ACCESSING NATIONAL DATA AND DISTRIBUTED MODELS FOR CATCHMENT SIMULATION

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http://www.pihm.psu.edu/announcement_20150526.html

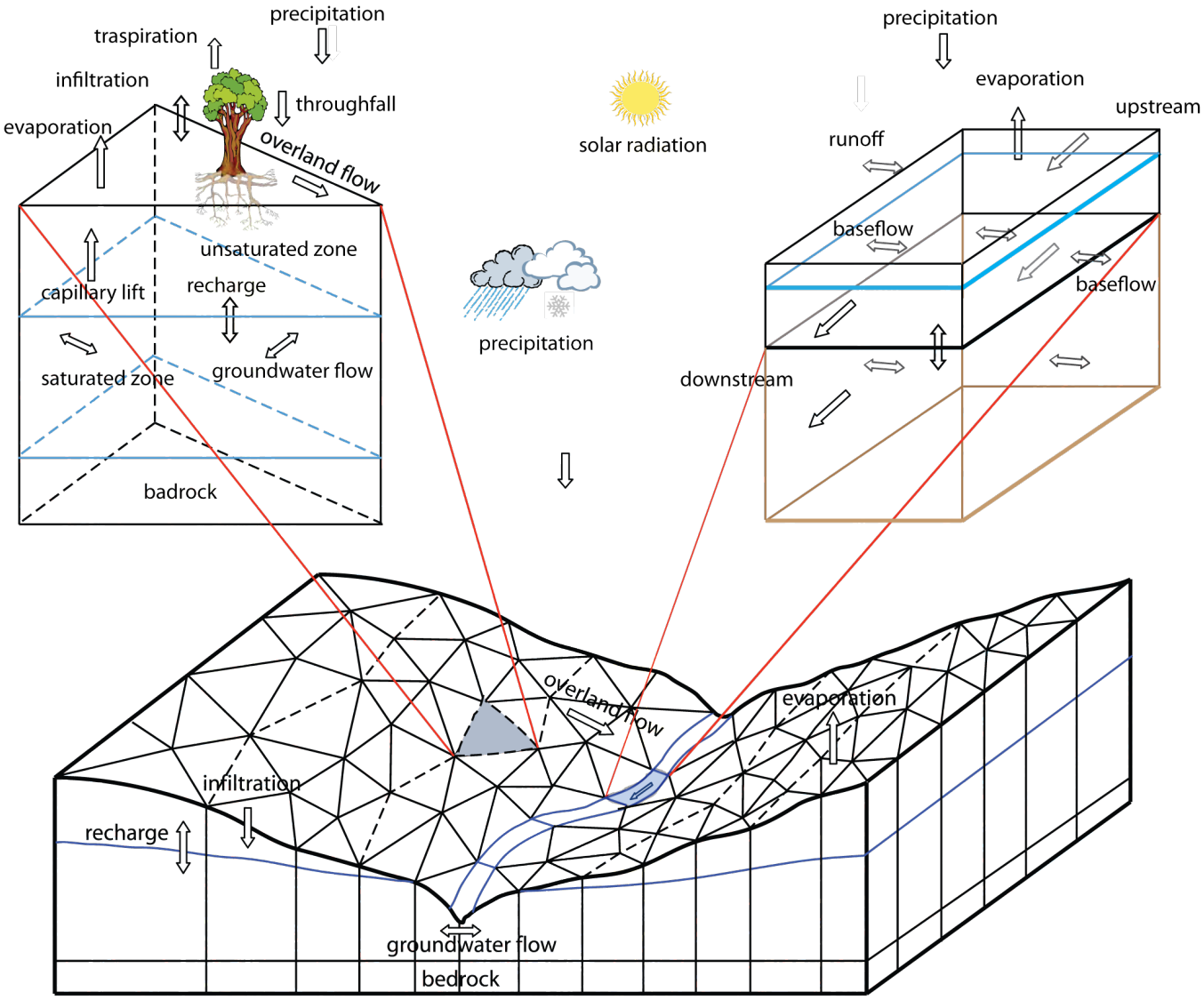
Clinic Outline:
the model-data workflow

1. Overview of catchment modeling process
2. Accessing national geospatial data
3. Catchment modeling using PIHM/PIHMgis
4. Discussion

- details regarding the modeling framework
- data needs for catchment modeling
- catchment modeling examples

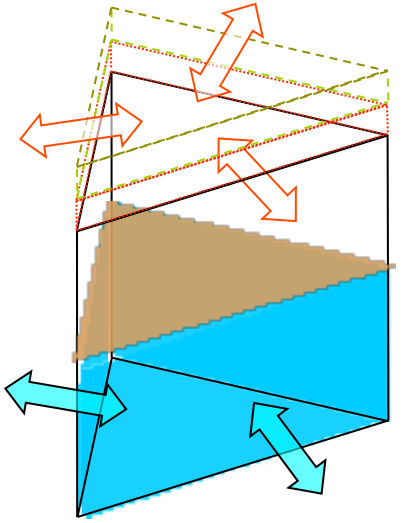
1. Overview of Catchment Modeling Process

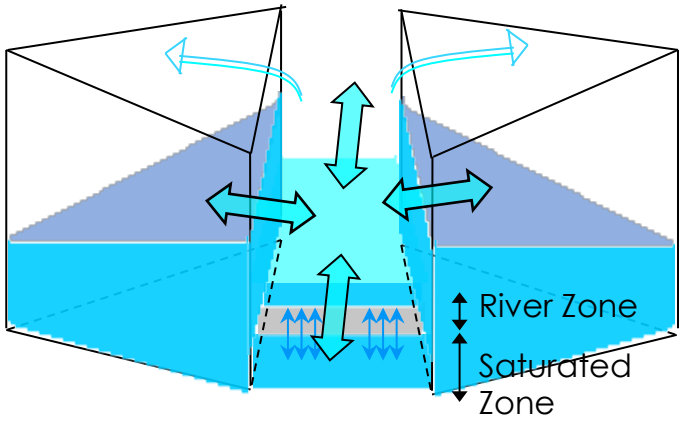
Penn State Integrated Hydrologic Model (PIHM)



Qu & Duffy 2007; Kumar, Bhatt, Duffy 2009

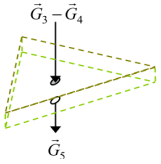
PIHM Control Volume Kernel: Semi-Discrete Finite Volume formulation of conservation equations. Finite Volume Method ensures mass balance locally (in each control volume) and globally.





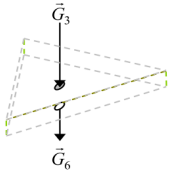
Interception

$$\frac{d\psi_0}{dt} = G_3 - G_4 - G_5$$



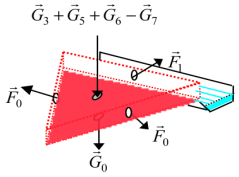
Snow Melt

$$\frac{d\psi_1}{dt} = G_3 - G_6$$



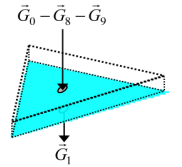
Overland Flow

$$\frac{d\psi_2}{dt} = G_3 + G_5 + G_6 + G_7 - G_0 + F_0 + \|F_1\|$$



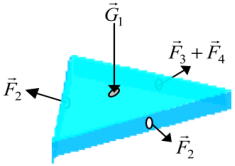
Unsaturated Zone

$$\frac{d\psi_3}{dt} = G_0 - G_1 - G_8 - G_9$$



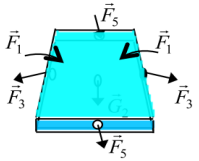
Saturated Zone

$$\frac{d\psi_4}{dt} = G_1 + F_2 + \|F_3\| + \|F_4\|$$



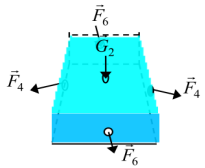
Channel

$$\frac{d\psi_5}{dt} = G_3 - G_2 - G_7 + F_1 + F_5 + \|F_3\|$$



Sub-Channel Aquifer

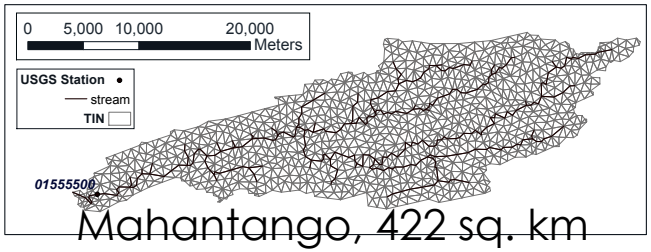
$$\frac{d\psi_6}{dt} = G_2 + F_4$$



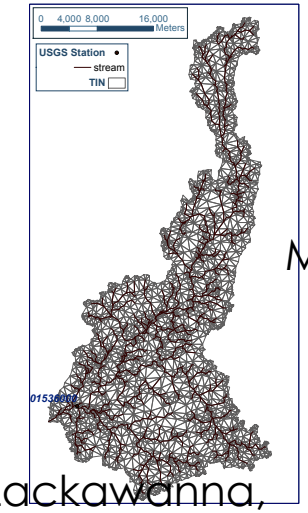
Basic data needs for catchment modeling

- Geospatial data
  - topography
  - soil classification and hydraulic properties
  - landcover/landuse and vegetation parameters
  - geologic classification and hydraulic properties
  - depth to bedrock
  - shape & hydraulic properties of rivers
  - … and more
- Time-series data
  - precipitation and meteorological data
  - monitoring dataset (streamflow, groundwater)
  - … and more

