AN OPERATIONAL FORECAST OFFICE PERSPECTIVE OF THE NATIONAL WEATHER SERVICE HYDROLOGIC DISTRIBUTED MODELING SYSTEM (HDMS)

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ABSTRACT

River flood flow forecasting is the primary mission of the National Weather Service River Forecast Centers. The current National Weather Service River Forecast System (NWSRFS) utilizes the conceptual Sacramento Soil Moisture Accounting Model, which was developed in the 1970s. NWSRFS is a geographically static, lumped parameter, basin-scale model that produces flow information at identified outlet points. The National Weather Service recognizes that an opportunity exists to improve their modeling system by exploiting recent technological advances, specifically the development of higher resolution datasets. This new system will advance the NWS river modeling and forecasting capability. Goals for this model include improved timing and more accurate crest forecasts at identified forecast points, flow forecasts at ungaged locations, and improvement in flash flood guidance products.

This paper highlights some of the results the Arkansas-Red Basin River Forecast Center (ABRFC) has observed with HDMS, a new modeling system. It includes the preliminary evaluation of the model's performance as well as a validation comparison to the NWSRFS model.

INTRODUCTION

The ABRFC, in collaboration with the Office of Hydrology Development - Hydrology Laboratory (OHD), is customizing and calibrating a prototype version of the NWS-Hydrologic Distributed Modeling System (HDMS), a model developed by OHD-HL (Smith *et al*, 2004). ABRFC has implemented 21 test basins. Seventeen basins are identified in the NWSRFS lumped model. Four basins are gaged, interior outlets only identified in the HDMS model. The basins range in size from 19,445 mi^2 (50,363 km^2) to 14 mi^2 (37 km^2). Figure 1 shows the location of the test basins within the ABRFC forecast area of responsibility while Appendix A lists the test basins, their corresponding NWS Handbook 5 ID, the USGS site number, their location information, and basin size.

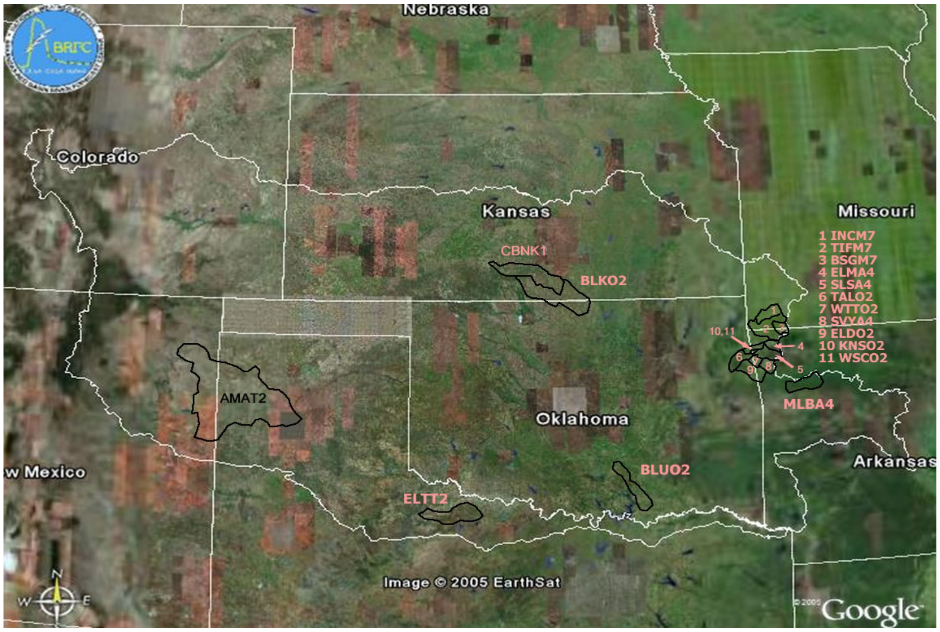

Figure 1: Geographical locations of the HDMS test basins. The Texas basins receive 18 to 25 inches of precipitation per year and river flooding is typically a result of a convective event that occurs downstream, closer to the gauge site. The BLKO2 basin, and its interior point of CBNK1, receives 25 to 30 inches per year, and the remainder of the sites receives in excess of 35 inches per year. (SCAS, 2005)

