FINAL REPORT

UCAR Award Number: UCSM0004

Project Title: Development and Assessment of Urban Parameterizations in the WRF-Hydro Framework

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NWS Office: National Water Center

Name of NWS Researcher Preparing Report: Fernando Salas, National Water Center

Type of Project (Partners or Cooperative): Cooperative

Section 1: Summary of Project Objectives

The objectives of this project are to: (1) demonstrate the capability to conduct experiments running hyper-resolution WRF-Hydro simulations in urban domains; (2) determine the value added from the simulations; (3) identify opportunities in the model code to improve urban representation; (4) document the computational requirements of hyper-resolution domains; and (5) test the sensitivity of the model to and calibrate for urban parameters.

Section 2: Project Accomplishment and Findings

The main simulation results for this project are from two urban domains in and near Denver, CO: Harvard Gulch and Sand Creek. See Figures 2.1 and 2.2 for location maps. Each domain was set up on 30m x 30m and 10m x 10m grids. The following methodology was used to set up the hyper-resolution domains:

- Ran the WRF pre-processor to create the domains over the specified regions;
- Processed geogrid files for each domain for each resolution with ArcGIS pre-processing tools (created by Kevin Sampson of NCAR);
- Utilized a new high-resolution 2D soils database for the land surface model, NoahMP;
- Forced the model with NLDAS atmospheric forcing and StageIV radar for precipitation forcing for time period of interest;
- Substituted in higher resolution landcover from the 30m NLCD database

After setting up both domains we spun up the model for at least 12 months prior to the events of interest. Harvard Gulch was spun-up from 01/01/2015 – 04/25/2016 and Sand Creek was spun-up from 01/01/2015 – 04/25/2015. Once spin-up was complete we ran the model from 04/25 - 08/31 (2016 for Harvard Gulch and 2015 for Sand Creek, both years were chosen for recorded flood events in/near those domains). The summer runs were completed using hourly NLDAS atmospheric forcing with StageIV precipitation. We ran several configurations, and settled on LSM and routing timesteps of six seconds, with subsurface routing (exponential method) and surface overland flow routing using the steepest descent (D8) method, and gridded channel routing using the diffusive-wave scheme.

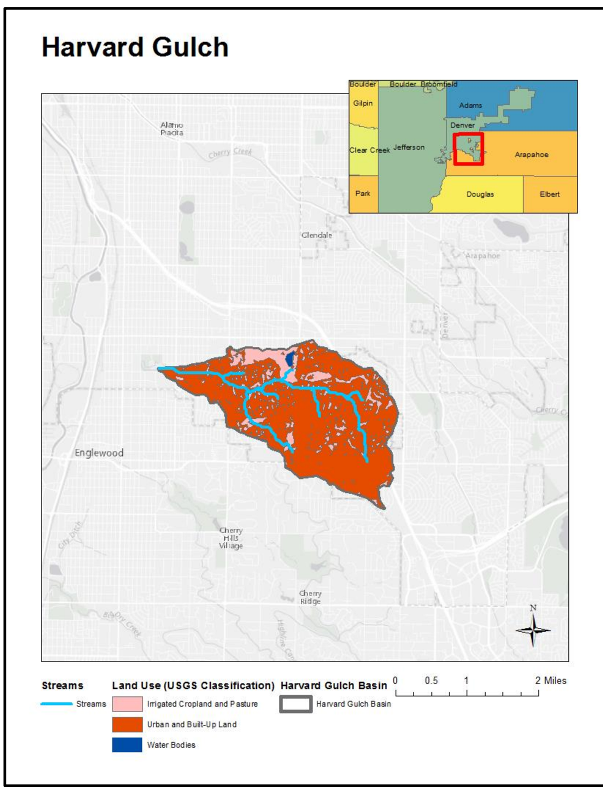

Figure 2.1: Harvard Gulch domain.

