Service Assessment

OHIO RIVER VALLEY FLOOD OF MARCH 1997

August 1998

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
Office of Hydrology
Silver Spring, Maryland

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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

The National Weather Service (NWS), a line office of the Department of Commerce's (DOC) National Oceanic and Atmospheric Administration (NOAA) is responsible for providing public forecasts and warnings of weather and river conditions for the protection of life and property and to enhance the Nation's economy. The NWS conducts a survey of significant weather events to thoroughly assess the performance of the forecast system.

A NWS evaluation team was sent to the Ohio River Valley following severe weather events in early March of 1997 that produced extensive flash flooding and record river flooding across the region. The team focused on the hardest hit areas in the Ohio Valley including north central Kentucky and southwest Ohio. The team met with staff members of NWS offices in Louisville, Kentucky, and Wilmington, Ohio, the Ohio River Forecast Center (OHRFC), and the National Centers for Environmental Prediction's (NCEP) Hydrometeorological Prediction Center (HPC), as well as with State Emergency Management Agencies (EMAs) in both Kentucky and Ohio.

The survey provides an evaluation of the NWS weather forecasting and warning program and offers recommendations for improvements in products and services. The survey team wishes to thank all of the NWS personnel and state EMA officials that contributed information to the team.

We wish to express our sympathy for the losses experienced by the survivors of the floods and extend our deepest regards to the friends and families of the ones lost to the disaster.

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

FOREWORD

The commitment to excellence was demonstrated in the products and services provided by the staffs at NWS offices throughout **the Ohio Valley Flood of March 1997**. These talented and dedicated NWS teams were honored by being recipients of important achievement awards in the months following the event.

NWSFO Louisville, NWSO Jackson, and NWSO Paducah each received the 1997 NOAA Bronze Medal Awards. NWS Ohio River Forecast Center and NWSO Wilmington were each presented the 1997 DOC Silver Medal.

The outstanding performance of these offices serves as examples for all of us.

Glenn S. Austin, Survey Team Leader
Deputy Chief, Hydrologic Operations Division
National Weather Service

SERVICE ASSESSMENT TEAM

Following a major storm in which there has been a loss of life or extensive damage, a service assessment team may be assigned by the NWS to provide an objective appraisal of products and services and to make findings and recommendations for improving service. Such a team was assembled to survey **The Ohio Valley Flood of March 1997.**

TEAM MEMBERS

Team Leader

Glenn Austin	Deputy Chief, Hydrologic Operations Division, Office of Hydrology, NWS Headquarters, Silver Spring, Maryland
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ACRONYMS AND ABBREVIATIONS

AFOS	Automation of Field Operations and Services
AFWS	Automated Flood Warning System
AHPS	Advanced Hydrologic Prediction System
API	Antecedent Precipitation Index
AWIPS	Advanced Weather Interactive Processing System
COMET	Cooperative Program for Operational Meteorology and Educational Training
CSI	Critical Success Index
CWA	County Warning Area
DAPM	Data Acquisition Program Manager
DCP	Data Collection Platform
DES	Department of Emergency Services
DWOPER	Operational Dynamic Wave Model
EM	Emergency Managers
EMA	Emergency Management Agency
EOC	Emergency Operation Centers
ESF	Flood Potential Statement
FEMA	Federal Emergency Management Agency
FFA	Flash Flood Watch
FFW	Flash Flood Warning
FLDWAV	Flood Wave (Dynamic Routing Model in NWSRFS)
FLW	River Flood Warning
GUI	Graphical User Interface
HAS	Hydrometeorological Analysis and Support
HPC	Hydrometeorological Prediction Center
HSA	Hydrologic Service Area
ICP	Interactive Calibration Program
IFLOWS	Integrated Flood Observing and Warning System
KDES	Kentucky Disaster and Emergency Services
KEWS	Kentucky Emergency Warning System
MAP	Mean Areal Precipitation
MIC	Meteorologist in Charge
NCEP	National Centers for Environmental Prediction
NEXRAD	NEXt Generation RADar
NOAA	National Oceanic and Atmospheric Administration
NWR	NOAA Weather Radio
NWSFO	NEXRAD Weather Service Forecast Office
NWSO	NEXRAD Weather Service Office
NWSRFC	National Weather Service River Forecast System
NWS	National Weather Service
NWW	NOAA Weather Wire

OFS	Operational Forecast System
OHRFC	Ohio River Forecast Center
PQPF	Probabilistic Quantitative Precipitation Forecasts
QPF	Quantitative Precipitation Forecasts
RFC	River Forecast Center
RVF	River Forecast Guidance
SOO	Science and Operations Officer
STORMS	State of Ohio Rain Monitoring System
USACE	U.S. Army Corps of Engineers
UTC	Coordinated Universal Time
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office
WSR-88D	Weather Service Radar-1988 Doppler

EXECUTIVE SUMMARY

Introduction: A record event

The Ohio Valley is frequented by floods on an annual basis. However, flooding of the magnitude comparable to the floods of March 1997 is a rare occurrence. Between March 1 and 3 , as much as 6 to 12 inches of rain fell in parts of northern Kentucky and southern Ohio. (See Figure 1.) This produced a variety of flooding ranging from flash flooding in hilly terrain and poorly drained areas, to small stream flooding in rural and urban areas, followed by very serious flooding that developed along the Ohio River as well as many of its tributaries.

Record flooding resulted along many rivers in northern Kentucky including the Rolling Fork River at Boston, South Fork of the Licking River at Cynthiana, and the Licking River at Blue Licks Spring and Falmouth. Record, or near record, flooding also occurred in Ohio with the most serious flooding reported along Brush Creek and the Scioto and Great Miami Rivers. Levels on the main stem of the Ohio were the highest in over 30 years.

Impact: Damages and fatalities

Disastrous flooding inundated dozens of river towns and cities forcing evacuations of thousands of people. Most of the town of Falmouth in Pendleton County, Kentucky, with over 2,400 residents, was evacuated. Flooding also inundated several other towns across the region including Boston, Kentucky, where the water level reached the rooftops of many homes and smaller businesses.

Several communities along the Ohio River were given notice to prepare for flooding a day or more in advance. This helped reduce damages significantly. Early warning of the flood allowed the city engineers in Louisville to make use of the 45 flood gates, installed after the historic floods of 1937, that protected all but the lowest elevations. Meanwhile, upstream, the NWS was given partial credit for saving Opening Day of the Cincinnati Reds Baseball season. Forecasts from the OHRFC were used in the flood warnings issued by NWSO Wilmington and relayed to the management at Cinergy Field. Flood gates were closed and pumps activated that kept the flood water out of the stadium. The flood warnings not only saved opening day, but also kept a new $2 million astroturf installation from being ruined.

Major flooding impacted a total of six states across the region. The most severe flooding occurred in Ohio and Kentucky with dozens of counties in each state declared natural disaster areas. Close to 14,000 homes were damaged or destroyed. Over 20,000 home and business owners applied for disaster relief. Damage estimates totaled more than $500 million.

Although effective lead time was provided by the NWS in the form of river flood and flash flood warnings, a total of 33 people lost their lives due to flooding, including 21 in Kentucky, 5 in Ohio, 4 in Tennessee, and 3 in West Virginia. Hundreds of injuries were also reported. Many of these

