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IMPROVED HYDROLOGIC FORECASTING WITH THE INTERACTIVE NWS RIVER FORECASTING PROGRAM

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1. INTRODUCTION

Since 1971, the National Weather Service has been developing and implementing the National Weather Service River Forecast System (NWSRFS) which consists of a series of computer programs that process data and model physical processes. It has typically been run as a batch program by forecasters at NWS River Forecast Centers (RFCs), submitted to the NOAA Central Computer Facility over dedicated communication lines.

As part of the modernization of the NWS, computer facilities at the thirteen RFCs throughout the country (Fig. 1) will be upgraded. NWSRFS will be run on-site at the RFCs and the forecasters will be running the interactive programs that control NWSRFS on scientific workstations. Among the benefits the workstation environment will offer are: (1) rapid running of the forecast programs and (2) a graphical user interface that will replace the card image job control and line printer output.

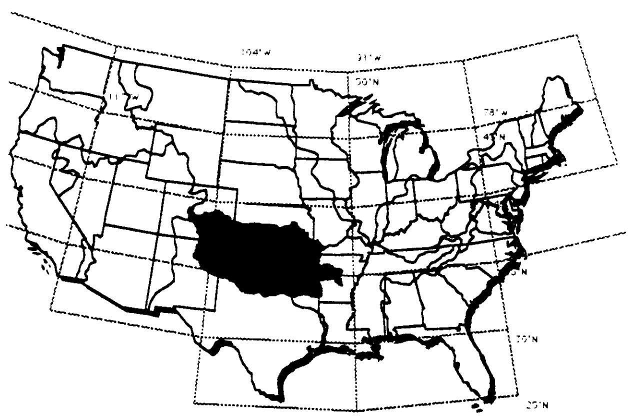

Fig. 1. Boundaries of the River Forecast Centers. The shaded area covers the Tulsa RFC.

The RFC river forecaster is confronted with vast amounts of information but has a limited time in which to produce a forecast. This information needs to be evaluated and possibly adjusted. The interactive forecast program is intended to enable the forecaster to run forecasts and respond to the results more efficiently and accurately.

2. RIVER FORECASTING IN THE NWS

The forecast component of NWSRFS consists of models that simulate snow accumulation and ablation; average evapotranspiration; base flow, interflow, and surface runoff; reservoir operations; and river routing (Curtis and Smith, 1976; Hudlow and Brazil, 1982; and Anderson, 1986). Several different models are available for most types of processes (Table 1). Observed data that is input to the models consist of precipitation, temperature, and river stages or discharges. Prior to computing the simulated river stages, the models within NWSRFS generate snowmelt, baseflow, and runoff from observed data, or the output of other models.

Table 1. Models and operations within NWSRFS.

<u>Snow</u>
- HYDRO-17 Snow Model

<u>Rainfall-runoff</u>
- Sacramento Soil Moisture Accounting
- Ohio RFC API Rainfall-runoff model
- Middle Atlantic RFC API Rainfall-runoff model
- Central Region RFC API Rainfall-runoff model
- Colorado RFC API Rainfall-runoff model
- Xinanjiang Soil Moisture Accounting

<u>Channel routing</u>
- Channel loss
- Dynamic wave routing
- Lag and K routing
- Layered coefficient routing
- Muskingam routing
- Tatum routing
- Stage-discharge conversion
- Single reservoir simulation model
- Unit hydrograph

<u>Utility operations</u>
- Baseflow generation
- Computation of mean discharge
- Instantaneous discharge plot
- Clear time series
- Add or subtract time series
- Weight time series
- Change time interval
- West Gulf RFC tabular operational display
- Table lookup
- Plot time series
- Tulsa RFC operational plot
- Adjust simulated discharge

River systems within the responsibility of the each RFC are divided into forecast groups which are further subdivided into river segments. The forecast group consists of a network of connected rivers. Segments are reaches of rivers to which the models are applied. The downstream boundary of a segment is the forecast point, the location to which the forecast of river stage applies. The forecast groups and forecast points within the Tulsa RFC shown in Figure 2.

The forecaster begins a forecast with the segment located at the upstream boundary of the forecast group (if the forecast group encompasses a confluence,there will be more than one upstream boundary). The forecast component of NWSRFS is applied to each segment of the forecast group in sequence working downstream. The time series that are produced for a segment serve as the upstream boundary conditions for the next segment downstream.

