Many small stations invested large sums of money in long-distance telephone calls to obtain continuous information on weather and flood conditions.

The staffs of all NWS offices in the basin performed admirably under extremely hazardous emergency working conditions. The staffing capacity for RFC Harrisburg was stretched near the breaking point as the effects of Agnes spread throughout the entire assigned forecast area.

As the flood rose to above-record proportions, 22 river gaging stations out of 60 on the river became inoperative or were destroyed, and communications systems began deteriorating. Portions of the Federal-State Radio River and Rainfall Reporting Network became inoperative.

Power failures were prevalent throughout the Susquenhanna Basin, affecting the timely collection of rainfall and river information as well as the preparation and dissemination of flood forecasts. Failure of the power system supplying RFC Harrisburg, at 7:14 a.m. on June 23, was most critical. The Center's staff then had to perform forecast operations manually, under lantern light. When the telephone and teletypewriter system at RFC Harrisburg failed, time-concuming emergency methods were employed to collect substation reports and disseminate forecasts. The staff was able to make outgoing calls, and this made it possible to obtain minimum data. There were no signals to indicate incoming calls.

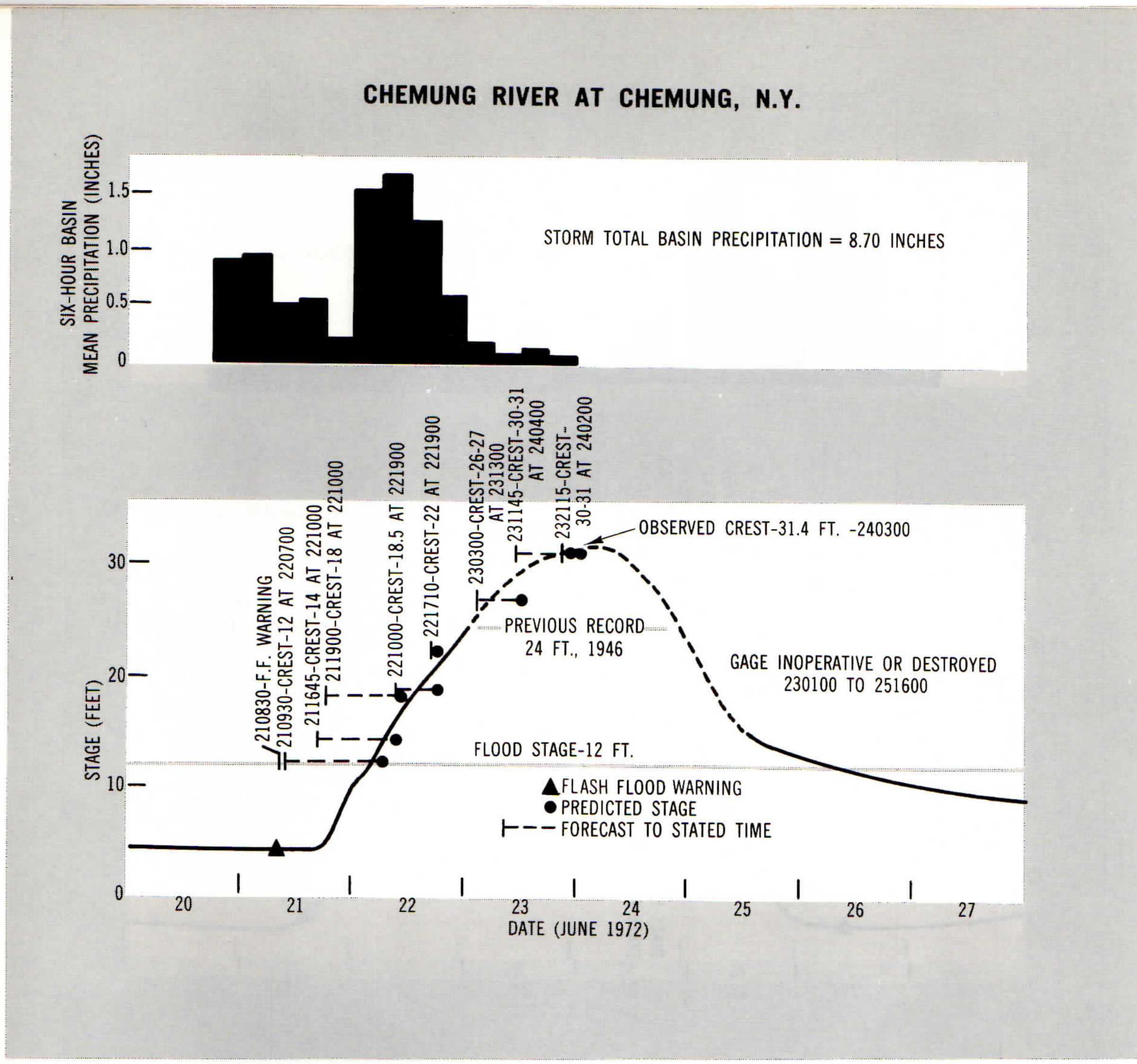
Public understanding and reaction varied. In the Covington/Mansfield area of Pennsylvania, one man was awakened in his mobile home and informed of the flood approach. He responded by turning over and going back to sleep. Instances were cited of people refusing to leave their homes, necessitating dangerous rescue efforts later, which cost the life of at least one rescuer in Painted Post, N.Y. At the other end of the scale, many people in Selinsgrove, Pa., reacted quickly enough to save personal belongings and even appliances. There was both criticism and praise for NWS operations, leavened by a widespread feeling that "everyone was having his problems" in this short-fuse phenomenon.

The Williamsport Mayor, John R. Coder, the local radio and TV media, and the Lycoming County Civil Defense Director expressed praise for the dedicated service renderd by the staff of WSO Williamsport. In Williamsport, Pa., th malfunctioning of a river gage, used by WSO Williamsport for its reports to the community, occasioned a complaint by the Lycoming County Commissioner.

Both flash floods and river floods occurred at Harrisburg, and the public was confused by the two types of warnings. Flash flood warnings requiring immediate action were in effect while river flood warnings were predicting flooding some hours later. For example, the publisher of the Harrisburg *Patriot News* reported that he and his staff came to work at 4:00 a.m. on Thursday morning, June 22. At 7:00 a.m., the river stage on the Susquehanna at Harrisburg was 11.2 feet, 5.8 feet below flood stage. But at 10:00 a.m. the newspaper staff was evacuated from its offices, with the loss of one life. Flash flood warnings were in effect at that time because of heavy rains during the night. The flooding of the *Patriot News* was from flash flooding on Paxton Creek. The Susquehanna reached the flood stage of 17 feet at Harrisburg at 2:00 p.m. that evening.

The effectiveness of the support provided is described in the following letter from Milton J. Shapp, Governor of Pennsylvania, to the Hydrologist-in-Charge of RFC Harrisburg:

> "On behalf of the people of Pennsylvania and the Commonwealth Government, I extend to you and your fellow workers in the Federal-State River Forecasting Service our sincere thanks for the highly valued service so capably rendered in connection with last month's disastrous flood.
>
> "The June 20 flash flood watch, changed to a warning the following day, provided people in the Lower Susquehanna River Valley with initial notice and forecast of things to come. During the next several days, the widespread disruption of communications systems and facilities admittedly resulted in some delays in the normal dissemination of crest forecasts and similar information. Nonetheless, the vital messages did 'get through.'
>
> "Should there be any doubt as to the value of the forecast operations, I need cite only the 40-foot crest predictions for Wilkes-Barre, which came early Friday morning, June 23. Passed to the Luzerne County officials by our State Civil Defense Director, with a recommendation that everyone 'behind the dikes' be evacuated, that single bit of essential information unquestionably was responsible for the saving of countless human lives, which otherwise would have been lost.
>
> "You and your associates have every reason to be proud of your contribution to our common safety."



Chemung River at Chemung, N.Y.

Significant rainfall began in the basin on the evening of June 20. The area had not been under a watch, and the first flash flood warning was issued by RDO Binghamton at 8:30 a.m. on June 21. At this time, sizeable rises had started in the headwaters but no rise had yet taken place at the station. The rainfall through June 21 was associated with a cold front. By the time precipitation ended late on June 23, tropical storm Agnes had contributed about 4 inches for a 4-day total of 8.7 inches over the basin. The heaviest amounts were in the upper portion of the drainage. A crest of 31.4 feet occurred on the morning of June 24. This is 19 feet above flood stage and 7 feet above the previous record of 24 feet in May 1946. The gage was destroyed. It became inoperative about 24 hours before the crest was reached, while the river stage was 8 feet below the maximum. Final forecasts for this point were prepared manually after power to the RFC computer was lost.

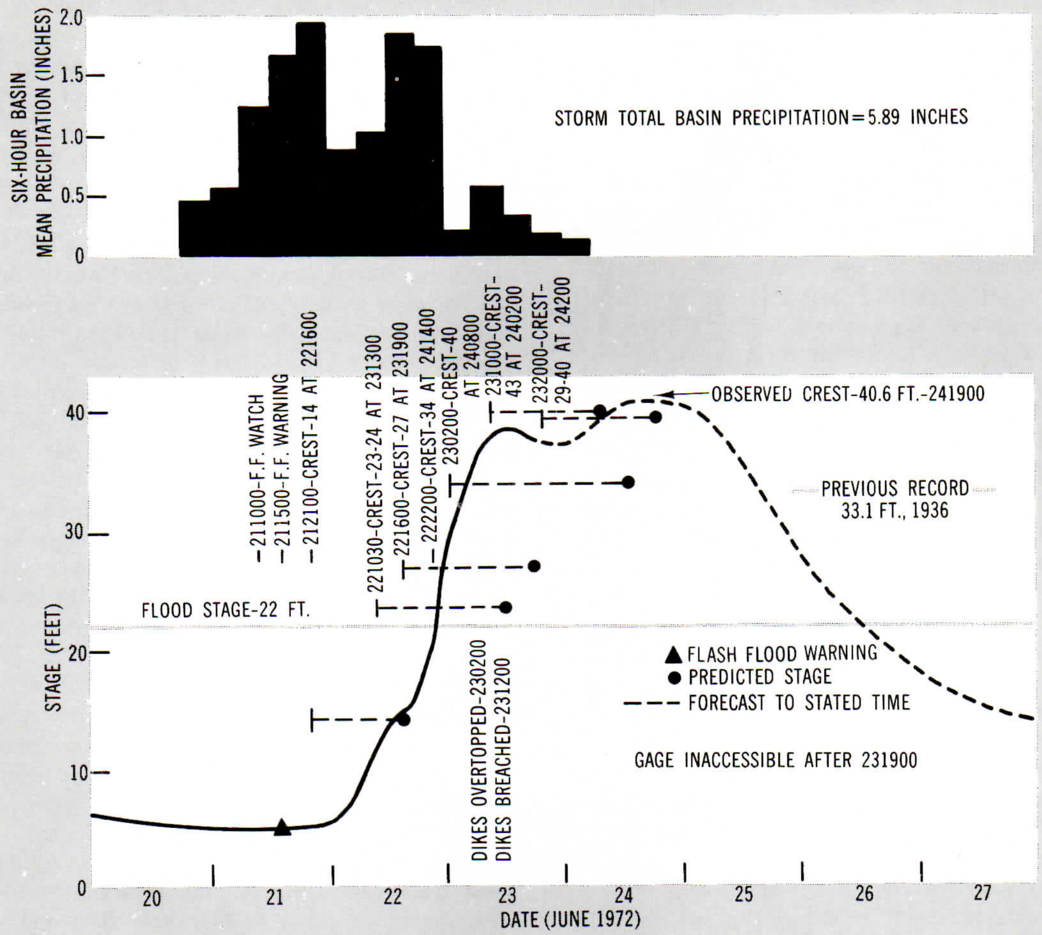
Failure of communication facilities in the area hampered protective and rescue operations. Information on the extent of these operations is sketchy.

Property damage in the area was extremely heavy. While no deaths have been reported in Chemung, there are said to have been 19 drownings in the upper basin near Corning.

Susquehanna River at Wilkes-Barre, Pa.

On the morning of June 21, no rain was falling in or near Wilkes-Barre, but the flood crest then developing above Chemung would eventually affect this area. A flash flood watch was issued at this time and replaced by a warning during the afternoon. Rain began in the area immediately north of Wilkes-Barre later on June 21 and continued through June 23, producing 6 inches in the local drainage below Chemung. This, added to the flood wave caused by even heavier rain above Chemung, produced a crest of 40.6 feet on the evening of June 24. This is 18.6 feet above flood stage and 7.5 feet above the previous record set in 1936. Preparation

SUSQUEHANNA RIVER AT WILKES BARRE, PA.



for the flood on the basis of the initial warnings and later forecasts was unusually good and involved the evacuation of 100,000 people. Property damage was heavy, but there is overwhelming evidence that a much greater loss was averted. One death by drowning has been reported in the Wilkes-Barre area.

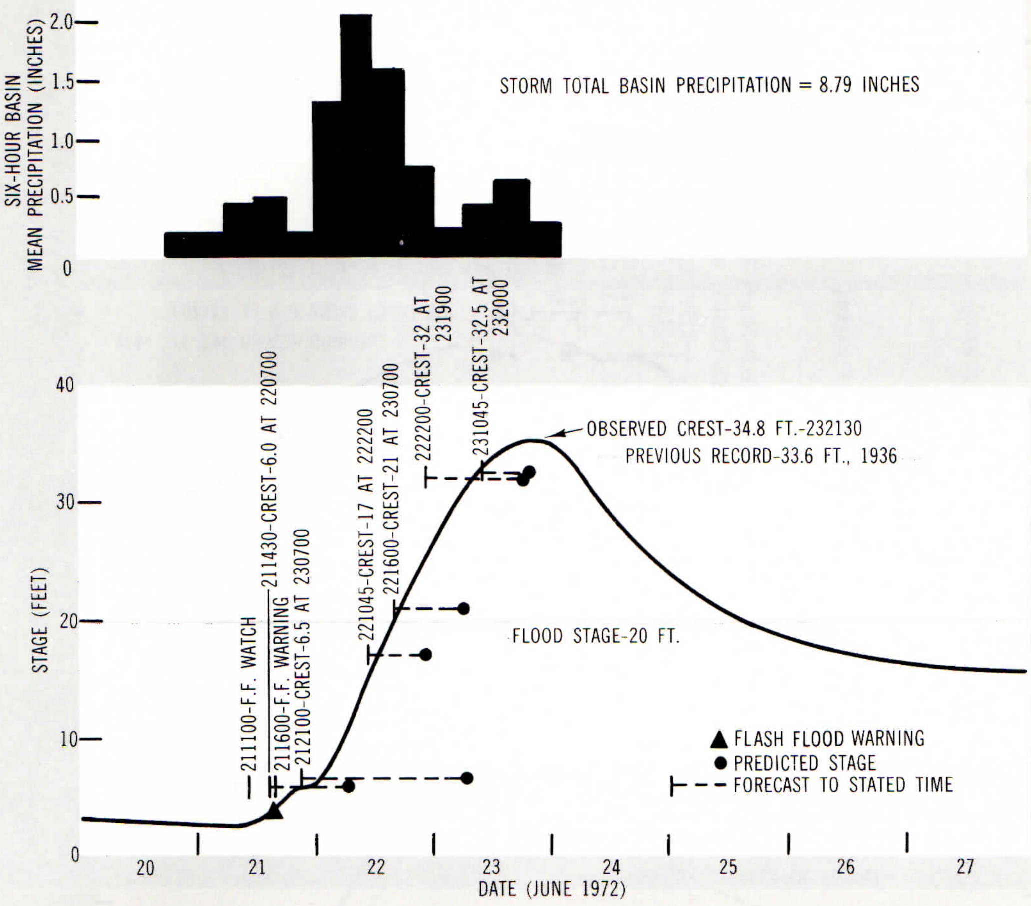
Although the river gage was not destroyed, radio communication with it was lost early in the water's rise. Later, inaccessibility of the gage required the use of a wire-weight gage and telephone communication with the local observer. A forecast of a 40-foot crest was prepared prior to the loss of power to the RFC computer. Although minor revisions were prepared manually later, the decision to evacuate areas in back of the dikes was based on the 40-foot forecast.

Several thousand teenagers, among others, volunteered for sandbag duty and worked around the clock. Despite their efforts, the dikes on both banks were overtopped and eventually breached. The breaching of the dikes probably resulted in a slight decrease in the stage in the main channel and a considerable increase in the size of inundated area.

West Branch Susquehanna River at Williamsport, Pa.

In the river basin above Williamsport, rain began slowly on the afternoon of June 20. On the morning of June 21, the intensity was increasing and the area was placed under a flood watch. The first warning was issued at 4:00 p.m. The rate of rainfall continued to increase through the night and most of the next day. By early morning of June 25, 13.5 inches had been observed at Williamsport. Average precipitation over the entire 5,682-square-mile basin above Williamsport was 8.8 inches. This heavy downstream concentraton caused disastrous flooding along small streams in the local area. The West Branch

W. BR. SUSQUEHANNA RIVER AT WILLIAMSPORT, PA.



crest occurred at 9:30 p.m. on June 23 at a stage of 34.8 feet, 15 feet above flood and one foot above the previous record in 1936.

