N93-25616

INTERACTIVE FORECASTING WITH THE NATIONAL WEATHER SERVICE RIVER FORECAST SYSTEM

George F. Smith and Donna Page
Office of Hydrology
National Weather Service, NOAA
Silver Spring, MD 20910

S55-47
150525
P- 10

ABSTRACT

The National Weather Service River Forecast System (NWSRFS) consists of several major hydrometeorologic subcomponents to model the physics of the flow of water through the hydrologic cycle. The entire NWSRFS currently runs in both mainframe and minicomputer environments, using command oriented text input to control the system computations. As computationally powerful and graphically sophisticated scientific workstations became available, the National Weather Service (NWS) recognized that a graphically based, interactive environment would enhance the accuracy and timeliness of NWS river and flood forecasts. Consequently, the operational forecasting portion of the NWSRFS has been ported to run under a UNIX operating system, with X windows as the display environment on a system of networked scientific workstations. In addition, the NWSRFS Interactive Forecast Program was developed to provide a graphical user interface to allow the forecaster to control NWSRFS program flow and to make adjustments to forecasts as necessary. The potential market for water resources forecasting is immense and largely untapped. Any private company able to market the river forecasting technologies currently developed by the NWS Office of Hydrology could provide benefits to many information users and profit from providing these services.

INTRODUCTION

The U.S. National Oceanic and Atmospheric Administration (NOAA) is responsible for using science and service to manage the resources of the United States. The National Weather Service (NWS) supports this mission by providing river and flood forecasts and warnings for protection of life and property, and by providing basic hydrologic forecast information for environmental and economic well being. The Office of Hydrology (OH) supports NOAA's and NWS's missions through the design, development, testing, implementation, and support of a physically-based hydrologic forecasting system - the National Weather Service River Forecast System (NWSRFS).

In general, a river forecast system (or almost any system) can be viewed as having major components of (1) forces that drive the system, or data, (2) a mechanism to analyze the driving forces, or processing, (3) the heart of the system where the physical laws of motion are modelled, and (4) products of the system, or guidance information output for decision making. The relationships of these general functions of a river forecast system are shown in Figure 1. This paper will concentrate on the modelling and some output features which, as part of an ongoing OH project tied to NWS modernization, have been converted to an interactive, graphical form on computationally powerful scientific workstations. The paper will also describe how this technology could be used by the private sector to provide additional water resources forecasting services.

There are many components which together form the NWSRFS. The next section will present a brief background and history of the evolution of the NWSRFS, including some of the rationale for the existing structure which allows NOAA/NWS to have one of the premier river forecast systems in the world.

