LUMPED AND SEMI-DISTRIBUTED MODELING USING NEXRAD STAGE-III DATA: RESULTS FROM CONTINUOUS MULTI-YEAR SIMULATIONS

Michael Smith, Victor Koren, Ziya Zhang, and David Wang

AUTHORS: Research Hydrologists, Hydrologic Research Lab, National Weather Service, 1325 East West Highway, Silver Spring, Md. 20910
REFERENCE: *Proceedings of the 1999 Georgia Water Resources Conference*, held March 30-31, 1999, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia

Abstract Nexrad precipitation products appear to be a viable data source for river forecasting model in the National Weather Service (NWS). Good simulation results at an hourly lumped scale were achieved for 3 basins near Tulsa, Oklahoma. In some cases, semi-distributed representation of these basins led to slightly better results. However, problems with parameterizing and calibrating a semi-distributed model with limited information arose. Possible explanations for the similarity between the lumped and semi-distributed simulations are discussed.

INTRODUCTION

Recent research within the Hydrologic Research Lab (HRL) of the NWS has been directed towards the use of NEXRAD precipitation products for improved river forecasting. These efforts are aimed at improving the ability of the NWS to provide accurate short term river forecasts at over 4,000 points nationwide. Currently, forecasts are produced by using the Sacramento Soil Moisture Accounting model at a 6 hour time step using mean areal precipitation values derived from rain gages.

BACKGROUND AND RELATED WORK

In contrast to traditional NWS approach of using lumped rain gage derived precipitation estimates to force simulation models, the NEXRAD precipitation products provide an opportunity to perform finer scale hydrologic modeling. The pressing question facing the NWS is how to best use these data to provide improved short term forecasts at gauged locations. Research has been focused on modeling scenarios that will consistently show improvement over the current lumped approach forced by rain gage measurements of precipitation. Modeling options currently under investigation are to use the standard hydrologic model in lumped and semi-distributed modes, with recalibration of the parameters in all scenarios to match the scale of the radar-derived precipitation forcing. Upcoming investigations in HRL include the development and testing of more contemporary approaches to distributed parameter modeling.

The emergence of various weather radar platforms including the recent nationwide completion of the NEXRAD system has led to numerous research efforts into distributed parameter models and related topics (Finnerty et al., 1997, Mimikou et al, 1996, Pessoa et al., 1993, Winchell et al., 1998, Obled et al., 1994). However, few studies have provided a direct comparison between lumped and distributed models that would validate the widely adopted view that finer resolution inputs will lead to better results in simulated hydrographs at gauged basin outlets. This is a critical concern for the NWS in that before any new model is adopted, it must be one that consistently outperforms current simulation programs and is supportable, able to be parameterized and calibrated, and amenable to run-time modifications.

Thus, the aim of this research is to evaluate one simplified approach to distributed modeling for improving NWS river forecasting. This approach consists of disaggregating the parent basin into a number of constituent sub-basins. Each sub-basin has its own Sacramento model and unit hydrograph and receives precipitation in the form of an areal mean derived from the 4 km. hourly NEXRAD estimates. The Sacramento model parameters are the same in each sub-basin. Thus, the simulations described here focus on distributed inputs, not distributed hydrologic parameters

METHODOLOGY

Lumped and semi-distributed simulations were performed on 3 basins ranging in size from 307 square miles to 959 square miles as listed in Table 1. At the time of this writing, a fourth basin with a drainage area of 872 square miles is being tested. All simulations were conducted at an hourly time step and were continuous over a 3 year period. Sub-basins for the semi-distributed modeling approach were derived using terrain analysis software. Parameters for the Sacramento soil moisture accounting model were calibrated at both the lumped and semi-distributed scales. Calibration for the semi-distributed approach consisted of uniformly adjusting the parameters in all sub-basins, resulting in the same parameters in each sub-basin. Unit hydrographs for the parent basin and sub-basins were developed and used to route runoff to the parent basin outlet; no explicit channel routing was performed. Time series of mean areal precipitation values for the lumped parent basin and the sub-basins were derived using the hourly Stage III NEXRAD 4 km. precipitation estimates. Hourly streamflow data was available from the United States Geological Survey.