The 34.8-foot stage is a wire weight gage reading. The maximum stage recorded in the well house was 31.4 feet. Information available at this time indicates that the discrepancy probably was the result of a malfunctioning intake.

WSO Williamsport issued 90 special statements during the emergency, prompting extensive preventive measures. Most damage in the vicinity of the city was caused by small stream flooding, the main channel being contained by dikes. Main stream damage was extensive below Williamsport, however. Five deaths were reported in Lycoming County.

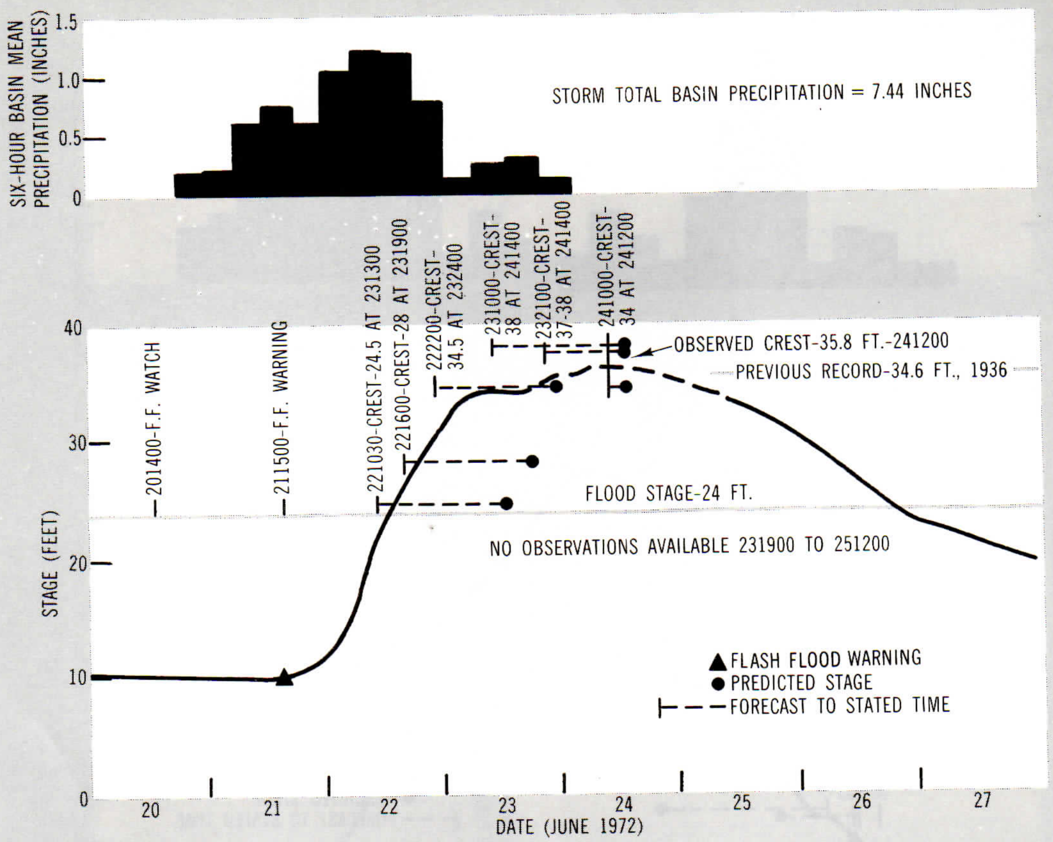
The river gage survived the flood, but radio communication was lost early in the rise. Fairly complete reports were received by telephone. The principal crest forecasts were prepared before power to the RFC computer was interrupted.

The crest at Williamsport was only one foot lower than the top of the dikes.

Susquehanna River at Sunbury, Pa.

Sunbury is located on the main river just below the junction of the North Branch with the West Branch. The local area received 10.3 inches of rainfall over the 4-day period, June 21–24, with a 14-inch rainfall center at Milton, Pa. Extensive small stream flooding resulted. The record main-channel flow, which included the tremendous upstream discharges, was contained by dikes with the aid of sandbagging and sand boil repair. A flood watch was issued on the afternoon of June 20, about 12 hours before the beginning of heavy rain. The first flood warning was issued at 4:00 p.m. on June 21. A crest of 35.8 feet occurred at noon on June 24.

SUSQUEHANNA RIVER AT SUNBURY, PA.



This was 12 feet above flood stage and 1 foot above the previous maximum in 1936.

A usable crest forecast was issued 36 hours before the crest arrived. The principal protective works were the dikes, although all of the people behind the dikes were evacuated. Property damage in and around Sunbury was caused primarily by small-stream flooding. Major main-stream damage occurred upstream and downstream from the dikes.

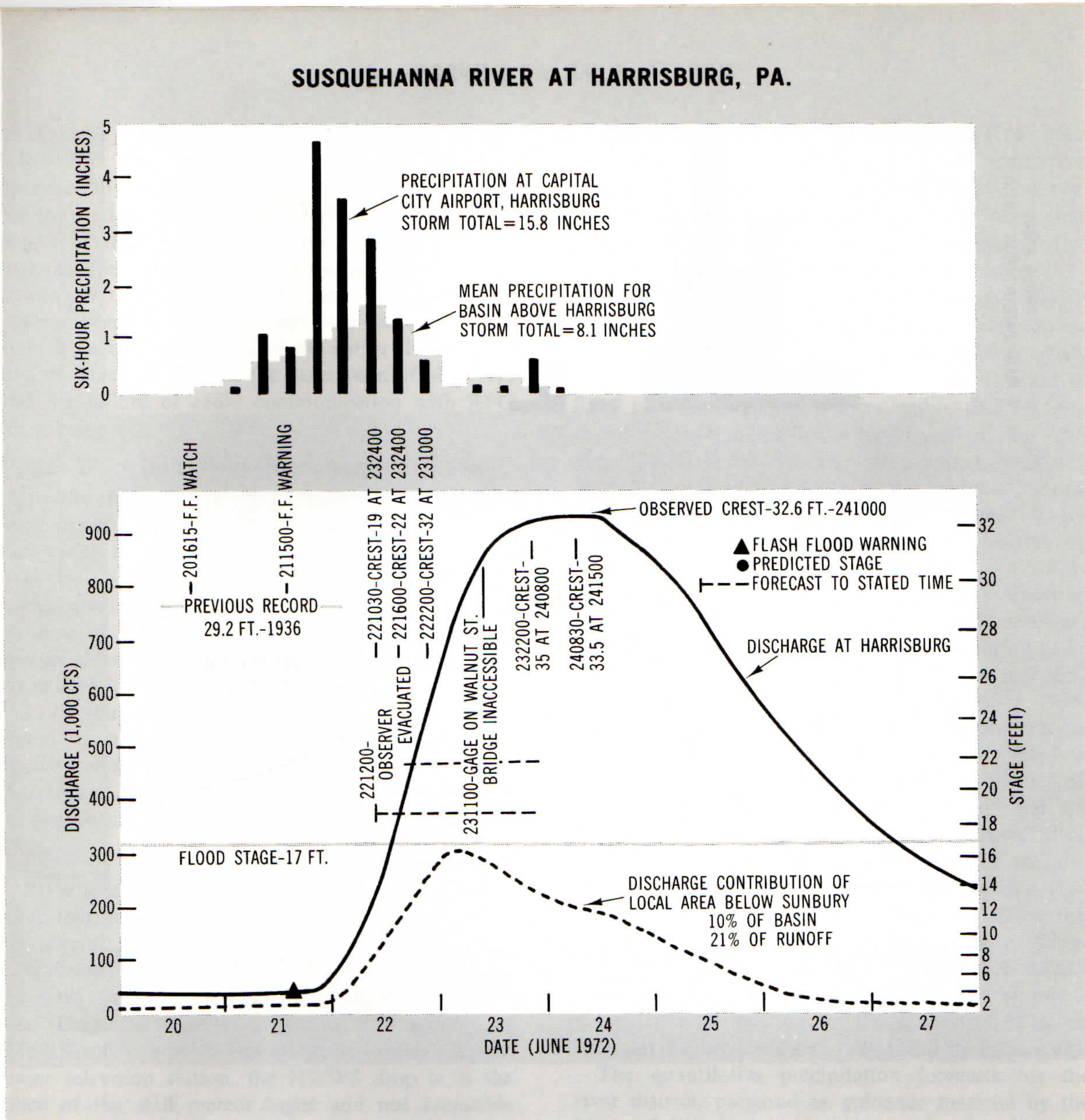
The river gage was not destroyed, but telemetering capability was lost owing to local power failure during the evening before the crest. Readings for an undetermined period prior to the failure were 1.5-feet low because of slippage of the telemark float cable. Loss of power to the RFC computer did not take place until after the principal crest forecast had been issued.

Susquehanna River at Harrisburg, Pa.

In the Harrisburg area, rain began on the morning of June 21 and continued for 3 days, accumulating to 15 inches. The main storm center was near Clingerstown, Pa. (about 30 miles north northeast of Harrisburg), where the rain totaled 19 inches. Harrisburg was placed under a flood watch on the afternoon of June 20. A warning was issued 24 hours later. A sharp rise began at 1 a.m. on June 22. At 2 p.m., the 17-foot flood stage was reached. At 5 a.m. on June 23, the 1936 flood crest record of 29.2 feet was exceeded. The water was rising at the rate of 0.6 foot per hour at this time. The crest of 32.6 feet was reached at 1:30 a.m. on June 24. However, during the 16-hour period from 6 p.m. on June 23 to 10 a.m. on June 24, the level was within one-half foot of the crest stage. A crest forecast of 32 feet was issued at 9:30 p.m. on June 22.

On Monday, June 20, 15 key executive personnel of the statewide civil defense organization began a week-long conference in State College, Pa. Based on the flood watch issued by Harrisburg RFC the next day, this conference was terminated and the personnel returned to their duty stations.

Evacuation in the Harrisburg area was started on

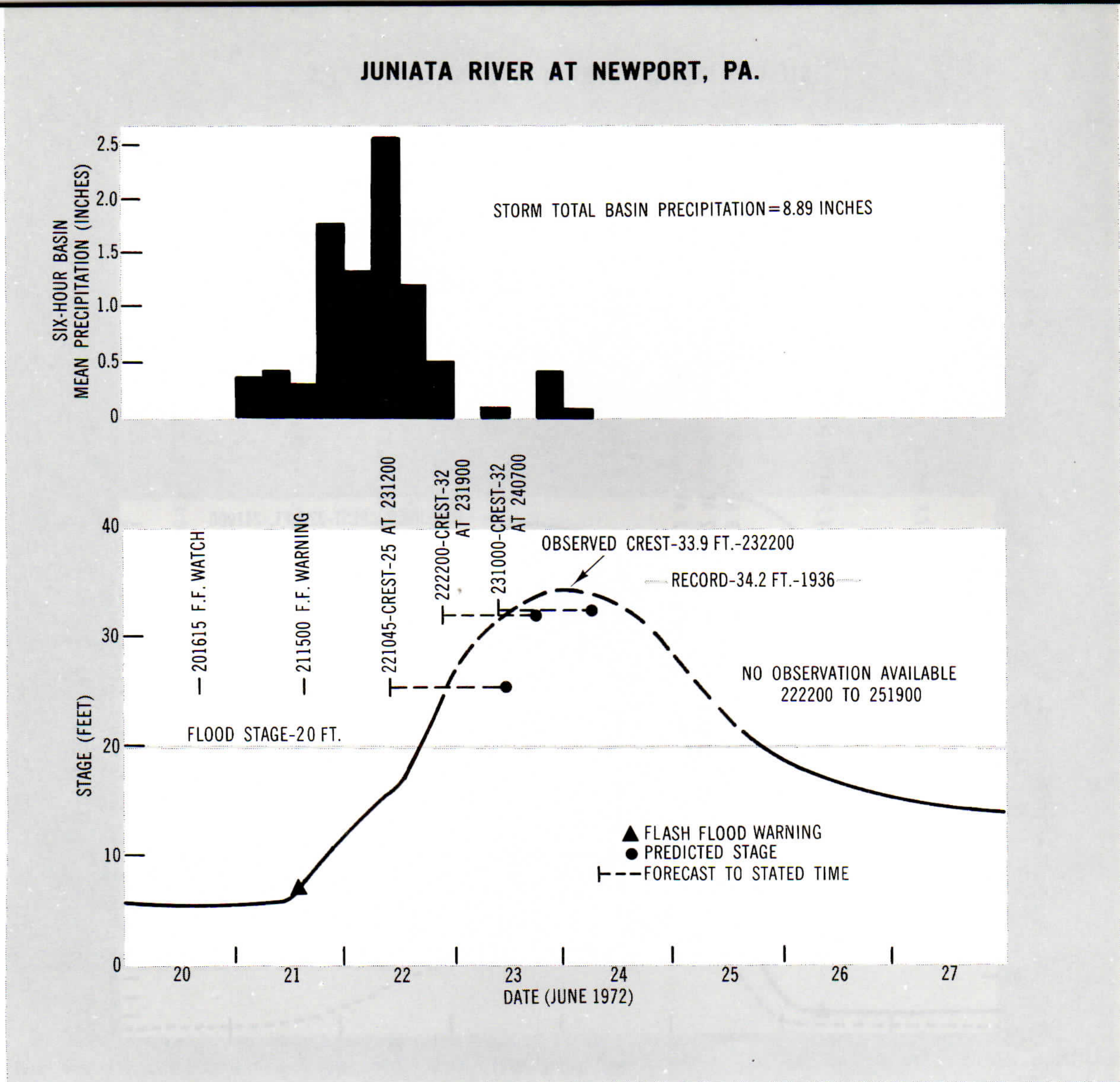


the evening of June 21, because of local flash flooding to 15 inches. The main storm center was near ing. Frequent statements issued by RFC, beginning with the 4 p.m. warning and continuing through the night, called for greatly worsening conditions and disastrous urban flooding from locally heavy rains. These warnings hastened and increased the scope of the evacuation operation. Property damage was severe in the city and surrounding area. One drowning occurred in the Harrisburg area.

The telemetering capability of the Harrisburg river gage was lost early in the rise owing to radio failure. Later, the local observer had to be evacuated because of urban flooding from local rains, at a time when the Susquehanna was still 7 feet below flood stage. Subsequent river readings were made by RFC personnel using the wire-weight gage on the Walnut Street bridge. When the bridge became inaccessible, a gage was improvised.

A 32-foot flood stage was forecast before power to the RFC computer failed, but considerable manual updating computations had to be made later.

Because the principal storm center was near Harrisburg, runoff from the portion of the basin immediately above the city was much heavier than that from the basin as a whole. The result was a very steep rise and an early peak from local inflow. Near-maximum stage at Harrisburg was reached many hours in advance of crests at upstream stations. Although forecasts for points along the river



correctly predicted this somewhat unusual response, some recipients were reluctant to accept these forecasts, being accustomed to the more typical case of a crest moving downstream from point to point.

Paxton Creek flows through the center of Harrisburg. The numerous small-bridge openings, together with intense local runoff, created a series of fixed-orifice reservoirs. This effect aggravated the local flooding condition and produced flash-flood stages (in the city and near the confluence with the Susquehanna) fully as high as those which occurred later from Susquehanna River backwater.

Juniata River at Newport, Pa.

The first flash-flood watch for this area was issued at 4:15 p.m. on Tuesday, June 20, about 12 hours before the beginning of rain. The rain began, at a moderate rate, very early on Wednesday, June 21, becoming heavy by night and remaining so all through the next day. The storm total for the basin was 8.9 inches, of which 6.8 inches fell in a 24-hour period. A flash flood warning was issued at 3 p.m. on Wednesday, June 21, just as the rise started. The river continued to rise for the next 55 hours, passing the 20-foot flood stage the following evening and cresting at 10 p.m. on Friday, June 23. The maximum stage was 33.9 feet, just 0.3-foot less than the 1936 record. Precautionary measures evidently consisted primarily of evacuation of residences. Approximately 700 people were removed, and a small army of volunteers moved large quantities of furniture to high grounds. Property damage was heavy, but deaths were not reported in Newport or in Perry County.

Reporting service from the gage ceased at 10 p.m.

on Thursday, June 22, 24 hours before and 10 feet below the crest. Observations were not available operationally until 2 days after the crest. The reason for the initial loss of communication was the evacuation of the observer from his home, where the remote river gage readout terminal was located. Later, the river gage itself became inaccessible.

Operational precipitation and river-stage data were lacking during the last half of the storm all along the Juniata River, because of the evacuation of observers and the failure of radio communication with RFC Harrisburg.

Upper Ohio (Allegheny–Monongahela) Basin

In southwestern New York State, flash flood watches were issued well in advance of flooding. Local knowledge of the flash flood characteristics of the river in this area resulted in prompt community action and timely evacuation of endangered areas. Because of the cooperation of county civil defense and local safety officials, there were no injuries and no loss of life.

In Pittsburgh, flood warnings were generally available with only a minimum of lead time, because of the suddenness of torrential rains and because these rains occurred at night, when dissemination of warnings is most difficult. There was no loss of life.

