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A LOCAL HEADWATER MODEL FOR OPERATIONAL USE IN THE MODERNIZED NATIONAL WEATHER SERVICE

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1. INTRODUCTION

The ongoing modernization of the National Weather Service (NWS) includes the deployment of new data collection systems, namely the Weather Surveillance Radars - 1988 Doppler (WSR-88D), the new Geostationary Operational Environmental Satellites (GOES), and the ground-based Automated Surface Observing System (ASOS) sensors. The data sets from these and other systems are to be used in scientific workstations at the 118 Weather Forecast Offices (WFO) and 13 River Forecast Centers (RFC) which share the responsibilities for the NWS hydrology program. The RFCs generate hydrologic forecasts, which are provided to the WFOs where they are reviewed and distributed to the public and local, interested parties.

The scientific workstations are being deployed as the primary component of the Advanced Weather Interactive Processing System (AWIPS) which integrates operations at NWS offices and is the linchpin and last major component of the NWS modernization. The NWS Office of Hydrology is developing a system on these powerful workstations to support the WFO hydrology program and integrate it with the other WFO program areas (Shelton and May, 1995). This system, the WFO Hydrologic Forecast System (WHFS), has been used operationally at several WFOs since October, 1994, on pre-AWIPS workstations and was deployed as part of the initial AWIPS delivery in August, 1996. The WHFS currently includes interactive applications which manage hydrological reference data sets, review and display operational data sets, and generate hydrologic products for public release.

In a future release of the WHFS, a local headwater model will be included that generates a time series of short-term stage and flow estimates for fast-response, gaged, headwater locations. This model, the primary component of the Site-Specific application, uses observed and select forecast data together with model state variables and parametric definitions provided by the supporting RFC. The impending arrival of a nationally-deployed, hydrologic model for WFO usage raises many issues related to certain hydrometeorological concepts incorporated within the model and the use of the model in an operational environment. This paper provides an overview of the model and discusses technical and operational issues associated with it.

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2. SITE-SPECIFIC APPLICATION

The heart of the Site-Specific application is its hydrologic model. A graphical user interface that uses a mouse-based, point-and-click approach allows the forecaster to review and control the specific manner in which the model is executed.

The scientific components of the hydrologic model are written in the FORTRAN language, while the user interface is written in the C language using the X/Motif windowing libraries. The application executes on scientific workstations using the Unix operating system. A relational database management system stores all the data used and generated by the model.

2.1 *Model Overview*

The headwater model within the Site-Specific application is a subset of the Operational Forecast System software, which is used at an RFC as their primary modelling system (Page, 1996). The headwater model executes a pre-defined "segment", which is defined for a hydrologic basin. The segment definition contains instructions on what input data are used, how the data are processed within the model, and what output data are generated. Each of the instructions is referred to as an operation, where a typical segment definition may have 8-12 operations that comprise the operations table for the segment. A segment definition includes an ordered set of operations that typically execute:

- o a rainfall-runoff operation which determines the amount of the basin average precipitation that enters the stream as runoff;
- o a unit hydrograph operation which transforms the runoff into the stream to a stream discharge; and a
- o a stage-to-discharge conversion operation which converts the estimated discharges to stage values.

Many additional operations are available, and each operation can be tailored. For example, snowmelt operations and different rainfall-runoff models can be used, and adjustments can be made to the estimates using observed values.

2.2 *User Interface*

The Site-Specific interface uses a geographic display of the area of responsibility for the WFO. This display may contain many overlays of data including river courses and headwater locations. By selecting a particular location from the graphical display, its data can be displayed, including information from NWS Form E-19 and time series data. The Form E-19 data provides information on the hydrologic characteristics and history of the headwater location. The time series data, such as precipitation and river stage data, can be reviewed in graphical or tabular form. Select input data, such as precipitation time series data, can be edited and used as model input. The instructions in the operations table can be reviewed to understand the specific manner in which the model is executed. The unitgraph and rating table for the location can also be displayed.

