6th International
NORTHERN RESEARCH BASINS Symposiums/Workshop
Michigan Technological University
January 26-30, 1986

THE NATIONAL WEATHER SERVICE RIVER FORECAST SYSTEM AND ITS APPLICATION TO COLD REGIONS

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ABSTRACT

The National Weather Service River Forecast System (NWSRFS) contains the models and procedures needed for a variety of river forecasting applications. The NWSRFS contains subsystems for historical data processing and model calibration, operational river forecasting, and Extended Streamflow Prediction (ESP). Over the past few years NWSRFS has been completely redesigned with a much greater emphasis on flexibility and modularity. The potential range of applications of NWSRFS has increased as has the ability to incorporate new technology. This paper reviews the current status of NWSRFS with an emphasis on its application to basins where snow and other cold regions phenomena have a significant effect on runoff. In addition, enhancements and research efforts which are needed to improve the application of NWSRFS in cold regions are explored.

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INTRODUCTION

The National Weather Service River Forecast System (NWSRFS) is a set of computer programs and associated documentation used to generate river forecasts. The NWSRFS is a generalized package, supported at the national level, that can be used with various data networks and under a wide range of hydrologic and climatic situations. Included are programs for processing historical data, model calibration, operational forecasting, and extended streamflow prediction.

Background

The original NWSRFS (Staff HRL 1972, Anderson 1973) was primarily designed for the calibration of conceptual hydrologic models. It contained data processing programs to convert historical records into the form needed by the conceptual models and programs to assist in calibrating the model parameters. Also included was a portion of an operational program to demonstrate how the models could be used for river forecasting. As the NWSRFS evolved (Curtis and Smith 1976), an operational program was developed by expanding the demonstration program so it could be used on multiple river systems and by adding components to process observed data reports into the form needed by the models. Subsequently, the operational program was enhanced by adding improved data management and file maintenance capabilities and a simple reservoir model. Also in the mid-1970's, a new technique was developed for using the conceptual models to make long-range predictions. This technique, known as Extended Streamflow Prediction (ESP) (Twedt et al. 1977), combined current model conditions with historical data to produce probabilistic forecasts.

By the late 1970's a number of improvements and additions had been made to the original NWSRFS programs; however, the system was still formulated based on specific conceptual models. The system had a number of basic deficiencies which prevented its complete use at most of the National Weather Service (NWS) River Forecast Centers (RFC's). These deficiencies included:

- It was very difficult to add new models and procedures to the system (changes required significant coding and data file modifications).
- The computational sequence was very rigid, thus limiting how the models could be applied to simulate non-standard situations.
- The computations were not organized by forecast points as required for iterative update techniques, estimation theory update procedures, interactive use, and efficient ESP processing for an entire river system.

In addition, incompatibilities had developed between the operational, ESP, and calibration systems. In 1979, an NWS advisory group recommended that the majority of the NWSRFS programs be redesigned. The redesign, coding, and testing was completed in late 1984. The new NWSRFS programs are now in the process of being implemented at the RFC's.

Purpose and Scope

This paper gives a general description of the current NWSRFS with an emphasis on the portions of the system used to generate operational forecasts. Examples used to illustrate the capabilities of the system are based on applications in cold regions. Also included is a discussion of the future of NWSRFS and research studies and enhancements needed to improve operational river forecasting in cold regions.

DESCRIPTION OF NWSRFS

NWSRFS is a large software system. It is not designed for application to specific river basins requiring only limited procedures and program options. Instead, it is designed for use by any of the 13 RFC's in the NWS. The RFC's deal with the full range of hydrologic conditions that exist across the United States. Operationally, a typical RFC in a single day can receive reports from 1000 precipitation stations, 250 river gages, and 75 reservoir sites, plus hundreds of stations reporting other variables such as temperature, snow data, and evaporation. Forecasts may be required several times during the day, as well as updates of advisories reflecting current hydrologic conditions and flash-flood potential. The current national historical data base used for model calibration and ESP applications contains in excess of 35 years of data for over 30,000 stations. Because of the volume of data and the number of points forecasted and products generated, much of the NWSRFS software is concerned with computational efficiency and user interfaces. The design of the data bases and the control structure of the programs are critical to overall efficiency. File maintenance features are important since data networks and forecast needs are constantly changing. A "user friendly" interface to the programs is a necessity in these days of increased demands with no increase in staff size. These requirements have resulted in a majority of the more than 230,000 lines of executable source code in the current NWSRFS being involved with something other than hydrologic models and procedures. This should be kept in mind even though the emphasis of this paper is on models and procedures and their application.

