Submitted by Harish Sangireddy
Term project report for CE397 Flood forecasting class.

Catchment modelling using PIHMgis
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Contents

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Goals:

The goal of the project is to use PIHMgis framework to simulate various hydrological state variables and fluxes for the Onion creek catchment located in Travis County, Texas. The project will allow us to compare fluxes generated at this catchment with other relevant models (e.g. NOAH MP) and assess the accuracy of such inputs in the broader NFIE hydro framework.

Introduction:

PIHMgis is an open source, platform independent, tightly coupled GIS interface to the core hydrological model PIHM (Penn state Integrated Hydrological Modeling system). PIHM is a hydrological model that simulates the physics within a catchment across space and time by incorporating various heterogeneous input data related to climate, land use, topography, and hydrogeology of the catchment. The procedural framework of PIHMgis is broadly divided into 6 components (see Figure 1) and the hydrological processes are fully coupled by the semi-discrete finite volume approach.

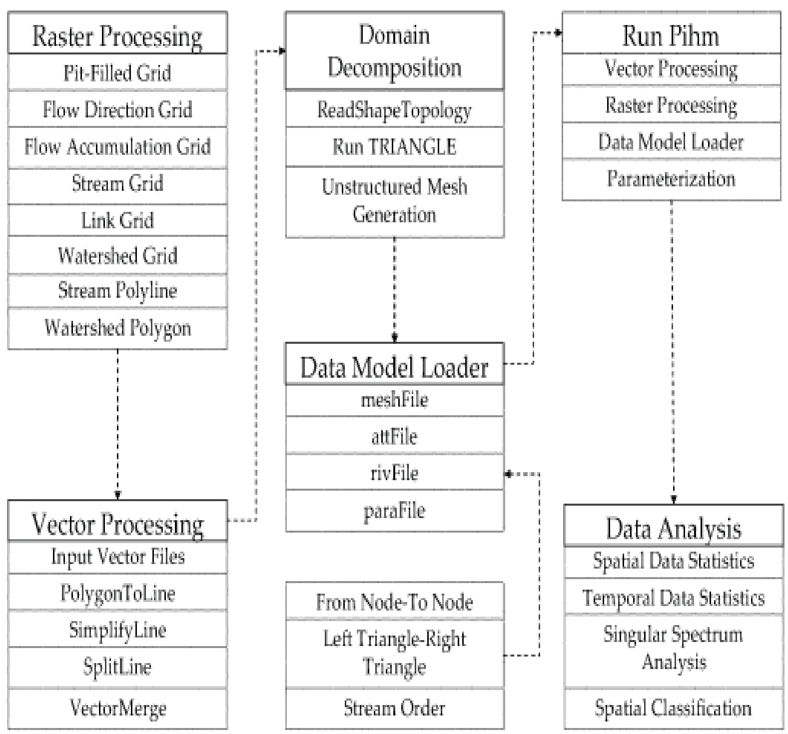

Figure 1: Workflow of PIHMGIS, http://www.pihm.psu.edu/pihm_home.html

PIHM and contribution to the NFIE hydro

The PIHM model simulates and produces a variety of outputs. Some of the most interesting and relevant state variables are surface water flow (meters), unsaturated/saturated soil moisture (meters), infiltration rate (meters/day), river stage (meters) and base flow to stream (meters/day).

These variables can be simulated for the Onion creek catchment over a wide range of input forcing parameters and thus help in assessing base flow and overland flow contributions within the catchment. Further these results can be used for comparing model outputs from NOAH MP and assess the effect of resolution and input forcing within the NFIE hydro framework.

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Study Site: Onion Creek

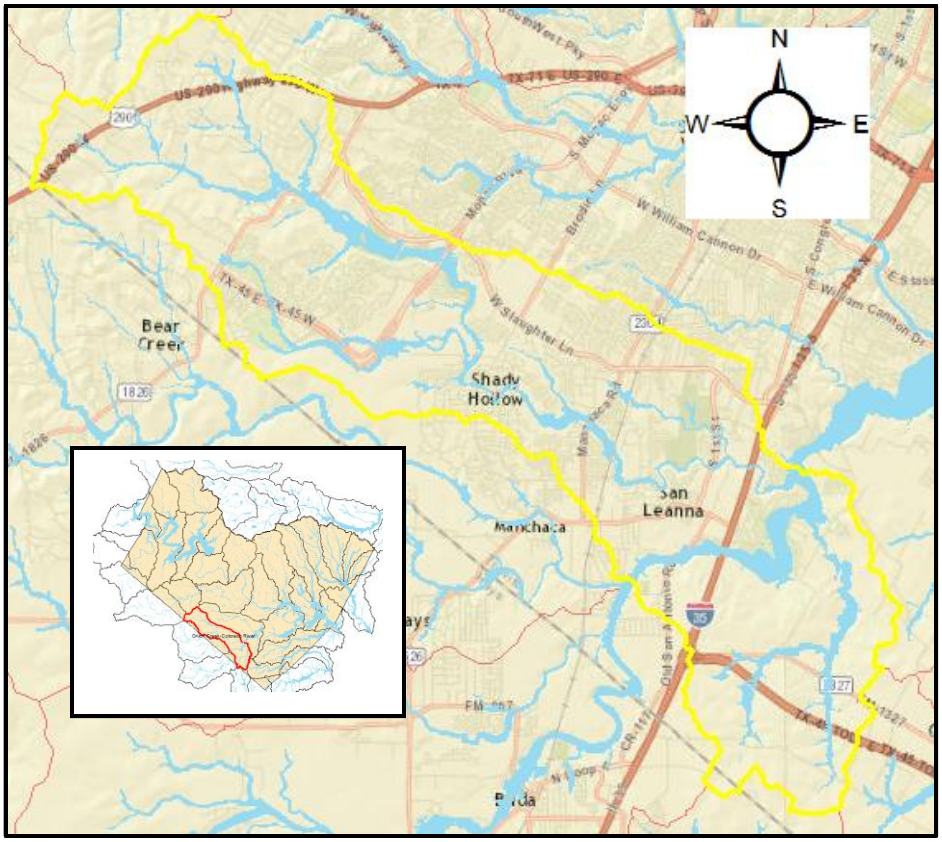

Figure 2: Map showing the outline of Onion Creek (yellow outline) overlaid on an ArcGIS base map of streets. The inset shows the Travis County, TX boundary (brown polygon), the HUC12 watershed overlaid with the warning zones (blue polygons) from FEMA and the catchment highlighted in red is the Onion creek catchment.