River forecasts for the upper Ohio are prepared by RFC Cincinnati. Flash flood watches and warnings are prepared and issued by WSFO Pittsburgh.

Warnings are provided to the general public by the news media which obtain their information from the NOAA Weather Wire Service. The number of NWWS subscribers in Pittsburgh is limited. At the major television station, the NWWS drop is in the office of the staff meteorologist and not accessible to others when he is off duty.

Some commercial interests within Pittsburgh received warnings through a prearranged telephone alerting service operated by the Chamber of Commerce. The Western Area Office of Pennsylvania Civil Defense received and relayed appropriate warnings to country directors. Direct telephone calls were made by the WSFO Pittsburgh staff to an extensive list of community representatives. Warnings also were released to the Army Corps of Engineers, Pittsburgh District, which relayed these to its installations along the Allegheny and Monongahela for local dissemination.

Flash flood watches for areas of western Pennsylvania were issued as early as 3:30 p.m. on June 20. Beginning on June 21, flash flood watches and warnings were issued frequently for numerous areas over the upper Ohio.

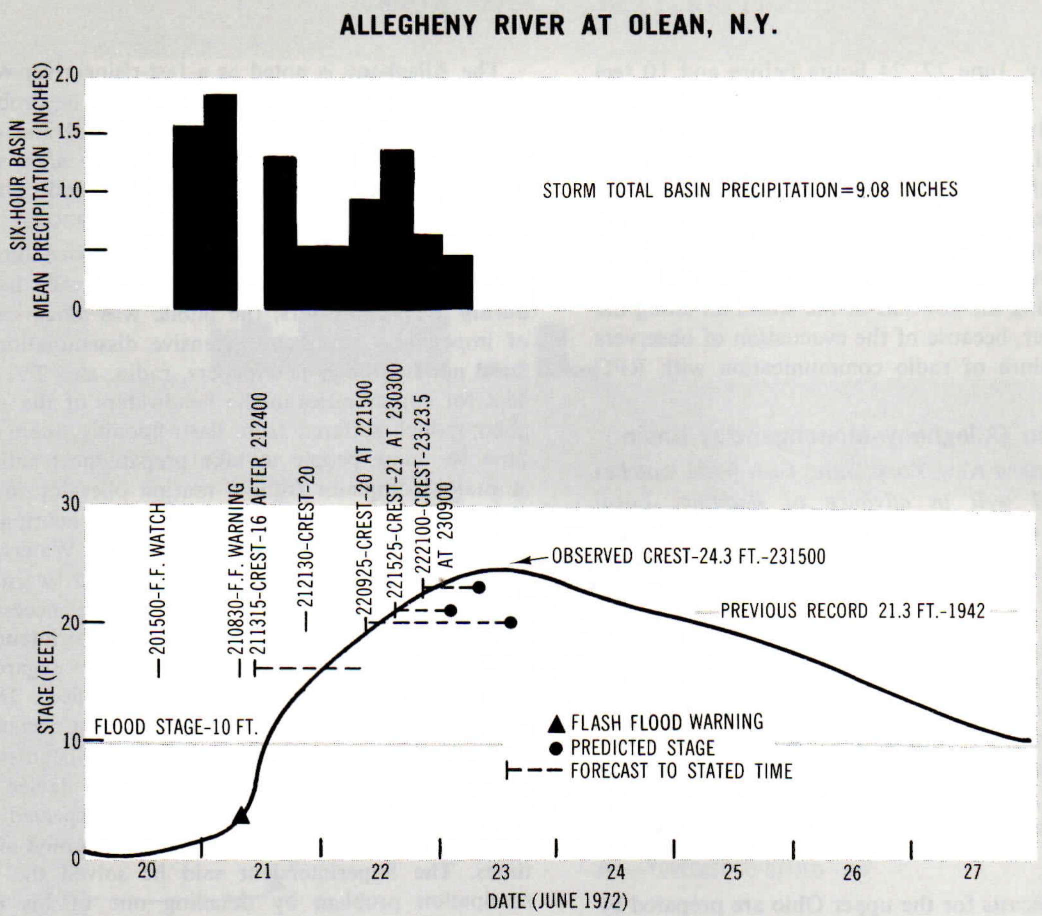
The Allegheny is noted as a fast-rising river when heavy rains occur over the headwaters. The problem was compounded in this flood by general and continuous very heavy rains. As a result, the main stem of the Allegheny rose like a flash flood, contributing to short lead times in the warning issuances.

Although official flood warnings provided limited lead time, and these warnings were generally issued during the night hours, the public was made aware of impending danger by extensive dissemination of flood news through newspapers, radio, and TV. Except for communities in the headwaters of the Allegheny which suffered from flash flooding, there was time for most people to take preparedness actions. A major complaint from a marina operator in the Pittsburgh area led to a Congressional hearing on June 29, 1972. The President of the Waterways Association of Pittsburgh stated that the warnings issued provided adequate time to take necessary preparedness actions. The Mayor and Superintendent of Police of Pittsburgh expressed concern regarding dissemination but otherwise were satisfied. There were problems in the dissemination of information. When the mayor's office was called in the dissemination process, a telephone-answering device responded. The Mayor stated that he expected the Superintendent of Police to be fully informed at all times. The Superintendent said he solved the dissemination problem by detailing one of his men to the forecast office with a walkie-talkie. Once this had been done, he had no further problems. There was no loss of life. The local NWS Environmental Meteorological Support Unit (EMSU) was advised to move from its location on the Monongahela River bank on Friday morning, well ahead of flood stage.

The quantitative precipitation forecasts for the river district, prepared as guidance material by the National Meteorological Center, did not provide an adequate picture of anticipated rainfall. Radar reports on the NOAA Weather Wire did not reflect the heavy rainfall rates during this event. Timely detection of precipitation was not available from the normal substation reporting network.

The local forecast staff did add additional rainfall amounts to the model, based on some knowledge of rainfall in the area. These turned out to be too low in all cases where this technique was used.

One trained hydrologist is on the staff at WSO Pittsburgh, supported by two technicians to carry out river district activities. This is not sufficient professional manpower to meet the hydrologic service needs of this district. During the flood emergency, the only hydrologist remained at his post 6 days and 5 nights. It became necessary to assign a hydrologist from RFC Cincinnati to assist him.



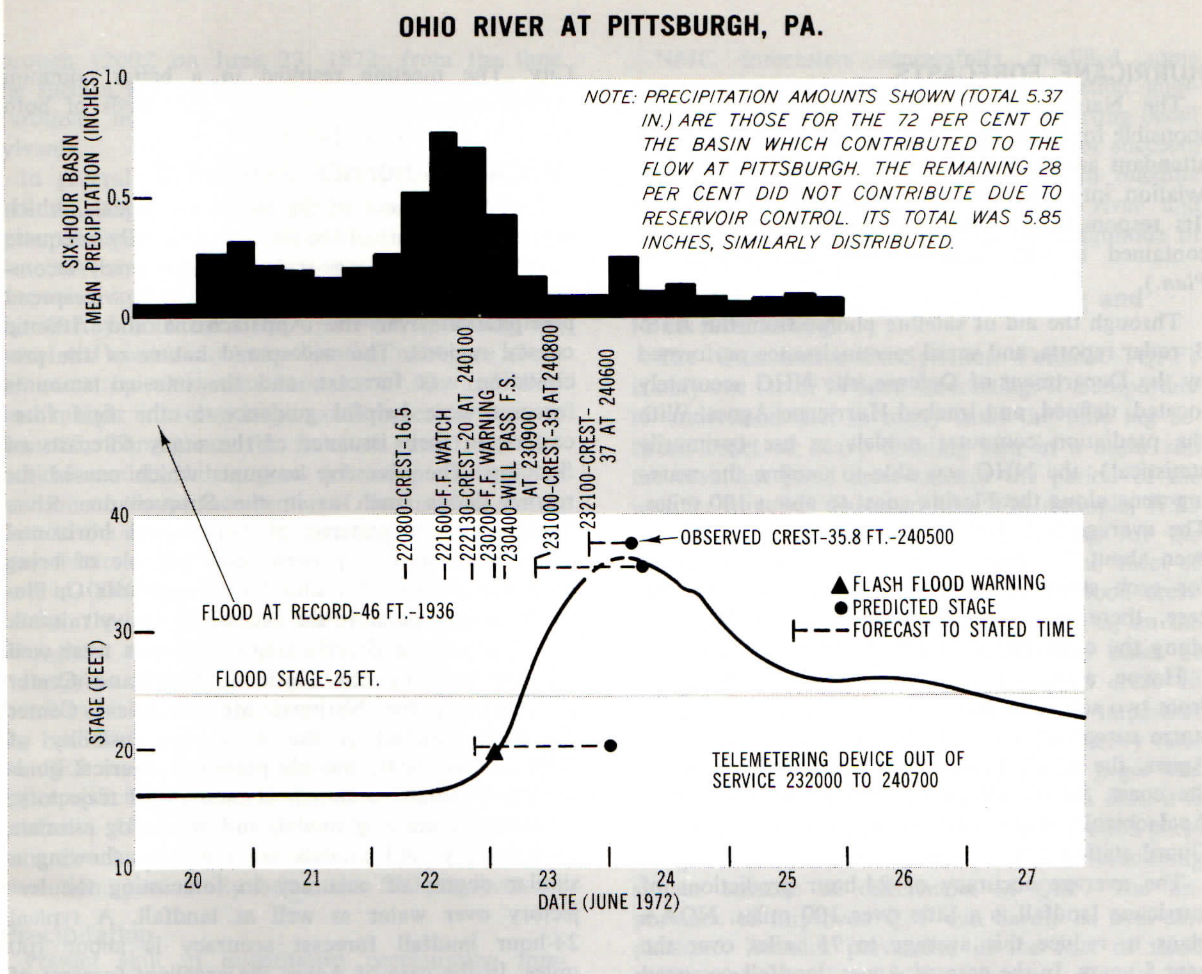
Allegheny River at Olean, N.Y.

The rain began in this basin rather suddenly on the evening of Tuesday, June 20. This rain was the result of a frontal passage and deposited 3.5 inches over the basin in the 12-hour period ending at 7 a.m. Wednesday, June 31. A flash flood watch had been issued at 3:50 p.m. on Tuesday, a few hours before the rain began. This was changed to a warning at 8:30 a.m. Wednesday, as a sharp river rise began. After the frontal passage, the rain stopped. During the afternoon, moisture ahead of tropical storm Agnes moved into the region, and another downpour began just as the river level passed the 10-foot flood stage. It lasted for the next 42 hours, adding 5.6 inches to the 3.5 inches already fallen. The river continued to rise until 3 p.m. on Friday, June 23, when it crested at 24.3 feet, 14 feet above flood and 3 feet above the previous record set in 1942.

As the rain continued, several crest forecasts were issued. Continued updating was necessary, but a satisfactory lead time was established.

Protective measures were timely and effective. The local civil defense office was warned at 8:45 a.m. Wednesday, June 21, and had 28 men on duty within 1 hour. Precautions were not extensive until early Friday morning, when it appeared that the 25-foot flood wall might possibly be overtopped. About 6,000 people—one third of the city's population—were evacuated from 1,500 homes. The National Guard moved both people and furniture. The area evacuated was that which had been covered by the 1942 flood which reached 21.3 feet. Although the crest fell 8 inches short of overtopping the flood wall, there was considerable leakage and sewer backup. Approximately 3,400 homes were affected. About 90 homes located outside the flood wall were heavily damaged or destroyed. The commercial area of the city is not large, and had relatively light damage. No deaths were reported. Throughout the event, radio station WHDL gave excellent cooperation and provided a valuable service.

A network of four rainfall observers reports to the city of Olean, which relays the data to RDO Pitts-



burgh. During the flood, telephone lines into Olean became overloaded, and the observers then reported directly to the RDO. The river gage is located at the Olean sewage plant, which was the city's flood operation headquarters. Readings were made and reported every 15 minutes throughout the rise.

Ohio River at Pittsburgh, Pa.

The entire basin above Pittsburgh received an average of 5.5 inches of precipitation, spread fairly uniformly over a 5-day period. Twenty-eight percent of the basin is controlled by reservoirs which did not release water during the rise. The average rainfall over this portion was 5.85 inches. The remaining 72 percent of the basin received 5.37 inches and produced all of the runoff that appeared at Pittsburgh. The greatest 6-hour amount which fell averaged 0.91 inches over the basin.

Although this was the largest flood ever to occur in June and although the concentration was downstream, the rise was only moderately steep. The 25-foot flood stage was reached at 7 a.m. on Friday, June 23, about 12 hours after the rise started. The 35.8-foot crest was reached 22 hours later at 5 a.m. on Saturday, June 24. It was 11 feet above flood stage, but 10 feet less than the record of 1936.

A flash flood watch was issued at 4 p.m. on Thursday, June 22, and a warning at 2 a.m. on Friday, June 23.

There were no failures of the telephone facilities at the RDO, but the five lines proved totally inadequate during the most critical part of the operation. At times, calls were coming in so fast that it was impossible to place outgoing calls. This resulted in complaints about the inability to contact the weather office. People calling this number for river information were told, via a recording, that the office was closed. NWS received severe public criticism as a result.

The telephone lines to the river gage were submerged and failed at 10 p.m. on Friday, June 23, and were out of service until late the following morning. During the interim, manual readings were relayed to the RDO by telephone.

HURRICANE FORECASTS

The National Hurricane Center (NHC) is responsible for providing tropical cyclone forecasts and attendant advice for the general public, marine and aviation interests, and the Department of Defense. (Its responsibilities and operational procedures are contained in the *National Hurricane Operations Plan.*)

Through the aid of satellite photos from the ATS-3, radar reports, and aerial reconnaissance performed by the Department of Defense, the NHC accurately located, defined, and tracked Hurricane Agnes. With the prediction computer models in use (primarily statistical), the NHC was able to confine the warning zone along the Florida coast to about 100 miles. The average warning zone for previous storms has been about 250 miles. The average length of havoc for each storm has been about 50 miles. In this case, there was complete destruction of buildings along the coast for a stretch of 20 to 30 miles.

Havoc along coastlines from hurricanes stems from two sources—winds and storm surges. Usually, storm surges are the more devastating. In Hurricane Agnes, the winds were below hurricane strength at the coast. Storm surges, forecast to be 7.8 feet at Apalachicola, were observed at 6.4 feet at a Coast Guard station 3 miles east.

The average accuracy of 24-hour predictions of hurricane landfall is a little over 100 miles. NOAA plans to reduce this average to 75 miles over the next 5 years. In the case of Agnes, landfall occurred within 50 miles of the 24-hour prediction.

Winds associated with Agnes were predicted to be about 85 m.p.h. with gusts up to 120 m.p.h. as the storm penetrated the coast. This forecast was based on a value of 75 m.p.h. reported by a reconnaissance flight at a location 25 miles off Cape San Blas. An 85 m.p.h. wind does not cause much public concern, but a 120 m.p.h. wind does. The news media picked out the latter figure, and used it in broadcasting warnings. The highest gust reported was 55 m.p.h. at Apalachicola. Use of the high wind speeds by news media caused unwarranted concern by the local populace and frightened away the tourist trade. To further compound this problem, Tyndall AFB announced through the press early in the afternoon of June 19 that the storm was over Albany, Ga., and that military personnel were recalled to duty. The NHC warning, however, was in effect until 6:00 p.m. The NHC warnings served to keep tourists away another day.

Apparent "overwarning" by NHC and consequent economic losses by the local merchants led Congressman Sykes to call upon senior NWS officials to meet with the concerned officials of Panama City. The meeting resulted in a better common understanding of the problems and needs of both government and the public.

CENTRAL GUIDANCE PRODUCTS

The performance of the numerical models, which represent the state-of-the-art, was generally adequate in predicting the large-scale flow patterns. Accompanying the large-scale flow patterns was widespread precipitation over the Appalachians and Atlantic coastal regions. The widespread nature of the precipitation was forecast, and the unusual amounts forecast were helpful guidance to the field forecasters, in their issuance of the many forecasts of flooding. The excessive amounts which caused the record floods, such as in the Susquehanna River Valley, fell in patterns of very small horizontal extent compared to patterns now capable of being predicted. Figures C1 and C2 of appendix C, illustrate the fine detail in the excessively heavy rainfall.

The landfall and early stages of Agnes were well forecast both by the National Hurricane Center (NHC) and the National Meteorological Center (NMC). Landfall is the direct responsibility of NHC. Three NHC models provide numerical guidance on landfall: a statistical estimate of trajectory; a barotropic steering model; and an analog estimate of trajectory. All models are currently showing a similar degree of accuracy in forecasting the trajectory over water as well as landfall. A typical 24-hour landfall forecast accuracy is about 100 miles. In the case of Agnes the excellent forecast of landfall was accurate within 50 miles. The accuracy of wind velocity and surface pressure estimates at the time of landfall was not studied here as no numerical model is involved.

Following a hurricane landfall, NMC is the sole source for guidance. Throughout this storm's history, however, an active dialog between the centers, NMC and NHC, was continued. The NMC produces the Central Computer Guidance for the Meteorological System. The models used by NMC are the Limited Area Fine Mesh Model (LFM) and the Primitive Equation Model (PEP).