Overview

Figure 1 shows an overview of all the NWSRFS software. There are three separate systems: the calibration system, the Operational Forecast System (OFS), and the ESP system. While the three systems are separate in many respects, they are integrated in many others. Much of the integration is due to the similarity of models and procedures in each system. In fact, the exact same coding is included in the three systems for all of the hydrologic and hydraulic models. Other examples of

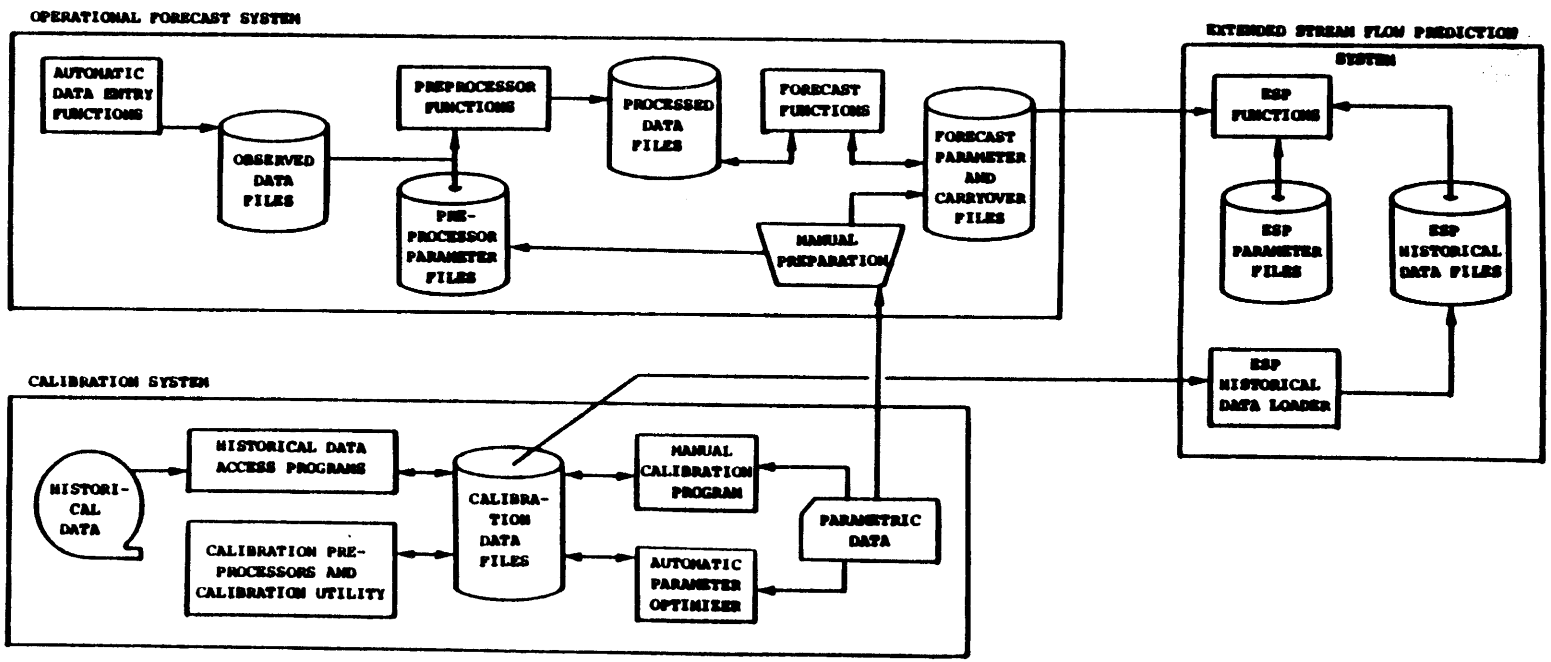

Figure 1. National Weather Service River Forecast System Software Overview

integration include: ESP obtaining most of its parametric data from the OFS and using the historical data generated for calibration; and OFS and ESP sharing the same user interface for controlling forecast runs. The current NWSRFS software is no longer designed around specific models and techniques and is able to incorporate new technology as it is available without making major changes to the system.

