# Applying the National Weather Service River Forecast System (NWSRFS) Interactive Forecast Program to Basins in Northwest Washington

by

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## ABSTRACT

The Northwest River Forecast Center has, during the past year, completed calibrating the National Weather Service River Forecast (NWSRFS) model in Northwest Washington. The next step in the process was to set the calibrated river basins up for the Interactive Forecast Program (IFP). This task requires defining headwater basins, routing reaches, reservoirs and downstream forecast points in the manner IFP demands. The IFP was run real-time during the 1995-96 winter forecast season. This paper will summarize the results of the model application in a complicated rain on snow environment. We will also present model enhancements resultant from this real-time test of the IFP.

## INTRODUCTION

The Northwest River Forecast Center (NWRFC) is in the midst of a major development effort to implement the National Weather Service River Forecast System. This new model offers a chance to improve real-time flood forecasting techniques and long-term water management forecasts.

Water resources of the Pacific Northwest include the Columbia River, Snake River, the coastal tributaries of Oregon and Puget Sound tributaries in Washington. Initial developments of water resource projects was primarily authorized for flood control, irrigation, transportation, and hydropower. Damage prevented by flood control in the Columbia basins in the decade 1981-90 totaled $ 538 million. The Bureau of Reclamation provided 9.9 million acre-feet of irrigation water to 2.7 million acres in 1992, in the states of Oregon, Washington, Idaho, and Montana (Bissell and Orwig, 1995). The region's hydropower system comprises a large share of the nations' hydropower resource. Growing concerns about salmon and steelhead fisheries have put intense pressure on water managers and revealed a need for more comprehensive modeling systems for use in water management decision making.

## NWSRFS IMPLEMENTATION

The rivers of the Northwest Washington are a subset of the total northwest system in which all of the water resources issues come into play. This area offered an opportunity to apply a new modeling system to aid in forecasting and water management decision making. The implementation of the NWSRFS in this area comes at a good time, providing a more robust model in a complicated rain on snow environment.

In the fall of 1993, the National Weather Service (NWS) NWRFC began the work to calibrate and set up the NWSRFS model in Northwest Washington. This model developed by the National Weather Service's Office of Hydrology has been designed to work in a complicated rain on snow environment. The NWSRFS is made up of hydrologic models; including the Sacramento Soil Moisture model, the Snow-17 Accumulation and Ablation model, several API models, routing algorithms, and reservoir regulation schemes (NWS, 1972; Burnash, R.J.C., et. al., 1973; and Anderson, E.A., 1973).

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As of March 1996, 44 basins have been calibrated in Northwest Washington from the Nooksack River in the north to the Nisqually River in the south. The calibration effort includes headwater basins, local subareas, routing reaches, and reservoir operations. The total river system is modeled from the headwaters through downstream reaches and reservoirs to the river outlet. This allows full assessment of the basin for flood forecast operation and for water management decision making.

The next step in the process was to install these calibrated basins in the NWS Interactive Forecast Program. This involves defining watersheds, routing reaches, and reservoir operations for each river system. The IFP is a graphical user interface which allows real-time interactive forecatsing. The definition for the IFP was completed just before the start of winter operations in October 1995. Since then, the NWSRFS/IFP model has been run regularly through the winter and early spring. Operations have included two periods of extremely high runoff from rainfall and snowmelt. The balance of the paper will describe the process of segment definition in the IFP and the experiences of operating the model from October through March.

## CALIBRATION

The NWSRFS is a modular forecast system that allows users to choose from various operations or models to simulate hydrologic conditions for a particular river basin. The NWSRFS will eventually replace the Streamflow Synthesis and Reservoir Regulation (SSARR) models system currently in use at the NWRFC. The NWSRFS is similar to SSARR, in that the entire river basin is modelled. A river basin is generally divided into separate segments for modelling purposes. Segments consists of three type; headwaters, reservoirs inflows, and local contributing areas.