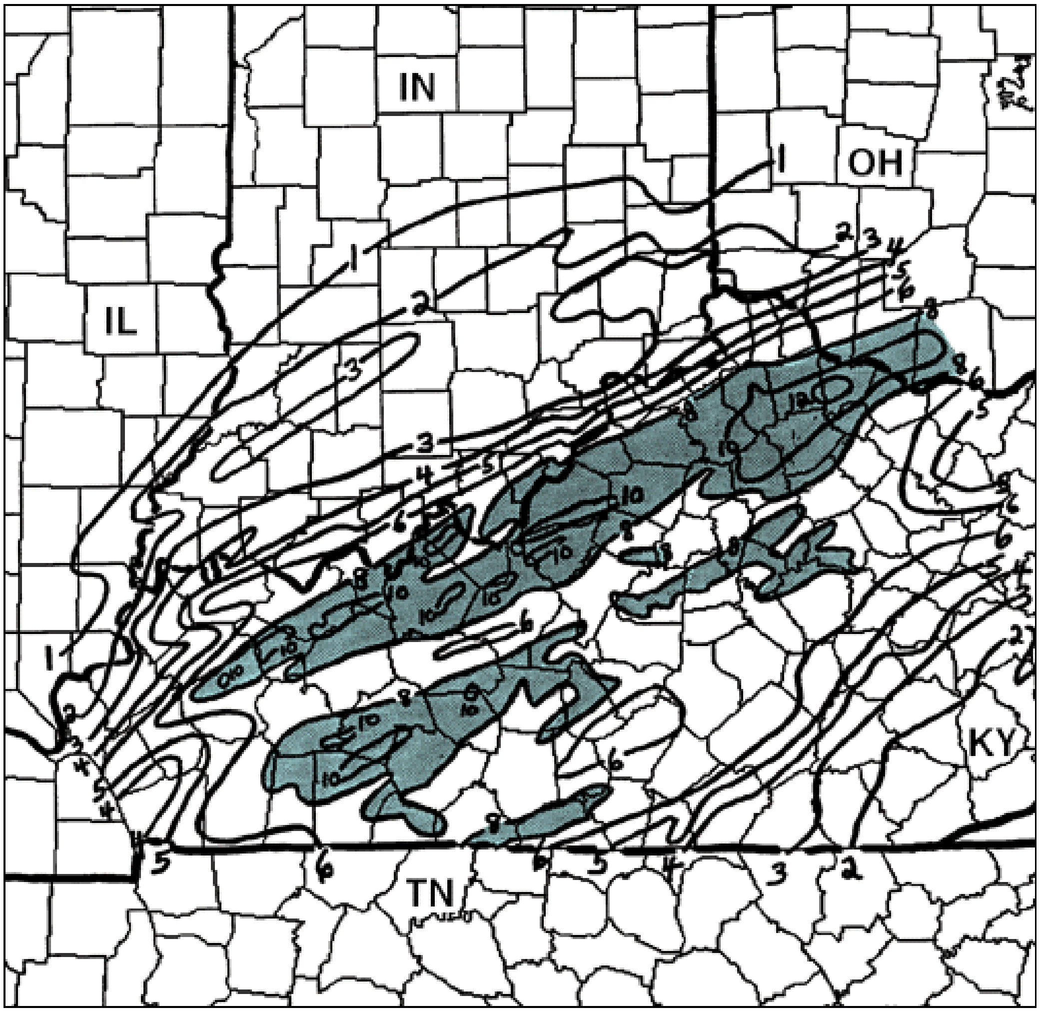

Figure 1. Storm Total Rainfall March 1-3, 1997.

losses may have been preventable. A dozen deaths were caused by drowning associated with vehicles being swept away by flood currents. One university professor drowned while kayaking on a flooded river, two drowned in a canoeing accident during the height of the floods, and another reportedly drowned while floating in a flooded stream in an inner tube. Five other victims of the floods were safely evacuated but became worried about their property and returned home only to be trapped by rising water and drowned. The specifics on the remaining deaths were not available.

Modernized NWS Forecast and Warning Services - An Operational Assessment

The NWS offices involved in this flood event produced literally hundreds of flood watches, warnings, and follow-up statements. NWSFOs at Cleveland, Indianapolis, Louisville, and Charleston issued flash flood watches for their respective forecast areas 4-8 hours ahead of the first occurrence flooding. New "spin-up" offices (e.g., NWSOs in Paducah and Jackson, Kentucky, and Wilmington, Ohio) were tested during this major event. Although many of their staffs had little or no previous experience dealing with a flood event of this magnitude, the service assessment revealed that each office performed admirably by providing timely and effective flood warnings for their service areas. Ironically, Jackson, Kentucky, assumed responsibility for their hydrologic service area (HSA) on March 1, 1997, the first day of the flood.

NWS modernization and restructuring includes the transferring of forecast and warning services from the original 52 weather service forecast offices (approximately one per state) to 121 "advanced" Weather Forecast Offices across the country. The transition for hydrologic services to the spin-up offices in the Ohio Basin was completed prior to the timing of the event. This produced many positive effects on field operations and services, as demonstrated during this flood. For example, the NWSFO Louisville office previously was responsible for 80 specific river forecast points. This number has now been reduced to 23 with the remaining sites distributed to several of the new offices; such as, Paducah, Jackson, and Wilmington.

Having the workload distributed to all of these offices helped make the job more manageable and helped the staffs produce more timely flood watches and warnings. One negative effect the transition has produced is that by dividing some of the river basins between two or more HSAs, it now makes data collection and forecasting more complex requiring the River Forecast Center and emergency managers (and other customers) to coordinate with more local NWS offices.

The implementation of a National quantitative precipitation forecasting (QPF) program was another NWS modernization milestone that helped NWS meteorologists and hydrologists perform more effectively. Forecasters are now able to use a combination of hydrometeorological tools provided by NWS modernization (e.g., mesoscale models, WSR-88D radar, and satellite estimates of precipitation, etc.) along with specialized training to predict the location and timing of significant rainfall.

The OHRFC has been engaged in a Modernization Risk Reduction Exercise that was initiated in 1991 to evaluate the interaction of the RFC HAS function in the production of QPF through the assimilation of QPF input from NCEP and the NWSFOs/NWSOs serving the Ohio Basin. As a result of this effort, two interactive operational software components (HASQPF and WINQPF) were developed. These were used effectively during this major event to create QPFs, produce an RFC mosaic of the QPF, and process the basin average QPFs into the OHRFC forecast model.

While the production of QPF is somewhat new to many local NWS offices (NWSO Wilmington started producing routine QPF in October 1996), the Hydrometeorologic Prediction Center (HPC) has been involved in producing National scale QPF for 20 years. Their expertise and leadership have been instrumental in helping develop similar abilities at the local offices.

The HPC QPF products are used as guidance by the local offices. Despite only modest success with the 24-hour QPFs, there was considerably more important information relayed to the field offices through the HPC 6-hourly forecasts and excessive rainfall forecasts. A special excessive rainfall discussion issued at 10:00 p.m. Friday, February 28 indicated a potential for flood producing rains in the Ohio Valley, and, as early as 2:00 a.m. Saturday, March 1st, the HPC sent messages to the field offices raising the concern of a very serious flood threat for the region. This was 6-12 hours before the first significant flooding developed.

Internal and External Coordination

A review of the official logs indicated that coordination of critical information (e.g., QPF gage data, etc.) was effectively accomplished between National, regional, and local NWS offices. Interviews with users revealed the transfer of forecast and warning information to state and local emergency management was performed with sufficient time to permit life-saving evacuations in many cases and property-saving emergency actions in several others.

The local NWS offices as well as regional public affairs specialists handled large volumes of queries from the media on national and local levels concerned about the flooding. Contacts included: ABC, CBS, and NBC television networks, Jim Lehrer News Hour, World News Tonight, Discovery Channel, NBC Dateline, Associated Press, “The Washington Post”, “USA Today”, and almost all of the local newspaper, radio and television outlets. A media advisory prepared by Eastern Region and distributed over the NOAA Fax Board and Internet system listed NWS personnel the media could contact for information in the Eastern, Southern, and Central Regions. Also included were NWS Internet addresses for online information.

Summary

The Assessment Team reports that NWS forecasts and warnings, along with extensive preparedness efforts, resulted in substantial savings in flood damages and helped reduce the number of deaths and injuries caused by the floods. Effective use of new technologies; such as, the WSR-88D radars and STORMS and IFLOWS raingage networks significantly helped forecasters monitor conditions and produce early flood watches and warnings. When equipment and communications failures did occur, NWS offices worked effectively to minimize the impact on operations.

Current efforts to implement more sophisticated river forecasting procedures were not in place during this event. This brings hope that these improvements will lead to even more timely and accurate forecasts of future floods. Restoration of stream gages that have been closed; such as, the one discontinued at McKinneysburg, Kentucky, will continue to be a high priority, especially for those gages located upstream of flood prone areas. Certainly, timely data from these gages would also improve the timeliness and accuracy of our forecasts and warnings.

However, the larger challenge for the NWS is to continue to develop the capability to predict large rainfall events that produce excessive amounts of rain and cause devastating floods. In order to advance our capabilities, we need improved science, modeling, operational enhancements, real-time automated data, and the ability to portray the uncertainties in the forecast data in a way the public and other NWS customers can understand and use. In addition, outreach efforts to better educate emergency managers, media, and the general public regarding the dangers associated with flooding need to be increased in order to help reduce the number of lives lost and damages incurred during floods like **the Ohio Valley Flood of March 1997**.

FINDINGS AND RECOMMENDATIONS

Ohio River Forecast Center

Finding A-1: Ohio EMA expressed interest in probabilistic river stage forecasts and urban flood inundation maps in order to assess the "worst case" scenarios and the magnitude of high, medium, and low-risk events.

Recommendation A-1: The OHRFC should implement procedures which can be used to create the types of river products Ohio EMA has requested.

Finding A-2: River forecasts are created by OHRFC and intended for the use of the local NWS offices it supports, as well as some special cooperators. Improper redistribution by some cooperators has made these "internal" products accessible to the public via the Internet.

Recommendation A-2: Appropriate labeling and disclaimer information should be used in these products and on webpages to eliminate any potential confusion between the content of the river forecasts issued by the OHRFC and the River Flood Warnings and Statements issued by the local NWS offices. OHRFC should coordinate with the USACE to ensure that river forecasts are not distributed, to the extent permitted by law.
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NWSFO Louisville, Kentucky

Finding B-1:   During the flooding, NWSFO Louisville was involved with multiple severe weather threats as well as the flood threat. All fatalities in the Louisville service area, however, were flood related.

Recommendation B-1: NWS Louisville should increase the visibility of the dangers associated with flooding in their weather education programs, and to the extent possible, increase their outreach efforts on flood preparedness.

