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11.5

# ADVANCED PRODUCTS AND SERVICES FOR FLOOD AND DROUGHT MITIGATION ACTIVITIES

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## 1. INTRODUCTION

The United States Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), has the responsibility to provide river and flood forecasts and warnings for the protection of life and property within the United States. These forecast services also provide for economic and environmental well-being through improved water resources management. The continuation and advancement of these services is occurring through NOAA's Water Resources Forecasting System (WARFS) program.

## 2. THE NECESSITY FOR IMPROVED FORECASTS

The deaths and economic losses resulting from The Great Flood of 1993 and our Nation's subsequent floods and droughts have forced the need for improved predictions to support flood/drought management and damage mitigation. Furthermore, the allocation of water among competing demands (i.e., fisheries, irrigation, hydropower and municipalities) looms as a national problem that requires improved water quantity forecasts for sustainable use. WARFS products with extended forecast lead times (up to several months) will greatly improve the Nation's capability to take timely and effective actions that will significantly mitigate the impact of major floods and droughts. The system will also provide products to water resource managers for the evaluation of water availability and allocation for water supply, navigation, hydropower, ecosystems and agriculture.

## 3. ADVANCED FORECASTING SERVICES

NWS River Forecast Centers (RFC) typically issue stage forecasts for only 1, 2, and 3 days into the future at most forecast points and crest forecasts out to about 1 week for a few selected forecast points. The NOAA "National Disaster Survey Report: The Great Flood of 1993" (NWS, 1994) reports that federal, state, and local groups have a need for advanced hydrometeorologic/ hydrologic forecast products with increased lead-times. Many of these groups express the need for a range of forecast stages with associated probabilities of occurrence. Similarly, during the widespread drought which affected most of the country in the mid-1980's, people were asking for hydrologic forecast information that was not available. During these events, agriculture, navigation, and water supply problems amassed damages in the billions of dollars. WARFS advanced hydrologic forecast products, with extended forecast lead-times, will greatly improve the capability of emergency managers to take timely and effective actions that will significantly mitigate the impact of major floods and droughts.

### 3.1 *WARFS Defined*

WARFS is a critical component of an Advanced Hydrologic Prediction System (AHPS; Fread, 1995) which builds upon the following: (1) partnerships with other water cooperators (federal, state, multistate, quasi-governmental, and private sector organizations); (2) the NWS infrastructure including the 13 RFCs and the NWS River Forecast System (NWSRFS), a very large software system used by RFC hydrologists to produce forecasts of

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time series of discharges or stages at selected locations (approximately 4,000 along the Nation's rivers); and (3) the NWS Modernization which is providing NWS River Forecast Centers (RFC) with Advanced Weather Interactive Processing System (AWIPS) equipment, a powerful suite of networked computer workstations with graphic capabilities. The modernization is also providing national coverage with approximately 140 WSR-88D Doppler radars which produce multisensor, high resolution (space and time) precipitation estimates utilizing gauge precipitation observations from networks such as the new Automated Surface Observing System (ASOS). The precipitation processing algorithms, using WSR-88D data, are being enhanced to account for bright band effects and to improve the rain gauge bias adjustment, while future enhancements will address orographic effects and snow accumulation.

The WARFS program is the fourth component which completes the AHPS. WARFS provides the pathway to: (1) make critical software enhancements to the NWSRFS; (2) develop a NOAA Hydrologic Data System (NHDS); (3) increase the use of short- to long-range weather and climate forecasts within the NWSRFS through appropriate hydrometeorological coupling algorithms; (4) effectively calibrate and field-implement the advanced hydrologic/hydraulic models within the NWSRFS; (5) implement a snow estimation and updating system (SEUS) which provides gridded estimates of snow water equivalent; and (6) provide more timely, accurate, and informative forecast products (e.g., Figure 1) to government and quasi-government water and emergency managers and to private sector intermediaries who provide value-added services to specific industries.