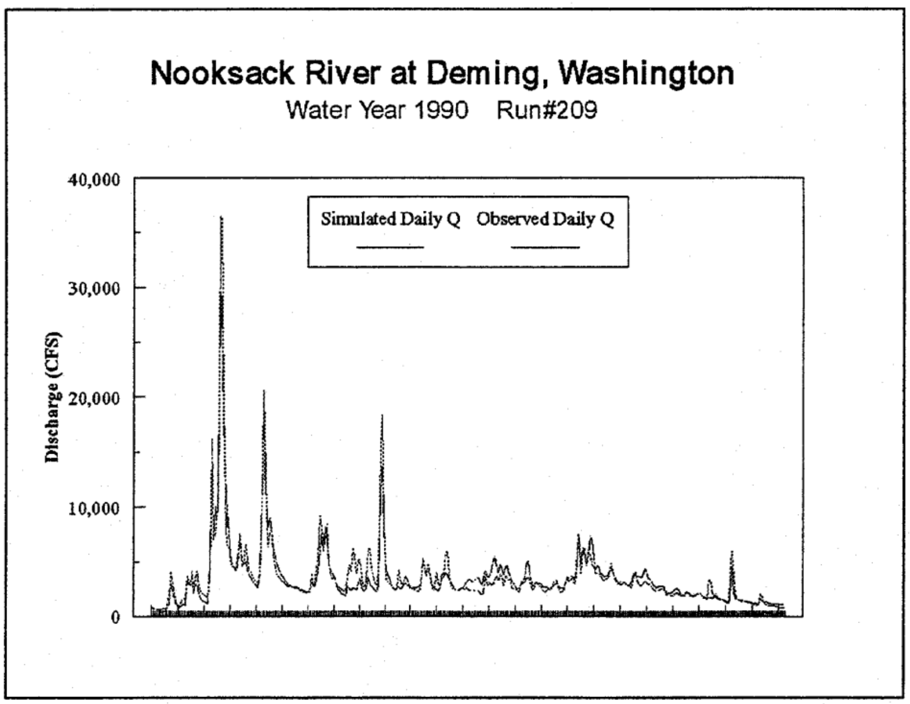


**Figure 1**

A *headwater* point is a forecast location on the river which has no control structures or forecast areas upstream of it. These are the least complex of the river basin segments. Figure1 is an example of a calibration performed in the headwater of the Nooksack River Basin.

A *reservoir inflow* point is essentially the same as the a headwater segment in that it also has no control structures upstream. A reservoir inflow segment, however; contains all of the reservoir controls available to regulate storage and outflow operations. The reservoir operation within NWSRFS allows for the modelling of many different operating schemes utilized in reservoir management. A reservoir can be operated to pass inflow, specify a discharge, specify an elevation to obtain, adjust to rule curves, fill and spill, utilize an uncontrolled spillway, discharge reduction, induced surcharge, and power generation. In Northwest Washington, all reservoir have been set up with a minimum of the specified outflow scheme. During potential flooding conditions, the NWRFC coordinates reservoir inflow forecasts with the operating agencies to obtain the expected release schedule. Each reservoir segment simulates inflow, pool elevation, and outflow which has been calculated and adjusted for observed values.

The final segment type is the *local* area. It is the difference in the flow between an upstream and downstream forecast point. In order that the difference in flow be meaningful, the upstream forecast point must first be routed downstream. The NWRFC currently uses two types of routing techniques; Lag and K and the SSARR routing routine (Linear Cascade type). The parameters specified in these routines are developed during the calibration process, then are fixed in the model setup. The complexity of the local area in increased when it is combined with the reservoir inflow type.