There is no numerical guidance other than the LFM and PEP for hurricanes over land. Neither LFM nor PEP were designed specifically for hurricanes, but each handled Agnes well.

The unusually large size of Agnes was a necessary condition for the numerical models to forecast it successfully. The LFM was designed to forecast smaller scale phenomena than PEP, but it is too early to judge how well it will handle hurricanes generally, most of them being smaller than Agnes.

The period of special concern in the flooding caused by Agnes extends from 1200Z on June 21 through 1200Z on June 23, 1972; from the time the surface low pressure began to deepen over the Carolinas until the storm dissipated over Pennsylvania.

In general, the 500-mb numerical progs forecast well the large-scale evolution of the extra tropical system initially over the Great Lakes and its relation to the smaller tropical system, Agnes. The deepening of the extratropical system was well signaled by both the LFM and PEP, including the associated counterclockwise rotation of Agnes about the extratropical system June 21 to 23, and their final merger into one large extratropical system on June 23. Throughout the forecast period, the numerical models did a good job of predicting the position of the surface center of the tropical storm, even to the extent of forecasting the storm's position over water at 1200Z on June 22 and to recurve inland at 0000Z on June 23. The model consistently missed the deepening of the low-pressure center throughout the period of intensification.

In terms of large-scale guidance the models performed well during this period. In a rapidly developing baroclinic system of this type, it is typical for the PEP model to move the system too slowly and underpredict the central pressures and attendant gradients. Underprediction of the storm's intensity may also have been caused by inadequate vertical resolution, particularly below the 500-mb level.

Precipitation

Present skill in quantitative precipitation forecasting (as opposed to forecasting occurrences) lags well behind skill in forecasting flow patterns especially in regard to numerical guidance. Quantitative information on the LFM is just beginning to emerge. This model clearly shows some skill in predicting 0.25 inches or more of precipitation, especially during the winter and in the more northern areas. It is the general consensus that positive skill is a reflection of large-scale, well-defined synoptic features. The excessively heavy rainfall which fell in the Susquehanna River Valley was smaller in areas than the features predictable by the models.

Although the state-of-the-art is not yet up to numerically forecasting excessively heavy rainfall that falls in small-scale patterns, it does produce smooth patterns that are generally regarded as useful by practicing forecasters. During the latter days of the Agnes episode, 1200Z June 21 to 1200Z June 23, the forecast patterns were generally forecast too far north and east, but the areas of observed 12-hour accumulations and their forecasts mostly overlapped. Still, the placement error was typically a couple of hundred miles or so, which is not unusual for today's models.

NMC forecasters successfully modified some characteristics of the numerical precipitation guidance by increasing the amounts and inserting detail in the mountainous regions. They did not succeed, however, in reducing placement errors in maxima to below the dimensions of mountain river and stream valleys, nor in forecasting the magnitude of 12-hourly accumulations.

The relation between rain forecasting and flood forecasting.

The Quantitative Precipitation Forecast (QPF) is only one factor in flood forecasting. It is important to understand that in many cases the time lag between onset of heavy flooding rain in a basin and the resultant flood crest exceeds the period of the weather forecasts discussed here. For example, WSO Richmond issued its first flood warning for the James River more than 12 hours after the onset of heavy rain but still 2 days before the flood crest. A flood watch was issued for Sunbury, Pa., on the Susquehanna River 12 hours before the onset of heavy rain and 4 days before the flood crest. In such instances the rain forecast is more important in terms of indications of continuance of heavy rain, but hard information such as from rain gages and river gages plays the predominant role. In fact, it is fair to say that generally such hard information plays the predominant role in today's flood forecasting system because of deficiencies in QPF. The importance of improved QPF can hardly be over-emphasized. Disaster prevention in the face of flood stages requires actions which are more effective the longer the lead time of the watch or warning. Accurate QPF could extend the lead time.

DATA COLLECTION

In addition to surface and upper air observations, forecasts of hurricane movement and intensity are based on observations by radar, reconnaissance aircraft, and satellites. Specialized data required for predicting floods and flash floods are obtained by precipitation and river gages, radar, and satellites.

Satellites

Information received from several environmental satellites was used in tracking and forecasting Hurricane Agnes from the storm's inception to its demise. These satellites are the geostationary Applications Technology Satellite, ATS-3, and the polar-orbiting satellites ESSA 8 (APT) and ESSA 9 (AVCS). Normally, one observation per day was available from ESSA 8 (about 1600Z) and from ESSA 9 (2200Z). The ATS and APT pictures were available at NHC in real time.

Nearly continuous viewing was provided by ATS-3 from about 1200Z through 2100Z. Because of the storm threat, the viewing period was extended to nearly 2200Z on 6 days (June 16, 17, 18, 20, 23, and 25) during the existence of Agnes and to nearly 0000Z on 3 days (June 19, 21, and 22). On June 22, the satellite operated until nearly 0100Z. The normal operating mode calls for the satellite camera to scan one full earth disc in about 24 minutes. The northern half can be scanned in half that time (12 minutes) when coverage of only Northern Hemisphere areas is required. This mode was used on 7 days (June 18, 19, 20, 21, 22, 23, and 25), after a series of about 10 full discs was received in support of Southern Hemisphere requirements.

Meteorologists at NHC and the National Environmental Satellite Service (NESS) Analysis Branch conferred frequently during the storm, exchanging information derived from the satellite data. When the storm entered WSFO Washington's area of responsibility, personal contact was made between NMC and the WSFO Washington meteorologists.

A system for classifying tropical disturbances based on satellite data is used when a disturbance is located over water. The maximum surface wind speed can be estimated by means of this system. A coded teletypewriter message (called Satellite Weather Bulletin) containing information derived from satellite pictures is transmitted once a day to field stations. Five such messages were sent concerning Hurricane Agnes when it was over the Gulf of Mexico—on June 14, 15, 16, 17, and 18. On June 18, the day before landfall, 65-knot winds were estimated from the satellite pictures. When the storm moved over land, satellite data continued to be useful in determining the extent of the most dense cloudiness and associated precipitation. Indications of ongoing intensification and weakening, and some idea of its motion, were inferred from satellite pictures.

The satellite information used during Hurricane Agnes came from all the spacecraft sensors available to NOAA at the time. These sensors use camera techniques for viewing only in the visible range. If the sensors planned for the future satellites had been available, monitoring of the storm by satellite during both day and night would have provided a constant and continuous watch over the track and intensity of Hurricane Agnes.

Radar

Weather radar is used to estimate precipitation rates by measuring the intensity of the reflected signal from precipitation particles.

The radar system used by NWS for flood and weather forecasting purposes is the WSR-57, which was designed in the 1950's. Flash flood warnings are issued when the observer or forecaster observes on the radar unusually heavy rain, or moderate rainfall over an extended period of time. These warnings are based on the judgment of the observer or forecaster and confirmd by rain gage observations.

Perhaps the most significant use of radar in flash flood forecasting during the passage of Agnes was by WSFO Washington. Based on intense returns received by the WSR-57 at WSMO Patuxent, WSFO Washington issued a flash flood warning for the Washington area and called for the evacuation of Four-Mile Run. Flash flooding did occur a few hours later, causing severe damage but no loss of life.

Radar systems in the areas affected by Agnes performed well throughout the period. Equipment outages were minimal, extra staffing was called in when needed, and the radar data were utilized extensively in tracking the storm center and to some extent monitoring the precipitation pattern. The radar reports were especially useful to NHC as Agnes approached the Florida coastline. Use of radar information in predicting floods and flash floods varied extensively throughout the system.

New techniques for presenting radar data have been developed recently. When these become operational, they can contribute to improvements in the flood forecasting system both in accuracy and reliability. The first system is a video integrator and processor (VIP), designed for use with the NWS WSR-57 radars to display contours of equal echo intensity on the radar precipitation map. This provides the operator and forecaster an immediate contoured map of the rainfall rates over an area of about 125 miles radius. Of the 17 WSR-57s in the storm area, only six stations had VIP available. Eventually, all stations will have VIP.

To automate the flood forecast procedure, a digitized radar data system (D/RADEX) is being developed and tested. D/RADEX will have a capability of recording rainfall rate and transmitting the data to a central computer where the cumulative rainfall by watershed area can be calculated. This end product will be useful for flood forecasting. An experimental D/RADEX system had been installed at the Buffalo WSR-57, but was not yet in operational use during the period under consideration. A network of four of these systems is undergoing operational tests in the Midwest severe storm area. With D/RADEX, the operator will still be a key link in flash flood warnings, since flash floods generally result from rapid developments in small areas.

River and Rainfall Reporting Networks

Prediction of river stages depends directly upon observations of areal rainfall and of current and past river stages. Reporting networks of about 5,000 gages supply this information daily and on a near-real-time basis. These are operated and maintained by the various River District Offices.

About 95 percent of the river gages in these networks are owned and operated by the U.S. Geological Survey or the U.S. Army Corps of Engineers, and are located by the owner agencies to serve their own missions rather than river forecasting. NWS has access to these gages either by telemetering devices or through citizen observers.

Rain gages are, for the most part, owned and located by NWS. Some of the NWS gages are located and operated by the Office of Hydrology, some are a part of the meteorological synoptic and hourly networks, while others are located and operated for climatological purposes. These are supplemented by gages observed by cooperative citizen observers. The location of gages depends on the availability of observers somewhere near the most desirable site and the availability of telephone service.

With only a few exceptions, data are transmitted by commercial telephone. A few gages are served by radio.

Observing networks, both river and rainfall, are invariably used by two or more agencies and the data relayed by a myriad of systems. In some instances, the citizen observer telephones data to two or three agencies. In others, the information is collected and relayed by one agency to the others. Cooperation among the user agencies, from funding to data sharing, is necessary.

The Agnes floods once again dramatized the weaknesses of the data collection network. In the case of river gages, the cooperative observer usually lives or works near the river. Not only does he have telephone lines vulnerable to flooding, but in serious floods he understandably is more concerned with saving his family and property than he is with reading the river gage. However, many cooperative observers continued observing and reporting at great personal inconvenience and risk throughout the Agnes flood episode. Rainfall observers, in many instances, had difficulty in reporting due to telephone failure.

At one time, all reporting river stations on the Schuylkill River in Pennsylvania were inoperative for one reason or another. Seven of the nine river gages on the James River were inundated. About 30 percent of the rainfall reporting network in the Harrisburg River District was not reporting owing to communications failures.

River forecasts continued to be generated despite missing (and sometimes conflicting) reports. The operations of the River Forecast Center were seriously hampered. Precious time was devoted to obtaining essential information, some of which was of doubtful quality. Forecasters were fully aware of the deficiencies of the available data and their effect on the accuracy and reliability of the forecasts. These forecasters had all worked long and hard under considerable pressure. Loss of reliable input data could only have the effect of further impairing their effectiveness. Rainfall accumulations and river stages were increasing at such a rate that the usual cycling (6-hour) of data collection and forecasting was inadequate.

The use of radar for precipitation determination is discussed in the radar section. However, coordinated effort between the radar program and the rainfall network program is required to improve precipitation reporting.

FLOOD AND FLASH FLOOD FORECASTS, WATCHES, AND WARNINGS

The forecasts, watches, and warnings issued by the field units of NOAA are based to a large extent upon guidance products issued by NMC and subsequently observed conditions. The guidance products and data-collection systems have been discussed in previous sections. This section will deal with the bulletins—especially the flood forecasts and flash flood watches and warnings—issued by the field units with emphasis on their timeliness, accuracy, and usefulness. A complete description of organizational responsibilities and definitions of the various types of bulletins are contained in appendix A. A compilation of all bulletins issued is published in *NOAA Technical Memorandum EDS NCC-1.*

The first action of the flood and flash flood warning system was the issuance by the WSFO Washington, D.C., Weather Service Forecast Office of a flash flood watch for parts of West Virginia. This watch was issued at 4:00 p.m. on June 19, while Agnes was still over Panama City, Fla. Flood watches and warnings were extended the next day to cover parts of Virginia. On Wednesday, June 21, as Hurricane Agnes deepened and began its movement up the east coast, a series of flash flood watches and warnings for New Jersey and eastern, central, and northwestern Pennsylvania was disseminated by all NWS offices in the area. At 6:00 p.m. that evening, a bulletin from WSFO Washington stated that flooding was expected to be near record levels on large streams in the Carolinas and Virginia Wednesday night and farther northeast on Thursday, June 22.

From June 21 through June 25, flash flood and flood watches and warnings were issued in profusion for specific localities throughout the five-State area of Virginia, West Virginia, Maryland, Pennsylvania, and Delaware. Figures 2, 3, and 4 show the areas where watches and warnings were in effect on June 21, 22, and 23.

Flash floods, by their nature, give very little time for warnings, and the warnings are primarily de-

Figure 2.—Watches and Warnings in effect at 10:30 a.m. EDT, June 21, 1972.

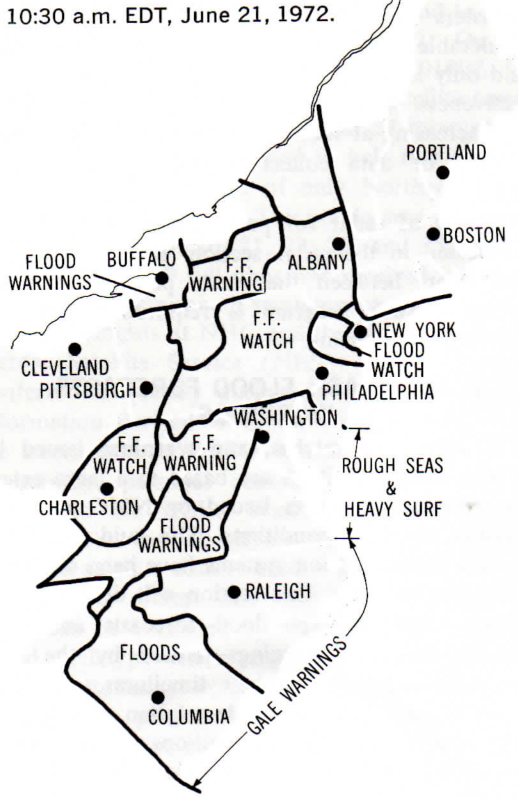
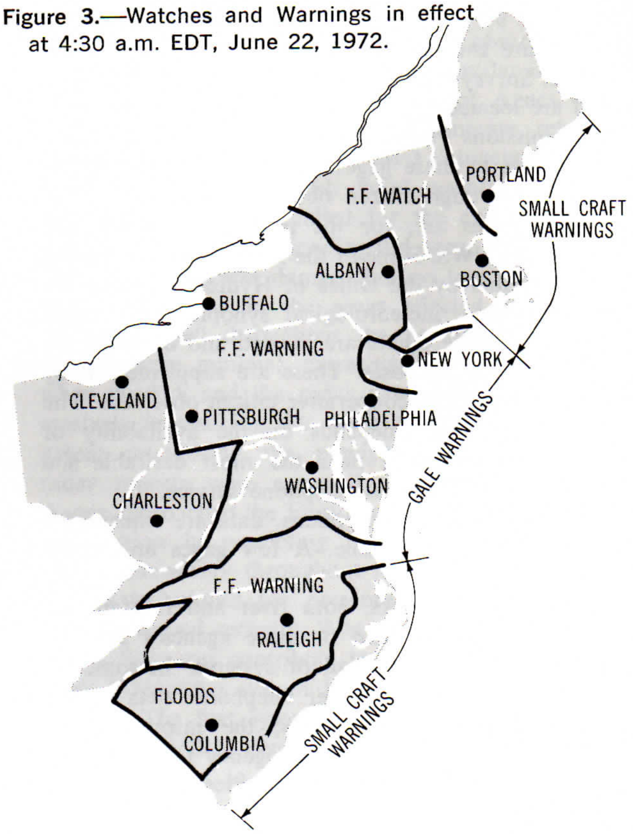


Figure 3.—Watches and Warnings in effect at 4:30 a.m. EDT, June 22, 1972.



signed to save lives. Consequently, the lead times for the flash flood warnings were short. Some communities on tributaries received no warnings or only those provided by alert local leaders.

The continuous heavy rains over entire river basins caused main stems to rise rapidly and, in effect, become somewhat like flash floods. This unusual condition contributed to reduced lead times in the river flood warnings.

Nevertheless, NWS bulletins triggered public disaster preparedness agencies into action throughout the five-State area. The coordinated actions of these agencies kept loss of life to a minimum. For example, close cooperation between the NWS River Forecast Center at Harrisburg and the Pennsylvania State Civil Defense office almost certainly saved many lives. The timely evacuation of 80,000 to 100,000 people from Wilkes-Barre and the surrounding area was an outstanding example of this teamwork.