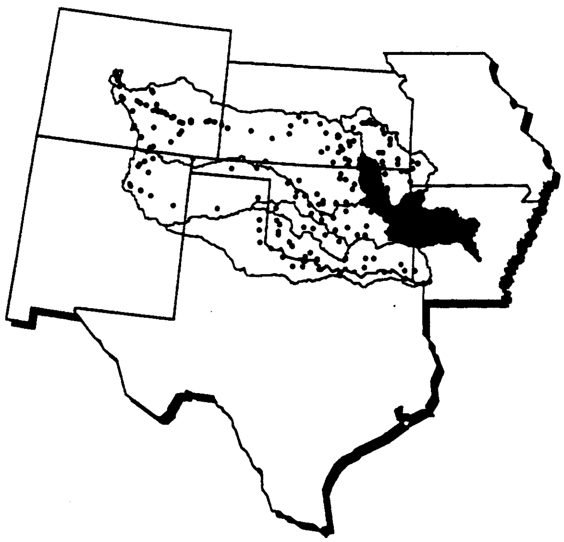

Fig. 2. Forecast groups and forecast points within the Tulsa RFC. The shaded area is the Keystone to Pine Bluff forecast group.

Currently, an entire forecast group is submitted as a batch job to the NWS Central Computer Facility in Suitland, Maryland. Run times are typically about five minutes, but may be as long as twenty minutes. If adjustments to the forecast are necessary (next section), they are made where necessary to each segment within the forecast group and the job is resubmitted.

With the modernization of the NWS over the next few years, the RFCs will have the facilities to run NWSRFS on-site (see Fread, Smith, and Day, 1991). The forecast component, under the control of the Interactive Forecast Program (IFP) will be run on a scientific workstation (see Page, 1991). Upon choosing a forecast group, an initial run of NWSRFS will produce a forecast for the entire forecast group. The forecaster will then be able to review the results and refine the forecast one segment at a time while working downstream.

The IFP is under development at the NWS Office of Hydrology (OH) as part of the PROTEUS Project. The modular structure of NWSRFS has allowed it to evolve since its initial release. New and modified operations have been added both at OH and by the RFCs to adapt NWSRFS to the particular needs and preferences of some RFCs. An interactive version of NWSRFS was first proposed by Brazil and Smith (1981).

3. FORECAST ADJUSTMENTS

Inaccurate reports of observed values, simplifications in conceptual models, insufficient accuracy in calibration, and conditions that deviate from the norm can all degrade the fidelity of simulations. The effects of these can be mitigated by the insight and judgement of the forecaster with the aid of procedures in NWSRFS that enable them to modify parameters and time series. These modifications (known within the NWS as run-time mods) are applied to segments where necessary and the segment simulations are rerun. A few of the adjustments available are discussed below.

3.1 Observed data

One set of modifications allows for the correction of observed data. Automatically reported river stages, for example, may include values that are clearly inconsistent with neighboring values, show no variation over a suspiciously long period of time (due possibly to a frozen gage), or extend beyond a reasonable range. The forecaster has the option of removing suspect data or substituting correct values supplied by another source. Figure 3a shows an example from the North Central RFC in Minneapolis that illustrates what might confront the forecaster. The stage reported automatically is obviously in error at day 23 and hour 7. It is orders of magnitude greater the maximum flood of record of 620 cms. Removal of that point, and the accompanying adjustment of the vertical scale, reveals the true hydrograph (Fig. 3b). The sharp rise at the end of the observed is consistent with hydrographs of nearby streams and the preceding precipitation.

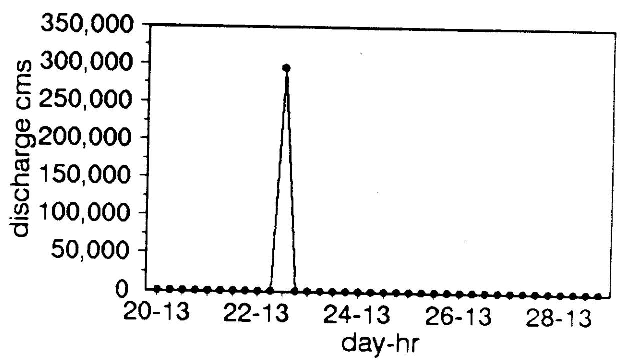

Fig. 3a. Discharge determined from automatically reported stages. The incorrect value at day 23, hour 7 is orders of magnitude above the maximum flood of record.

