Development and Application of Hydrologic Forecast Systems

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ABSTRACT

Hydrologic forecast systems generally consist of several components which include computer hardware and software to perform data handling functions and enable users to calibrate hydrologic models and use the models to generate forecasts. The functional components of a forecast system are described, using the National Weather Service River Forecast System as an example. This paper focuses on the transfer of technology that must occur among the various types of individuals contributing to the research, design, coding, testing, implementation and support of a hydrologic forecast system.

INTRODUCTION

Hydrologic forecasting is a subject of growing concern as evidenced by the large number of sessions and presentations devoted to the topic at this conference. The purpose of this paper is to serve as an introduction to hydrologic forecasting and provide a description of forecasting from the perspective of one contributor to the overall forecasting process.

Forecast System Components

Hydrologic forecasting, or river forecasting, as which it often is referred, generally is performed today with the use of some type of hydrologic forecast system (HFS). An HFS typically consists of various software elements which have specific functional capabilities. As shown in Figure 1, the elements can be categorized as four functional components: data collection, modeling and data processing, forecast analysis and preparation, and forecast dissemination and tailoring. Data collection is the process of obtaining data which can be used as input to the data processing component. The data may be in the form of inputs which drive the system, such as precipitation or temperature, or observations which can be used to check or correct model outputs, such as river stage or discharge. The modeling component in an HFS actually may consist of several data processing elements. For instance, models may be available for computing mean areal precipitation, mean areal temperature, snow accumulation and melt, runoff, hydrologic and hydraulic routing, and stage/discharge conversions. Many of the models must be

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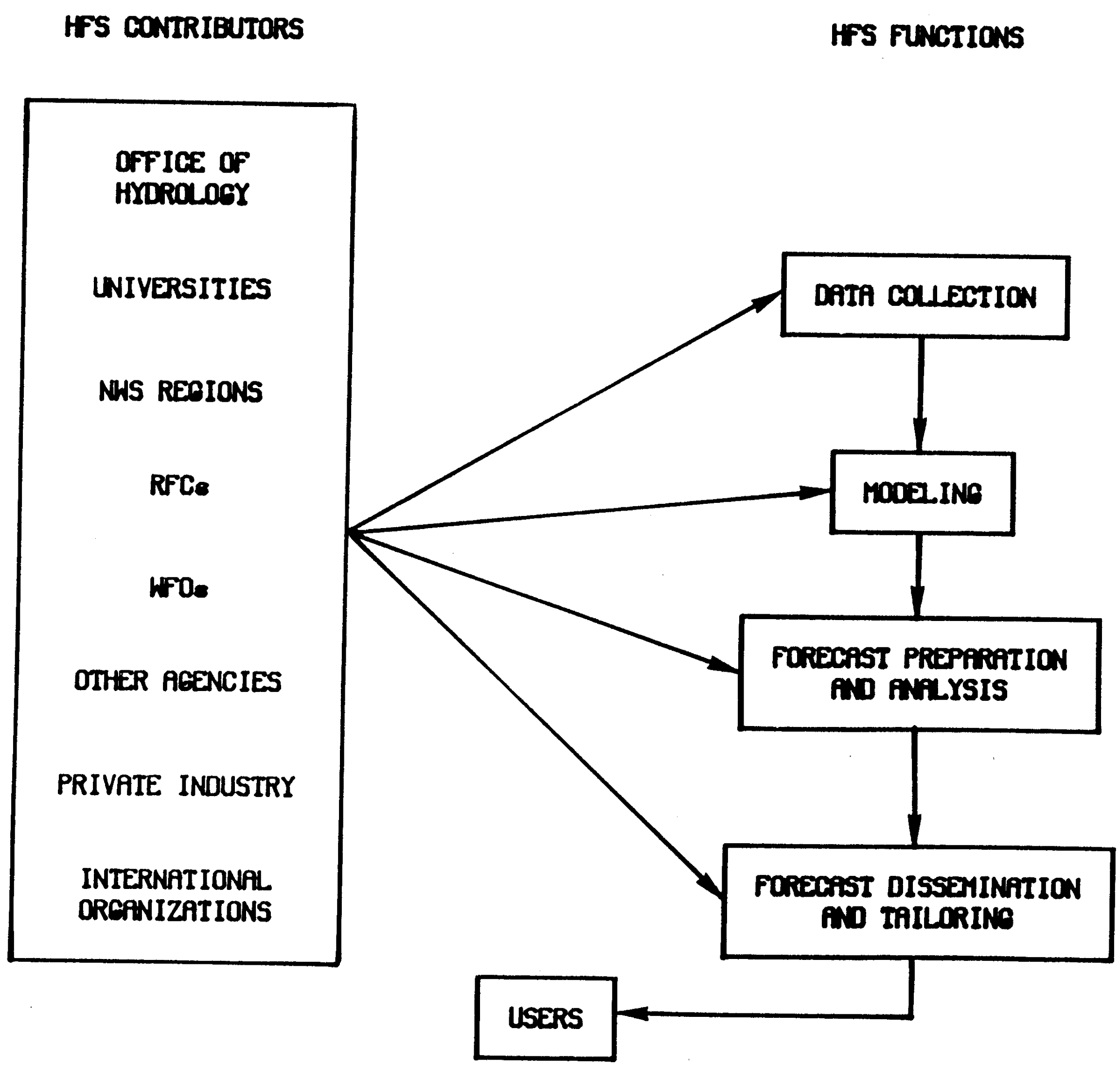