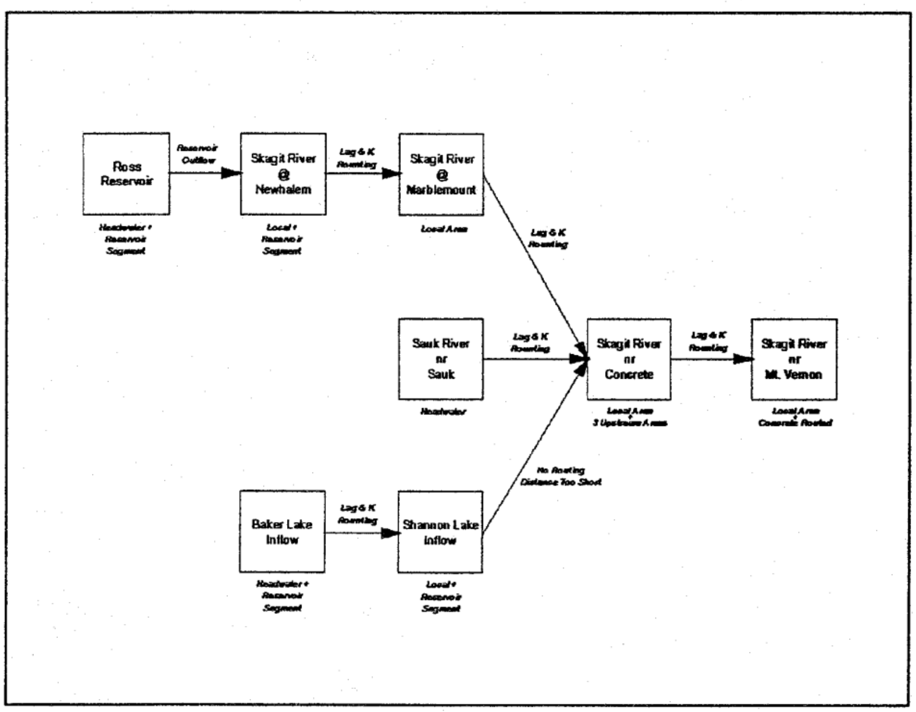


**Figure 2**

Figure 2. illustrates the use of different types of segments in defining the NWSRFS forecast scheme used in the Skagit River basin. It consists of a total of 8 segments, two are reservoir inflows, one is headwater, and 5 are local area components. Included within these 8 segments are 5 reservoir operations and 4 Lag and K operations. The Skagit River basin is probably the most complicated of the basins modelled so far by the NWRFC. It has been a good test of how well all of the various pieces come together to simulate the basin as a whole.MODEL INPUT

Regardless of how well the model is calibrated and defined in an operational system, it will only perform to the quality of the observed and forecasted metoerological inputs. In Northwest Washington, the Seattle office of the National Weather Service provides forecast precipitation and temperature. The quantitative precipitation forecast (QPF) is provided at least once per day with updates issued as needed. The QPF product contains six hourly precipitation values for the first two days and 24 hour precipitation for the third day. These are site specific forecasts, not basin wide average amounts. The Seattle office provides freezing level forecasts for the next three days. Freezing level forecast are used to type the precipitation (rain or snow) which is applied to the basin snow model.

Before NWSRFS can utilize precipitation forecasts, the site specific values must first be converted to basin average values. This process is accomplished in three steps. First, each station's six hourly precipitation total is converted to a percent of normal value. Next, each sub-area within a segment has assigned to it weighting factors for two or three of these QPF stations. These weights are applied to the forecast sites and then summed together to arrive at a sub-area basin average percent of normal. Finally, based on a calibrated monthly mean average precipitation value for the sub-area, this percent of normal is converted to an actual forecast 6 hour value.

The mountainous terrain, of the Pacific Northwest, provides another complicating factor in the forecast process. The model must determine whether the precipitation has fallen as rain or snow. Within the NWSRFS model there is an operation called Rain-Snow. This operation utilizes the forecast freezing level to determine if the moisture input will be rain or snow and at what elevation the split will occur. The liquid portion is added to any snowmelt to determine the total liquid moisture input entered into the rainfall runoff model. The portion falling as snow is accumulated by the snow model. The snow water equivalent and energy balance terms are then updated to reflect the current state of the snow pack.