DISSEMINATION OF FORECASTS, WATCHES, AND WARNINGS

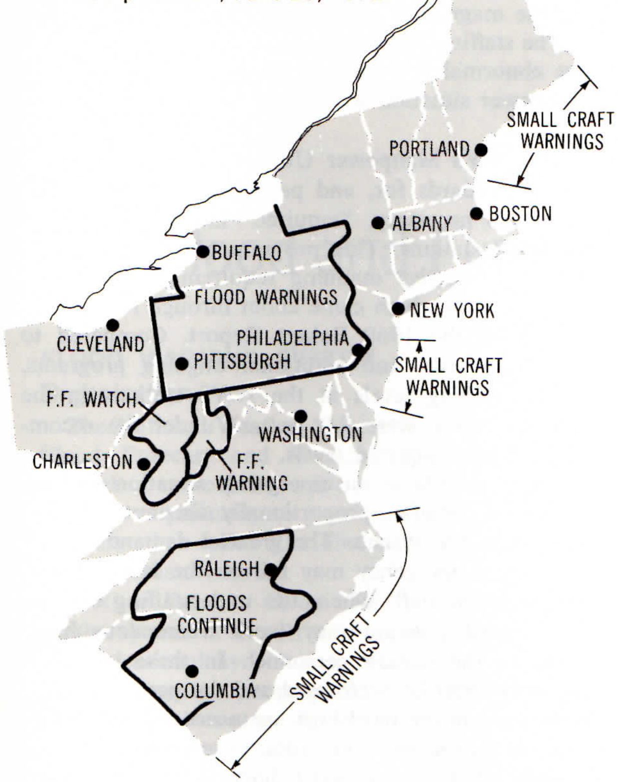
A major problem encountered throughout the affected area was NWS's inability to communicate warnings directly to the public in a timely and effective manner.

The primary method of disseminating NWS forecasts and warnings to the public is through the mass news media, such as radio and television. Radio and television stations acquire the information principally from the press wire services. The NOAA Weather Wire Service and telephone calls to radio/TV stations also are used to keep the media informed about latest developments, NOAA Weather Wire Service is a direct teletypewriter circuit from weather offices to subscribing news media and other interest groups requiring the latest information.

In addition, NWS uses automatic telephone answering devices, direct broadcasts on commercial radio stations, manually answered telephones, continuous VHF-FM radio broadcasts, and indirect channels such as State and community action agencies, to convey warnings to the public. Telephones, both automatic and manual, and direct radio broadcasts, both commercial and Government-owned, are the only real means of direct dissemination to the public.

During the east coast flood emergency, State action agencies were served by direct telephone calls from the weather offices and by the NOAA Weather Wire. Action agencies relayed NWS information to their community offices by internal teletypewriter

Figure 4.—Watches and Warnings in effect at 4:30 p.m. EDT, June 23, 1972.



circuits and/or telephone calls. Isolated delays were noted in the relay process.

A substantial number of timely warnings were transmitted on the NOAA Weather Wire Service, but delays occurred before the warnings were broadcast to the public. In the area affected by this disaster, NOAA Weather Wire is available on a statewide basis only in Pennsylvania, where the percentage of the media is very low and concentrated in the Philadelphia area. In the other affected states, the Weather Wire is limited to the cities having a weather office. Overall, less than 10 percent of the news media in the affected area had continuous access to the latest forecasts and warnings. Even where many stations subscribe to the NOAA Weather Wire, the Service does not appear to be the most effective means to disseminate warnings to the public. Delays occurred before the advisories were actually broadcast. In some cases, forecasts and bulletins were actually overlooked by the subscribing station. For example, when the power failed at Harrisburg, the WSO Williamsport transmitted Harrisburg's advisories and warnings on the Weather Wire. However, radio and television stations overlooked these data and were unaware that they originated at Harrisburg.

Press wire services gave "bulletin" status to most of the warnings. However, delays occurred between release of warnings by the NWS and their broadcast by the radio/TV stations. Time is required for retyping at the press wire office, transmission over the press circuits, receipt, and reading by the radio/TV announcer. Previous episodes have shown that delays exceeding 1 hour can occur between a release by NWS and eventual reading by radio/TV announcers. The public's radio/TV listening habits and broadcast schedules also kept many of them unaware of the situation until they heard the warnings during the late evening or early morning news broadcasts. Such delays are very critical in "short-fuse" events, such as flash floods.

Despite the built-in delays, radio and television stations did a good job of disseminating the forecasts and warnings during the Agnes episode.

The urgency of the situation required a substantial portion of the public to have direct access to flood information on an "on-demand" basis. This need can best be served by either telephone or continuous radio broadcasts. Within the primary flooded areas, only eight persons out of each 10,000 could be served by publicly listed, manually answered phones at NWS offices. One of the VHF-FM continuous weather broadcast sites is located at Washington, D.C. The tone-alert signal demuted special radio receivers in the Washington area to forewarn of flash flooding. Activation of this tone provided the District of Columbia's emergency headquarters with one of the initial warnings of the seriousness of the situation. Manual telephone calls placed by NWS offices to special interest groups caused numerous problems. Call-up lists are extensive, requiring significant times to complete. In some instances, they appear to exceed the NWS staff's ability to respond even under normal conditions. The use of these lists, although important in warning dissemination, drained manpower resources to such an extent that other important high-prority duties were in serious jeopardy. Many recipients of these calls received the warnings more than an hour after release.

PUBLIC RESPONSE

Public response varied widely, according to the urgency reflected by the mass news media, past experiences, wording of the releases, and the length of lead time. When radio/TV announcers conveyed a feeling of the seriousness of the situation (which was generally more intense as the event began), the public became more responsive. Wording such as that employed by WSO Richmond—"Prepare for severe flooding—Do You Remember the Camille Flooding of August 1969?"—prompted quick public awareness and response. Past experiences, generally related to the respondee's age, contributed to differences in response. Older persons, living in areas which experience occasional minor flooding, were prone to ". . . stand pat and stick it out," even if it meant moving to the upper floor of their homes. Younger people living in the same areas appeared to be more likely to move.

Public response was tempered somewhat by confusion and misunderstanding. Few people know the difference between watch and warning, and between flash floods and river floods. The watch/warning misunderstanding gave some the feeling that NWS was "crying wolf," when in fact watches had been issued to alert the populace to possible warnings. Confusion between flash floods and floods caused poor response to river flood warnings issued after flash flood waters began to recede.

Lack of knowledge by action agencies in several communities, or failure to translate warnings into community actions, as in Washington, D.C., caused problems. The inability of the local action agencies and news media to equate forecast stages with potential flood damage areas delayed public response.

Lack of community focal points and community preparedness plans was evident throughout the disaster zone.

FACILITIES AND STAFFING

Facilities

Inadequate heat and air conditioning are provided during nights, weekends, and holidays to NWS offices located in Federal Buildings. In addition, WSO and RFC Harrisburg experienced an extended electric power failure during the height of the episode. This affected the offices' operations and welfare of the staff. Sanitary, elevator, and lighting facilities were all inoperative.

Manpower

The Agnes emergency demanded especial effort from all concerned, and NWS personnel throughout the system met the challenge by responding with exceptional motivation and unselfish devotion to duty throughout the long grueling hours of the ordeal. The system reacted remarkably well, considering the magnitude of the emergency.

The staffing patterns along the path of Agnes were not abnormal compared with the prevailing overall manpower situation within the NWS (see Appendix C).

The NWS Manpower Utilization Staff has established standards for, and periodically evaluates and revises as necessary, "required" manning levels for all NWS stations. This program of defining objective and effective manning requirements is an ongoing activity which came about through recommendations of the 1969 Bohart Report. Compared to these standards, and additional ongoing programs, overall staffing levels at the NWS stations in the path of Agnes were 7.9 percent under the recommended and required levels.

The demands of an emergency situation such as Agnes are not often proportionally distributed among stations in the system. The greatest demand for action in an emergency may fall on the lesser station with a small staff, where the understaffing of only one needed position may work tremendous hardships on the station personnel. In these instances, the work must be performed and the personnel must endure whatever hardships are necessary to accomplish it. However, their endurance may be at the expense of peak personal efficiency from tired individuals who must also temporarily eliminate other important station functions because of the priority demands of the emergency. While large stations may frequently be better able than smaller stations to cope with the understanding of one or two positions during an emergency, their personnel also suffer a very similar fatigue problem when performing a key role in an exceptional emergency as great as Agnes.

NWS is currently developing several programs designed to improve manpower systems and utilization within the service. These innovations will help NWS handle more effectively such unusual emergencies as Agnes. These new programs will also require additional staffing over the next few years.

APPENDIX A.
The Flood and Flash Flood Warning System

FLOOD WARNING SYSTEM
Organization

The National Weather Service's (NWS) River and Flood Forecast and Warning Program functions through a two-echelon system of forecast offices. It is designed primarily to provide river stage and crest forecasts that follow the observable causative event by more than 4 hours.

a. *River Forecast Center (RFC).* The first echelon of the system is the River Forecast Center, staffed by professional hydrologists, where river and water supply forecasts are prepared. The RFC processes rainfall and river stage data in order to prepare river forecasts and warnings for primary points along the river system. Its products vary from crest forecasts a few hours in advance for small drainage areas to forecasts made days in advance for downstream points on large rivers. RFCs also provide guidance information on river and soil conditions to other NWS offices for use in preparing flash flood alerts, watches, and warnings. Figure A1 shows areas in the Eastern Region for which RFCs have been assigned responsibilities.

b. *River District Office (RDO).* The area served by RFC is divided into several districts. In each district, a Weather Service facility is designated as the RDO, the second echelon of the forecast organization. This office is directly responsible for the end product. The district offices maintain networks of observing stations that report river stages, precipitation amounts, and other parameters as required. These reports are collected and relayed to the RFCs. Forecasts prepared at the centers are then transmitted to the river districts for dissemination. Issuance of river forecasts and flood warnings to the general public, specialized users, and media such as newspapers, radio, and TV stations is one of the RDO's principal functions. When conditions warrant, RDOs may issue preliminary warnings before detailed forecasts have been prepared by the River Forecast Center. Figure A2 shows the areas of responsibility for RDOs in the Eastern Region.

Flood Forecast Products

In pursuing their responsibilities, RFCs and RDOs issue the following products:

a. *Flood Forecast Bulletin.* A flood bulletin, predicting specific stages at specific locations, is issued whenever flooding is imminent or existing. Flood Forecast Bulletins normally originate at a RFC, because the formulation of specific stage forecasts requires complex computations involving rainfall-runoff relations and/or river-routing techniques. Flood bulletins/statements are issued at periodic intervals as long as flooding exists, to keep the public informed.

b. *River Forecasts.* Operational river forecasts are prepared for specific points within a river system and are issued in terms of stage, volumetric flow, velocity of flow, or combinations of these. The time range contained in the forecast may vary from a few hours to several weeks.

c. *Headwater Statements.* Advisory or planning data on headwater conditions, such as basin rainfall amounts required to produce bankfull stages or cessation of flow are issued as "Headwater Statements." These statements prepared by the RFCs contain guidance material for use by the RDOs, to meet situations in which forecasts and warnings are not otherwise immediately available.

FLASH FLOOD WARNING SYSTEM
Introduction

NWS Operations Manual Chapter E-13 provides the national guidance and procedures for establishing and issuing: (a) flash flood alerts, (b) flash flood watches, and (c) flash flood warnings. This document provided for regional modification of these procedures where necessary. The following is taken from the Eastern Region Operations Manual Letter 70–30.

Flash Flood Watch Bulletin

a. *Objective.* The purpose of a Flash Flood Watch Bulletin is to *alert* the *public* and cooperating agencies to the fact that current and developing meteorological conditions are such that the area covered by

Figure A1.—River Forecast Center Hydrologic Service Areas.

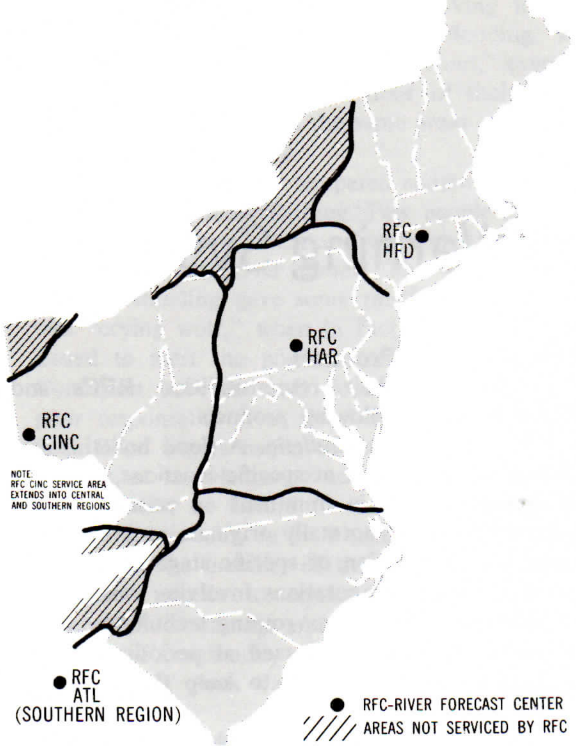
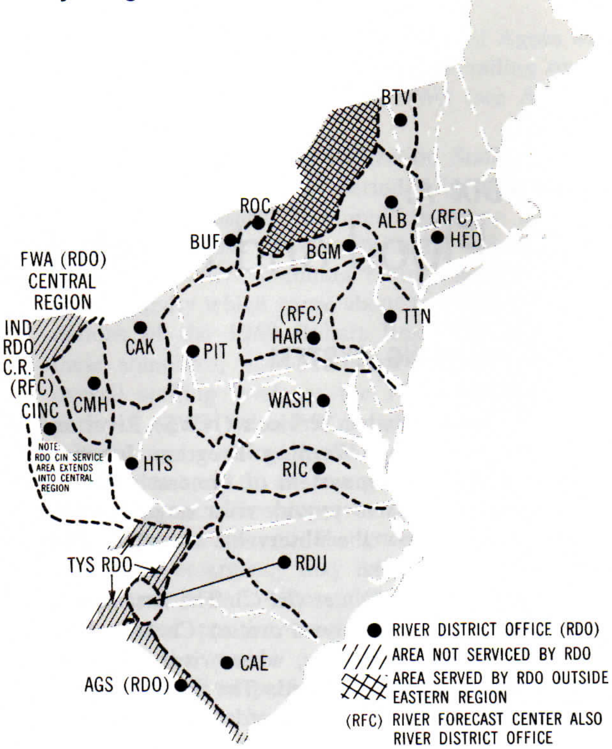


Figure A2.—River District Office Hydrologic Service Areas.



the watch is threatened by flash flooding of a damaging or dangerous magnitude.

b. *Rationale.* The earliest possible public alert to the likelihood of the development of serious or dangerous conditions is of prime importance. It will enable action agencies and individuals to *plan* for evasive or protective measures in the event that a Flash Flood Warning is issued or a flash flood occurs without further warning.

c. *Procedures.* Conditions that require a Flash Flood Watch Bulletin and responsibility for issuance of the Bulletin follow.

(1) A Flash Flood Watch Bulletin will be issued when:

(a) a combination of meteorological and antecedent conditions indicate a good probability (greater than 30 percent) that flash floods will develop in a designated area; or

(b) the sudden break up of an ice jam threatens persons and property immediately downstream.

A Flash Flood Watch may be issued whether or not it has been preceded by a Flash Flood Alert.

(2) Initiation of a Flash Flood Watch. RDOs are solely responsible for the issuance of a Flash Flood Watch Bulletin. Prior to the release of a Flash Flood Watch Bulletin, the RDO *will* consult with the WSFO(s) having responsibilities in the area to be covered by the Watch and with the RWC. In addition, if the RDO is supported by an RFC, that Center will also be consulted.

Any NWS facility may call the RDO's attention to a situation which it feels may warrant the issuance of a "Watch." However, it will remain the function and responsibility of the RDO to issue the Flash Flood Watch Bulletin.

RDOs are uniquely qualified for this responsibility inasmuch as they are the only NWS elements having (a) a good knowledge of existing and forecasted river conditions in their area, (b) up-to-date knowledge and understanding of antecedent conditions of soil and vegetation, (c) access to the very latest river and rainfall reports from substation networks, and (d) the procedures and equipment for effective dissemination of public river bulletins.

A Flash Flood Watch Bulletin will be issued at *any time* that, in the opinion of the RDO, the conditions described above exist. To be most effective, these bulletins should be issued before 4 p.m. local time if hazardous conditions are likely to develop within the following 18 hours.

d. *Content of the Flash Flood Watch Bulletin* *(see example).* The bulletin shall contain the following information:

- The geographical area covered by the bulletin. This may be described in terms of well-known river basins or in terms of sections or portions of states.
- The effective time of the bulletin. The time need not be expressed in terms of hours but wording such as "this evening and tonight" is quite acceptable.
- The extent of the hazardous condition expected, i.e., localized or widespread.
- The relative magnitude of the hazard, i.e., moderate or extreme. (Conditions indicating only light flooding do not warrant the issuance of a Flash Flood Watch.)
- The time of issuance and the originating RDO.
- The statement that further clarifying advisories or statements will be issued and the expected time of this issuance.

e. *Dissemination.* The RDO will make every effort to ensure that the public in the threatened area is informed. This will be done through the mass news media (radio, television, and wire services), action agencies (State and local police, Red Cross, Offices of Emergency Preparedness, Civil Defense, etc.), and by contact with responsible individuals in the area concerned (Flash Flood network personnel or substation observers).