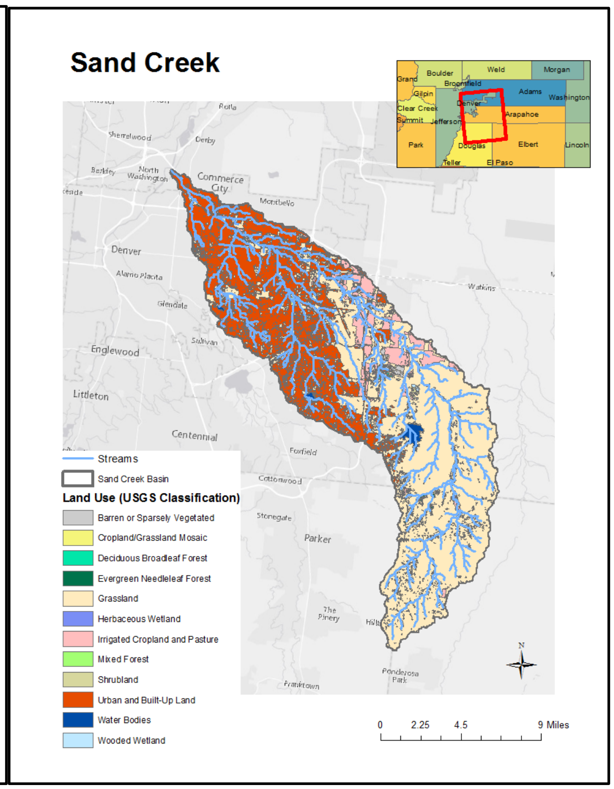

Figure 2.2: Sand Creek domain.

Atmospheric forcing:

In order to further assess the performance of the model we compared the modeled precipitation with observed precipitation at the Harvard Gulch rain gauge (USGS gauge 06711575) over the summer period. This gauge is located at the outlet of the Harvard Gulch watershed, at a longitude of 39.67º and a longitude of -104.9 (NAD83). We compared both the NLDAS and StageIV precipitation values to the observed measurements. We assumed that the precipitation was relatively uniform throughout the domain because of its small area, so in order to make the comparisons we used both the mean and max modeled values over the whole domain.

As is seen in Figures 2.3 and 2.4 the modeled precipitation universally underestimated the true precipitation. This muted the modeled stream flow and other outputs, which is seen in Figure 2.5 as the observed peaks are never met. Furthermore, as seen in Figure 2.3 and 2.4, there are many false precipitation instances, which likely contributed to the false peaks seen in Figure 2.5.