METHODS OF MODEL COMPARISON

Preliminary assessment of the HDMS simulated flow was performed on the cluster of basins in the eastern portion of the ABRFC Basin. These basins were manually calibrated to varying degrees using the ABRFC operational gridded precipitation datasets from August 1996 through March 2002. The calibration of a basin included determining basin-wide scalar values to apply to the SAC-SMA model parameter, a priori gridded data sets derived by Koren *et al* (2000). As discussed in Schmidt *et al* (2000), prior to Aug 1996, ABRFC used STAGE III to perform its mosaicing of the radar precipitation estimates and the rain gauges. This program utilized a different rain gage weighting scheme than the multi-sensored precipitation, mosaicing software, P3, currently used by ABRFC. Hence, to alleviate the introduction of a precipitation bias, the ABRFC archive prior to August 1996 was not used in the HDMS analysis. The calibration was performed mainly on the larger basins. Within most of these larger basins, or parent basins, exist smaller, interior gauged basins. These interior basins were purposely not calibrated in order to evaluate the model's skill to simulate interior, non-gauged outlet points. Thus, the interior basins were defined with the parameter scalars of the parent basins.

The StatQ statistical program (Zang, 2004) was used to perform the statistical analysis work. The hourly instantaneous observed discharge was obtained from the United States Geological Survey (USGS). This flow data is not quality controlled. So, manual inspection was performed by the NWS prior to use in this project. The flow data was converted to a six-hour time series by extracting the instantaneous synoptic hour discharge from one-hour instantaneous discharge time series. The HDMS simulations were compared to the one-hour instantaneous discharge; while the six-hour NWSRFS model simulations were compared to the six-hour instantaneous discharge time series. An additional comparison to the one-hour instantaneous discharge time series was performed on the NWSRFS simulations to provide a more realistic measure of the NWSRFS performance. This comparison is identified as the Adjusted or "Adj." results.

RESULTS

As depicted in Table 1, the analysis shows that the skill of the HDMS model varies for each test basin. In addition, when compared to the NWSRFS model simulations, the degree of improvement of the HDMS model was inconsistent. The correlation coefficient for the HDMS model varies from 0.94 for INCM7 to 0.81 for EMLA4, while the NWSRFS correlation ranges from 0.78 for ELDO2 to 0.63 for ELMA4. (Note: The simulation time series were not available at non-headwater points. In addition for two locations, the NWSRFS time series was very short.) The HDMS correlations do suggest an improvement to the NWSRFS model; however, the percent bias indicates that simulations are not accurate. WTTO2 has a large positive bias of 60.69 even though the correlation coefficient is 0.88, while ELDO2 has a small percent bias of 0.26. The mean time to peak error also indicates that for some basins, the HDMS model yields an improvement over the NWSRFS model; however, for other basins it is much worse.

Table 1 Statistical Analysis For The HDMS and NWSRFS Discharge

The table is a summary of selected statistical parameters. The Correlation Coefficient and Percent Bias were derived from the multi-year time series analysis. The HDMS simulation was compared to the one hour observed and the NWSRFS simulation was compared to the six hour observed discharge. The NWSRFS "Adj." information is a comparison of the six hour NWSRFS simulations to the one-hour instantaneous discharge time series. Note: The "†" indicates that the multi-year analysis was from March 2005 through August 2005, as these locations were added to NWSRFS in March 2005. Elsewhere, the multi-year period was from April 2002 through August 2005.

	HDMS			NWSRFS			
Basin	*Correlation Coefficient*	*Percent Bias*	*Mean Time to Peak Error(hr)*	*Correlation Coefficient*	*Percent Bias*	*Mean Time to Peak Error (hr)*	*Adj Mean Time to Peak Error (hr)*
BSGM7	0.90	29.36	2.31	0.65†	-70.42†	-6†	-5.5†
ELDO2	0.92	0.26	-1.18	0.78	-28.22	-4.36	-4.18
ELMA4	0.81	7.84	7.2	0.63	-22.43	-2.8	-2.2
INCM7	0.94	20.03	-0.69	0.70†	-68.97†	0†	1.5†
KNSO2	0.89	6.77	3	N/A	N/A	N/A	N/A
SVYA4	0.88	-0.02	6.35	0.79	0.51	2.73	3.36
TALO2	0.94	38.82	-1.95	N/A	N/A	N/A	N/A
WTTO2	0.88	60.69	9.33	N/A	N/A	N/A	N/A

DISCUSSION

Timing of the Crest

From an operational perspective, one of the key aspects to forecasting an event is accurately simulating the time of the crest. A question to consider, when using a longer analysis time period, is how much variance occurs in the simulations? For example at ELDO2, does the HDMS model typically simulate the crest one hour early, or does the dataset include many "poor" simulations which average to a mean error of -1 hour? Figures 2 and 3 are plots of the Crest Time Errors for ELDO2 and ELMA4 respectively. Figure 2, excluding two events, indicates that the HDMS model simulates the time of the crest at ELDO2 reasonably well, while both of the NWSRFS assessments show a consistent, early simulated crest. At ELMA4, which had a mean error of 7.2 hours, the HDMS model did perform slightly worse than the NWSRFS model. Also, the HDMS model consistently simulated the crests too late, while the NWSRFS model tended to be early. One note of operational interest is that for the largest event, the HDMS model performed better than the NWSRFS model.