3.2 *WARFS Implementation*

During fiscal year 1995, NOAA began WARFS implementation activities within the upper Mississippi River basin through a significant commitment by personnel of the North Central River Forecast Center (NCRFC), the Regional Hydrologist and other staff of the NWS Central Region, and the NWS Office of Hydrology. WARFS short-term implementation goal is to demonstrate an operational long-term probabilistic

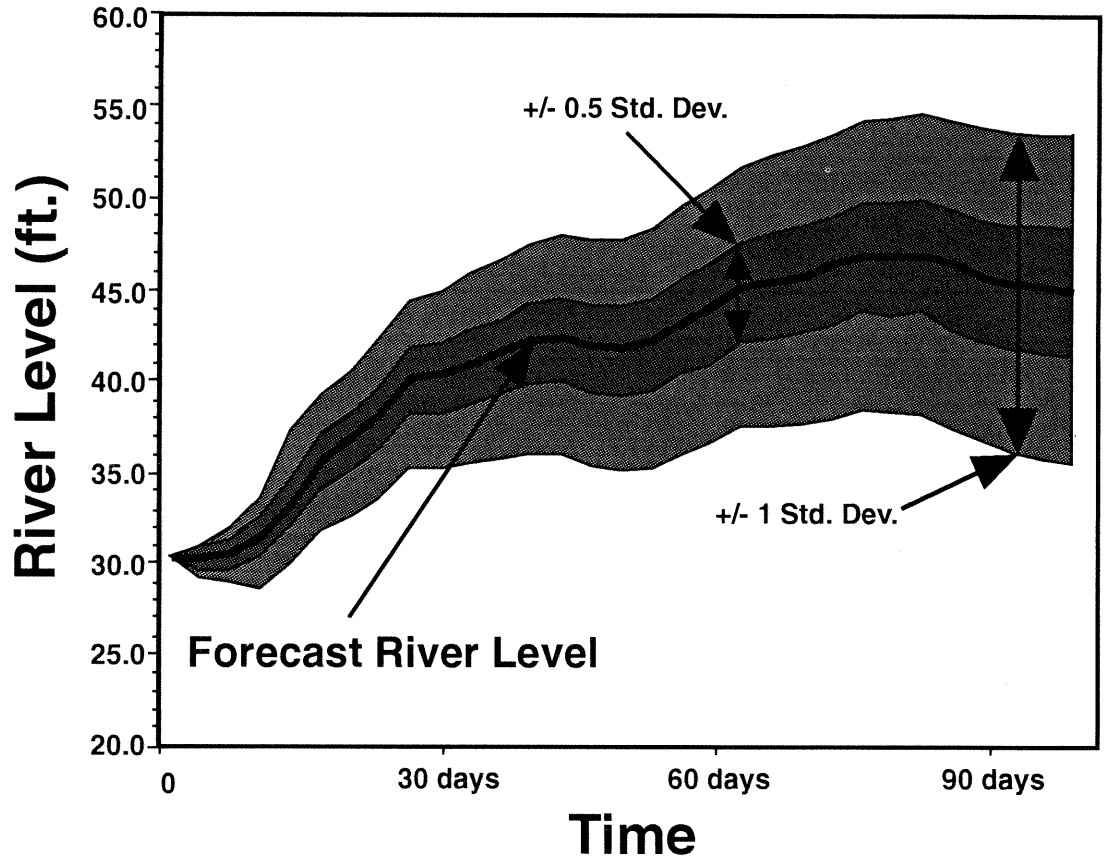


**Figure 1**. Long-term probabilistic forecast of river stage at a stream gaging station.

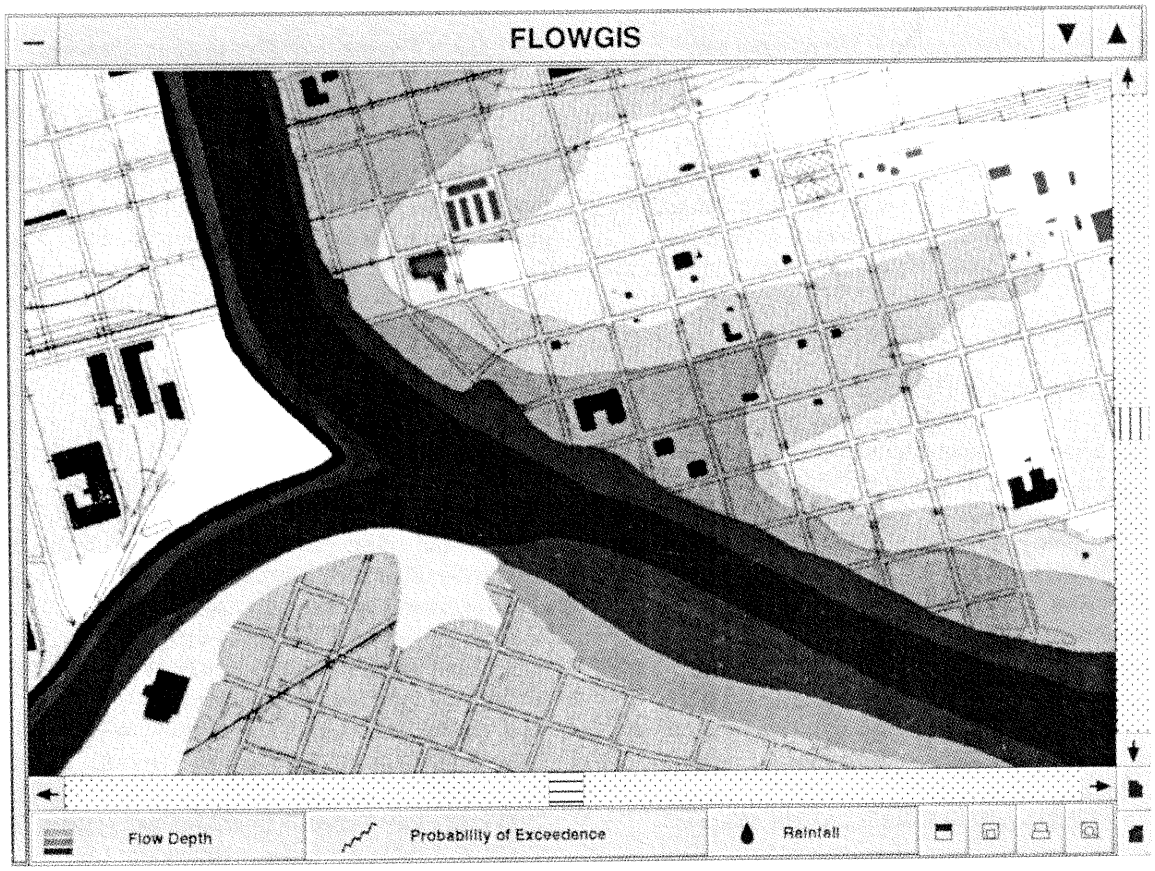


**Figure 2**. Flooded area map, providing inundation depth information, using real-time or advanced hydrologic forecast data for a future time window.

forecast system for the Des Moines River basin by the Spring of 1997. WARFS functionality and associated implementation activities at the NCRFC include:

- Provide advanced hydrometeorologic/hydrologic modeling procedures that better account for the natural and man-made complexities of the nation's river basins;

- Implement dynamic streamflow modeling in river reaches with significant dynamic effects caused by backwater, levee overtopping, or other transient phenomena;

- Implement the Extended Streamflow Prediction (ESP) procedure in order to provide probabilistic hydrologic forecasts into the future from weeks to months (e.g., Figure 1);

- Include the effect of reservoir operations in both short-term and long-term forecasts;

- Couple meteorologic forecasts at all time scales within the Extended Streamflow Prediction (ESP) procedure; and,

- Provide advanced products (e.g., probability of occurrence information and inundated area mapping, Figure 2) for water resources management activities to other federal, state and local organizations.