The Onion creek watershed (Figure2) is located on the eastern boundary of Travis County, Texas. The watershed is heavily urbanized downstream while having a fair portion of green belt in the upstream part of the basin. Two major roads the IH 35 and US 290 highway cross the watershed at the downstream and the upstream end of the watershed respectively. Table 1 shows the various catchment attributes.

Table 1: Catchment properties

Catchment Attributes	Catchment attribute values
HUC_8	12090205
HUC_10	1209020504
HUC_12	120902050407
HUC_10_Name	Onion creek – Colorado River
HUC_12_Name	Slaughter creek – onion creek

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Catchment area in acres	238860.9755

Figure3 and Figure4 show the land cover and geology of this region respectively. Figure4 shows that the geology of the watershed changes from loamy to clayey and then to fine silt soils as we move from the upstream portion of the watershed towards the downstream portion of the watershed. The middle portion of watershed has a high impermeable cover.

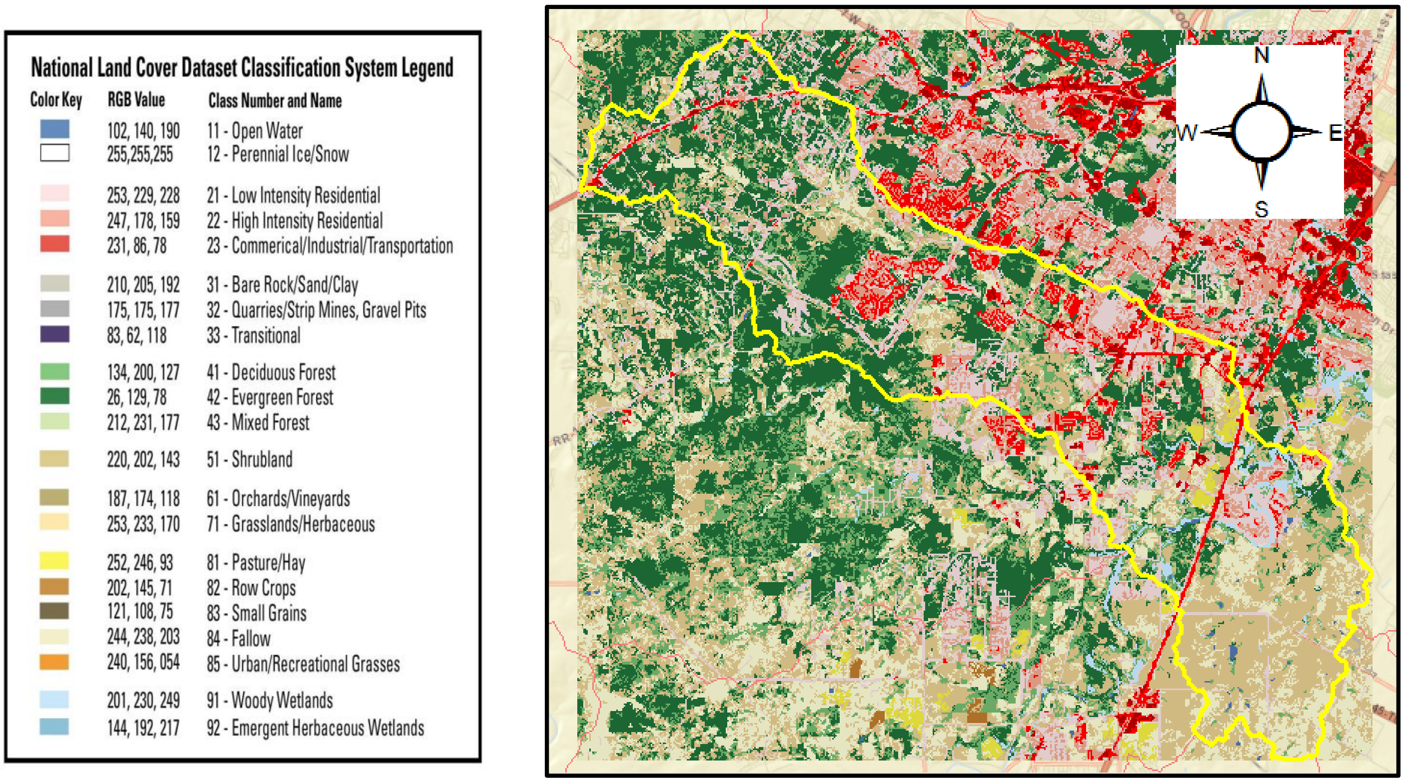

Figure 3: Map showing the Land cover over the Onion Creek watershed, with legend on the left.

Project workflow:

1) Download the geospatial and NLDAS data from Hydroterre server for the Onion Creek HUC12 catchment in Travis County, Texas.
2) Translate the Hydroterre data into a format that can be read by PIHMgis by using the HydroTerre data conversion tool.
3) Define the watershed, stream network boundaries, and construct an optimal unstructured mesh (e.g. small mesh near channel) for stream reach lengths and hillslopes within PIHMgis.
4) Run and prepare transfer functions to form a-priori parameters for model mesh elements from geospatial products (soils, hydrogeology, land cover, weather) downloaded from Hydroterre (http://www.hydroterre.psu.edu/HydroTerre/Help/Ethos.aspx)
5) Run PIHM and visualize data in ArcGIS.