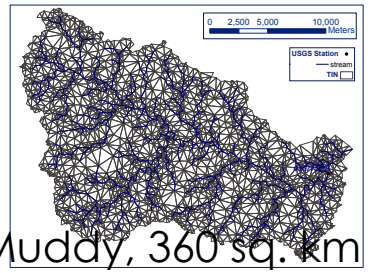
Catchment modeling examples



Mahantango, 422 sq. km

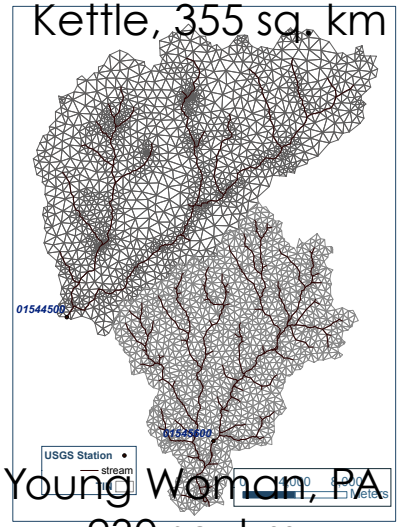


Lackawanna, 902 sq. km



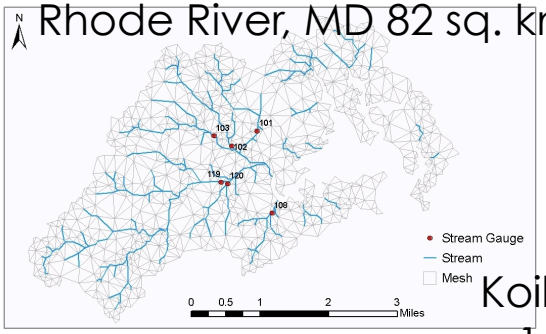
Muddy, 360 sq. km

Kettle, 355 sq. km

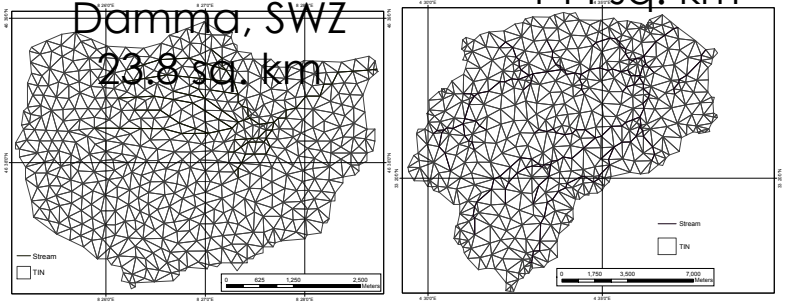


Young Woman, PA 230 sq. km

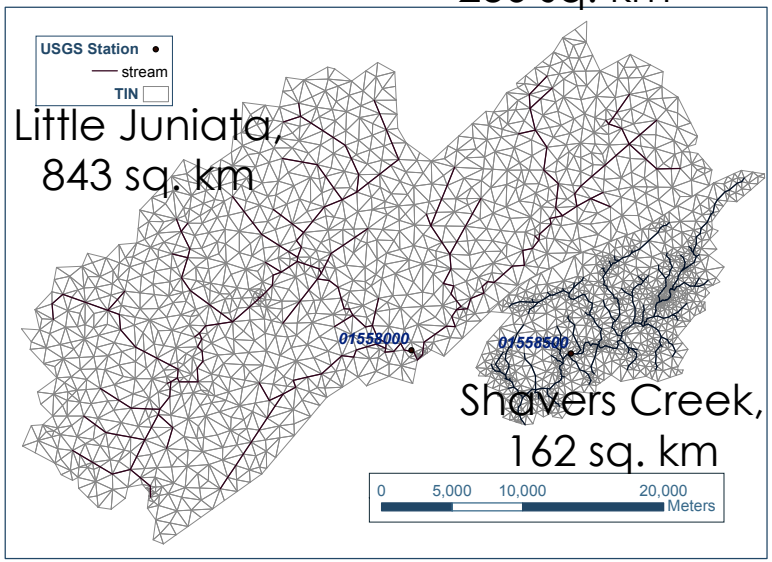
Rhode River, MD 82 sq. km



Koiliaris, Crete 144 sq. km

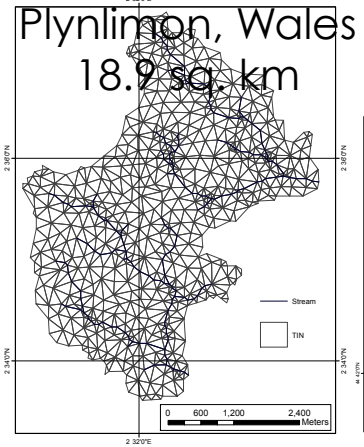


Damma, SWZ 23.8 sq. km

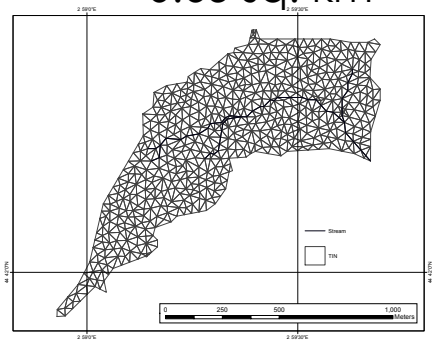


Little Juniata, 843 sq. km

Shavers Creek, 162 sq. km

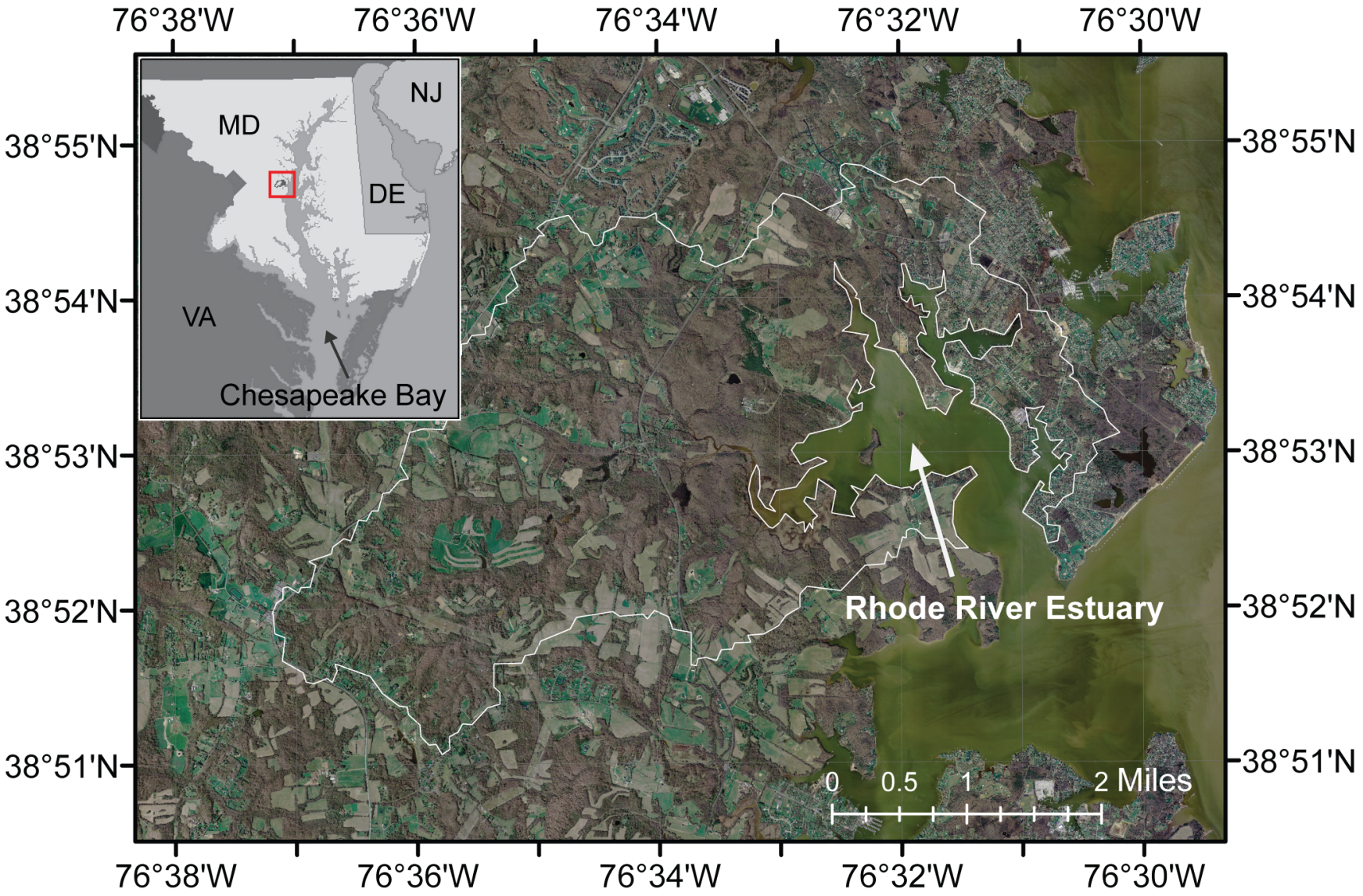


Plynlimon, Wales 18.9 sq. km



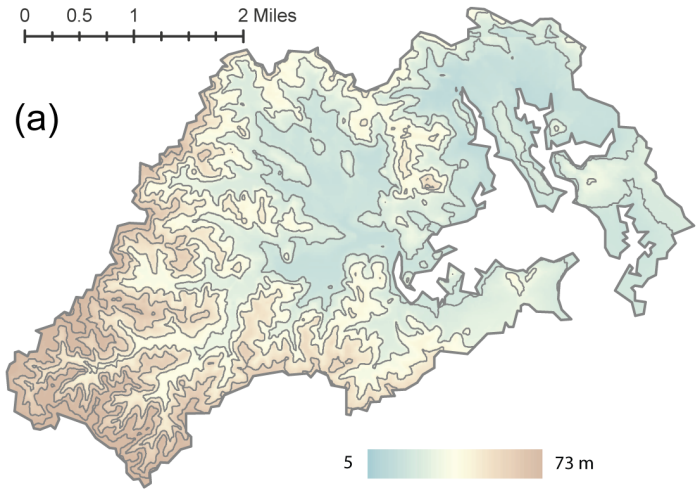
Lysina, Czech 0.65 sq. km

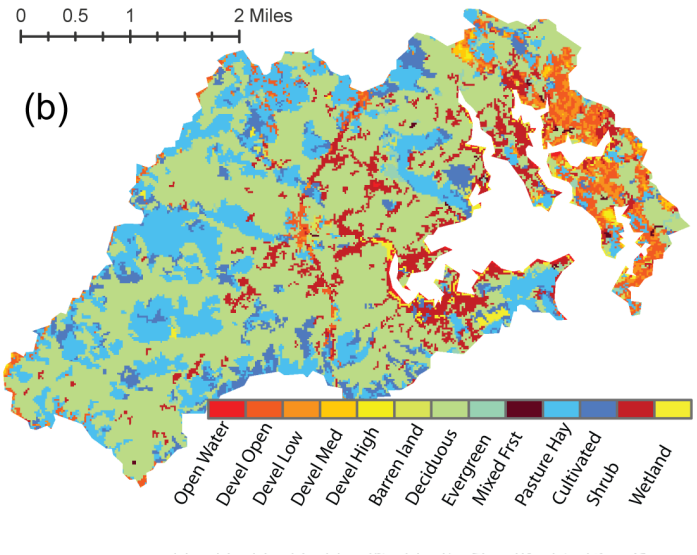
Example 1: Rhode River Basin

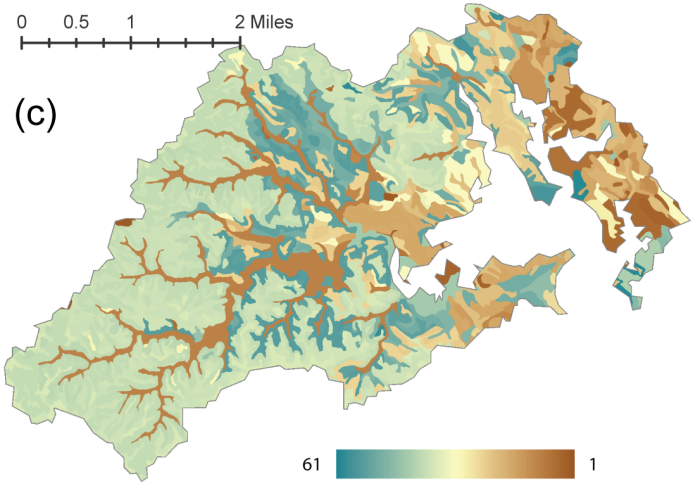


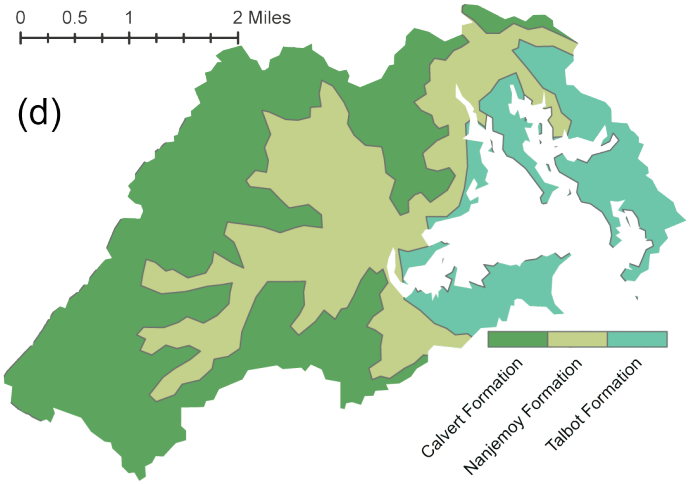
AREA = 38 sq. km. (5.06 sq. km. estuarine)

