Final Report

Project Title:

Exploring Alternative Channel Routing Options for WRF-Hydro's Runoff Maps

Principal Investigator

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Partners of Cooperative Project:
The Iowa Flood Center, University of Iowa and NWS Office of Water Prediction

NWS Researcher Preparing Report: Michael Smith

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1 Summary of Project objectives:

Our main objective in this study is to investigate the contribution of routing components to the overall magnitude of errors in stream discharge estimates of the national flood forecasting framework proposed by the National Water Center (NWC).

During the National Flood Interoperability Experiment (NFIE), the NWC introduced a flood modeling framework which consists of a rainfall runoff generation model (WRF-Hydro) driven by the Noah-MP land surface model (LSM), described in Gochis et al. 2015, and a runoff routing component (RAPID); this runoff-to-discharge combination is called NFIE-Hydro. National flood forecasting is a difficult task, and we believe that collaborative effort in the regional assessment of this model's performance would lead to an understanding of its limitations and exploring different ways to improve it.

Our research group in the Iowa Flood Center (IFC) has interest in knowing WRF-Hydro's performance in comparison to the model that IFC has developed. As a result, during the NFIE 2015 summer institute Ph.D. student Mohamed ElSaadani worked on monitoring WRF-Hydro's performance over the state of Iowa. His study concluded that the model was able to capture major events that occurred in different watersheds inside the state of Iowa, however, the accuracy of the discharge magnitudes and peak times were not accurate. It was evident that the model tends to produce very sharp peaks compared to the observed flow, and these peaks often occur prior to the actual peak time. The severity of the errors in the hydrographs strongly correlates with watershed size, with larger watersheds experiencing relatively less errors than smaller watersheds.

The outcome of the NFIE summer institute encouraged us at the IFC to try to improve the results of WRF-Hydro within the state of Iowa. Currently, the NFIE-Hydro configuration routes the runoff maps using RAPID, which is based on the simplified Muskingum method, through the National Hydrography dataset Plus NHDPlus V2 stream network. On the other hand, the IFC produced a hydrologic model that includes a non-linear routing component based on the methodology described in Mantilla 2007. We believe that the flashy behavior of NFIE-Hydro's discharges could be a result of the routing methodology. By integrating WRF-Hydro in an alternative platform that takes advantage of the nonlinear IFC model's routing component it is likely to obtain improved discharge estimates. The results of this model modification is described in the next section.

2 Project Accomplishments and Findings:

In this study we replaced the routing component of NFIE-Hydro by the IFC routing component. In order to achieve our goal we set up an automated platform that combines Geographical Information Systems (GIS), database management, and flood modeling together on our IFC servers. We used the output surface and subsurface runoff maps from Noah-MP to drive the IFC routing component. In this configuration we used the NHDPlus V2 network to aggregate the discharges. The IFC routing component requires information about the river network properties; this includes the channel connectivity information and the upstream areas from each element in the network and the area served by each element. The NHDPlus V2 dataset contains connectivity information that we transformed into relational database tables that the IFC model can utilize. A crucial step that followed obtaining the area served and the total upstream areas by each stream was to match the irregular sub-catchment geometry with the geometry of the runoff grid, which will be referred to as geogrid in this document. We intersected the geogrid which consists of 3km x 3km pixels with the sub-catchment geometries, this provided us with the correct water depth at each sub-catchment. Note, that one sub-catchment can be shared by more than one geogrid pixel; a weighted average estimate will be used in this case. A combination of PostgreSQL, PostGIS, GDAL and Python was used to perform this task. Once the model inputs were ready, we ran the IFC flood model on our University of Iowa High Performance Computing HPC system. Our study area is the Cedar River basin located in the state of Iowa and covers an area of 16,862 Km2. In this basin there is little to no effect of artificial storage (e.g. reservoirs and ponding). We evaluated the output of the hydrologic model at 11 USGS stream gauge locations. The gauge locations are shown in figure 1 and the gauges' USGS ID and total area served is shown in Table 1. The gauges cover a wide range of scales, this allows us to observe the performance of the hydrologic models across scales. For both routing components we used the same runoff input from WRF-Hydro (Noah-MP). All simulations were performed for the warm season of the year 2014 (May-September).