NWSO Wilmington, Ohio

Finding C-1: NWR coverage is poor in Scioto County, Ohio, and the surrounding area.

Recommendation C-1: The NWS should continue to work with the Ohio EMA and others on getting the necessary equipment installed and operating in the Portsmouth, Ohio, area.

Emergency Management

Finding D-1: Kentucky and Ohio emergency operations centers (EOCs) have a tremendous workload during severe weather and flooding events as they become inundated with numerous watches, warnings, and follow-up statements from several different NWS offices. The EOC has a difficult time assimilating this information and relaying it to the county EMs.

Recommendation D-1: Changes should be considered in NWS products to make them easier to understand and use by customers such as the EOCs.

Finding D-2: Kentucky Emergency Management Officials were not fully aware of modern information technologies; such as, the Internet and the Emergency Management Weather Information Network (EMWIN), that can provide them with access to important NWS weather forecasts and warnings.

Recommendation D-2: NWSFO Louisville should inform and educate Kentucky Emergency Management on these information technologies.

Finding D-3: There is a high turnover rate at the local (county) offices of emergency management. These people play a critical role in disseminating important weather warnings and information in their communities.

Recommendation D-3: The local NWS should become more active in working with the state and county emergency management officials in Kentucky and help plan and conduct periodic training workshops.

Finding D-4: Emergency management officials experienced added levels of complexity in interpreting NWS products issued under different regional policies.

Recommendation D-4: Recognizing that products are tailored to meet the needs of several different local customers, NWS headquarters and regional offices must address product uniformity and standardization to reduce impact on users; such as, state EMs, who rely on products from several different NWS offices.

Finding D-5: A valuable supplemental service was provided to the emergency management community by the use of pagers to alert EMs in Ohio of the issuance of watches and warnings. Pagers have been particularly useful in areas where NWR coverage is poor or when EM directors are away from their homes or offices.

Recommendation D-5: EMs should take advantage of commercial pager services that currently deliver NWS watches and warnings available from EMWIN or NWW.

Finding D-6: The video "Low Water Crossing - The Hidden Danger" that was produced by the NWS Office of Hydrology (OH) has become a very popular tool in revealing the dangers that develop when roads and bridges become covered by flood water. (Over one-third of the fatalities caused by the severe flooding during this event were operators or passengers of vehicles that were swept away by flood waters.) The Kentucky DES would like to get sufficient copies of the video to provide one to each of their 120 county EMs.

Recommendation D-6: OH should provide copies of the video to Kentucky DES.

Observational Data

Finding E-1: Weather Service Radar-88D (WSR-88D) precipitation estimates were the invaluable tool that most flash flood warnings were based on. Radar precipitation estimates were within an inch of reliable ground truth measurements. The WSR-88D performed superbly during the event.

Recommendation E-1: None.

Finding E-2: The rain gage network in many parts of Kentucky (including the Licking River Basin) is not adequate to provide a good estimate of the areal rainfall.

Recommendation E-2: NWS officials at local, regional, and National levels, as well as the EM community, need to remain focused on reducing this problem. If funding becomes available, the Kentucky IFLOWS Network should be expanded to include these data-sparse areas. Also, all efforts should be made to expand and complete the STORMS system in Ohio as originally planned.

Finding E-3: Many manually read stream gages (including those located at Falmouth and Blue Licks Spring, Kentucky) were inaccessible due to high water during the flooding.

Recommendation E-3: NWS should produce a prioritized list of sites that could be automated and continue to work with cooperators to establish a more effective stream gage network as funding permits.

Dissemination

Finding F-1: The Internet played an important and significant role supplementing NOAA Weather Wire (NWW) and NOAA Weather Radio (NWR) in the warning information dissemination process. However, not all NWS products are currently available over the Internet.

Recommendation F-1: The Interactive Weather Information Network (IWIN) should be enhanced and become a reliable database that includes access to all NWS public products.

APPENDIX A

HYDROMETEOROLOGICAL SUMMARY

Antecedent Conditions

Soil moisture was near normal across the Ohio Valley prior to the March floods. While precipitation had been at, or above, normal in the fall, the winter months of December through February saw precipitation amounts averaging nearly 200 percent of normal. The growing season had not started. Therefore, once heavy rain developed, greater runoff volumes were produced than would have occurred had the vegetation been active. Stream levels were well within their banks and the main stem rivers, including the Ohio River were at seasonal levels. There was no snowpack in the Ohio River Basin on the last day of February, the day before the heavy rains started to fall.

Hydrometeorological Discussion

Large scale mechanisms provided all of the right ingredients to produce excessive rainfall. An upper level ridge was positioned over the east coast with a longwave trough located just east of the Rocky Mountains at 00Z Coordinated Universal Time (UTC) on Saturday, March 1, 1997. This produced a southwest flow aloft over the Ohio Valley throughout the first weekend in March. Perturbations were ejected out of the base of the trough and traveled over the Ohio Valley producing an unstable atmosphere. A low level jet with wind maximums of 50 knots developed and persisted for more than 24 hours. The low level jet helped transport abundant moisture and warm temperatures northward into the region Friday night and Saturday. Precipitable water values increased to nearly 200 percent with surface dew-points in the region reaching into the mid-60s.

A warm front proceeded to move slowly northward during the day reaching north of the Ohio River by Saturday night. Widespread moderate to heavy rainfall developed over Arkansas and Missouri then spread northeast across the Ohio Valley. Extremely strong storms over the mid-south produced destructive tornadoes with the greatest devastation occurring in Arkansas where over 20 deadly twisters developed during the day.

The instability axis shifted northeast and intersected with an outflow boundary over Kentucky late Saturday. Steady rainfall conditions developed over northern Kentucky, as well as adjacent parts of southern Indiana and Ohio, and western West Virginia, fed by a persistent influx of Gulf moisture transported northward by the low level jet. Copious rainfall continued Saturday night and into Sunday morning as numerous thunderstorms repeatedly tracked over the same area. The rain temporarily subsided Sunday but reintensified as the main upper level storm system kicked out and traversed the region Sunday night and early Monday.

APPENDIX B

FOCUS AREAS

QPF

QPF is a future basin average precipitation forecast product which is input directly to rainfall runoff models for river forecasting. The end-to-end QPF process starts with the issuance of QPF from NCEP's HPC. These National-scale QPF products are used as guidance by the Weather Forecast Office (WFOs) and RFCs. WFOs issue local-scale QPF based on several factors, including HPC products, atmospheric model output, current hydrometeorological factors, including remote-sensed data (e.g. satellite, sounding, and radar information, etc.), and knowledge of local climatology. All the WFOs in the OHRFC area send their QPF to the RFC where it is mosaicked together, and significant inconsistencies between adjacent areas are resolved using verbal communications or with software tools. In this particular event, the HAS forecasters called HPC and the WFOs to coordinate on the final QPF estimates before using them as input to the hydrologic models.

Figures 2a, 2b, and 2c, show QPF from the HPC, WFOs (NWSFOs and NWSOs), and OHRFC, respectively, spanning from 12Z on March 1 through 12Z on March 2. Figure 2d shows the observed mean areal precipitation (MAP) for the event. Figure 2a shows the HPC QPF forecasts attempted to resolve the large-scale temporal and spatial character of the precipitation and generally predicted the rainfall pattern to be in an elongated southwest to northeast pattern.

WFO QPF attempted to resolve these same precipitation characteristics at a much finer resolution. Figure 2b is a composite of QPF forecasts issued by several NWS offices in the OHRFC area of responsibility. As these forecasts were issued a couple of hours after the HPC guidance, it is clear that forecasters made some adjustments moving the area of greatest rainfall expected northward and closer to the forecast position of the warm front. The magnitude of the expected maximum rainfall was increased as well. The figure also illustrates significant spatial differences in forecasts that can occur between different offices. (For example, notice 3 inches (light purple) v.s. 1 inch (red) in northern Kentucky.)

Figure 2c depicts how the Hydrometeorological Analysis and Support (HAS) forecaster at the RFC eliminated these sharp differences by smoothing the spatial variability of the QPF into an RFC-wide product. Figure 2d shows the observed basin average rainfall for the 24-hour period. The figure identifies the sharp spatial boundaries and variability of the observed rainfall. Although the mosaicked QPF did not capture the small scale differences and maximum rainfall that occurred in these sub-basins, it was accurate at depicting the basins where the rainfall was concentrated. Updated QPF was used in later model runs as forecasters and hydrologists continued to produce forecasts and warnings of the rising river levels.