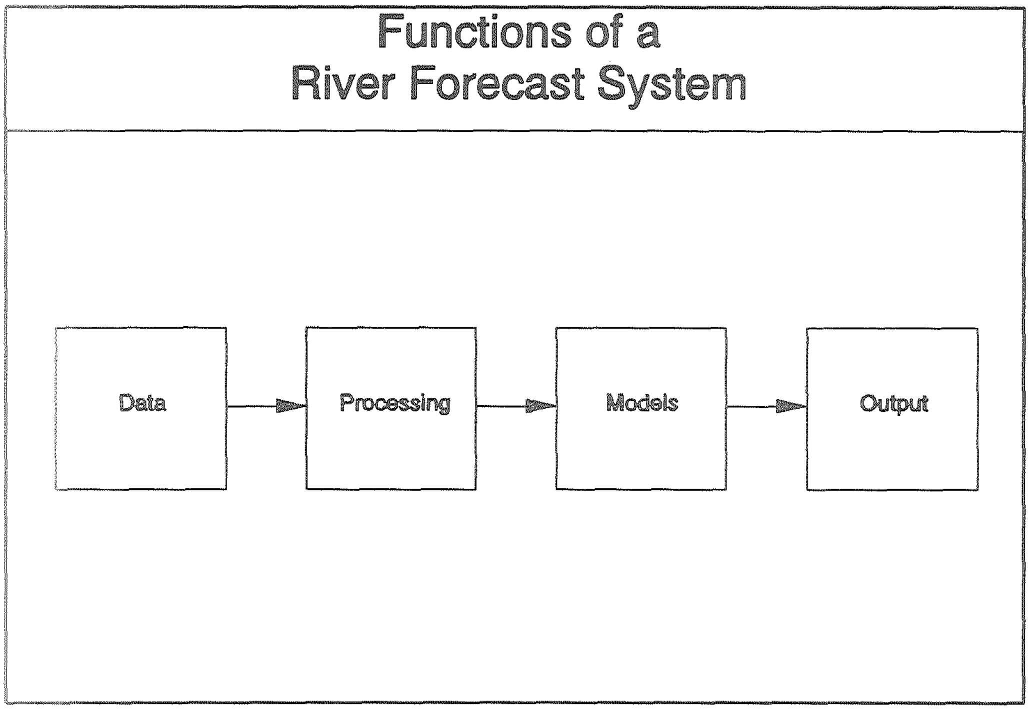


Figure 1

BACKGROUND/HISTORY

Prior to the advent and availability of digital computers many graphical or hand calculation methods were used for determining the flow of water in rivers. Because the hydrologic conditions varied greatly from one portion of the U.S. to another, different techniques for forecasting river conditions were developed by River Forecast Centers (RFC) responsible for different areas. There are presently 13 RFCs in the U.S. The areas of responsibility for the 12 which cover the coterminous U.S. are shown in Figure 2. The thirteenth RFC is responsible for the state of Alaska.

In the 1960's and early 1970's computers were introduced into the RFCs. Consistent with their pre-computer activities, each of the RFCs independently developed river forecasting software. Often this software was simply a computer representation of the graphical techniques used previously. These locally developed software programs introduced two major problems into the NWS forecasting activities. First, the forecasting software was dependent on the individual who did the initial development. When that person changed jobs or retired, much of the knowledge of how to run the programs, or how to maintain or enhance the programs was lost to the NWS. Second, forecasters at one RFC were trained in forecasting software that was, in general, only applicable to that RFC. If someone moved from one RFC to another they would have to be retrained in the forecast programs used at the new RFC. This also was a major burden to the NWS river forecasting mission.

In the early to mid 1970's the OH began development of the NWSRFS to (1) meet the forecasting needs of all RFCs, (2) be supported and documented at the National level, and (3) have enhancements and software configuration management coordinated by OH. One of the initial goals was to design a system which included existing techniques from many of the RFCs so that a single system could be used for river forecasting throughout the U.S.

