Understanding WRF-Hydro within the NFIE-Hydro Framework

Matt Hiatt

CE397 Project Report

May 8, 2015

Introduction

The National Flood Interoperability Experiment (NFIE) utilizes the Weather Research and Forecast Model for hydrology (WRF-Hydro), developed at the National Center for Atmospheric Research (NCAR), for the NFIE-Hydro. The NFIE-Hydro is concerned with the high-resolution estimation of streamflow at the continental scale. WRF-Hydro is a model architecture designed to couple the WRF model comprising atmospheric inputs and outputs with terrestrial land surface models (LSM) and their hydrology options [*Gochis et al.*, 2013]. WRF-Hydro provides a platform for the NFIE-Hydro to generate surface and subsurface runoff to input into a flow routing software to estimate streamflow across the country. In order to effectively generate streamflow information, NFIE-Hydro researchers will need to effectively inform and operate the WRF-Hydro system, which requires a thorough understanding of model inputs, parameterization, outputs, and post-processing, as well as a basic knowledge of high-performance computing environments.

This report summarizes the procedure required to generate overland flow and channel flow routing outputs using WRF-HYDRO in a multi-processor environment. Specifically, this work focuses on the generation of inputs and parameter files to operate the WRF-Hydro model and highlights information that would be important to a user within the NFIE. Additionally, results from a test model run in Travis County, TX are presented as an example of the WRF-Hydro outputs. The NFIE-Hydro utilizes the NFIE-Geo, the geospatial elements describing the topography and hydrology for a region of interest, as the basis for characterizing the important hydrologic features for the study region (Figure 1).

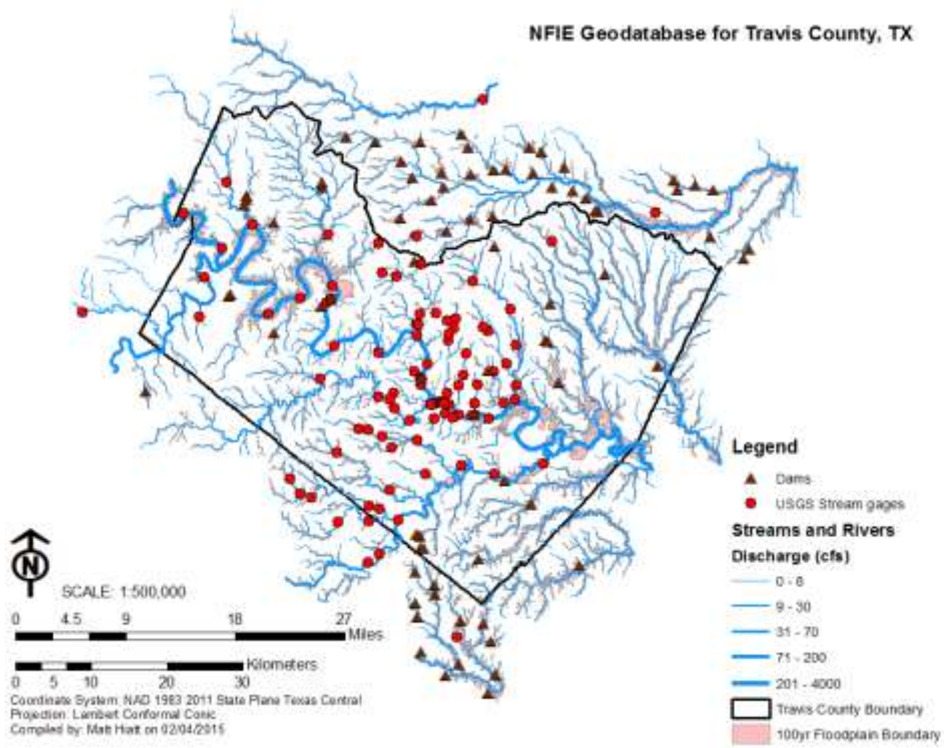

Figure 1: NFIE-Geo for Travis County

Pre-processing for WRF-Hydro

Note: The tools described in this document are available on the WRF-Hydro website (http://www.ral.ucar.edu/projects/wrf_hydro/). However, these tools are consistently updated and change with each version of the WRF-Hydro model. This report utilized the version 2.0 tools. As of May 1, 2015, however, WRF-Hydro has been updated to version 3.0 and the tools are likely to slightly change.

WRF-Hydro requires two types of input data: a "geogrid" and atmospheric forcing files. The geogrid is a netcdf file that spatially covers the area of interest. The geogrid file is relatively course resolution (e.g., three kilometer grid spacing). Comprising the geogrid are many variables but the required inputs to WRF-Hydro are topography, green faction, latitude, longitude, land use, albedo, and top layer soil information. It is created using the WRF-Preprocessing System (WPS). The geogrid netcdf file can also be custom created by the user using ArcGIS or another analysis software like Matlab. The specifications of the geogrid file required for input into WRF-Hydro are described extensively in *Gochis et al.* [2013]. An example of the topography portion of the geogrid file for Travis County, Texas is presented in Figure 2.