Forecast Component

Before briefly describing each of the systems within NWSRFS, it is best to first describe what is referred to as the "forecast component." The forecast component is the portion of the system that contains all of the hydrologic models and procedures needed to generate forecasts. The forecast component is common to all three systems. The "preprocessing" of observed data reports into the form needed by the models takes place outside the forecast component. All other forecasting computations are included within the forecast component.

The forecast component is designed around what is referred to as the "operations table concept." The operations table concept is basically that each model or procedure is coded in such a way that a control structure can be developed so that the operations can be combined in whatever sequence is needed for a particular application. The computational sequence is referred to as the "operations table." Operations can include:

- Hydrologic or hydraulic models of processes such as snow accumulation and ablation, soil moisture accounting, temporal distribution of runoff, channel routing, river mechanics, and reservoir regulation.

- Procedures for updating the state variables or the output of models based on observations.

- Procedures for displaying model output or computing statistics involving model output and/or observations.

- Algorithms that perform basic computations with time series data such as addition, subtraction, weighting values, and changing time intervals.

Information is passed from one operation to the next in the form of time series. Table I lists the operations currently in NWSRFS and those under development. Not only is it easy to add new operations to the system, but the procedure for adding an operation doesn't require that a person understands the data base or control structure of the forecast component. The operations table concept overcomes all of the deficiencies listed earlier for previous versions of NWSRFS.

As an illustration of the capabilities of the operations table concept, let's take a mountainous basin in an area where snow is significant.

Table I
NWSRFS Operations

Available Operations:

- Temperature index snow accumulation and ablation model (Anderson 1973).
- Sacramento soil-moisture accounting model (Burnash et al. 1973).
- Antecedent Precipitation Index (API) rainfall-runoff models used in the Missouri basin, north central, Ohio basin, and southwestern parts of the U.S.
- Unit hydrograph with a constant baseflow option.
- Lag and K, Muskingum, layered coefficient, and Tatum routing procedures.
- Reservoir model that allows the user to select and combine 13 modes of regulation to simulate the operation of a single, independently controlled reservoir.
- Stage/discharge conversion using single valued rating curves with log or hydraulic extensions and dynamically induced loop ratings.
- Simple flow adjustment and blend procedure.
- Simplified channel loss procedure.
- Computation of mean discharge from instantaneous values.
- Set time series values to zero.
- Add and subtract time series.
- Weight time series.
- Change the time interval of a time series.
- Plot instantaneous discharge.
- Operational hydrograph display.
- General time series plot.
- Daily flow plots (calibration use only).
- Calibration statistics package.

Under Development

- Dynamic wave routing (Fread 1985).
- Estimation theory updating procedure using the Kalman filter technique for a non-snow headwater basin (Kitanidis and Bras 1980a, 1980b).
- Unit hydrograph with baseflow recession and local flow adjustment options.
- Conceptual channel loss model.
- Operational statistics package.
- Estimation theory updating procedure for use on an entire river system (Georgakakos 1983).
- API rainfall-runoff model used in the Middle Atlantic region.
- Tabular runoff display.
- Constrainted Linear Systems (CLS) model.
- General purpose time series analysis, state space modeling, filtering and parameter estimation package including an integrated hydrometeorological forecast system (Georgakakos 1984, Georgakakos and Hudlow 1985).

Snow accounting and melt computations could be performed on a lumped basis, on a subarea basis (subareas based on any physiographic variable(s)), or on a pure elevation zone basis. There would be one snow model operation for each zone or subarea. Subsequently, soil moisture accounting or rainfall-runoff computations could be performed on the output from each snow area or the output from one or more snow areas could be weighted before runoff is computed. Again the runoff values generated could each be routed to the basin outlet or runoff values could be combined in various ways before routing. Thus, it can be seen that the operations table concept gives almost unlimited flexibility in determining which models are used and how they are used for a specific application without having to explicitly program all of the possible sequences.

The operations table concept has other advantages for river forecasting. First, the operations table allows for new models and procedures to be tested in parallel with existing ones. Results from the new technology can easily be compared to the old. Second, once a decision has been made to implement a new method over an entire RFC area, the process can occur in an incremental fashion. Different operations can be used in different parts of the area, yet the user interface remains the same. Analogously, different operations can be used in different parts of an RFC area due to differences in hydrologic and climatic conditions.