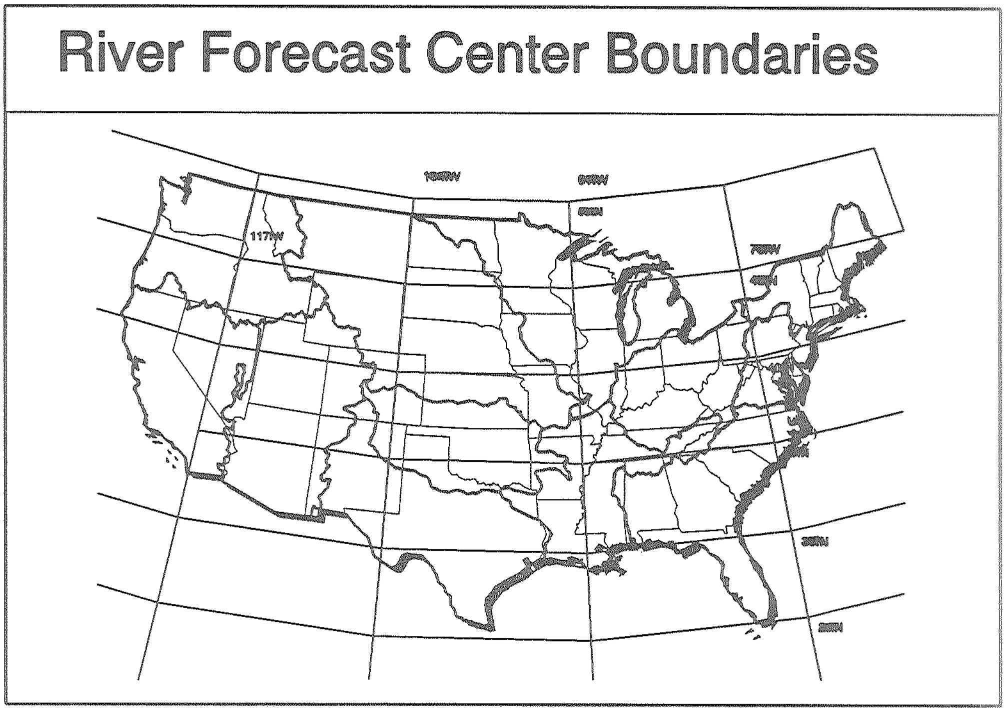


Figure 2

In the mid to late 1970's, initial versions of the NWSRFS were developed by software contractors under guidance from OH. These initial versions met some of the intended requirements of a national river forecast system, but they suffered from several basic flaws. Early versions of NWSRFS did not include all the features needed to model the flow in rivers in the varied hydrometeorologic regimes found throughout the U.S. Also, they did not account for the growth and evolution of computer technology and advances in hydrologic science. Versions 1 through 4 of the NWSRFS had a rigid program structure which made it difficult to add new modules as additional features were developed. The hydrologic modelling structure required that all basins use the same models in a fixed sequence. With the hydroclimatic variation found in the U.S. from humid to arid, and snow to sub-tropical conditions, this restriction was very limiting. New models or technology were very difficult to add to these early versions of the NWSRFS.

NWSRFS VERSION 5

In 1979, the OH began a project to completely redesign the NWSRFS. In addition to fixing the shortcomings found in previous versions, a major objective of the project was to develop a system structure which looked toward the future of hydrometeorologic forecasting. The initial requirements for NWSRFS Version 5 were developed from extensive interactions between designers in OH and the RFCs. Version 5 differed from previous ones in several ways, a major one being that scientific algorithms were designed to be independent of any specific computer system, and were coded by OH and RFC hydrologists who were intimately familiar with the physics of the processes being modelled. Specifications for data access and command decoding routines were developed by OH and RFC staff, and were coded by software contractors. The functional requirements which guided the design of NWSRFS Version 5 were to:

1. allow for a variety of models and procedures,
2. let the user control selection of models and sequence of use,
3. easily add new models and procedures to keep up with technological changes,
4. efficiently process large amounts of data to produce forecasts at hundreds of locations for each RFC, and
5. allow the user to flexibly control real-time processing.

Version 5 was designed to be modular, so that components could be developed by a number of individuals and then combined into a total system. References in the program code to system specific routines were isolated so that the entire NWSRFS could be ported from one hardware/operating system platform to another with minimum effort. Routines which performed scientific algorithms were separated from input/output routines so that the science could be run on any computer without needing changes in the reading or writing of information from the computer system. Scientific algorithms were organized into modular functions so that the functions could be shared, unchanged, among major components of the NWSRFS.

The functions representing one scientific algorithm, such as a snow, soil moisture, or river routing procedure are called an operation. In general, an operation in the NWSRFS is a set of functions that performs actions on a time series. Typically an operation describes the equations of motion governing the flow of water through a portion of the hydrologic cycle. There are also operations to display results, or to perform utility functions such as adding two time series. Table 1 provides a list of some of the currently available operations in the NWSRFS.

Table 1. NWSRFS Hydrologic Models

Snow
- HYDRO-17 Snow Model

Soil
- Sacramento Soil Moisture Accounting
- Ohio RFC API Rainfall-Runoff Model
- Middle Atlantic RFC API Rainfall-Runoff Model
- Central Region RFC API Rainfall-Runoff Model
- Colorado RFC API Rainfall-Runoff Model
- Xinanjiang Soil Moisture Accounting
- Continuous API Model
- Middle Atlantic RFC API Rainfall-Runoff Model #2

Channel
- Channel Loss
- Dynamic Wave Routing
- Lag and K Routing
- Layered Coefficient Routing
- Muskingum Routing
- Tatum Routing
- Stage-Discharge Conversion
- Single Reservoir Simulation Model
- Unit Hydrograph

The operations that model the flow of water through the hydrologic cycle fall generally into the categories of (1) one location to another on a river. Operations form the scientific heart of the NWSRFS and are shown in Figure 3 to be shared by the major sub-systems which comprise the NWSRFS Version 5. Because of the modular nature of the functions which make up any operation, functions can be shared with no change whatsoever among the programs which form the NWSRFS. This also allows new scientific techniques to be developed in the structure specified for an operation, and once tested to be immediately available for use in forecasting with the NWSRFS.