All this information is used by the forecaster to assess the hydrologic situation at the headwater location and to help interpret the results of the subsequent execution of the hydrologic model. The model is then executed and the generated forecast stage and discharge time series can be reviewed. The model can be executed multiple times, using different input data to evaluate "what-if" scenarios. When the generated forecast is deemed to be satisfactory, an option is available to save the forecast time series data to the relational database.

2.3 *Data Requirements*

The hydrometeorological data required depends upon the data specifications of the operations table for the given headwater location. Precipitation and river stage time series data for the location are also required. The model uses basin average values for the input time series of precipitation data, which are determined using point data, gridded data, or a combination of the two. A preprocessor is coupled with the hydrologic model that automatically generates the basin average, or Mean Areal Precipitation (MAP), values. Forecast precipitation values such as Quantitative Precipitation Forecasts (QPF) can also be used. Evaporation, temperature, or other hydrometeorological data may be required for certain operations.

To execute the model, the segment definition is used, which defines the operations table discussed above. Associated with each operation are the parameter information that defines assorted values, switches, and options, and the time series information which defines which time series are used in the model, whether they be input, internal, or output, and which specifies the time series used by each operation.

The parameter information includes data from Form E-19 and other information such as a unitgraph table and a rating table. Also needed are the flood stage, drainage area, etc. The operations table, parameter, and time series information are typically defined once and changed rarely thereafter. One other set of segment information, the carryover data, changes regularly. Carryover data indicate the hydrologic state of the various operations within the operations table. A classic example is carryover data used for rainfall-runoff operations that quantify the moisture state of the soil in the watershed. This information is updated at regular intervals, possibly daily, with data from RFC hydrologic model runs.

3. MODEL SETUP

To operate the model for a given location, the location's segment definition must be completed. Part of this definition is the specification of which hydrometeorological data to use in the operation of the model. Many factors must be considered since the model is for use in a real-time operational setting where data availability and quality is always a consideration. Of course, the model must also accurately represent the hydrologic response of the basin.

With these and other considerations, it becomes a significant effort to configure and calibrate a segment for operational use. Defining which operations to use and their sequence is not overly difficult as the NWS has much experience doing this with existing river locations. The standard approach for a headwater location uses the basic steps listed earlier. Routing of channel flows is currently not available, so the segment operations need not include this step.

However, defining the parameter values for each operation can be demanding. This includes the unitgraph table for the location, which requires calibration of the basin, ideally using historical data that represent many events under different scenarios. Also, the rating table requires physical measurements of the stream channel flows and corresponding stages, or an existing rating table can be used.

Although many rainfall-runoff operations are available for selection, the Soil Moisture Accounting (SMA) operation is currently the de facto standard for the NWS. This lumped parameter, continuous model divides the watershed into horizontal zones, where the path of each unit of precipitation is followed through the various zones and components thereof, until the precipitation reaches the stream channel (Burnash, 1995). The rainfall-runoff operation requires a significant amount of calibrated parameter data. The burden of this can be lessened somewhat by regionalizing certain values for watersheds that have similar characteristics.

3.1 *Temporal and Spatial Considerations*

A critical aspect of the calibration process is determining the proper time step to use for the input data and internal computations. The time interval of the input precipitation data, and therefore the interval for the runoff time series, has a major impact on the characteristics and accuracy of the model.

Most river locations currently modelled at an RFC are located on mainstem rivers which have slow response times ranging from 6 hours to many days, or even weeks. Therefore, most segment definitions for river locations use a time step of 6 hours. However, for headwater locations, the response can be very quick, often less than 6 hours, and certainly quick enough that a model time step of 6 hours would provide only a crude estimate of the stream flows. Time steps of no longer than 1 to 3 hours are needed for the headwater locations. The NWS does not have as much experience generating specific stage forecasts using models that operate at such time steps.

Headwater basins also differ from mainstem river locations in the size of their drainage areas. Their area is generally smaller than the river locations, even when considering that many river locations are modelled by partitioning their upstream basins into sub-basins. Again, the NWS does not have as much experience modelling these smaller drainage area basins.