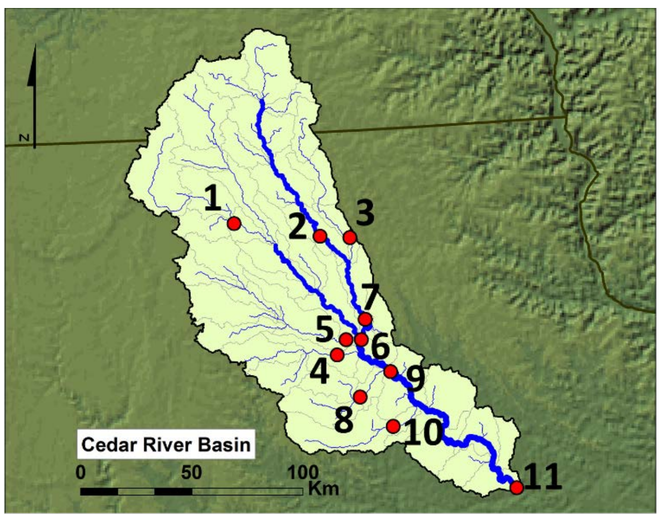

Figure 1 The Cedar River Basin with the USGS stream gauge locations (Red points). The gauge labels correspond to the ranking in Table 1.

Now we can proceed to compare the hydrographs (Figure 2) from the new configuration (red lines) and the old configuration (blue lines) to the observed USGS stream discharges (black lines). The comparison shows a significant improvement in the NFIE-Hydro framework's performance, offering smoother hydrographs with better base flows, peak discharge timing and magnitudes, and recession curves, especially at smaller scales. We calculated three skill scores for both configurations, the normalized root mean squared error RMSE, the correlation coefficient, and the Nash Sutcliffe Efficiency (NSE) at all stream gauge locations. The new configuration's average RMSE values improved by about 30% (Table 2) and the correlation coefficient and NSE values are considerably higher than those of the old configuration, as shown in Figure 3 and Table 2. An interesting observation in Table 2 is that the new configuration has high skill score standard deviation in comparison to those of the IFC model and the NFIE-Hydro framework. This can be observed in Figure 3 as relatively less improvements in the skill score performances at some stations, e.g. 1, 4, 5, and 8 located in the west side of the basin. These weak improvements are caused by over-estimation in the discharges during the June-July period at these locations, as illustrated in Figure 3, in addition to the over-estimation in September discharges, which affected all stations.