Operational Forecast System

Figure 2 shows an overview of the latest NWSRFS Operational Forecast System (OFS). This is version 5 of the OFS. The system consists of a number of programs, data bases, and functional components. The four primary data bases are:

- The Preprocessor Data Base (PPDB) which holds observed data for all stations in the data network plus some forecast and projected values.

- The Preprocessor Parametric Data Base (PPPDB) which holds parametric data for the preprocessor functions including general network information.

- The Processed Data Base (PDB) which holds data in time series form as needed by the models. The time series values are either generated by the preprocessor functions or by the forecast component.

- The forecast component data base which holds rating curves, parametric data for the operations, and the state variables (carryover) needed to initiate the computations. Carryover values are retained for several dates in the past so the user has a choice of when to start a forecast run.

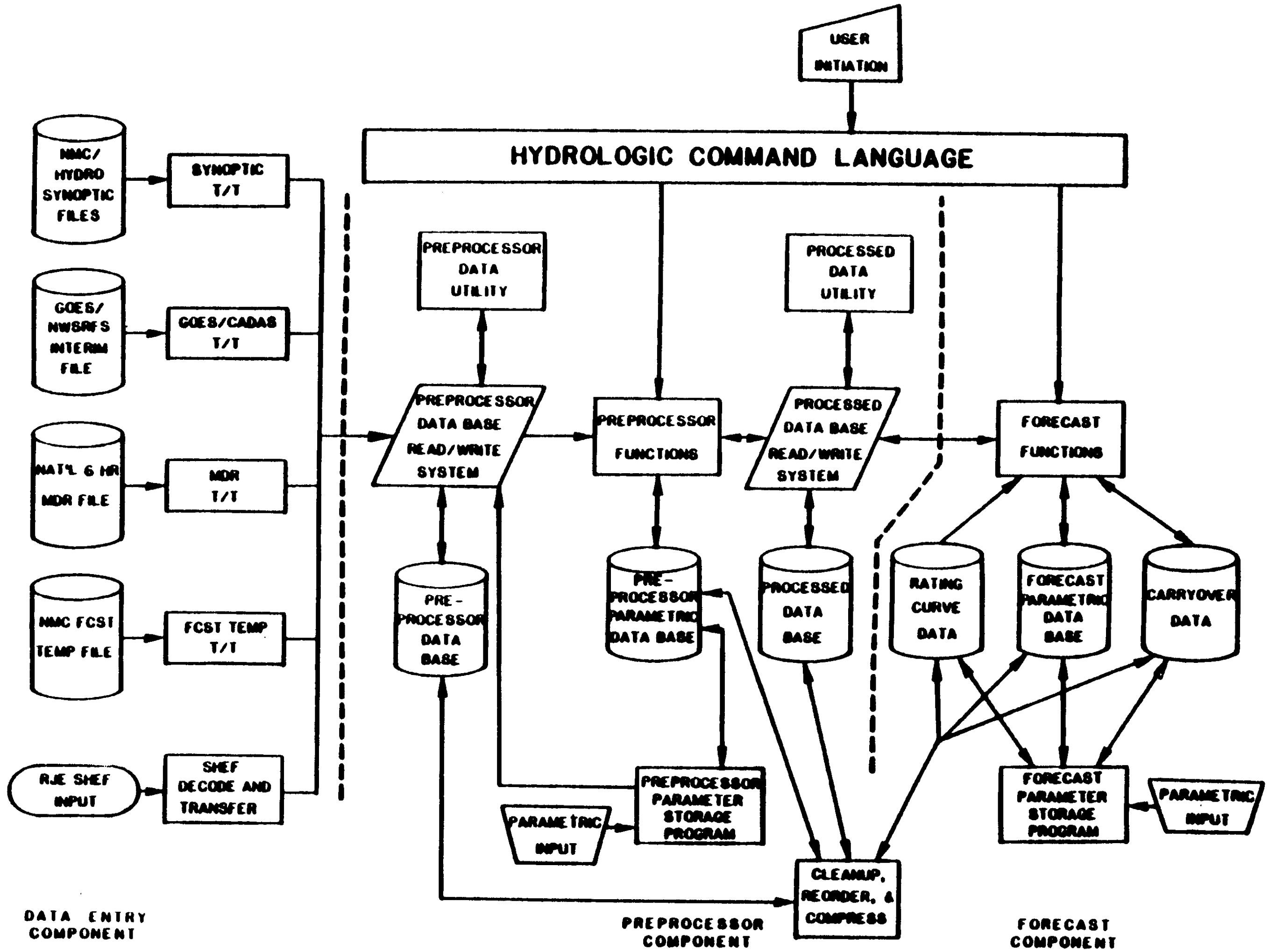

Figure 2. NWSRFS Operational Forecast System Version 5.0

General read/write packages are used to access each of the data bases. Hashing algorithms are used to increase access efficiency. A file reorder and compress program is being developed to remove unused records, reorganize the files for minimal accesses, and to change file size.

The parameter storage programs are used to define all of the parametric information needed to initialize the system. This includes data network information, basin boundary and area definitions, rating curves and the operations table with the parametric data for each operation. These programs are also used to maintain the parametric files by adding new information, changing existing information, deleting entries, and displaying the contents of the data bases.

The data entry component contains programs to enter observed and forecast data values into the PPDB. Decode and post programs are used to enter data in the Standard Hydrometeorological Exchange Format (SHEF) (NWRFC 1985). SHEF is a machine decodeable standard data transmission format that has been adopted by the NWS and other agencies in the U.S. for exchanging and sending data reports. The other data entry programs are unique to NWS and are used to transfer data from various sources on the central computer facility to the PPDB for each RFC.

The preprocessor functions are used to convert observations into the time series form needed by the forecast component. Currently the following preprocessors are included:

- Mean Areal Precipitation (MAP) -- computes areally averaged precipitation estimates using station data and, as an option, Manually Digitized Radar (MDR). Station weights can be specified by the user (common in mountainous areas) or computed automatically based on station locations.

- Mean Areal Temperature (MAT) -- computes areally averaged temperature estimates using observed maximum/minimum and instantaneous values and maximum/minimum forecasts. Again station weights can be specified by various methods.

