MODERNIZED HYDROLOGIC FORECAST OPERATIONS AT NATIONAL WEATHER SERVICE WEATHER FORECAST OFFICES

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1. INTRODUCTION

One of the primary goals of the National Weather Service's (NWS) current modernization effort is to provide an integrated forecast environment that enables the weather forecaster to effectively deal with a wide range of weather and forecast scenarios from a networked suite of scientific workstations, with tools and data sets appropriate to specific weather problems readily available. This collection of workstations, which form the basis of the Advanced Weather Interactive Processing System (AWIPS), serve as the integrating platform for merging the data sets made available through the implementation of the Next Generation Weather Radar (NEXRad), the Automated Surface Observation System (ASOS), and the Next Generation Geostationary Orbiting Earth Satellites (GOES Next) into the hydrometeorological forecast applications defined for in the modernized NWS.

The NWS Office of Hydrology is currently developing a subset of these applications, referred to as the WFO Hydrologic Forecast System (WHFS), that provide the WFO forecaster with the capability to issue warnings of flood and flash flood events in real-time. The WHFS was implemented at the Norman, Oklahoma Weather Service Forecast Office (WSFO) in November 1994, as part of a national risk reduction effort, in order to evaluate the capability in an operational setting. Efforts are currently underway to prepare the WHFS for integration with AWIPS, with the first WHFS components scheduled for release in July 1996.

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2. BACKGROUND

In the United States, floods, and in particular flash floods, are responsible for more weather-related deaths than any other type of weather event, resulting in an average of over 100 deaths per year. Flash floods are typified by fast rises in small rivers and streams brought about by heavy precipitation events depositing large amounts of rainfall over a relatively short time duration. Dam failures also represent a significant source of flash flood threat, due to the large volume of water that may be released when a dam is breached. Although each of these types of events are generally constrained to a small geographic area, the resulting damage and loss of life can be great due to the intensity of the event, and the relatively short warning lead time often associated with flash floods.

In the early 1980s, in an effort to provide the WFO forecaster with the tools necessary to effectively forecast and report these types of events, the Forecast Systems Lab (FSL), with funding support from the NWS, began PROFS (Program for Regional Observing and Forecast Services), which was a proof of concept project for an NWS field office advanced workstation environment. The PROFS workstations added considerable functionality in data handling, graphical display capability, and additional local model generation capability. The NWS and FSL, as a risk-reduction activity, then cooperated in the DARRRE (Denver AWIPS Risk Reduction and Requirements Evaluation) in the mid 1980s. The DARRRE project was designed to put a series of the PROFS developed workstations into an operational Weather Service Forecast Office (WSFO) with a goal of replacing AFOS. Neither PROFS nor the early DARRRE implementations had much functionality to address the hydrologic operations at the WSFO. In the late 1980s, the Office of Hydrology provided a Hydrologic Program Manager to FSL in an attempt to provide additional hydrologic capability to the system. Over the next few years, through 1992, some limited success was achieved in adding hydrologic displays and applications to the DARRRE system, and the Pre-AWIPS system at Norman. However, by mid-1993, the limitations of the Pre-AWIPS system and the need to develop capabilities and applications in the AWIPS environment forced a decision to terminate hydrologic application development on the Pre-AWIPS system, and move the WSFO hydrologic development effort to OH.

3. INTEGRATED DATA MANAGEMENT

The WHFS features an integrated data management approach, employing a relational database management system (RDBMS) as the core data repository, for storing the large volume of data necessary for hydrologic forecast operations. The WHFS database incorporates a disparate collection of data elements, ranging from modernized data sets such as NEXRAD precipitation estimates and GOES satellite imagery, to more traditional hydrologic data sets provided by automated reporting stations and cooperative observers. Locally produced data sets, such Quantitative Precipitation Forecasts (QPF) and local model output is stored in the same manner, providing a common method of access and management of all data elements, regardless of origin.

The supporting River Forecast Center (RFC) is the primary source of hydrologic guidance, providing river stage forecasts on a daily and event-oriented basis. RFC guidance is also provided in the form of modernized flash flood guidance products that indicate current soil moisture conditions and associated rainfall thresholds necessary to induce flood activity.