## OPERATIONAL ANALYSIS OF NWSRFS DURING THE WESTERN WASHINGTON FLOODS OF NOVEMBER 1995

### A. Overview of the event

A strong weather system moved into the Pacific Northwest on November 27, 1995. The storm generated widespread heavy precipitation. Freezing levels rose rapidly from around 5000 feet to 10000 feet resulting in considerable snowmelt in the Cascades. Soils were already saturated due to earlier storms. All these conditions combined to produce major flooding throughout Western Washington from November 27 to November 30, 1995. Several rivers reached record peak flows. This event was the first significant event during which NWSRFS was run in test mode at the NWRFC for basins in Western Washington.

### B. Operational steps in producing a NWSRFS forecast

Producing a NWSRFS forecast involves quality control of input data, an interactive forecast run during which adjustments are made to the model, and finally running a forecast output procedure.

Quality control of data is very important since the input to NWSRFS is automated. Observed temperature and precipitation data in the NWSRFS database must be screened for erroneous values before running NWSRFS. This avoids large errors in moisture input into the model. Errors in river gage data are usually caught and rectified during the analysis of a NWSRFS run.

Once the precipitation and temperature data is quality controlled, and forecasted temperatures and precipitation are entered into the model, the hydrologist can run NWSRFS. He/she picks a starting period (carry-over date), and forecast period. For each basin, two graphical displays are produced: one showing observed nad forecasted freezing levels and rain/snow lines; the other showing observed flow/stage values, simulated flow/stage, and forecasted flow/stage. Changes can be made to the model parameters in order to have the simulated values match more closely with observed values. Parameters most often changed during this event were moisture input (liquid precipitation and snow melt) and baseflows. Blend periods can also be modified by blending observed values into simulated values over a longer or shorter period of time. The hydrologist also inputs expected reservoir releases where necessary. When the hydrologist is satisfied with the model's output and the forecasts, he/she runs the "sets" program which takes the latest observed data and forecasts and puts them into a format that can be sent out to the field offices.

**C. Performance of NWSRFS during the November 1995 event**

Forecasts generated by NWSRFS on three consecutive days and observed peak stage can be found in table 1. For the purpose of this paper, only crest forecasts were tabulated. When analyzing this information, one needs to keep in mind the magnitude of the event; many of these rivers reached record flows. Also, the forecasts generated by NWSRFS is highly dependent on the forecasted precipitation that was entered into the model. On November 28 for example, the quantitative precipitation forecast (QPF) entered in NWSRFS for the Skagit basin was much too high, and this is well illustrated by the higher stages forecasted on that day (three first lines of the table).

Looking back at how NWSRFS performed during this event, we were able to identify problems with the system. Solutions are being worked on to resolve some of these problems. One problem during this event was the fact that the NWSRFS database was only being updated on an hourly basis. It was found that this wasn't frequent enough. Changes have been made to the system to update the database every ten minutes. Another problem was discovered when the forecasts were plotted against observed data after the event: routing problems were apparent for certain basins. Some of the basin calibrations will need to be revisited to correct those problems. The poor routings result from the fact that basins are calibrated on daily time steps. For critical routing reaches, 6 hourly time step calibrations are needed. This routing problem can also be seen in the table, where Monroe and Snohomish have excessively high forecasts on November 29th, while upstream points were more accurate.

The NWRFC staff also identified items that need to be improved by the Office of Hydrology which supports NWSRFS. One item involves temperature adjustments. It is labor intensive to adjust freezing levels for several basins in order to specify more valid rain or snow in the model. The NWRFC staff would like to have the option to change freezing levels in one quick operation for a group of basins at a time. Another time consuming manipulation, is reservoir regulations input, which is currently done manually in NWSRFS. The solution to this problem (soon to be implemented) is to add the SSARR (Streamflow Synthesis and Reservoir Regulations) reservoir regulation model to NWSRFS. On the positive side, NWSRFS was stable and did not crash during this event. Timeliness for issuing a forecast was not a concern since the forecasts generated by NWSRFS was not used operationally, but it was easy and relatively quick to produce a forecast once all the data was entered into the system. When one looks at the data in the tables, the forecasts generated by NWSRFS were reasonable, and could have easily been used operationally.