Geospatial Input Data









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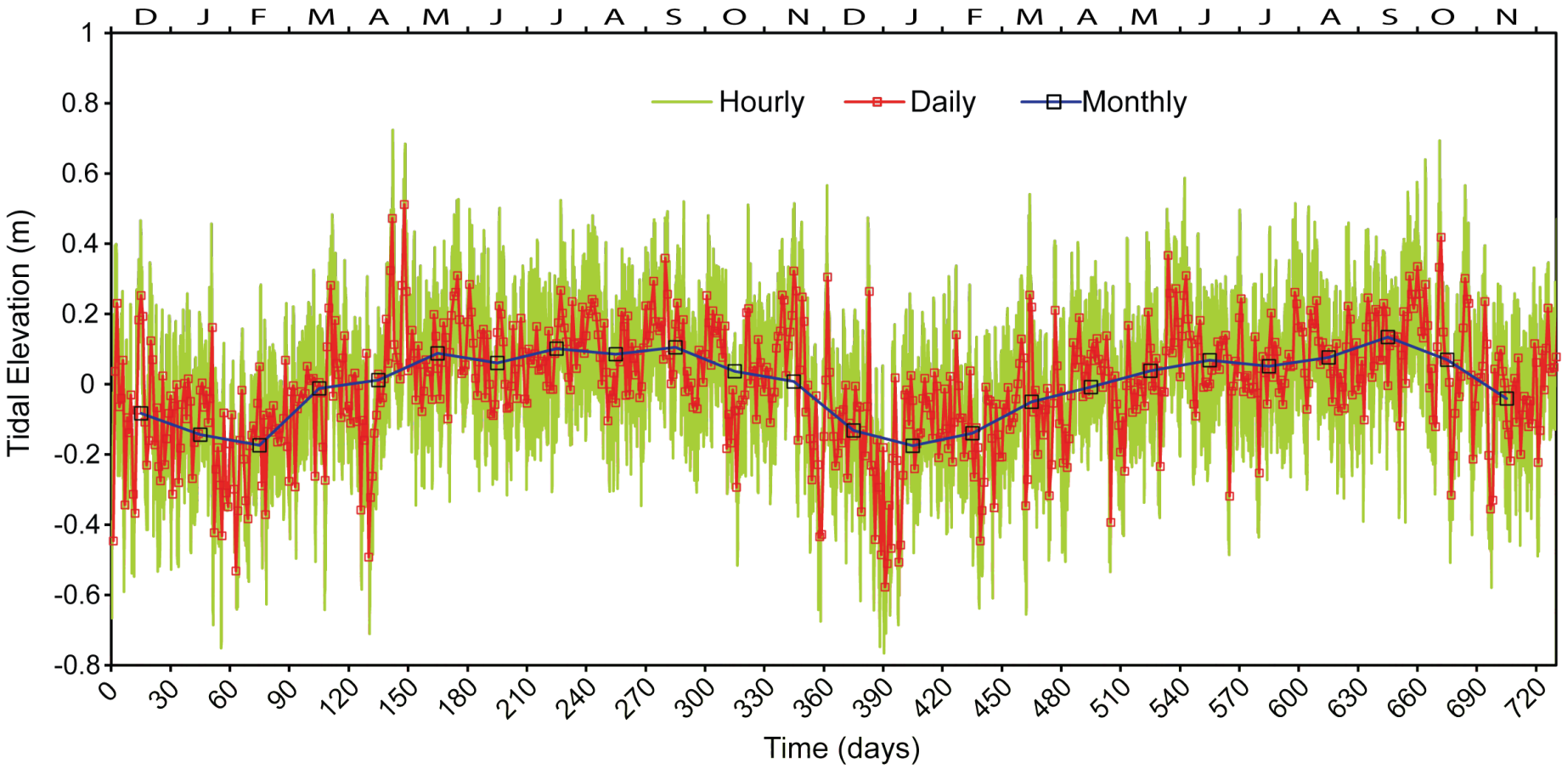
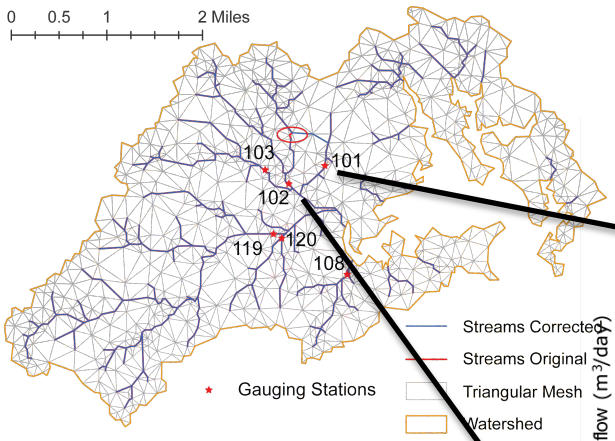
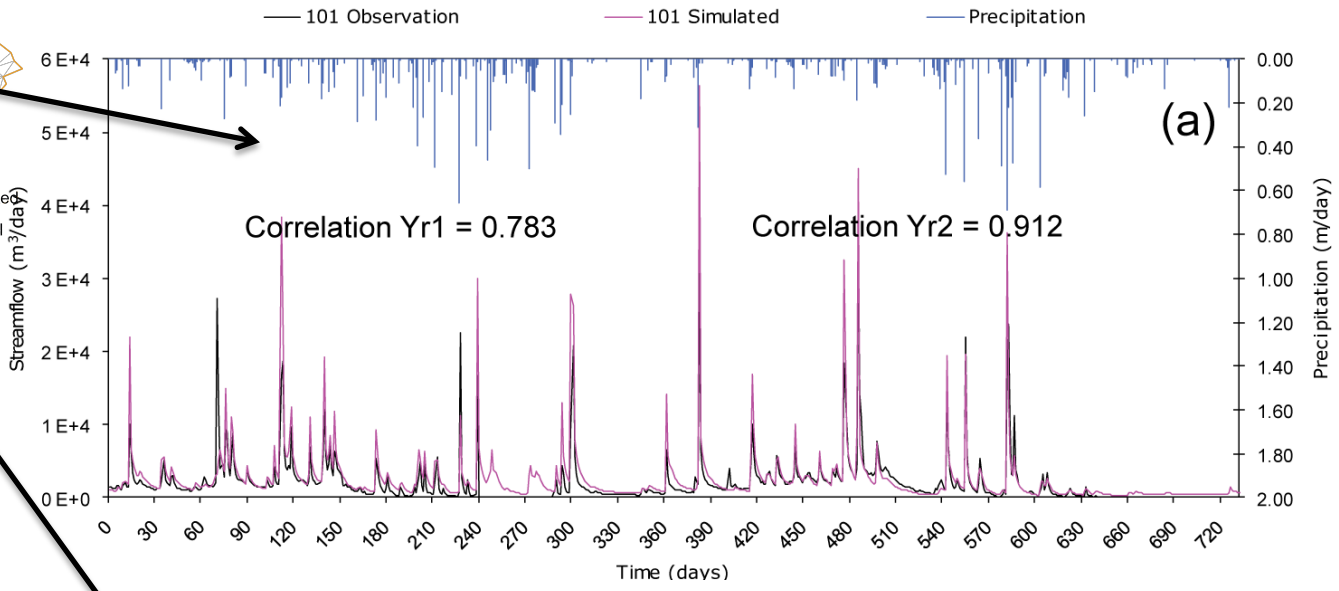
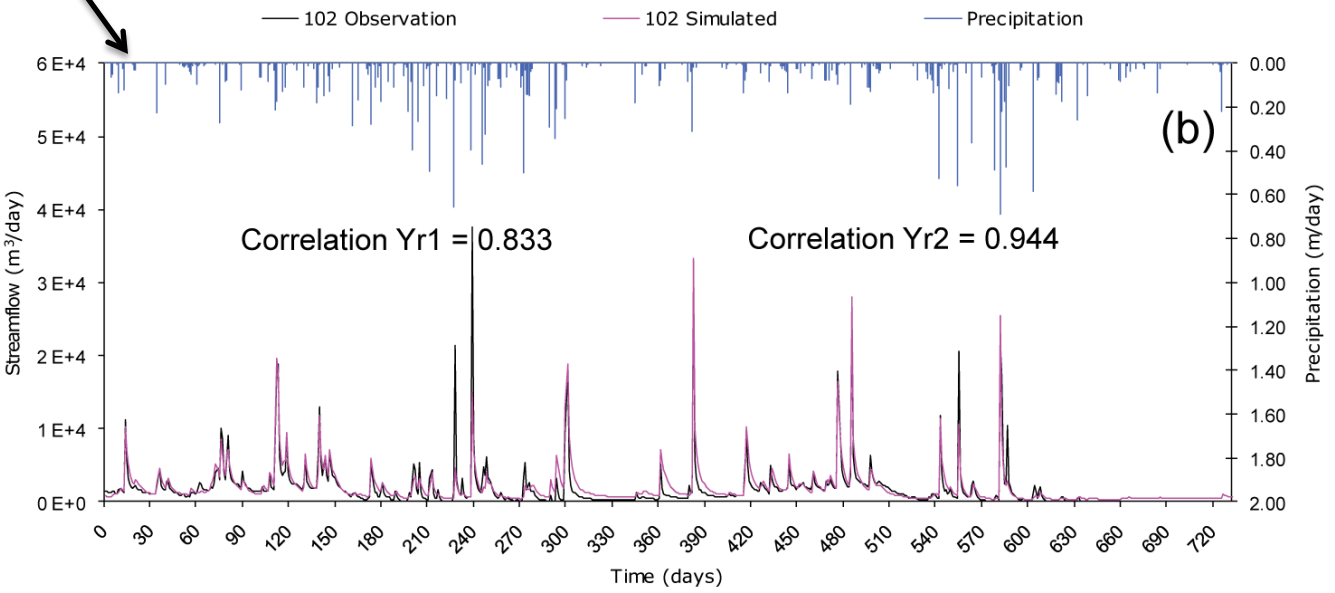
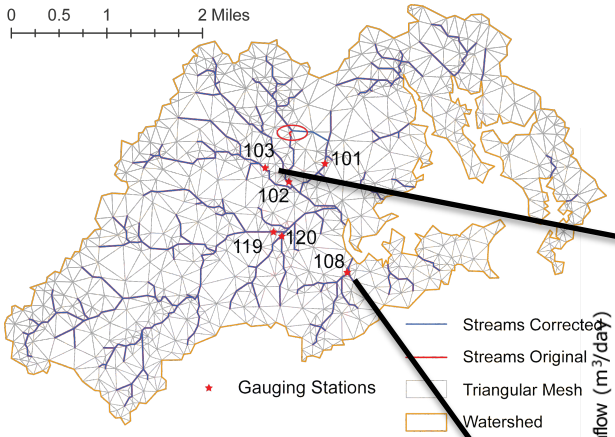
Model Tidal Forcing …