Once WARFS has been implemented for the Des Moines River basin, activities for its implementation in other NCRFC basins will occur. As an increase in resources become available, WARFS implementation can be expedited within the Mississippi Basin as well as early implementation in one or more additional basins in the United States, e.g., the Columbia River Basin which is of critical economic and environmental importance to the Nation.

## 4. PRODUCT PACKAGING/DISSEMINATION

Coordination among individual Weather Service Forecast Offices (WSFO)/Weather Service Offices

(WSO), RFCs, national centers, and regional and national headquarters is a vital part of the warning process. As the NWS issues forecasts and warnings, those products are distributed in near real-time to a wide variety of other federal, state, and local agencies. In the Modernized NWS, this internal coordination and product dissemination will be enhanced, in part, through the application of advanced hydrologic forecast products.

4.1 *Past Hydrologic Forecast Services*

The magnitude and duration of the Great Flood of 1993 (NWS, 1994) placed enormous stress on the forecast system infrastructure and NWS forecasters. Given the system's limitations and the resources available during that event, the forecasts and warnings were incredibly good (Braatz, 1994). For example, at the peak of the flood along a stretch of the Mississippi River near Hannibal, Missouri, approximately 50 percent of the estimated 4 million gallons of water per second was flowing outside the "main channel" of the river and behind the levee systems. In spite of these complex hydraulic conditions, the NCRFC provided forecasts for the city of Hannibal that were sufficiently accurate and timely to allow the U.S. Army Corps of Engineers (USACE) and the city of Hannibal to take action to reinforce the major levee system protecting the city. Although numerous anecdotes of major mitigation actions can be cited, there are still substantial opportunities for improvements that will provide significant benefits during future flood events and pay even larger dividends to the Nation.