A collection of tools is provided to allow the hydrologic focal point, most often the Service Hydrologist, to manage this vast array of data elements through a series of graphical user interfaces. Chief among these tools is the HydroBase application. HydroBase provides a method of managing station meta-data, allowing for definition of station attributes such as reporting parameters, geophysical characteristics, and event thresholds. Much of the parametric data utilized by the forecast applications is also defined through HydroBase, eliminating the requirement for forecasters to manipulate this data during operations. Program management tools, such as automated generation of monthly flood stage reports have also been incorporated.

3.1 Quality Control

Due to problems inherent in the collection and transmission of observations from automated data sources, a set of quality control procedures is provided to ensure the highest quality of data is available for the WHFS modeling and forecast applications.

Station observation reports are subjected to a series of quality control checks to determine their validity and usability in forecast operations, with the first of these checks designed to ensure that an observed value falls within an acceptable range of tolerances, defined for a particular station and observation type. As an example, observed precipitation reports are checked to ensure that the reported value indicates a non-negative precipitation accumulation and does not exceed a defined maximum threshold. A secondary quality check (temporal consistency) compares observed values against previous observations to ensure the value does not increase at a higher than acceptable rate for the reported period. A final check (model consistency) is performed to test the reliability of the reported value against model output by comparing the observation to a forecast value for a similar time period or duration. Each of these checks results in the adjustment of a Data Quality Descriptor (DQD) value, associated with each observation, indicating the result (pass/fail) of the test. Observations failing a validity check will be marked as unacceptable and stored for subsequent manual review and editing. Failure to pass either the temporal or model consistency checks does not disqualify an observation from operational use, but causes the DQD to be assigned a value indicating the data is questionable and should be reviewed for accuracy.

Quality control measures are also applied to the NEXRAD-generated precipitation estimates in order to correct errors associated with anomalous propagation, ground clutter, range effects, and missing data. A first level of quality checks (Stage I) occurs within the NEXRAD Radar Product Generator (RPG), employing a series of techniques as described in Proposed "On-Site" Precipitation Processing Subsystem for NEXRAD (Ahnert, Hudlow, Johnson, and Greene). The RPG also hosts a Rain Gage Data Acquisition Function that performs an hourly gage bias-adjustment procedure using station precipitation observations as ground truth for further quality control. During rainfall events, the RPG provides the WHFS with a precipitation status message indicating that rainfall is occurring, causing the WHFS to initiate an application responsible for transmission of gage precipitation observations (accumulated or incremental) to the RPG. These precipitation reports, quality controlled in the manner defined above, are encoded in SHEF (Standard Hydrometeorological Exchange Format) and provided to the RPG at a forecaster defined interval continuing to the end of the precipitation event. The current NEXRAD implementation (Build 8.0) limits the number of gages allowed for ground truth adjustment to 50, with future releases allowing for inclusion of up to 200 gages.

A secondary phase of precipitation processing, referred to as Stage II, is applied to the NEXRAD generated precipitation products to eliminate errors not detected during Stage I processing, resulting in enhanced hourly precipitation estimates for the NEXRAD coverage area. Stage II processing, implemented as a software technique within the WHFS, first compares the Stage I estimate to GOES Next infrared imagery to determine if the precipitation field indicates rainfall for an area in which no cloud cover has been observed. A secondary check is subsequently performed to compare the areas in question to observed precipitation station reports to determine if rainfall has been reported. If no gage-reported rainfall has been detected, the areas (precipitation field) in question are zeroed out to indicate no rainfall has occurred. Stage II produces 2 digital output products, a multisensor and a gage-only precipitation field.

4. FORECAST ENVIRONMENT

During a typical hydrologic situation the forecaster may employ many aspects of the WHFS in combination to evaluate the current hydrologic conditions, evaluate forecast data sets, and issue products notifying the public of actual or forecast flood activity.

4.1 Monitoring

The Stage and Precipitation Display (HydroView) application provides the forecaster with a method of monitoring and tracking the hydrologic situation in real-time. The base application display provides a geographic depiction of the WFO County Warning Area (CWA), adjustable in scale and projection, with the capability to overlay an array of hydrometeorological data sets. Station icons, representative of any of the observation networks within the CWA may be overlaid, either individually or in combination with hydrologic or geopolitical boundaries such as rivers, river basins, county outlines, or major towns and highways. River station icons, including reservoirs are color-coded to indicate the proximity of the latest observation to action or flood stage. Precipitation stations are color-coded to represent a precipitation accumulation for a forecaster selected time duration. This display is automatically refreshed at 15 minute interval, using the most recent observations and forecasts available.