- River, Reservoir, and Snow (RRS) -- computes time series for point locations using all available data.

- Mean Areal Potential Evaporation (MAPE) -- computes areal evaporation estimates using point observed meteorological data.

- Future MAP (FMAP) -- generates future precipitation time series from user supplied areal estimates.

Much of the forecast component has been described in a previous section. In the OFS, the operations table is divided into groups called segments. Each segment typically contains all the operations needed for a forecast point. Segments are then combined into larger groups typically representing river basins. The grouping of the operations improves program efficiency and user control over the forecast computations. Another feature included in the OFS forecast function is the capability provided to the forecaster to make run-time modifications (MODs). MODs can be used to change or ignore time series data, adjust state variables, and modify a few selected parameters. The MOD feature allows the forecaster to interact with the models to alter the computed values and hopefully improve the forecasts. Examples of MOD's are: changing the form of precipitation computed by the snow model, if needed, to match observed conditions; adjusting simulated water-equivalent or areal snow cover based on observations; modifying snowmelt rates; and ignoring observed stages affected by ice when making discharge adjustments.

The user controls the operational forecast program (preprocessor and forecast functions) through a set of instructions referred to as the Hydrologic Command Language (HCL). HCL is used to set run options (e.g., period or area to be run, information to be displayed, etc.), pass MODs to the functions, and control which functions are executed. Default values are maintained for all options. Sets of HCL instructions which are commonly used can be stored as a named procedure and then run by merely executing the procedure. Procedures can contain symbolic references so that options within the procedure can easily be changed. HCL gives the user a great deal of flexibility in controlling how the forecast program is used.

Calibration System

The NWSRFS calibration system is needed for two primary purposes. First, to determine parameter values for the models used in the OFS and ESP and second, to prepare historical time series of MAP and MAT for use by ESP. The calibration data files (see Figure 1) are used to store all of the time series needed for the processing of historical data and model calibration. Historical records of precipitation, temperature, discharge, etc., are copied from their archive form on tape to the calibration data files when needed. MAP, MAT, and MAPE preprocessing programs are provided to convert these data into mean areal time series. The calibration preprocessing programs contain similar options to their OFS counterparts except that the types and frequency of data vary as do the station networks. After the preprocessing programs are run, the data are in the form needed for use in ESP or for calibration of the model parameters.

