Service Assessment

Hurricane Floyd Floods of September 1999

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Cover: Hurricane Floyd Floods of September 1999. Aerial view of Grifton, North Carolina, with flooding from the Neuse River. (Photograph courtesy of the U.S. Army Corps of Engineers.)

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June 2000

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

National Oceanic and Atmospheric Administration
D. James Baker, Administrator

National Weather Service
John J. Kelly, Jr., Assistant Administrator

Preface

Hurricane Floyd impacted the U.S. East Coast from September 14 to 17, 1999. Torrential rains caused major river and flash flooding from the Carolinas to New England. In some areas, particularly North Carolina, the magnitude of the flooding was unprecedented and lasted through much of October. There were 56 deaths in the United States directly attributed to Floyd—the deadliest hurricane in more than a quarter of a century. Flood damage estimates range from $4.5 billion to over $6 billion.

Due to the magnitude of the flooding, a Service Assessment Team was assembled to examine the flood-related aspects of warning services provided by the National Weather Service (NWS) offices to citizens and public officials of the areas affected. Service assessments are critical to the ongoing efforts of the NWS to improve the quality and timeliness of our warning services. Findings and recommendations resulting from this review ensure NWS forecast techniques, products and services will continue to improve.

John J. Kelly, Jr.
Assistant Administrator
for Weather Services

June 2000

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Service Assessment Team

This Service Assessment Team was activated on September 30, 1999. All team members traveled to Eastern Region Headquarters in Bohemia, New York, for an overview briefing on October 5. The team then divided into groups, spending the rest of the week visiting NWS offices and customers in the northeast United States and the National Centers for Environmental Prediction (NCEP). The team reassembled the week of October 18, visiting with NWS offices and customers in the Southeast. After completion of the field work, the team continued to gather and review information before preparing the final version of this Service Assessment.

The team was comprised of the following individuals:

Steven Thomas	Team Leader, Meteorologist in Charge, Weather Forecast Office (WFO) St. Louis, Missouri
Harold Opitz	Hydrologist in Charge, Northwest River Forecast Center, Portland, Oregon
Julia Dian-Reed	Service Hydrologist, WFO Wilmington, Ohio
James Noel	Hydrometeorological Analysis and Support (HAS) Forecaster, Ohio River Forecast Center, Wilmington, Ohio
James Butch	Warning Coordination Meteorologist (WCM), WFO Jackson, Mississippi
John Leslie	National Oceanic and Atmospheric Administration (NOAA)/NWS Public Affairs Officer, Silver Spring, Maryland
Mark DeMaria	Regional and Mesoscale Meteorology Team Leader, National Environmental Satellite, Data and Information Service (NESDIS)/ Cooperative Institute for Research in the Atmosphere, Fort Collins, Colorado
Jasmin Riad	Social/Community Psychologist, Disaster Research Center, University of Delaware

The team would like to thank those people with the following entities who took time to talk to team members. Valuable information was gathered during these interviews.

NWS Offices

WFO Brookhaven, NY
WFO Mt. Holly, NJ
WFO Wakefield, VA
WFO Morehead City, NC
WFO State College, PA
WFO Sterling, VA
WFO Raleigh, NC
WFO Wilmington, NC
Northeast River Forecast Center (NERFC), Taunton, MA
Middle Atlantic River Forecast Center (MARFC), State College, PA
Southeast River Forecast Center (SERFC), Peachtree City, GA
NWS Eastern Region Headquarters, Bohemia, NY
NWS Headquarters, Silver Spring, MD
Tropical Prediction Center (TPC), Miami, FL
Hydrometeorological Prediction Center (HPC), Camp Springs, MD
Climate Prediction Center (CPC), Camp Springs, MD
Marine Prediction Center (MPC), Camp Springs, MD
NESDIS Satellite Analysis Branch, Camp Springs, MD

State Emergency Managers

New York State Emergency Management Agency
North Carolina State Emergency Management Agency
Virginia Department of Emergency Services

County Emergency Managers

Somerset County, NJ
Nash County, NC
Craven County, NC
Hertford County, NC
Georgetown County, SC
Bucks County, PA
Edgecombe County, NC
New Hanover County, NC
Wayne County, NC
Horry County, SC

City Emergency Managers

New York, NY
Paterson, NJ
Newport News, VA
Paramus, NJ
Franklin, VA

Other City Officials

West Paterson, NJ
Lincoln Park, NJ, Police
Totowa, NJ, Fire Department

Federal Officials
Federal Emergency Management Agency (FEMA) Region II, New York, NY
U.S. Geological Survey (USGS), West Trenton, NJ
USGS, Raleigh, NC

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Media
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WECT-TV, Wilmington, NC
WAAV-TV, Wilmington, NC
WNCT-TV, Greenville, NC
WCTI-TV, New Bern, NC

Other valuable contributors include:

Glenn Austin — Acting Chief, Hydrologic Operations Division, Office of Hydrology, NWS Headquarters, Silver Spring, Maryland

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Larry Wenzel — Hydrometeorological Technician, Office of Hydrology, NWS Headquarters, Silver Spring, Maryland

William Lerner — Meteorologist, Office of Meteorology, NWS Headquarters, Silver Spring, Maryland

Linda Kremkau — Technical Editor, Office of Meteorology, NWS Headquarters, Silver Spring, Maryland

Service Assessment Summary

Overview

Hurricane Floyd impacted the East Coast of the United States from September 14 to 17, 1999. Torrential rains fell from the Carolinas to New England, resulting in major river and urban flooding. There were 56 deaths in the United States directly attributed to Floyd, and flood damage estimates range from $4.5 billion to more than $6 billion. Due to the magnitude of flooding, a Service Assessment Team was assembled to examine the flood-related aspects of warning services provided by the NWS. The hurricane path resulted in the evacuation of nearly 3 million people from coastal areas of Florida, Georgia, and the Carolinas. An assessment of the evacuation effort is provided in a Federal Emergency Management Agency (FEMA) and U.S. Army Corps of Engineers (USACE) publication titled "Hurricane Evacuation Study Program: Status Report on Lessons Learned." It is available from FEMA Region IV.

Numerous NWS offices were involved in the forecasting and delivery of advanced warnings for the threats from Floyd. These include WFOs along and near the coast and three River Forecast Centers (RFCs). National Centers that played a major role include the Tropical Prediction Center (TPC) and Hydrometeorological Prediction Center (HPC) of the National Centers for Environmental Prediction (NCEP). Overall, NWS offices performed in an outstanding manner in providing high-quality warning and forecast services to the impacted areas.

The Southeast River Forecast Center (SERFC) in Peachtree City, Georgia; the Middle Atlantic River Forecast Center (MARFC) in State College, Pennsylvania; and the Northeast River Forecast Center (NERFC) in Taunton, Massachusetts, recognized the potential for severe flooding several days in advance. Several of the NWS field offices noted the excellent services provided by the RFCs. The three RFCs issued a total of 252 river forecast guidance products to WFOs during the flood.

The SERFC was very proactive in relaying information to the user community. Daily conference calls were initiated to the USACE, USGS, FEMA Hurricane Liaison Team, and Divisions of Emergency Management in Virginia, North Carolina and South Carolina. In an attempt to focus additional attention on the major inland flood threat, the SERFC contacted Cable News Network (CNN) and The Weather Channel. An SERFC hydrologist was detailed to Conway, South Carolina, where he worked with city officials to help determine the flood crest and consequences of the severe flooding.

WFOs issued a total of 300 Flood Warnings and Flood Statements during Floyd. Every WFO impacted by Floyd issued either a Special Weather Statement or Flood Potential Statement, highlighting the high flood danger 30 to 48 hours before flooding began. A total of 532 Flash

Flood Warnings were issued by 13 WFOs for areas from northeast South Carolina through New England. Verification of these warnings indicated a much higher level of accuracy than normal.

On September 16-17, WFO Wakefield, Virginia, lost all phone service. WFOs Morehead City, North Carolina, and Sterling, Virginia, are commended for their extra efforts to provide quality warning and forecast services for the Wakefield area during this period of service backup.

The WFOs performed admirably during Hurricane Floyd. For example, the WFO Wakefield staff spent hours navigating around closed or flooded roads trying to report to work. A staff member of WFO Morehead City traveled about 60 miles to the Greenville forecast point to manually take river observations. This employee traveled back and forth several days to take readings, having to avoid numerous flooded highways.

All WFOs made numerous advance "heads up" calls to emergency officials from 2 to 5 days before rainfall from Floyd began. As the events of Floyd unfolded, WFOs continued to conduct once- or twice-a-day conference calls with state and county officials.

Emergency Management and Media Response

Emergency management officials in all WFO service areas commended the WFOs on their outstanding coordination efforts before and during Floyd. Officials stressed how they appreciated the "person-to-person service" provided. They were pleased to know if they had questions about NWS products or wanted specific detail, their questions were answered quickly and courteously. Emergency officials were unanimous in their praise of WFO/RFC use of conference calls to provide advance notice and continual updates of information.

Emergency officials found that flood forecasts that provided river forecast crest comparisons were very helpful. Providing examples of how severe the flooding would be compared to another historic flood crest gave them better insight for planning emergency operations.

All WFOs received compliments from emergency management officials for their actions during this event. An example of how well NWS services were received came from the Emergency Management Coordinator for the City of Newport News, Virginia.

> *"As I stated during the last meeting, the Wakefield office without a doubt saved lives in the City of Newport News during the Hurricane Floyd response. With the timely forecast for heavy rains, we were able to position jon boats at each of the fire stations. These boats were used to rescue 1100 people from flooded apartments and homes. This is the kind of teamwork and help we have come to rely on and appreciate during the work of emergencies affecting the City. Please express our appreciation for a job well done to your fellow weather staff. You should be very proud knowing you did help save the lives of our citizens."*

The NWS received favorable marks by media whose job it was to broadcast and translate crucial NWS products. Leading up to Floyd's landfall in North Carolina, the national media highlighted the intensity of Hurricane Floyd's winds and size, often describing it as just as powerful as Hurricane Andrew, but three times larger. This may have delayed focusing attention from the threat of high winds and storm surge along the coast to the threat of severe inland flooding. Many people evacuated because of the hurricane, but thousands more had to be rescued from their homes and cars as flood waters rose.

Before Hurricane Floyd made landfall, NWS Eastern Region Public Affairs issued a press release on September 15, 1999. The release stressed the dangers from flooding hundreds of miles inland and was printed in numerous newspapers.

Local media made effective use of products issued by WFOs as Hurricane Floyd neared the coast. The Governor of North Carolina was on statewide television the morning of September 16, after Hurricane Floyd had passed, warning everyone that devastating flooding still lay ahead.

Public Response

Of the 56 deaths from Hurricane Floyd, 48 were due to drowning in inland flooding. Of those, more than half occurred when vehicles were either driven into high water or were swept away by rapidly rising waters. Aggressive preparedness efforts by NWS offices prior to Floyd continued to stress the dangers of inland flooding from hurricanes and the life-threatening consequences of driving into flood waters. Although the loss of life was high due to the record flooding, especially in North Carolina, emergency officials indicated NWS preparedness initiatives prevented an even greater loss of life.

Tropical Summary

Floyd's origin can be traced to a tropical wave that emerged from western Africa on September 2, 1999. Tropical Depression Eight formed September 7 about 1000 miles east of the Lesser Antilles (Figure 1). The system was upgraded to Tropical Storm Floyd on September 8. Floyd became a hurricane at 8 a.m. Eastern Daylight Time (EDT)[1] on September 10 (see Appendix A). Early on September 12, Floyd turned west and began a major strengthening episode. The peak intensity of Floyd, 156 miles per hour (mph) maximum wind and 27.20 inches surface pressure, occurred on September 13. This was at the top end of Category 4 intensity on the Saffir-Simpson Hurricane Scale (Appendix B).