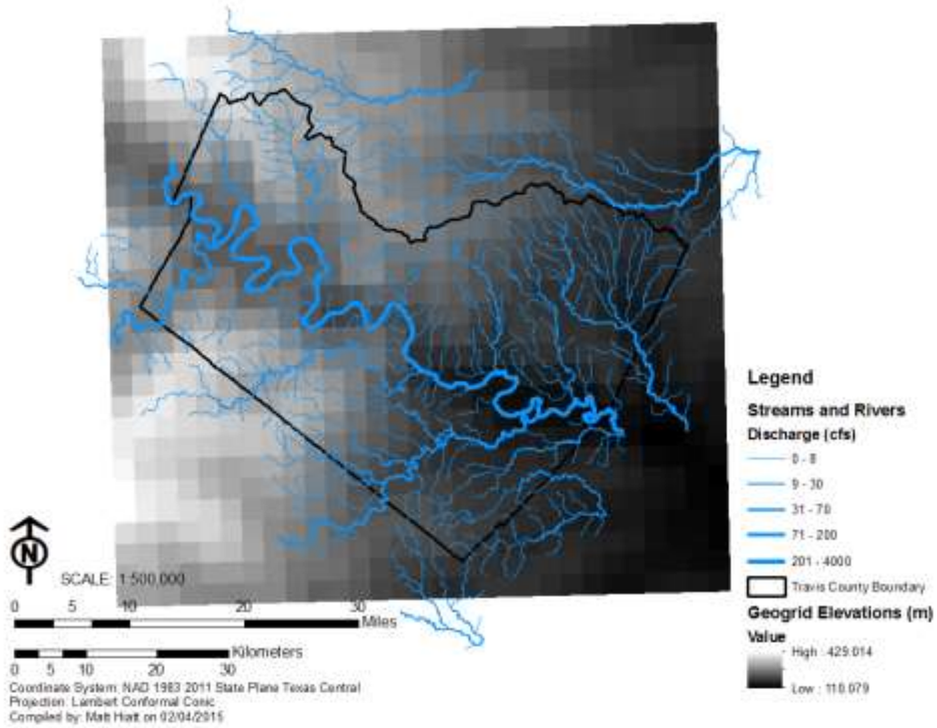

Figure 2: A 3-km scale geogrid featuring elevation for Travis County

The second required input file type for WRF-Hydro is atmospheric forcing. For this project, the Noah Multi-physics (Noah MP) LSM was utilized within the WRF-Hydro uncoupled framework. When running WRF-Hydro in the uncoupled mode (i.e., not integrated directly with a atmospheric model) the atmospheric forcing must be specified. The High Resolution Rapid Refresh (HRRR) model is currently ingested into WRF-Hydro as the atmospheric forcing within the NFIE-Hydro framework. The structure of the atmospheric forcing is described in *Gochis et al.* [2013].

For the case study in this project, forecast data from the HRRR model was downloaded for various rain events during April 2015. The input data contain hourly forecasts for shortwave radiation, longwave radiation, u and v wind velocity components, specific humidity, surface pressure, and surface temperature and fifteen minute forecasts of precipitation rate. However, the idealized precipitation case was used in the development and testing of the WRF-Hydro model used in this project. Time constraints limited the runs to testing only the idealized base case, but the archived HRRR model forecasts are available from the author to test the channel routing results against gaged measurements.

The idealized atmospheric forcing is hardwired into the WRF-Hydro model for testing purposes. This option was selected to determine whether the overland flow routing output is consistent with a specified, easy-to-follow precipitation model. The precipitation rate was set at 25.4 mm/hr (1 inch/hr) for the duration of 1 hour at the start of the model run and was uniformly distributed across the domain. The rainfall was turned off after the first hour to allow for runoff to be routed without additional input. The remaining atmospheric inputs were set to either constant values or diurnal cycles as in the case of temperature.

The above inputs are required to run the LSM model portion of the WRF-Hydro system. However, for the purposes of flood forecasting, runoff must be routed across the landscape and through stream channels to give predictions of streamflow. Within WRF-Hydro, overland and channel routing options are available. The routing options require the generation of additional input files.