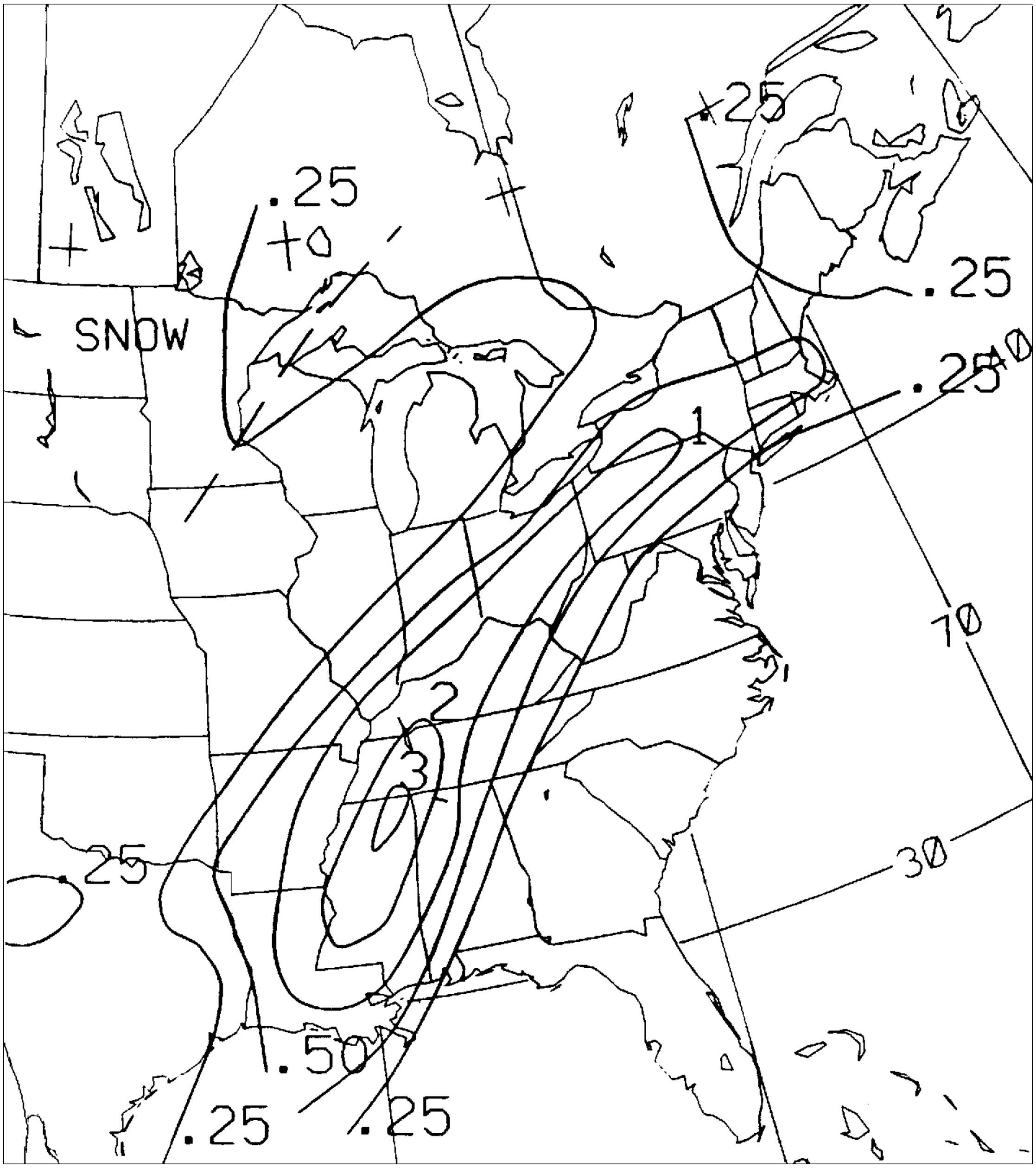

Figure 2a. HPC 24-hour QPF ending 12Z, March 2, 1997

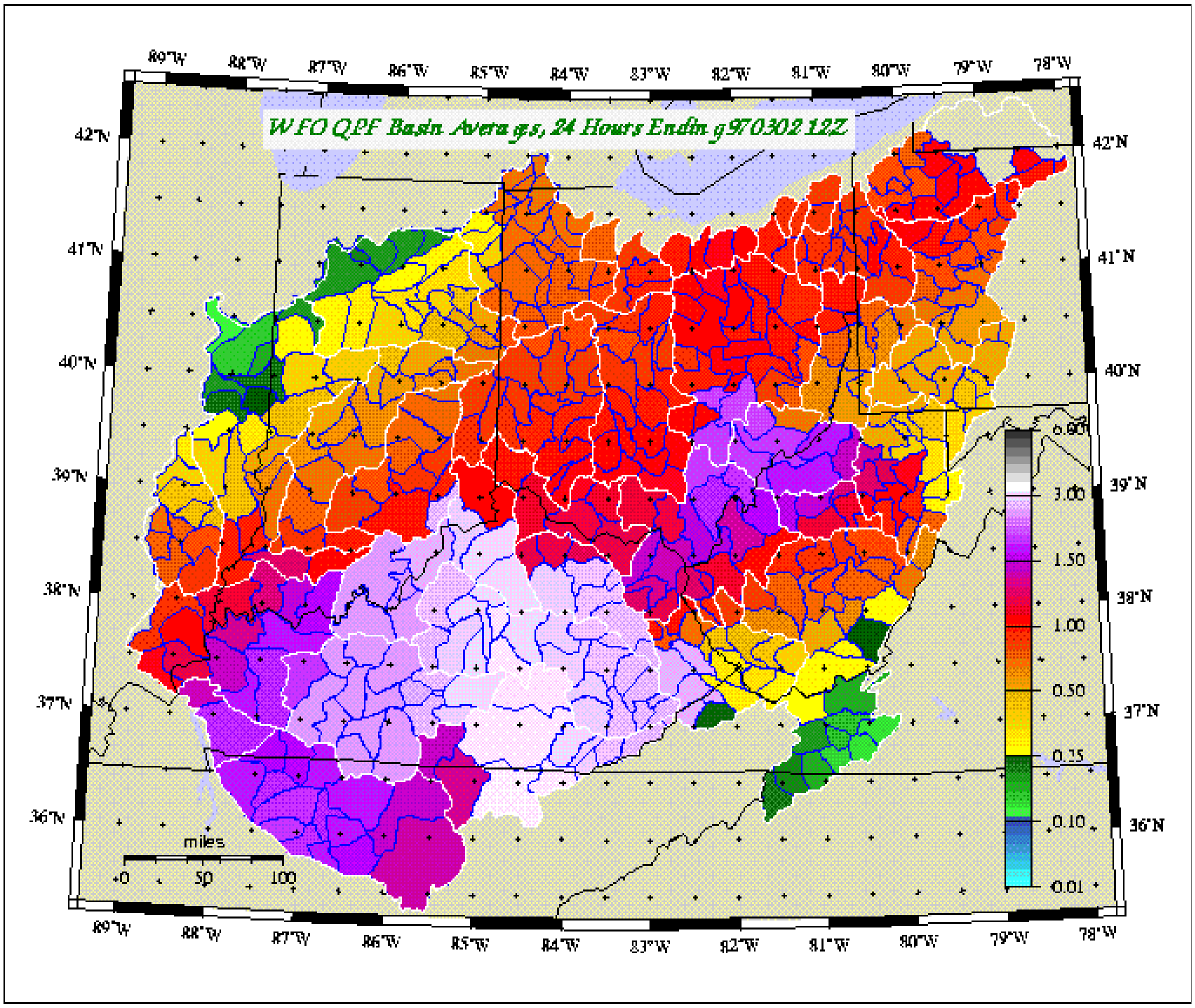

Figure 2b. WFO 24-Hour QPF Ending 12Z, March 2, 1997

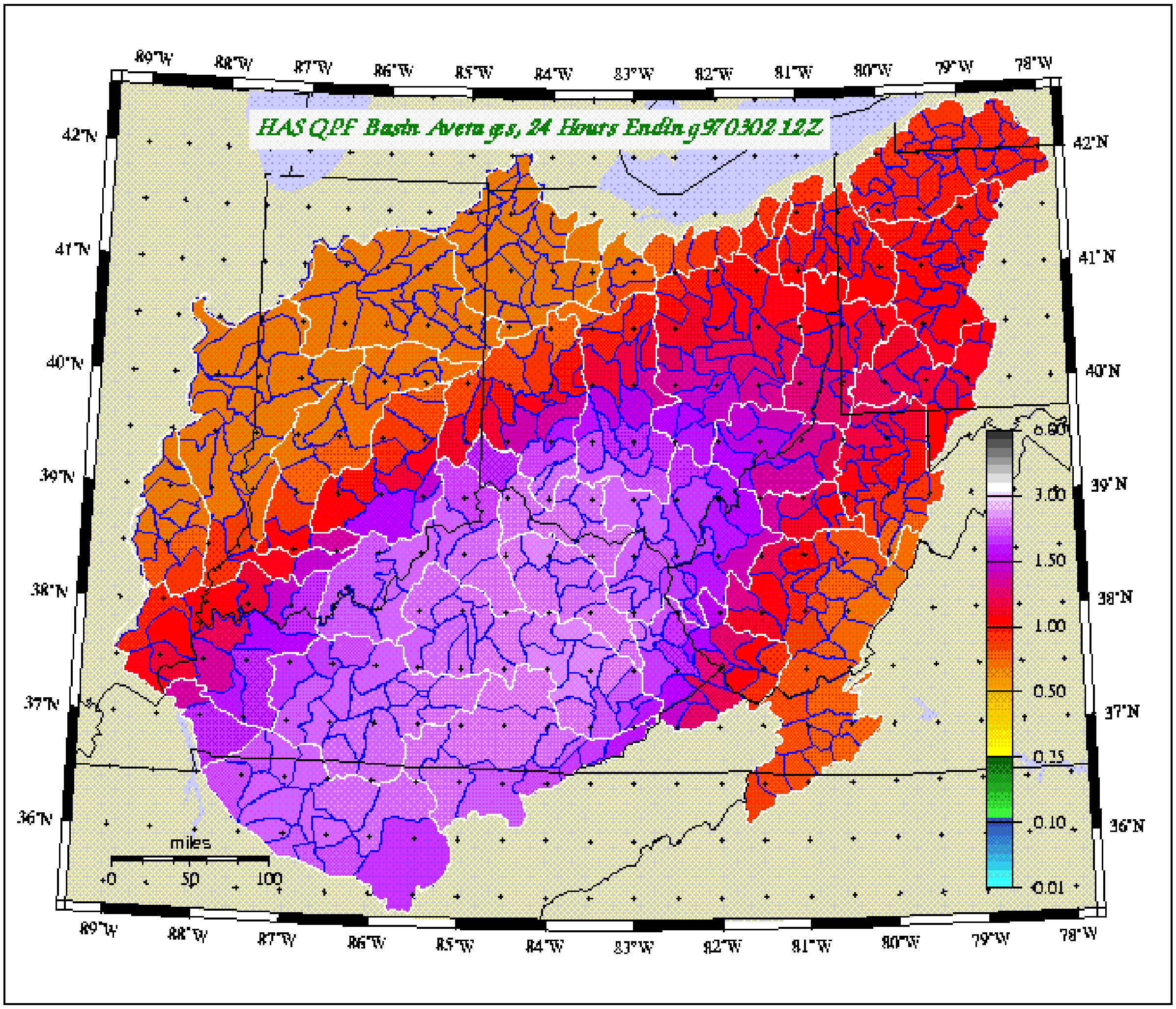

Figure 2c. HAS 24-Hour QPF Ending 12Z, March 2, 1997.

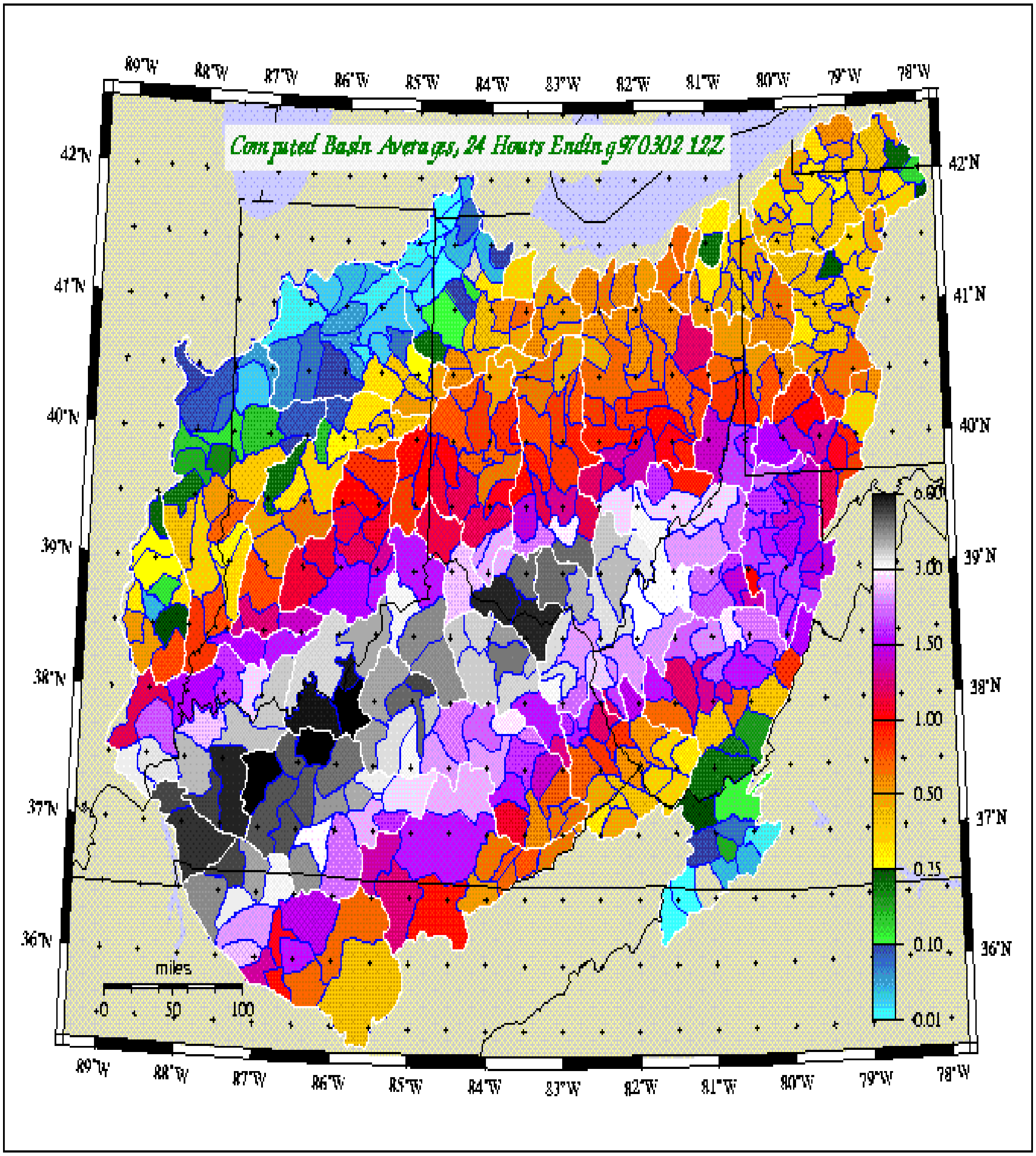

Figure 2d. Actual 24-Hour Basin Avg. Rainfall Ending 12Z, March 2, 1997

Significant training (i.e., repetition of heavy showers over the same area) occurred over numerous river basins in parts of north central Kentucky and southern Ohio. One of the hardest hit areas included the Licking River Basin in which lies the town of Falmouth, Kentucky that was evacuated of its approximately 2,400 residents. Figure 3 shows the location of the Licking River Basin, towns, and NWS offices. A comparison of this map with the previous QPF charts clearly shows the difficulty presented to forecasters and hydrologists who are challenged with predicting the timing and amount of heavy rain over basins of this small a scale.

Stream Gage Reduction

Up until 1994, an automated stream gage and data collection platform (DCP) was maintained by the USGS upstream of Falmouth at McKinneysburg, Kentucky. The site was funded under a cooperative agreement between the U.S. Army Corps of Engineers, U.S. Geological Survey, and the state of Kentucky. The gage was removed due to loss of funding in the fall of 1994. The NWS strongly opposed the closure of the site and made unsuccessful attempts to keep it active.

A wire-weight gage exists at Falmouth, Kentucky. Cooperative observers take manual readings and report river stage levels to the NWS typically once a day. During high water episodes, the cooperative observers can be relied upon to provide updates to the NWS more than once a day. Darkness and extreme flooding make reporting difficult or impossible. This was the case during the March 1997 flood event.

The lack of telemetered stream level information delayed critical information from being relayed to NWS forecasters and hydrologists. However, the impact on the timeliness and accuracy of the river stage forecast at Falmouth is not exactly known as the river forecast system could not be reproduced during the service assessment.

External Coordination

The emergency management agencies of both Kentucky and Ohio reported being very satisfied with the levels of coordination experienced during the event. They had high praise for the responsiveness of NWS offices to meeting their needs and the levels of interaction that occurred between the NWS and their own agencies. Two issues that were raised were 1) the complexity of dealing with the large volume of products issued during the flooding event from multiple offices and 2) non-standardization of product content and format.