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[1] All times listed in this Service Assessment are EDT.

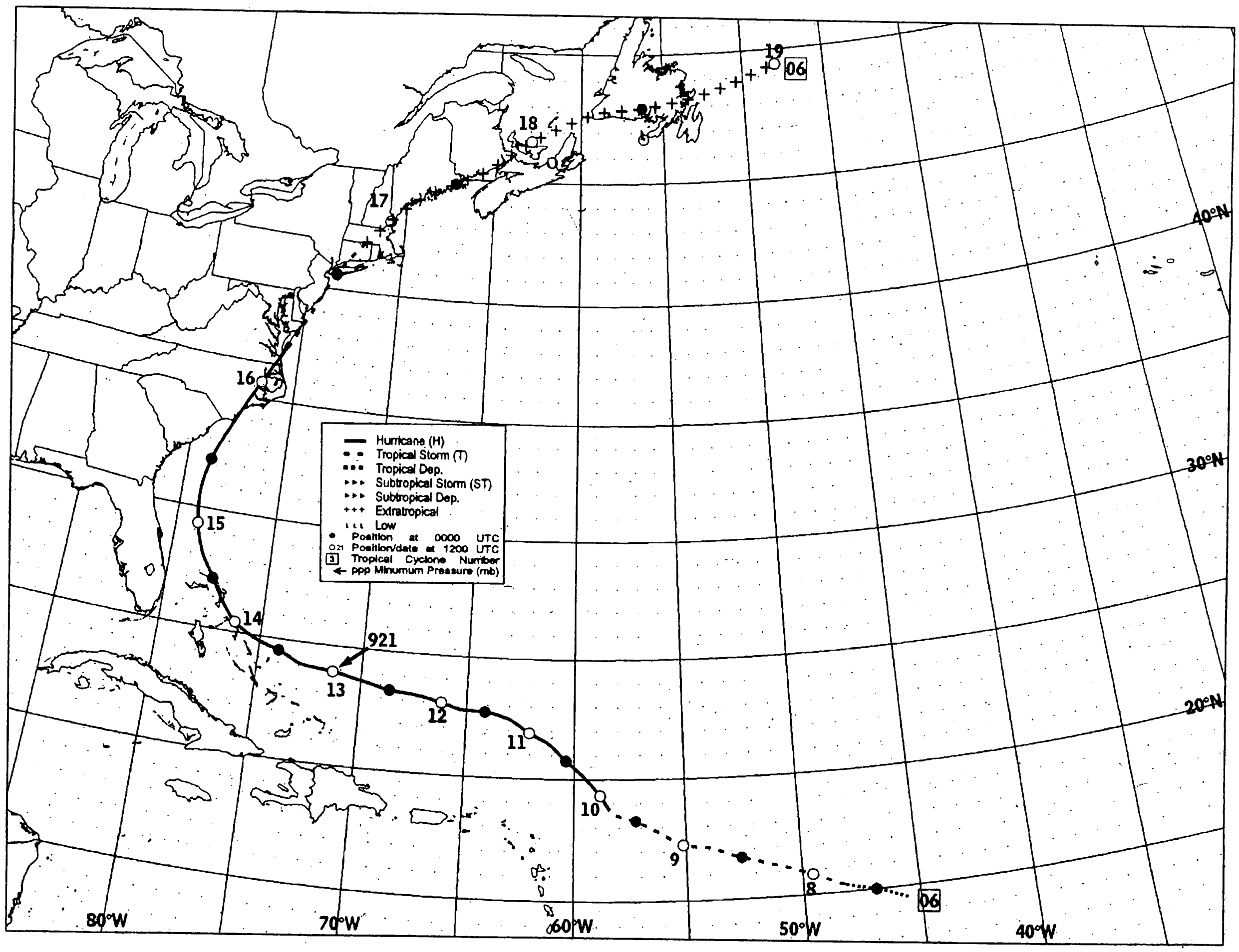


Figure 1. Track of Hurricane Floyd, September 7-17, 1999.

Floyd came withing 110 miles of Cape Canaveral as it paralleled the Florida coast on September 15. Floyd then moved slightly east of north and increased in forward speed, coming ashore near Cape Fear, North Carolina, at 2:30 a.m. on September 16. At the time of landfall, Floyd was a Category 2 hurricane with maximum winds of 104 mph. Floyd continued to accelerate north-northeast after landfall. Its center passed over extreme eastern North Carolina and over Norfolk, Virginia. Floyd then weakened to a tropical storm and moved swiftly along the coasts of the Delmarva Peninsula and New Jersey, reaching Long Island by 8 p.m. September 16. The system was extratropical by the time it reached the coast of Maine at 8 a.m. September 17.

Sustained tropical storm force winds and gusts close to hurricane strength were recorded at many locations from the Florida Keys to New York. Sustained winds of 96 mph with gusts to 122 mph were measured by a University of Oklahoma portable anemometer (10-meter height) near Topsail Beach, North Carolina, around 3 a.m. on September 16. Storm surge values as high as 10 feet were reported along the North Carolina coast.

Heavy Rains and Flooding

Much of Floyd's impact was due to extreme rainfall (Figure 2). Although Floyd was moving quickly, its large circulation interacted with a pre-existing frontal zone extending from central North Carolina through the mid-Atlantic states. This caused the heaviest rainfall to fall along and left of Floyd's track. Rainfall totals of 4 to 12 inches were common from northeast South Carolina through eastern North Carolina, eastern Virginia, eastern Maryland, Delaware, eastern Pennsylvania, New Jersey, eastern New York into the Northeast. Within this region, two areas of extreme rainfall occurred with totals as high as 15 to 20 inches recorded in portions of eastern North Carolina and southeast Virginia. At Wilmington, North Carolina, the storm total of 19.06 inches included a 24-hour record of 15.06 inches. In Yorktown, Virginia, the storm total was 18.13 inches. The second region of extreme rainfall totaled 10 to 14 inches in parts of Maryland, Delaware, New Jersey, southeast Pennsylvania and southeast New York. A new record was set in Philadelphia for most rain on a calendar day—6.63 inches.

This heavy rainfall caused widespread flooding and flash flooding from northeast South Carolina to southern New England. The flooding in North Carolina was the most damaging in the State's history. Some rivers in eastern North Carolina were already in flood due to 5 to 10 inches of rainfall from Hurricane Dennis (Figure 3) occurring about a week prior to Floyd. The extreme rainfall produced by Floyd across the Carolinas and Virginia caused widespread flooding on larger rivers and tributaries as well as flash flooding on smaller streams and creeks.

Nine record floods occurred on rivers in North Carolina and one in Virginia (see Appendix C). Farther north across the remainder of the mid-Atlantic states and into parts of the Northeast, rainfall and faster-responding streams and rivers produced serious flash and urban flooding. This was especially the case in the major metropolitan areas of Philadelphia and New York City.

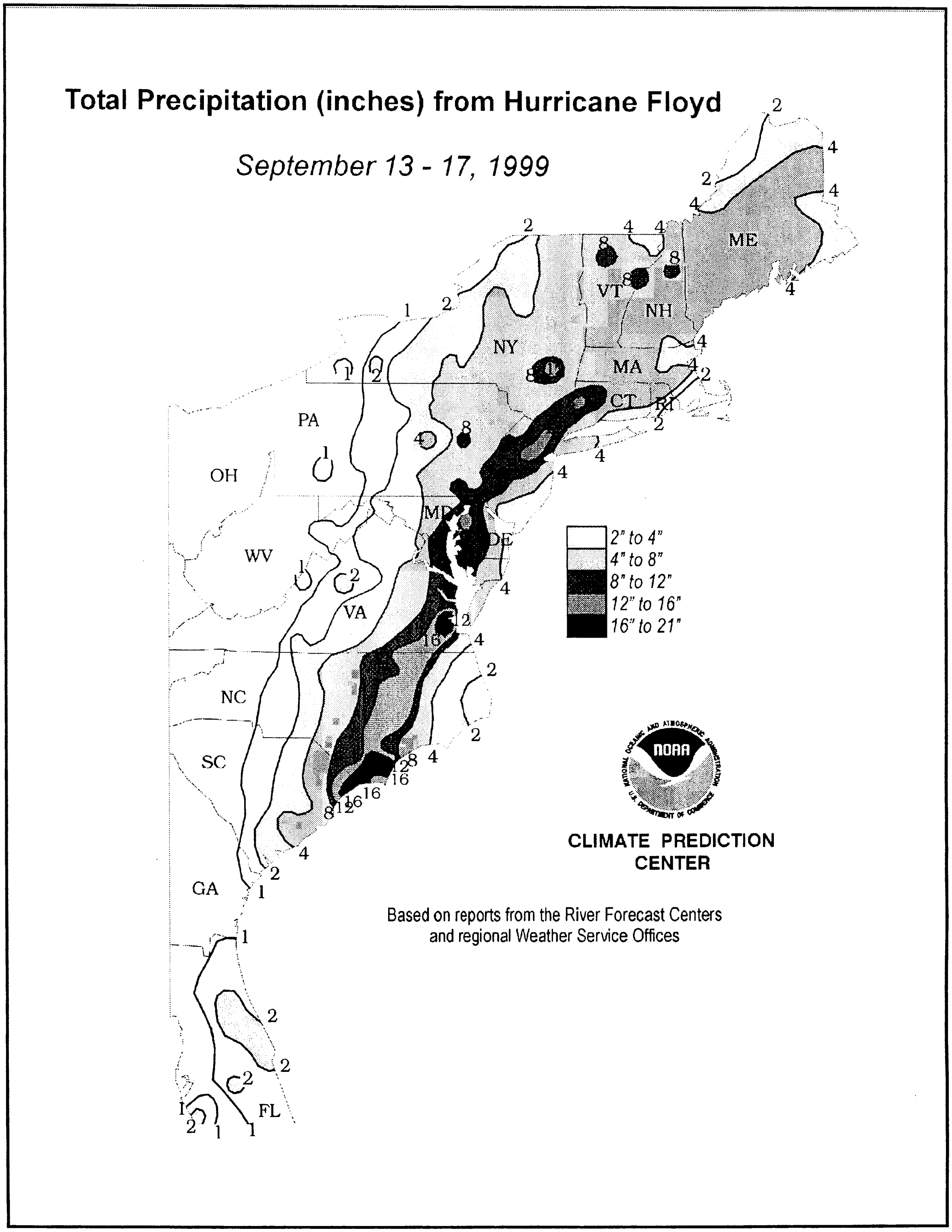


Figure 2. Total Precipitation (inches) from Hurricane Floyd, September 13-17, 1999.