Figure 1. Hydrologic Forecast System Contributors and Functions

calibrated to each site in order to be effective. A typical HFS may include a particular hydrologic or hydraulic model in several programs, such as a continuous simulation program, an event-oriented forecast program or a calibration program. Depending on the information provided by the data collection and modeling steps the forecast analysis and preparation component may be very complex and difficult to automate. The component consists of the steps a forecaster uses to analyze output from the model and prepare a forecast. The steps must include a comprehensive interpretation of results from the numerical models. The fourth component consists of a timely distribution of forecast information to users in a form that is appropriate for their application. At a national level this step can be an enormous task. For many smaller scale applications, the user often is actually running the HFS, and the problems with this component are minimized.

Forecast System Contributors

The development and application of an HFS requires contributions from a number of participants. Examples of these cooperative efforts include the systems developed at the National Weather Service (NWS). Two major components of an HFS can be seen in the NWS River Forecast System (NWSRFS). Details of the software are described later in this paper. Figure 1 shows a list of the types of participants who contribute to the overall NWS hydrologic forecast process.

The NWS is responsible for providing hydrologic information and forecasts for rivers and watersheds throughout the United States. The NWS hydrology program is under the direction of the Office of Hydrology (OH). Development of the original NWSRFS was accomplished under a project jointly supported by the Hydrologic Research Laboratory (HRL), the Hydrologic Operations Division (HOD), and the RFCs. All three of these groups continue to support the software. The majority of HRL and HOD efforts have been aimed at improving the modeling and data processing capabilities. Significant research work to enhance particular technical details of the system has been performed at universities under the direction of or in cooperation with HRL.

River Forecast Centers (RFCs) located throughout the country (as shown in Figure 2) issue hydrologic forecasts for over 2500 locations. The RFCs are staffed with professional hydrologists responsible for preparation of hydrologic forecasts within the RFC area. In addition to collecting data and preparing daily forecasts, the hydrologists contribute to the development of the hydrologic forecasting procedures. Administration of the RFCs is under the direction of the appropriate NWS Region. Regions are responsible for planning and managing resources in such a way that the hydrologists have the necessary tools to perform operational forecasting. NWS Warning and Forecast Offices (WFOs) will be responsible under the NWS reorganization for collecting data, disseminating hydrologic forecast information, and analyzing hydrometeorological conditions for potential flash flood situations. In addition to the WFOs, private industry is becoming more involved in the distribution of NWS forecast information and is offering information tailored to users' specific needs. NWS hydrologic forecasting operations consistently interact with other U.S. and foreign government agencies. The exchange of information has directly contributed to the enhancement of the NWS hydrologic forecast systems.