The routing options within WRF-Hydro require the generation of “terrain” files. Terrain files are netcdf format grids that delineate the flow directions and stream flowlines. The terrain files for flow routing are higher resolution than the geogrid input files. The geogrid file resolution must be an integer multiple of the high-resolution terrain grid scale and have the same spatial extent. The file preparation is streamlined through the use of a shell script available through the WRF-Hydro website. The script creates a combined netcdf of the required gridded datasets for input into WRF-Hydro. Input into the script is composed of individual netcdf files congaing topography, a binary channel grid detailing the location of stream channels, a Strahler stream order grid, a lake location grid (optional), groundwater basin grid (optional), monitoring points (optional), and latitude and longitude grid (optional but required for georeferencing). The generation of these files using ArcGIS is described in *Gochis et al.* [2013] and an example of the flow direction output is displayed in Figure 3. However, the concatenated terrain files developed in the project found issue with the inclusion of the latitude and longitude grids, which were generated with a larger spatial extent than the other files by the WRF-Hydro pre-processing tools in ArcGIS, which is an issue for the concatenation process. Users will need to manually edit their latitude and longitude grid files to match the terrain file’s spatial extent.

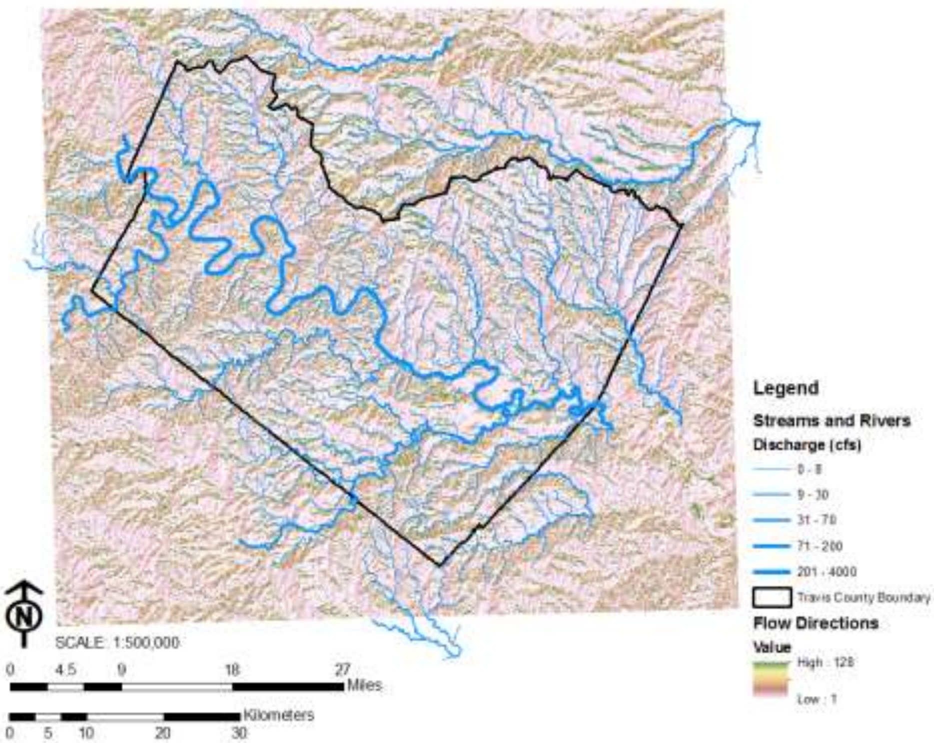

Figure 3: Flow direction grid generated in ArcGIS by the pre-processing tools for the WRF-Hydro terrain files

Designating the WRF-Hydro Model Options

Two parameterization and model option files are required to operate WRF-Hydro: the hydro.namelist file and the namelist.hrldas. These files allow the user to specify what components of the WRF-Hydro to utilize in a model run and the input and output file directory locations. A summary of the options necessary to perform flow routing are described in this document and templates for the namelist files are provided in the appendix of *Gochis et al.* [2013]. The two namelist files must be saved in the same directory as the model executable file in order to run WRF-Hydro.

The namelist.hrldas file allows the user to specify information regarding the model time stamp, model options for various components of the hydrological cycle, the forcing type, and the location of the runoff grid. The option 'MMF_RUNOFF_FILE' should be populated with the full file path location of the concatenated high-resolution terrain file. Subsequently the user should specify the initial time step for the model and the length of the run in hours, denoted by the variable 'KHOUR.' The user also must specify the model timestep and the frequency of the output. The 'FORCING_TIMESTEP' variable is in units of seconds and must match the timestep of the input forcing files. The user can then specify in seconds the timestep for the LSM with 'NOAH_TIMESTEP.' The 'OUTPUT_TIMESTEP' is also specified similarly. Finally, another important parameter is the 'FORC_TYP' option, which allows the user to specify what type of atmospheric forcing data will be input into the WRF-Hydro model. There are six options for this section. Users within the NFIE will likely use either option 1, the High Resolution Land Data Assimilation System (HRLDAS) hour format for atmospheric data, or 6, which is the same as option 1 but requires a separate precipitation file that allows the user to input precipitation data at a finer resolution than the hour time step from option 1. However, for model testing purposes, users may wish to specify the idealized precipitation case, which was utilized in this project. This allows for testing of the model components by using a simple forcing system so that the user can more easily verify the LSM and routing results related to the hydrology.