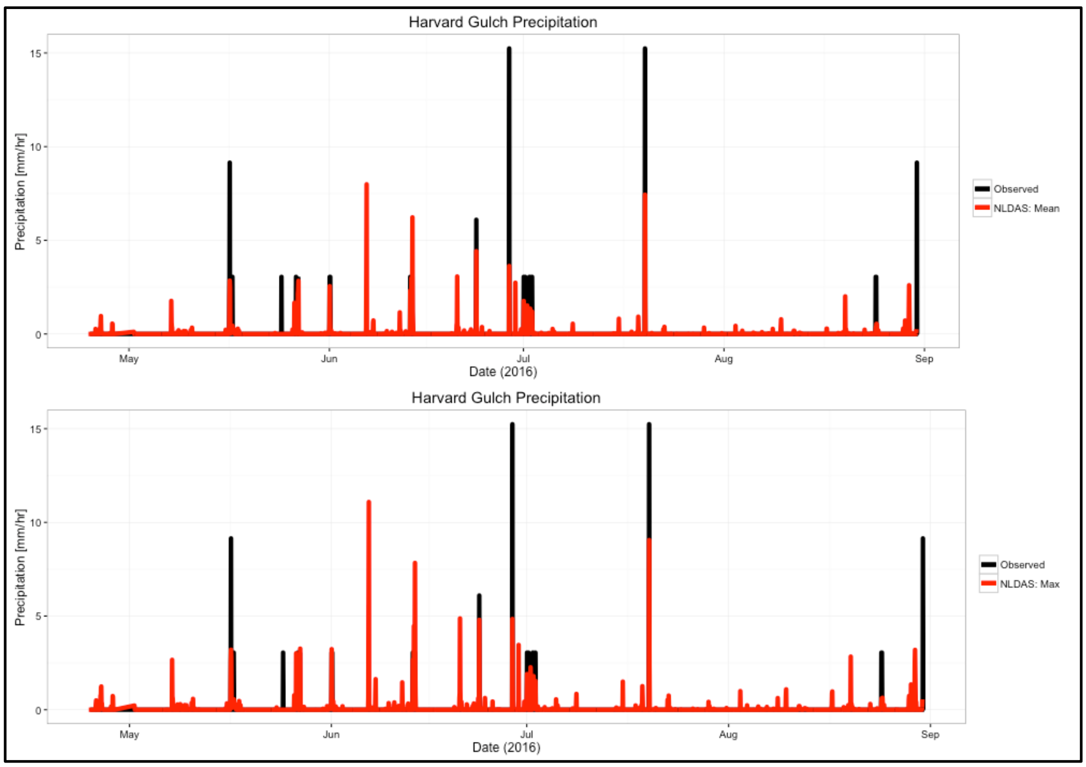

Figure 2.4: Observed and modeled (NLDAS) precipitation.

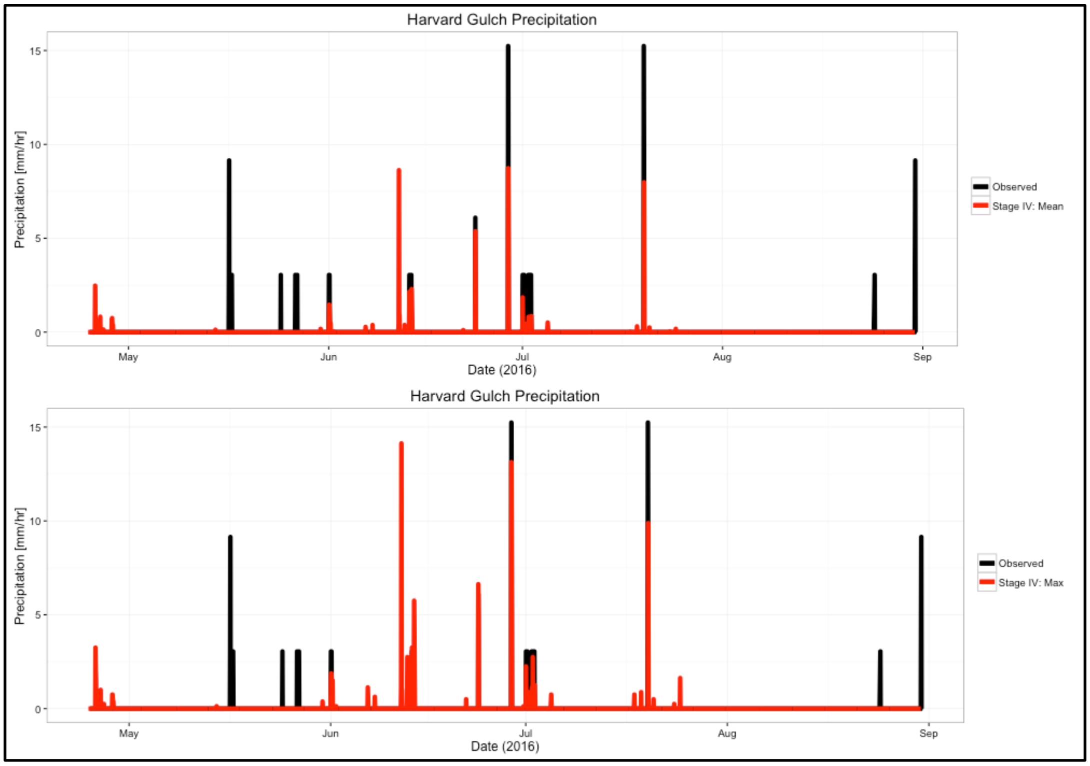

Figure 2.5: Observed and modeled (StageIV) precipitation.

<u>Urban parameterization:</u>

To test the sensitivity to the parameter controlling maximum infiltration (INFMAX) over urban land grid cells, we used Harvard Gulch and varied the INFMAX from 20% to 100% in increments: default (near 100%), 80%, 60%, and 20%. For clarity, if INFMAX = 20% then only 20% of the flow is available to infiltrate, versus 100% if INFMAX = 1. We then compared the streamflow output from the model to the USGS gage at Harvard Gulch for a four month period and computed statistics to assess the impact of changing INFMAX (Table 2.1). As is seen in Figure 2.5, 60% better captured the peak events than the default value, but did a poorer job at capturing the baseflow. Since the goal of this project is to model flood events, which occur during peak flows, INFMAX was set to allow for 60% maximum infiltration over urban surfaces.

