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REAL-TIME INTERACTIVE PROCESSING IN SUPPORT OF WATER RESOURCES FORECASTING IN THE MODERNIZED NATIONAL WEATHER SERVICE

Donald P. Laurine[1]

1. INTRODUCTION

Proper management of water resources is vital to the Nation's economy, the quality of our environment, and our overall social well-being. Increased resource demands, pollution, and climate variability have made water a scarce resource in most areas at one time or another and have stressed our water resources systems. While some parts of the Nation are experiencing water shortages, other parts may be experiencing serious flooding. Water management decisions that affect water resources systems are a daily routine. Industries and utilities must decide how much effluent can be safely discharged into an estuary without adversely affecting water quality and endangering fish. Reservoirs are continually operated with the conflicting objectives of flood control, water supply, hydropower generation, navigation, water quality, recreation, etc. These objectives work against one another by seeking to raise/lower the reservoir pool level and to hold/release water. In most cases, these water management decisions are based on localized ad-hoc information systems that cause inefficient and wasteful utilization of the Nation's water resources.

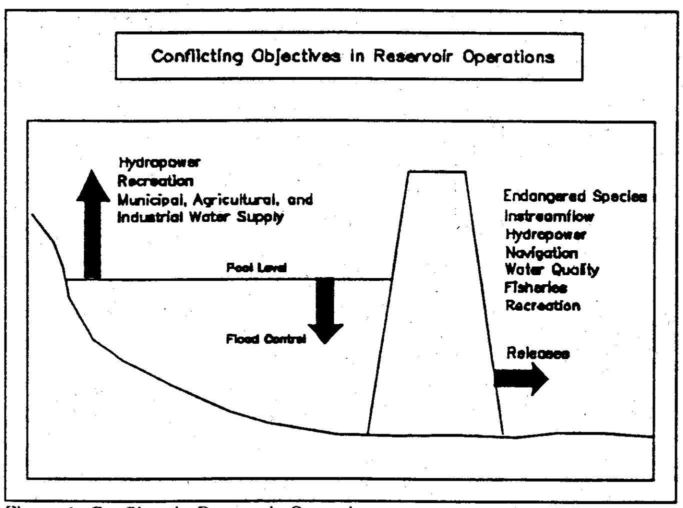

Figure 1. Conflicts in Reservoir Operations

[1]WARFS Implementation Leader, Colorado Basin River Forecast Center, National Weather Service, 337 North 2370 West, Salt Lake City, Ut 84116 (801)524-5130

The science of real-time hydrologic forecasting, and potential computer and telecommunications resources to support the associated data processing, has reached the point that significant advances can now be made in river forecasting to provide improved information for water managers. The National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) is working with a number of other federal, state, multi-state, quasi-governmental and private sector organizations toward cooperative efforts in this area. As part of these collaborative efforts, NOAA is planning a new initiative designated Water Resources Forecasting System (WARFS).

This paper outlines the system components of WARFS and discusses development activities designed to utilize advancements introduced through the modernization of the NWS. The role of real-time interactive processing is emphasized as the critical component to provide improved forecast products for water management and flood forecasting.

2. WATER RESOURCES FORECASTING SYSTEM

The WARFS Initiative will provide urgent improvements in NOAA hydrologic prediction services. The infrastructure for WARFS is the current National Weather Service River Forecast System (NWSRFS). The NWSRFS is at the heart of the WARFS schematic and is shown in Figure 2. WARFS model and data improvements within the NWSRFS will benefit all scales of forecasting, bringing badly needed improvements in flood warnings as well as longer-term forecast services. WARFS will take advantage of both hardware and software components of the NWS modernization programs including the Next Generation Radar (NEXRAD) called WSR-88D, the Automated Surface Observing System (ASOS), and the Advanced Weather Interactive Processing System (AWIPS). The NEXRAD and ASOS programs will provide much of the necessary technology to observe precipitation amounts on a nationwide basis at the temporal and spatial resolution required. Achieving the required accuracy of precipitation estimates, however, will require data management, integration, and analysis procedures which incorporate a large variety of precipitation data sources from other federal, state, and local gage