The hydro.namelist requires the user to specify the file paths for the geogrid ('GEO_STATIC_FLNM') and the terrain files for routing ('GEO_FINEGRID_FLNM'). The user must also specify what type of WRF-Hydro model is to be run, whether than be uncoupled or otherwise. This is done through the 'sys_cpl' variable. NFIE users will select option 1 to specify the uncoupled offline version running the NoahMP LSM using HRLDAS format data. The restart file parameters are also defined in this file, but restart files were not used in this project and are not described in this report. There are various physics options that users looking to parameterize components of the LSM may wish to edit. The hydro.namelist file also contains the options for surface and subsurface routing. By default these options are turned off and the user must specify the desired routing options. The routing model timestep in seconds is also specified under variable 'DTRT.' Variables 'OVRTSWCRT' and 'CHANRTSWCRT' must be set to 1 to activate the overland flow and channel routing, respectively. Groundwater routing option can also be specified but were not used in this project.

Case study for Travis County

A case study was performed using the WRF-Hydro model with idealized forcing and routing options on for the Travis County area in Texas. The pre-processing described in the previous sections was performed for the area of interest. The WRF-Hydro model was compiled and run on a multi-processor supercomputing platform at the Texas Advanced Computing Center (TACC). The Lonestar Linux Cluster at TACC was utilized for the running of the model. Information about the Lonestar system and the user requires are available at the TACC Lonestar webpage (https://portal.tacc.utexas.edu/user-guides/lonestar). TACC requires that users submit job files to run batch jobs on the Lonestar platform. An example of the batch job file for running WRF-Hydro is displayed in Figure 4.

```

#!/bin/bash
#$ -V
#$ -cwd
#$ -N WRF_Run1
#$ -j y
#$ -o $WRF_Run_2015_04_28outi
#$ -pe 12way 12
#$ -q normal
#$ -l h_rt=00:20:00
#$ -M mhiatt@utexas.edu
#$ -m be
#$ -A NFIE
set -x
ibrun /work/03491/mhiatt/hydro/Run/wrf_hydro.exe

```

Figure 4: Batch job file example for the TACC Lonestar system

The user must specify the full file path name to the executable file of interest for Lonestar to find and run the program. The other options are explained on the Lonestar webpage. It is important that users specify a unique output file (option #$ -o $Filename) for evaluation of each model run. This command will produce a log file that is useful for diagnosing errors within the model run.

For the production of the high-resolution terrain grids for the routing options, the 3 km geogrid was supported by the 30 m National Elevation Dataset within the NHDPlus. The high-resolution stream channel terrain grid was generated to match as closely as possible the streams delineated in the NHDPlus. An upstream accumulation area of 2000 30m pixels was used to delineate the streams using the WRF-Hydro preprocessor tools. Figure 5 shows an example of the match between the WRF-Hydro channel system and the NHDPlus flowlines. There is reasonable agreement between the two datasets, but there are some clear discrepancies in small channels. This was done to provide an opportunity to compare the WRF-Hydro routing output with the RAPID flow routing done within the NFIE framework.