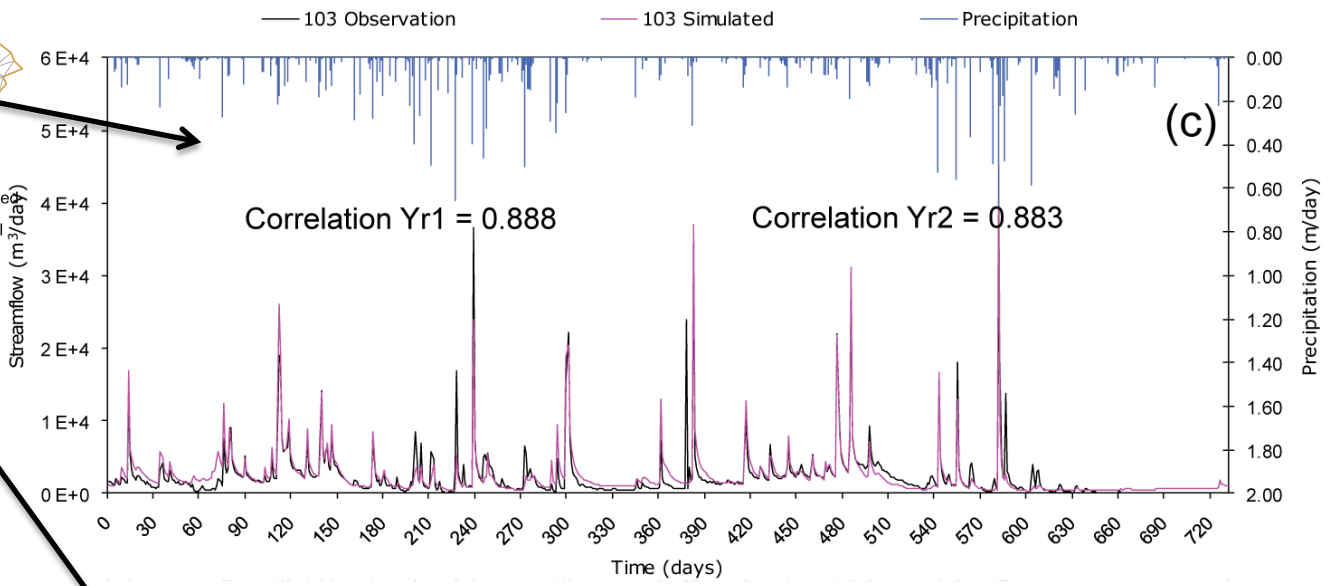


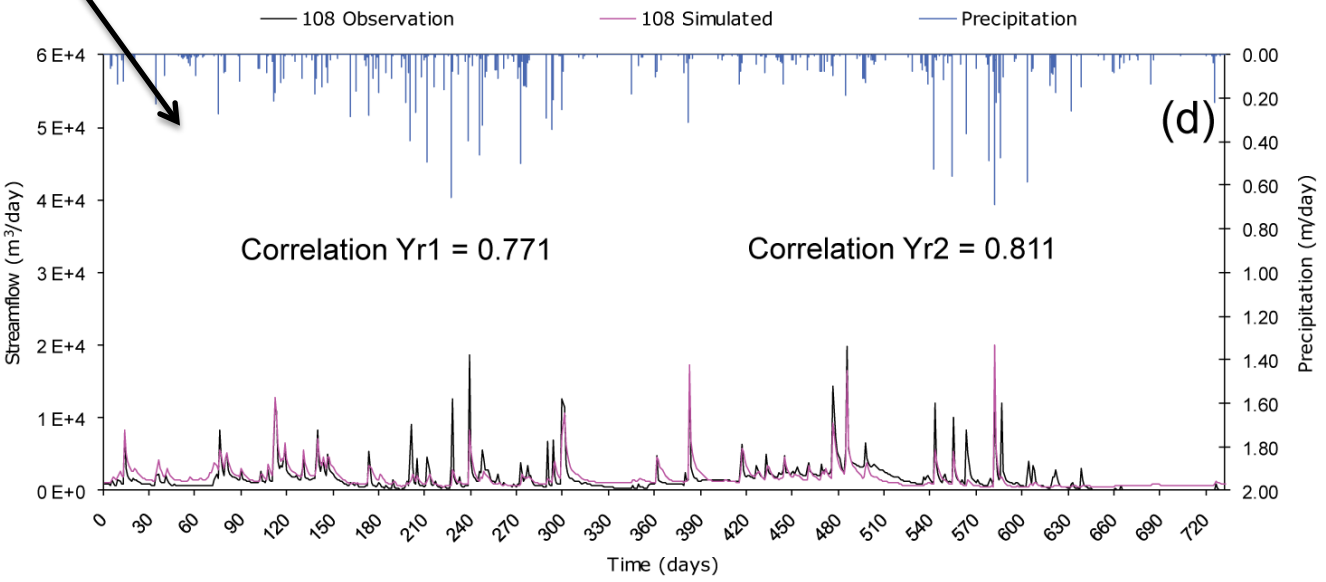

0 0.5 1 2 Miles
103
101
102
119
120
108
Streams Corrected
Streams Original
Triangular Mesh
Watershed
Gauging Stations


101 Observation
101 Simulated
Precipitation
(a)
Correlation Yr1 = 0.783
Correlation Yr2 = 0.912
Streamflow (m3/day)
Precipitation (m/day)
Time (days)

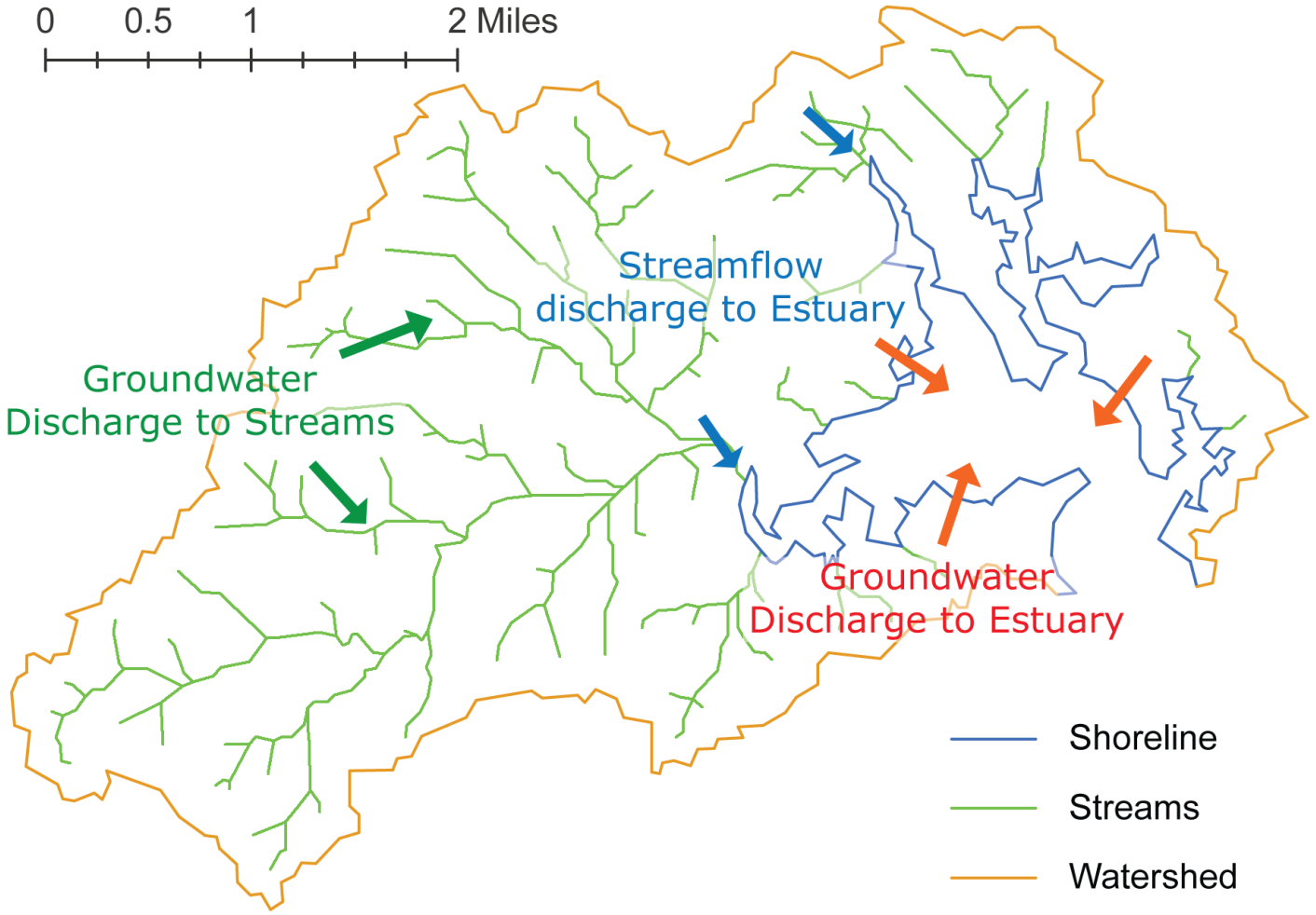

102 Observation
102 Simulated
Precipitation
(b)
Correlation Yr1 = 0.833
Correlation Yr2 = 0.944
Streamflow (m3/day)
Precipitation (m/day)
Time (days)


0 0.5 1 2 Miles
103
101
102
120
119
108
Streams Corrected
Streams Original
Triangular Mesh
Watershed
Gauging Stations

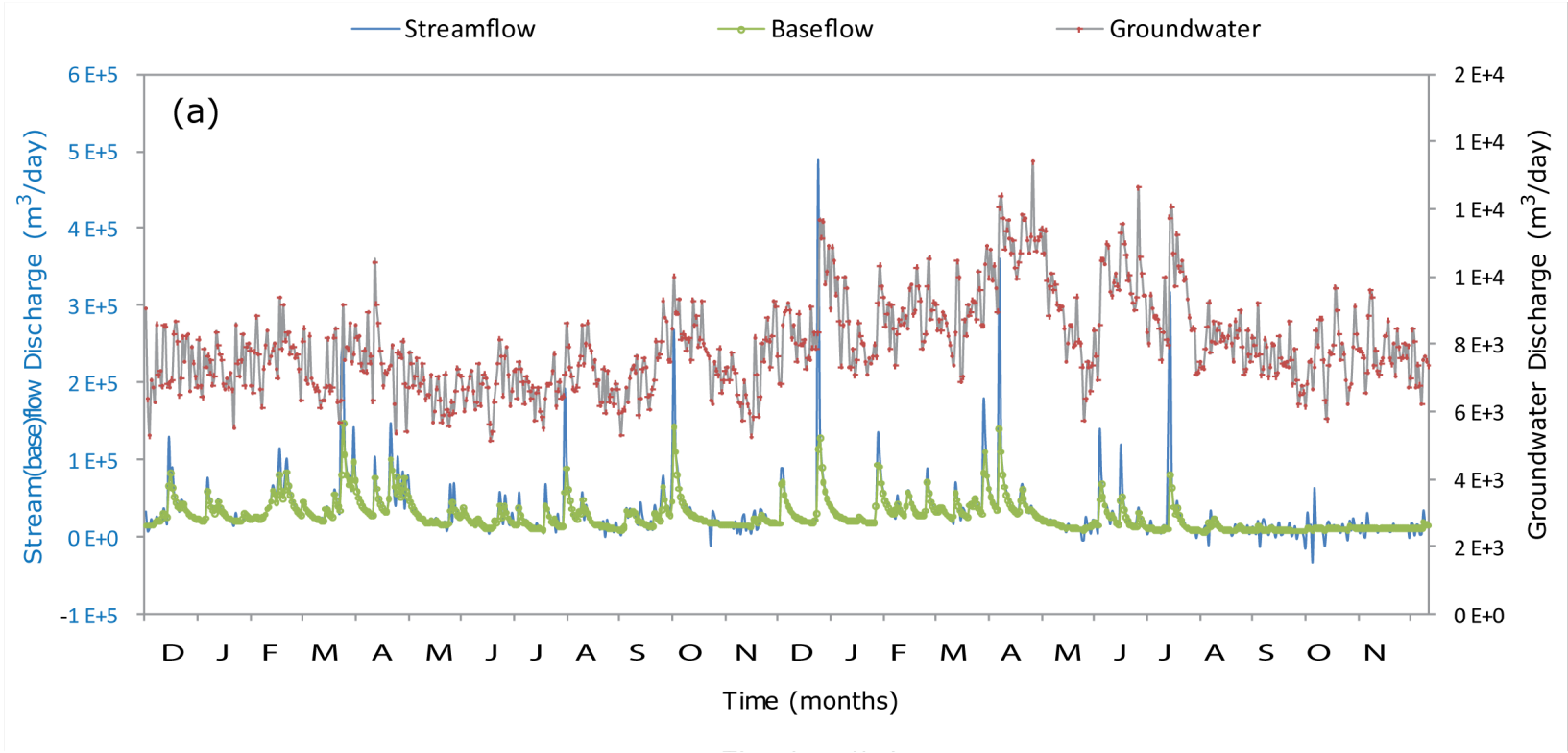

103 Observation
103 Simulated
Precipitation
(c)
Correlation Yr1 = 0.888
Correlation Yr2 = 0.883
Streamflow (m3/day)
Precipitation (m/day)
Time (days)