Typically, RFCs made model runs on a mainframe computer at the NOAA Central Computer Facility (NCCF) in Suitland, Maryland. Input information was prepared at each RFC and submitted via dedicated lines for batch processing at the NCCF. Once the batch job was executed, model output was returned via dedicated lines to the RFC and the forecaster examined forecast output on large volumes of printer paper or, in the case in the NCRFC, on a monitor. This output format typically did not show enough detail or other useful information. Furthermore, the forecaster had to flip line-printer output (or monitor screen images) "back-and-forth" to examine upstream basins that may affect the downstream forecasts. Next, if the forecaster determined that data-input or model variables needed to be altered, it was cumbersome and a time-consuming process to resubmit the job to the NCCF, wait for the results, and work through a second pile of line-printer output. Clearly, a cumbersome forecast process adds unnecessary stress to forecast periods of critical need. Implementation of WARFS, with its array of forecaster/user products, will streamline RFC operations.

4.2 *Today's Transition of Forecasts and Services*

As the NWS issues forecast and warning products, they are distributed in near real-time to a wide variety of other federal, state, and local agencies. This information dissemination involves coordination issues, data exchange, product formatting and user services. Major cooperating agencies include the Federal Emergency Management Agency (FEMA), the USACE, and local and state emergency management agencies.

In most cases during the Great Flood of 1993, the coordination activities among the cooperating agencies were exceptional. In the aftermath of that major event, many meetings and conferences were held which provided recommendations involving hydrologic forecasts and information exchange. For example, from the Illinois Governor's Workshop (Illinois, 1994), an action statement directs government at all levels to "explore the potential benefits of exploiting the telecommunications infrastructure to its fullest." These product and service enhancements include the dissemination of forecasts via graphic interactive displays and improved communication with cooperating agencies via teleconferencing. And, from The Great Flood of 1993 Post-Flood Report, Upper Mississippi River Basin (USACE, 1994) , it is understood that agencies can improve upon their coordination activities, especially during periods of flooding, to ensure that the best information and data are made available to local interests and the media. For this need, interagency communication could be enhanced during periods of flooding by on-site NWS personnel being available to provide rapid clear interpretation of the NWS forecasts, warnings and informative products.

While the media were highly complimentary of NWS cooperation and the high level of information provided during the Great Flood, some members of the media have suggested ways in which timely coordination can be improved. One suggestion to help broadcasters meet public demand for early, daily information is for better coordination of river stage data and flood forecast product issuance with broadcast schedules. This will allow radio and television meteorologists to receive such products with sufficient time to tailor them for specific audiences.

As the NCRFC moves forward toward a WARFS suite of advanced products, changes have occurred regarding new approaches based on input from these and other sources. For instance, the NCRFC is now staffing for 16 hour days which provides greater access for NWS forecast offices and cooperating agencies to talk with a hydrologist. And soon, mainstem stage and flow

forecasts will be issued twice daily. For this purpose, benchmark tributary locations are being selected. Additionally, the NCRFC has six Government Development Platforms (GDP) on line providing workstation processing of hydrologic models and graphic interactive displays. This advanced technology provides the NCRFC with AWIPS capabilities creating an environment for development of WARFS activities in addition to meeting day-to-day forecast requirements more timely and effectively.

Teleconferencing, another transition component, was introduced during the 1993 Great Flood and has now caught on as an accepted method of coordination and information exchange. During the Upper Mississippi and Ohio River basins flooding this past Summer of 1995, the NCRFC was involved with two conference calls daily between agencies at all levels of federal and state government. The success of those coordination activities was measured in more timely information being received for agencies to make objective decisions.

Discussions continue on how the NWS offices can best serve other cooperating agencies in a flood scenario. This need is being addressed in the following manner: have an individual from the St. Louis WSFO on site in the Emergency Operations Center (EOC) at the St Louis District, USACE; field office staff dedicated to answering media inquiries; provide graphic product displays for local media's use; make use of NOAA Weather Radio (NWR), etc. These activities are leading to future needs and requirements as the Illinois Governor's Conference (Illinois, 1994) suggests they are "an integral ingredient to a more holistic view of floodplain management" and flood fighting capabilities.