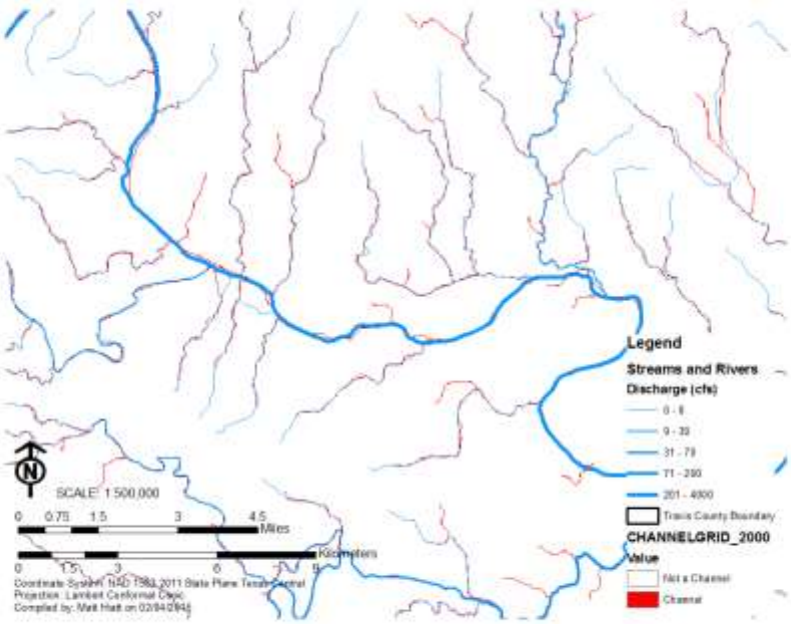

Figure 5: Comparison of WRF-Hydro flowlines with the NHDPlus dataset

The WRF-Hydro model was run with 25.4 mm/hr rainfall for the first hour timestep then rainfall was turned off for the remainder of the 22-hr model period. The runoff (output in mm) was analyzed for the five hours after the rainfall event, at which time runoff ceased. The cumulative runoff results are displayed for the hourly timesteps in Figures 6-10. While precipitation was uniform over the domain, runoff had a distinct spatial pattern that was maintained throughout the period of active runoff. The western portion of the domain, where elevations are the highest, the runoff was relatively low compared to the runoff in the central portion. This result is due to the steepest descent algorithm used for the overland flow routing. Water tends to quickly runoff in the high elevation high slope regions then move downhill. Therefore, the cumulative runoff in low elevations should, on average, have the highest values. However, the results from Travis County show the areas of relatively average runoff in the lowest elevation areas and the medium elevation areas (central portion) tend to have the highest runoff.