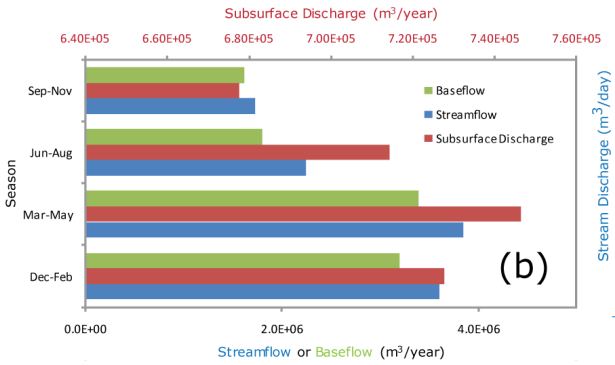

108 Observation
108 Simulated
Precipitation
(d)
Correlation Yr1 = 0.771
Correlation Yr2 = 0.811
Streamflow (m3/day)
Precipitation (m/day)
Time (days)

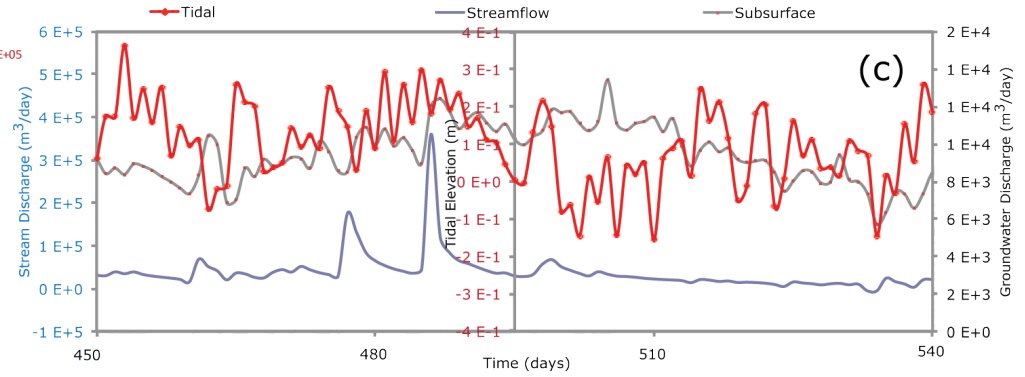
Sources of Freshwater Exchange



Simulated Freshwater Exchanges







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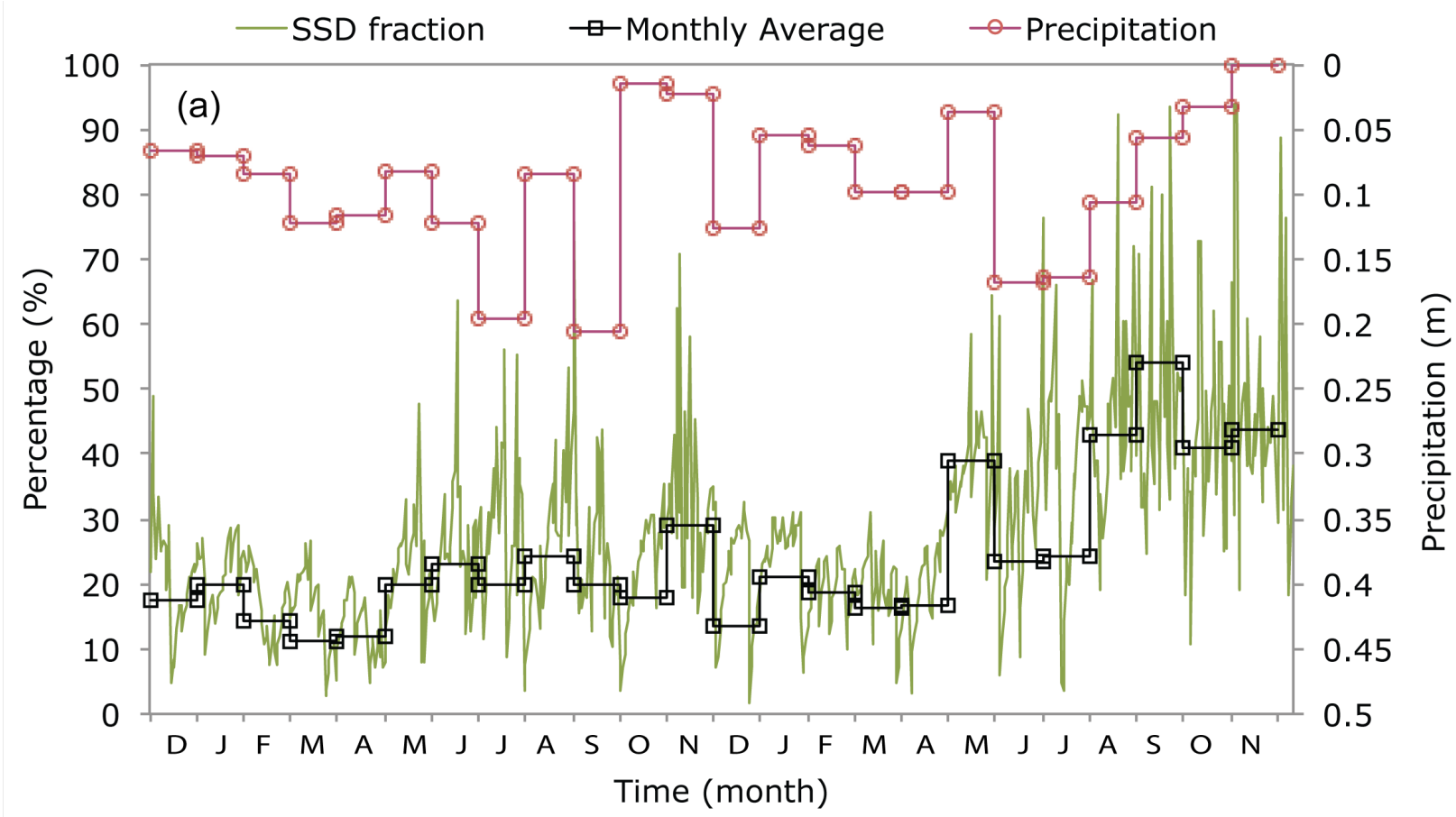
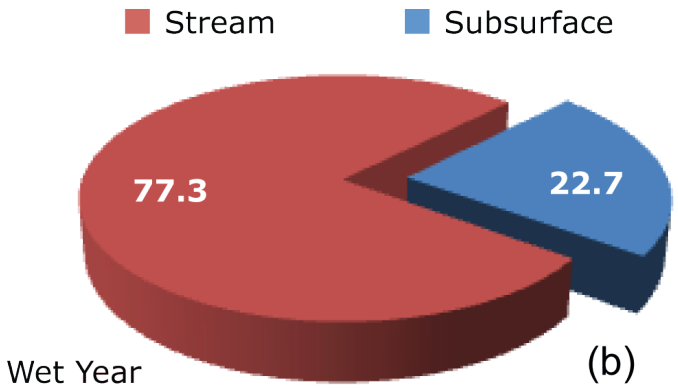
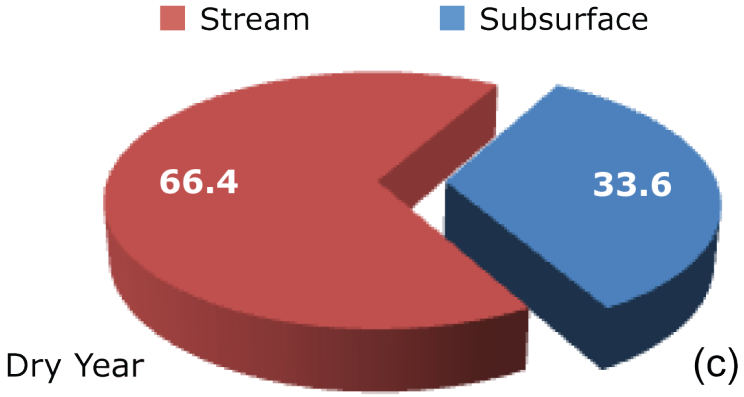
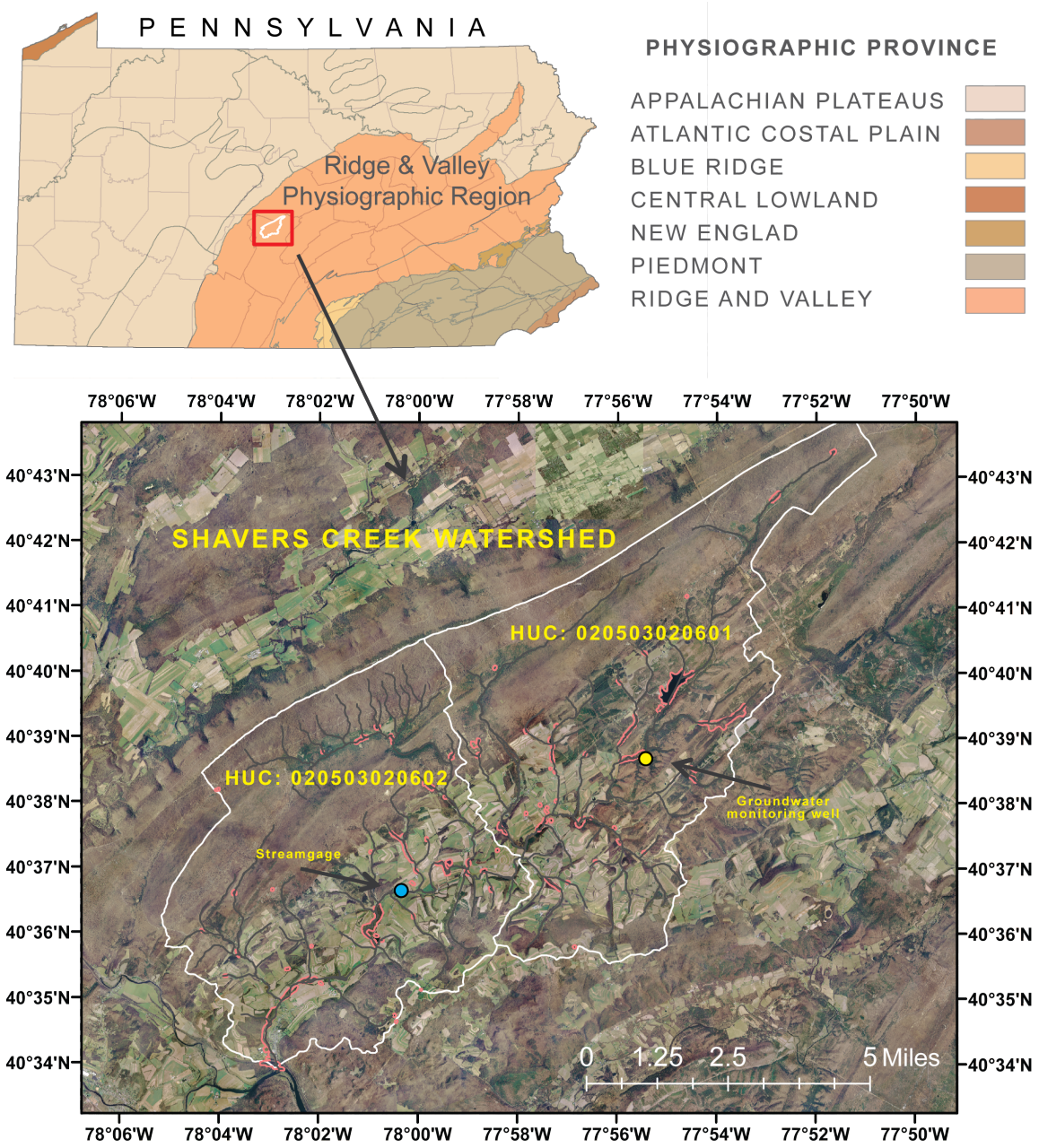