Cooperating agencies such as the U.S. Army Corps of Engineers, U.S. Geological Survey, and State Water Resources agencies, shall also be informed.

All NWS facilities in the affected area and in adjacent or nearby areas will also be addresses of the Watch Bulletin as well as the experimental Regional Weather Center and the Hydrologic Services Division in NWS Headquarters. This will include Radar stations which are not in the "Watch" area but have coverage within the area.

Dissemination will be by telephone, NOAA Weather Wire (or local loops), or TWX to recipients external to NWS. Internal dissemination will be by RAWARC, IWX, TWX, or telephone.

f. *Cancellation of the Watch Bulletin.* The bulletin may be cancelled by the issuing office at any time that it becomes evident that the threat no longer exists. The WSFO(s) and the RWC will be consulted before cancellation. All addresses of the Watch Bulletin will be notified of its cancellation.

Flash Flood Warning Bulletin

a. *Objective.* The purpose of a Flash Flood Warning Bulletin is to *warn the public* and action agencies that flash flooding is in progress or is definitely imminent.

EXAMPLE: FLASH FLOOD WATCH STATEMENT

HSDC ER HYDRO RWC
ABE EWR and NYC
M1 Attn 141830Z

NOAA National Weather Service Trenton
1:30 PM EDT Tuesday April 14, 1970

Flash flood watch for central and northern New Jersey and eastern PA for this afternoon and evening.
The Washington DC and Atlantic City radars report an area of heavy to very heavy rainfall extending from eastern MD across southern DEL into southern NJ. This area is moving north northeastward. It is expected to pass across NJ and eastern PA this afternoon and may cause localized flooding. Persons living in normal low lying areas or areas subject to flash floods should remain alert and keep tuned to their radio or TV. An additional statement will be issued later this afternoon.

EXAMPLE: FLASH FLOOD WARNING

ALCKT M1 A A PITC 161645Z

NOAA National Weather Service WBFO Pittsburgh PA
10 AM EDT June 16 1970

Flash Flood Warning
Flash flooding is occurring at Greensburg PA, Ligonier PA, and Latrobe PA. Radar reports indicate that heavy thunderstorms and showers are still being observed in the Loyalhanna Creek drainage and are expected to continue throughout the morning.
Residents in Westmoreland County should remain alert to the possibilities of additional flash floods and further rises in the streams.

b. *Rationale.* NWS has the responsibility of *warning the public* of existing or imminent dangerous conditions so that persons in the affected area may take immediate action to avoid loss of life or property.

c. *Procedures.* Conditions that require a Flash Flood Warning Bulletin and responsibility for issuance of the Bulletin follow:

(1) A Flash Flood Warning Bulletin will be issued immediately (a) if flash flooding is reported or (b) if precipitation sufficient to cause flash flooding is reported.

(2) Initiation of a Flash Flood Warning Bulletin. Any NWS facility has the responsibility and authorization to issue a Flash Flood Warning Bulletin. The necessity for immediate action is so great under these conditions that any delay cannot be justified. However, responsible care should be taken to ensure that the reports of flooding or havy rainfall are not spurious.

d. *Content of the Flash Flood Warning Bulletin (see example).* Owing to the urgency and seriousness of flash floods, the initial warning bulletin need only contain the following:

- the location of the observed and reported flooding or heavy rainfall;
- the streams and rivers being affected, if known;
- the magnitude of the flooding, if known; and
- the location and movement of the flood producing storm, if known.

Follow up statements or advisories by the RDO(s) involved will clarify, to the extent possible, the nature, extent, and probable movement of the flood-producing storm. These subsequent statements or advisories should be the result of coordination with any of the several NWS facilities concerned.

e. *Dissemination.* Every effort will be made by the issuing office to warn persons in the area of immediate danger. This must be done by any means available. Police or Civil Defense personnel in the affected area should be notified either directly or through the State police or other action agencies.

Immediately *after* the initial warning has been given, the issuing office, if not an RDO, will notify the RDO having responsibility in the area covered by the warning. The RDO will then issue all subsequent statements and advisories concerning this event. All questions and requests for information will then be referred to the RDO.

The RDO, upon notification that a Warning has been issued in its area will notify affected WSFO(s), RDO(s), RFC(s), and the experimental Regional Weather Center of this action. In addition, the RDO will to the extent possible verify that the warning has reached the affected area and any additional threatened areas. Further warnings, as warranted, will be issued by the RDO.

APPENDIX B.

Winds During Hurricane Agnes

The accompanying charts (figs. B1 through B11) depict the position of Agnes and the areal extent of wind warnings given in advisories for Agnes at 12-hour intervals. (Winds are 1-minute average winds as reported in hourly observations. Gusts are peak winds observed within 10 minutes prior to the observations. Higher winds occurring between observations are quite likely.)

Gale warnings and a hurricane watch were issued from Dry Tortugas to Key West, Fla., at 6:00 p.m. EDT June 17, when Agnes was still near western Cuba. At noon on June 18, a hurricane watch was issued for the upper Florida coast from Cedar Key to Pensacola. At 6:00 p.m. on June 18, hurricane warnings were issued from St. Marks to Panama City (Fla.) Beaches. Highest winds of *85 mph were reported by NOAA reconnaissance aircraft* on June 18, while Agnes was about 275 miles south of Panama City. As Agnes approached the coast on June 19, a reconnaissance flight reported winds of 75 mph at a location 25 miles off Cape San Blas. Agnes crossed the coast near Cape San Blas, a short distance southeast of Panama City, during the late afternoon of June 19. The highest wind gust reported by a land station in this area was 55 mph at Apalachicola, Fla.

Once over land, winds diminished rapidly: e.g., June 19, 6 p.m. advisory, "winds estimated 55 mph in squalls;" June 20, 6 a.m. advisory, "highest winds estimated 35 mph;" and at noon on the 20th, "highest winds estimated at 25 mph." While the winds were no longer a significant feature of the public forecasts, gale and/or small craft warnings were continued in coastal areas.

On June 21, Agnes increased in intensity, and the winds were once again significant, especially in the coastal marine areas where gale warnings were in effect. With this intensification of Agnes, the bulletins issued to the public and news media on June 22 not only carried gale warnings, but also indicated winds of 45 mph with gusts to 60 mph to the immediate southwest of the storm center. The Chesapeake Bay Bridge Tunnel reported a maximum wind of NW 57 mph with gusts to 69 mph. Wallops Island reported a maximum wind of NW 45 mph with gusts to 64 mph.

As Agnes continued to move northward, the maximum winds tended to decrease. Storm warnings were issued for the lower Great Lakes, although minimal storm force winds were expected. The abnormally high lake levels combined with the winds to cause extensive shore front damage due to wave battery action.

After landfall on the coast of Florida, wind was not the dominant feature of this storm. However, an examination of the advisories and bulletins issued on this storm indicate that the public and coastal marine interests were well advised on wind conditions. Further, a comparison of forecast winds and actual maximum winds appears to be in reasonably good agreement.

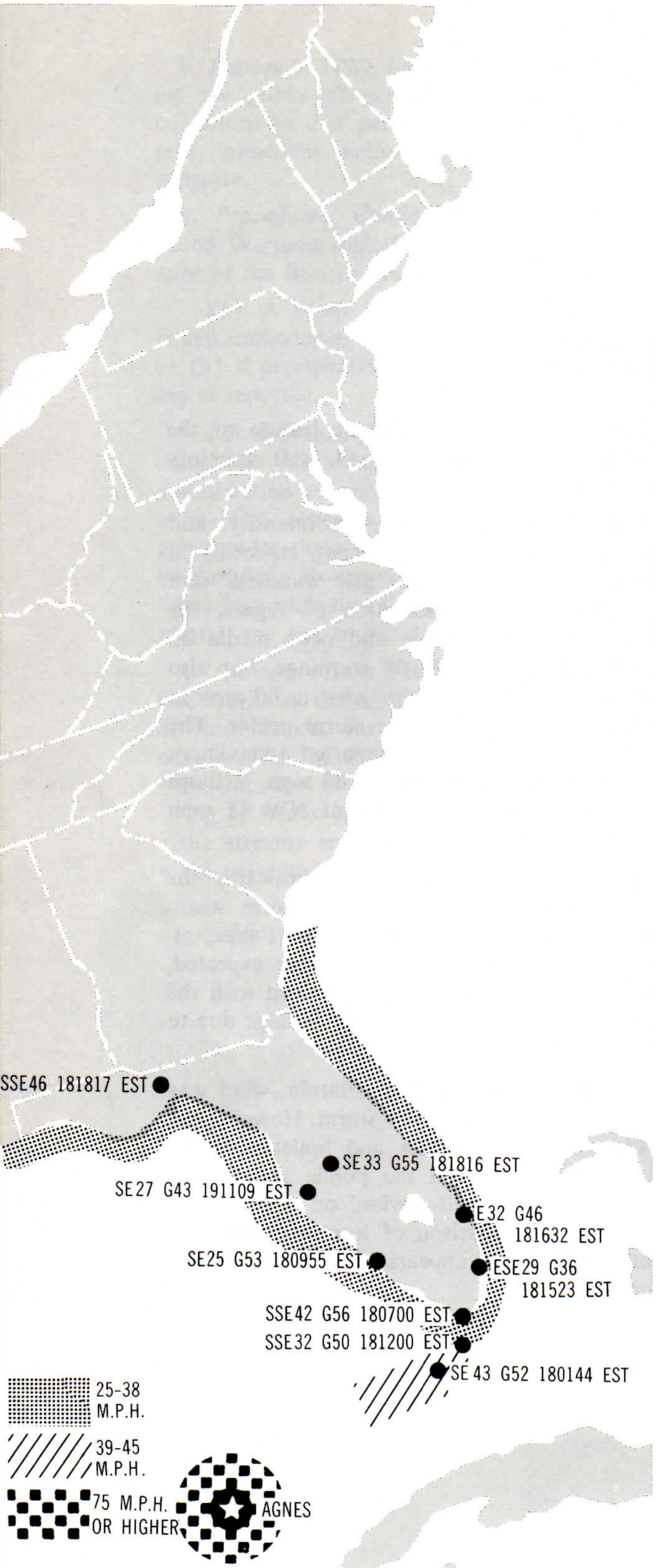


Figure B1.—Wind warnings includes in 6-a.m. advisory number 8, June 18, 1972.

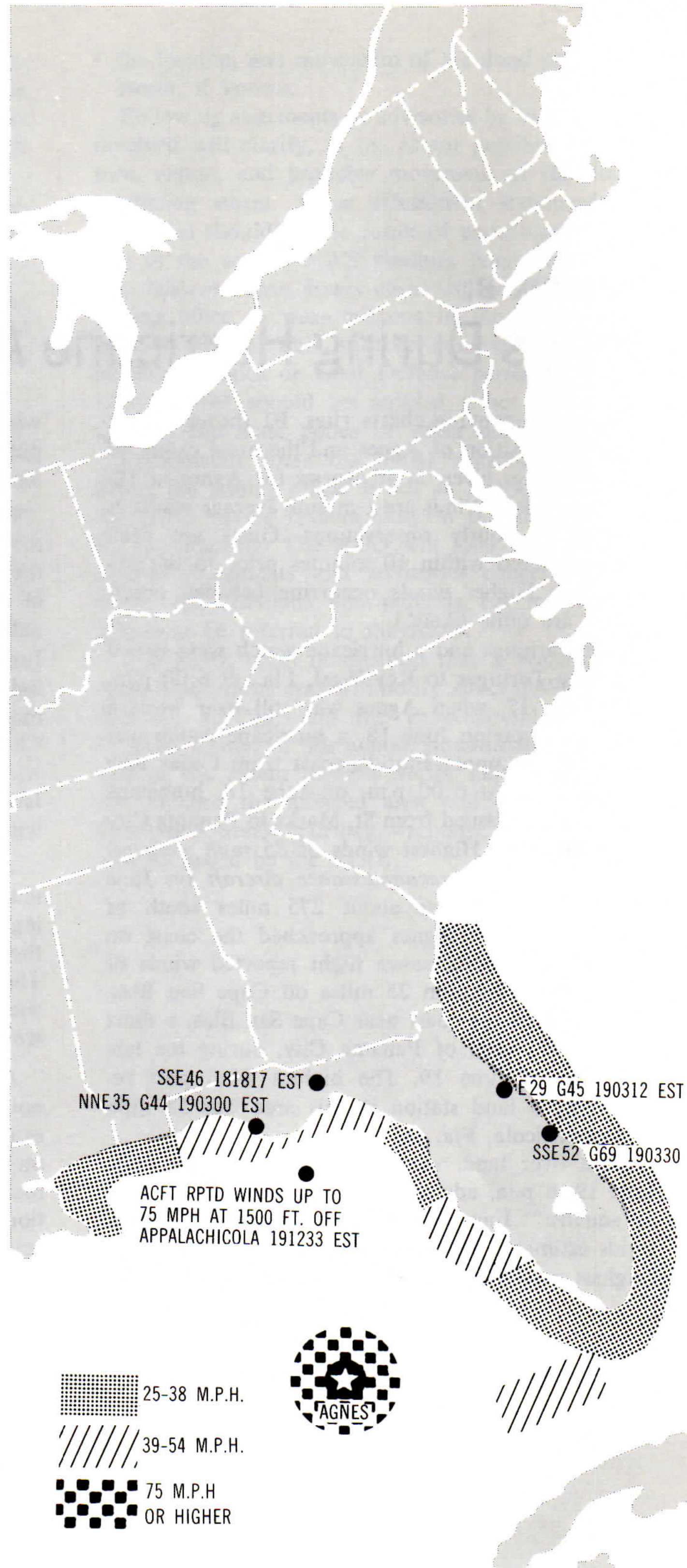


Figure B2.—Wind warnings included in 6-p.m. advisory number 10, June 18, 1972.

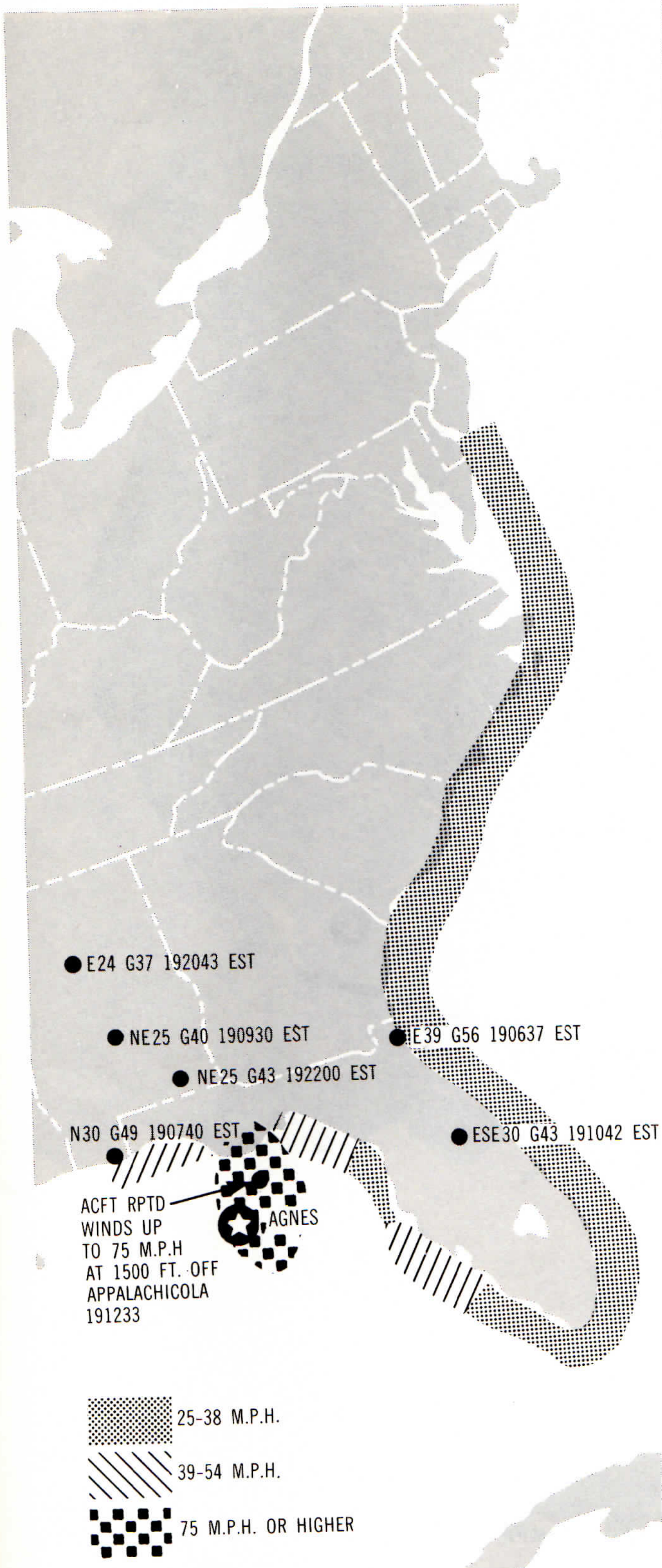


Figure B3.—Wind warnings included in 6-a.m. advisory number 12, June 19, 1972.