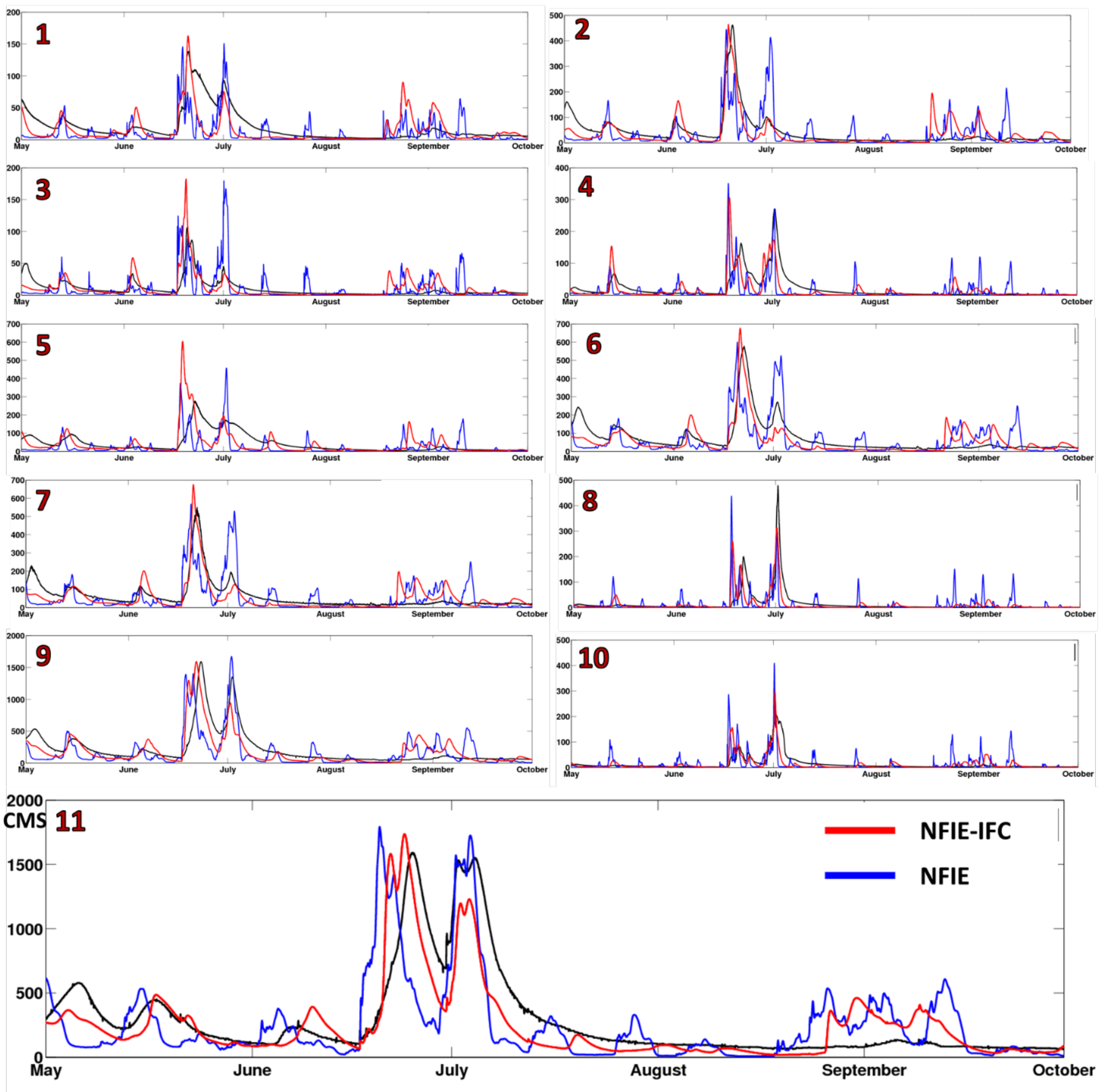

Figure 2 Hydrographs at the USGS station locations, red line represents the NFIE-IFC model, blue line represents NFIE-Hydro, and black lines are the observations. The labels correspond to the ranking in Table one.

Rank	USGS ID	Area (km^2)
1	05459500	1,342
2	05457700	2,792
3	05458000	766
4	05463000	911
5	05458900	2,213
6	05458500	4,338
7	05458300	4,044
8	05463500	780
9	05464000	13,333
10	05464220	773
11	05464500	16,862

Table 1 USGS ID and area served by each stream gauge

Skill Score	RAPID	NFIE-IFC
%RMSE		
Max	22.94	24.00
Mean	16.29	12.09
Min	9.44	6.39
SD	3.32	4.57
NSE		
Max	0.24	0.70
Mean	-0.22	0.32
Min	-1.20	-0.63
SD	0.36	0.39
Corr.		
Max	0.61	0.85
Mean	0.47	0.73
Min	0.33	0.46
SD	0.08	0.11

Table 2 Statistics of the skill scores of all stream stations. The skill scores are the normalized Root Mean Squared Error (%RMSE), Nash Sutcliffe Efficiency (NSE) and Correlation Coefficient. For each skill score we show Max, Min and Mean values and the standard deviation SD.