**D. Conclusion**

NWSRFS is only in the beginning stages of it's development and implementation at the NWRFC. Several events have occurred since November 1995, and each one brings new problems, and allows the NWRFC staff to make appropriate changes in the way NWSRFS is set up in the office. Although a lot of work remains to be done, NWSRFS is continually evolving toward a more usable and reliable modelling system for the Pacific Northwest.

## FUTURE ENHANCEMENTS

The National Weather Service River Forecast System is a set of conceptual, continuous, hydrologic models used primarily to provide flood forecasts for major river basins in the United States. Significant advances have

# NWSRFS CRESTS FORECASTS
# ISSUED ON 11/27, 11/28, AND 11/29

| STATION (RIVER) | NWSRFS FORECAST 11/27/96 | NWSRFS FORECAST 11/28/96 | NWSRFS FORECAST 11/29/96 | OBSERVED STAGE |
|---|---|---|---|---|
| Deming (Nooksack) | 13.9 | 18.7 | 16.5 | 14.9 |
| Concrete (Skagit) | 37.5 | 44.6 | 39.6 | 41.6 |
| MtVernon (Skagit) | 36.2 | 40.4 | 37.8 | 37.4 |
| Arlington (Stillagu.) | 15.6 | 18.1 | 16.1 | 17.0 |
| Snoqualmie (Snoqualm.) | 48.9Kcfs | Missing | 49.9Kcfs | 50.2Kcfs |
| Carnation (Snoqualm.) | 60.5 | 58.7 | 61.5 | 60.3 |
| Monroe (Snoqualm.) | 24.4 | 25.8 | 38.4 | 24.1 |
| Snohomish (Snohomish) | 33.5 | 34.3 | 36.6 | 33.1 |
| Orting (Puyallup) | 9.6 | 7.6 | 9.7 | 10.2 |
| National (Nisqually) | 9.1 | Missing | 10.0 | 11.3 |
| Satsop (Satsop) | 31.9 | 32.5 | 37.3 | 34.3 |

Values are Stage in feet, unless specified.

table 1.

occurred in the last few years in the capabilities of computers and real-time communications. Corresponding gains in the science of river forecasting have also occurred. The resulting forecasting systems provide better flood forecasting information as well as improved long-range water resource information.

For the past decade, the NWS has presented concepts and demonstrations of advanced technologies for improved hydrologic forecasting. The fall of 1995 mark the beginning of the full scale implementation of these technologies in the Northwest. These advances are built around the foundation of NWSRFS, described in previous sections. Key elements have been developed and added to NWSRFS to enhance forecast quality and timeliness.

A. SSARR Models in NWSRFS

Components from the SSARR modelling system have been adapted to operations with in the NWSRFS. The SSARR reservoir and regulation was transferred to provide consistency with Corps of Engineers procedures and to improve the forecast capabilities in response to dynamic flood control operations. The SSARR river reach routing model was utilized to take advantage of calibrated routings and insure mass conservation of routed flows. Current NWSRFS routing techniques do not conserve flow volumes. SSARR three variable lookup table method was added to NWSRFS to provide a simple method of handling backwater effects. Converting these modelling operations for NWSRFS will provide consistent flow values between the NWSRFS and SSARR modelling systems during the transition period.

B. Interactive Forecast System (IFP)

The IFP is the real-time graphical user interface of the NWSRFS Operational Forecast System (OFS). This system allows a forecaster to interactively generate forecasts for hours or a few days into the future. IFP uses the same models used in the OFS and allows the forecaster to perform "what-if" scenarios. A stand-alone program called *SETS*, can then SHEF format forecasts into 4 days of 6 hourly forecasts.Crest forecasts are also avilable.