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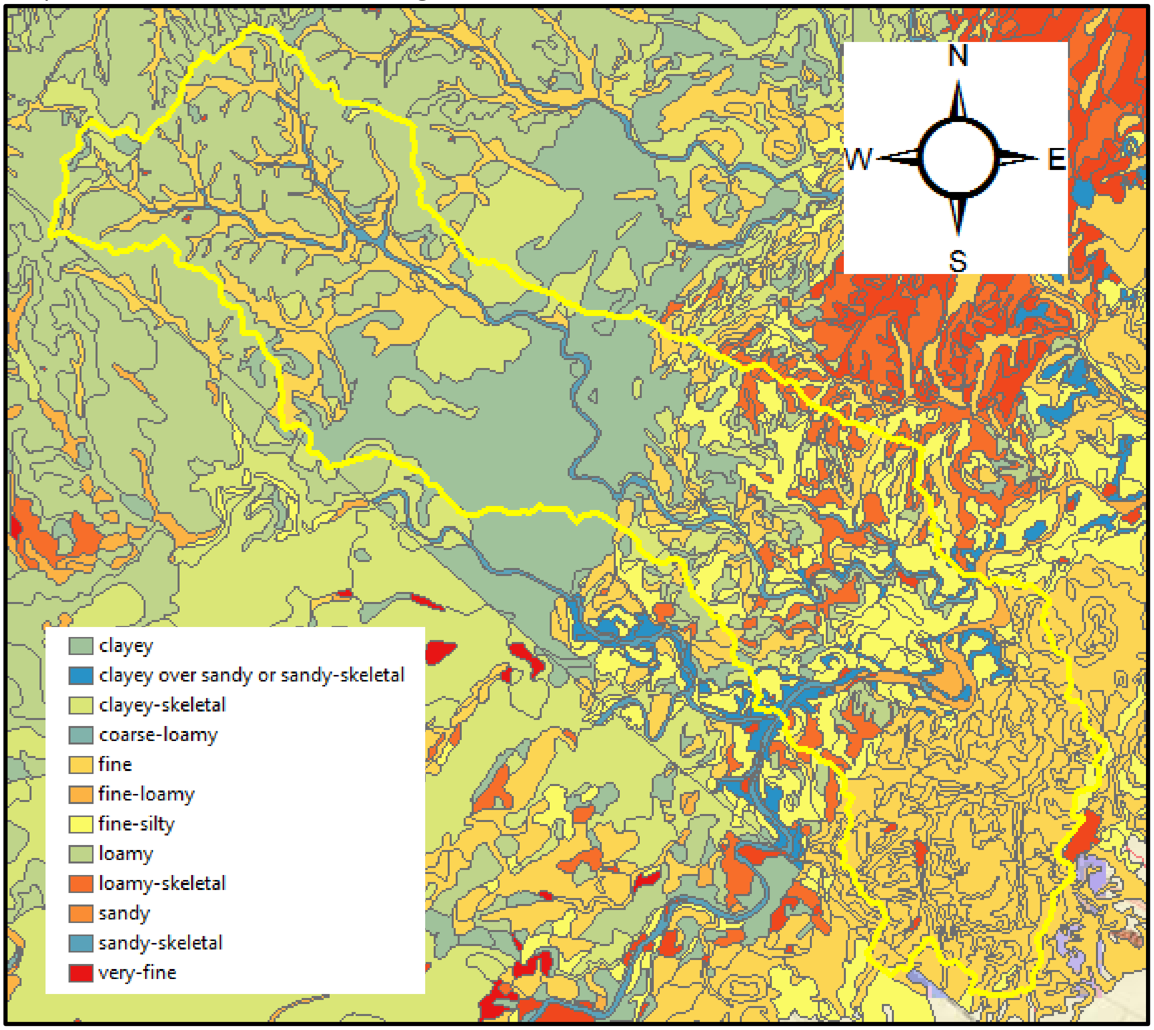

Figure 4: Geology of Onion Creek from SSURGO

Importing the input data from Hydroterra server:

The input data required for PIHM GIS can be downloaded from http://hydroterre.psu.edu/Development/HydroTerre_National/HydroTerre_National.aspx and click on the ETV services (Download ETV data). After selecting the watershed of interest we fill in out email address, select the time period of the forcing data and then select generate data. Here I downloaded the data for the HUC12 "120902050407"(Figure 5).

All the required data are compressed in a zip file and made available for download.

Data Overview

The essential terrestrial variables required to complete the workflow of distributed water resources modeling using PIHM GIS are

- Atmospheric forcing
    - U wind component (m/s) at 10 meters above the surface
    - V wind component (m/s) at 10 meters above the surface
    - air temperature (K) ** at 2 meters above the surface
    - specific humidity (kg/kg) ** at 2 meters above the surface

- surface pressure (Pa) **
- surface downward longwave radiation (W/m^2) **
- surface downward shortwave radiation (W/m^2) -- bias-corrected
- precipitation hourly total (kg/m^2)
- fraction of total precipitation that is convective (no units): from NARR
- CAPE: Convective Available Potential Energy (J/kg): from NARR
- potential evaporation (kg/m^2): from NARR

- Digital Terrain model
- Rivers and streams
- Soils data
- Groundwater
- Surface water bodies
- Landcover
- Water use