Two programs are provided for use during the model calibration process. There is a Manual Calibration Program (MCP) and an automatic parameter Optimization Program (OPT). The MCP program is used for trial-and-error runs. The OPT program contains a direct search optimization technique that can be used to minimize various objective functions computed from observed and simulated mean daily discharges. The latest versions of these programs (MCP3 and OPT3, i.e., version 3 of each) contain the operations table and are completely compatible with Version 5 of the

OFS. The current NWSRFS model calibration procedure (Brazil and Hudlow 1981) involves first making initial estimates of the parameters based on guidelines developed over the years. This is followed by trial-and-error runs to improve the parameter estimates. The OPT program can then be used to refine the estimates even further. The mix between the use of MCP and OPT varies with the user. The more experienced user tends to rely almost totally on the trial-and-error method.

ESP System

The Extended Streamflow Prediction (ESP) system is used to make forecasts for periods of weeks or months into the future (Day 1985). ESP uses the current states (carryover) from the OFS and combines these with sequences of future precipitation, temperature, and PE to make probability predictions for a number of streamflow variables. The future sequences of the input variables are generally obtained by assuming that any of the recent historical years has an equally likely chance of occurring this year. Each of the historical years is run through the operations table to generate a series of possible streamflow traces. About 20 years of historical data are typically used to insure accurate probability estimates. Current short range meteorological forecasts can be used with the historical data to provide the proper transition into the future. Also the historical years can be weighted if there is an indication that some past input sequences are more or less likely to occur during the current year. The probability forecasts are generated by analyzing the series of discharge traces for certain periods of time (windows) and specific streamflow variables (e.g., mean, maximum, minimum, and total flow or time to reach, fall to, stay above, or stay below a specified level).

The current version of ESP (Version 3) uses the operations table concept and is completely compatible with the model calibration programs and the OFS. In fact, Version 5 of the OFS must be used in order to use ESP3. ESP uses the same files as the OFS for the operations table, model parameters, rating curves, current state variables, and short range meteorological forecasts. In addition, the command language (HCL) used by the operational program is also used to control the ESP function. The current ESP program, unlike its predecessors, can be used on entire river basins. The streamflow traces at each flow-point are retained until used as input to downstream points.

ESP was primarily developed for use in providing long range water supply forecasts in the western and northeastern portions of the U.S. and Alaska plus for spring flood outlooks in the Upper Midwest. However, the ESP technique can be used whenever current conditions can significantly affect the future. ESP has been used for low flow forecasts during drought situations (Sheer 1980, Smith et al. 1982). Other applications include long range forecasting for navigation and recreational uses. For all these applications, ESP has some major advantages over previously used methods, primarily regression type models. One likely advantage is that the conceptual models that are typically used with ESP should provide improved extrapolation capability during periods of abnormally high or low flows. However, from an operational river forecasting perspective there are two other advantages that are possibly even more important. One is that the same models used for normal river and flood forecasting operations can be used for extended predictions, thus saving considerable time and resources. The other is that ESP can analyze any streamflow variable for any window in the future, thus a variety of products, including special requests, can be provided without additional procedure development.

FUTURE OF NWSRFS

The current NWSRFS software has been designed to overcome the deficiencies of previous versions. It is now possible to add new models and procedures to the system without changing the control structure. The operations table concept gives the user total control over the models to be used and their computational sequence. The data bases, though designed for access efficiency by the current preprocessor and forecast functions, are general enough so that new data types can easily be added. The command language (HCL) used to control the operational program and ESP function is very flexible and allows for adding new functions with minimal difficulty. Thus, it is very unlikely that a complete redesign of NWSRFS will occur again, at least not within the foreseeable future.

In the future, enhancements to NWSRFS will center around the addition of new hydrologic technology and the modification of the programs to keep pace with available advances in computer hardware and software. Table I shows some of the new technology that is being added to the forecast component, especially the Kalman filter based estimation theory procedures to make adjustments to model states based on observations. Work is also beginning to integrate into NWSRFS estimates of precipitation based on merging radar and rainfall data (Krajewski 1983). Such estimates should become the primary source of precipitation data for operational forecasting east of the Rocky Mountains once the Next Generation Weather Radar (NEXRAD) system is installed.