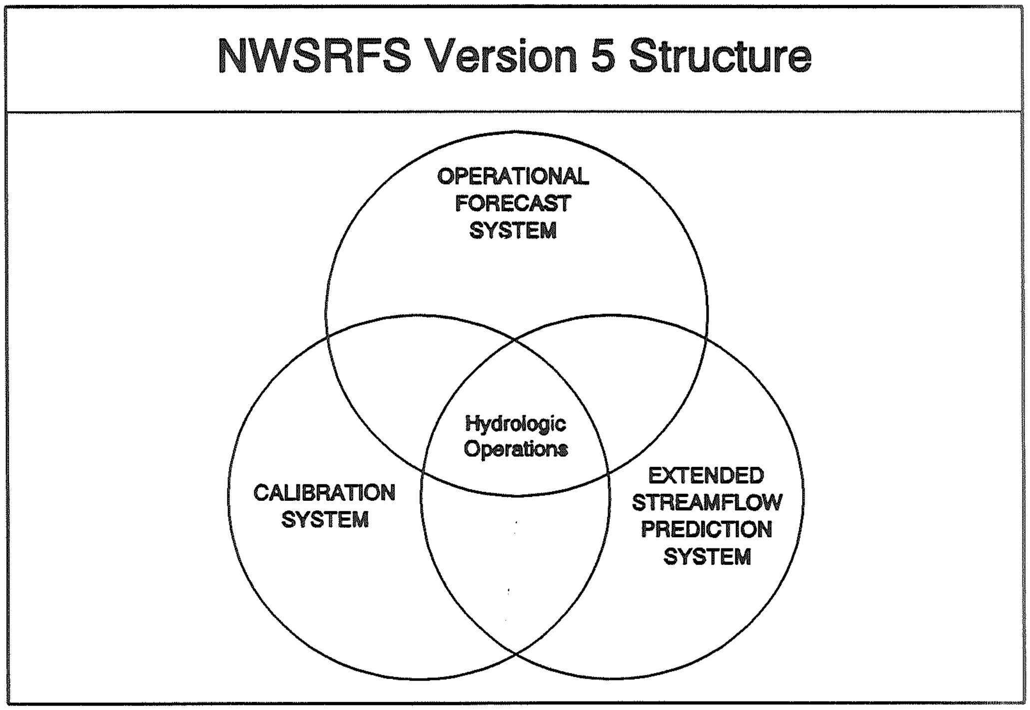
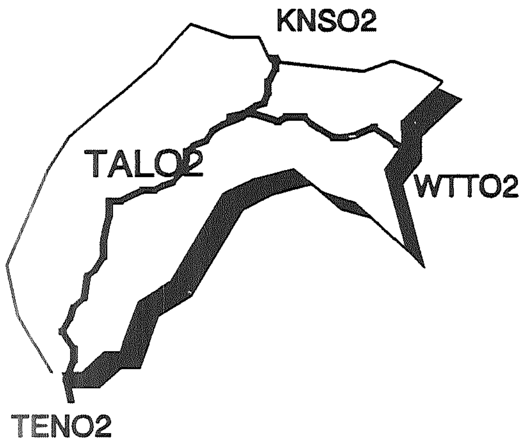


Figure 3

Hydrologic operations in NWSRFS are organized into an "operations table" to specify the physics of water movement for any subbasin. Operations can be selected from the list shown in Table 1. The order in which they are computed depends on the hydrometeorologic conditions of the subbasin being modelled. RFC forecasters can use their hydrologic expertise to determine the best sequence of scientific algorithms (operations) to model each subbasin. In this way, NWSRFS provides a generalized river forecasting system which can be used to model basins in any hydroclimatic regime. An example of the specific operations table for the Tahlequah, Oklahoma subbasin in the Arkansas-Red Basin RFC area is shown in Figure 4.