C. Extended Streamflow Prediction System (ESP)

This is a program which has been available for over a decade but limited in its implementation. The enormous amount of resources required to run the program and the cumbersome process to produce outputs have now been overcome. The NWRFC will implement this component of NWSRFS along with OFS beggining in the summer of 1996.

The ESP system uses present watershed conditions and the updated values of the state variables produced by OFS, combined with future time series of precipitation, temperature, and freezing level to produce probability estimates for a number of streamflow variables (figure 3). The procedure assumes that any of the historical time series of precipitation and temperature have an equal probability of occurring in the current year. When these time series and the current model state variables are combined in the forecast simulation, a set of discharge time series are produced. In the NWRFC area, the water years 1949 through 1993 are used to ensure accurate probability estimates. Current short-term meteorological forecasts are used to provide a transition into the future. Probability forecasts are then generated by analyzing the series of discharge for a given period of time (forecast window) and for certain streamflow variables (Day et al. 1992).

D. ESP Analysis and Display Program (ESPADP)

ESPADP will enable a forecaster to analyze steamflow traces generated by ESP, present the results through meaningful displays, apply adjustments to the forecasts, and generate outputs that can be used as forecasts products. ESPADP development is under contract and is schedule for delivery during the summer of 1996. The goal of ESPADP is to provide a tool that will enhance the capability of forecasters to produce accurate extended

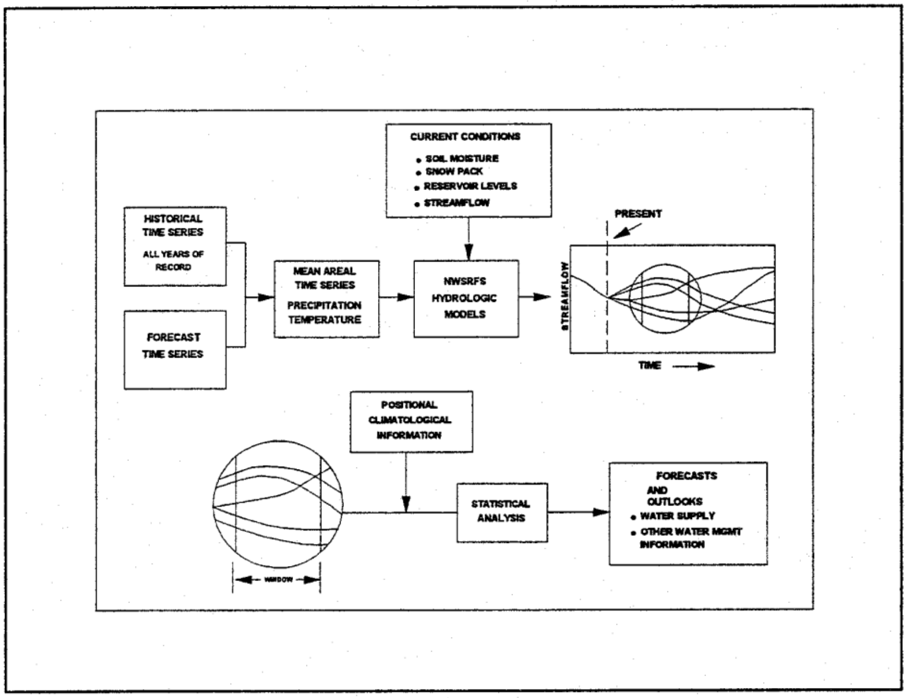


**Figure 3**

water resource forecasts and increase user confidence and understanding of the ESP process.

After the initial July release, climatological and other hydrometeorologic couplings are planned. Techniques will allow forecasters to vary weights based on inputs from these couplings. It is anticipated that weights would be assigned based on analog/anti-analog forecasts (classifying historical years as being similar or dissimilar to the current year), El Nino/Southern Oscillation type signals, and/or Climate Prediction Center (CPC) monthly/seasonal outlooks forecasts.