Table 1. Basins Used in the Simulations

USGS No.	Name	Area (sq. mi.)
07197000	Baron Fork at Eldon, OK	307
071955	Illinois R. at Watts, OK	635
07196500	Illinois R. at Talequah, OK	959

RESULTS

Modeling results showed that lumped representations of the three basins produce adequate basin outlet simulations using the NEXRAD precipitation estimates. Figures 1 and 2 present the simulation results for the Illinois River at Talequah, OK., and Watts, Ok., respectively for two rainfall events. It is surprising to note that the semi-distributed simulations were quite close to the lumped simulations even given the presence of strong precipitation gradients across the basin. Table 2 presents the RMS error statistic of the lumped and semi-distributed simulations compared to hourly streamflow discharge. and only in a few cases did the use of sub-basins to capture the spatial variability of precipitation lead to improved simulations. In those cases, however, the improvement was not significant over the lumped simulations. The simulations shown in Figures 1 and 2 are typical for the 3 basins used in this study in that often, little difference was seen between the lumped and semi-distributed simulations. Figure 3 shows that the semi-distributed representation led to slight improvement in the hydrograph peak for the event in May, 1995.

Table 2. RMS Error Statistic for Lumped and Semi-Distributed Simulations

	RMS	
	lumped	semi-distributed
Eldon	7.38	7.22
Watts	10.07	12.55
Talequah	9.22	9.55

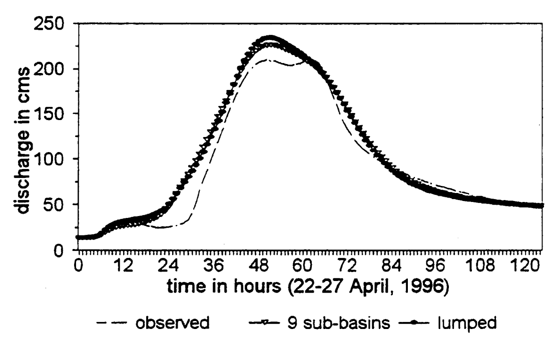

Figure 1. Hourly lumped and semi-distributed simulations for the Illinois river at Talequah, OK.

DISCUSSION

Surprisingly, the attempt to account for the spatial variability of the precipitation by using sub-basins did not lead to significant improvement over the lumped simulations for the 3 basins studied. In agreement with Obled et al., (1994) and Beven and Hornberger, (1982), the authors believe that the spatial variability of the

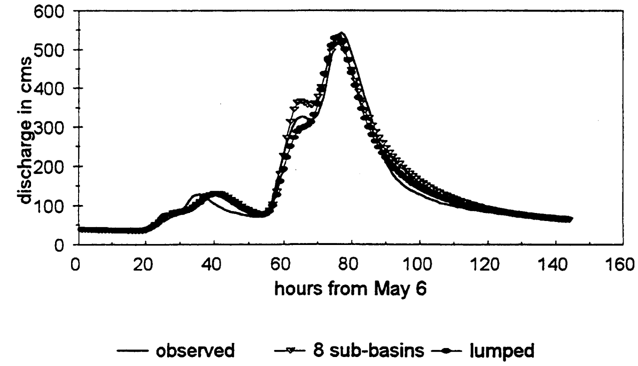

Figure 2. Hourly lumped and semi-distributed simulations for the Illinois River at Watts, OK.