One of the above mentioned forecast system contributors is the Office of Hydrology (OH). The following sections will describe in more detail the contributions that OH has made to the NWS forecast system.

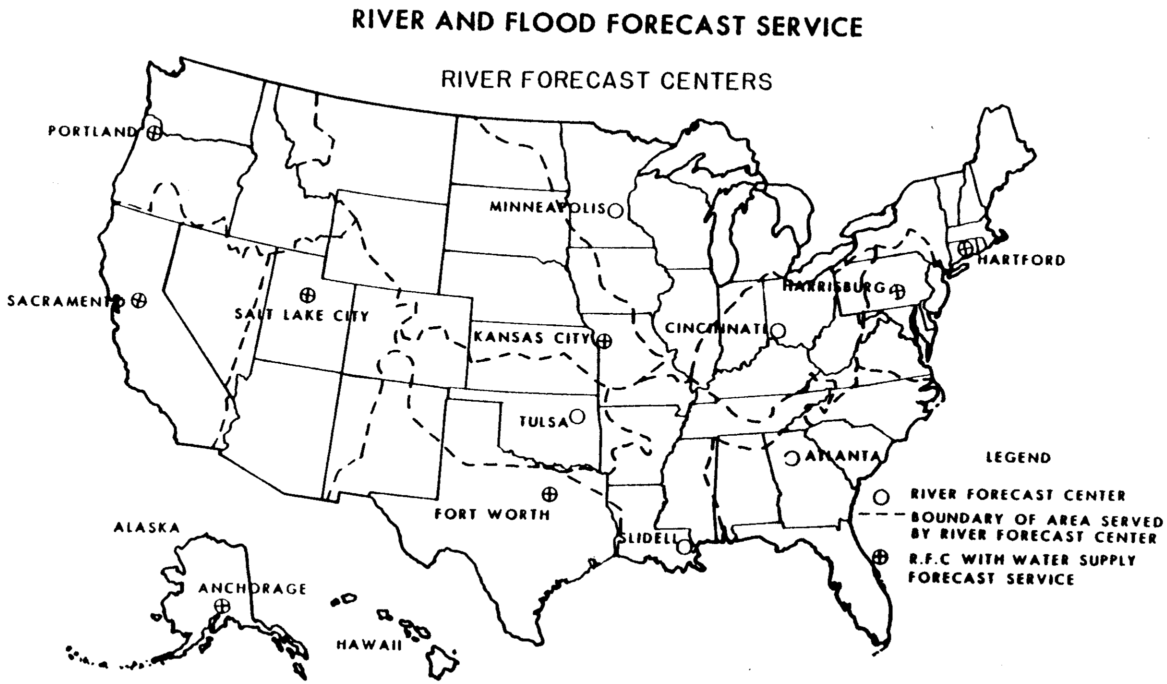

Figure 2. NWS River Forecast Center Areas

THE ROLE OF OH

Overview

The Hydrologic Research Laboratory and Hydrologic Operations Division are two divisions in the National Weather Service Office of Hydrology. The Laboratory's research program is in direct support of the NWS's mission of issuing forecasts and warnings of river conditions affecting the Nation's safety and economic welfare. The objectives of the Laboratory are to increase the understanding of the hydrologic cycle and to develop techniques for applying new knowledge to hydrologic forecasting and related water resources problems. Major research areas in the HRL include hydrologic modeling, river mechanics, radar hydrometeorology, snow and cold regions, extended streamflow forecasts, hydrometeorologic data, enhanced calibration procedures, systems analysis and estimation theory applications.