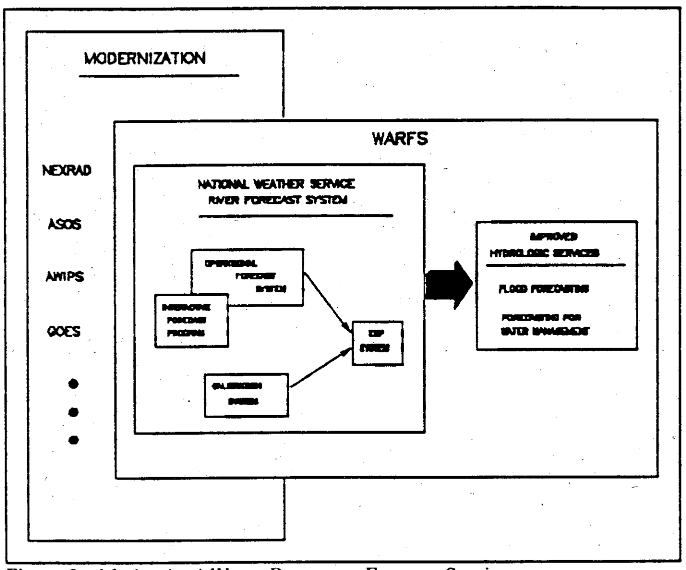

Figure 2. Modernized Water Resources Forecast Services

networks. The AWIPS system provides a modern interactive processing environment which will be the center of all forecast operations in an office. Data analysis and quality control, forecast modeling, forecast interpretation, and production formulation will be carried out interactively at modern workstations, providing forecasters with a milieu for efficient and timely development of WARFS products and services. The data and computer systems provided by the NWS modernization programs, along with the technology of advanced hydrologic and climate forecast models will be used to: 1) support forecast service requirements of government and quasi-government water managers, 2) provide basic water resources forecasts to private sector intermediaries, who will tailor the forecasts to serve specific industries, 3) satisfy needs for forecast services at near-, mid-, and long-term time scales for a wide variety of water use situations nationwide, 4) provide critical information on hydrometeorological forecast reliability that can be used for risk-based water management decision-making, 5) incorporate improved weather and climate forecast information into hydrologic models, and 6) improve other short- and mid-range forecast capabilities.

2.1 National Weather Service River Forecast System

The NWSRFS software system (over 350,000 lines of computer code) consists of many programs used to perform all steps necessary to generate streamflow forecasts. The system includes the Calibration System (CS), the Operational Forecast System (OFS), and the Extended Streamflow Prediction (ESP) System.

2.1.1 Calibration System

The Calibration System performs the tasks needed to process historical hydrometeorological data and to estimate model parameters for a specific basin. The models simulate snow accumulation and ablation, calculate runoff, time distribute runoff from the basin to the basin outlet, and channel route streamflow. The NWSRFS is a modular system that allows the hydrologist to select from a variety of models and to configure them in a manner that is descriptive of the basin. All of the models are common to the Calibration, Operational Forecast, and ESP systems. As part of the calibration procedure, for a particular basin, the simulated streamflow is statistically and visually compared to the observed streamflow to determine the necessary model parameter adjustments. The ideal model parameters are those with which the model simulated streamflow most closely matches the observed streamflow. Brazil and Hudlow (1980)

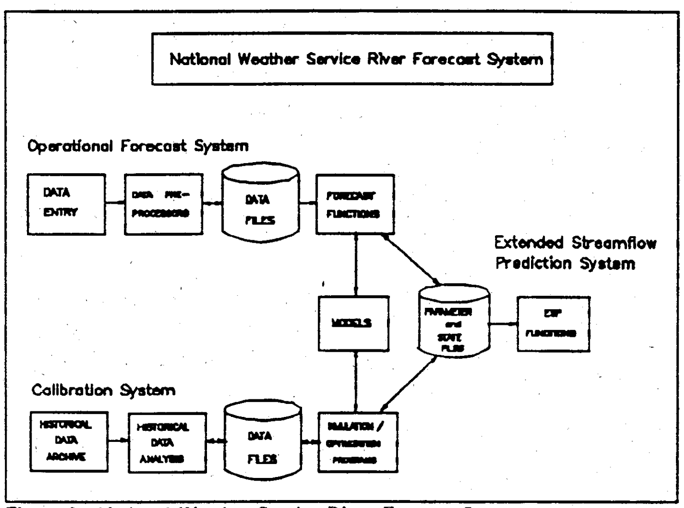

Figure 3. National Weather Service River Forecast System

discuss calibration procedures in more detail.