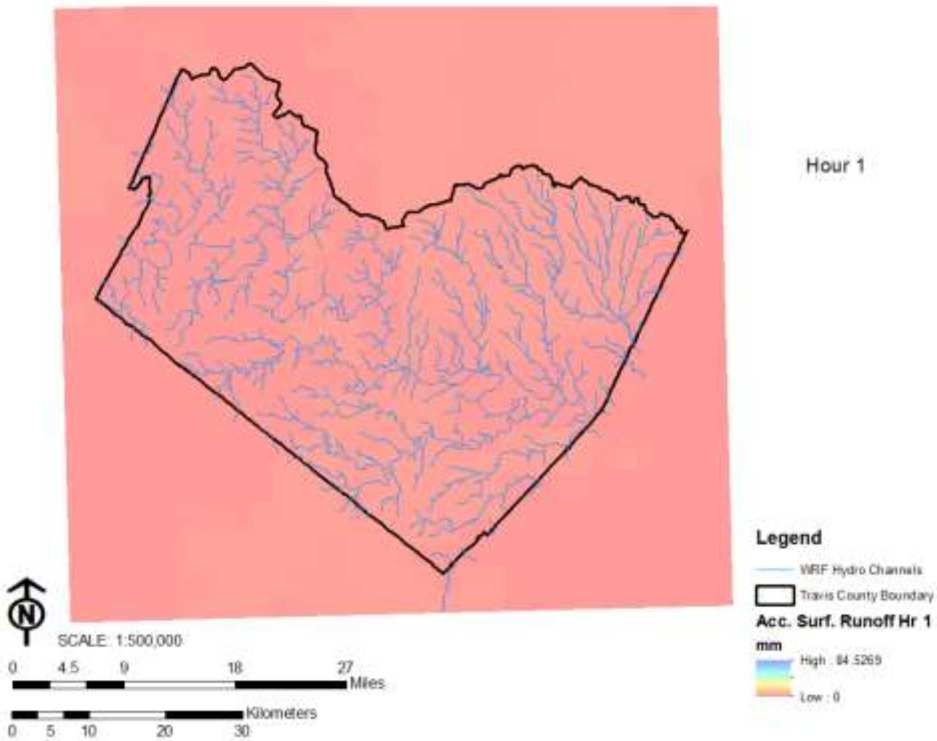

Figure 6: Runoff in mm for the first hour of the model run

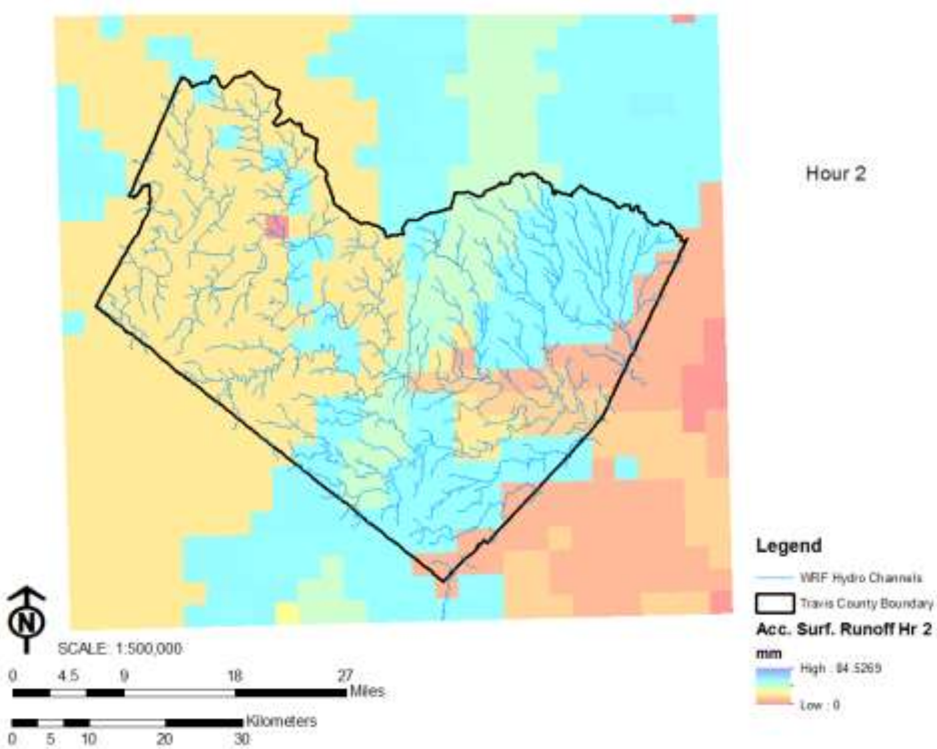

Figure 7: Runoff in mm for the second hour of the model run

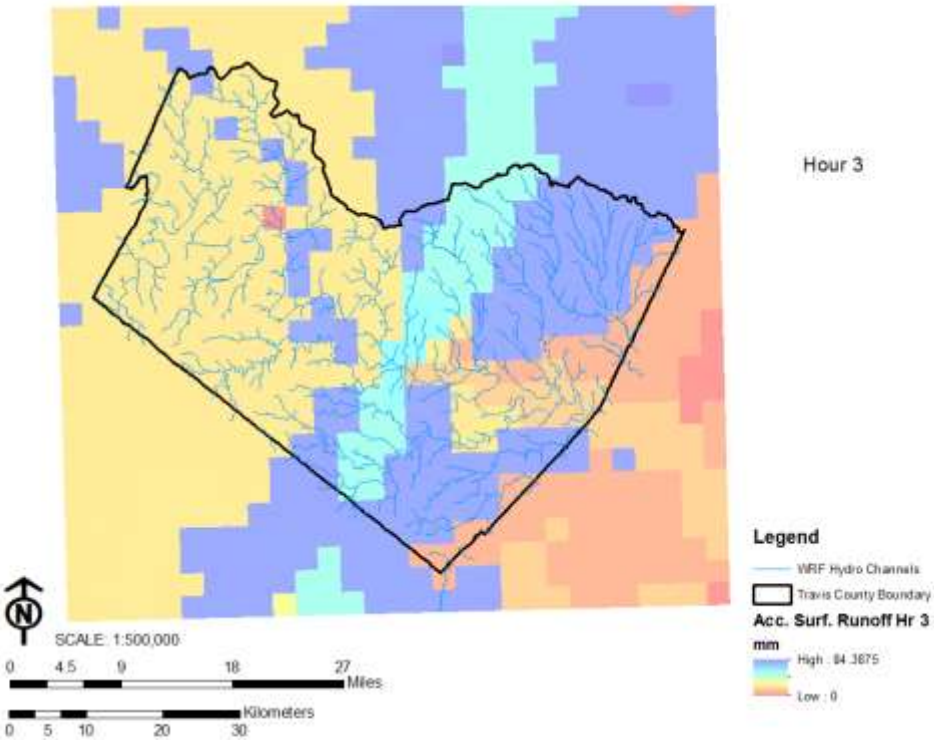

Figure 8: Runoff in mm for the third hour of the model run

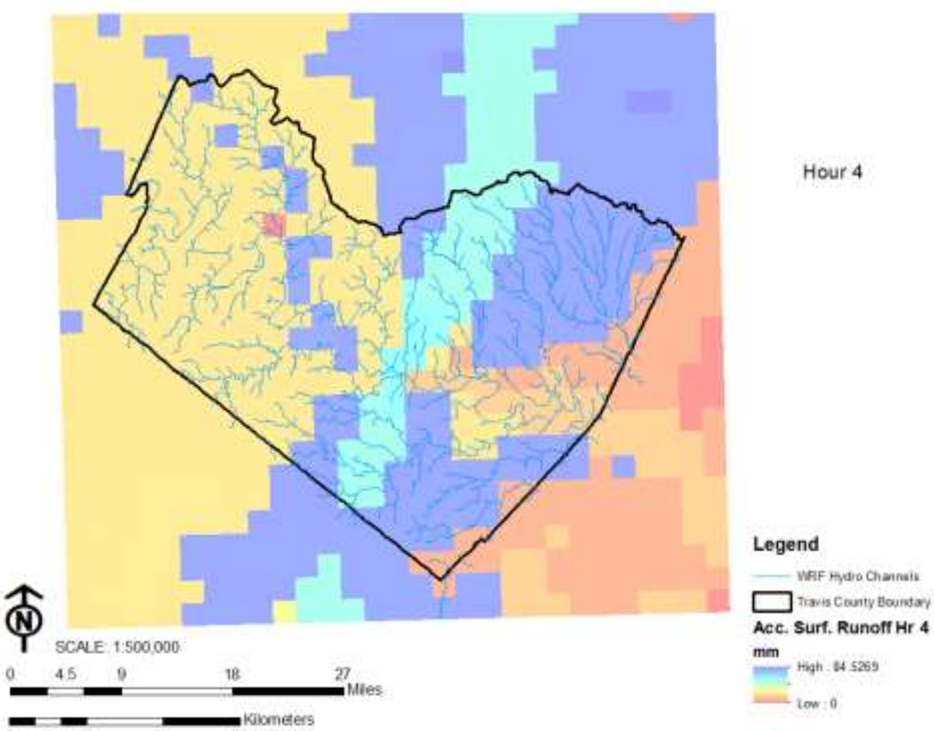

Figure 9: Runoff in mm for the fourth hour of the model run

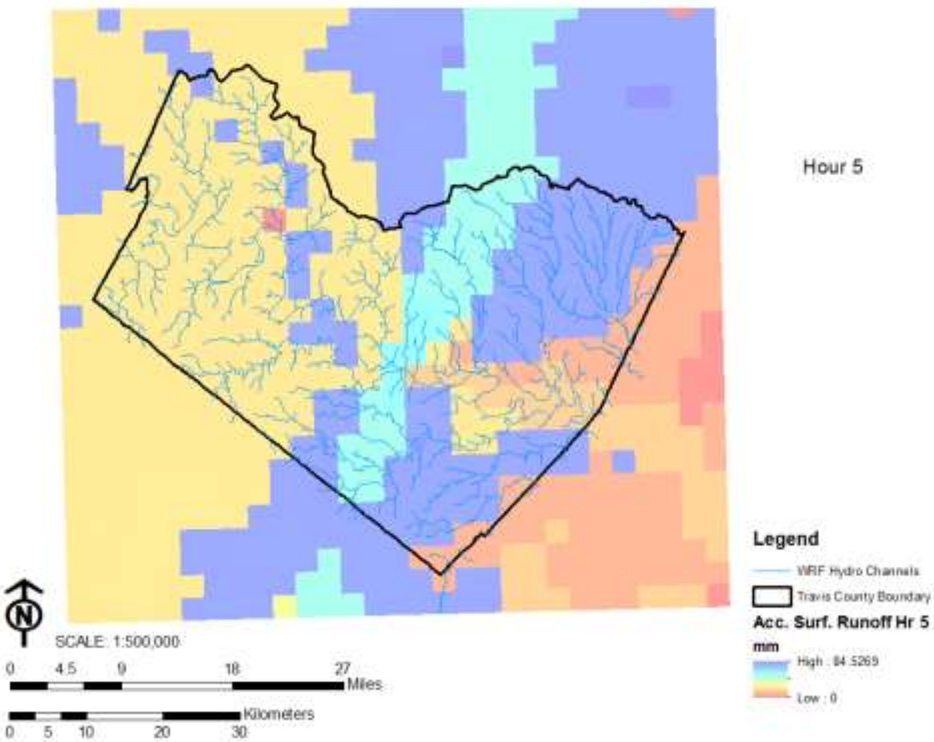

Figure 10: Runoff in mm for the fifth hour of the model run

However, it should be noted that elevation characteristics are only a portion of the story in determining the magnitude of runoff at a particular location. Many other factors including land use, vegetation type, and soil type, etc. have an impact on the amount of runoff generated at a given grid cell. WRF-HYDRO's LSM incorporates all of these aspects into the generation of runoff values. After visual inspection of the many parameters that influence runoff, land use seems to have some spatial correlation with the runoff patterns observed in the Travis County output. The gridded land use values contained within the input geogrid are displayed in Figure 11. Relatively low runoff values in the low elevation areas seem to correlate well with the areas of dryland, cropland, and pasture (index 2), while high runoff seems to correlate well with grassland and urban areas (indices 1, 5, and 7). The low runoff values in the index 2 areas may be due to significant infiltration due to a lack of soil moisture and relatively low slopes, which in tandem discourage water to accumulate and runoff on the surface. Further investigation of the processes at play is warranted to better characterize the runoff regime.