Currently most of the RFC's are connected by a dedicated line to the NWS central computer facility and are only able to operate in a batch mode. Though the current OFS is set up for batch use, most of the system was designed for easy conversion to an interactive mode as demonstrated by Brazil and Smith (1981). Soon work will begin on a comprehensive interactive version of the OFS for use when significant local processing capability is provided to each RFC as part of the upgraded NWS communication and local processing system scheduled for the 1990's. This interactive version should make extensive use of computer graphics to assist the forecaster. A project has also started that will do away with the current data entry component of the OFS. A generalized Data Base Management System (DBMS) will be used to store and manage most if not all of the operational data used by the RFC's. The DBMS will be a source of data for all real-time applications including the merging of radar and rainfall data, flash flood forecasting, and the NWSRFS OFS. Automated quality control features will be developed to assist in managing the data.

Research into developing an improved model calibration system has also begun. Components of the MCP and OPT programs will be combined with new parameter estimation procedures and interactive graphics capabilities to form a single model calibration program. An attempt will be made to include expert systems features so that some of the logic of an experienced calibrator can be made available to everyone performing calibrations.

RESEARCH AND ENHANCEMENTS FOR COLD REGIONS APPLICATIONS

Previous sections of this paper have concentrated on describing the current NWSRFS and some major enhancements planned for the future. Before concluding the paper, however, there is a need to discuss features that could improve operational river forecasting in cold regions. The comments in this section are based on personal experience from research studies and operational applications and on feedback from the RFC's. Improvements are needed in the following areas:

- Methods are needed to objectively update snow model state variables based on observations. Most operational snow models are driven by precipitation and temperature observations reported at least daily. Using these data, the models simulate the water-equivalent and snow cover outflow for the area or zone to which they are applied. Some models also simulate the areal extent of the snow cover. Direct measurements of these states are made less frequently and thus are seldom required input. Point water-equivalent observations are usually available, but generally are measured at weekly, monthly, or random intervals. Remotely sensed area snow cover estimates are also periodically available for some basins. Snow cover outflow measurements are virtually non-existent in real-time, but snow cover outflow is reflected in streamflow data. While improved and new methods, especially remote sensing methods, are needed to more accurately measure these variables, the main problem in most cases is how to objectively combine these observations with simulated values.

  Currently the RFC's can generally only make subjective use of observations such as point snow course measurements, gamma flight line estimates of water-equivalent, and areal extent of snow cover values derived from satellites or airplanes. Objective updating techniques need to account for errors in the measurements and the simulated values as well as the differences in the types of estimates (i.e., point, line, areal). The correlation area method proposed by Johnson et al. (1982) offers a way to do this in non-mountainous areas such as the Upper Midwest. A procedure based on this method will be added to NWSRFS as resources permit to update water-equivalent. Carroll (1978) proposed a method to update simulated water-equivalent using snow course data in mountainous areas. This method showed some promise during the accumulation season, but was not applicable during melt periods. Further research is definitely needed on objective water-equivalent updating techniques for use in mountainous areas.

Run-time modifications can be used to change the snow-cover outflow based on differences between simulated and observed discharge during the melt season. Again, these adjustments are subjective and may require a time consuming trial-and-error approach. Objective procedures, probably utilizing estimation theory, are needed to adjust snow model states based on discharge errors and snow cover measurements during periods of snowmelt.

- Dynamic procedures are needed to extrapolate data, especially precipitation, in mountainous areas. Current procedures for extrapolating measurements into portions of mountainous basins with no observations (usually extrapolating low elevation data to high elevations) are based on long term averages. For example, extrapolation of precipitation is generally based on an isohyetal analysis. For individual storms the orographic distribution of precipitation can vary significantly based on the type of storm, the direction of the storm, and other factors. Fortunately in heavy snow areas the effects of different distributions for individual storms are damped out in terms of the overall snow accumulation. Though this is true for most years, the extreme years, which are most critical, are the most likely to have abnormal distributions.

- Models are needed to account for the effect of frozen ground on runoff. Frozen ground can have a very significant effect on winter and spring flood runoff, especially in agricultural areas. A frozen ground index was developed by Anderson and Neuman (1984) and tested with the Sacramento soil-moisture accounting model on several Minnesota basins. This model was also tested operationally as part of NWSRFS (Neuman 1983) though minimal frozen ground occurred during the test period. A significant amount of research has been conducted on the hydrologic effects of frozen soil, but most of this has involved experimental or theoretical studies and has not considered the inclusion of frozen ground into simulation models. More research and development effort is needed in this area.