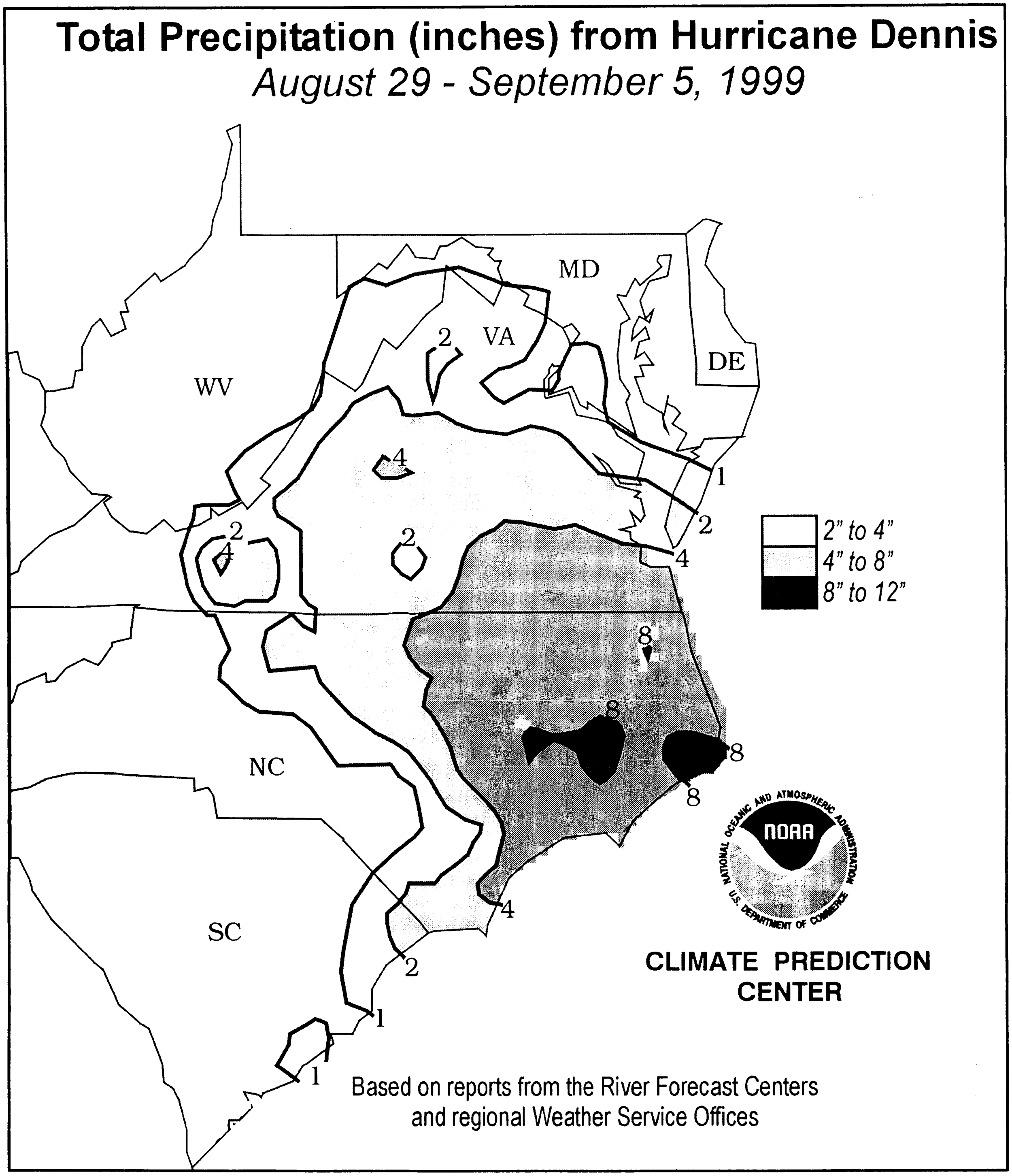


Figure 3. Total Precipitation (inches) from Hurricane Dennis, August 29-September 5, 1999.

Record river flooding occurred in parts of New Jersey and southeast Pennsylvania with six record floods in New Jersey and two in Pennsylvania.

In the SERFC area of responsibility, record flooding occurred in the Cape Fear, Chowan, Neuse, Pee Dee, Tar, and Waccamaw River Basins. There were ten record floods at SERFC forecast points. Hardest hit were the Tar and Neuse River Basins. New record floods were recorded at Louisburg, Rocky Mount, Enfield, Tarboro, and Greenville, North Carolina, in the Tar River Basin, with greater than a 500-year flood occurring at Tarboro, Rocky Mount, and Enfield. In the Neuse River Basin, new record floods occurred at Clayton, Goldsboro, and Kinston, North Carolina. Two additional forecast points observed record floods—Chinquapin, North Carolina, in the Cape Fear River Basin, and Sebrell, Virginia, in the Chowan River Basin.

Farther north in the MARFC area of responsibility, major to record flooding occurred in the Raritan, Passaic, Delaware, Schuylkill and Christina River Basins. There were nine record floods at MARFC forecast points. Hardest hit was the Raritan River Basin in north-central New Jersey. Record floods were recorded at Bound Brook, Manville, and near Raritan along the Raritan River. In addition, new record floods occurred at Blackwells Mills, New Jersey, along the Millstone River and at Lodi, New Jersey, along the Saddle River. In southeast Pennsylvania, a record flood occurred in the Lower Delaware River Basin at Chadds Ford along Brandywine Creek.

Major flooding in the NERFC area was confined to the Schoharie Creek River Basin in Prattsville, New York. The river crested near 18 feet, short of the record flood of 19.4 feet. Elsewhere, minor to moderate flooding occurred along some NERFC forecast points in New York, Connecticut, New Hampshire, and Maine. Even though rainfall was in the 4- to 12-inch range across the Northeast, the prolonged drought prior to Floyd helped lessen the flooding. Reservoirs were very low and able to store water. This was not the case farther south as prior rains in late August and early September had already begun lifting reservoir levels.

Casualty and Damage Summary

There were 57 deaths directly attributed to Floyd—56 in the United States and one in Grand Bahama Island (see Appendix D). The death toll by state is as follows.

North Carolina	35
Pennsylvania	6
New Jersey	6
Virginia	3
Delaware	2
New York	2
Connecticut	1
Vermont	1

Of the 56 deaths, 48 were due to drowning in inland, freshwater flooding. Vehicle-related deaths accounted for 55 percent of casualties, and of these, about 80 percent were male. Floyd was the deadliest hurricane in the United States since Agnes of 1972.

Damage estimates as a result of Floyd range from $4.5 billion to over $6 billion. Portions of ten states were declared major disaster areas, from Florida north to Connecticut. Whole towns were under water; roads flooded, including portions of Interstate highways; bridges washed out; dams failed; livestock drowned; water treatment plants failed and water supplies were cut off.

North Carolina alone had damage over $3 billion, with over 7000 homes destroyed, 56,000 homes damaged, 1500 people rescued from flooded areas, and more than 500,000 customers without electricity.

Flooding along the Tar River, Princeville, North Carolina. (Photograph courtesy of U.S. Army Corps of Engineers.)

Warning and Forecast Performance

River Forecast Centers

The NWS includes 13 RFCs. The function of these centers is to produce timely hydrologic daily and flood forecasts. During Hurricane Floyd, three centers were impacted: SERFC, MARFC, and NERFC.

SERFC, MARFC, and NERFC performed admirably and are commended for their efforts throughout the event. The RFCs recognized the potential for severe flooding early on. Upon notification of the potential for a major hurricane event, the RFCs took appropriate and well-timed preparedness actions before and during the storm. Several of the NWS field offices interviewed during the flood assessment noted the excellent services provided by the RFCs. Normal operation at these centers is 16 hours a day. However, all three impacted centers went to 24-hour hydrologic and HAS operations prior to the arrival of Floyd.

On Tuesday, September 14, SERFC and MARFC issued contingency forecasts prior to the arrival of Hurricane Floyd based on 9 inches of forecast rainfall. This information was coordinated internally via telephone and fax to impacted WFOs and communicated with many emergency managers. These forecasts indicated the risk of major to record flooding if that amount of rainfall were to occur. SERFC indicated in North Carolina and southeast Virginia the flood potential from Floyd could be "similar to or greater than Hurricane Fran in 1996."

RFCs issued timely river forecasts through the River Forecast (RVF) product. The accuracy of these forecasts increased as flood crests approached. A total of 252 river forecasts were issued during the flood by the three affected RFCs. These forecasts were issued daily and were updated every 6 hours or when needed. The initial flood warnings were low and were raised with the ingest of observed rainfall and higher Quantitative Precipitation Forecasts (QPF). Official forecasts provided lead times of several hours to a few days prior to the onset of flooding, depending on the response times of rivers. Lead times of up to several days were achieved on river crest forecasts. In addition, hydrologists at all RFCs coordinated closely with WFOs and local officials.

QPF for 24-hour durations was generated throughout the event by WFOs and RFC HAS staff and used in river forecasts. QPF beyond 24 hours is not normally included in forecasts due to uncertainties in the storm tracks and locations of heavy rainfall. NERFC requested 48-hour QPF from WFOs prior to the arrival of Floyd. The QPF from WFOs and RFCs was comparable to HPC guidance. The NERFC and associated WFOs improved the QPF on September 15 by changing the forecast of the heaviest rainfall to areas farther inland.

All three RFCs were involved in the coordination of hydrologic services prior to and during the event. Coordination was performed between the HAS/Hydrologist staff and WFOs using three methods: Hydrometeorological Discussions (HMDs), Hydrometeorological Coordination Messages (HCMs), and the telephone. The HMD product was used to coordinate hydrometeorological issues (i.e., QPF changes, rainfall estimates, flood threats). Numerous and timely HMDs were issued by all RFCs. The HCM product was used to coordinate RFC operational issues (i.e., extended hours of operations, requests for additional or extended QPFs, and Flash Flood Guidance [FFG] issues). These products were issued in a timely manner. Telephone calls were also initiated by both the WFOs and HAS to coordinate QPF changes. The improvement in outreach by the MARFC during this event was especially noted by one WFO. All three RFCs participated in the Hurricane Hotline calls between the WFOs and TPC and in several FEMA conference calls. This coordination ensured effective communication on QPF and river forecasts for the effected areas.

The SERFC was very proactive in relaying information to the internal and external user community before and during the warning period. Some examples include:

- Daily conference calls, initiated by the SERFC, brought together WFOs, USACE, USGS, FEMA Hurricane Liaison Team, and Divisions of Emergency Management in Virginia, North Carolina and South Carolina.

- In an attempt to focus additional attention on the major inland flood threat, the SERFC contacted CNN, The Weather Channel, NWS Eastern and Southern Region Headquarters, and the FEMA Hurricane Liaison Team.

- The SERFC provided flood potential information through the use of Geographic Information System (GIS) graphics. Up to 50 graphics were disseminated, via a SERFC Hurricane Floyd Web site, pin-pointing the threat of "widespread and major flooding" days in advance of heavy rains. These products were well received by customers, especially FEMA.

- The SERFC issued a product called the Excessive Streamflow Discussion (ESD) to convey flood impact and forecast information to customers. An ESD, disseminated 3 to 7 days in advance of rivers cresting and even before the rain started to fall, called for major flooding over the areas impacted the most.

- An SERFC hydrologist was detailed to Conway, South Carolina, where he worked with city officials to help determine the flood crest and consequences of the severe flooding.

Weather Forecast Offices

The WFOs have the responsibility of issuing timely meteorologic and hydrologic warnings, forecasts and statements. These offices are the contact for state, county and local agencies, as well as the media and general public. During Hurricane Floyd, 13 WFOs were impacted with high winds and tornadoes, coastal flooding, flash flooding and river flooding, or a combination of all these events.

Six WFOs (Wakefield, VA; Raleigh, NC; Wilmington, NC; Morehead City, NC; Mt. Holly, NJ; Brookhaven, NY) had record river flooding, record rainfall, or both. While rainfall from Floyd was the primary contributor to the devastating flooding, rainfall from Hurricane Dennis a week before set the stage for these events.