4.3 *Tomorrow's Products and Services*

Additional enhancements to NWS communication during a flood event are being made through implementation of WARFS and the advanced technologies it will provide. The WARFS short-term design features include probabalistic long-range outlook hydrographs for stage, discharge and flow volume that have accompanying indicators of uncertainty (e.g., Figure 1). Long-term design features include gridded estimates of snow-water equivalent, soil moisture and flash flood guidance, and probabalistic flood inundation mapping capabilities (e.g., Figure 2). For WARFS, forecast and user requirements regarding new types of products based on probabalistic forecasting techniques are being investigated and new software to generate those products are being developed. Many of the product requirements are being developed through coordination with NWS forecast offices and other federal agencies, such as USACE and FEMA.

WARFS advanced hydrologic forecasts will provide ESP time series trace ensembles of streamflow out to several days and months. Probabalistic forecasts can then be generated from analyses of the time series traces. Forecasters will be able to perform such analyses and display results with the software tool called the ESP Analysis and Display Program (ESPADP). ESPADP will enhance forecast evaluation in several ways. First, the ease with which the analyses can be accomplished will lead to greater use of the ESP forecasting technique. Second, by providing a variety of interactive graphical displays the forecaster will be able to understand more easily and completely the probabilities generated by an ESP forecast. Finally, by providing more attractive and easily read graphical outputs, NWS cooperators will find it easier to utilize forecast products. ESPADP analyses which will be provided include forecast probability hydrographs, historical probability hydrographs, automatic forecast adjustment to account for model error, hydro-meteorological analyses to link past and present years, and forecast verification.

With the added flexibility and graphical displays available through this modernized software, a variety of enhanced forecast products can be generated by the RFCs. Investigations into possible products are underway to assess cooperator interest and system development including data input, data storage, software design and product formats. For example, several end users of NWS long range stage forecasts have requested that National Meteorological Center long lead meteorological outlooks be included in these long range stage forecasts. Inclusion of such forecasts requires the development of new scientific algorithms, the definition of new input data streams, new data storage facilities and the development of appropriate displays of the forecast data. The WARFS program has provided the impetus for such improvements.

One enhanced product that will be available for the WARFS demonstration project on the Des Moines River basin in the Spring of 1997 will be probabalistic hydrographs (Figure 1). With this product, forecasts with explicit probabilities will convey to the product user the likelihood of a variety of flow scenarios. In addition, coupled with the ESPADP software will be utilities that permit the user to verify the effectiveness of the forecast over selected periods of the past. With forecast verification, the forecaster will be able to provide a measure of confidence to any specific forecast. This information is essential for water resource and emergency managers as they integrate a multitude of data

into a single decision. In this manner, modernized hydrologic forecast products will not only provide the forecaster with a mechanism to impart critical hydrologic forecast information, but will also provide water resource managers risk analysis products for alternative hydrologic scenario decision making. This new product is a huge step forward from the previous ESP output format. In the past, forecasters were forced to review tabular output for a limited period, they now will be able to easily review the expected flows over a range of future time periods. In addition, it will be possible to pass the graphical displays on to decision makers directly, thus enhancing their understanding of the state of the hydrologic system. This is the type of easy to read detailed forecast product that disaster managers requested after the Great Flood of 1993.

Two long-term goals of the WARFS project are to develop the capability to generate inundation maps (Figure 2) based on the probabalistic stage forecasts and to provide gridded estimates of a variety of state variables describing the hydrologic system. The first goal of inundation mapping will be to provide local emergency managers a clear definition of the areas that are likely to experience flooding and the depth of flooding likely to occur at a given location. Also, by coupling the mapped areas with probabalistic forecasts, emergency managers will be able to evaluate the risk of future inundation and recommend appropriate actions for the threatened areas. Therefore, the translation of the forecast river stage to actual locations on the ground will be more readily communicated with these types of inundation maps. The second goal, gridded estimates of hydrologic variables, will provide forecasters and users with an in depth view of the natural system. Gridded estimates of the snow cover, and soil moisture, will enable forecasters and managers to evaluate the probability of flooding in more localized areas.

## Summary

NOAA has the national responsibility to provide river and flood forecasts and warnings for the protection of life and property and for the economic and environmental well-being of the Nation. The advanced hydrometeorologic/hydrologic forecast products provided by WARFS will greatly improve NOAA's capability to provide more timely and accurate forecasts. For these multiple uses of WARFS advanced products and services, NOAA will provide users tools which mitigate a wide range of their objectives. Thus, floodplain management decisions are more effectively arrived at then previously possible. With these advanced products, the operational WARFS will contribute to the Department of Commerce leadership role in fostering economic gains for environmentally sound decision making for all streamflow regimes.

## References


Braatz, Dean T., January 1994: Forecasting the Great Flood of 1993. The Great Flood of 1993 Symposium, American Meteorological Society, Nashville, Tennessee.