The Hydrologic Operations Division is responsible for defining hydrologic service requirements and for coordinating the implementation of field programs. The Hydrologic Systems Branch of HOD supports the development, implementation, and operational readiness of the NWSRFS.

Organization

Work in the HRL is organized by Project Area and Implementation Project. The four Project Areas are River Mechanics, Hydrologic Modeling, Systems Analysis, and Hydrologic Data. The major Implementation Projects are the NWSRFS Operational Forecast System (OFS) version 5 (Anderson, 1986), Extended Streamflow Prediction (ESP) (Day, 1985), and NWSRFS Calibration (Brazil and Hudlow, 1980). An ongoing special activity in the HRL is the Next Generation Weather Radar (NEXRAD) (Ahnert et al., 1983, Walton et al., 1985).

Interactions

OH interacts with many other groups in the hydrologic forecast arena. Within the NWS structure HRL and HOD deal routinely with RFCs in support of the NWSRFS and with the NWS Regional offices to coordinate the technology transfer to NWS field offices. Numerous universities have contributed to the NWS hydrology program. The usual mechanism for HRL/university interactions is a Cooperative Agreement. With Cooperative Agreements both the university and HRL designate a Principal Investigator for the project and both organizations contribute to the proposed research. This interaction has been an extremely effective way for the universities to fund students to work with HRL staff on problems with real world applicability. Private contractors have had two major roles with HRL: software development and the crossover of technology from other scientific disciplines. OH has ongoing contracts for the development and maintenance of portions of the NWSRFS OFS and calibration systems, as well as in support of the NEXRAD project. Although the vast majority of operational code has been written in-house certain specific applications (usually related to data storage or the user interface) have been contracted. In all cases the functional specifications (and most times the program design) are defined in HRL, and the task of coding is given to a software contractor. Cross fertilization of technology from other scientific disciplines is one way for the field of hydrology to advance. In the past OH has contracted with engineering consulting firms to provide some preliminary research in the use of estimation techniques for hydrologic forecasting. These estimation theory techniques were originally applied in the fields of electrical engineering, and navigation and aiming control. The ability of these estimation techniques to keep a computer model of some real world process on track by analyzing both model output and observed data, and producing an improved estimate of the current process states should advance our ability to forecast river conditions. The NWSRFS OFS is being enhanced to allow these techniques to be tested by OH and made available to RFCs for operational use. OH cooperates with many other U.S. Government agencies (such as the USGS, Corps of Engineers, Bureau of Reclamation, etc.) as well as other research laboratories (NCAR, ERL, CRREL, GLERL). Technology transfer among nations is promoted through liaisons with WMO and other international organizations.

The HRL is involved in research and development in two of the major functional components of a Hydrologic Forecast System (HFS). HRL has done extensive work in the preliminary processing of data, in the design and development of hydrologic and hydraulic models, and in developing tools for forecast analysis.

NWSRFS

One of the major contributions by OH to the NWS hydrologic forecast program is the design and development of the NWS River Forecast System (NWSRFS). The NWSRFS consists of several programs, data bases, and documentation to produce river forecasts. The NWSRFS is a nationally supported system which can be applied to a wide range of hydroclimatic conditions. Programs in the NWSRFS can be used to process historical data, calibrate models, and produce operational and extended streamflow forecasts.

Historical Background

Before the development of the NWSRFS each RFC had its own set of forecast programs and procedures. Some of the difficulties recognized with this structure were

- the inability to provide national level support for many independent programs,
- the training period required on a totally new system whenever a person moved from one RFC to another,
- the introduction of new technology to the NWS hydrology program, and
- the length of institutional memory because often one person in an RFC developed their operational forecast program and the ability to support or enhance the system was lost when they left.