During the event, Ohio EMA received volumes of flood bulletins from NWS offices in three states. The EMA reported that efforts to ingest information coming from different offices and decipher it all into a single composite increased the difficulty of their tasks. Kentucky

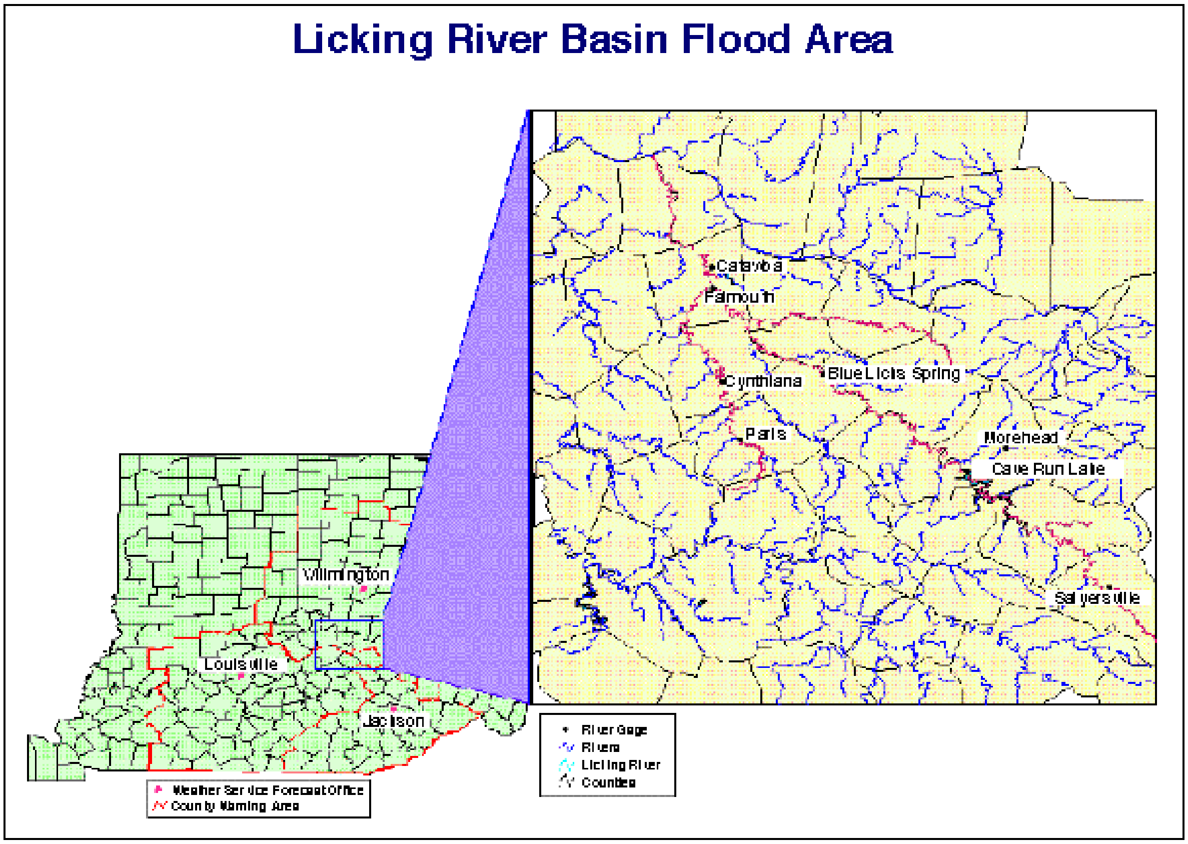

Figure 3. Licking River Basin Flood Area.

Department of Emergency Services (KDES), which was involved with products from NWS offices in two different states (in two different NWS regions), reported similar experiences and expressed a desire for the NWS to provide some relief from their information recompositing and mosaicking requirements.

Ohio EMA, which, unlike Kentucky, does not have a watch officer on duty at the state EOC 24 hours a day, also expressed being very pleased with pager notification of watch and warning issuances by NWS offices within the state. They reported receiving excellent "heads up" information from the NWS state liaison office (NWSO Wilmington) in order to spin up their operations and follow up on information as the event developed. They requested that NWS offices located outside the state boundaries that serve Ohio counties provide a similar service. Pager notifications, however, could become a significant work load issue for local offices if not controlled in some manner under some consistent policy. Automating the entire procedure to eliminate any extra steps by a forecaster would help address this potential.

APPENDIX C

DATA COLLECTION SYSTEMS

Background

Most automated data collection networks that provided river stage and rainfall information to the NWS and EMs performed well during the event. However, the frequency of information from automated DCPs was limited to the 4-hour reporting criteria established by the U.S. Army Corps on Engineers (USACE). Automated networks; such as, the STORMS and IFLOWS provided near real-time reporting updating every 15 minutes. A computer failure at NWSO Wilmington did, for a time, compromise the availability of STORMS and IFLOWS data to the Wilmington office (see below). There were also a few stream gages lost during the flood, but most operated reliably throughout the event.

Manual coop observer networks were significantly degraded at critical times during the event as observers became increasingly involved in efforts to protect their own lives and property. NWSFO Louisville lost about 30 percent of all its observers as the event unfolded. Losses were greatest in areas where rain fell the heaviest and from which the information was most needed. While NWSO Wilmington lost the input from only a few manually collected observations, one of those lost was from Falmouth, Kentucky. The last stage reading NWSO Wilmington received from Falmouth, taken by a dedicated observer using a wire-weight gage, was about 12:00 noon on Saturday, after which the observer was evacuated. Police and emergency management personnel attempted to continue to keep the Wilmington office informed of river stage; but as the gage site became increasingly inaccessible, and eventually totally submerged, only crude estimates from a distance could be provided.

WSR-88D doppler radar estimates of rainfall were very accurate and were the primary tool by which both NWSFO Louisville and NWSO Wilmington issued their flash flood warnings. While extreme catches of rainfall at specific gages (13.42 inches for IFLOWS and 9.18 inches for STORMS) did exceed radar estimates, the WSR-88D depicted rainfall distribution and average intensities very accurately and was indispensable in keeping forecasters appraised of the developing situation.

Automated Flood Warning Systems

Automated flood warning systems (AFWS) utilize real-time event-initiated precipitation gages, stream gages, and other automated sensors to provide the NWS and emergency management (EM) community time-critical information on flash flood threats. Information is provided on a time frame, at a frequency, and from locations at which it otherwise might not be available. Whether used independently or in conjunction with WSR-88D radar information and other modernized NWS technologies, such systems can be a very effective tool for forecasters to use in maximizing lead times for flash flood watches and warnings and to provide input into river forecast models for the preparation of main stem river forecasts.

Kentucky IFLOWS

The Kentucky IFLOWS is operated under a cooperative program administered by the State of Kentucky and the NWS. As one of the original IFLOWS states, Kentucky operates and maintains the system while costs of capital infrastructure replacement are funded through the NWS.

Kentucky IFLOWS is a combined broadcast and polled system. As one of the earliest implementations of the IFLOWS concept, only local NWS offices, the state Emergency Operations Center (EOC) in Frankfort, and five state emergency operations centers are fully networked with full two-way communications capability. The 37 Kentucky county base stations that are also part of the system operate in a receive only (broadcast) mode. The state computer system in Frankfort controls information on the Kentucky network and distributes data and message traffic to all computers attached to the network including machines at NWS offices in Jackson, Louisville, and Wilmington. Information is passed on further through gateways to other IFLOWS networks including those of Virginia and West Virginia.

The Kentucky Emergency Warning System (KEWS), a state-wide microwave network, is used extensively for many of these connections. The NWS Automation of Field Operations and Services (AFOS) network connection to Kentucky IFLOWS is at NWSFO Louisville. With the integration of a USACE flood mitigation project in Harlan County, Kentucky, there are now 165 precipitation gages and four streamgages in Kentucky available to the NWS and EM personnel over this network. All are located in the eastern portion of the state and, with one exception, in the service areas of NWSFO Charleston, NWSO Wilmington, and NWSO Jackson. NWSFO Louisville has one IFLOWS gage located in its warning area.

Ohio STORMS

STORMS is a cooperative effort by the State of Ohio and the NWS and fully funded through the State of Ohio. The state supplies all equipment and maintenance for the system. Ohio plans to install STORMS precipitation gages in at least 44 of its counties and has begun implementation with its most flash-flood-prone counties first.

STORMS presently uses a modified version of NWS IFLOWS software to collect precipitation data via a state-operated microwave system which passes it on to base stations at the state emergency operations center in Columbus and NWSFO Cleveland. Information is then passed via the IFLOWS AFWS network to Weather Service Offices in Wilmington, Charleston, and Pittsburgh. Ohio counties dial into the state emergency management computer site at Columbus for information on rainfall, flash flood guidance, etc., in their own areas. Ohio STORMS data enters AFOS at NWSFO Cleveland. Together with a City of Cincinnati and Hamilton County data system, which has been integrated into the STORMS and IFLOWS networks, there are now 105 precipitation gages and 4 stream gages installed in 23 Ohio counties. At the time of the event, a computer at NWSO Wilmington was controlling the exchange of information between NWSO Wilmington, NWSFO Cleveland, and the state EMA in Columbus.

System Performance

IFLOWS and STORMS data were characterized as being extremely valuable, and practically indispensable, by offices having parts of these gaging networks in their service areas. This information was used by offices to keep ahead of the event as it progressed from urban flooding to flash flooding to small stream flooding and, finally, to river flooding. The information helped forecasters make critical and timely decisions to warn as the event unfolded.

The excellent performance of the WSR-88D in this event offset, to some extent, NWSFO Louisville's absence of real-time gage data. Extensive coordination between Louisville and offices with IFLOWS and STORMS information under their radar umbrellas (e.g., Wilmington, Jackson, and Cleveland), appears to have also increased and verified the confidence Louisville staff placed in the high values the WSR-88D was reporting for rainfall intensity during the event.