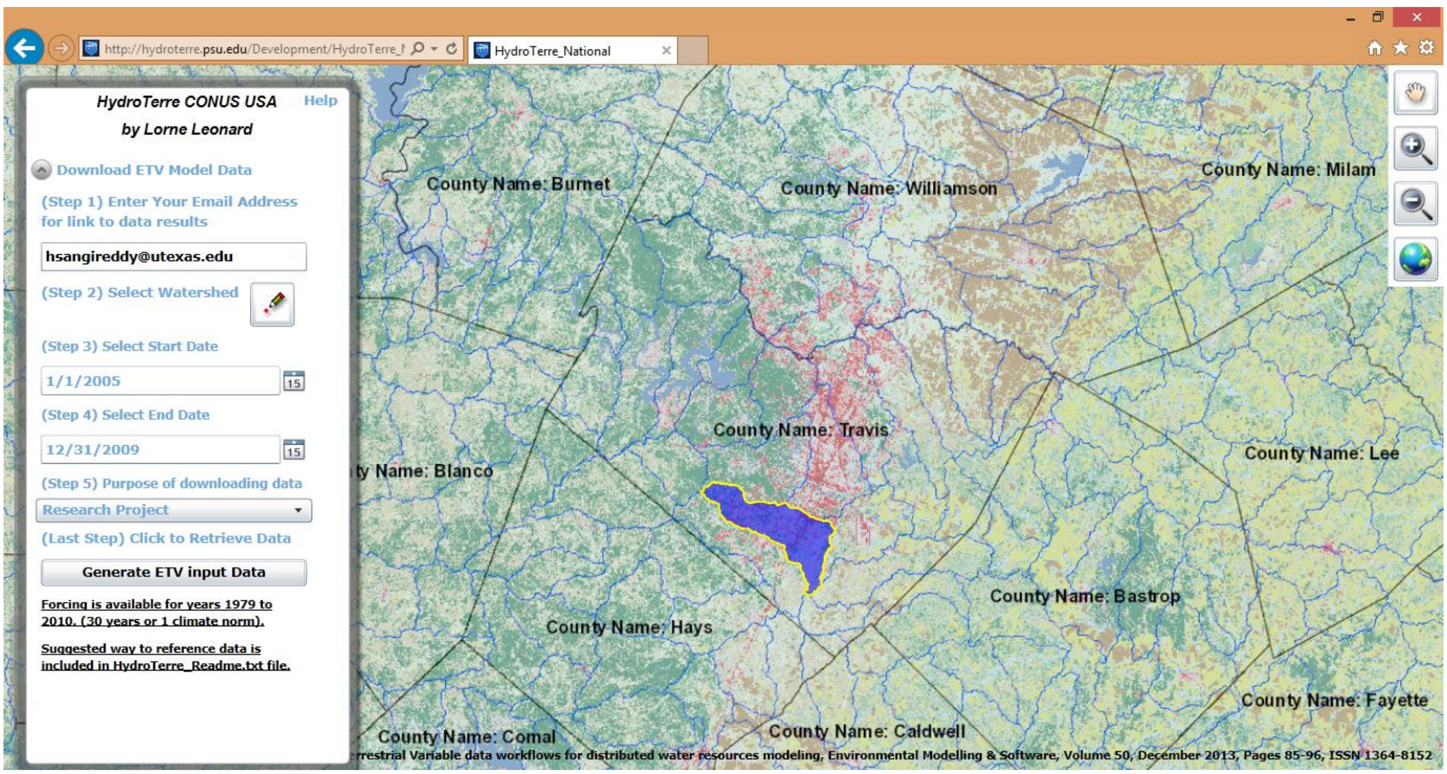

Figure 5: HydroTerre server download page. Here HUC12 120902050407 is shown selected and the data is downloaded.

After downloading the input data, the process workflow shown in Figure 1 is followed to do raster processing, vector processing, domain decomposition, data model loader, and finally running PIHM GIS model.

A triangulated irregular model (TIN) of the watershed is the basin element of PIHM model. The Reynolds Transport Theorem is solved over this TIN model (Figure 6). The TIN model is unstructured in the sense that the TIN model is denser over the river channels and less dense over the hillslopes. This allows the TIN model to be optimized over the entire domain.

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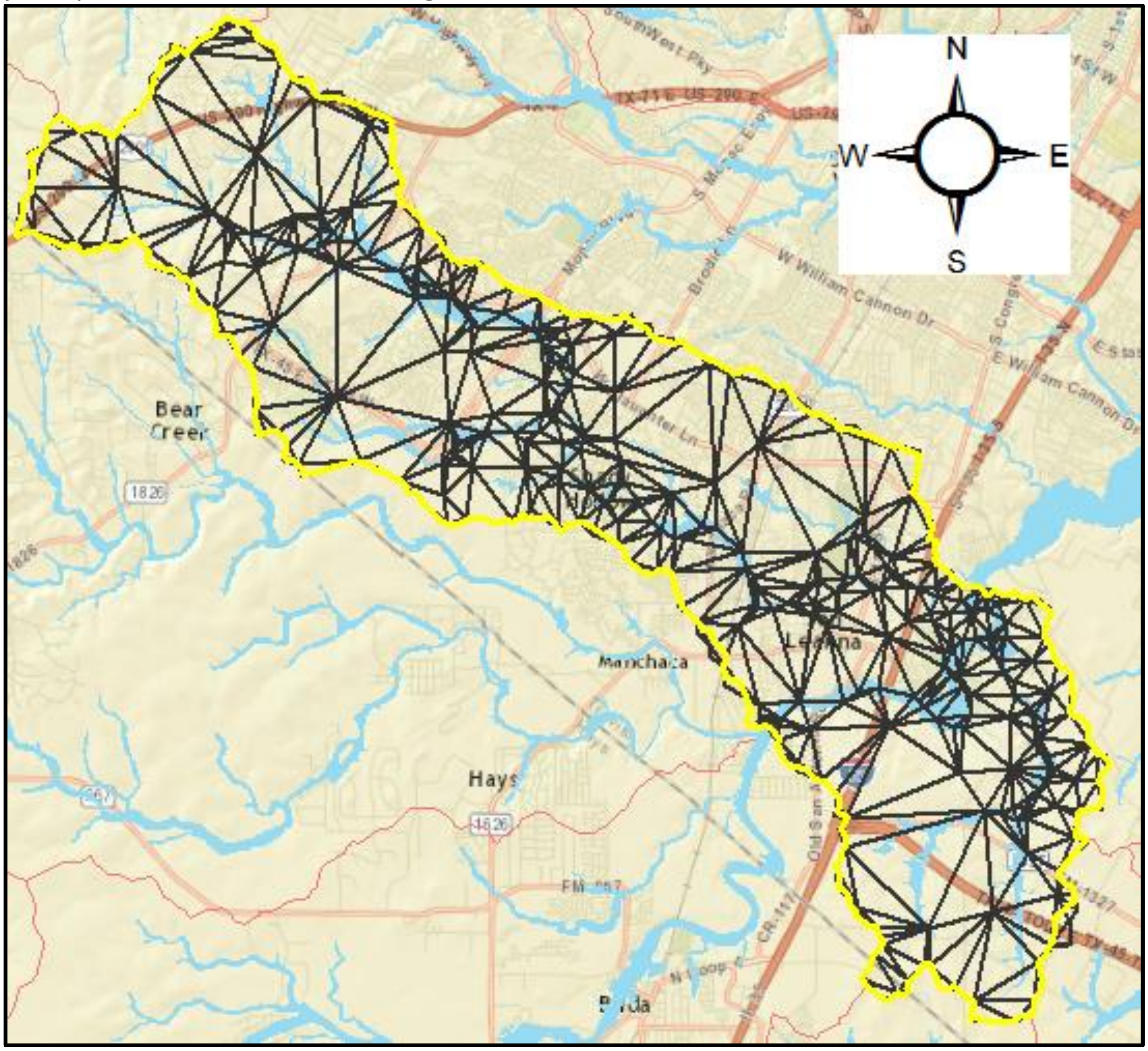