In an attempt to overcome these deficiencies in the hydrologic forecasting program OH began to develop the NWSRFS as a generalized package of modeling and forecasting tools that could be implemented by all RFCs. Several versions of the NWSRFS were developed and tested in the early to mid 1970s with each being a stepping stone to overcoming the problems listed above. Each of the versions 1 through 4 had a basic design flaw in that they were built around a particular soil moisture accounting model and were very rigid in how the hydrology of a basin could be represented. These early versions had also not accounted for inconsistencies that arose among the calibration, operational, and extended streamflow forecast systems. By the late 1970s it was clear that the current NWSRFS could not be patched any further and the Operational Program Advisory Group, with representation from OH, the Regional offices, and RFCs recommended that NWSRFS be completely redesigned. Thus began a five year project to design and develop an NWSRFS that could be used by all RFCs, could be supported at a national level, would streamline the introduction of new technology, and would make the calibration, operational, and extended forecasting systems compatible. NWSRFS accomplished these objectives by not relying on a single model as its nucleus but instead on an "operations table concept" which allows any model to be incorporated into the forecasting package. OH took a lead role in the design, development, and testing the current version of NWSRFS, but large contributions were made by RFCs (a number of whom have coded modeling and display operations), and software contractors who provided substantial code for the command language and several data bases.

Related Programs

Another advantage of the current NWSRFS over previous versions is that the three major subsystems (calibration, the OFS version 5, and ESP) are totally compatible and, in fact, share all the hydrologic modeling code, and read and write to common data bases. As shown in Figure 3 the programs are also integrated in that the ESP system uses temperature and precipitation data directly from the calibration data files, and gets current snow and soil conditions and most of its parametric information from the OFS forecast files. The parameters determined in the calibration system are used directly in the OFS.

Operational Forecast System

A schematic of the NWSRFS Operational Forecast System version 5 is presented in Figure 4. The major functional components of the NWSRFS OFS are

- Data Entry - observed hydrometeorological data enter the OFS from a number of sources and are stored in the Preprocessor Data Base (PPDB),
- Preprocessor Component - observed data are prepared for use by hydrological models in the Forecast Component, and stored as time series in the Processed Data Base (PDB),
- Forecast Component - data from the PDB are input to the hydrologic and hydraulic models to generate forecast guidance,
- Hydrologic Command Language - provides the user interface and calls the appropriate OFS components to perform the forecaster's commands.

The Preprocessor Functions are

- Mean Areal Precipitation (MAP) - produces areal averaged precipitation estimates from point precipitation data,

