Advanced Hydrologic Forecasting for Flood and Drought Mitigation

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Abstract. 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 NWS is now advancing its hydrolgoic forecasting capability through its Advanced Hydrologic Prediction System (AHPS) program. AHPS products, with extended forecast lead times (up to several months), will greatly improve the capability of emergency and water facility managers 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.

THE NECESSITY FOR IMPROVED FORECASTS

Over 80 percent of the world's natural disasters that occurred in the last three decades consisted of tropical storms, floods, and droughts; each of these events were meteorologically driven. However, two-thirds of the catastrophic damages resulting from these events were in response to adverse hydrologic impacts. Additionally, the world's water resources are finite and are becoming the major factor limiting development, sustainable or otherwise, in many regions of the world, and the global demand for fresh water will continue to rise into the next century as the world's population is projected to double in the next fifty years. In addition to population increases, associated development will infringe upon flood plains and other areas subject to hydrologic impacts. Therefore, the importance and enhancement of hydrologic services, which assess when and where water will be, cannot be highlighted enough and needs to be fully represented in advanced forecasting service programs.

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 expressed 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. AHPS 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.

AHPS Defined

AHPS builds upon: (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 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 RFCs 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 Weather Surveillance Radar - 88 Doppler (WSR-88D) 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 provision of advanced modeling and product generation completes the AHPS. The pathway to the completion of AHPS (Fread, 1995) includes: (1) make critical software enhancements to the NWSRFS; (2) develop a NOAA Hydrologic Data System; (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 which provides gridded estimates of snow water equivalent; and (6) provide more timely, accurate, and informative forecast products (e.g., Fig. 1) to government and quasi-government water and emergency managers and to private sector intermediaries who provide value-added services to specific industries.

AHPS Implementation

During Fiscal Year 1995, the NWS began AHPS preparation activities for its implementation 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. The AHPS near-term implementation goal is to demonstrate an operational long-term probabilistic forecast system for the Des Moines River basin by the Spring of 1997. AHPS functionality and associated implementation activities at the NCRFC include: (1) provide advanced hydrometeorologic/hydrologic modeling procedures that better account for the natural and man-made complexities of the nation's river basins; (2) implement dynamic streamflow modeling in river reaches with significant dynamic effects caused by backwater, levee overtopping, or other transient phenomena; (3) implement the Ensemble Streamflow Prediction (ESP) procedure in order to provide probabilistic hydrologic forecasts into the future from weeks to months (e.g., Fig. 1); (4) include the effect of reservoir operations in both short- and long-term forecasts; (5) couple meteorologic forecasts and climate predictions at all time scales within the ESP procedure; and, (6) provide advanced products (e.g., probability of occurrence information and inundated area mapping, Fig. 2) for water resources management activities to other Federal, state and local organizations.

Once AHPS has been implemented for the Des Moines River basin, activities for its implementation in other NCRFC basins will occur. As resource increases become available, AHPS 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 American River and the Columbia River basins which are of critical economic and environmental importance to the Nation.

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.

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 exceptional (Braatz, 1994). 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, in the not too distant past, 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. The forecaster then examined forecast output on large volumes of printer paper or, in the case at 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 could affect the downstream forecasts. Next, if the forecaster determined that data-input or model variables needed to be altered, it was a cumbersome and 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 AHPS, with its array of forecaster/user products, will streamline RFC operations.

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. 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, 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.

As the NCRFC moves forward toward an AHPS 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 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 AHPS activities in addition to having more timely and effective day-to-day requirements.

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 in the summer 1995, the NCRFC was involved with two daily conference calls between agencies at all levels of Federal and state government. The success of those coordination activities was measured in that more timely information was received for agencies to make objective decisions.

Discussions continue on how 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 at the St Louis District, USACE; have field office staff dedicated to answering media inquiries; provide graphic product displays for the local media's use; make use of NOAA Weather Radio, 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.

Tomorrow's Products and Services

Additional enhancements to NWS communication during a flood event are being made through the implementation of AHPS with its suite of advanced technologies. The AHPS short-term design features include probabalistic long-range outlook hydrographs for stage, discharge, and flow volume that have accompanying indicators of uncertainty (e.g., Fig. 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., Fig. 2). Also for AHPS, 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.

The main engine for the provision of AHPS advanced hydrologic forecasts is the generation of ESP time series trace ensembles of streamflow out to several days and months. Probabalistic forecasts for future time windows can then be generated from analyses of the trace ensembles. Forecasters will be able to perform the 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 less cumbersome to use forecast products. Envisioned ESPADP analyses and displays include hydrometeorologic analyses to link past and present years, automatic forecast adjustment to account for model error, forecast verification, forecast probability hydrographs, historical probability hydrographs, and probability of inundation and soil-moisture distribution maps.

A variety of enhanced graphical forecast products may be generated by the RFCs with ESPADP. Investigations regarding the initial and potential array of these products are underway to assess cooperator interest and system requirements including data input, data storage, software design, and product formats. For example, some users of NWS long-range stage forecasts have requested that the long-lead meteorologic outlooks of the National Center for Environmental Prediction (NCEP; previously, National Meteorological Center) be included in these long-range stage forecasts. The integration of NCEP 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 AHPS program has provided the impetus for such improvements.

One enhanced product that will be available for the AHPS demonstration project on the Des Moines River basin in the spring of 1997 will be probabalistic hydrographs (Fig. 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, other utilities will permit the user to verify the effectiveness of the forecast over selected past time intervals. 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; now they 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 AHPS program are to develop the capability to generate inundation maps (Fig. 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. Additionally, gridded estimates of snow cover and soil moisture will enable forecasters and managers to evaluate the probability of flooding in more localized areas.