Table 2.1: Statistics of model runs with different INFMAX values over the Harvard Gulch domain (4/25/2016 – 08/31/2016) using USGS observations at station 06711575

INFMAX	**RMSE**	**NSE**	**% Bias**
Default (100%)	0.34	-0.18	13
80%	0.35	-0.25	13
60%	0.36	-0.35	14
20%	0.42	-0.82	18

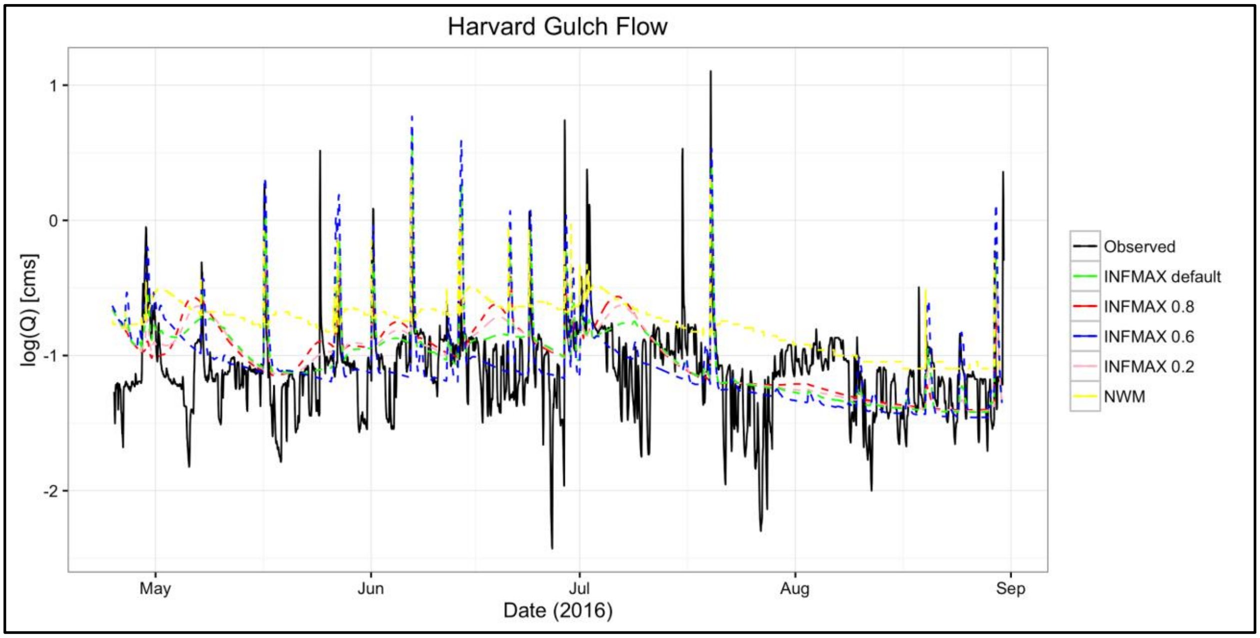

Figure 2.5: Observed and modeled streamflow values.

<u>Computational requirements:</u>
Table 2.2 shows the computation requirements for running 10m and 30m hyper-resolution instances of WRF-Hydro over the specified domains.

Table 2.2: Computational requirements for the model simulations in the urban basins tested. All runs had the gridded channel routing turned 'on' and used 128 nodes on Yellowstone.
* indicates streamflow output files were written
^ indicates inundation output files were written

Domain	**Number of Grid Cells**	**Resolution**	**Output Timestep**	**Model Run Length**	**Wall Clock**	**Run Time for 1 Day of Output**	**Core Hours**
Harvard Gulch*	47,712	30m	30 days	480 days	2700 seconds	21 seconds	99.5
Harvard Gulch*	47,712	30m	hourly	128 days	1440 seconds	11 seconds	49.2
Harvard Gulch*	425,000	10m	hourly	1 day	41 seconds	41 seconds	1.4
Harvard Gulch^	47,712	30m	hourly	128 days	1080 secods	8 secods	34.2