- Models or procedures are needed to improve the prediction of ice jams and their effect on forecasting river levels. The RFC's currently use empirical methods or "rules of thumb" that are based on experience. Improved winter discharge measurements or ways to account for ice effects on stage/discharge relationships would be of some help since currently most offices ignore stages during periods of ice effects and assume the simulated value is the best estimate. However, the most critical need is for methods that would allow for more accurate forecasts of river levels during ice jams.

- Methods are needed, especially for Alaskan forecast operations, to handle the special problems caused by glaciers. Melt calculations can vary depending on whether the glacier is snow covered or not. The effects of a glacier on the movement of meltwater to the stream channel cannot be accurately modeled, at least when considering daily time intervals or less. Also predictions of the timing and magnitude of the sudden release of water from glacier dammed lakes have considerable room for improvement.

- Snowmelt estimates need to be improved under certain situations. Temperature index models, if property calibrated, provide completely adequate estimates of snowmelt under most conditions. However, there are times when melt rates differ from those calculated using the calibrated melt factors. Some of these situations involve extremely high melt rates which can cause flooding, such as periods of high dew-points and wind speeds. The obvious solution to this problem is to use an energy balance method to calculate snowmelt, however, it is not quite that simple. First, the data needed to drive an energy balance model are not available, especially in real-time. Second, even if the data are available, the quality of the data must be very good to insure that the overall results will be as good as those attainable using a temperature index model. Anderson (1976) showed that even with high quality data at a point location the comparison between an energy balance and temperature index model indicated that the results from both models were basically identical except during a few periods of abnormal melt rates. When modeling a watershed, the point to area extrapolation problems, especially for radiation and wind data, can quickly reduce the accuracy of the areal inputs. This may be more of a data problem than a modeling problem. Currently, most if not all of the operational snowmelt models use the temperature index method. Someday it should be possible to use energy balance estimates at least during periods of abnormal melt rates.

- Rainfall-runoff models are needed that are suited for all applications. Currently there are two types of rainfall-runoff models used by the RFCs. Some use conceptual models such as the Sacramento soil-moisture accounting model and others use empirical models such as the API rainfall-runoff models. Both types of models have a physical basis though only the conceptual models try to simulate the physical processes. The main advantage of the empirical models are that they are easy to use and easy to update. The conceptual models provide improved simulation capabilities especially after dry periods and during periods with significant interflow and baseflow runoff. Thus, in general, the empirical models are preferred by many for operational flood forecasting, while the conceptual models are better for ESP usage. It is very difficult in an operational office to maintain the states of two models for the same river, thus currently each RFC uses one type of model or the other. What is probably needed is either efficient automatic updating techniques for use with the conceptual models or improved empirical models that have adequate simulation capabilities.

The above discussion lists a number of high priority items that should result in improved river forecasts in cold regions. However, if someone asks a forecaster at an RFC what single thing would result in the greatest improvement in forecasts, the answer would undoubtedly be more and better data. Even though there are specific modeling deficiencies, the prevailing feeling in an operational office is that the models are much better than the real-time data available to run the models.

CONCLUSION

The NWSRFS now contains a structure that allows for the inclusion of a wide variety of models and procedures and gives the forecaster complete control over the computational sequence. The data bases and program structure are designed for efficient operations even when large volumes of data are being processed. New models and procedures can be added with a minimal knowledge of the data base and program structure. There is nearly complete compatibility between the calibration and ESP systems and the OFS. It is not envisioned that the structure of the NWSRFS programs will change drastically in the future, however, there will continue to be evolutionary changes to keep up with new hydrologic technology and advances in computer hardware and software.

ACKNOWLEDGEMENTS

Many people have contributed to the development of the current NWSRFS. Though it is impossible to list everyone, certain contributions need to be acknowledged. Edward Johnson, Joseph Ostrowski, George Smith, and Scott VanDemark had major roles in the development of the OFS. The RFC's at Tulsa, Minneapolis, and Atlanta assisted by providing an operational facility to test the system. Gerald Day was in charge of the development of the Version 3 ESP system. Larry Brazil developed the OPT3 program.

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