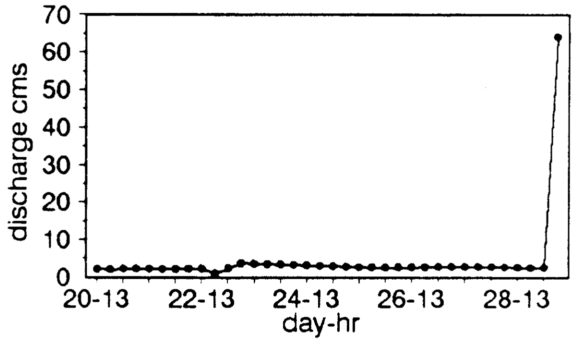

Fig. 3b. True hydrograph after removal of the bad value shown in 3a.

3.2 Rainfall-runoff models

If the simulated hydrograph significantly differs from reliable observed values, the models can be temporarily altered to account for differences between calibration and current conditions. This can be illustrated with an example using rainfall-runoff models.

Rainfall-runoff models are used to determine surface runoff from precipitation. Some models, such as Antecedent Precipitation Index (API) models, are calibrated for average conditions for a given time of year. Figure 4 shows part of a nomograph typical of API type models. The family of curves represent the effect of the time of year. If conditions preceding a storm event differ from the average conditions used for calibration, it can be represented in the model by shifting the position along the ordinate.

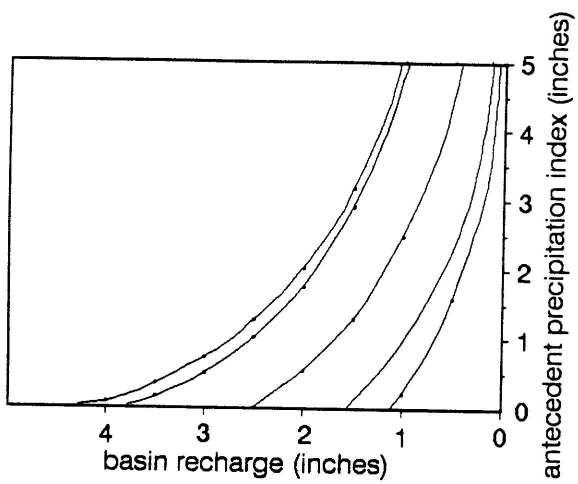

Fig. 4. Northwest quadrant of a nomograph used in Antecedent Precipitation Index rainfall-runoff models (After Linsey, Kohler, and Paulhus, 1982, Fig. 8-5). Each curve represents conditions for a given time of year.

3.3 Unit hydrograph

The translation of runoff in a basin to stream discharge represented by a unit hydrograph implicitly assumes uniform precipitation over the basin. Local variability of rainfall intensity, which can strongly affect the response time of the stream, in the individual events used to synthesize the unit hydrograph are averaged out. One of the modifications available in NWSRFS allows for the distortion of the unit hydrograph to account for variability in rainfall intensity. Currently, forecasters must depend upon gage data, which can be sparse, but with the implementation of NEXRAD (Next Generation Weather Radar, see Shedd and Smith, 1991) a far more complete picture of rainfall distribution will be available.

3.4 Blending

Under mild conditions, river forecasts can be routinely generated. If river stage is well below flood stage, small differences between simulated and observed, except where navigability of rivers is important, are of relatively little consequence. Under active conditions, however, producing simulations that show good agreement with observed by adjusting basic physical parameters may not be possible in the time available. Blending procedures that combine the simulated and observed provide a best estimate under these conditions.

A method of blending is illustrated in Figure 5. Here, the best estimate in the forecast period is determined by adding a linearly decreasing percentage of the difference between the simulated and last observed values to the subsequent simulated values.