SSD fraction
Monthly Average
Precipitation
(a)
Percentage (%)
Precipitation (m)
Time (month)
D J F M A M J J A S O N D J F M A M J J A S O N
100 90 80 70 60 50 40 30 20 10 0
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5


Stream
Subsurface
77.3
22.7
Wet Year
(b)

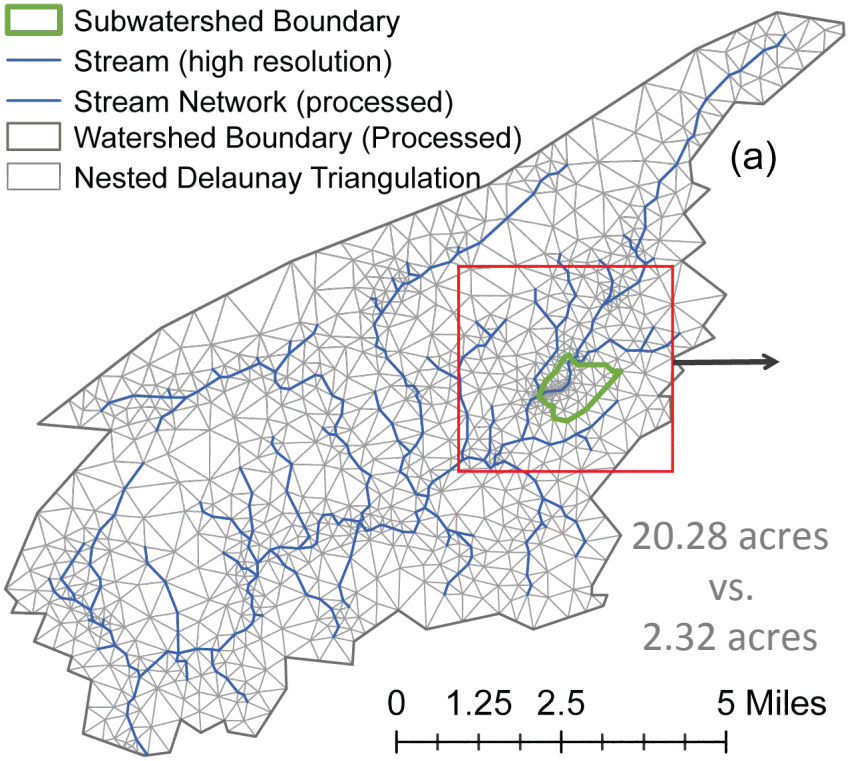

Stream
Subsurface
66.4
33.6
Dry Year
(c)

Example 2: Shavers Creek Watershed

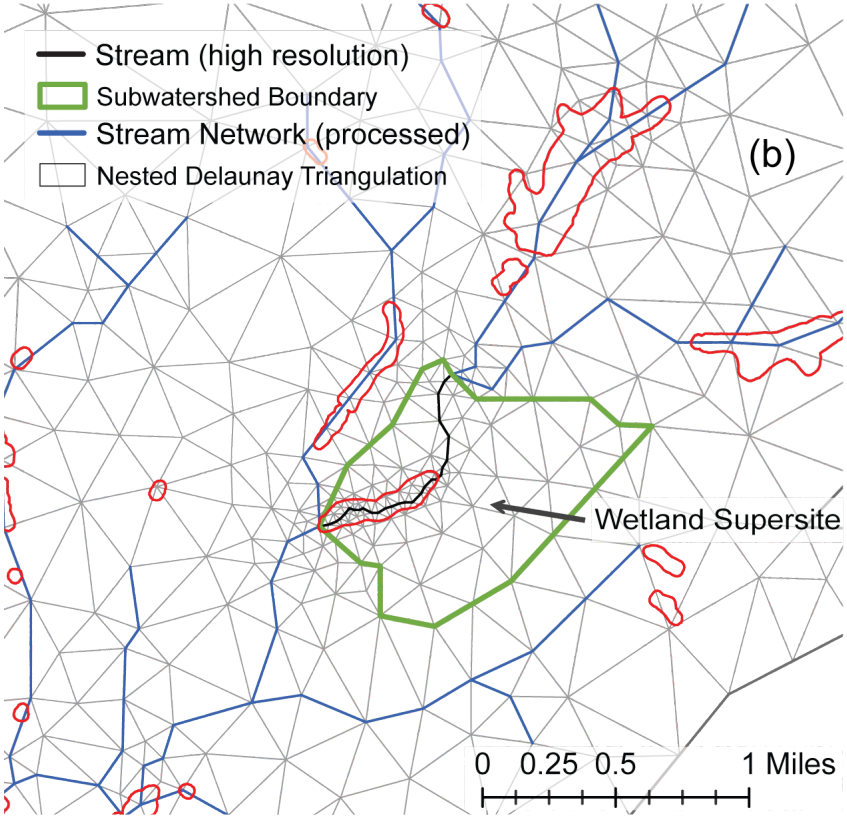


163 sq. km.