Figure 6: TIN generated for Onion Creek using the PIHM GIS model

Forcing parameters for the PIHM Model

The precipitation, temperature, humidity, wind velocity, solar radiation and vapor pressure are initialized with a uniform value of 1 unit (Figure 7). Other initial conditions such as interception, snow, overland flow, soil moisture, groundwater, boundary conditions, and sources are initialized to a value of 0 units (Figure 8). The time series of forcing used for this region varies from 2005 to 2009. Finally after preparing all the forcing variables, the mode is run. Note the results here are based on a uniform climate forcing, where a unit value of precipitation, humidity, wind velocity, solar radiation and vapor pressure is established as the forcing value.

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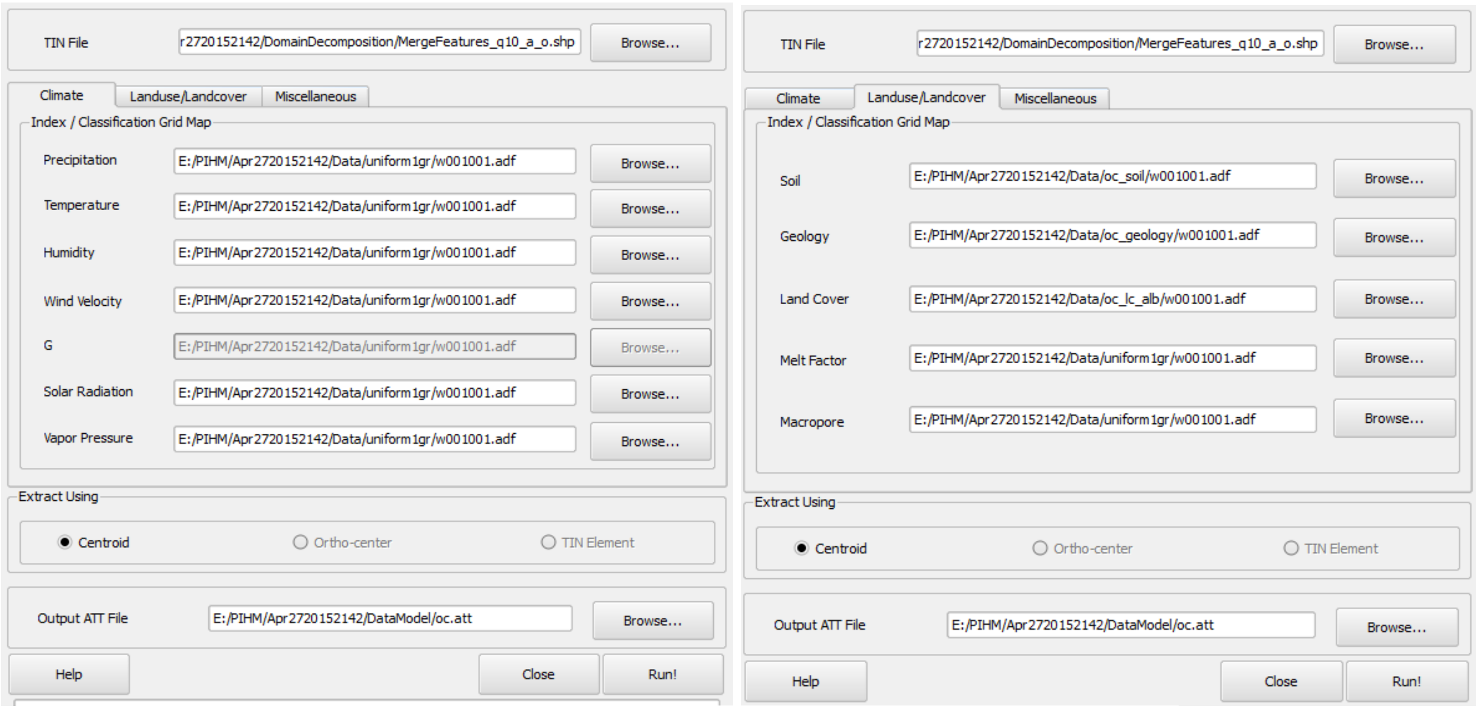