The SMA model parameters vary in a non-linear fashion with respect to changes in space or time scales, due to the complex nature of the hydrologic response characteristics of headwater basins. These differences in the temporal and spatial scales preclude the use in headwater models of the existing model parameter data calibrated for river locations. From a workload perspective, it is desirable to transfer much of the parameter and other calibration information already defined for modelled river locations, and apply it to headwater locations. Studies have been conducted to investigate the impact on the SMA rainfall-runoff operation using different space and time scales for the precipitation data (Finnerty et. al., 1995; Smith et. al., 1995). These studies have shown that some parameters of the SMA operation are quite sensitive to variations in the spatial and temporal resolutions. The differences between observed and simulated streamflow on small basins when using calibration parameters for larger space-time scales were unacceptably high. Therefore, the demands of the calibration process for small headwater basins become greater without the use of the regionalized, calibrated data.

3.2 *Precipitation Data*

The operational data that most stream flow models rely on are precipitation and stream stage data. Because stage data is generally reliable, it is the existence of accurate and timely precipitation data which is the most critical data set for stream flow models. Traditionally, point gage data is used as the source of precipitation data. With the availability of gridded, radar-based precipitation estimates, a new class of precipitation data is now available. The radar estimates are available in near real-time and provide estimates of rainfall for durations as short as 5-6 minutes. The radar grids have an excellent spatial resolution of 4 x 4 km. The fine time and space scale data make them highly attractive for use in modelling quick-response headwater locations, and it is expected that the gridded, radar-based estimates will be the primary source of precipitation data for the headwater model.

To address concerns about accuracy of the radar estimates, a bias adjustment procedure is employed to use available real-time gage precipitation data to adjust the radar estimates. A separate procedure also executing on the WFO AWIPS workstations merges the radar and point values to derive a multi-sensor grid. These procedures are part of the overall precipitation processing system employed in the modernized NWS (Shedd and Fulton, 1993).

The effect of the space and time scale issues discussed earlier are most evident in the precipitation data. The space and time scale chosen must make maximum use of the information embodied in the precipitation data. As with any model, it is critical to calibrate the model with the same type of data used operationally for the model. Because of the dearth of archived radar-based data, it is difficult to calibrate the model in this respect. Also, the quality of the radar estimates has not yet been fully reviewed.

The actual precipitation data used in the rainfall-runoff model are the basin average MAP values computed from the gridded and/or point precipitation data by a pre-processor incorporated within the application. Additionally, the forecaster can interactively specify the precipitation time series for use in the model. The adjustment of these precipitation values to reflect various scenarios can provide valuable insight into the hydrologic response of the location.

4. OPERATIONAL ISSUES

The previous section discussed many of the issues affecting the calibration of the model. These issues are intrinsically tied to the operational use of the model. In addition, there are numerous other practical issues which must be addressed to ensure the viability of the application in an operational environment.

The model can be executed by any member of the WFO forecast staff. Because a certain level of expertise is required to use the model and to interpret the data, the forecaster should have a knowledge of hydrologic modelling techniques and hydrologic characteristics of the headwater location. Training on the use of the model is imperative. The Service Hydrologist or hydrologic focal point is expected to play a role in training the WFO staff. The model is designed to require minimal mouse-clicks to execute while allowing the user access to a large number of options and control of model execution. However, to properly interpret the model output, it requires an appreciation of the hydrologic science contained in the model.

4.1 *Model Definition*

As described earlier, the segment definition resulting from the calibration process can be a laborious effort that requires in-depth knowledge of the hydrologic science and operational characteristics of the model operations. A practical question is "who performs this critical task?" The RFC staff is undeniably the most qualified to perform the task as they have the most experience; however other factors must also be considered. Historically, the RFCs have the responsibility for the forecasts of mainstem rivers while the WFOs handle the smaller creeks and streams. It would be most helpful for the WFO staff, especially the Service Hydrologist or hydrologic focal point, to be involved in headwater model calibrations, as this experience greatly aids in the understanding of the model usage. WFO and RFC offices have limited resources to expend on additional activities, so a balance must be found between WFO and RFC support for the headwater model calibration workloads.