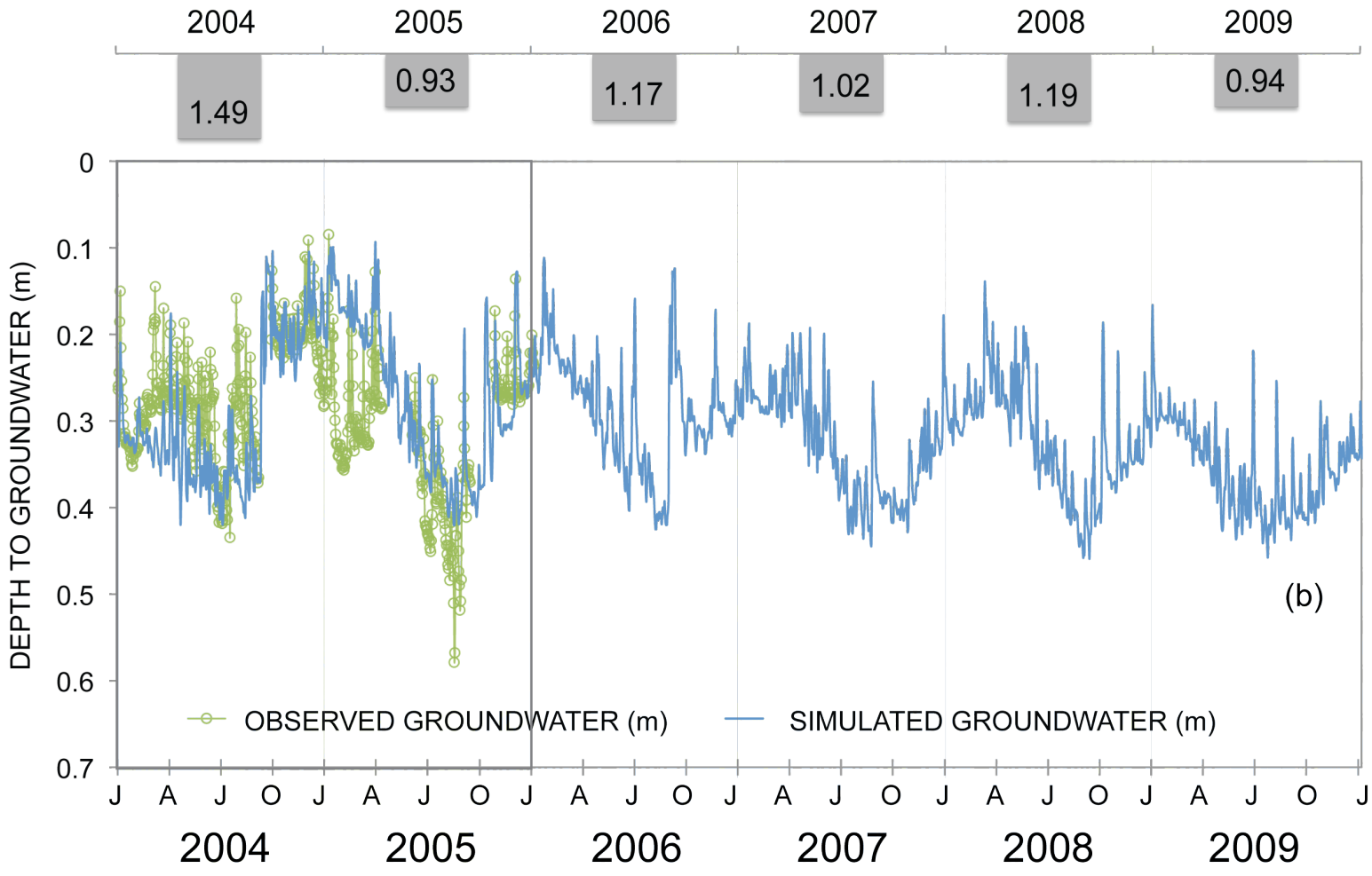
Nested Domain Decomposition



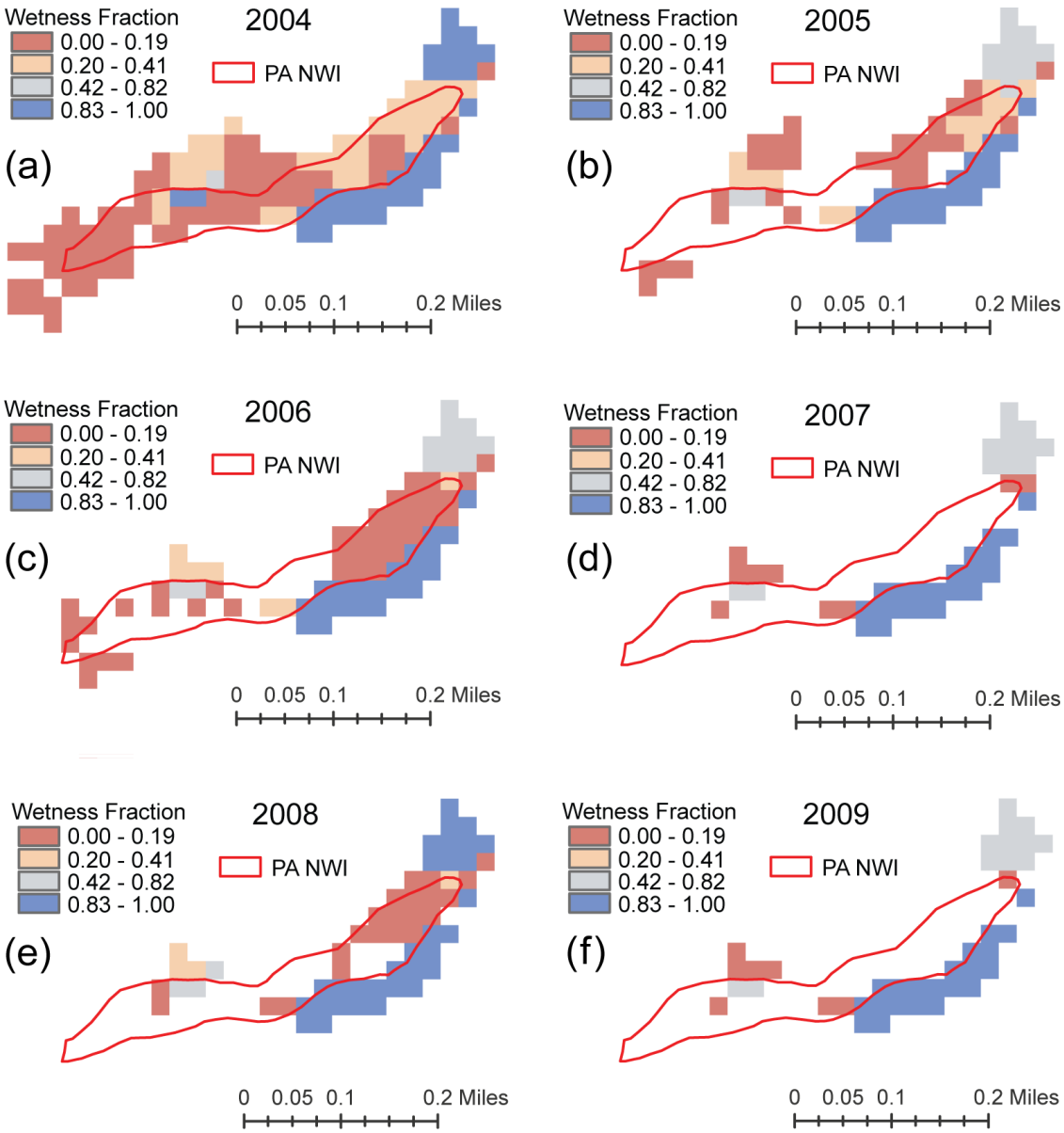
1986, 414



1986, 182, 75

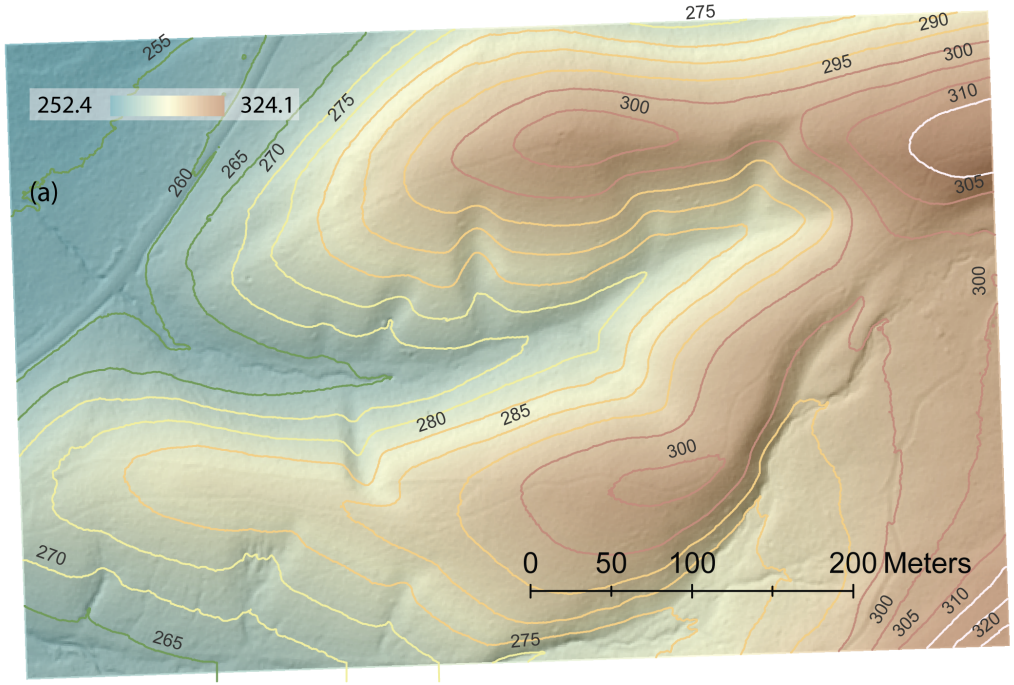

2004
2005
2006
2007
2008
2009
1.49
0.93
1.17
1.02
1.19
0.94
DEPTH TO GROUNDWATER (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
(b)
OBSERVED GROUNDWATER (m)
SIMULATED GROUNDWATER (m)
J A J O J A J O J A J O J A J O J A J O J A J O J
2004
2005
2006
2007
2008
2009

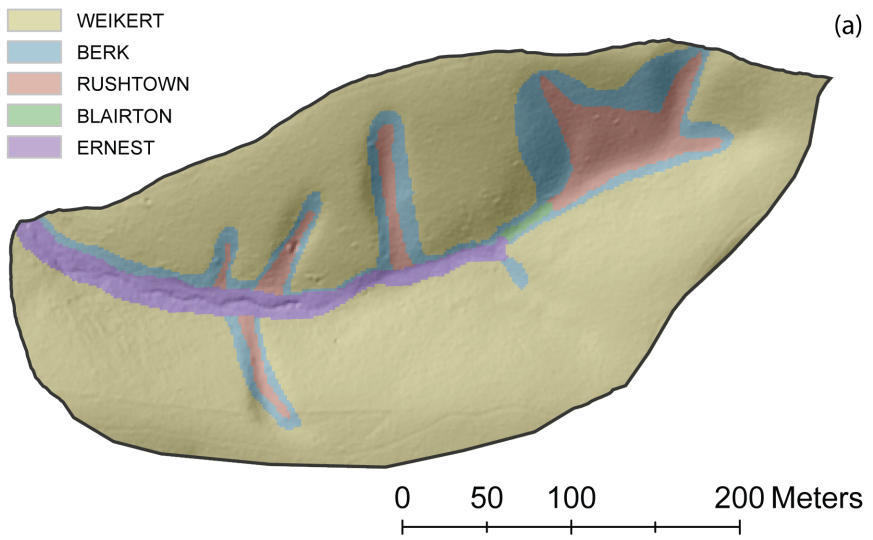
Inter-annual Dynamics of Wetland

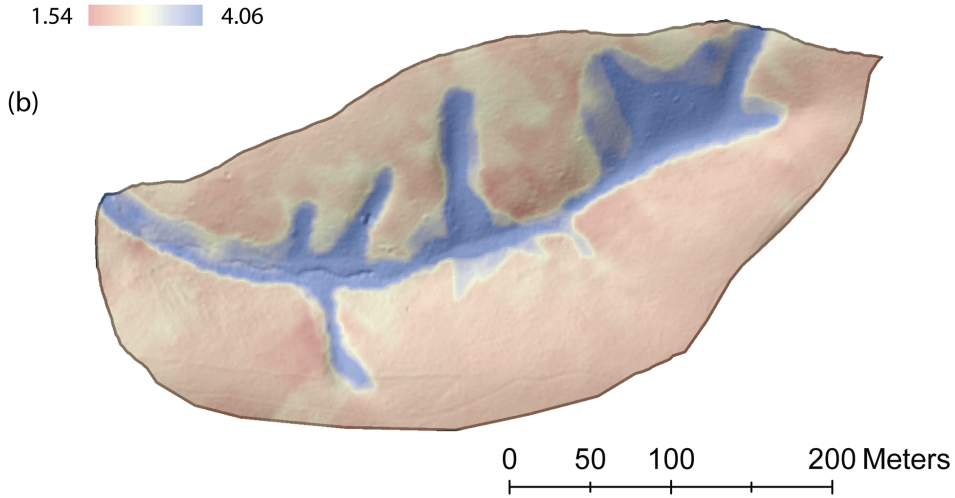


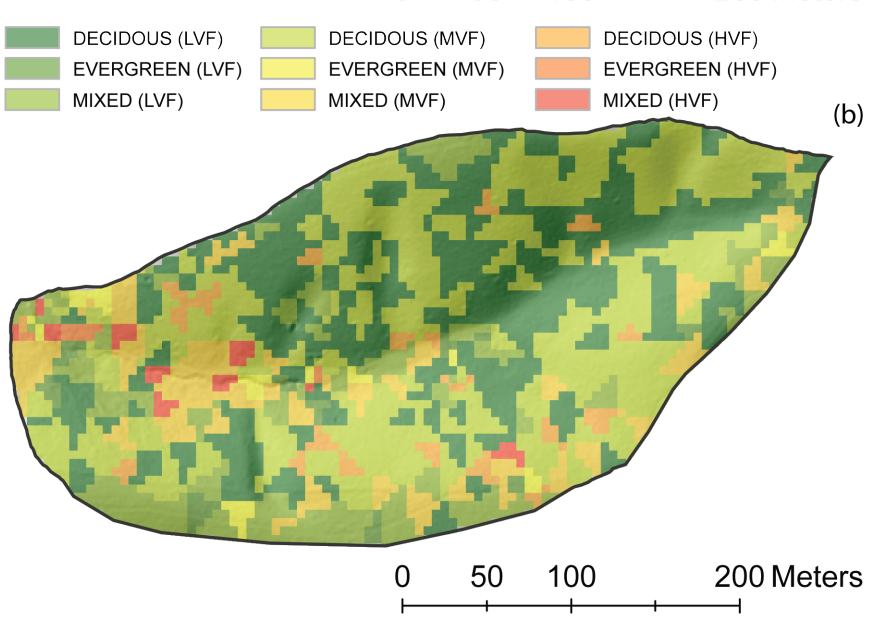
29.36, 17.57, 17.57, 9.34, 13.43 and 9.12 acres