Fread, Danny L., June 1995: A Pathway Toward Improving Hydrologic Predictions. Issues and Directions in Hydraulics Colloquium, The University of Iowa.

NWS, February 1994: The Great Flood of 1993, NOAA Natural Disaster Survey Report. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Office of Hydrology, Silver Spring, MD.

U.S. Army Corps of Engineers District, St. Louis, September 1994: The Great Flood of 1993 Post-Flood Report, Upper Mississippi River Basin, Appendix C. St. Louis, Missouri.

Illinois, Office of the Governor, March 1, 1994: The Great Flood of 1993, Long Term Approaches to the Management of the Mississippi and Illinois Rivers Including Lessons Learned and Information Gaps. Governor's Workshop, Illinois Department of Agriculture, Springfield, Illinois.

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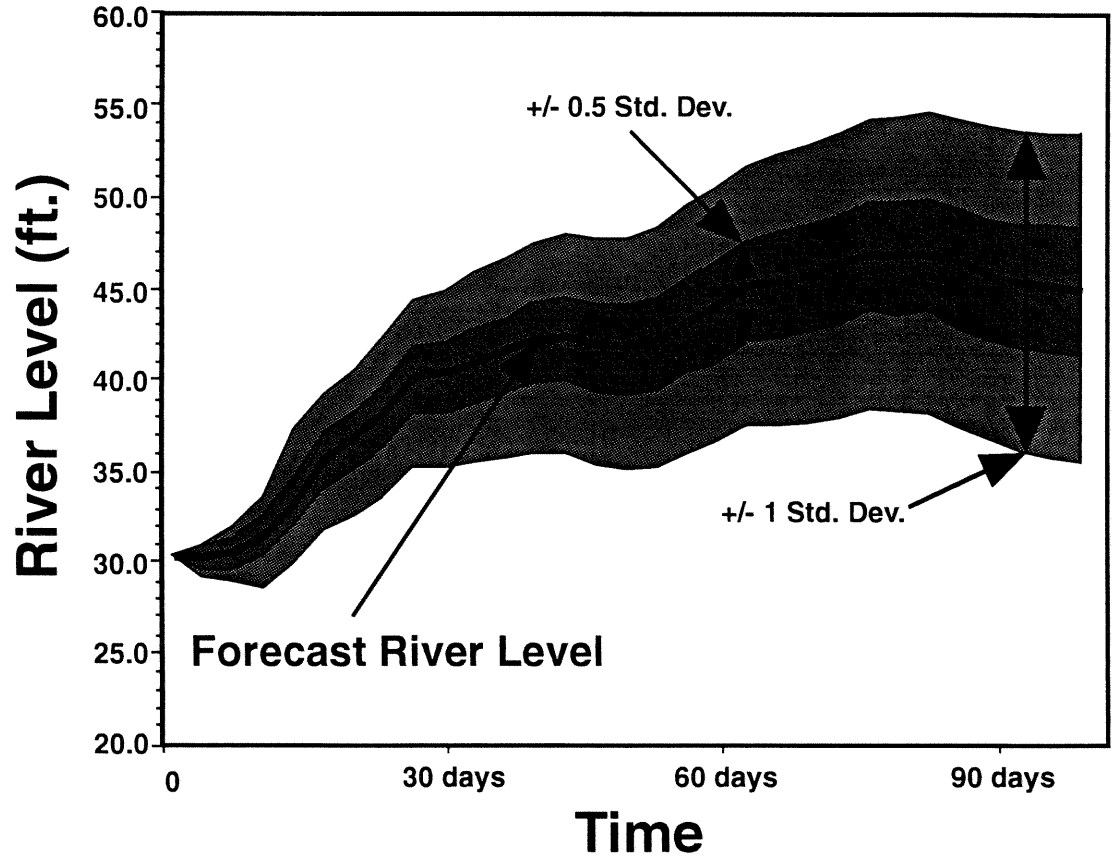