Through selection of any station icon, the forecaster may be view a time-series display of river stage and precipitation observations for a period of up to 21 days. Forecast data, if available, is provided for a 5 day time period. Action and flood stage markers are displayed as the river stage approaches either of these thresholds. In support of user requirements for graphical products, the forecaster may save an image of the display for subsequent distribution to external users.

Numerous auxiliary displays are available to provide the forecast additional insight into the hydrologic situation, providing displays indicating the expected flood impact and damage associated with the current conditions. Displays are also provided to illustrate the effects of flood activity on adjacent river stations, provide information regarding individuals to contact in the event of severe weather, and provide indication of stations exceeding normal reporting durations.

4.2 Site Specific Modeling

The Site Specific Hydrologic Prediction System (SSHPS), a local hydrologic model, is provided to allow the WFO forecaster to supplement RFC river forecast guidance by generating time-series data sets of forecast river stages for small, fast-response headwater and river basins not modeled by the RFC. River stage observations, and precipitation estimates and forecasts are provided as input to a rainfall-runoff model, which produces a time distributed estimate of streamflow rise due to runoff and groundwater flow reaching the river channel. Initial soil moisture conditions are accounted for through model state variables provided by the RFC on a daily basis. Dependent upon the model definition, other inputs such as snowmelt runoff and potential evapotranspiration may also be considered. Model definitions for individual basins are calibrated by the RFC, employing the NWS River Forecast System (NWSRFS) hydrologic models as a baseline.

Gridded or point precipitation estimates may be used as model input, and are selectable by the forecaster prior to the execution of the model. Each of these forms of estimates is ingest through a precipitation preprocessor that calculates a time series of basin average precipitation values for a time duration (generally 1 hour) specified by the model definition. Gridded estimates are utilized on a best-available basis, employing Stage III, Stage II, and Stage I estimates within a single time series, using each for a specific time period up to their period of last availability. Future precipitation estimates are also incorporated through ingest of gridded Quantitative Precipitation Forecasts (QPF) products generated locally or by the RFC. Once gain, the forecaster may select the QPF product they wish to use prior to execution of the model.

The forecaster interacts with the SSHPS through a graphical user interface, that allows for interactive review and adjustment of model results and input. Input precipitation estimates and forecasts may be adjusted through a mouse-based point-and-click methodology, allowing the forecaster to quickly edit input, and subsequently rerun the model. When satisfied with the output results the forecaster may save the forecast time series to the database for subsequent use by other applications. Use of a graphical interface allows the details of the underlying hydrologic model to be hidden from the forecaster, allowing them to concentrate their efforts on ensuring the accuracy of the precipitation estimates being used as model input.

4.3 Product Generation

The River Product Formatter (RiverPro) is provided to automate the generation and issuance of the Flood Warning (FLW), Flood Statement (FLS), and River Statement (RVS) public hydrologic products, providing NWS users with information detailing flood conditions and river stage levels at hydrologic forecast points within the WFO Hydrologic Service Area (HSA). Upon initiation, RiverPro extracts observed and forecast river stage time series information from the hydrologic database, compares this information to categorical values representing the flood magnitude associated with a defined river stage, and subsequently presents the forecaster with a product recommendation indicating the current hydrologic conditions.

Product format and content is controllable by the forecaster through creation and modification of product content control definitions and templates that specify both the overall product format, as well as the format for individual product sections. At the product level, templates allow specific control of the overall product format, such as the ordering of product sections and the format of section headers. Templates defined for individual product sections provide a higher level of flexibility, allowing for format and variable definitions for individual forecast points. In most instances the hydrologic focal point, with guidance from the Meteorologist-in-Charge or the Warning Coordination Meteorologist, will develop products templates for in the generation of hydrologic products, providing the public with a consistent format and information content.

Generated output products are transmitted to NWS users via the Weather Wire, with encoded county identifiers (Universal Generic Codes) embedded in the product header indicating the county(s) affected by flooding at the points identified in the product. In addition, generated products will also be transferred to an automated voice digitizer, referred to as the Console Replacement Subsystem (CRS) for broadcast over NOAA Weather Radio.

4.4 Area Wide Modeling

The Area Wide Hydrologic Prediction System (AWHPS) will provide the forecaster at the WFO with an analysis of flash flood threat in the forecast area, caused by urban or small-stream flooding. AWHPS uses data from NEXRAD and gridded flash flood guidance from the servicing RFC to provide a graphical depiction of (1) Critical Rainfall Probability, (2) 1-hour rainfall projection, and (3) difference display.