Figure 7: screen shot showing Forcing parameters of PIHM GIS

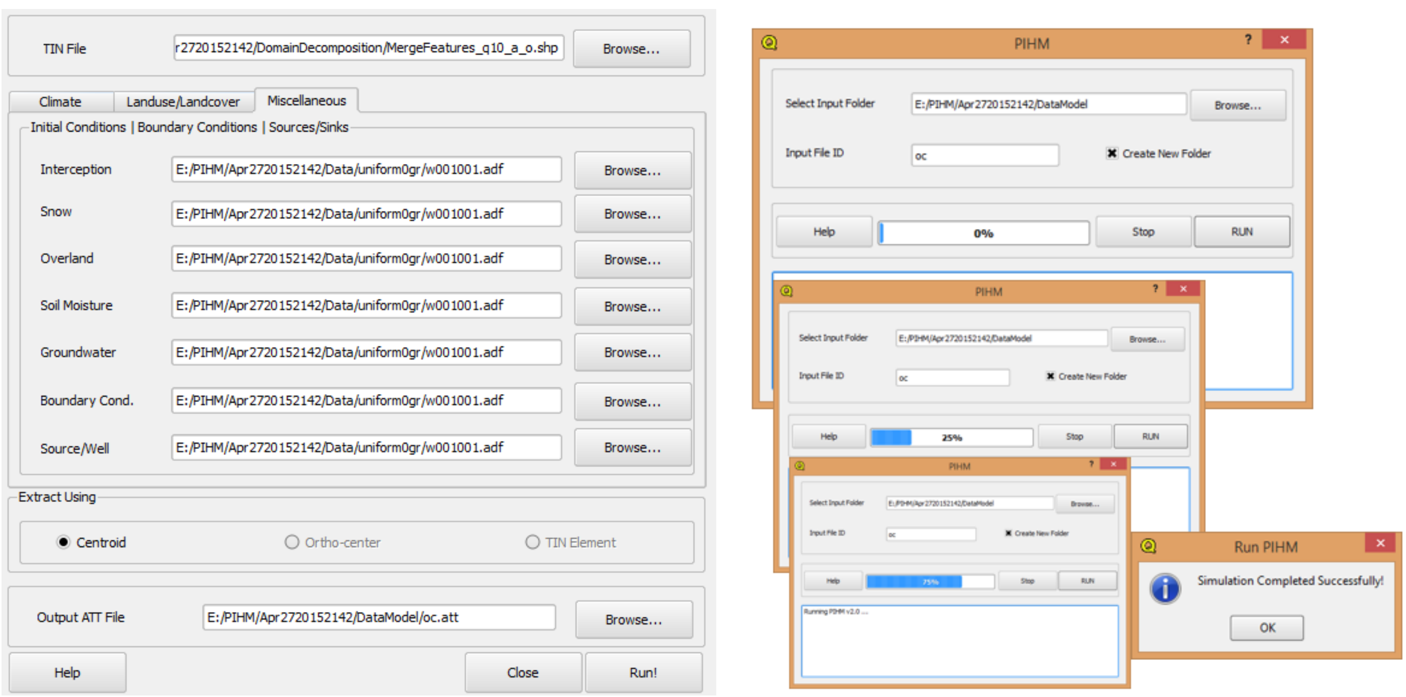

Figure 8: Forcing parameters initialization in PIHM GIS and running the PIHM gis model.

PIHM Outputs

The outputs generated from PIHM can be visualized in both space and time. The spatio-temporal outputs can be visualized in the PIHM model using the infoviz toolbox in QGIS. All the forcing data was fed into the model and a simulation was performed over the entire Onion creek domain for a period of 7 days. The results of the simulation are discussed below.

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Time series visualization

The simulation time period for 7 days produced a very flashy stream outflow response as expected in a urban watershed. The stream flow increases initially and then decays over a time period of 25 hours (Figure 9). A small peak is later observed towards the end of the forecast period. The flashy response in the watershed could be due to the high urban development in the middle part of the watershed. As water flows downstream, the land cover changes substantially and there is a major stream junction in the downstream portion of the watershed that could also be partially responsible for the flashy response of this urban watershed.

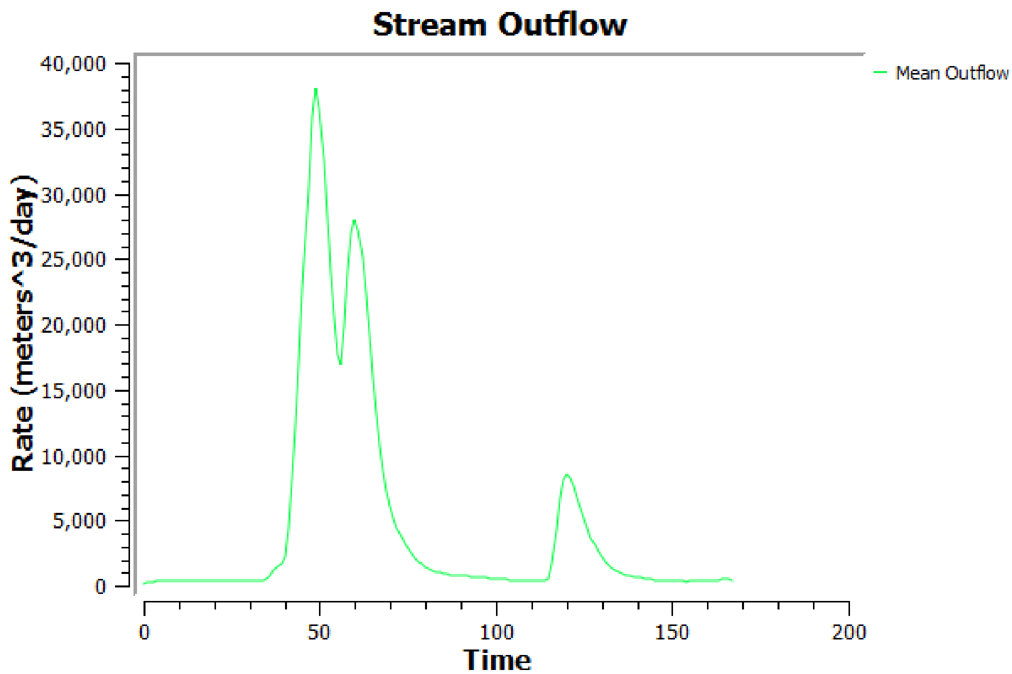

Figure 9: Time series of discharge generated from PIHM gis model for an uniform climate forcing.