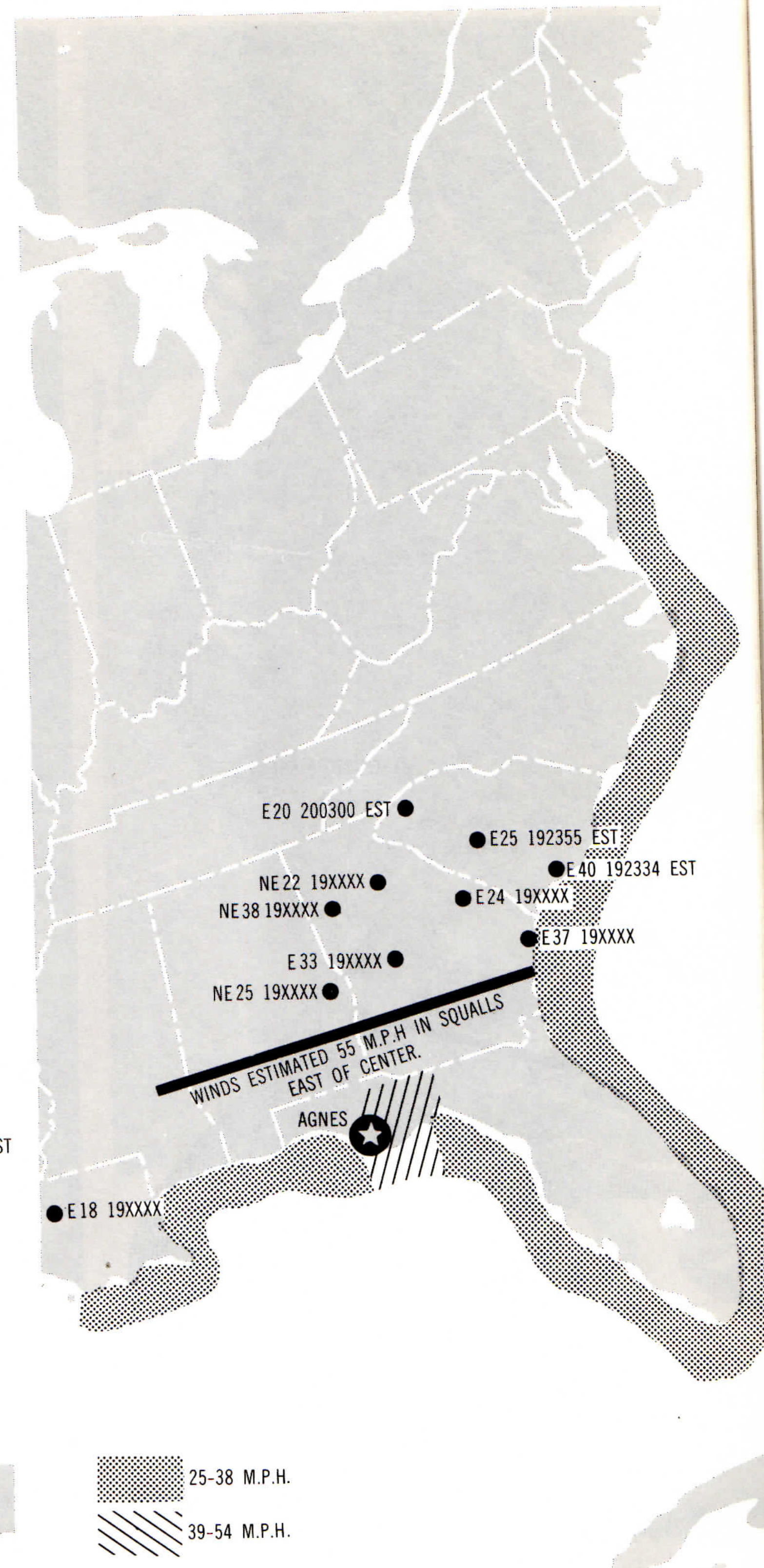


Figure B4.—Wind warnings included in 6-p.m. advisory number 14, June 19, 1972.

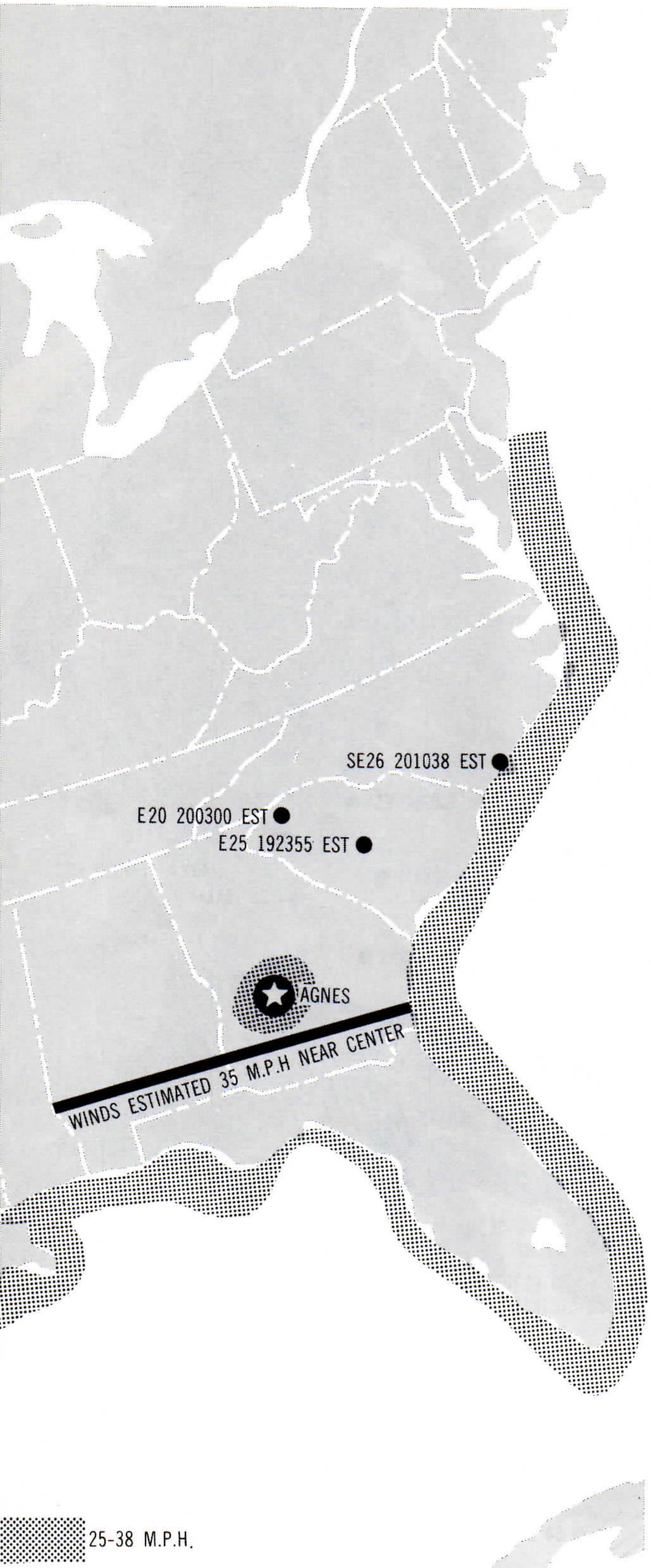


Figure B5.—Wind warnings included in 6-a.m. advisory number 16, June 20, 1972.

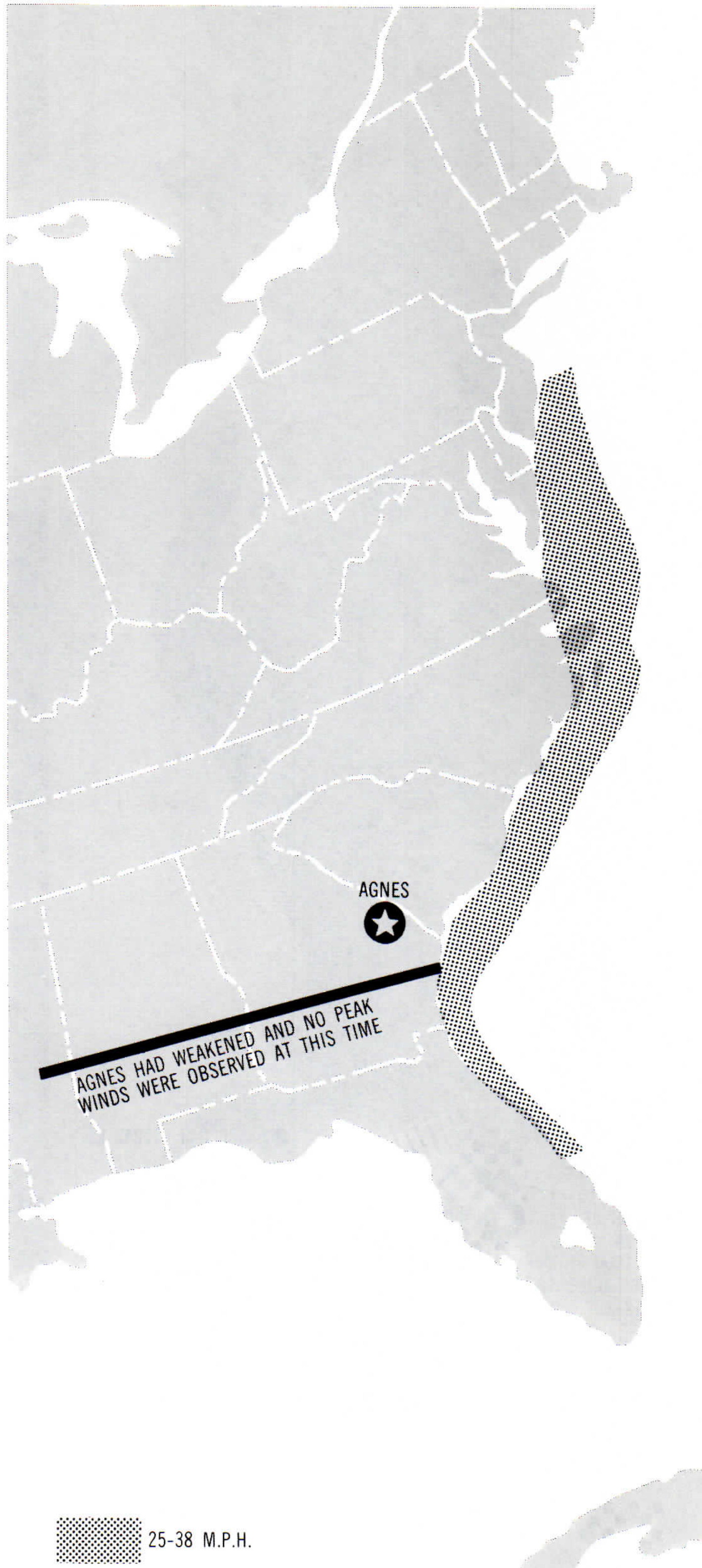


Figure B6.—Wind warnings included in 6-p.m. bulletin June 20, 1972.

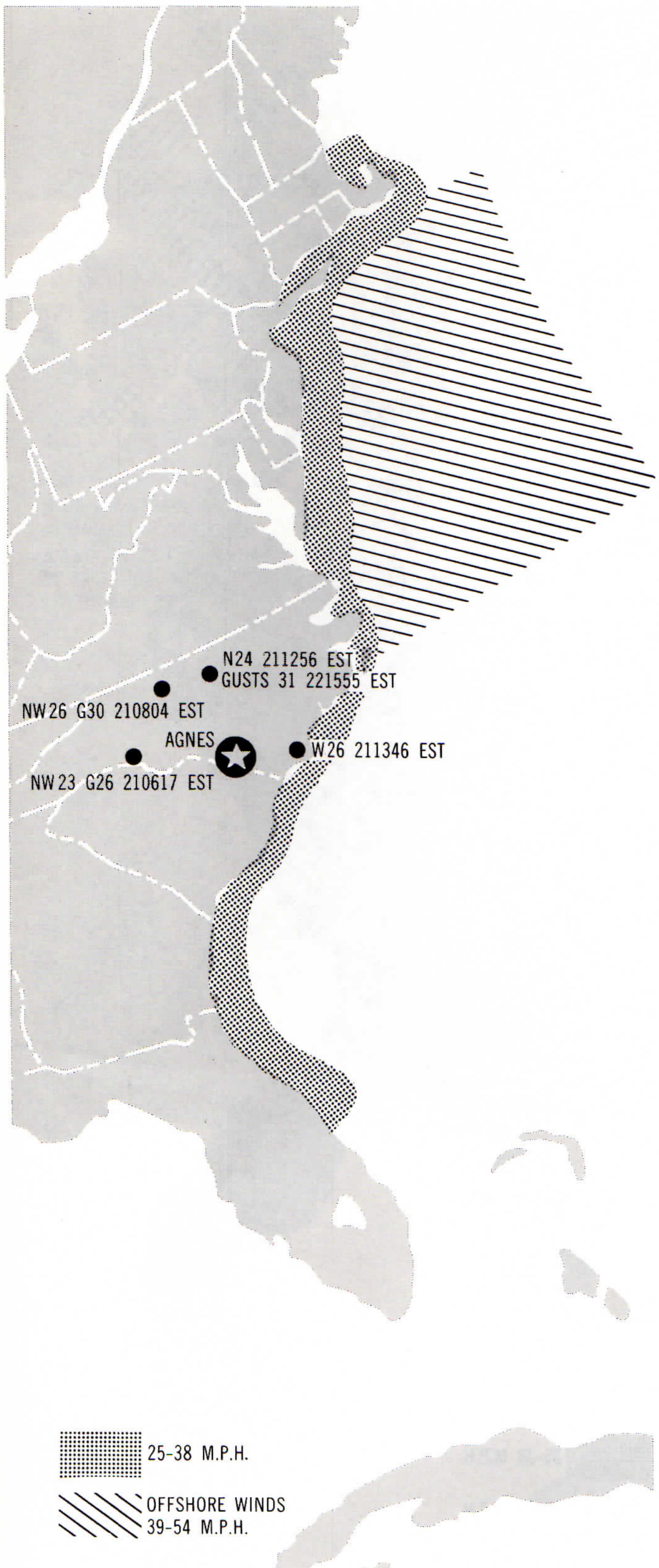


Figure B7.—Wind warnings included in 6-a.m. bulletin June 21, 1972.

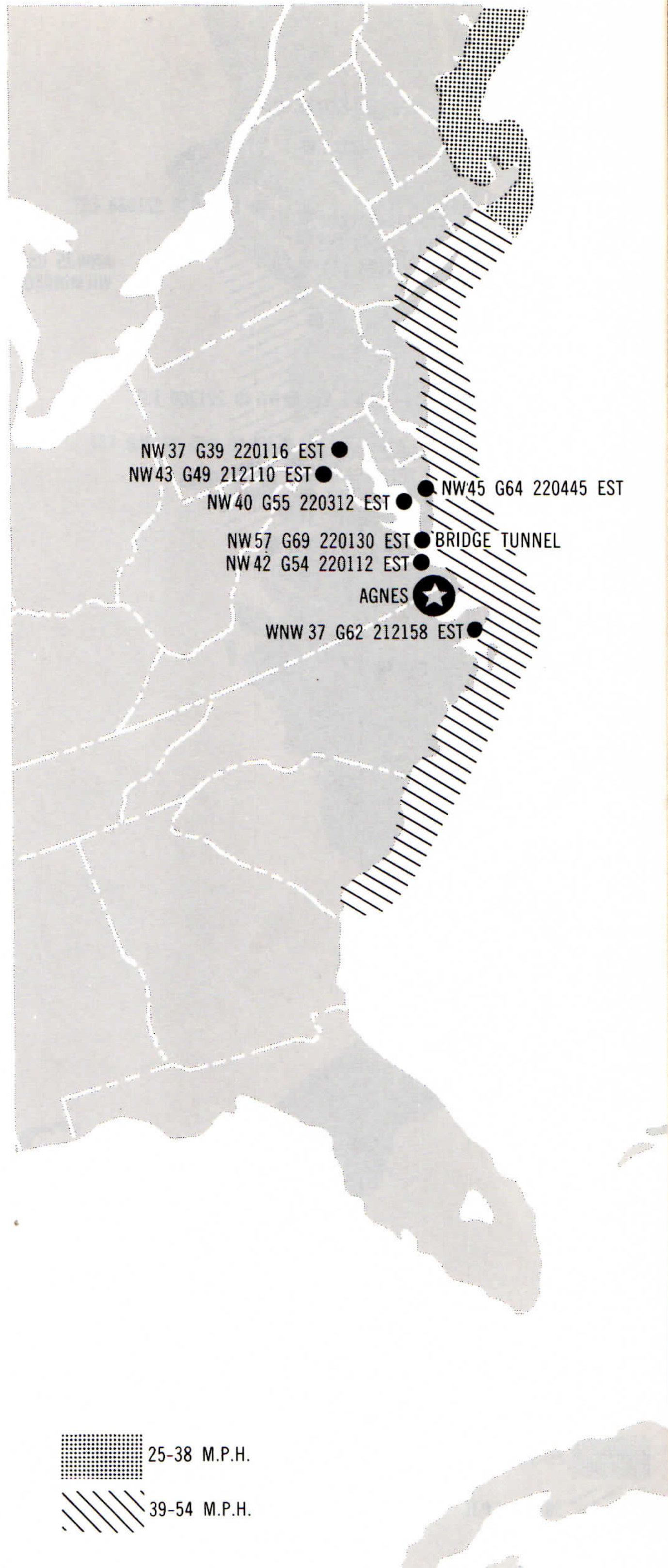


Figure B8.—Wind warnings included in 6-p.m. bulletin June 21, 1972.