At approximately 8:34 UTC on February 27, the NWSO Wilmington computer which is the office's link to both the Kentucky IFLOWS and the Ohio STORMS networks, stopped communicating. Initial efforts to restart the system and reestablish communications were unsuccessful. Since Wilmington was the controlling system among the three networked offices in Ohio, information exchange over this network ceased between NWSO Wilmington, the state EOC at Columbus, and NWSFO Cleveland. However, both the state EOC at Columbus and NWSFO Cleveland continued to receive STORMS information over their direct connections to the state microwave system. NWSFO Cleveland continued to pass information on to other NWS offices over the AFWS system. The time intensive task of rebuilding Wilmington's computer system files was later undertaken and the system brought back into the networks at approximately 14:34 UTC on March 1.

During the time the computer was off line, NWSO Wilmington relied on AFOS for hourly STORMS and IFLOWS information. Wilmington also dialed into the state STORMS computer at Columbus for STORMS graphical applications and data of increased frequency. There was some initial confusion involving a 12-hour time shift on time stamping for the onset of the event, and data representation, on the state STORMS computers. The Ohio

EMA is continuing to investigate what may have caused this. They are now of the opinion that it was a software problem which had not manifested itself previously because of the nature of this event. It was of such intensity that it was the first time so many reports from so many of the increasing numbers of STORMS gages were processed at the same time. The state is taking steps to address such scenarios in the future. These irregularities were limited to STORMS computers and were not reported in Ohio STORMS gage data that was processed by NWS IFLOWS computers and passed into the AFWS network.

With regard to the Wilmington computer failure, it does appear the problem was at Wilmington and was specific to the machine and not with the communication links to it. Rebuilding the files to get it back up and running, however, destroyed much of the information on the status of the system when it failed and may make the ultimate conclusions as to what actually caused the failure speculative.

NWSO Wilmington has responsibility for 12 Kentucky counties, but only four have IFLOWS data. Gage data was not available in the Kentucky area where the NWS believes the heaviest rain fell (based on radar analysis). There is an active co-operative observer program in this area, but their gages were destroyed, or they were unable to report due to personal need to evacuate.

The State of Ohio is in the process of expanding STORMS coverage to five gages per Ohio County. The NWSO Wilmington is very satisfied with the support from the State of Ohio for the STORMS network.

Alternative Data Collection/Dissemination Sources

Approximately one week prior to the event, NWSFO Louisville implemented the transfer of Kentucky IFLOWS information to an office Internet Web page. Since then, data from other states has been added. This serves as a secondary source of precipitation information on a frequency greater than that which is transferred over AFOS for data from Ohio as well as that from Kentucky in the event of a future systems failure. In addition, the State of Ohio intends to link NWSO Wilmington to the STORMS data collection network with a dedicated line in order to provide NWSO Wilmington with direct access to unfiltered STORMS data. While failure of communications links has not been identified as a cause of any data flow interruption during this event, the additional connectivity would further ensure Wilmington's access to the STORMS data stream in the future.

APPENDIX D

OFFICE SUMMARIES

<u>Ohio River Forecast Center</u>

Hydrologic Modeling and Transition Status

River forecasts produced by the OHRFC, in particular those on the main stem of the Ohio River, were both accurate and timely and provided excellent lead-time for users. The OHRFC used a locally developed river forecast system called the Interactive Forecast Model (IFM), which was developed in 1988 and designed specifically for the Ohio Basin. This unique IFM system is DOS based and runs on a personal computer . It was started with early versions of the NWS River Forecast System (NWSRFS).

The latest version of NWSRFS is a nationally supported Unix workstation based modular forecasting system which allows an RFC to: process radar data for flood forecasting, change model time step output to a shorter time step; such as, 3 hours, uses the Sacramento model which is the cornerstone of NWS hydrologic forecasting; calibrate both runoff and snow melt models; generate probabilistic ensemble forecasts; perform reservoir modeling; and implement the advanced dynamic channel routing techniques in Operational Dynamic Wave Model (DWOPER) and Flood Wave Dynamic Routing Model in NWSRFS (FLDWAV).

The OHRFC transition to modernized operations was initiated in 1995 but was side-tracked due to a shortage of staffing and extensive flooding that occurred in the Ohio Valley in 1996 and 1997. The transition includes a conversion from IFM to the Interactive Forecast Program (IFP) which consists of the proven hydrologic physical process modeling of the NWSRFS's Operational Forecast System (OFS) combined with a graphical user interface (GUI) to provide river forecasters with: (1) the information needed to make decisions about the correctness of data or model results, and (2) the capability to easily and quickly put those decisions into action to produce forecasts reflecting their best judgement about current and future hydrometeorologic conditions.

Completion of the transition plan will provide the foundation for advanced hydrologic modeling techniques; such as, flood inundation mapping, distributed modeling, and the processing of probabilistic quantitative precipitation forecasts (PQPF) required to produce probabilistic river stage forecasts (PRSF).

The computer hardware required to perform the transition plan to NWSRFS is already in place at the OHRFC. Training of the OHRFC staff has been given in the areas of NWSRFS, the operational forecasts system (OFS), the Sacramento model and snow model calibration, and the interactive calibration program (ICP).

HAS Activities

The HAS program was implemented at OHRFC in 1989 (see reference to Risk Reduction exercise mentioned in the Executive Summary.) Three HAS forecasters on staff are joined by HAS-qualified hydrologists to assist with the workload when necessary. Routinely, they work two shifts covering 7:00 a.m. to 10:00 p.m. seven days a week. The HAS function went on 24 hours a day shift work starting at 5:30 a.m. on Saturday, March 1, and continued until March 10.

There are many demands on the person performing the HAS function; such as, quality control of the multi-sensor precipitation estimations (Stage III) and coordinating QPF with all the forecast offices in the RFC boundary. The HAS function is ultimately responsible for finalizing QPF for input into the hydrologic models. OHRFC HAS forecasters specifically mentioned the possibility of heavy rain as early as 6 days prior to the flood event and did an excellent job of coordinating with local offices and the HPC during the event.

During the flooding, WFOs are generally updated QPF twice a day and submitted it to the OHRFC. The OHRFC produced a mosaicked version of the QPF input from the WFOs that was then used as input to river forecasts.

Radar Precipitation Estimates - Stage III

Stage III is an hourly gridded precipitation product which mosaics together all the various radars in the RFC area and optimally merges them with the gage precipitation estimates. The HAS forecaster reviews the hourly Stage III products for problems. This manual quality control procedure is very time consuming.

Stage III has been running at the OHRFC since 1995 but was not used directly as input to hydrologic models during the flood. HAS forecasters experienced extended periods of time where Stage III products did not get reviewed because attention was concentrated on monitoring the event at hand, updating QPF, and coordinating with WFOs.

When Stage III was run, and when the Post Analysis was produced, it was helpful and provided accurate hourly precipitation estimates. The 1-hour precipitation estimates were very helpful when 6-hour gages had not reached their reporting times and for assessing the precipitation fields at odd synoptic times. Figure 4 shows a Post Analysis product which compares 24-hour storm totals from the Stage III hybrid precipitation estimates with that of the gage-only precipitation estimates. The figure shows that Stage III performed very well.