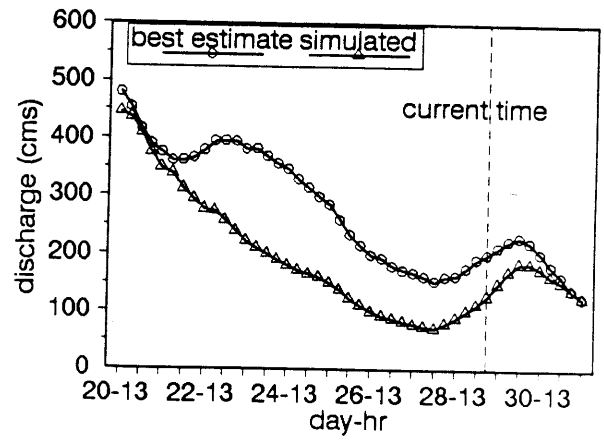

Fig. 5. Blending produces a best estimate in the forecast period based on the difference between the last observed value and the corresponding simulated value. A linearly decreasing percentage of that difference is added to the simulated over the next eight time periods.

4. A CASE STUDY

The Keystone to Pine Bluff Forecast Group is located within the area covered by of the Tulsa, OK RFC (Fig. 6). Tahlequah and Watts segments are two connected reaches on the Illinois River (not to be confused with the Illinois River in Illinois) and are shown in Figure 7. Watts is the upstream-most segment; its discharge is determined solely by precipitation within the basin surrounding the segment. The discharge is determined directly from the runoff with a unit hydrograph. The Watts discharge serves as an upstream input to the Tahlequah segment.

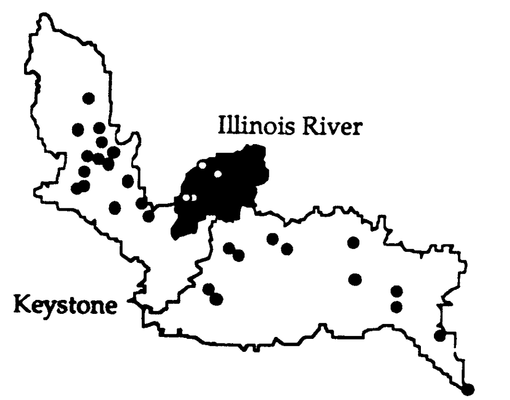

Fig. 6. Keystone to Pine Bluff forecast group. The shaded area highlights the Illinois River Basin shown in Figure 7.

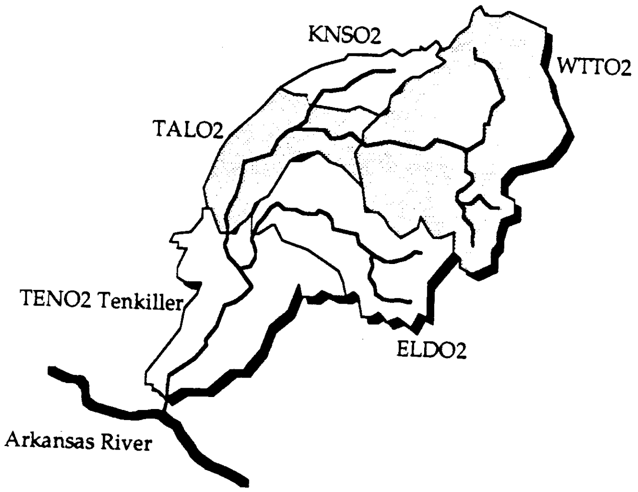

Fig. 7. The Watts (WTTO2) and Tahlequah (TALO2) segments within the Keystone to Pine Bluff forecast group.

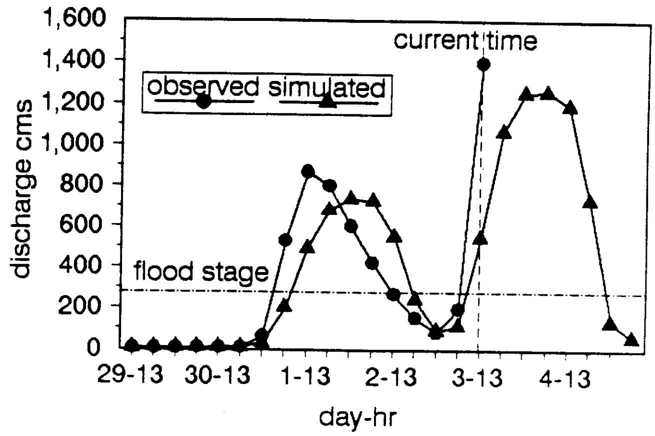

Fig. 9. Initial simulation of discharge at the Tahlequah forecast point prior to any adjustments. Note the undersimulation at the end of the observed period.