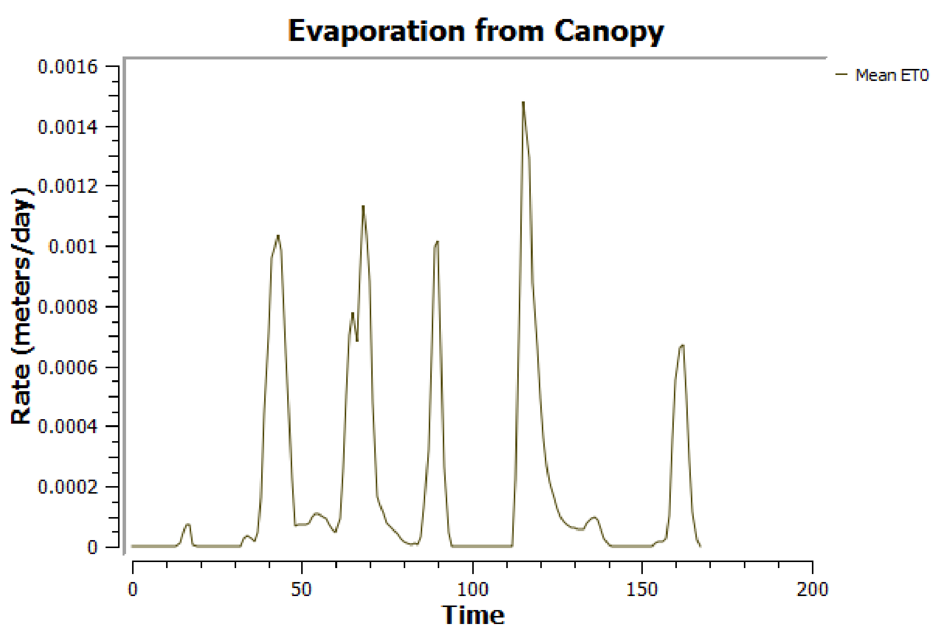

Figure 10: Time series of evaporation from the canopy

Another important output of the model is the evaporation from the canopy. The time series of evapotranspiration from the canopy over this watershed shows an inter-diurnal variation, i.e. increase in evapotranspiration during the day and

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then decrease during the night (Figure 10). These time series outputs confirms that the lumped hydrological model is able to simulate the state variables accurately over the entire domain.

Spatial data output

The output generated from the PIHM gis model can be also visualized spatially over the elements of the TIN model.

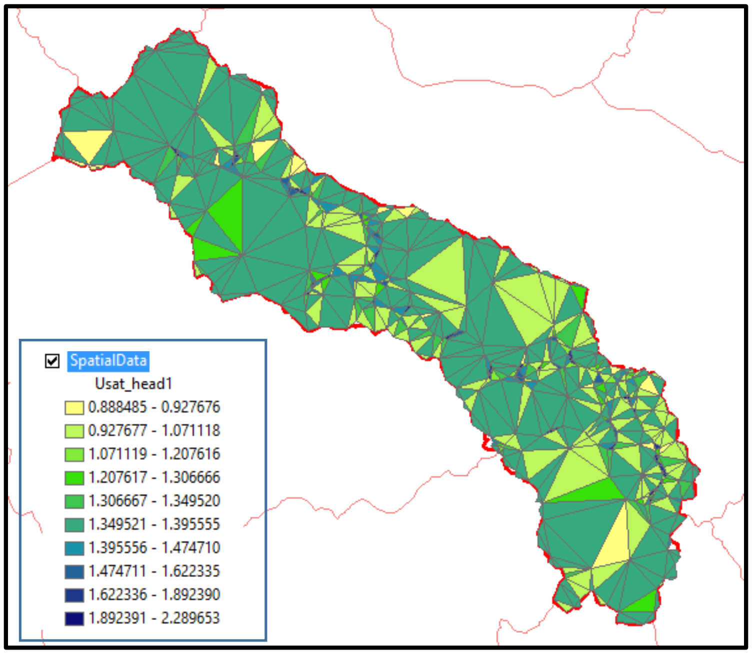

Figure 11: Spatial distribution of unsaturated regions head [m] over Onion Creek.

The spatial distribution of the head of unsaturated regions over the region is shown in Figure 11. It is observed that the head of the unsaturated regions correlates well with the channel network and low lying regions within the watershed.

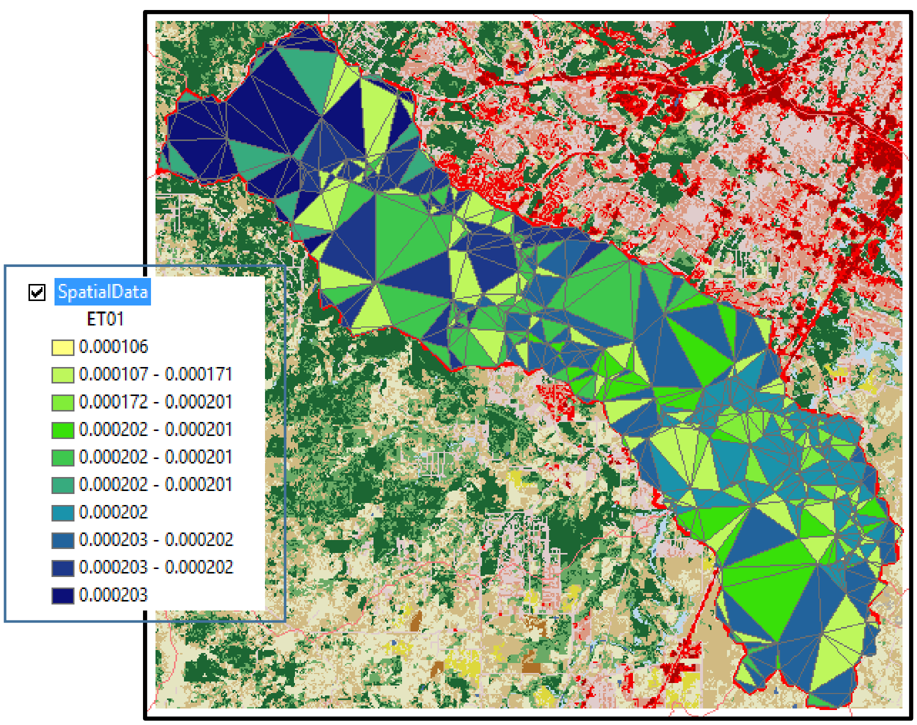

Figure 12: Spatial distribution of evapotranspiration in Onion creek

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The spatial distribution of evapotranspiration in the onion creek predicted matches very well with the spatial distribution of land cover in the watershed. It is observed that regions with higher tree cover produced higher rates of evapotranspiration compared to regions with low tree cover towards the downstream potion of the watershed.