Sand Creek*	1,548,467	30m	30 days	120 days	3528 seconds	28 seconds	123
Sand Creek*	1,548,467	30m	hourly	122 days	3960 seconds	31 seconds	142
Sand Creek^	1,548,467	30m	hourly	7 days	322 seconds	46 seconds	11

Future Evaluation:
In addition to comparing modeled streamflow at gage locations with observations, we have also processed MODIS NDWI products from Google Earth Engine to compare surface inundation. We are still in the process of processing these images for validation of the ponded water depth on the surface produced by the model.

Section 3: Benefits and Lessons Learned: Operational Partner Perspectives

The body of work presented in this report has been beneficial to both the NOAA/NWS Office of Water Prediction (OWP) and National Water Center (NWC) as it aligns well with the hyper-resolution hydrologic modeling and forecasting goals of the organization over the next few years (i.e. demonstrating a nested modeling capability at the scale of 10-30 meters at the onset of a flood event to provide "street" level flood guidance). OWP is currently in the process of developing a white paper providing a strategic path forward for its hyper-resolution modeling efforts. The outcomes presented in this report will help inform the white paper by summarizing the results of several experiments using the WRF-Hydro modeling framework. As WRF-Hydro is the modeling framework used for the National Water Model (NWM), at the scale of 250 meters, these experiments provide evidence of model capability at the hyper-resolution scale. Due to operational requirements, it was important in this report to not only assess model skill as it relates to formulation of model components and parameters (at multiple scales) but also inform on computational needs. To this end, this COMET grant has provided preliminary insights to inform future development. Developing a hyper-resolution strategy is an organizational priority moving forward as the implementation of such a capability will provide NWS field offices and centers guidance on impending flood impacts and facilitate Impact-Based Decision Support Services (IDSS) with stakeholders.

Section 4: Benefits and Lessons Learned: University Partner Perspectives

This project has afforded both technical and educational opportunities to engage the National Water Model with students and the academic community at the Colorado School of Mines. The overall technical achievement from this project is the advancement in simulating hyper-resolution nests of WRF-Hydro in urban basins, including the benchmarking of computational resources and file size requirements. Since the inception of this project, others have become interested in running hyper-resolution cases, and the outcome of this project has substantially facilitated others in academia who are engaging with the model in this way.

One lesson learned by the the University perspective has been the challenge of engaging a single student for this project given the funding level, which is not enough to pay for a graduate research assistant. Several students were engaged throughout this project, which is a positive outcome, however, due to the higher startup cost of becoming familiar with and running WRF-Hydro, it is important to have consistency throughout the length of the project.

Section 5: Publications and Presentations

American Geophysical Union, 2015, Read, L.K., Salas, F.R., Hogue, T.S., Gochis, D.G., "Street Level Hydrology: An urban application of the WRF-Hydro Framework in Denver, Colorado", poster presentation.

American Meteorological Society, 2017, Read, L.K., Salas, F.R., Hogue, T.S., Gochis, D.G., "Identifying Priorities in the WRF-Hydro Framework for Urban Parameterizations using Hyper-Resolution Simulations", poster presentation.

CUAHSI Hydroinformatics, 2017, Read, L.K., Brown, J., Salas, F.R., Hogue, T.S., Gochis, D.G., "WRF-Hydro Hyper Resolution Development", oral presentation.

Pending paper: "Development of hyper-resolution nest capability for WRF-Hydro"; Read, L.K., Gcohis, D.G., Brown, J., Hogue, T.S.
Pending paper: "Validation of hyper-resolution inundation modeling using WRF-Hydro", Sava, E., Read, L.K., Brown, J.

Section 6: Summary of University/Operational Partner Interactions and Roles

The interaction between the university and operational partners was on-going throughout the duration of the project, with the results being of interest to others at the National Water Center and to other academics seeking to conduct hyper-resolution studies. The final results of this work have contributed to a white paper on hyper-resolution feasibility of WRF-Hydro for scaling out, and were presented at the CUAHSI Hydroinformatics conference held at NWC.