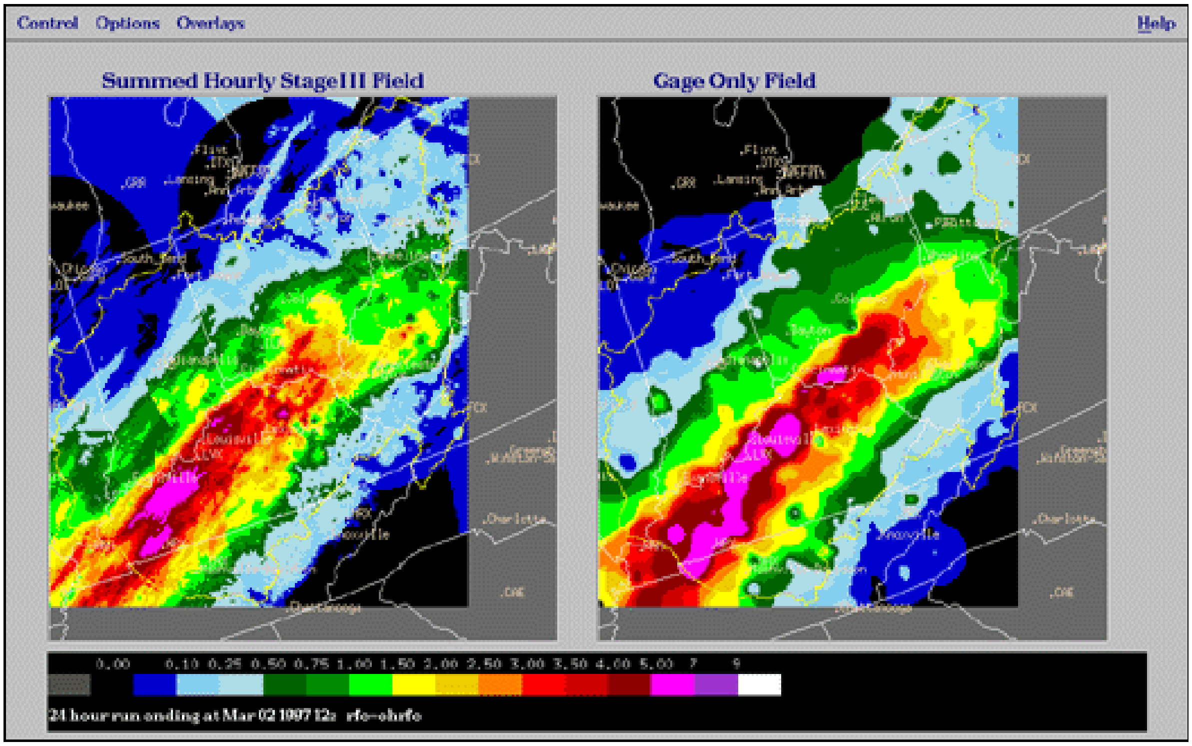

Figure 4. Stage III Precipitation Estimate Ending 12Z, March 2, 1997

Operations at OHRFC During a Record Flood Event

Hydrologic forecast shifts are staffed at OHRFC from 6:00 a.m. to 10:00 p.m. However, once the radar and ground based gage networks observed significant precipitation developing in the Ohio Valley, OHRFC began 24-hour staffing starting 5:30 a.m. Saturday, March 1, 1997, and continuing for 10 days until midnight on Monday, March 10, 1997.

Using precipitation data and QPF, the RFC created numerous river forecasts that were used by local weather offices who issued dozens of critical flood warnings that helped save hundreds of lives. One such area was Falmouth, Kentucky, where an accurate and timely flood forecast and warning was instrumental in helping to initiate the evacuation of the town's residents.

OHRFC had a tremendous number of telephone calls to deal with. The media contributed a disproportionately large volume of calls to the RFC workload. Even the public was calling the RFC for information without going through the established channels. Barge operators on the Ohio River were reported to have called from their towboats using cellular phones in order to get the most up-to-date river information.

NWSFO LOUISVILLE

Operations at a Forecast Office During a Record Flood Event

Residents across northern Kentucky and southern Ohio all had the same thing to say about this event. They never saw it rain that hard in their entire lives. It rained, and it rained, then it rained harder. Storm drains failed to handle the excessive runoff rates. Highways became channels for handling storm water surpluses. Cars and trucks became amphibious vehicles, many with passengers trapped within.

The NWSFO Louisville hydrologic service area (HSA) stretches from southern Indiana counties located across the Ohio River from Louisville south to the Tennessee border. As frequently happens, portions of the HSA were under Severe Weather Watches and Warnings while the forecaster was busy issuing the first Flash Flood Watch for the area before dawn Saturday. Flash flood warnings quickly followed before the midnight shift had a chance to be relieved that morning. Rainfall of 1 to 3 inches was already measured in some areas by 12:00 UTC Saturday, March 1.

The threat of severe weather persisted all day over Kentucky. However, actual severe storms remained isolated and primarily developed over the south central and southeast parts of the state. Before noon, forecasters shifted their focus to the heavy, persistent rainfall but still didn't know what kind of a flood fight they were getting into. Additional rainfall during the day on Saturday averaged about 1 to 2 inches.

River gages and cooperative observers began to signal that the excessive runoff was reaching many of the smaller streams and tributaries by early that afternoon. The first of the river flood warnings were issued while flash flood warnings continued to be reissued and updated for nearly every county in the NWSFO Louisville area of responsibility. The precipitation estimates from the new WSR-88D Doppler radars compared well with "ground truth" reports. Point maximums were exceeding 6 inches with basin averages amounting to more than a few inches.

The Louisville HSA includes 23 official river forecast points. Before the end of the day, the forecast office staff had issued river flood warnings with lead times ranging from 0.5 hour to as much as 30 hours for all but one of the 23 locations. (The gage was reading 0.1 foot above flood stage when the warning was issued for the 23rd site.)

A new 24-hour rainfall record was established on March 1, 1997, for Louisville as 10.48 inches of rain occurred. The previous rainfall record for Louisville was 6.97 inches set back on March 9, 1964. This also establishes a new state-wide record for 24-hour rainfall breaking the previous 24-hour rainfall record for Kentucky which was set at Dunmor in Muhlenberg County on June 27-28, 1960, when 10.40 inches were recorded. Although the rain finally diminished, the flood fight lasted for days. Storm total rainfall estimates from the multi-sensor Stage III processing at OHRFC indicated a maximum of 12-13 inches centered over northern Kentucky close to the capital city of Frankfurt. A large swath of 10+ inches covered over 100 square miles.

QPF Activities

NWSFO Louisville has been issuing QPF on a routine basis for over 5 years. QPFs are typically prepared once per day by the midnight public forecaster and issued around 6:00 a.m. Updates were provided whenever requests were received from the OHRFC HAS forecasters. The NWS Central Region has instituted a QPF verification program. Also, the Science and Operations Officer at Louisville has initiated a Cooperative Program for Operational Meteorology Education and Training (COMET) partnership with St. Louis University with a goal to develop improved QPF forecasting methodologies.

NWSO WILMINGTON

Operations at a Spin-up NWSO During a Record Flood Event

NWSO Wilmington is a spin-up office that was commissioned on October 1, 1994. It serves 36 counties in the southwest half of Ohio, 12 counties in north central Kentucky, and eight counties in Southeast Indiana. NWSO Wilmington assumed HSA responsibility on December 1, 1994.

On the evening of Friday, February 28, 1997, a Flood Potential Statement (ESF) was issued just before 2000 UTC emphasizing the possibility of flooding on Saturday night in West Central Ohio. A follow-up telephone call was made to the State Emergency Management Office by the service hydrologist. After coordination with NWSFO Cleveland, Ohio, a Flash Flood Watch (FFA) was issued around midnight and included the Ohio portion of NWSO's Wilmington's HSA. Flash Flood Watches were issued by NWSFOs Louisville and Indianapolis for the Indiana and Kentucky portion of NWSO Wilmington county warning area before daybreak the next morning.

NWSO Wilmington began issuing Flash Flood and Flood warnings between 1200 and 1300 UTC Saturday, based on WSR-88D radar precipitation estimates and precipitation measurements based on STORMS rain gages. Data supplied by both systems proved to be highly reliable. At 1310 UTC a Flood Warning (FFW) was issued for Pendleton County (Falmouth) for urban and small streams. This was followed by a River Flood Warning (FLW) for the Licking River at Falmouth issued at 1524 UTC predicting that river flooding would begin in the late afternoon. Another FFW for Pendleton County issued at 2105 UTC warned that the serious flash flooding was going to continue into Saturday evening. It is estimated the Licking River at Falmouth reached flood stage sometime early Saturday afternoon and crested approximately 24 feet above flood stage Sunday afternoon.

A total of 62 flash flood warnings were issued on March 1-2, 1997. Two of the initial flood warnings were based on RFC headwater advisory tables. Thirteen forecast points flooded. There were two new record flood stages established. The average lead time to flood was between 5 and 6 hours, with the longest lead time over 36 hours. Sixty-five river flood products (warnings and statements) were issued. An important aspect of NWSO Wilmington's operations during the event were human resources. All readily available staff (seven people) worked extra duty during that period. The heavy workload associated with the event pushed the limits of staff's physical and mental ability.

QPF Activities

Prior to this flood event, NWSO Wilmington had been issuing QPF on a routine basis for only 5 months. It was the first spin-up office in the NWS Eastern Region to begin issuing QPF. A QPF training session was given to the staff in September 1996. There is no QPF performance feedback to the forecast staff at this time.

QPFs are typically prepared once per day by the midnight forecaster and issued around 6:00 a.m. For significant rainfalls, additional QPFs are issued in the evening between 6:00 a.m. and 8:00 p.m. NWSO Wilmington contributed to each request for updated QPF input during the event.

Special Coordination Activities with Emergency Managers

NWSO Wilmington maintains a very proactive hydrologic preparedness program in cooperation with the Ohio EMA. Letters were sent to each county Emergency Manager (EM) concerning hydrologic preparedness as part of the annual Ohio Severe Weather and Flood Safety Week. Preparedness activities in Kentucky included individual letters sent to each county explaining hydrologic watches and warnings. Additionally, in 1996, a letter was sent to each county emergency management supervisor requesting information on flash flood prone areas.

Specific briefings to the Ohio EMA began on the afternoon of Friday, February 28, 1997, for potential heavy rain on March 1-2, 1997. Additional telephone calls were made to individual counties as warnings were being issued on March 1, 1997. Additional subsequent briefings to the Ohio EMA were conducted during the late morning and early evening Saturday, March 1, 1997. Daily briefings then continued through March 10, 1997.

Watch and warning information was also distributed by the Wilmington staff through a pocket paging system. This paging system provided information to rural areas not covered by NOAA Weather Radio. Flood information, but no flood warnings, was also posted on the NWSO Wilmington (and OHRFC) homepage.