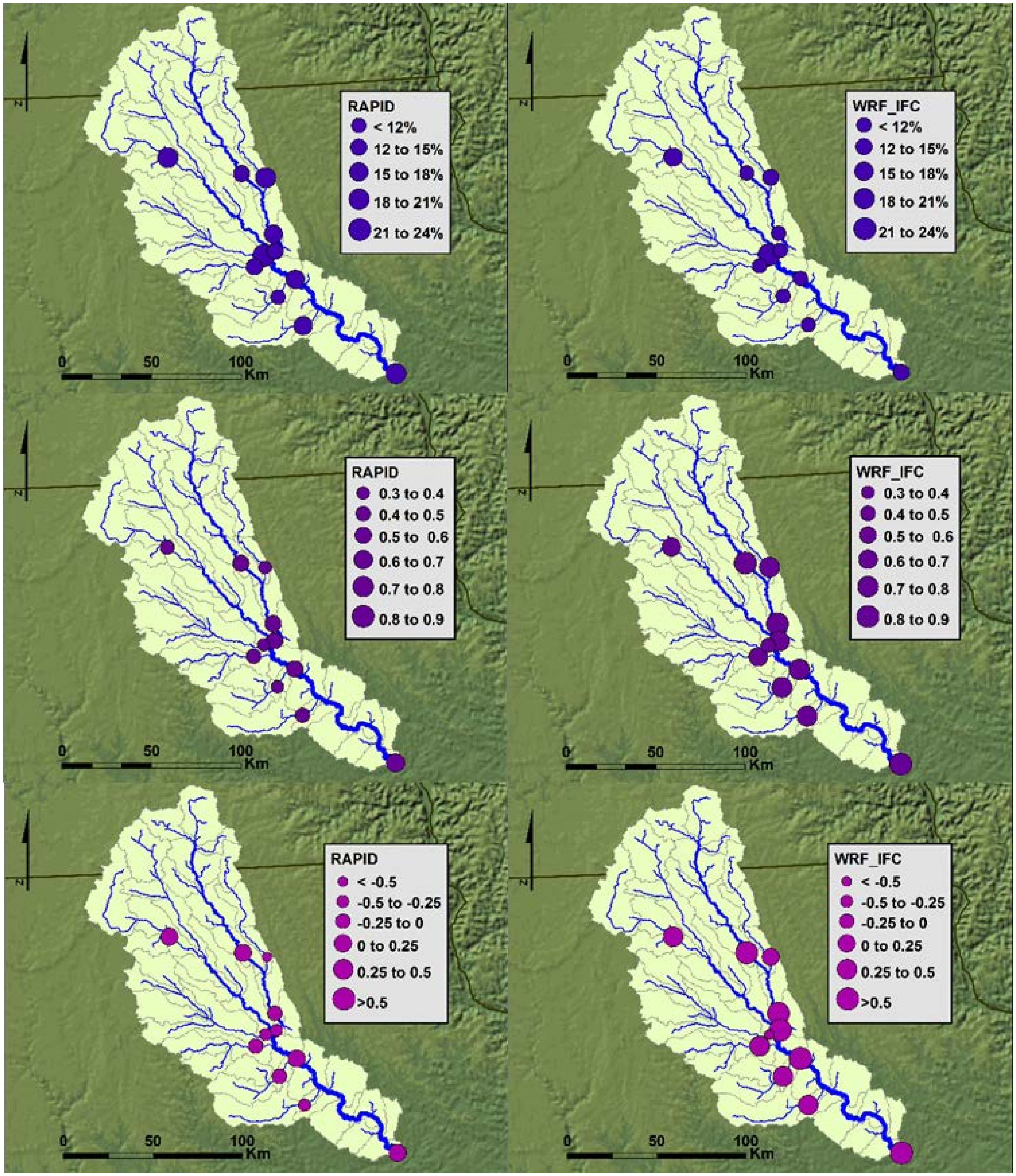

Figure 3 comparison of the statistical skill scores, % RMSE top row, Correlation middle row, and NSE bottom row, with RAPID on left column and NFIE-IFC on the right column.