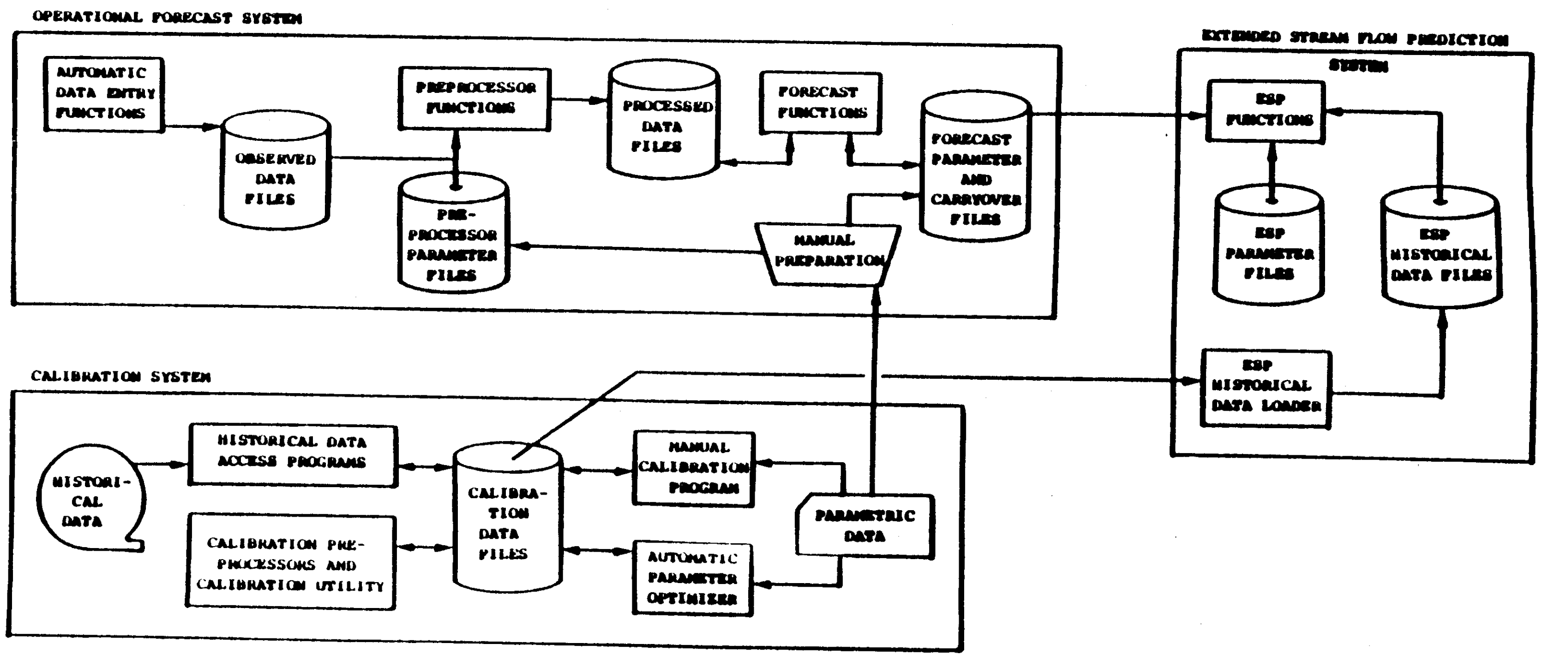

Figure 3. National Weather Service River Forecast System Software Overview

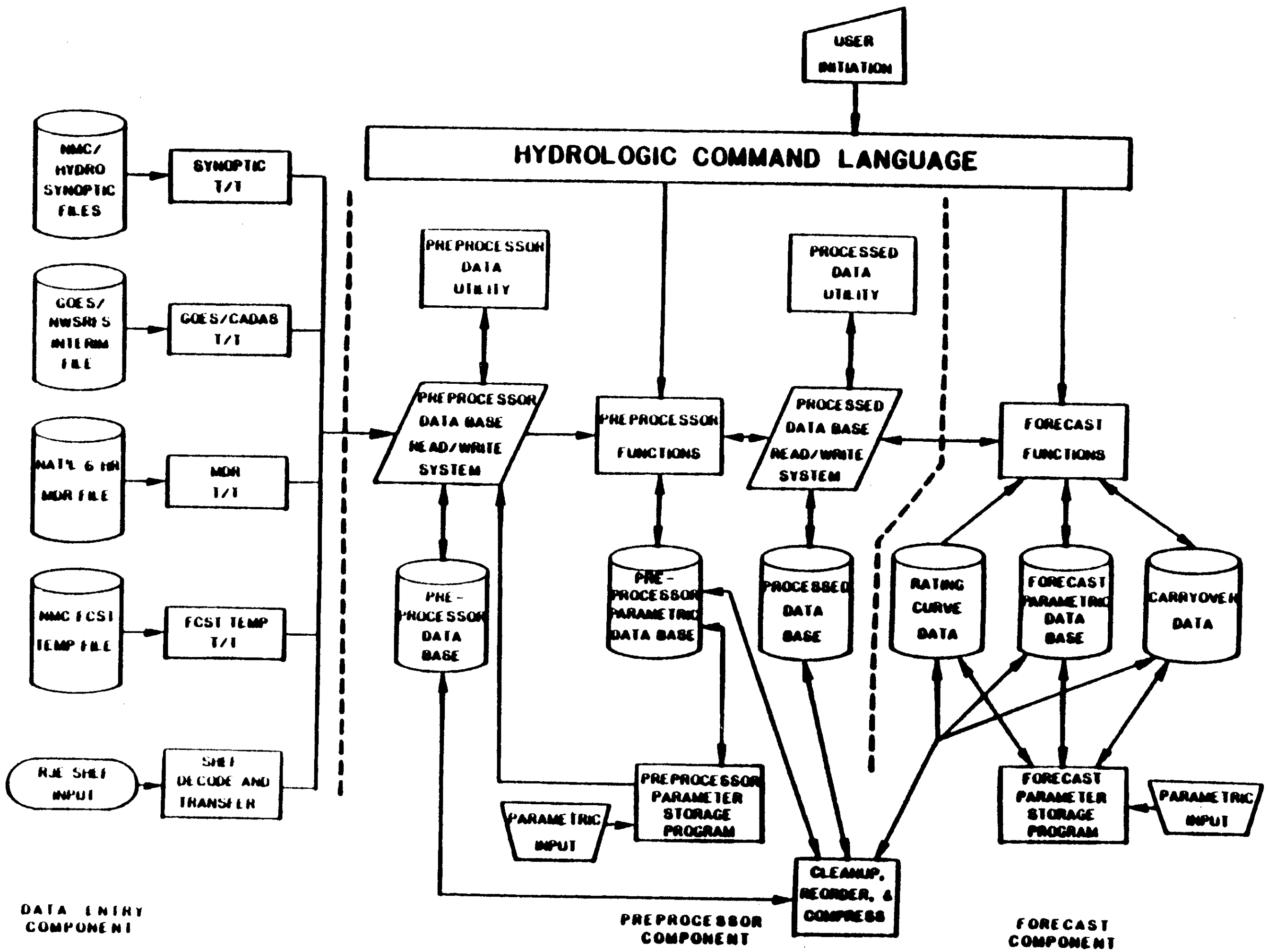

Figure 4. NWSRFS Operational Forecast System Version 5.0

- Mean Areal Temperature (MAT) - produces areal averaged temperature estimates from instantaneous and maximum/minimum point temperature data,

- River, Reservoir, and Snow (RRS) - produces point time series from uneven interval and period average data,

- Mean Areal Potential Evaporation (MAPE) - produces areal averaged evaporation estimates from point meteorological data, and

- Future MAP (FMAP) - computes future precipitation time series from user input areal values.

Parameters describing how the observed data are to be processed are held in the Preprocessor Parametric Data Base (PPPDB). This data base is maintained by the Preprocessor Parametric Initialization (PPINIT) program.

The Forecast Component contains a variety of models and procedures called operations. The tasks that these operations perform generally include

- hydrologic or hydraulic models of physical processes such as snow accumulation and ablation, soil moisture accounting, temporal distribution of runoff, channel routing, and reservoir regulation,

- procedures for modifying model outputs based on observations,

- displays for model outputs, statistics of model outputs, and observations, and

- basic manipulations of time series such as adding time series, weighting time series, and changing time intervals.

Parametric information in the Forecast Component Data Base (FCDB) is stored and maintained by the Forecast Component Initialization (FCINIT) program.

Read/write packages are available for all the data bases (PPDB, PPPDB, PDB, and FCDB). Other application programs needing data from these data bases can access them with the read/write packages.

Utility programs are available to define, display, and delete information from the PPDB and PDB. The PPINIT and FCINIT programs serve as utility programs for the PPPDB and FCDB respectively.

National Level Support

OH can provide implementation assistance and operational support at a national level to the NWSRFS version 5. Focal points have been defined in OH who provide routine support to the 10 RFCs implementing or using version 5 operationally. This relieves the RFC staff of a large burden they carried alone in the days of independent forecast systems. Maintenance, enhancements, and user and system documentation are also coordinated through OH. This standardization has reduced the training period when a forecaster moves from one RFC to another. Now the learning can focus on the hydroclimatic differences between the RFC areas and not on learning a new forecast system.