Initial NWSRFS Version 5 development occurred from 1979 through 1984. In 1985 NWSRFS Version 5 was delivered to the Arkansas-Red Basin RFC for initial operational forecasting use. Since then Version 5 has been installed in other RFCs and has been used daily to produce operational forecasts at thousands of locations along rivers throughout the U.S. New subbasins are continuously being calibrated and added as operational forecast locations by RFC hydrologists. Many new scientific algorithms and enhancements to existing operations have been added to improve the hydrologic modelling capabilities of the NWSRFS.

Tahlequah Forecast Point with operations



TALO2 Operations Table

Lag/K	WTTO2
Clear-TS	
Add/Sub	WTTO2
Lag/K	KNSO2
Add/Sub	KNSO2
Snow-17	TALO2
Sac-SMA	TALO2
Clear-TS	
Unit-Hg	TALO2
Clear-TS	
Add-Sub	Routed
Add-Sub	Local
Stage-Q	TALO2
Adjust-Q	TALO2
Stage-Q	QUINE
Plot-Tul	TALO2

Figure 4

As computer technology has evolved the NWSRFS has kept pace. The initial NWSRFS design and development was on mainframe computers (NAS 9000s) at the NOAA Central Computer Facility (CCF). As minicomputers became powerful enough to support the system requirements of the NWSRFS, the NWSRFS Operational Forecast System (OFS) was ported to Prime minicomputers which are at OH and several of the RFCs. With the explosive growth in computational capabilities for scientific workstations, OH initiated a project in the late 1980's to prepare for modernization of the entire NWS by moving the scientific operations and forecasting component of the NWSRFS onto IBM RS/6000 workstations.

When the NWSRFS is run from the NOAA CCF, command input is sent over Remote Job Entry (RJE) lines from RFCs to the CCF. Line printer results are sent back to the RFC for display on standard printers or on text display screens.

Beginning in 1989, graphical display and user interface capabilities were developed for the NWSRFS. The result is the NWSRFS Interactive Forecast Program (IFP) which will be discussed in more detail in the next section of this paper.

INTERACTIVE FORECAST PROGRAM

The process of hydrologic forecasting requires human-machine interaction. This is because:

1. the equations with which we represent the physics of the hydrologic cycle do not perfectly

model the actual movement of water,
2. the process we use to calibrate, or find specific parametric values for, the models does not produce perfect results, and
3. we do not perfectly observe rainfall or stream conditions as input to the models.

In order to properly forecast a hydrologically connected series of subbasins, a forecaster must make decisions for each location along the river where observed river conditions are available. If values simulated by NWSRFS do not agree with observations, the forecaster must decide on the most likely source(s) of error, and make adjustments. When a river system is forecast with NWSRFS on the NOAA CCF or a Prime minicomputer, a group of subbasins are processed in a single batch run. Errors in upstream subbasins propagate into downstream basins, making forecasts for those basins less reliable. The only way to avoid this problem is by making adjustments to reduce or remove the error in any subbasin before processing downstream subbasins. The NWSRFS IFP provides the forecaster with this capability. An additional benefit of the IFP is the enhanced display capabilities of high-resolution color display terminals above those of line printer output.

As described above, hydrologic forecasting is inherently interactive. The initial designers of NWSRFS recognized this, but were limited because computational requirements demanded that the forecast system run on a mainframe computer with little interactive capabilities. The computational capabilities of scientific workstations have evolved so that the initial design features of NWSRFS Version 5 to allow for interactive forecasting can be realized.

Graphical user interface (GUI) and graphical display capabilities were developed on scientific workstations. Figure 5 shows in heavy outlines those portions of the mainframe and minicomputer versions of NWSRFS that were ported to scientific workstations and linked with the GUI and graphical display modules. The division of components among those solely in the NWSRFS OFS, those solely in the IFP, and those shared by both programs is shown in Figure 6.