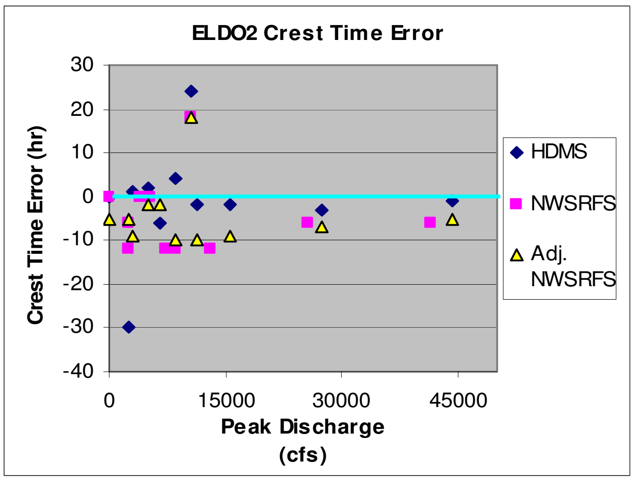

Figure 2 ELDO2 Crest Time Error

Plot of ELDO2 Crest Time Error for individual events identified between April 2002 and August 2005. The simulations that lie on the Aqua line indicated an accurate timing simulation while positive errors indicate a late simulated crest and negative errors indicate an early simulated crest. The difference in the peak discharge between NWSRFS and the Adj. NWSRFS, which is more obvious at the high flow event, is due to the respective comparison differences of the six hour and one hour instantaneous discharge times series.

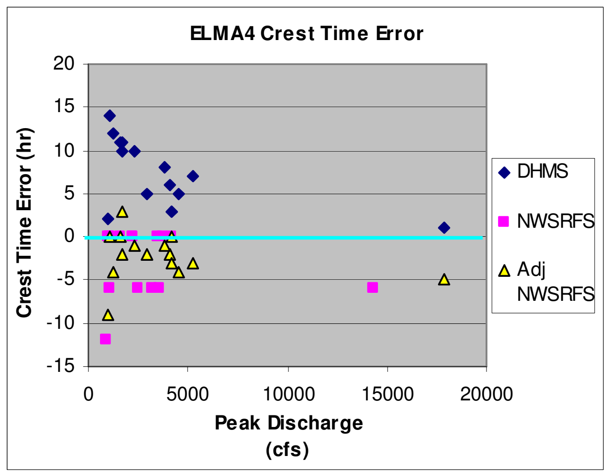

Figure 3 ELMA4 Crest Time Error

Plot of ELMA4 Crest Time Error for individual events identified between April 2002 and August 2005. The simulations that lie on the Aqua line indicated an accurate timing simulation while positive errors indicate a late simulated crest and negative errors indicate an early simulated crest. The difference in the peak discharge between NWSRFS and the Adj. NWSRFS, which is more obvious at the high flow event, is due to the respective comparison differences of the six hour and one hour instantaneous discharge times series.

Peak Discharge

In addition to the timing, the ability of the model to accurately simulate the peak discharge is extremely important. The 2-year flood frequency peak discharge estimate was used to normalize the peak discharge errors and allow for inter-basin comparison. The USGS has published Flood Frequency Estimates for basins within Oklahoma as well as a few bordering States' basins *(Tortorelli and McCabe, 2001*). However, the report does not encompass all of the HDMS test basins. To eliminate the introduction of a bias, analysis to the USGS annual peak discharges for the period of record was performed for each test basin. (For all the basins, except 3, the period of record ranged from 39 to 68 years. For SVYA4, the period of record was 12 years, for INCM7 the period was 5 years and for BSGM7 the record was only 4 years.) The return periods were derived using the following equation:

$$T_r = (n+1)/m$$

where "T_r" is the return period, "n" is the number of years of record and "m" is the rank of the event in order of magnitude equation (Lindsey *et al,* 1983). The corresponding peak discharge to the "T_r" value nearest to "2" was assigned as the 2-year flood frequency peak discharge. To affirm the validation of this calculation, a comparison was performed between the sites listed in the USGS study and the derived values. Figure 4 is the HDMS normalized peak discharge errors for all events identified in the test basins. For the lower peak discharges, the error clusters around 0.00. However, as the peak discharge increases, a low bias is evident, especially at ELMA4 and SVYA4. This is of concern since the NWS hydrological forecaster's mission is to protect lives and property by producing accurate forecasts of the time and crest of high flow events.