The forecaster needs to be able to evaluate the forecast information generated through analysis of ESP traces and then have an effective means of communicating these probabilistic forecast information to those who will use it, i.e. emergency management or water resource management agencies. ESPADP will use graphical and tabular displays to present the results of ESP trace analysis. The displays currently planned for ESPADP are:

***Probability plot*** - a time series plot depicting probability ranges associated with values of the output variable.

***Expected Value plot*** - a time series plot of the expected value of an output variable for a given set of traces. The plot will include the mean and standard deviation.

***Time Series Trace plot*** - sometimes referred to as the "spaghetti" plot, shows all the traces plotted on the same time scale.

***Exceedance Probability plot*** - presents the results of a frequency analysis of a given output variable for a specific time window. The output variables, which have been fitted to a probability distribution is plotted against the exceedance probability.

***Geographical displays*** - will be used to show the spacial variability of variables throughout the different basins.

***X-Y plot*** - will allow the forecaster to plot one output variable against another. For example, the historical computed output could be plotted against the historical observed to visualize the quality of the calibration for this time window and output variable.

***Summary plot*** - compares the mean, maximum, minimum, and standard deviation of the output variables for the observed, historically simulated, conditionally simulated, and the adjusted conditional time series.

***Tabulations*** - will include the frequency and summary tables corresponding to the summary plot.

User products will be in the form of tables, exceedance probability traces, and/or ESP time series traces. Verification statistics for ESP forecasts at specific forecast points will be produced and will be available to users of these products.

E. Snow Estimation and Updating System (SEUS)

SEUS utilizes ground based and airborne snow water equivalent (SWE) data to update estimations of snowpack conditions in the NWSRFS snow model. Conditions are updated prior to making water supply or ESP runs (Day, 1990). Observations are collected in real-time and calculations of standardized deviates for each observation is performed. These values are then interpolated into a gridded field and a spacial estimate of snow water equivalent is made using the deviates and long-term normals field. Outputs from the SEUS system are standardized deviates, snow water equivalents and percent of average. The system can be run at anytime, however, in an operational mode it is normally run for the first and mid-month updates. A new state-space version of the NWSRFS snow model has just been released. This will accept an estimation of snow water equivalent and its associated uncertainty (variance). This will optimize the use of snow water equivalents in NWSRFS and provide for improved streamflow forecasting (McManamon, et al., 1993).

<u>REFERENCES</u>

Anderson, E.A., "National Weather Service Forecast System - Snow Accumulation and Ablation Model", NOAA Technical Memo NWS-Hydro-17, Department of Commerce, Silver Spring, MD., 1973.

Bissell, V.C. and Orwig, C.E., "Calibration of the Northwest: A Status Report", Proceedings of Western Snow Conference, pp 135-138, Sparks, NV., April 1995.

Burnash, R.J.C., et.al., "A Generalized Streamflow System", Joint Federal-State Report, California River Forecast Center, CA., 1973.

Day, Gerald N., "A Methodology for Updating a Conceptual Snow Model with Snow Measurements", NOAA Technical Report NWS 43, Department of Commerce, Silver Spring, MD., March 1990.

Day, G.N., Brazil, L.E., McCarthy, C.S., and Laurine, D.P., "Verification of National Weather Service Extended Streamflow Prediction Procedure", AWRA Proceedings on Managing Water Resources During Global Change., Reno, NV., November 1992.

McManamon, A., Szeliga, T.L., Hartman, R.K., Day, G.N., and Carroll, T.R, "Gridded Snow Water Equivalent Estimation Using Ground-Based and Airborne Snow Data", Proceedings of Eastern Snow Conference, Quebec City, pp 75-81., 1993

National Weather Service, "National Weather Service River Forecast System (NWSRFS)", NOAA Technical Memo NWS-Hydro-14, Department of Commerce, Silver Spring, MD., 1972.