2.1.2 Operational Forecast System

Once the models have been calibrated for a basin, they can be used operationally with real-time hydrometeorological data to forecast streamflow. The OFS contains three major components that are needed for operational river forecasting: Data Entry, Preprocessor, and Forecast. The Data Entry Component is a set of programs that transfer hydrometeorological data from a variety of sources to the observed data base. The Preprocessor Component reads raw station data, estimates missing data as required, and then uses these data to calculate mean areal time series of precipitation, temperature, and potential evapotranspiration for a particular basin. These processed time series are used by the Forecast Component to perform requested hydrologic and hydraulic simulations. The Forecast Component maintains an account of the current model states. These states describe the hydrologic condition of the basin, including the snow cover, soil moisture, and channel storage. They are needed as starting points for subsequent forecasts.

2.1.3 Extended Streamflow Prediction System

ESP is the portion of the NWSRFS which enables a hydrologist to make extended probabilistic forecasts of streamflow and other hydrological variables (Day, 1985). ESP assumes that historical meteorological data are representative of possible future conditions and uses these as input data to hydrologic models along with the current states of these models obtained from the Forecast Component. A separate streamflow time series is simulated for each year of historical data using the current conditions as the starting point for each simulation. The streamflow time series can be analyzed for peak flows, minimum flows, flow volumes, etc., for any period in the future. A statistical analysis is performed using the values obtained from each year's simulation to produce a probabilistic forecast for the streamflow variable. This analysis can be repeated for different forecast periods and additional streamflow variables of interest. Short-term quantitative forecasts of precipitation and temperature can be blended with the historical time series to take advantage of any skill in short-term meteorological

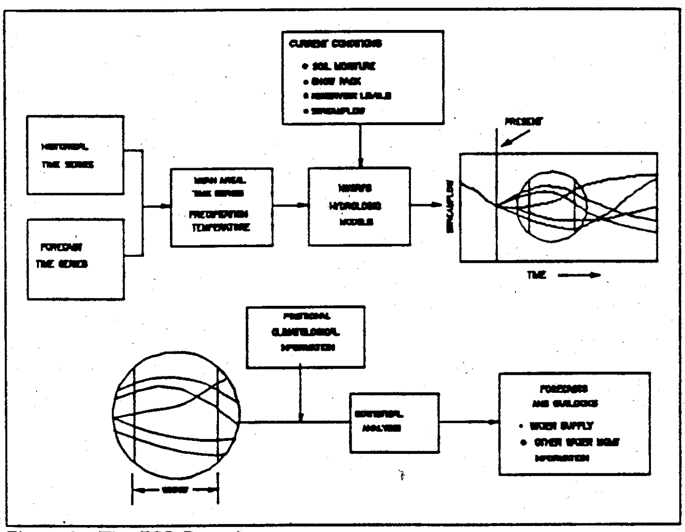

Figure 3. The ESP Procedure

forecasting. In addition, knowledge of the current climatology can be used to weight the years of simulated streamflow based on the similarity between the climatological conditions of each historical year and the current year.

ESP allows flexibility in the streamflow variables which can be analyzed, the capability to make forecasts over both short and long time periods, and the ability to incorporate forecast meteorological data into the procedure. Because of ESP's flexibility and conceptual basis, it has many applications, including water supply forecasts, flood control planning, drought analysis, hydropower planning, and navigation forecasts. The ESP probabilistic forecasts provide uncertainty information needed by water managers for risk-based decisions. The streamflow time series generated by ESP can be output as products, so that they can be used in reservoir simulation/optimization models to investigate how operations might be improved. The ESP forecast information is based on our best estimate of current hydrometeorological conditions, as well as an analysis of the local historical climatological variability.