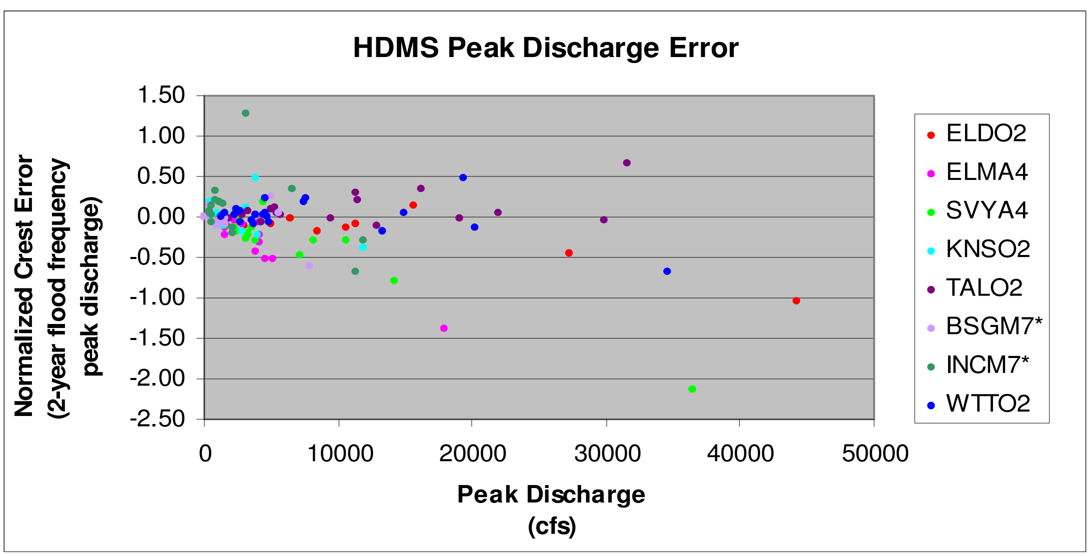

Figure 4 HDMS Peak Discharge Error

Plot of the peak discharge errors for all of the HDMS basins for identified events between April 2002 and August 2005. For the basins noted with an "*", the Annual Peak Discharge's period of record is less than 10 years. So the confidence that the normalization factor is an accurate 2-year flood frequency peak discharge is lower.

Even though the HDMS does not produce an accurate peak discharge for all events, does it yield better results than the NWSRFS model? Figures 5 and 6 show that the model differences vary for the individual event peak discharge errors at ELDO2 and ELMA4, respectively. ELDO2 displays an improvement for the HDMS over the NWSRFS. However, it still has a large error for the high flow event, a magnitude of 16800 cfs or a 62% of the event's peak discharge. Figure 6 indicates that the error is more clustered between 0.0 and -0.5 at ELMA4 for the majority of the events. Yet, the higher flow event has an error of 7600 cfs or 73% of the event's peak discharge. These errors at the high flows could be a significant liability in an operational environment.

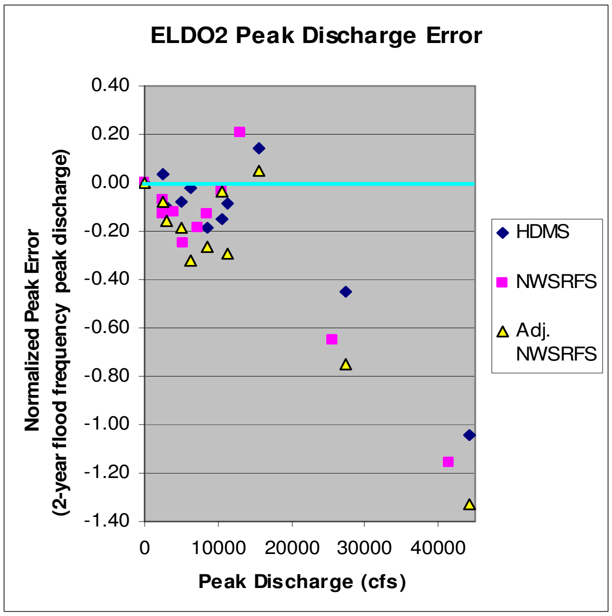

Figure 5 ELDO2 Peak Discharge Error
Plot of the peak discharge normalized to the 2-year flood frequency peak discharge (16200 cfs). For most events, both models under forecast the peak, especially at high flows. However the NWSRFS model tends to consistently yield a higher error. Also, the difference in the peak discharge between NWSRFS and the Adj. NWSRFS, which is more obvious at the high flow event, is due to the respective comparison differences of the six hour and one hour instantaneous discharge times series.