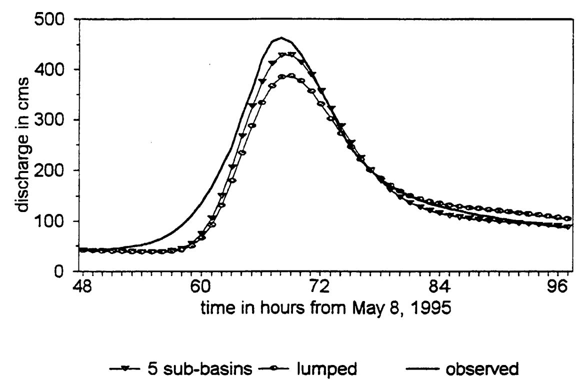

Figure 3. Hourly lumped and semi-distributed simulations for Baron Fork at Eldon, OK.

precipitation, as measured here by the sub-basin areal mean, is not sufficiently organized to overcome any dampening that occurs in these basins. In fact, the model responded to rainfall by producing simulated hydrograph peaks that were not evident in the observed data. In one case, (not shown here) precipitation predominately fell on two sub-basins near the main outlet, but no response was seen in the observed streamflow, while a comparatively large response was generated by the model. In this case, the model parameters for these sub-basins should be quite different than the parameters in the rest of the sub-basins.

It appears that lumped representations of these basins, with hydrologic model parameters recalibrated for use with the NEXRAD, would provide reasonable simulations. The slight gains realized by basin disaggregation do not warrant the required effort given the added difficulties associated with parameterizing and calibrating a semi-distributed model.

One possible explanation for our results may be taken from recent research. Obled et al(1994) and Winchel et al(1998) postulate that the spatial variability of precipitation is less important in areas dominated by saturation excess runoff generation. They propose that in such areas, the localized intensities of the precipitation are delayed and attenuated as the water moves through the soil. Where infiltration excess is a dominant process, excess rainfall enters the stream channel system quickly to produce more of an immediate response. Perhaps the basins on the current study are dominated by saturation excess flow and therefore less sensitive to the spatial variations in the precipitation.

Another possible explanation may be the limitation that the approach outlined here considers only distributed inputs, not distributed hydrologic parameters. In several cases the semi-distributed model responded to precipitation forcing to produce streamflow rises that were not seen in the observed streamflow record.

RECOMMENDATIONS

Efforts should continue to investigate modeling approaches that account for the spatial variability of precipitation as provided by NEXRAD. In addition to continued testing of the semi-distributed approach outline here, two modifications of the Sacramento model are planned for testing. Moreover, cooperative research is underway with the Massachusetts Institute of Technology to perform comparison studies between the lumped Sacramento model and a fully gridded physically based distributed parameter model. The model to be used is one that computes both saturation excess and infiltration excess runoff. Continuous simulations using hourly NEXRAD data will be generated by both models in several basins across the nation. It is anticipated that this study will help identify improvements to be gained by distributed modeling approaches. In addition, it will be interesting to note which type of runoff generation mechanism predominates in those cases where the distributed model provides better simulations compared to a lumped application of the Sacramento model.

LITERATURE CITED

Beven, K.J., and G.M. Hornerger, 1982. Assessing the effect of spatial pattern of precipitation in modeling stream flow hydrographs. *Water Resources Bulletin, 18(5):823-829.*

Finnerty, B.D., M.B. Smith, D.J. Seo, V. Koren, and G.E. Moglen, 1997. Space-time scale sensitivity of the Sacramento model to radar-gage precipitation inputs. *Journal of Hydrology, 203:21-38.*

Mimikou, M.A. and E.A. Baltas, 1996. Flood forecasting based on radar rainfall measurements. A.S.C.E. *Journal of Water Resources Planning and Management. 122(3) 151-156.*

Obled, C., J. Wendling, and K. Beven, 1994. The sensitivity of hydrological models to spatial rainfall patterns: an evaluation using observed data. *Journal of Hydrology, 159: 305-333.*

Pessoa, M.L., R.L. Bras, and E.R. Williams, 1993. Use of weather radar for flood forecasting in the sieve river basin: a sensitivity analysis. *Journal of Applied Meteorology, 32(3):*

Winchell, M. H.V. Gupta, and S. Sorooshian, 1998. On the simulation of infiltration - and saturation-excess runoff radar-based rainfall estimates: effects of algorithm uncertainty and pixel aggregation. *Water Resources Research, 34(10 2655-2670.*