The mean areal precipitation (MAP) for the run period preceding the current time is determined from a weighted average gages in or near the basin (Fig. 8). An initial run of NWSRFS using rain gage data produced the simulated stage shown in Figure 9, which

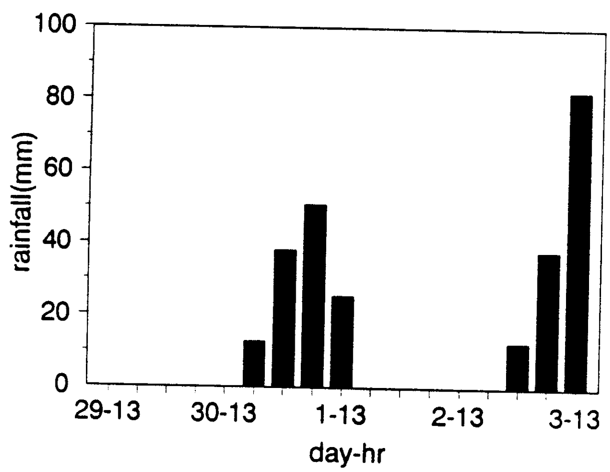

Fig. 8. Mean areal precipitation over the Watts segment for the observed period.

also shows the reported observed stages. The simulated hydrograph agrees well with the observed up to the point where the hydrograph begins to rise near the end of the observed period. The radar image displaying the distribution of the rainfall shows that the storm did not cover a large area and that its locus is close to the Watts forecast point (Fig. 10). The undersimulation of the rising limb of the hydrograph is most likely a result of the bulk of the rainfall and runoff occurring near the location of the stage recorder, which is also close to the forecast point.

There are several ways this could be accounted for in NWSRFS. While the amount of precipitation in a basin can be adjusted, its distribution cannot. To account for an uneven distribution of precipitation within a basin, the forecaster would have three choices: adjust the amount and the timing of the precipitation, adjust the runoff, or adjust the unit hydrograph. The first two could be accomplished by entering new values at the appropriate times that replace the reported (precipitation) or calculated (runoff) values that were input to the runoff and routing models.

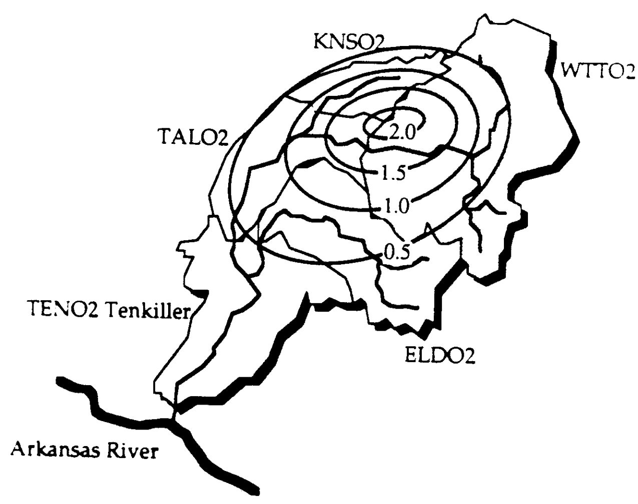

Fig. 10. Isohyetal map showing the uneven distribution of precipitation in the Watts segment.

Although not necessarily the easiest modification to make or the one all forecasters would choose, the change to the unit hydrograph is demonstrated here. The unit hydrograph for the Tahlequah segment is shown in Figure 11. To reflect the effect of the rain distribution in this case, it should be skewed to the left. There are currently no analytical methods of determining the shape of the unit hydrograph that best suits unusual conditions, but NWSRFS does automatically adjust the new coordinate in such a way that volume is conserved. A few iterations produces the unit hydrograph shown in Figure 11. The new simulated hydrograph (Fig. 12) agrees well with the observed values.