Important features of the NWSRFS IFP include:

1. an operationally proven set of hydrologic models,
2. a system configuration which uses the UNIX operating system with X Windows graphical display protocol and Open Software Foundation (OSF) Motif,
3. adherence to OSF standards to be computer hardware platform independent,
4. a GUI that provides easy, powerful user interactions,
5. scientific applications that are isolated from the operating system specific function calls and input/output, and
6. the use of both C and FORTRAN programming languages; C for user interface and graphical display routines, FORTRAN for physical process modelling.

The IFP currently runs in two configurations, depending on the equipment available at a site. In the first, a Prime minicomputer runs the NWSRFS OFS and creates a current set of model conditions and time series. A forecaster at a scientific workstation networked to the minicomputer begins an IFP session by asking for information about a set of subbasins. This initial information is transferred from the minicomputer to the workstations. The remainder of the IFP session is performed on the workstation with computations of the operations tables for subbasins being forecast, adjustments made through the IFP GUI, and results displayed for forecaster interpretation. At the end of an IFP session, adjustments made for any subbasins are transferred to the minicomputer to become incorporated in further forecasting activities.

In the second configuration (Figure 7), a UNIX based fileserver replaces the Prime minicomputer. This eliminates the need to transfer information between different operating system environments and allows the NWSRFS OFS and IFP to operate more efficiently.