Nineteen official NWS river forecast points had record flooding due to the rainfall from Dennis and Floyd. Another 36 forecast points had major flooding. Record river flooding occurred in both the Southeast (NC, SC, VA) and the Northeast (NJ, PA). WFOs issued a total of 300 Flood Warnings and Flood Statements for Hurricane Floyd flooding.

The coastal North Carolina WFOs were severely impacted by Hurricane Floyd. River flooding due to Dennis was ongoing when Floyd brought high winds and tornadoes, and coastal and flash flooding. The day before Floyd made landfall, WFOs Morehead City and Wilmington, North Carolina, issued 28 tornado warnings in a 10-hour period. The resulting tornadoes were occurring at the same time as hurricane force winds and flash flooding. The flash flooding was more severe than residents had ever remembered.

The northeast WFOs did not have the long-lasting flooding of the South but were affected by record flash and urban flooding. The hardest hit areas were along the Raritan River in Bound Brook, New Jersey; other areas of New Jersey and southeastern Pennsylvania; small streams in southwestern Connecticut; and in New Castle County, Delaware. Many locations in the Northeast also experienced damage due to wind speeds in excess of 50 mph.

A particular problem in the Northeast region, where population density is high and terrain is flat, is the extreme effect just a foot rise along some area tributaries can have on the areal extent of flooding. This was particularly a problem in portions of New Jersey. The result was property damage affecting thousands of homes and businesses.

Every WFO issued either a Special Weather Statement or Flood Potential Statement, highlighting the high flood danger 30 to 48 hours before flooding began from Floyd. Flood or Flash Flood Watches were issued by all affected WFOs from 12 to 36 hours before the onset of flooding due to Floyd.

A total of 532 Flash Flood Warnings were issued by 13 WFOs for areas from northeast South Carolina through New England. Verification of these warnings for the 13 WFOs combined is outstanding (Table 1).

Table 1. Flash Flood Warning Verification During Hurricane Floyd (combined statistics for 13 WFOs).

	During Floyd	1998 NWS-wide
Probability of Detection	0.97	0.85
False Alarm Rate	0.13	0.42
Critical Success Index	0.85	0.52
Lead Time (minutes)	99	52

Accuracy of forecast crest with respect to lead time for selected record floods in New Jersey and Pennsylvania is shown in Figure 4 below. Flood warnings for these locations were issued by WFOs Brookhaven, New York, and Mt. Holly, New Jersey, using river forecasts from MARFC. Figure 4 shows the average forecast error decreased as the time between forecast and crest decreased. Average forecast error is the difference between forecast and observed river crest. Lead time from the initial flood warning to observed flood crest was more than 11 hours. Lead time is the time, in hours, the forecast was issued prior to the observed crest. Flood forecasts issued the morning of September 16 were too low due to underestimation of rainfall and were raised during the day with the inclusion of observed rainfall and higher QPF. See Appendix E for more details on record floods in New Jersey and Pennsylvania.

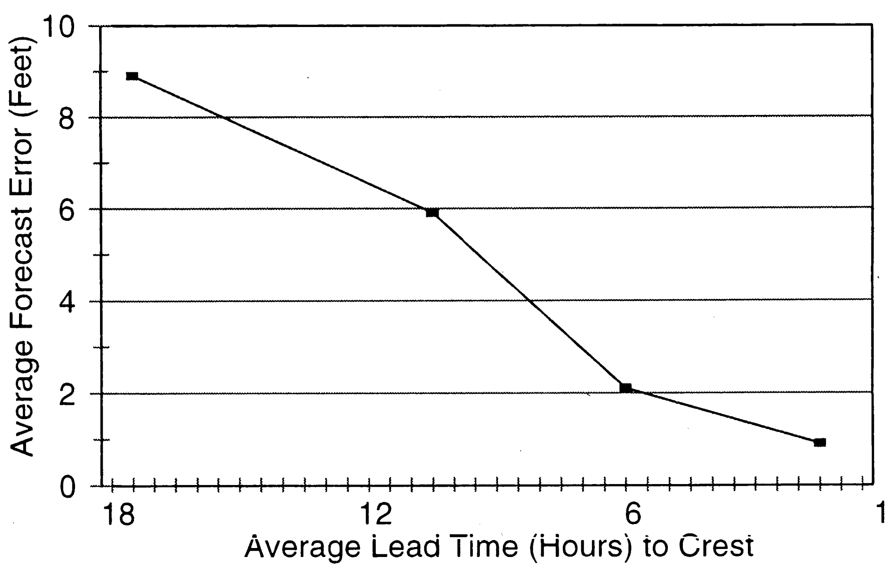


Figure 4. Accuracy of forecast crest with respect to lead time for fast-responding rivers. For more detailed information, see Appendix E.

Accuracy of forecast crest with respect to lead time for selected record floods in Virginia and North Carolina is shown in Figure 5. Flood warnings for these areas were issued by WFOs Wakefield, Virginia, Morehead City and Raleigh, North Carolina, using river forecasts from SERFC. Rivers in these areas rose and receded more slowly than those farther north in New Jersey and Pennsylvania. Figure 5 shows the average forecast error decreased as the time between forecast and crest decreased. Many of the initial flood warnings predicted river crests too low due to underestimation of record rainfall. However, some initial flood warnings were accurate. A record flood crest was forecast at Kinston on the Neuse River with a lead time of 178 hours—more than 7 days in advance. Flood forecasts at the Neuse River at Kinston, North Carolina, and Tar River at Greenville, North Carolina, were within 2 feet of observed crest with 72-hour or greater lead time. Lead time to crest on these slower responding rivers on the coastal plain averaged 108 hours.

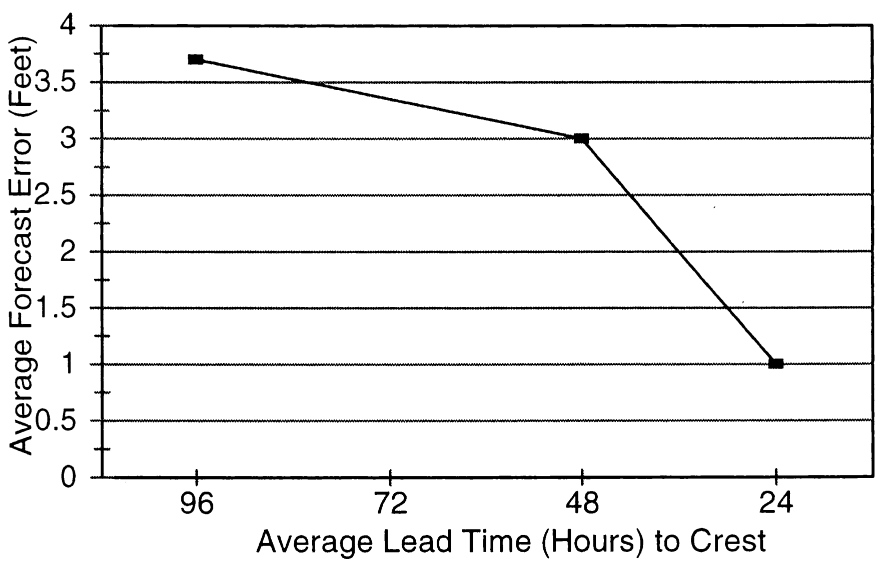


Figure 5. Accuracy of forecast crest with respect to lead time for slow-responding rivers. For more detailed information, see Appendix F.

During hurricane and tropical storm events, it is common practice for staff from non-affected WFOs to be detailed to WFOs where the greatest impact from the storm is anticipated. While additional NWS staff was detailed to WFOs Charleston, South Carolina, and Wilmington, North Carolina, the historic and widespread river flooding affected WFOs in the Southeast that had not received additional staffing. The impact of Dennis and Floyd was particularly long lasting for the North Carolina WFOs, where flooding along the Tar and Neuse Rivers in North Carolina and the Waccamaw River in South Carolina continued into mid-October. Some of these rivers were in flood for over a month due to the combination of Dennis, Floyd and subsequent rainfall events.

At 3:45 p.m. Thursday, September 16, WFO Wakefield lost all phone service. Wakefield initiated full-service program backup, contacting backup offices on cell phones. Long-fused backup responsibility transferred to WFO Morehead City, while short-fused backup was split among WFOs Sterling, Virginia, Morehead City and Raleigh, North Carolina. However, WFO Morehead City was dealing with severe flooding and hurricane-related products in their own area. In order to more evenly distribute the workload, public zone forecast and hydrologic warning responsibility for Wakefield was transferred to WFO Sterling, the secondary backup office for Wakefield. WFO Morehead City continued to issue all marine-related products and Hurricane Local Statements for the Wakefield area. WFO Wakefield was able to assume forecast responsibility at 2 p.m. Friday, September 17. WFOs Morehead City and Sterling are commended for their extra efforts to provide quality warning and forecast services for the Wakefield area during this period of service backup.

The WFOs performed admirably during Hurricane Floyd. There were many examples of outstanding staff dedication under trying circumstances. For example, at WFO Wakefield, staff spent hours navigating closed or flooded roads trying to report to work. When all access to Wakefield became cut off, the staff on duty was stranded at the office for up to 36 hours. During much of this time, WFO Wakefield was without commercial power, phone service and water. While virtually all communication was cut off, the staff continued to monitor the ongoing event, via their satellite-received data on the Advanced Weather Interactive Processing System (AWIPS), and assist the backup WFOs where possible.

As the Tar River was nearing crest in eastern North Carolina, the USGS automated river gage at Greenville malfunctioned. Realizing the importance of timely observations during an anticipated record flood, a staff member of WFO Morehead City traveled about 60 miles to the Greenville forecast point to manually take river observations from the wire-weight gage. The observations were then taken hourly and forwarded to both the Morehead City WFO, local emergency officials and the SERFC. He traveled back and forth several days to take readings, having to avoid numerous flooded highways.

Telemetered river gages were invaluable to RFCs and WFOs. However, at least 15 critical river gages became inoperable during the flood. Gage houses were submerged and telecommunications were lost. This loss of data made it more difficult to forecast river crests and to monitor flood levels. Examples where this occurred include the floods at Lodi, New Jersey, on the Saddle River and Tarboro, North Carolina, on the Tar River.

WFO Raleigh and SERFC coordinated closely with the USGS before and during the event. The interaction helped the USGS determine which river gages needed to be quickly restored to support flood forecasting and reduced the amount of time vital stage information was lost. The USGS made significant efforts to restore high impact gages quickly and passed river information on to WFOs and SERFC.

While some of the manually read river gage reports from Cooperative Observers were not available due to phone outages, the observers continued to take observations and relayed them to the NWS once communications were restored. All WFOs found the cooperative observations reliable and timely while communications were available. Overall, the cooperative network was a tremendous asset to WFOs and RFCs.

WFOs began preparation for the hurricane season by conducting media and emergency management workshops and outreach specifically on the dangers of hurricanes and flooding. All offices conducted Hurricane Awareness Weeks prior to hurricane season with an emphasis on inland flooding. Preparedness activities conducted by all WFOs in the affected areas helped customers make the necessary preparations for flooding. Of particular note, the hurricane focal point at WFO Raleigh conducted an extensive hurricane outreach program that emphasized the dangers of inland flooding due to hurricanes. Statistics and graphics were presented to illustrate the fact that inland flooding resulted in more hurricane deaths in North Carolina than any other type of hurricane-related dangers. The program was presented through much of central North Carolina to print and electronic media, as well as state, county and local emergency officials. It was often a surprise to these groups that inland flooding due to hurricanes was so deadly, and many came away with a new respect for this hurricane danger. Emergency officials had high praise for this outreach effort by WFO Raleigh, indicating it saved many lives.