3. WARFS RELATED PROJECTS

Numerous projects are underway to integrate new technologies for the purpose of improving water resource and flood forecasting services of the NWS. Successful forecasting relies on: (1) an abundant and quality observations, (2) an understanding of the hydrologic processes, (3) the ability to model these physical processes, and (4) to provide efficient interfaces for data analysis and modification of model parameters and functions.

3.1 NEXRAD Precipitation Estimate Project

A fundamental input to hydrologic modeling is precipitation. In the past, forecasts models relied on point observations of limited spatial and temporal resolutions. With the deployment of over 110 NEXRAD radar systems, precipitation estimates will be greatly enhanced. This one piece of data will greatly improve lead time for flood forecasting and provide crucial information to hydrologic forecasters preparing mainstem river forecasts. The Office of Hydrology (OH) is taking the lead in efforts to upgrade the precipitation estimation procedures.

OH has defined three stages to improving precipitation estimations. Stage I will incorporate a limited number of rain gage data (<50 sites) to perform a mean field bias computation while executing a number of quality control procedures to remove erroneous radar data. This will be performed at the radar site. Stage II will use additional rain gage data and satellite information to provide further quality control. A multi-sensor field of radar and gage data will be produced using objective analysis techniques. These data fields will be produced on the Weather Forecast Office (WFO) AWIPS system. Stage III will be run at the River Forecast Centers (RFC), to mosaic stage II products from multiple radar and WFO sites. Stage III will provide interactive interfaces to the hydrologic forecaster to provide additional quality control and the opportunity to select which sensors fields to use in hydrologic forecasting.

3.2 Snow Estimation and Automatic Objective Snow Model Updating Project

The accuracy of streamflow forecasts in the western mountains is limited by the ability to estimate accurately current snow conditions. Improved spatial estimation of, snow water equivalent is required for forecasting rain on snow events and to update snow pack simulation models used in daily forecasting and long range prediction of water supplies.

A project is currently under way to transfer new methodologies into operational procedures for spatially estimating snow water equivalent and incorporating these values into NWSRFS. The OH has developed techniques to consolidate real-time, ground-based, snow water equivalent data collected by the Soil Conservation Service (SCS) with airborne terrestrial gamma radiation, collected by NWS low flying aircraft, and satellite snow cover data obtained from Advanced Very High Resolution Radiometer (AVHRR) sensors on the NOAA polar orbiting satellites.

The estimating procedures will run in three stages: (1) at the National Remote Sensing Center, data will be collected and then objectively and optimally combined to estimate gridded snow water equivalent, (2) these data are then transferred to the RFC where additional data can be included and further quality control will be performed, and (3) the data sets are transferred back to the Remoter sensing Center where national and regional products will be generated and disseminated. Interactive processing is essential for the forecasters to be able to analyze the large volumes of data accessible in the project.

3.3 Interactive Forecast Program Project

The advanced observations, enhanced data integration techniques, improved models, and expanded historical and real-time hydrometeorological data bases provide a strong technological base for comprehensive water resource forecast information. These complex data and software systems can only be effective if the user interfaces are designed for efficient interaction with the hydrometeorologist. In the future, interactive processing will play an extremely important role in historical data analysis, model parameter estimation, real-time data quality control, precipitation field estimation, hydrologic forecasting, and ESP post-analysis and interpretation. Interactive programs are currently being developed to assist the hydrometeorologist in estimation of the precipitation field from gage, radar, and satellite data to assist the hydrologist in the preparation of streamflow forecasts. The Interactive Forecast Program (IFP) is an enhancement of the NWSRFS Forecast Component that provides the forecaster with a powerful, interactive, and user-friendly interface for real-time hydrologic forecasting.

The OH is developing a prototype hydrologic forecast environment expected to be available in the NWS River Forecast Centers of the modernize Weather Service era. All of the NWSRFS hydrologic models currently used by the NWS forecaster have been include in the IFP. Windowing capabilities, of the IFP scientific work stations, will allow the forecaster to have multiple processes displayed simultaneously. This will allow updates and modifications to be made and at the same time see the change in model results displayed.