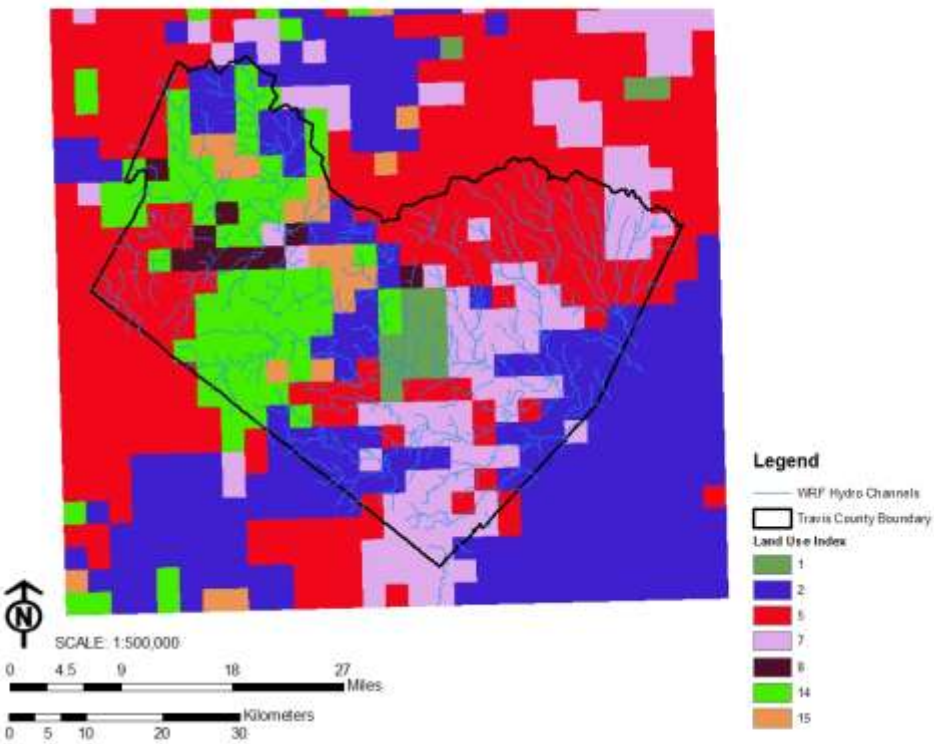

Figure 11: Land use values for Travis County. The land use index values are according to the USGS Land Use Index. 1 = Urban and Built-up Land, 2 = Dryland, Cropland, and Pasture, 5 = Cropland/Grassland Mosaic, 7 = Grassland, 8 = Shrub land, 14 = Evergreen Needle leaf, and 15 = Mixed Forests

The channel routing output file is of the format 'YYYYMMDDHHMM.CHRTOUT_DOMAIN' and is in netcdf format. 'Streamflow' is the variable of interest within the netcdf file and it is delivered in vector format. Unfortunately, the streamflow generated in this project delivered empty results. The streamflow variable within the netcdf file generated zero streamflow at each location even though runoff was clearly generated. Upon further investigation, this result may have been due to one of two minor errors identified within the model run log file. The high-resolution terrain file was generated without the latitude and longitude grids, which causes a minor warning within the WRF-Hydro log. However, the routing does not seem to require geographic coordinates as the scheme operates on a cell-by-cell basis within the grid. The more likely culprit is a slope warning generated within the WRF-Hydro log file. Erroneously high topographic slopes were calculated during the channel routing portion of the model run. Topographic slope calculations may have been hampered by the resolution of the geogrid or the domain of the area of interest. Further investigation is warranted.

The spatial resolution of the geogrid relative to the density of flowlines within the NHDPlus flowlines may pose an issue to accurate representation of overland flow routing times within the NFIE framework. For each 3 km geogrid cell, the scale at which runoff is generated for this project, there is at least one NHDPlus flowline. Because of this, overland routing of flow within a cell must directly run into a stream, effectively eliminating the possibility of cell-to-cell overland flow routing. This forces runoff to be immediately routed to the stream for each model time step. This may pose an issue if a user is attempting to accurately characterize the overland flow routing time for use in a flood forecasting analysis. To remedy this issue, the geogrid resolution must be significantly finer and he model time step may need to be reduced.

Conclusion

This project aimed to summarize the LSM and routing outputs available within the WRF-Hydro model architecture for consideration within the NFIE-Hydro framework. A summary of the requirements for pre-processing the input data into the WRF-Hydro model was presented. Information regarding the parameterization of the WRF-Hydro operation files and the model set up within the TACC Lonestar system was provided to assist future users of the WRF-Hydro system within a TACC. An example of the outputs from the WRF-Hydro LSM and overland flow routing scheme was completed, but the evaluation and trouble shooting of the channel routing option is left to future work.

References

This project was performed in conjunction with D.R. Maidment's CE397 Flood Forecasting course taught at UT Austin. All of the materials presented in the class were utilized in the generation of this report.

Gochis, D.J., W. Yu, D.N. Yates, 2013: The WRF-Hydro model technical description and user's guide, version 1.0. NCAR Technical Document. 120 pages. Available online at: http://www.ral.ucar.edu/projects/wrf_hydro/