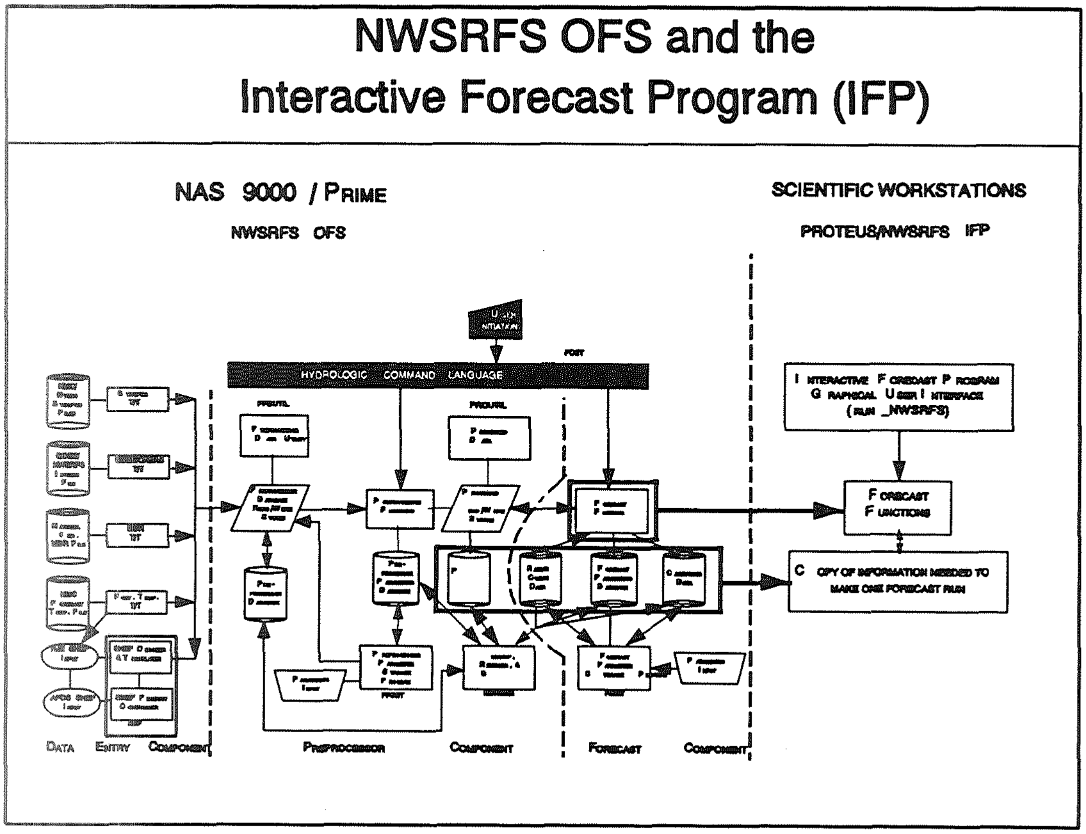


Figure 5

FUTURE ACTIVITIES

As the NWS moves forward with planned modernization activities, interactive forecasting with the NWSRFS will evolve to continue to fulfill NOAA's mission and make the best use of newly available data to provide forecasts and warnings for protection of life and property, and for environmental and economic well being. A major new data source in the modernized NWS is the WSR-88D radar data which will provide high resolution quantitative estimates of rainfall. The computational configuration which includes the Prime minicomputer networked to scientific workstations is not adequate to process the WSR-88D data which will become available soon to the RFCs. WSR-88D radars are being installed to cover:

18% of the continental U.S. by January 1993,
41% of the continental U.S. by January 1994,
81% of the continental U.S. by January 1995, and
95% of the continental U.S. by January 1996.

Enhanced computational capabilities provided by the UNIX based file servers will allow OH to realize the benefits of this high resolution radar data for hydrologic forecasting. The next phase of OH's modernization activities will be to demonstrate the operational use of WSR-88D radar data and the IFP. This activity will not only provide benefits to the U.S. as WSR-88D radars are commissioned, but will also allow for a smooth transition of hydrologic forecasting applications into the modernization plans for the NWS.

The configuration shown in Figure 7 allows NWSRFS OFS and IFP to operate efficiently. This fully networked system will process WSR-88D radar data and provide an interactive environment for hydrologic forecasting.

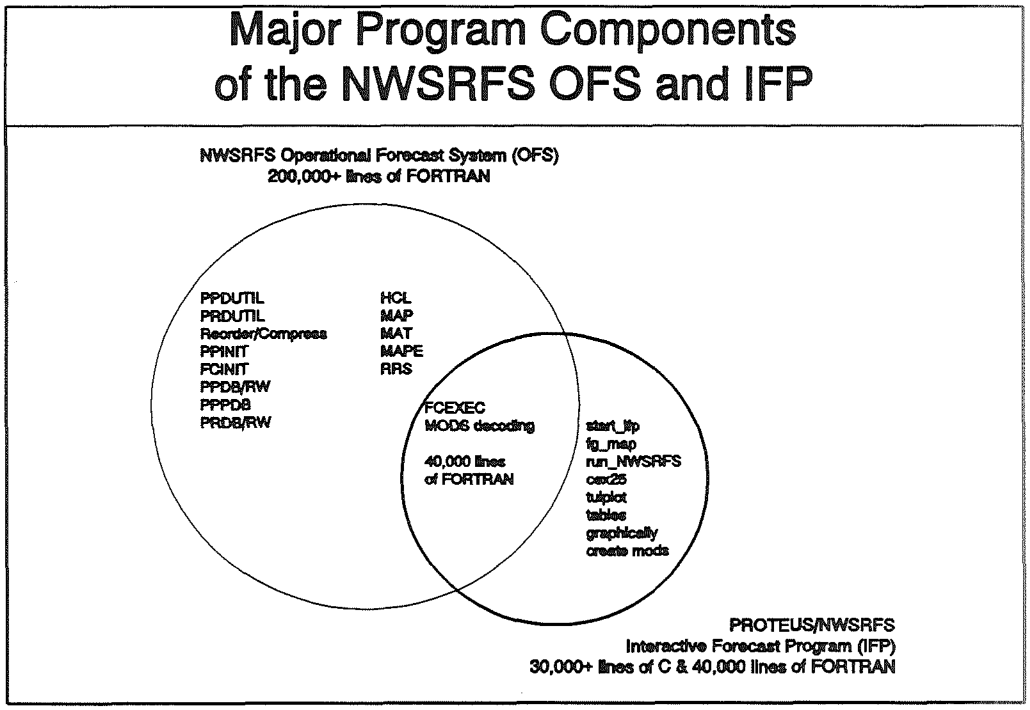


Figure 6

COMMERCIAL POTENTIAL

The demand for hydrologic forecasting services has been demonstrated by the response of the private sector to two subcomponents of the NWSRFS that are currently marketed by software engineering firms. The software firms have been successful in their sales of the dynamic wave river model and the dam break flood prediction model they have repackaged.