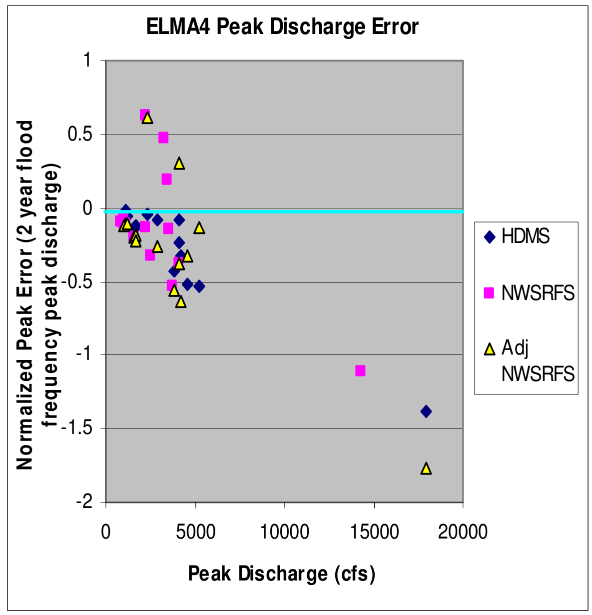

Figure 6 ELMA4 Peak Discharge Error
Plot of the peak discharge for ELMA4 normalized to the 2-year flood frequency peak discharge (5480 cfs). For most events, both models under forecast the peak. For the lower discharges, the model errors are more clustered, but at higher flows, they yield a large error. Also, the difference in the peak discharge between NWSRFS and the Adj. NWSRFS, which is more obvious at the high flow event, is due to the respective comparison differences of the six hour and one hour instantaneous discharge times series.

CONCLUSIONS

The HDMS does show promising results for improved crest timing and peak discharge simulations over the NWSRFS Model. However these improvements are not consistent from basin to basin, even for those basins of similar size, topography, and soil characteristics. Thus further analysis needs to be performed and improvements made to the HDMS before it can be considered for operational use. Other areas of future study include: Analysis to determine conditions for when the model performs well and when it performs poorly; Compare simulation results from the University of Arizona reanalysis, Gupta *et al* (2004), of the a priori gridded SAC-SMA parameter dataset to the original data set; Evaluate new mainstem channel routing techniques.

ACKNOWLEDGEMENTS

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APPENDIX A

ABRFC HDMS TEST BASINS			
NWS Handbook 5 ID	USGS Site Number	Gauge Location	Basin Size mi^2 (km^2)
CVSA4	07194880	Osage Creek at Cave Springs, AR	35 (90)
DMLA4	07196900	Barron Fork Creek at Dutch Mills, AR	40 (105)
ELMA4	07195000	Osage Creek at Elm Springs, AR	130 (337)
MLBA4	07252000	Mulberry River near Mulberry. AR	373 (966)
SLSA4	07195430	Illinois River at Siloam Springs, AR	575 (1489)
SVYA4	07914800	Illinois River at Savoy, AR	167 (433)
SPRA4	07195800	Flint Creek at Springtown, AR	14 (37)
CBNK1	07151500	Chikaskia River at Corbin, KS	794 (2056)
BSGM7	07188653	Big Sugar Creek at Pineville, MO	141 (365)
INCM7	07188885	Indian Creek at Anderson, MO	239 (619)
TIFM7	07189000	Elk River at Tiff City, MO	872 (2258)
BLKO2	07152000	Chikaskia River at Blackwell, OK	1859 (4815)
BLUO2	07332500	Blue River near Blue, OK	476 (1233)
CPCO2	07196973	Peacheater Creek at Christie, OK	25 (65)
ELDO2	07197000	Barron Fork River at Eldon, OK	307 (795)
KNSO2	07196000	Flint Creek at Kansas, OK	110 (285)
TALO2	07196500	Illinois River at Tahlequah, OK	959 (2484)
WSCO2	07195865	Sager Creek at West Siloam Springs, OK	19 (49)
WTTO2	07195500	Illinois River at Watts, OK	635 (1645)
AMAT2	07227500	Canadian River at Amarillo, TX	19445 (50363)
ELTT2	07312200	Beaver Creek near Electra, TX	10298 (26672)

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