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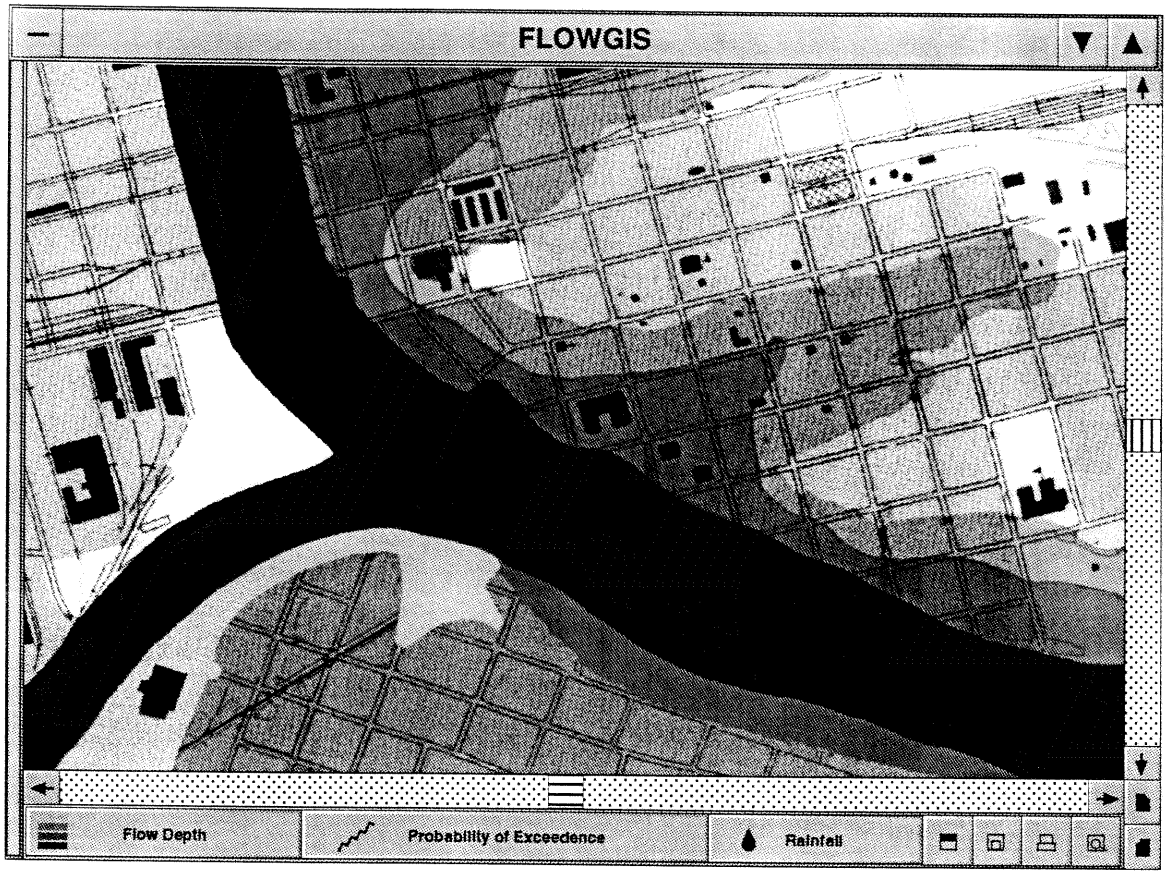


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Discussions continue on how the NWS offices can best serve other cooperating agencies in a flood scenario. This need is being addressed in the following manner: have an individual from the St. Louis WSFO on site in the Emergency Operations Center (EOC) at the St Louis District, USACE; field office staff dedicated to answering media inquiries; provide graphic product displays for local media's use; make use of NOAA Weather Radio (NWR), etc. These activities are leading to future needs and requirements as the Illinois Governor's Conference (Illinois, 1994) suggests they are "an integral ingredient to a more holistic view of floodplain management" and flood fighting capabilities.

4.3 *Tomorrow's Products and Services*

Additional enhancements to NWS communication during a flood event are being made through implementation of WARFS and the advanced technologies it will provide. The WARFS short-term design features include probabalistic long-range outlook hydrographs for stage, discharge and flow volume that have accompanying indicators of uncertainty (e.g., Figure 1). Long-term design features include gridded estimates of snow-water equivalent, soil moisture and flash flood guidance, and probabalistic flood inundation mapping capabilities (e.g., Figure 2). For WARFS, forecast and user requirements regarding new types of products based on probabalistic forecasting techniques are being investigated and new software to generate those products are being developed. Many of the product requirements are being developed through coordination with NWS forecast offices and other federal agencies, such as USACE and FEMA.