All of the WFOs impacted by Floyd were proactive in their efforts to get the word out early. Perhaps most appreciated by emergency officials were WFO efforts in using conference calls to provide advance notice and continual updates of Floyd's track and resulting river flood crests. All WFOs made advance "heads up" calls to numerous emergency officials from 2 to 5 days before rainfall from Floyd began. With the realization that Floyd would cause massive inland flooding, emergency officials were again briefed days in advance. As the events of Floyd unfolded, WFOs continued to conduct once- or twice-a-day conference calls with state and county emergency officials. These conference calls typically occurred just following the internal TPC/HPC/RFC/WFO conference calls, thus providing emergency officials with the latest updates on Floyd.

Tropical Prediction Center

When averaged over the entire lifetime of the hurricane, the TPC track forecasts for Floyd were excellent. The average official forecast errors at 12, 24, 36, 48 and 72 hours were 32, 61, 84, 84 and 120 miles. These are much smaller than the most recent 10-year average errors of 55, 103, 147, 189 and 279 miles. On average, the official forecasts were better than all of the model guidance except the United Kingdom Meteorological Office's (UKMET) global model which had track errors comparable to the official forecast errors.

Although the *overall* average official track forecast errors for Floyd were small, the official forecasts during the period when hurricane warnings were in effect for the United States (5 p.m. on September 13 to 11 a.m. on September 16) were average. The average 24-hour track forecast error for this latter period was roughly the same as the most recent 10-year average. The track forecasts during the latter period had a westward bias and were somewhat slow. For example, the 36-hour track forecasts during the period when hurricane warnings were in effect for the United States were an average of 120 miles too far west and 81 miles too far south. All of the track guidance models showed a similar westward and slow bias.

The official intensity forecasts averaged over Floyd's lifetime were good. The average official errors at 12, 24, 36, 48 and 72 hours were 12, 17, 20, 20 and 14 mph, respectively. These errors were considerably smaller than the errors of forecasts based upon climatology and persistence (the usual benchmark for evaluation of forecast skill) of 15, 22, 28, 32 and 44 mph. However, there were some large under-forecasts of intensity, by as much as 30 to 40 mph, from September 10-12 when Floyd was strengthening rapidly. After Floyd reached its maximum intensity, the official forecasts did not predict enough weakening. From September 13 onward, the wind speed was over-forecast in the advisories at practically every forecast interval.

When Floyd moved towards south Florida and then up the U.S. East Coast, tropical storm warnings were issued from as far south as the Florida Keys to as far north as Merrimack River, Massachusetts. Hurricane warnings were posted along sections of the coastline from Florida City, Florida, to Plymouth, Massachusetts, at various times during the storm. In reality, only a small fraction of the coast with hurricane warnings experienced sustained hurricane force winds.

Hurricane warnings were issued for the coast of North Carolina at 11 p.m. on September 14. This is about 27 hours prior to the arrival of the eyewall in the Cape Fear area. For the coasts of South Carolina and North Carolina, hurricane warnings were issued at least 24 hours before the onset of tropical storm force winds.

Hydrometeorological Prediction Center

The HPC is responsible for issuing short-range (Day 1 and Day 2) and medium-range (Day 3-5) QPFs. HPC also produces extended range (Day 3-5) surface pressure charts which include tropical cyclone positions. The tropical cyclone positions on the extended range forecast charts are coordinated with TPC once a day.

The primary tools for the extended range track forecasts are the output from the NCEP Medium-Range Forecast Model (MRF), the European Center for Medium-Range Weather Forecasting (ECMWF) global model, the UKMET's Unified Model, and the Navy Operational Global Atmospheric Prediction System (NOGAPS). Table 2 shows the average errors of the 4- and 5-day track forecasts for HPC and the four global forecast models. Although long-term error statistics of the 4- and 5-day forecasts were not available, the 10-year average track errors from TPC increase with time from 24 to 72 hours. Extrapolating the 10-year average TPC track errors would imply average errors of 367 and 454 miles at 4 and 5 days, respectively. Table 2 shows HPC and model errors were smaller than what might be expected from extrapolated TPC errors. Just as the overall TPC track errors were much lower than average through Day 3, the HPC 4-

and 5-day track forecasts were much better than would be expected from extrapolating the 10-year average TPC 3-day forecast error.

Table 2. Average 4- and 5-day track forecast errors (nm) for Hurricane Floyd from HPC and four global forecast models. The samples for HPC and each model are not homogeneous. (NOGAPS errors provided by James Goerss, Naval Research Laboratory, Monterey, California; others from David Reynolds, HPC)

	4-day		5-day	
	Error (nm)	#Cases	Error (nm)	#Cases
HPC	160	7	228	6
ECMWF	196	8	247	7
MRF	220	9	323	9
NOGAPS	217	10	382	8
UKMET	215	7	364	6

Because the medium-range track forecasts were very good, HPC recognized the potential for heavy rainfall in eastern North Carolina 4 to 5 days in advance. For example, the HPC QPF from September 12, about 4 days prior to landfall in North Carolina, placed 5-day areal average rainfall totals of 6 to 8 inches from northeast South Carolina through eastern North Carolina into southeast Virginia (Figure 6). Fairly consistent 5-day QPFs continued to be issued on September 13 and 14.

In the short range, HPC continued to issue good temporal and spatial QPFs. One parameter for verifying QPFs is the threat score which is based upon the amount of overlap between the forecast and observed areas of precipitation greater than some specified threshold. If there is no overlap between the forecast and observed areas, the threat score has a value of 0, and if there is complete overlap (a perfect forecast), the value is 1.

Table 3 shows the average threat scores for the 2-inch threshold of the 24-hour manual QPFs from HPC and the numerical guidance model QPFs for the period September 14-17. This table shows that the HPC threat scores were comparable to those of the Nested Grid Model (NGM) and Eta, and somewhat better than the aviation run (AVN) of the MRF. In addition, the average threat scores of the HPC forecasts (0.59) during this period were much greater than the mean of the scores from the previous 11 months, which was about 0.2. Although the threat scores of the 0-24 hour QPFs for the 2-inch threshold for the Eta model were comparable or better than the NGM and AVN, the Eta model did not perform as well in terms of higher rainfall amounts. The 24-hour QPF threat score for September 14-17 for the 4-inch threshold of the Eta model was only 0.12, compared with 0.42, 0.41 and 0.27 for HPC, the NGM and the AVN, respectively.

Table 3. Combined Quantitative Precipitation Forecast threat scores of the 2-inch rainfall threshold for HPC and three numerical forecast models for the period September 14-17, 1999. Threat scores can range from 0 (useless) to 1 (perfect).

Forecast Period	HPC	NGM	ETA	AVN
0-24 hr	0.59	0.60	0.60	0.52
0-6 hr	0.31	0.31	0.02	0.25
6-12 hr	0.36	0.24	0.00	0.23
12-18 hr	0.33	0.22	0.00	0.26

HPC is also responsible for issuing 6-hour rainfall totals for forecasts periods of 0-6, 6-12, 12-18, 18-24, and 24-30 hours. Threat scores for the HPC 6-hour rainfall forecasts and the numerical guidance models are also shown in Table 3. Although the scores are not as large as for the 24 hour totals (which is typically the case), HPC added value to the model forecasts and had threat scores much larger than their longer term averages.

HPC also issues an Excessive Rainfall Outlook. In this product, flash flood areas were identified prior to the onset of flash flooding due to Floyd.

Climate Prediction Center

The CPC is responsible for issuing guidance beyond Day 5. In addition, beginning in the summer of 1999, the CPC issued an experimental U.S. Threats Assessment product available via the CPC Web site. This product describes possible threats from a number of weather conditions in the 3-10 day range. The CPC correctly identified the threat of heavy rain, high winds and risk of flooding about a week prior to Floyd making landfall, as shown in Figure 7.

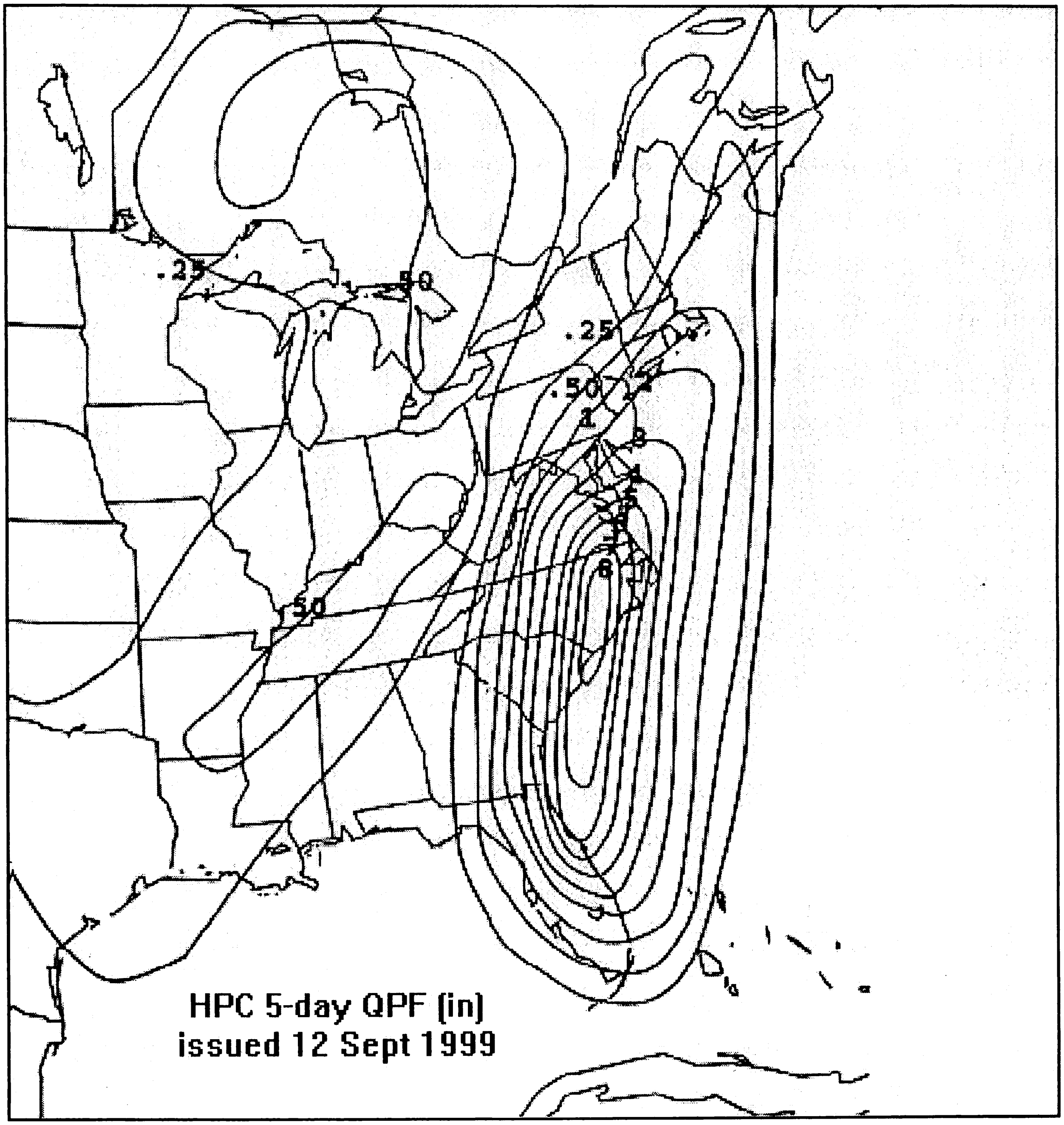


Figure 6. Hydrometeorological Prediction Center 5-day QPF (in) issued September 12, 1999.