The potential market for timely and accurate hydrologic forecasts is immense and largely untapped. Navigation and recreation interests need information to help efficiently determine appropriate activities and resources for the river systems on which they operate. Reservoir operators have a tremendous potential gain by using river flow forecasts to help balance the competing needs of water supply, flood control, hydroelectric power generation, and ecological viability of the river.

An example of how these NWSRFS OFS and IFP technologies can be used commercially is provided by the Bonneville Power Authority (BPA) which operates a series of reservoirs on the Columbia and Willamette Rivers in the northwestern United States. Among the goals of their reservoir operations are flood mitigation, power generation, and maintenance of the river ecology to support the fishing industry in the northwest. In order to optimize these interests, BPA decision makers must, at times, balance the survivability of fish fingerlings with profits from power generation in their reservoir operations.

The information provided by the NWSRFS OFS and IFP would be useful to BPA in making those decisions.

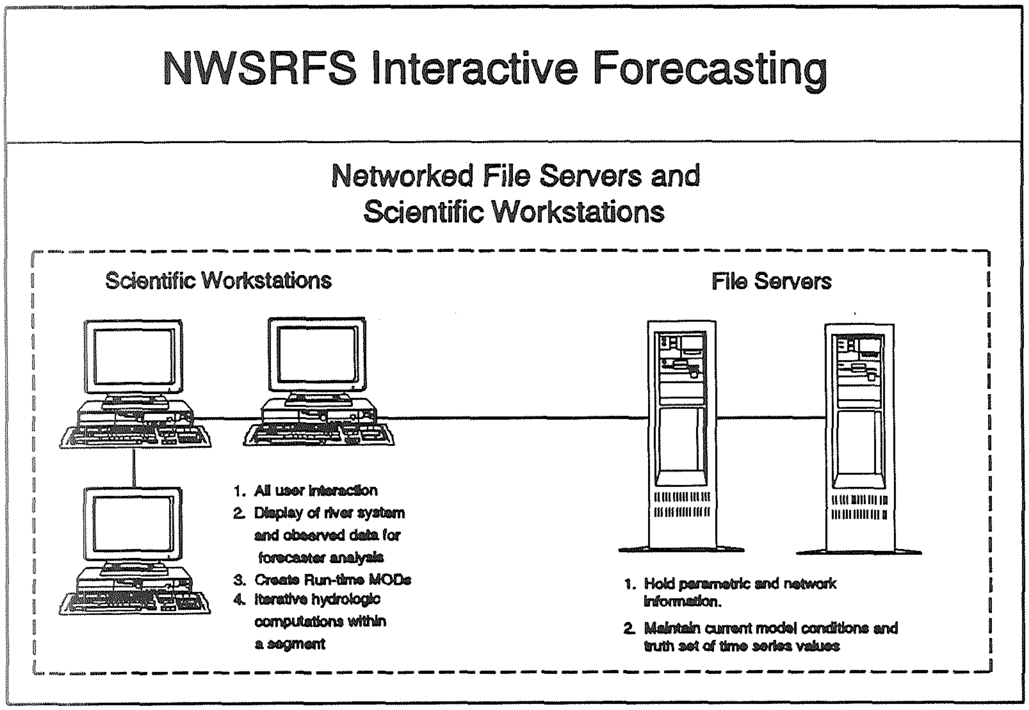


Figure 7

The IFP provides a graphical display of flows into the reservoirs and along the river system. These flows can be used to estimate power generating capabilities and track favorable fish migration conditions. The IFP also provides a flexible, easy-to-use interface to the powerful capabilities of the NWSRFS OFS that allows forecasters to try numerous what-if scenarios to visualize the effects of their reservoir operations.

The BPA is currently working with a private engineering firm to provide this information to their decision makers to optimize revenue from both fishing and power generating activities. This is just one example of the commercial potential of the NWSRFS OFS and IFP technologies. Any private company able to market the river forecasting technologies currently developed by the NWS Office of Hydrology could benefit any of the information users mentioned above (and many others) and profit from providing these services.