The purpose of the IFP is to allow the forecaster to use hydrologic expertise and judgement to develop a forecast while streamlining the tasks to produce the forecast. The IFP will provide a graphical user interface which presents information needed to make better hydrologic decisions and allows any required adjustments to be made with the minimum of effort. Based on (1) parameter information describing the structure of the models used at each forecasting point, (2) network information describing how the forecast points are linked together, and (3) observed data describing the locations of meteorological and hydrological sensors as well as their current data values at the time the forecast is made, the forecaster can decide whether to accept a model generated forecast or make needed adjustments. The biggest advancement in the procedures is the forecaster can quickly make changes and immediately see the results.

3.4 ESP Post Analysis Project

ESP is a component of NWSRFS that permits the hydrologist to make probabilistic forecasts of streamflow and other hydrologic variables for extended future periods. ESP assumes that historical meteorological data are representative of possible future conditions and uses these as input data to NWSRFS models along with the current states of these models. A separate streamflow time series is simulated for each year of historical data using the current conditions as the starting point for each simulation. A statistical analysis is performed using the values obtained from each year's simulation to produce a probabilistic forecast for a particular streamflow variable. This forecast can be repeated for different forecast periods. All of these forecasts are currently executed using batch computer technology.

A ESP post analysis project is underway to develop a interactive ESP analysis and display system in a workstation environment, that will provide statistical analysis of ESP time series independent of the program which produced these time series. The program will produce additional tools for analysis of ESP outputs, provide a method for automatically adjusting the conditional simulated output for model biases, and provide automatic product generation.

3.5 WARFS Demonstration Project

A project is underway that will demonstrate the value of WARFS, integrating new technologies for the purpose of improving water resources forecasting services in the Colorado Basin and, in particular, the Blue and Williams Fork River Basins. It will provide the basis for planning and preparation of the national WARFS program. The project is a cooperative effort involving Denver Water (DW), Riverside Technology, inc. (RTi), and Colorado State University (CSU).

The objectives of the project are to (1) define a methodology of incorporating ESP forecasts into reservoir operations and (2) quantify the benefits of incorporating ESP forecast information in reservoir operations. The project is divided into two parts; the first provides a mechanism to transfer ESP information from the NWS to DW. The second part will develop procedures to incorporate ESP forecast information into reservoir operations and perform an analysis of the benefits.

The technical approach will be based on a reconstitution of historical events at a site where Extended Streamflow Prediction information is now available. The site consists of two reservoirs on adjacent rivers (Williams Fork and Dillon Reservoirs). A reservoir simulation model will be selected and modified to allow use of ESP forecast information. Optimization will be made using a generalized dynamic programming code. Benefits associated with the optimization and the additional ESP information will be computed and the results will be used to modify the operational model for use in real-time by DW operations personnel. The project will result in the development of state-of-the-art decision support tools that can be used to improve the management of DW reservoirs.

ESP verification will be performed by generating and statistically analyzing ESP forecast traces for the verification period. The verification information will be used to determine the accuracy of the forecasts and how representative the results of the project will be for other locations.

4. SUMMARY/CONCLUSIONS

The improved data collection and analysis systems of NEXRAD and ASOS work together with the forecast program to provide the best possible information for water resource and flood forecasting. Stage III precipitation processor has been designed to produce the highest quality precipitation data available to the forecasters at spatial and temporal scales not previously achievable.

Advanced data and computer systems have provided an efficient environment to perform data analysis, forecasting, and interpretation. The interactive forecast program demonstrates how a complex software system can be made manageable and responsive to a hydrologist operating under severe time constraints. The purpose of adjustments made through the IFP is to provide a better representation of the current hydrometeorologic conditions within a forecast area so forecasts starting from these conditions can be more accurate.

All of these systems working together have provided an efficient environment to perform data analysis, forecasting, and interpretation. They will ensure that the best possible hydrometeorological information is available on which to base probabilistic water resources forecasts and daily river forecasts. This all leads to the best available information being presented to decision makers so as to optimize the benefits which can be realized from our water resources.

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