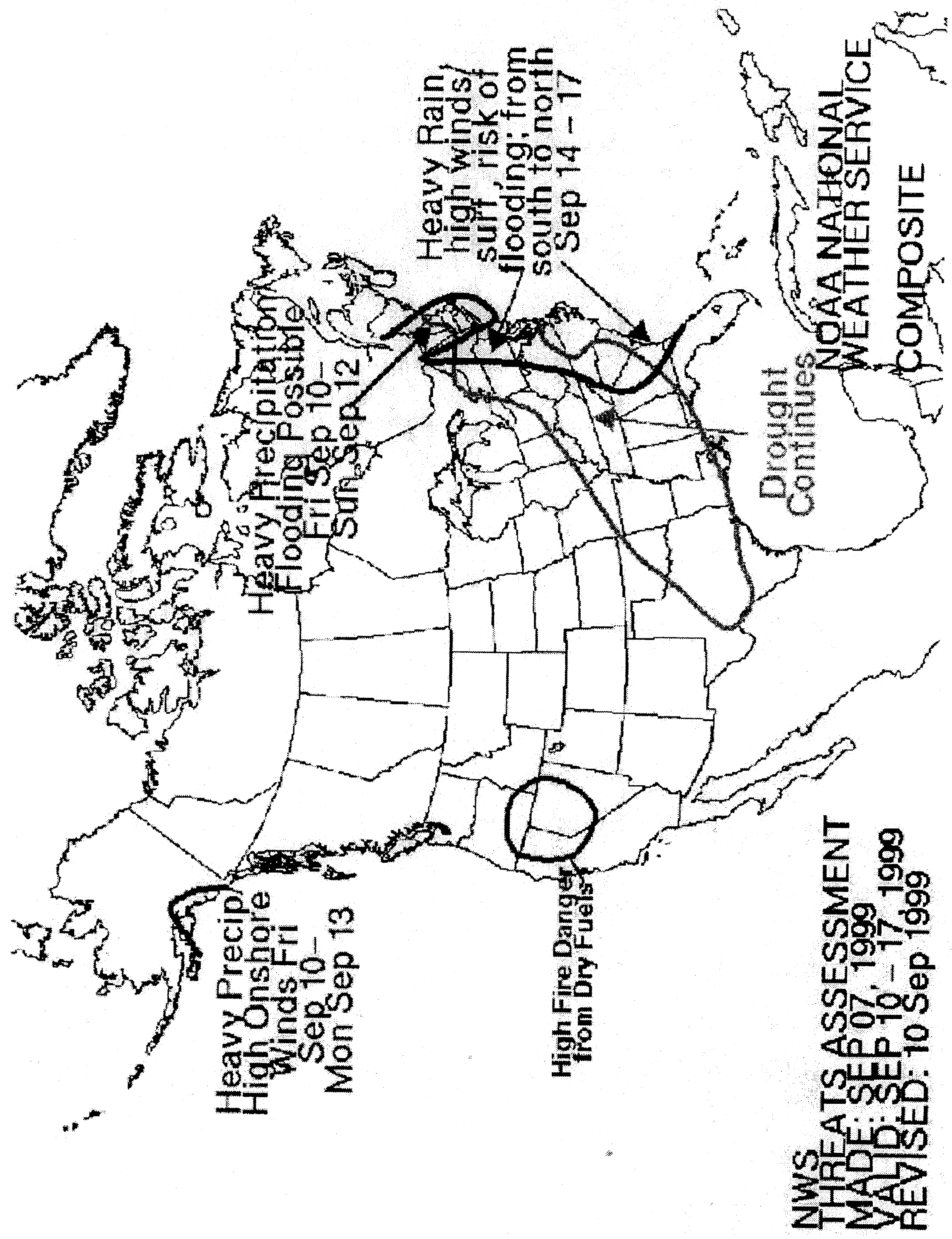


Figure 7. NWS Threats Assessment composite.

Facts, Findings and Recommendations

Observations

Finding 1: The USGS is the agency responsible for maintaining the national stream gage network. The Geostationary Operational Environmental Satellite (GOES) transmission schedule of stream gage data during Hurricane Floyd was every 4 hours. This hindered RFC forecasters' ability to provide more timely and accurate river forecasts.

Recommendation 1: Regions should instruct field offices to contact the USGS with their requests for hourly GOES data collection and distribution.

NCEP Products and Services

Finding 2: Coastal WFOs received real-time Sea, Lake, and Overland Surge from Hurricanes (SLOSH) forecasts from TPC during Hurricane Floyd. These products are not routinely provided during hurricanes. WFOs indicated these forecasts allowed them to provide more specific storm surge forecasts to their customers, and requested real-time SLOSH output during hurricanes.

Recommendation 2: Provide real-time SLOSH output to WFOs when a hurricane is within 12 hours of landfall.

RFC Models and Guidance

Finding 3: RFCs provide Flash Flood Guidance (FFG) to WFOs on the amount of rainfall needed to cause flash flooding. WFO Wakefield is served by MARFC and SERFC. MARFC, serving the northern portion of the warning area, provided lower values than the SERFC. It was difficult for Wakefield forecasters to determine which guidance to use.

Recommendation 3: Ensure Flash Flood Guidance is consistent across RFC boundaries.

Finding 4: Several WFOs requested MARFC and SERFC issue river forecasts containing river stage every 6 hours instead of forecasts containing river stage every 24 hours. The SERFC and NERFC now issue forecasts with river stage every 6 hours.

Recommendation 4a: MARFC should issue river forecasts containing river stage every 6 hours.

Recommendation 4b: With input from partners, customers, and associated WFOs, the remaining ten RFCs determine if river forecasts should contain river stage information every 6 hours.

Finding 5: SERFC provided flood potential graphics on their Internet Web site. Graphics depicted the threat of "widespread and major flooding" days in advance of heavy rains. These products were well received by customers, especially FEMA.

Recommendation 5: Based on customer feedback, RFCs determine whether similar flood potential graphics should be provided.

FACT: SERFC, MARFC and NERFC issued a combined total of 252 River Forecasts (RVFs) for Hurricane Floyd flooding.

Local Offices Warnings, Forecasts and Services

Finding 6: WFOs issue a Flood Warning (FLW) when a river is forecast to reach or exceed flood stage. A Flood Statement (FLS) is issued to update a river forecast when a river is in flood. Flood Statements do not raise public awareness as do Flood Warnings but may be the only place where an update to major or record flooding is mentioned.

Recommendation 6: Change policy to require WFOs to issue a Flood Warning rather than a Flood Statement.

FACT: WFOs issued a total of 300 Flood Warnings and Flood Statements for Hurricane Floyd flooding.

FACT: A total of 532 Flash Flood Warnings were issued by WFOs for areas from northeast South Carolina through New England.

Systems and Communications

FACT: Affected WFOs switched to the Tropical Z/R relationship for the Weather Surveillance Radar-1988 Doppler (WSR-88D) radar precipitation estimates before Floyd. Several WFOs commented on the excellent WSR-88D rainfall estimates during the event.

Finding 7: Precipitation estimates from the WFO Sterling, Virginia, WSR-88D significantly underestimated observed rainfall during Floyd. This problem with underestimating rainfall has previously been documented.

Recommendation 7: Fix the Sterling WSR-88D precipitation underestimation problem.

FACT: The Internet was used extensively during Hurricane Floyd. A special effort was made to increase the accessibility of the TPC Web site, which handled up to three million "hits" per day during Floyd.

Internal and External Coordination

Finding 8: WFO Wakefield, Virginia, collected hourly river stage observations for Emporia, Virginia. When WFO Sterling, Virginia, assumed backup responsibility for Wakefield, observations were collected every 6 hours. Sterling was adhering to the Eastern Region policy that the servicing RFC, in this case SERFC, should provide data collection during backup. SERFC, however, was adhering to the Southern Region policy of data collection being provided by the WFO with backup responsibility.

Recommendation 8: Make backup policy for collecting river stage observations consistent nationwide.

FACT: All WFOs in the affected areas participated in or initiated numerous conference calls with emergency managers, USGS, USACE, and other decision-making agencies of government before, during and after the event. WFO Taunton, Massachusetts, also conducted conference calls with the media. These calls were well received and helped keep media reports consistent with NWS products.

FACT: The Service Assessment Team interviews with state, county and local emergency officials revealed a common remark: Emergency officials were pleased with the accessability, cooperation and coordination by the WFOs. Officials spoke highly of the "personal touch" provided to their areas by the local WFO.

FACT: Prior to the hurricane season, all offices conducted Hurricane Awareness Weeks with emphasis on inland flooding. Awareness Week activities included seminars, conferences, office visitations and mailings. Preparedness activities conducted by all WFOs in the affected areas helped customers make the necessary preparations for the record floods.

Response

FACT: Of the 56 deaths directly attributed to Hurricane Floyd, 48 (86 percent) were due to freshwater, inland flooding. Vehicle-related deaths accounted for 55 percent of casualties, and of these, about 80 percent were male.

Media

FACT: Before Hurricane Floyd made landfall, NWS Eastern Region Public Affairs, in collaboration with NOAA Public Affairs, issued a press release to the media on September 15, 1999, about the dangers of inland flooding along the East Coast. The release was printed in numerous newspapers.

FACT: The Associated Press ran a story on September 21, 1999, for worldwide distribution complimentary of the Hurricane Floyd forecast, based on an interview with Louis Uccellini, Director of NCEP.

Practices to Emulate

The Service Assessment Team identified practices at some NWS offices that were particularly effective and other field office managers may wish to emulate.

Innovative Wording to Heighten Awareness: WFO Mt. Holly, New Jersey, realized the potential problem with their customers becoming "desensitized" to Flash Flood Warnings (FFWs). When they decided to issue an FFW on the anticipation of major flash flooding due to extreme rainfall, a decision was made to change the header to read "SEVERE FLASH FLOOD WARNING." While unconventional, media and emergency officials liked the idea, stating it gave them an indication as to just how serious the flooding would be.

Providing Detail in Flash Flood Statements: WFO Raleigh, North Carolina, issued numerous Flash Flood Warnings for flash flooding and severe urban flooding in central North Carolina. As a follow-up to these warnings, the WFO issued detailed Flash Flood Statements every 2 to 3 hours. The statements provided details of the specific flash flooding areas, mentioning flooding problems in numerous cities and towns specifically. These statements also provided cautionary wording that historic river flooding would follow along mainstem rivers. This detail was exemplary of the flash flood warning process.

WFO Preparedness Activities

All WFOs in the affected areas conducted extensive preparedness activities. Some examples include the following.

- The Wilmington, North Carolina, WFO held a Hurricane/Storm Surge Seminar for all emergency managers and media in their warning area at the beginning of the hurricane season. The WCM also made coordination visits to all emergency managers in his warning area prior to hurricane season.

- During Hurricane Awareness Week, WFO Wakefield, Virginia, spent considerable effort on inland hurricane effects, especially on flooding. They issued Public Information Statements and participated in various interviews and presentations, including the 1999 Virginia Emergency Management Conference.

- WFO Morehead City, North Carolina, held an Open House prior to hurricane season for emergency management and media in their forecast area. The agenda focused on coordination issues, NWS products, and hurricane presentations dealing with the 1999 hurricane season forecast, storm surge components, and inland flooding from hurricanes. The WFO also gave numerous hurricane preparedness presentations throughout their area.