The comparison between the old and new configurations shows that new configuration outperformed the old configuration. Our major finding for this project is that we were able to significantly improve the performance of WRF-Hydro by choosing an alternative routing component.

We hope that that the results and modifications to WRF-Hydro in this work will help the users and producers of WRF-Hydro understand some of the sources leading to its performance deficiencies.

References

David, C. H., D. R. Maidment, G. -Y. Niu, Z.- L. Yang, F. Habets, and V. Eijkhout, 2011. River network routing on the NHDPlus Dataset. *Journal of Hydrometeorology*, 12, 913-934, DOI: 10.1175/2011JHM1345.1

Gupta, V. K., E.C. Waymire, 1998. Spatial variability and scale invariance in hydrologic regionalization. In: Scale dependence and scale invariance in hydrology, Sposito, G. (Editor), *Cambridge University Press, Cambridge*, U.K., pp. 88-135.

Mantilla, R., 2007. Physical Basis of Statistical Scaling in Peak Flows and Stream Flow Hydrographs for Topologic and Spatially Embedded Random Self-similar Channel Networks, *Thesis, University of Colorado.*

3 Benefits and Lessons Learned: Operational Partner Perspective

The work documented a shortcoming in the national hydrologic modeling system used in the NOAA/NWS- and CUASHI- sponsored 2015 Summer Institute at the National Water Center.

The investigators conducted a diagnostic analysis of the channel routing component of the hydrologic modeling system, confirming that improvements can be made in the channel routing process in Iowa. The project also demonstrates that outputs from the current NWS National Water Model can be effectively integrated into other frameworks for analysis. Along the way, the U. of Iowa collaborators identified and corrected many problems in underlying NWC data sets, such as the NHD-Plus Version 2 connectivity. These issues will be forwarded to the NWC.

The project serves as an example of the type of analyses to be considered for the NWC Water Resources Evaluation Service currently under development. Lastly, the project exemplifies the type of collaborations that are needed to improve the NWS's national water modeling capability.

4 Benefits and Lessons Learned: University Partner Perspective

1- The resources provided by the project paid for IFC team personnel (graduate student ElSaadani) go through the steps of the model implementation.
2- The project enabled the student to interact with Dr. Smith from the NWS and receive valuable comments from him about how to overcome some of the obstacles and how to interpret the results.
3- The project provided a valuable learning experience to graduate student ElSaadani. He conducted a comparison between RAPID and the IFC routing components, by going through the project steps and observing the results he gained an understanding of how the routing component can have a significant effect on the resulting discharge magnitudes.
4- The results showed significant improvement in the model performance when using the alternative (IFC) routing component.

5- Mr. ElSaadani is submitting a technical note of the project results to the Journal of the American Water Resources Association (JAWRA)

No Major problems were encountered.

5 Presentations and publications

ElSaadani, M. 2016: The contribution of the routing component to total errors in discharge estimates: Case study, NFIE-Hydro. IIHR—Hydroscience & Engineering Student Seminar, September 2016.

ElSaadani, M., W.F. Krajewski, R. Goska, and M. Smith, 2016: Understanding the Sources of Error in NFIE-Hydro Framework's Stream Discharge Estimates; How Much Does the Routing Component Contribute to the Overall Error? Technical Note to be submitted to *Journal of the American Water Resources Association,* September 2016.

6 Summary of University/Operational Partner Interactions and Roles

Dr. Witold F. Krajewski, PI, University of Iowa, held weekly meetings with graduate student ElSaadani to discuss the progress of the project and make suggestion about the direction of the analysis.

Graduate student Mr. Mohamed ElSaadani, constructed the new configuration, conducted the model runs, and organized the comparison between the two configurations.

IIHR research engineer Mr. Radoslaw Goska helped Mr. ElSaadani by constructing the Postgres relational data bases for network geometries and stored the data in Postgres tables.

Dr. Michael Smith, PI, NWS, held bi-weekly meetings with both Dr. Krajewski and Mr. ElSaadani to discuss the project progress and help in result interpretation, he is also a co-author of the technical note.