Spatial distribution of saturate zones and warning zones from FEMA:

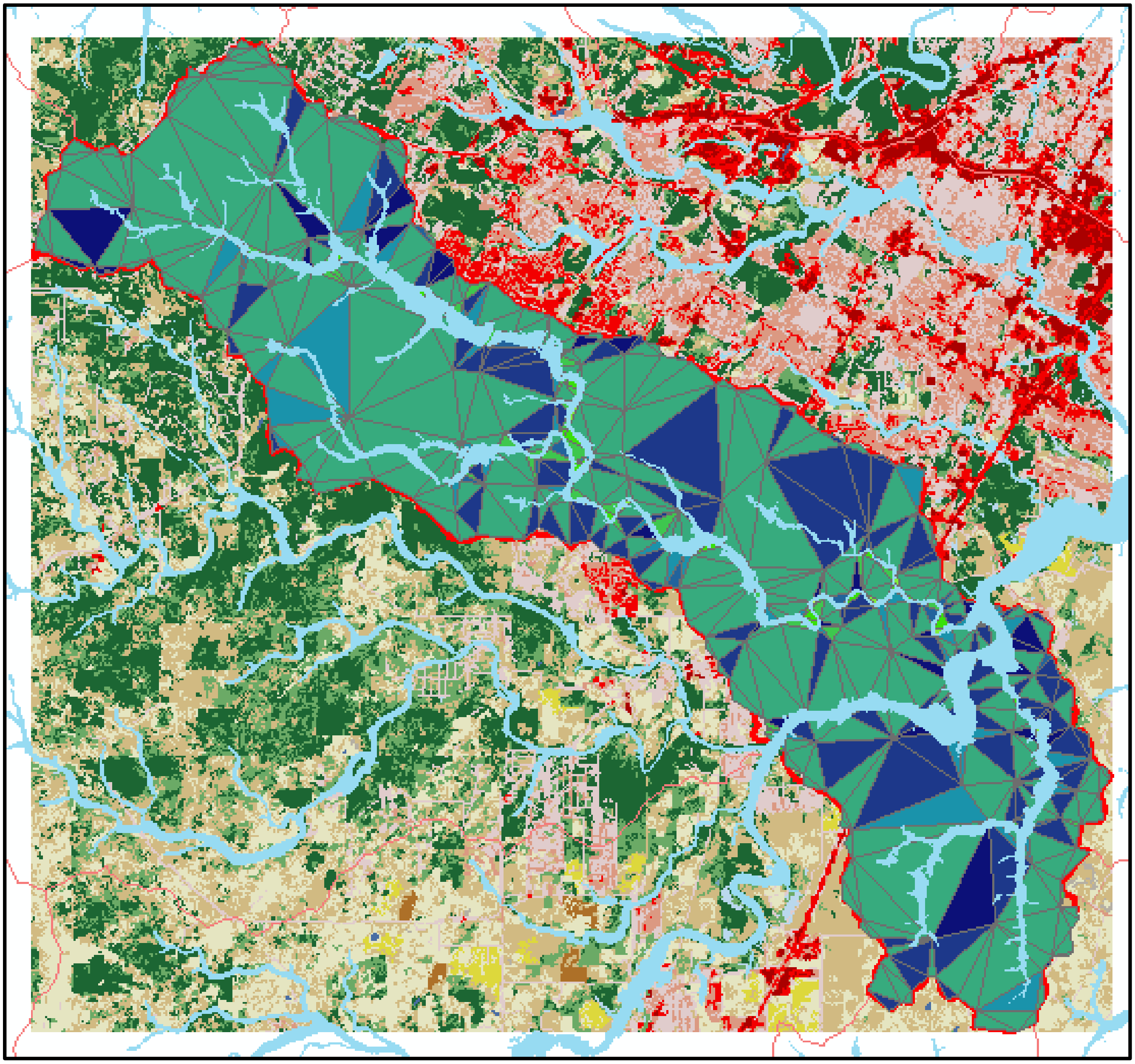

Figure 13: Spatial distribution of saturated zones in conjunction with the warning zones from FEMA

The spatial distribution of saturated zones is shown in Figure 13 for the Onion creek watershed. This spatial distribution is particularly of importance when compared to the warning zones provided by FEMA for this region. It is observed that the regions of saturation predicted by the model are in good agreement with the warning zones provided with FEMA. In spite the fact that the saturated zones are produced over a seven day period forecast using uniform climate forcing over the entire watershed, the spatial correlation between the polygons is promising. This result shows promise in being able

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to predict the zones of saturation and hence the warning zones given a climate forcing pattern. May be an ensemble of such forecasts would be useful in predicting the extent of saturation in a better way.

Conclusions

- PIHM gis is a strong and versatile interconnected hydrologic model that can be used to model watershed response for given climatic, geological, and environmental forcing.
- The use of Reynolds Transport Theorem over an unstructured TIN model allows spatial modeling of various fluxes over fairly large regions.
- The TIN model which is central to modeling fluxes has some limitations in terms of how many nodes and elements of TIN faces can be modeled properly and in a manner that is computationally efficient.
- The model requires in depth knowledge of various initial parameters like river depth, and bedrock depth, which could be difficult to constrain over large watersheds.
- The creation of TIN model itself needs some manual intervention, and thus an automatic method is crucial if the PIHM gis model is to be used at continental scale. Also scaling the TIN model over the entire domain of USA appears to be quite challenging.
- The preprocessing of input data, which includes getting appropriate input data for PIHM has been stream lined to a great extent via HydroTerre web services, yet there remains some scope for further improvement, like
    - The data preprocessor works on MAC OSX only. I updated part of the shell scripts so that the data processor now works on windows using Cygwin.
    - I also observed that when we download more than 5 years of forcing data, the preprocessor crashes and so the model also fails to run. Hence there is limitation on how many years of forcing we may use to train the model.
    - There are also issues with the creation of soil properties file. The file requires finding percentage of sand, silt, and clay per each soil type. This issue was overcome by me by manually downloading the SSURGO database for Travis County and then finding the percentages of sand, silt and clay for each soil type.
- The spatial correlation of saturated zones with the warning zones is of promise in respect to the NFIE hydro part of the experiment. The zones can be used to produce potential regions of flooding with warning levels classified by the extent of saturation and may be helpful during determination of flood stage warnings.

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Acknowledgements

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