- The WFO Raleigh, North Carolina, hurricane focal point conducted extensive preparedness activities before the hurricane season to focus on the effects of hurricanes, emphasizing inland flooding. Lectures and preparedness talks were given to television stations, newspapers, emergency management agencies and the Civil Air Patrol. Several hurricane articles were published in newspapers and journals. Emergency officials had high praise for these outreach efforts, indicating they saved many lives.

- WFO Mt. Holly, New Jersey, conducted two live, 1-hour interviews over NOAA Weather Radio (NWR) addressing hurricanes and inland flooding. Call-in questions were also accepted. Feedback from the NWR programs was very positive and requests for copies of the programs were received.

- WFO Mt. Holly hosted an annual hurricane/storm surge seminar for their emergency managers. The 2-day event included discussion on hurricane-related products issued by TPC and the WFO, and hands-on training on the use of HURREVAC and SLOSH output. In addition, WFOs Mt. Holly and Wakefield participated in a 5-day hurricane exercise for the Delmarva region. The training helped emergency managers better understand NWS products and services.

- WFO Sterling, Virginia, sent daily e-mails to all emergency managers in their warning area beginning September 10. The e-mails focused on Floyd and possible impacts. Earliest e-mails based outlooks on guidance from a Threats Assessment Product issued by CPC.

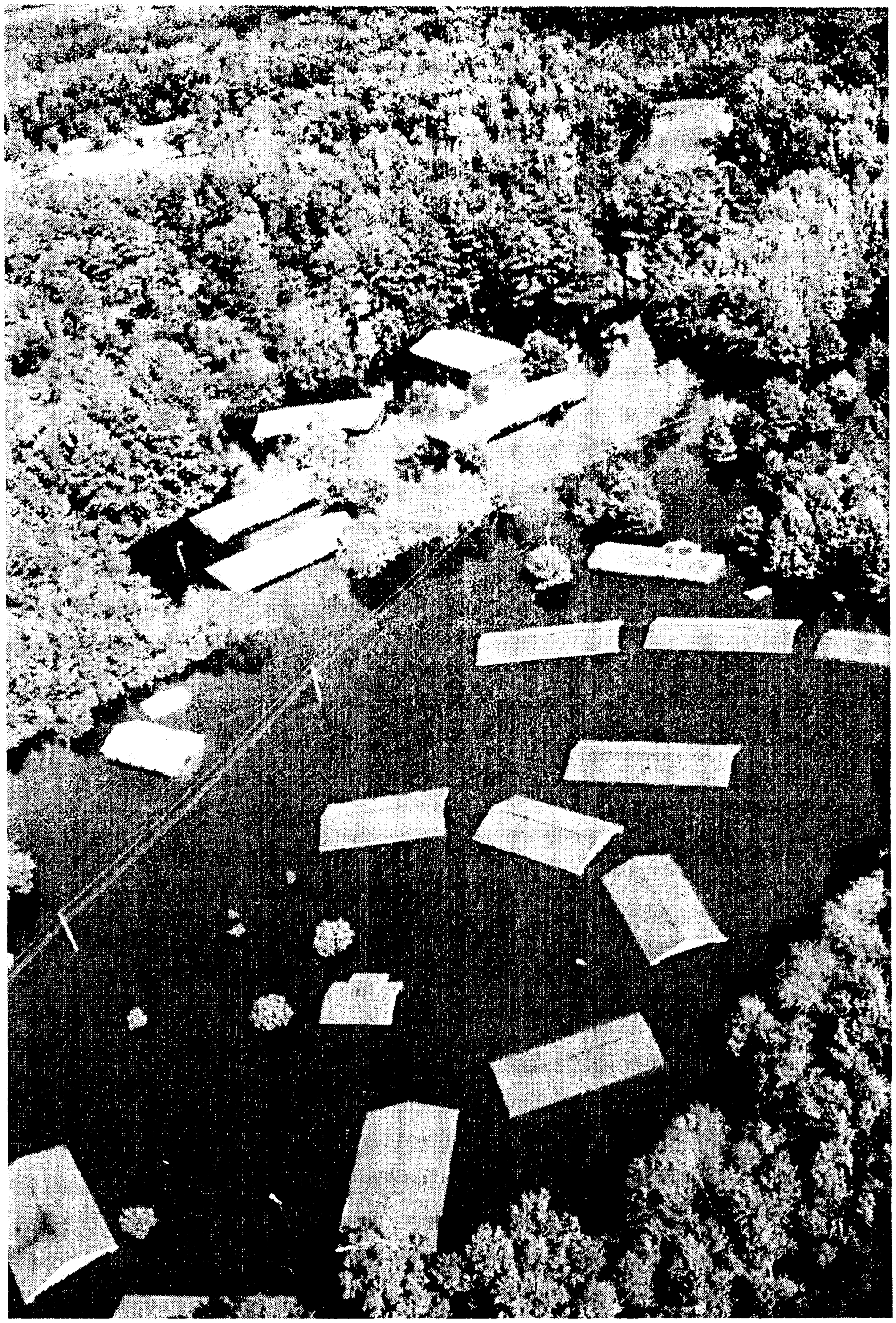
- WFO Brookhaven, New York, participated in a 3-day FEMA-sponsored Hurricane Exercise for New York emergency management. The WFO was also involved in the Hurricane Awareness Tour on Long Island with awareness training given to emergency managers and schools.

SERFC Coordination and Outreach Activities

The SERFC was very proactive in relaying information to the internal and external user community before and during the warning period. Some examples include the following.

- Daily conference calls, initiated by the SERFC, brought together WFOs, USACE, USGS, FEMA Hurricane Liaison Team, and Divisions of Emergency Management in Virginia, North Carolina and South Carolina.

- In an attempt to focus additional attention on the major inland flood threat, the SERFC contacted CNN, The Weather Channel, NWS Eastern and Southern Region Headquarters, and the FEMA Hurricane Liaison Team.



Flooding in Grifton, North Carolina. (Photograph courtesy of J. Jordan, U.S. Army Corps of Engineers.)

- The SERFC provided flood potential information through the use of GIS graphics. Up to 50 graphics were disseminated, via a SERFC Hurricane Floyd Web site, pin-pointing the threat of "widespread and major flooding" days in advance of heavy rains. These products were well received by customers, especially FEMA.

- The SERFC issued a product called the ESD to convey flood impact and forecast information to customers. An ESD, disseminated 3 to 7 days in advance of rivers cresting and even before the rain started to fall, called for major flooding over the areas that were impacted the most.

- An SERFC hydrologist was detailed to Conway, South Carolina, where he worked with city officials to help determine the flood crest and consequences of the severe flooding.

Completed Actions

These findings, identified by the Service Assessment Team, have actions that are completed.

Issue 1: Telemetered river gages were invaluable to RFCs and WFOs. However, at least 15 critical river gages became inoperable during the flood. Gage houses were submerged and telecommunications were lost. This loss of data had a negative impact on the quality of river forecasts.

Action 1: The Office of Hydrology, using input from RFCs and WFOs, provided the USGS with NWS stream gaging requirements. The Office of Hydrology will monitor progress on meeting these requirements at quarterly NOAA/USGS meetings.

Issue 2: WFOs were unable to interrogate several automated river-gaging stations via computer. Gaging stations that had to be manually dialed were Sutrons (primarily in the northeast) and Campbell dataloggers (in Virginia).

Action 2: The Office of Hydrology developed software to enhance the capabilities of AWIPS Local Data Acquisition and Dissemination to collect data from remote sensors. The ability to interrogate Campbell dataloggers is scheduled for AWIPS Release 5.0. The ability to interrogate Sutron dataloggers is scheduled for Release 5.1.

Issue 3: AWIPS does not have the capability to graphically display hurricane information contained in TPC products.

Action 3: The capability to plot current and forecast hurricane positions from TPC products will be included in AWIPS Release 4.3.1. The capability to plot wind radii, hurricane strike probabilities, and hurricane track forecasts from guidance models is scheduled for Release 5.0.

Appendix A

National Hurricane Center Best Track
Hurricane Floyd
September 7-17, 1999

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (°N)	Lon. (°W)			
7/1800	14.6	45.6	1008	25	tropical depression
8/0000	15.0	46.9	1007	30	"
0600	15.3	48.2	1005	35	tropical storm
1200	15.8	49.6	1003	40	"
1800	16.3	51.1	1000	45	"
9/0000	16.7	52.6	1000	45	"
0600	17.1	53.9	1003	45	"
1200	17.3	55.1	1003	50	"
1800	17.9	56.3	996	60	"
10/0000	18.3	57.2	995	60	"
0600	18.6	58.2	990	60	"
1200	19.3	58.8	989	70	hurricane
1800	20.2	59.6	975	70	"
11/0000	20.8	60.4	971	80	"
0600	21.4	61.1	963	95	"
1200	21.9	62.0	962	95	"
1800	22.5	63.0	966	90	"
12/0000	22.7	64.1	967	85	"
0600	22.8	65.2	960	95	"
1200	23.0	66.2	955	105	"
1800	23.2	67.4	940	115	"
13/0000	23.4	68.7	931	125	"
0600	23.6	70.0	922	135	"
1200	23.9	71.4	921	135	"
1800	24.1	72.9	923	125	"
14/0000	24.5	74.0	924	115	"
0600	24.9	75.3	927	105	"
1200	25.4	76.3	930	105	"

1800	26.1	77.0	930	110	"
15/0000	27.1	77.7	933	115	"
0600	28.2	78.5	935	110	"
1200	29.3	78.9	943	100	"
1800	30.6	79.1	947	95	"
16/0000	32.1	78.7	950	90	"
0600	33.7	78.0	956	90	"
1200	35.7	76.8	967	70	"
1800	38.0	75.3	974	60	tropical storm
17/0000	40.6	73.5	980	50	"
17/0600	42.1	72.1	983	50	tropical storm
1200	43.3	70.6	984	45	extratropical
1800	44.2	68.9	985	45	"
18/0000	44.8	67.3	987	40	"
0600	45.4	65.5	990	35	"
1200	46.6	63.0	992	35	"
1800	47.7	59.3	992	35	"
19/0000	48.0	56.3	992	35	"
0600	48.5	52.5	994	35	"
1200	49.5	48.0	992	40	"
1800					merged with low

13/1200	23.9	71.4	921	135	minimum pressure
14/1200	25.4	76.3	930	105	landfall near Alice Town, Eleuthera
14/1900	26.3	77.1	932	120	landfall near Cherokee Sound, Abaco
16/0630	33.8	78.0	956	90	landfall near Cape Fear, North Carolina

Appendix B

Saffir-Simpson Hurricane Scale*

Category	**Definition—Likely Effects**
ONE	**Winds 74-95 mph (65-82 kts.):** No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal flooding and minor pier damage.
TWO	**Winds 96-110 mph (83-95 kts.):** Some roofing material, door, and window damage of buildings. Considerable damage to vegetation, mobile homes, etc. Flooding damages piers, and small craft in unprotected anchorages break moorings.
THREE	**Winds 111-130 mph (96-113 kts.):** Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain may be flooded well inland.
FOUR	**Winds 131-155 mph (114-135 kts.):** More extensive curtainwall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Terrain may be flooded well inland.
FIVE	**Winds greater than 155 mph (greater than 135 kts.):** Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation of residential areas may be required.

Note: A "major" hurricane is one that is classified as a Category 3 or higher.