WARFS advanced hydrologic forecasts will provide ESP time series trace ensembles of streamflow out to several days and months. Probabalistic forecasts can then be generated from analyses of the time series traces. Forecasters will be able to perform such analyses and display results with the software tool called the ESP Analysis and Display Program (ESPADP). ESPADP will enhance forecast evaluation in several ways. First, the ease with which the analyses can be accomplished will lead to greater use of the ESP forecasting technique. Second, by providing a variety of interactive graphical displays the forecaster will be able to understand more easily and completely the probabilities generated by an ESP forecast. Finally, by providing more attractive and easily read graphical outputs, NWS cooperators will find it easier to utilize forecast products. ESPADP analyses which will be provided include forecast probability hydrographs, historical probability hydrographs, automatic forecast adjustment to account for model error, hydro-meteorological analyses to link past and present years, and forecast verification.

With the added flexibility and graphical displays available through this modernized software, a variety of enhanced forecast products can be generated by the RFCs. Investigations into possible products are underway to assess cooperator interest and system development including data input, data storage, software design and product formats. For example, several end users of NWS long range stage forecasts have requested that National Meteorological Center long lead meteorological outlooks be included in these long range stage forecasts. Inclusion of such forecasts requires the development of new scientific algorithms, the definition of new input data streams, new data storage facilities and the development of appropriate displays of the forecast data. The WARFS program has provided the impetus for such improvements.

One enhanced product that will be available for the WARFS demonstration project on the Des Moines River basin in the Spring of 1997 will be probabalistic hydrographs (Figure 1). With this product, forecasts with explicit probabilities will convey to the product user the likelihood of a variety of flow scenarios. In addition, coupled with the ESPADP software will be utilities that permit the user to verify the effectiveness of the forecast over selected periods of the past. With forecast verification, the forecaster will be able to provide a measure of confidence to any specific forecast. This information is essential for water resource and emergency managers as they integrate a multitude of data

into a single decision. In this manner, modernized hydrologic forecast products will not only provide the forecaster with a mechanism to impart critical hydrologic forecast information, but will also provide water resource managers risk analysis products for alternative hydrologic scenario decision making. This new product is a huge step forward from the previous ESP output format. In the past, forecasters were forced to review tabular output for a limited period, they now will be able to easily review the expected flows over a range of future time periods. In addition, it will be possible to pass the graphical displays on to decision makers directly, thus enhancing their understanding of the state of the hydrologic system. This is the type of easy to read detailed forecast product that disaster managers requested after the Great Flood of 1993.

Two long-term goals of the WARFS project are to develop the capability to generate inundation maps (Figure 2) based on the probabalistic stage forecasts and to provide gridded estimates of a variety of state variables describing the hydrologic system. The first goal of inundation mapping will be to provide local emergency managers a clear definition of the areas that are likely to experience flooding and the depth of flooding likely to occur at a given location. Also, by coupling the mapped areas with probabalistic forecasts, emergency managers will be able to evaluate the risk of future inundation and recommend appropriate actions for the threatened areas. Therefore, the translation of the forecast river stage to actual locations on the ground will be more readily communicated with these types of inundation maps. The second goal, gridded estimates of hydrologic variables, will provide forecasters and users with an in depth view of the natural system. Gridded estimates of the snow cover, and soil moisture, will enable forecasters and managers to evaluate the probability of flooding in more localized areas.

## Summary

NOAA has the national responsibility to provide river and flood forecasts and warnings for the protection of life and property and for the economic and environmental well-being of the Nation. The advanced hydrometeorologic/hydrologic forecast products provided by WARFS will greatly improve NOAA's capability to provide more timely and accurate forecasts. For these multiple uses of WARFS advanced products and services, NOAA will provide users tools which mitigate a wide range of their objectives. Thus, floodplain management decisions are more effectively arrived at then previously possible. With these advanced products, the operational WARFS will contribute to the Department of Commerce leadership role in fostering economic gains for environmentally sound decision making for all streamflow regimes.

## References


Braatz, Dean T., January 1994: Forecasting the Great Flood of 1993. The Great Flood of 1993 Symposium, American Meteorological Society, Nashville, Tennessee.

Fread, Danny L., June 1995: A Pathway Toward Improving Hydrologic Predictions. Issues and Directions in Hydraulics Colloquium, The University of Iowa.

NWS, February 1994: The Great Flood of 1993, NOAA Natural Disaster Survey Report. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Office of Hydrology, Silver Spring, MD.

U.S. Army Corps of Engineers District, St. Louis, September 1994: The Great Flood of 1993 Post-Flood Report, Upper Mississippi River Basin, Appendix C. St. Louis, Missouri.

Illinois, Office of the Governor, March 1, 1994: The Great Flood of 1993, Long Term Approaches to the Management of the Mississippi and Illinois Rivers Including Lessons Learned and Information Gaps. Governor's Workshop, Illinois Department of Agriculture, Springfield, Illinois.