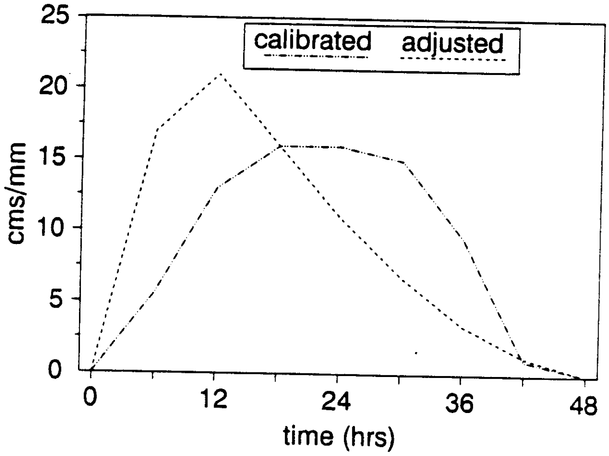

Fig. 11. The calibrated unit hydrograph and modified unit hydrograph for the Tahlequah segment.

The forecast can be further refined with the addition of the Quantitative Precipitation Forecast (QPF) which consists of a predicted volume of rainfall that will occur over a given area within the next forecast period, usually six hours. The QPF is currently made by the National Meteorology Center and distributed to the RFCs by Weather Service Forecast Offices. With the implementation of NEXRAD (Shedd and Smith, 1991), the QPF will be refined at the RFC by a hydrometeorologist for use in the forecast.

The effect of an addition of 2.5 cm for the next 6 hours can be seen in Figure 13. More rain on an already waterlogged soil drives the peak discharge up another 170 cms.

With good agreement between the observed and simulated, the forecaster would be ready to move on to the Tenkiller segment where the Tahlequah discharge would be used as inflow.

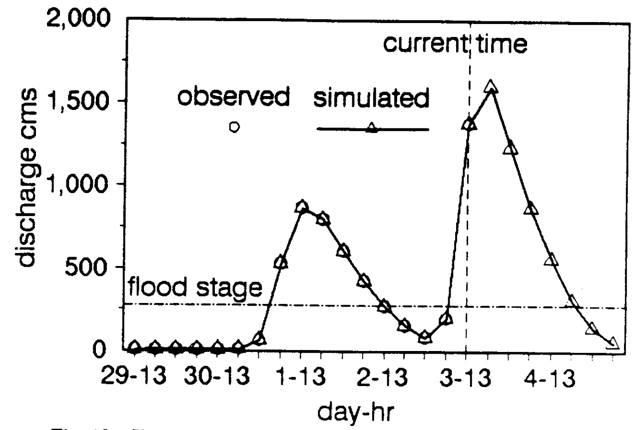

Fig. 12. Simulation of the discharge at the Tahlequah forecast point after adjustment of the unit hydrograph.

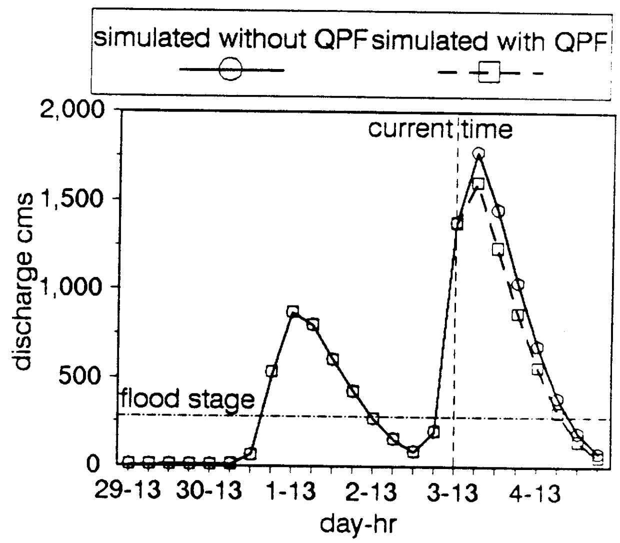

Fig. 13. Simulation of the discharge at the Tahlequah forecast point after adjustment of the unit hydrograph and addition of QPF.

5. SUMMARY

NWSRFS is a conceptual hydrologic model that is capable of producing river forecasts with minimum human interaction. Under some circumstances, however, the forecast can be greatly improved by knowledgeable users. NWSRFS has the flexibility to reduce errors due to inaccuracies in the calibration or inherent in simplifying assumptions or due to unusual conditions. The ability to take advantage of this flexibility has been dampened by the relatively cumbersome and sluggish off-site batch runs and line printer graphical displays. The ability of the Interactive Forecast Program to run the models rapidly, view the results, and modify the input if necessary will help forecasters take full advantage of NWSRFS and make better forecasts.

6. ACKNOWLEDGEMENTS

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