The NEXRAD product that is used in the AWHPS system is the Hourly Digital Precipitation (HDP) product, which provides a gridded (HRAP grid, approximately 4 km x 4 km) 255 level accumulation for the previous hour each volume scan of the radar. The modernized flash flood guidance from the RFC indicates, for each HRAP grid, the amount of rainfall required in a particular duration to cause over-bank flow of small streams. The common durations for the rainfall in the flash flood guidance computations are 1, 3, and 6 hours.

The 1-hour precipitation projection of the AWHPS will be computed after the arrival of the HDP each volume scan (volume scans are completed every 5-6 minutes while in precipitation mode). The projection is based on the rainfall rate computed between the latest HDP and the previous HDP, and the movement of the rain areas between the scans.

Two CRPs are computed for each duration: the first is the CRP based on the radar estimated rainfall, and the second is the CRP based on the radar estimated rainfall plus the 1-hour projection. The CRP gives a statistical probability that the rainfall in a particular HRAP grid has exceeded the flash flood guidance for that grid square.

The difference fields are a graphical depiction of the quantitative difference between the flash flood guidance and the radar estimated rainfall for each duration. A second difference graphic will depict the same information for the radar estimated plus 1-hour projected rainfall totals.

Subsequent to review of the AWHPS output products, the forecaster may employ an automated product formatter to issue Flash Flood Watches or Flash Flood Warnings. While viewing any of the CRP products, using the WARNGEN application the forecaster will be able to graphically outline the area they wish to issue a watch or warning for and the formatter will produce the desired public product.

5. FIELD IMPLEMENTATION

In November 1994, the WHFS was implemented at the Norman, Oklahoma WSFO for the purpose of evaluating the system in an operational forecast environment. Since that time the WHFS has been used in daily hydrologic operations, significantly enhancing the WSFO's hydrologic warning capability during major flood events that occurred in June and August of 1995. Each of these events was marked by extensive flood activity along the Red River and its tributaries, caused as a result of high-intensity, short duration precipitation events, with peak rainfall amounts measured at 14 inches in less than a 24 hour period (Vernon, Texas, August 2, 1995).

During the first two weeks of June, flood events occurred at over 20 river forecast points within the WSFO warning area causing considerable property damage and evacuations in central Oklahoma. In response to this activity, the WHFS was employed by the forecast staff to quickly assimilate large volumes of observed and forecast data, assess the hydrologic situation, and subsequently generate and issue the appropriate hydrologic warnings. During this two week period, 26 River Flood Warnings and 105 River Flood Statements were issued by the Norman WSFO staff using the WHFS. Operational input provided by the WSFO Norman forecast staff, based on their experiences with the WHFS during these events, has served as the basis for many of the enhancements and refinements incorporated into the system over the past 14 months.

Recognizing the need to evaluate the system in a variety of hydrologic conditions and situations, the WHFS was implemented at Weather Service Office (WSO) State College, Pennsylvania in October 1995, and at the Seattle, Washington WSFO in November, 1995. Hydrologic conditions at these office vary considerably from those generally present at WSFO Norman, in that snowmelt runoff and snow cover characteristics often play a significant role in flood events. Snowmelt considerations provide the opportunity to evaluate additional hydrologic modeling, data ingest, and data display capabilities.

Further operational implementation of the WHFS is scheduled to begin at WFOs in Boise, Idaho (January 1996), Houston, Texas (January 1996), San Juan, Puerto Rico (February 1996), Anchorage, Alaska (February 1996), Charleston, West Virginia (March 1996), and Denver, Colorado (March, 1996).

6. CONCLUSION

WFO hydrologic forecast operations in the AWIPS-era will differ dramatically from those in the pre-modernized NWS. The advent of more powerful, yet affordable, computing technologies provides the opportunity to implement sophisticated hydrologic modeling, analysis, and forecast tools in a manner suitable for use in dealing with the wide range of hydrologic conditions and situations present throughout the NWS. Field implementation of AWIPS is scheduled to begin in July 1996, with nationwide deployment to be completed by 1999. Significant portions of the initial WHFS capability will be fielded as part of AWIPS implementations beginning in the fall of 1996, with the full hydrologic forecast capability available by mid-1997. This WHFS implementation will provide the WFO forecaster with the tools necessary to meet the goals of the NWS hydrologic services program, as well as serve as the baseline for future enhancement.

7. REFERENCES

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