In light of these demands, it becomes important to judiciously select which basins to model. A typical WFO has anywhere from 20 - 50 official forecast points, and an RFC may provide forecasts for forecast points in about 10 - 20 WFOs. This itself represents a large component of the RFC forecast services provided to WFOs. Depending on the WFO, there may be anywhere from 5 - 15 headwater locations that would benefit from forecasts provided by the headwater model. This represents a significant effort on the RFCs, not just in terms of any calibration support provided, but in the ongoing operational support provided in the form of regular, carryover data updates.

Other factors also exist with regard to selecting locations. Data availability must be weighed, including reliable stage data and reliable precipitation information, whether from radar-based or gage-based data. The potential impact of future flood events and the probability of these events occurring must also be factored.

4.2. *WFO/RFC Coordination*

In the event that the output from the headwater model and the RFC forecast guidance differ, it is suggested that the WFO, which is responsible for disseminating the forecasts to the public, discuss these discrepancies with the RFC. It is imperative that the forecast information provided to the public by the WFOs and RFCs is consistent. Coordination may be difficult during overnight hours as the RFCs operate 16 hours/day while the WFO operates around the clock.

Differences will undoubtedly arise due to the different hydrometeorological data on hand at the WFO and the RFC. Another set of data which may vary are the carryover data, which contain the state variables for characteristics such as the soil moisture conditions. This data will be sent from the RFC to the WFO on a regular basis, perhaps daily. As a rule, the carryover data for a given basin should be sent to the WFO whenever it is updated.

4.3 *Model Output*

The manner in which the WFO-generated forecasts are used must be considered. The forecast can be used for internal guidance at the WFO and for "what-if" scenarios. If these forecasts are deemed reliable, they can be used as official forecasts for inclusion in river products issued from the WFO. This determination is the responsibility of the WFO forecast staff and must be carefully considered. These models can be sensitive to inaccurate input data and are capable of yielding erroneous results if they are not operated properly. The model output should never be accepted without reviewing the model operations closely and thoroughly.

5. CONCLUSION

The Site-Specific application and its associated headwater model will provide needed hydrologic model capabilities to the WFO. The model is founded on the established methodology used for RFC forecast operations, and its output will complement the mainstem river forecasts and other forecast services provided by an RFC. It will allow the WFO to generate specific stage and flow forecasts for their smaller, headwater locations. Each location must be carefully chosen and the model must be calibrated. The RFC must provide regular updates to the model state data, while the WFO must be proficient in the model usage to properly interpret its forecast output. Some important procedures must be established regarding how the WFO operates the model and coordinates its use with the RFC. With this framework, the Site-Specific application and its headwater model will enhance the hydrologic forecast services provided by the NWS.

6. REFERENCES

Burnash, R., 1995: The NWS River Forecast System - Catchment Modeling, Computer Models of Watershed Hydrology, 311-366.

Finnerty, et.al., 1995: Sensitivity of the Sacramento Soil Moisture Accounting Model to Space-Time Scale Precipitation Inputs from NEXRAD, Hydrologic Research Laboratory Internal Publication.

Page, D., 1996: "The Implementation of an Interactive River Forecast System for the National Weather Service," 12th International Conference on Interactive Information and Processing System (IIPS) for Meteorology, Oceanography, and Hydrology, AMS, Atlanta, Georgia.

Shedd, R.C., and R.A. Fulton, 1993: "WSR-88D Precipitation Processing and its use in National Weather Service Hydrologic Forecasting," Proc. of the International Symposium on Engineering Hydrology, San Francisco, CA, ASCE.

Shelton, D.R., and May, E.L, 1996: "Modernized Hydrologic Forecast Operations at National Weather Service Weather Forecast Offices," 12th International Conference on Interactive Information and Processing System (IIPS) for Meteorology, Oceanography, and Hydrology, AMS, Atlanta, Georgia.

Smith, et.al., 1995: "Distributed Parameter Hydrologic Modeling and NEXRAD for River Forecasting: Scale Issues Facing the National Weather Service," Hydrologic Research Laboratory Internal Publication.