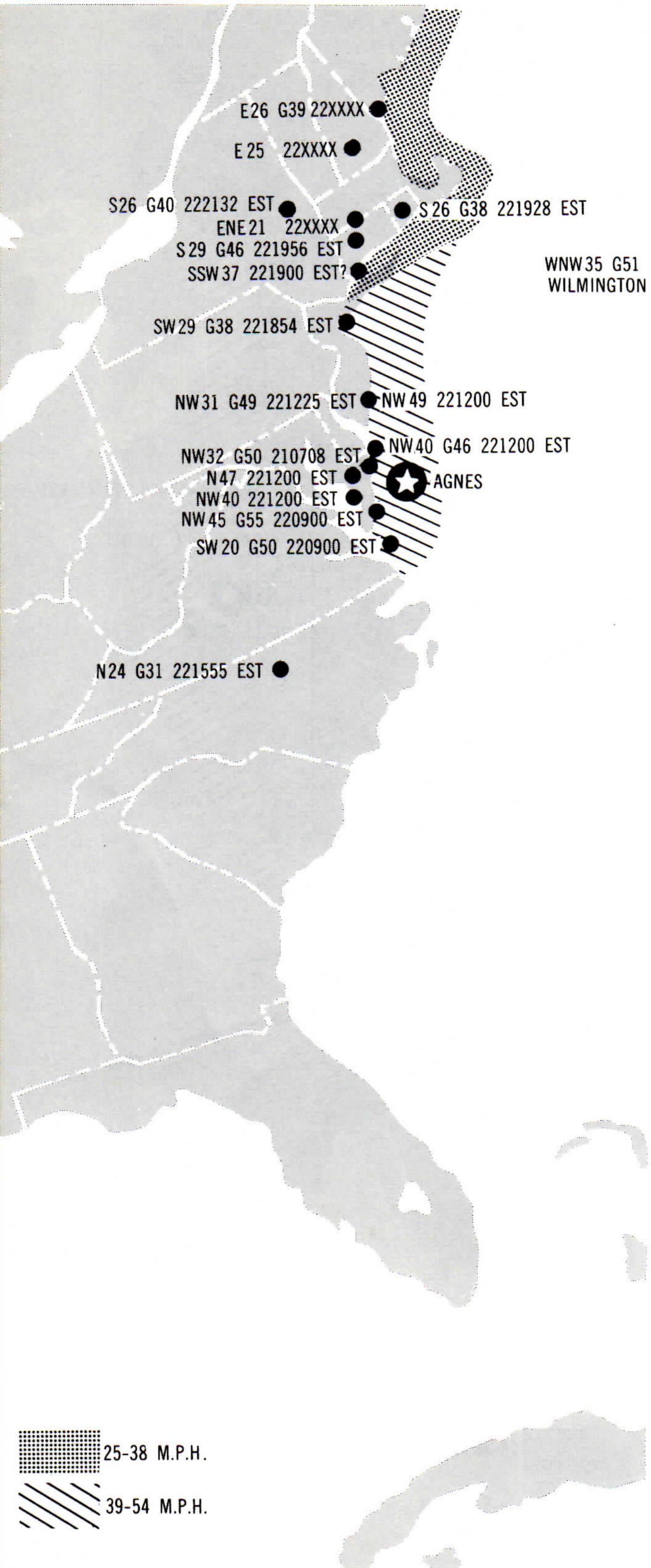


Figure B9.—Wind warnings included in 6-a.m. bulletin June 22, 1972.

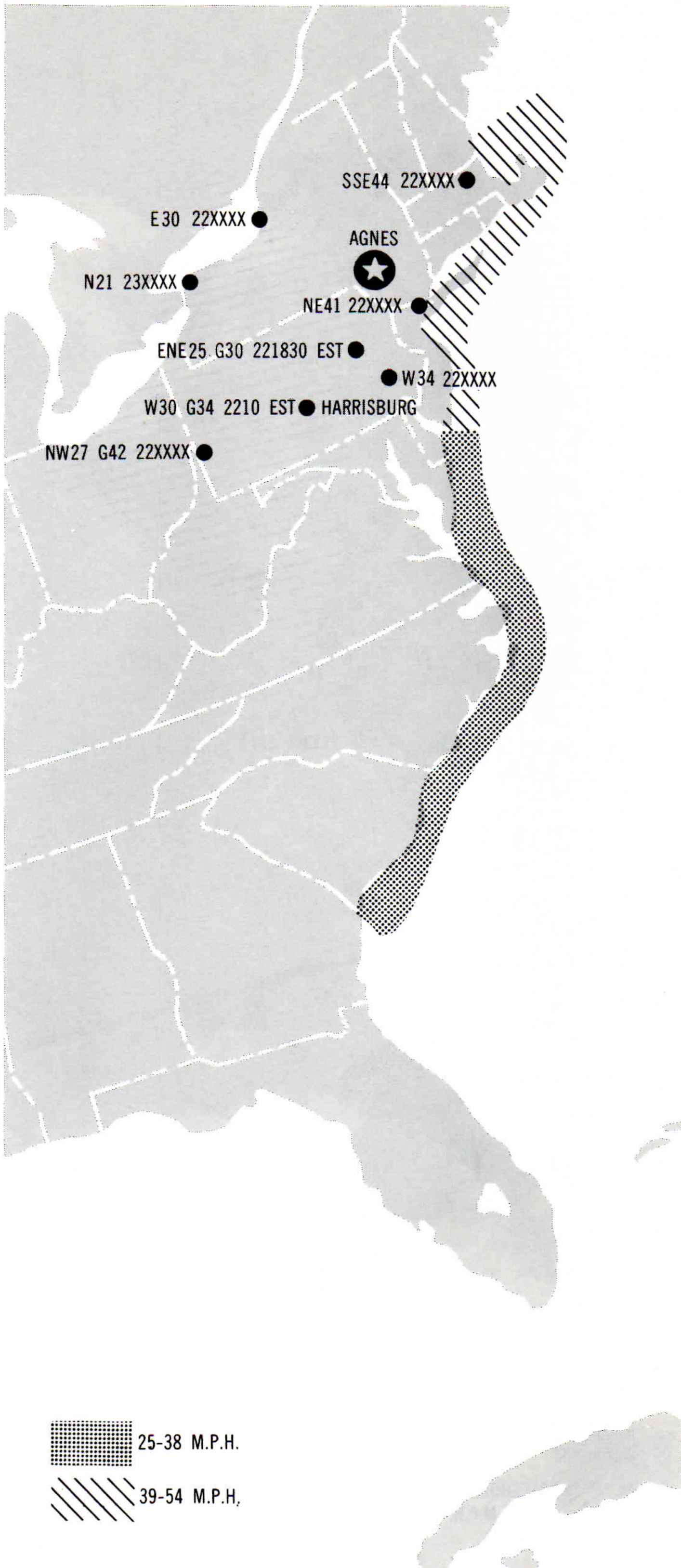


Figure B10.—Wind warnings included in 6-p.m. bulletin June 22, 1972.

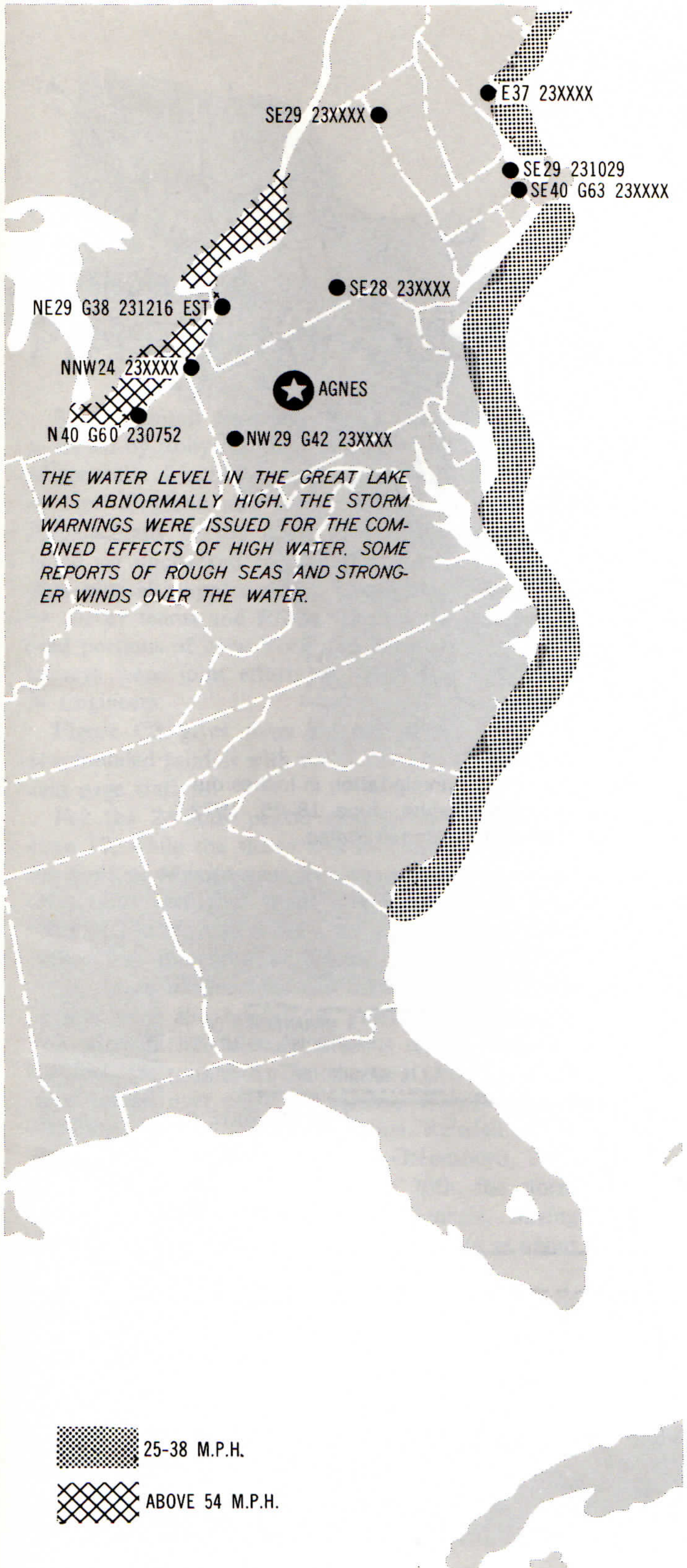


Figure B11.—Wind warnings included in 6-a.m. bulletin June 23, 1972.

Figure C1.—Total precipitation in inches during Hurricane Agnes, June 18–25, 1972, for southeastern United States.

Figure C2.—Total precipitation in inches during Hurricane Agnes, June 18–25, 1972, for northeastern United States.

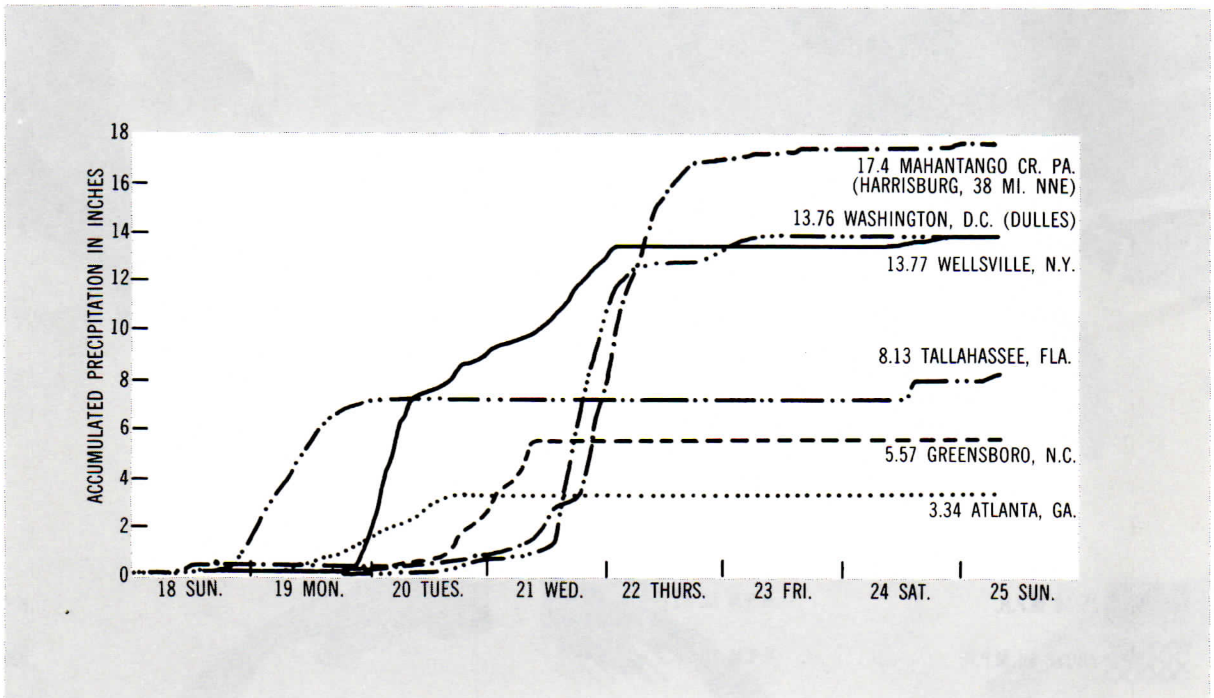


Figure C3.—Cumulative rainfall curves for selected locations during Hurricane Agnes, June 18–25, 1972.

APPENDIX C.

Precipitation During Hurricane Agnes

Storm rainfall for the period June 18–25, 1972, is shown by isohyetal maps (figs. C1 and C2). Rains of generally 4 inches or more extended from Florida to New England and from the east slopes of the Appalachians to the coast. This isohyetal map is based on unchecked regular reporting precipitation data plus all supplementary measurements gathered by survey teams and RDOs. The survey teams covered portions of New York and Pennsylvania. These surveys were joint efforts of NWS and the Corps of Engineers.

Figure C3 gives mass rainfall curves (plots of accumulated rainfall with time) for selected recorder rain gage stations.

For the 24-hour period ending the morning of June 19, while the storm was moving due north in the Gulf of Mexico near the longitude of Apalachicola, rains averaging about 6 inches occurred over most of Florida and south Georgia. A peak of 14.5 inches was measured at Titusville on the mid-Atlantic coast of Florida and 12.9 inches at High Springs near the border of Florida and Georgia. The curve for Tallahassee, Fla., is representative of the first day's rainfall. For the next day, June 19, rains spread over eastern Alabama, Georgia, South Carolina, and into southern Virginia. Rainfall curves are given for Atlanta, Ga., and Greensboro, N.C. (fig. C3). By the morning of the 20th, the storm center was located near central Georgia, having crossed the Florida coast near Panama City at about 5 p.m. on June 19.

For the 24-hour period ending on the morning of June 21, rains were widespread over much of the eastern seaboard from Georgia to New York. Largest values were near the eastern Appalachian slopes. Of particular importance were heavy rains of up to 6 inches near the central border line between New York and Pennsylvania. The curve for Wellsville, N.Y. (Fig. C3) shows this earlier rain burst.

For the next 24-hour period, ending the morning of June 22, heaviest amounts were measured along a north-south swath near central Pennsylvania. Figure C3 shows cumulative curves for Washington, D.C., and Harrisburg, Pa. (38 mi NNE). Washington was deluged with over 11 inches in less than 18 hours. Harrisburg (38 miles NNE) had over 13 inches in the 24-hour period ending near 6 p.m. on June 22. For the 24-hour period ending the morning of June 23, rainfalls occurred generally from Maryland northward. During this period, a second heavy burst occurred in central New York, as shown by the mass curve for Wellsville.

For the next 24-hour period, rains covered approximately the same region. The last day of the storm period (ending on June 25) few rainfalls were greater than half an inch and were generally from Pennsylvania northward.

Of particular interest is the region covered by the large eight-inch isohyet (36,000 sq. miles) centered in Pennsylvania, but extending into New York, Maryland, and Virginia. Average rainfall over this area for the storm period was close to 11 inches. About 9 inches fell in 48 hours, and 6 inches in 24 hours.

Rainfall within the 14-inch isohyet in Pennsylvania, covering about 3,000 sq. miles, averaged over 15 inches; almost 11 inches of this fell in 24 hours.

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