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FIGURE CAPTIONS

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

Fig. 2 Flooded area map, providing inundation depth and probability of occurrence information, using real-time or advanced hydrologic forecast data for a future time.

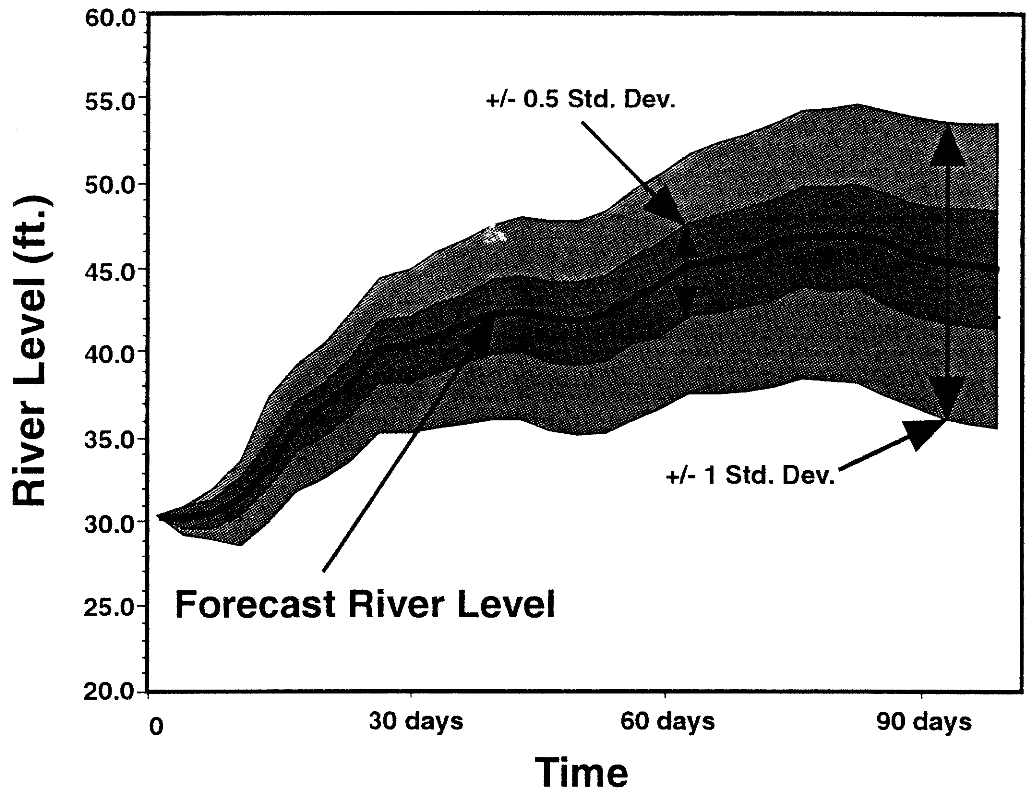

Figure 1

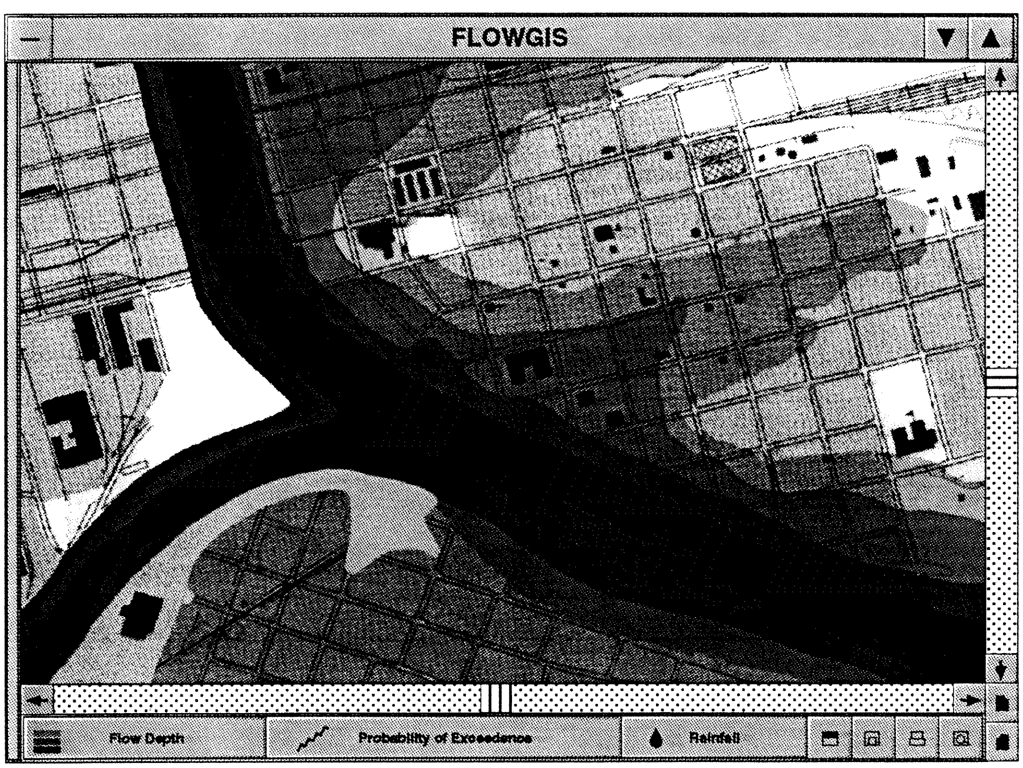

Figure 2