Several of the RFCs currently run with hybrid systems (NWSRFS version 5 usually through runoff generation and their own models thereafter).

Technological Upgrades

As mentioned above the subroutines that define the hydrologic and hydraulic models are shared among the major subsystems in NWSRFS. Ideally a new hydrologic or hydraulic procedure is initially tested in the calibration subsystem. Because of this sharing of code the procedure is immediately available in all subsystems once it is coded for any component in version 5. All the RFCs that use version 5 run from the same version which is updated by the OH support group. Once an enhancement has been made to the current version of NWSRFS it is available to all RFCs. This structure has greatly reduced time between testing and operational availability and greatly enhanced our ability to get new technology to the RFCs for use in forecasting.

Implementation

When version 5 was initially designed and coded in the early 1980s the only computer resource available for operational forecasting was the NOAA Central Computer Facility (CCF) in Suitland, Maryland, and the RFCs communicated with the CCF via Remote Job Entry (RJE) dedicated lines. Version 5 was designed to operate efficiently under the batch processing environment imposed by this hardware and communications structure. The user interface in the batch version 5 is the Hydrologic Command Language (HCL) which gives a broad range of options for the level of sophistication with which a user can interact with version 5. Since HCL is the way a user interacts with the various parts of version 5 the structure of the input has been designed to keep the information needed at run time as simple as possible. Also, since HCL is the only way a user interacts with the parts of version 5, the input must be very flexible to accommodate the variety of information that may be required. Some very simple input will allow the user to produce a forecast run, but a great many options are available to control all aspects of the program flow. A series of commands can be stored in HCL files and performed with an abbreviated input stream.

As local minicomputers have become available at RFCs version 5 has moved to a local batch mode on a minicomputer. The scale of the NWSRFS has made this a formidable job. With about 250000 lines of executable FORTRAN source code and 2000 subroutines in the eight main programs that make up version 5, OH has devoted substantial time and resources to the conversion of batch NWSRFS from the CCF to local minicomputers. This task is really just a step along the path toward interactive forecasting which is a goal of the entire NWS. The Advanced Weather Interactive Processing System for the 1990s (AWIPS-90) has specified that the NWS will use interactive forecast procedures in the AWIPS era. We are moving NWSRFS in this direction. The initial design of version 5 looked ahead to the day of interactive forecasting and much of the system structure is designed to operate efficiently in an interactive mode (Brazil and Smith, 1981). OH has established a project to convert version 5 to an interactive system.

PROTEUS

The path to the AWIPS era for the NWS hydrology program is through the Prototype RFC Operational Test, Evaluation, and User Simulation (PROTEUS) project. The design and development of an interactive NWSRFS OFS will be done in coordination with PROTEUS, as well as the OH OFS support group. The plans for an initial interactive OFS would replace the HCL user interface currently in the batch forecast system with a more graphically oriented interface running on a microprocessor. The main hydrologic computations and data and parameter file definition and updating would occur on the local minicomputer. In this way the interactive user interface would be controlled by the microcomputer with a significant computational and input/output burden being handled by the minicomputer. This structure will allow the RFCs to test a preprototype interactive system operationally before the coming of AWIPS.

SUMMARY

Hydrologic forecast systems generally consist of components for data collection, modeling and data processing, forecast analysis and preparation, and forecast dissemination and tailoring. The development and application of an HFS requires contributions from numerous sources. NWSRFS is described as exemplifying two components of an HFS which has been developed through the cooperative efforts of many individuals. NWSRFS consists of major subsystems for calibration and both short- and long-range forecasting. The software is supported at the national level and technological upgrades are easily implemented. An interactive version of the NWSRFS Operational Forecast System soon will become available as the NWS moves toward the AWIPS era.

ACKNOWLEDGEMENTS

The authors wish to thank Drs. Richard Farnsworth and Eric Anderson for their review of this paper, and Mr. Willie Senn and Ms. Lianne Iseley for their assistance with the figures.

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