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* In operational use, the scale corresponds to the 1-minute average sustained wind speed as opposed to gusts which could be 20 percent higher or more.

Appendix C

Record Floods at NWS Forecast Points for Hurricane Floyd (1999)

(Data Provided by NWS/USGS)

Date	Location	Flood Stage (Ft)	Old	New
9/17/99	Nottoway River near Sebrell, VA	16	24.43	27.01
9/17/99	Tar River at Louisburg, NC	20	25.34	26.05
9/17/99	Tar River near Rocky Mount, NC	15	23.67	32.35
9/18/99	Fishing Creek near Enfield, NC	16	17.72	21.65
9/20/99	Tar River at Tarboro, NC	19	31.77	41.51
9/21/99	Tar River at Greenville, NC	13	22.07	29.72
9/17/99	Neuse River near Clayton, NC	9	20.12	20.67
9/20/99	Neuse River near Goldsboro, NC	14	26.21	28.85
9/23/99	Neuse River at Kinston, NC	14	23.26	27.71
9/18/99	Cape Fear River at Chinquapin, NC	13	20.16	23.51
9/17/99	Saddle River at Lodi, NJ	5	12.36	13.94
9/17/99	North Raritan River near Raritan, NJ	10	15.51	18.78
9/17/99	Raritan River at Manville, NJ	14	23.80	27.50
9/17/99	Millstone River at Blackwells Mills, NJ	9	18.68	20.97
9/17/99	Raritan River at Bound Brook, NJ	28	37.47	42.13
9/17/99	Rahway River at Springfield, NJ	5.5	9.76	10.67
9/17/99	Christina at Coochs Bridge, DE	9	13.12	13.92
9/17/99	E. Br. Brandywine blw Downingtown, PA	7	13.40	14.74
9/17/99	Brandywine Creek at Chadds Ford, PA	9	16.56	17.15

Appendix D

U.S. Tropical Cyclone Deaths Directly Attributed to Hurricane Floyd (1999)

(Data Provided by Dr. Edward N. Rappaport, TPC)

Date	Cause	County/Parish	Age	Gender
9/16/99	Drown in vehicle*	Delaware, PA	67	M
9/16/99	Drown in vehicle*	Montgomery, PA	49	M
9/16/99	Drown in vehicle*	Montgomery, PA	71	F
9/16/99	Drown in vehicle*	Montgomery, PA	47	M
9/16/99	Tree fell on home	Chester, PA	53	F
9/16/99	Tree fell on car	Philadelphia, PA	48	M
9/16/99	Drown*	Salem, NJ	40	M
9/16/99	Drown *	Somerset, NJ	85	F
9/16/99	Drown *	Somerset, NJ	58	M
9/16/99	Drown near vehicle*	Bergen, NJ	27	M
9/16/99	Drown*	Bergen, NJ	53	M
9/16/99	Drown*	Passaic, NJ	82	M
9/16/99	Drown swept into sewage pipe	New Castle, DE	11	F
9/16/99	Drown swept into sewage pipe	New Castle, DE	12	F
9/17/99	Tree fell on camper	Orange, VT	69	M
9/16/99	Drown swept into stream*	Dutchess, NY	9	F
9/17/99	Drown*	Rockland, NY	53	M
9/16/99	Drown kayaker on Quinnipiac River*	New Haven, CT	34	M
9/16/99	Tree blew on to car at 2030 UTC	Fairfax, VA	61	F
9/16/99	Tree fell on trailer	Halifax, VA	22	F
9/16/99	Drown from vehicle*	Southampton, VA	9	F
9/16/99	Drown near vehicle*	Bertie, NC	43	M
9/17/99	Drown drove into flood waters*	Craven, NC	76	M

Date	Cause	County/Parish	Age	Gender
9/22/99	Drown*	Craven, NC	55	M
9/16/99	Drown in vehicle*	Duplin, NC	42	M
9/16/99	Drown in vehicle*	Duplin, NC	63	M
9/17/99	Drown*	Duplin, NC	70	M
9/16/99	Drown*	Edgecombe, NC	75	M
9/16/99	Drown in capsized boat*	Edgecombe, NC	24	F
9/16/99	Drown in capsized boat*	Edgecombe, NC	45	F
9/16/99	Drown in capsized boat*	Edgecombe, NC	51	M
9/16/99	Drown in capsized boat*	Edgecombe, NC	5	F
9/16/99	Drown in capsized boat*	Edgecombe, NC	5	F
9/16/99	Drown in capsized boat*	Edgecombe, NC	3	F
9/16/99	Drown*	Edgecombe, NC	51	M
9/16/99	Drown in vehicle*	Halifax, NC	65	M
9/16/99	Drown in vehicle*	Johnston, NC	30	M
9/16/99	Drown in vehicle*	Johnston, NC	31	M
9/16/99	Drown in vehicle*	Johnston, NC	5	F
9/16/99	Drown*	Jones, NC	65	M
9/16/99	Drown near vehicle*	Lenoir, NC	55	M
9/16/99	Drown in vehicle*	Nash, NC	87	F
9/16/99	Drown in vehicle*	Nash, NC	79	M
9/16/99	Drown in vehicle*	Nash, NC	46	M
9/16/99	Drown in vehicle*	Nash, NC	40	M
9/17/99	Drown in vehicle*	Nash, NC	47	F
9/16/99	Drown in vehicle*	Pender, NC	47	M
9/16/99	Drown in vehicle*	Pender, NC	70	M
9/16/99	Drown in vehicle*	Pitt, NC	26	M
9/16/99	Drown in vehicle*	Pitt, NC	18	M
9/16/99	Drown in vehicle*	Pitt, NC	27	M
9/16/99	Drown near vehicle*	Pitt, NC	43	M

Date	Cause	County/Parish	Age	Gender
9/16/99	Drown in vehicle*	Warren, NC	72	M
9/16/99	Drown in vehicle*	Warren, NC	55	M
9/16/99	Fatal injury in car/swept away	Wayne, NC	51	M
9/16/99	Drown in vehicle*	Wayne, NC	42	F

* Fresh water fatality.

Appendix E

Verification of Selected Record Floods at NWS Forecast Points for Hurricane Floyd Middle Atlantic RFC Area

(Data Provided by NWS/USGS)

Station	Flood Stage (feet)	River Flood Warning/ Statement Time (EDT)++	Forecast Crest (feet)	Observed Crest (ft)/time of Crest	Departure (forecast crest - observed crest) in feet	Lead Time (issuance to observed Crest)
Saddle River at Lodi, NJ*	5	16/1259	10.0	13.94 9/17/99 ~0000 EDT	-3.94	11 hr, 1min
(WFO Brookhaven)		16/1622	10.0		-3.94	7 hr, 38 min
		16/1943	10.5		-3.44	4 hr, 17 min
N. Raritan River nr Raritan, NJ	10	16/0942	9.0	18.78 9/16/99 2300 EDT	-9.78	13 hr, 18 min
(WFO Mt. Holly)		16/1510	10.5		-8.28	7 hr, 50 min
		16/1916	15.5		-3.37	3 hr, 44 min
		16/2159	19.0		+0.22	1 hr, 1 min
Raritan River at Manville, NJ*	12	16/0942	14.5	27.50 9/17/99 0000 EDT	-13.0	12 hr, 18 min
(WFO Mt. Holly)		16/1510	19.5		-8.0	8 hr, 50 min
		16/1916	27.0		-0.5	4 hr, 44 min
Millstone River at Blackwells Mills, NJ	9	16/0942	11.0	20.97 9/17/99 0345 EDT	-9.97	18 hr, 3 min
(WFO Mt. Holly)		16/1510	12.5		-8.47	12 hr, 35 min
		16/1916	18.5		-2.47	8 hr, 29 min
		16/2159	20.5		-0.47	5 hr, 46 min
		17/0212	21.5		+0.53	1 hr, 33 min
Raritan at Bound Brook, NJ *	26	16/0942	29.8	42.13 9/16/99 2230 EDT	-12.33	12 hr, 48 min
(WFO Mt. Holly)		16/1510	33.5		-8.63	7 hr, 20 min
		16/1916	40.0		-2.13	3 hr, 14 min
		16/2159	41.0		-1.13	31 min

Brandywine at Chadds Ford, PA	9	16/1112	13.0	17.15 9/17/99 0100 EDT	-4.15	13 hr, 48 min
(WFO Mt. Holly)		16/1648	15.5		-1.65	8 hr, 12 min
		16/2055	18.5		+1.35	4 hr, 5 min

* Gage outage occurred during flood.

++ Only warnings/statements with updated crest values and/or times are included.

Average lead time to observed crest from initial flood warning: 11 hours, 11 minutes.

Average error for initial forecasts: 8.9 feet .

Average error for all updated forecasts: 3.4 feet.

Appendix F

Verification of Selected Record Floods at NWS Forecast Points for Hurricane Floyd Southeast RFC Area

(Data Provided by NWS/USGS)

Station (Note: All Stations in table had gage outages sometime during flooding)	Flood Stage (feet)	River Flood Warning/ Statement Time++	Forecast Crest (feet)	Observed Crest (ft)/time of Crest	Departure (forecast crest - observed crest) in feet	Lead Time (issuance to observed Crest)
Nottoway River nr Sebrell, VA (WFO Wakefield)	16	16/0652	21.0	27.1 9/19/99 ~ 0800 EDT	-6.1	73 hr, 8 min
		16/1358	24.9		-2.2	66 hr, 2 min
Issued by WFO Sterling		16/2250	25.5		-1.6	57 hr, 10 min
Issued by WFO Sterling		17/1245	26-27		-1.1 to -0.1	43 hr, 15 min
		18/2240	27		-0.1	9 hr, 20 min
Neuse River at Kinston, NC (WFO Morehead City)	14	15/1310	21.5	27.71 9/23/99 2245 EDT	-6.21	201 hr, 35 min
		16/1243	23-24		-4.71 to -3.71	178 hr, 2 min
		20/1300	24-25		-3.71 to -2.71	81 hr, 45 min
		20/2244	26		-1.71	72 hr, 1 min
		21/1249	27		-0.71	57 hr, 56 min
		21/2318	27.5		-0.21	46 hr, 33 min
		22/1246	28		+0.29	33 hr, 29 min
Tar River at Greenville, NC (WFO Morehead City)	13	15/1310	18.0	29.73 9/21/99 ~1000 EDT	-11.73	140 hr, 50 min
		16/1000	24-25		-4.73	120 hr
		17/1425	26.5		-3.23	91 hr, 35 min
		18/1135	28.5		-1.23	70 hr, 25 min
		18/1925	29		-0.73	62 hr, 35 min
		19/1245	29.5-30		-0.23 to +0.27	45 hr, 15 min
		20/1300	30		+0.27	27 hr

Tar River at Rocky Mount, NC (WFO Raleigh)	15	15/1430	23	32.40 9/16/99 ~1900 EDT	-9.40	28 hr, 30 min
		16/0940	34-35		+1.6 to +2.6	9 hr, 20 min
Tar River at Tarboro, NC (WFO Raleigh)	19	15/1409	26	41.5 9/19/99 ~1500 EDT	-15.5	96 hr, 51 min
		16/0940	33-34		-8.5 to -7.5	77 hr, 20 min
		16/2204	34		-7.5	64 hr, 56 min
		17/2000	38		-3.5	43 hr

++ Only warnings/statements with updated crest values and/or times are included.
Average lead time to observed crest from initial flood warning: 108 hours, 11 minutes.
Average error for initial forecasts: 9.8 feet.
Average error for all updated forecasts: 2.4 feet.