Example 3: ShaleHills CZO









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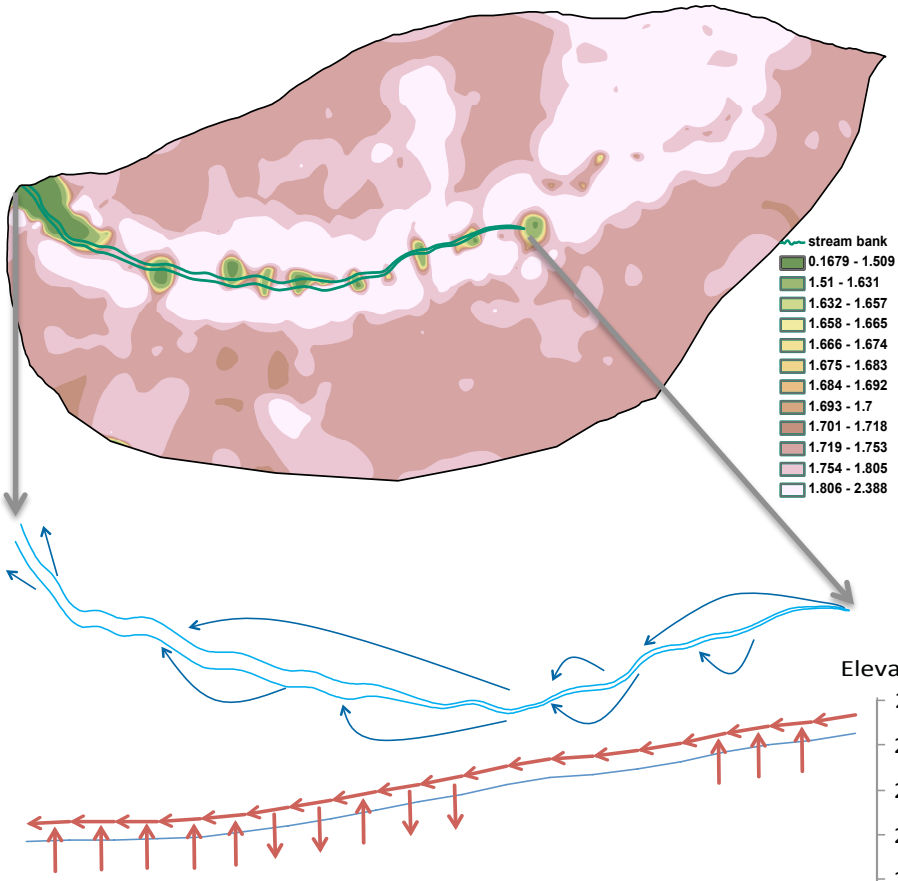
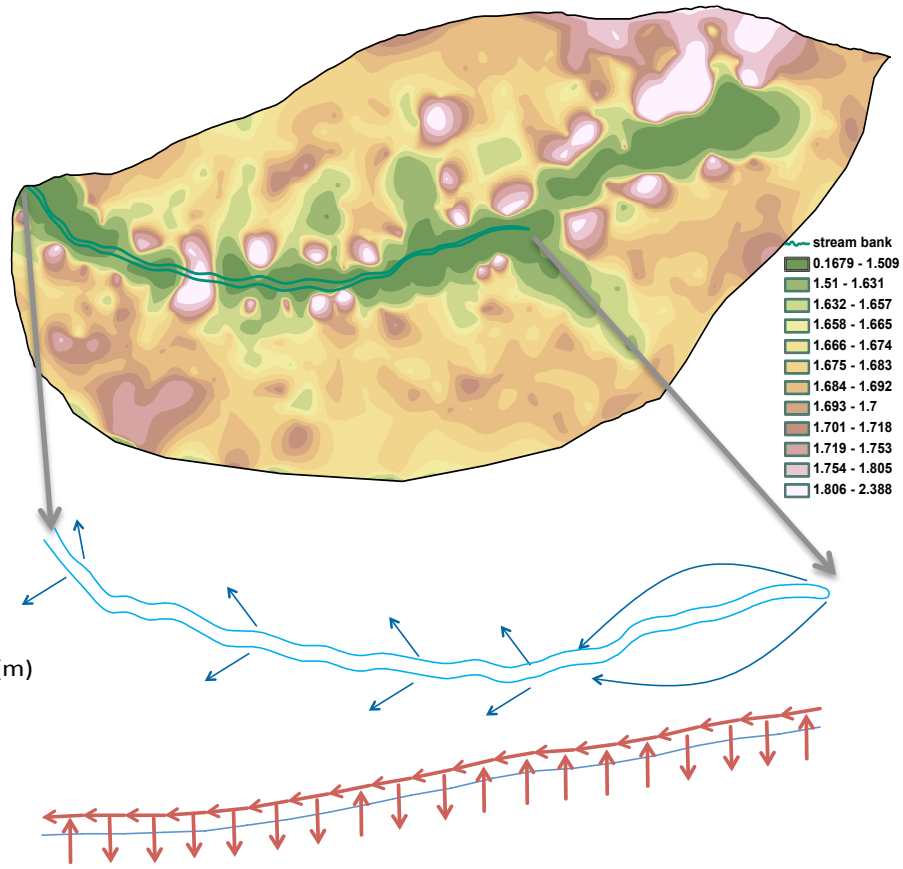
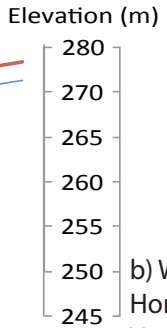
Comprehensive Hi-Res Geospatial Data

Hydrology: Hyporheic Exchange Flow







a) Dry watershed: Pre-event groundwater table depth and HEF path.
Horizontally, HEF vaies (gaining/loosing) with stream reaches.
Vertically, some reaches have no exchange with the river beds.

b) Wet watershed: During-event groundwater table depth and HEF path.
Horizontally, the stream is mainly recharging the aquifer.
Vertically, all the reaches have dynamic HEF with the river beds.

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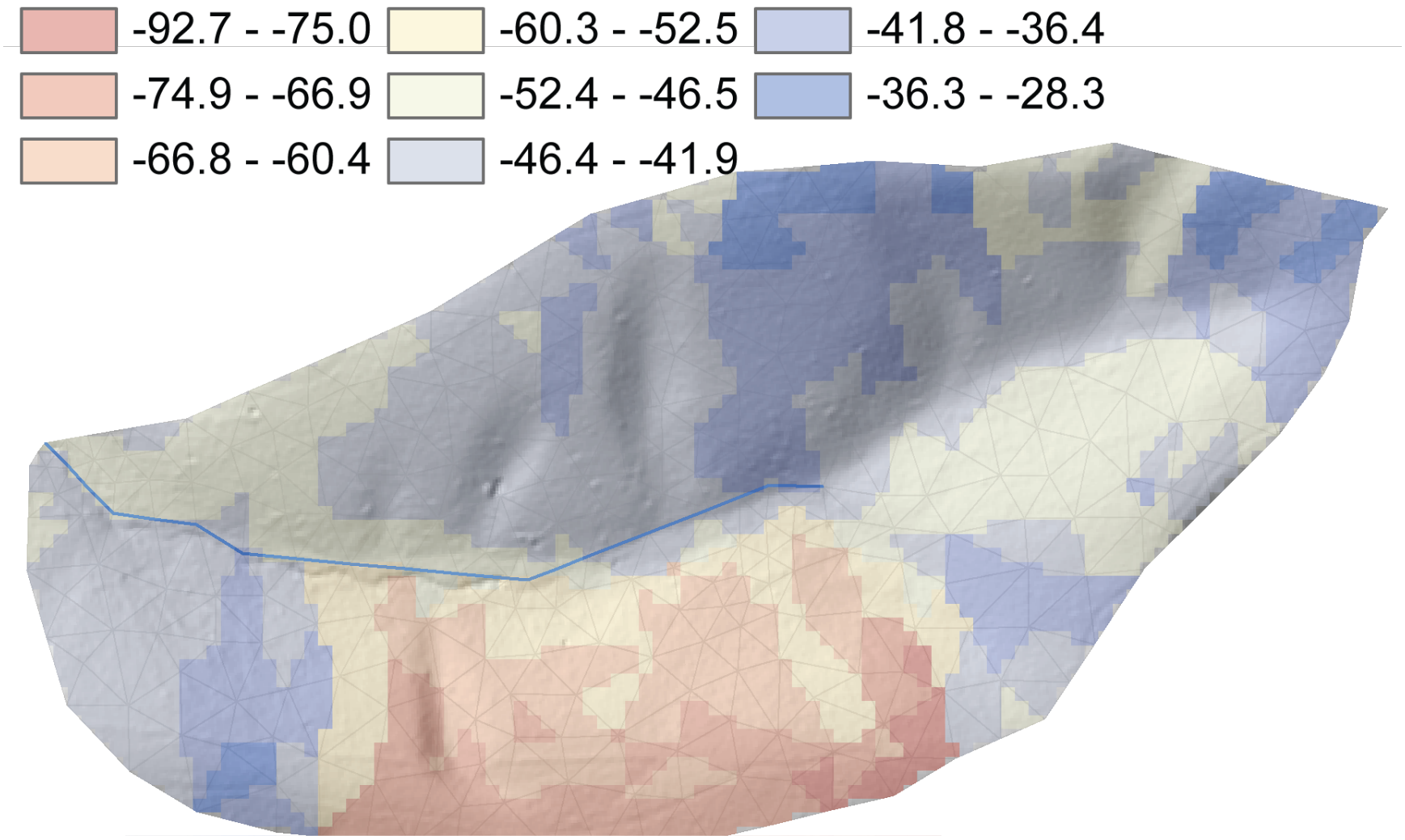
Yu, Bhatt, Duffy

Simulated Spatial Isotopic Ratio δ2H (2009-2010)



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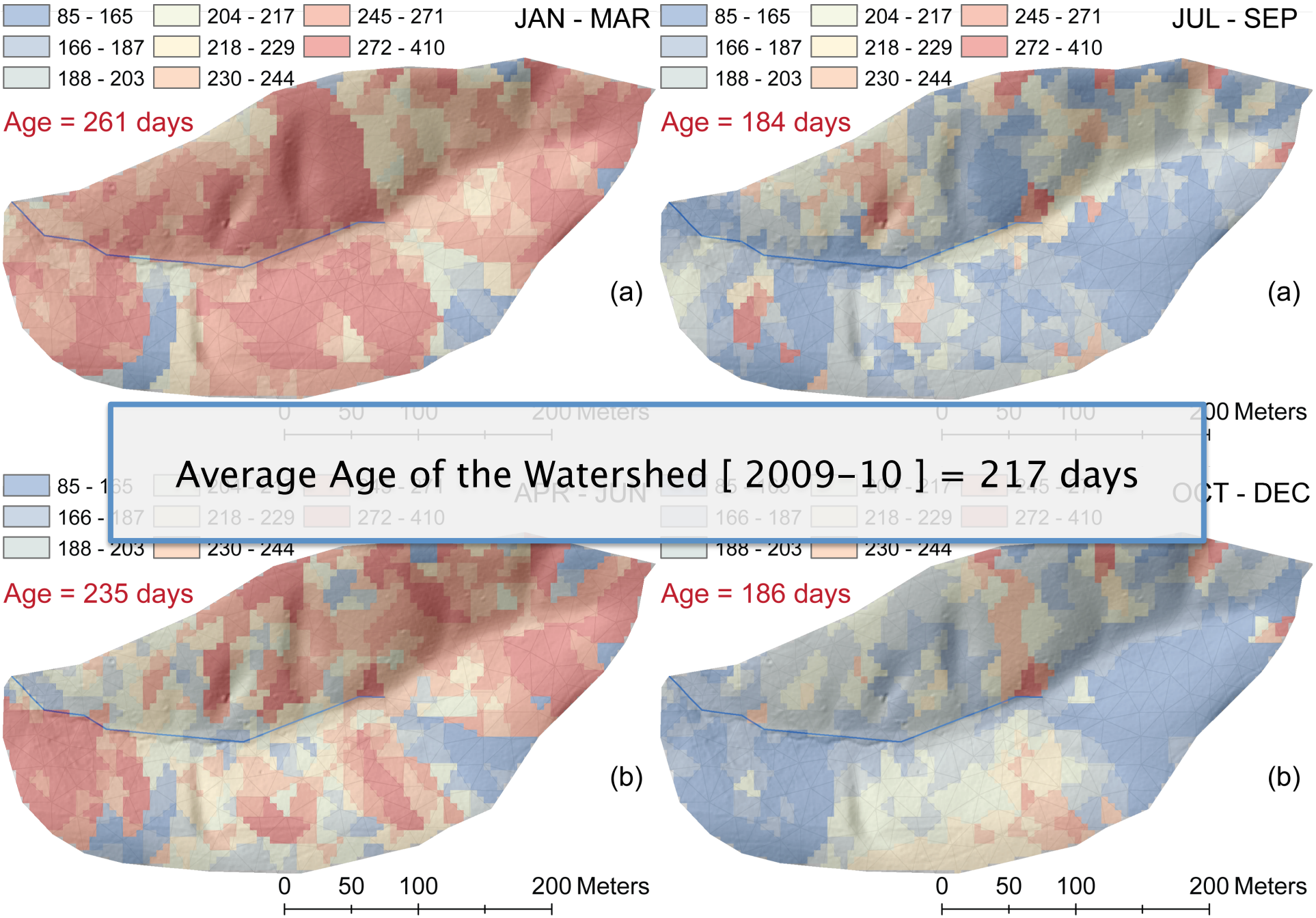

85 - 165
166 - 187
188 - 203
204 - 217
218 - 229
230 - 244
245 - 271
272 - 410
JAN - MAR
Age = 261 days
(a)
JUL - SEP
Age = 184 days
(a)
0 50 100 200 Meters
Average Age of the Watershed [2009-10] = 217 days
APR - JUN
Age = 235 days
(b)
OCT - DEC
Age = 186 days
(b)
0 50 100 200 Meters

- geospatial data from national data
- geodata data translator for catchment modeling

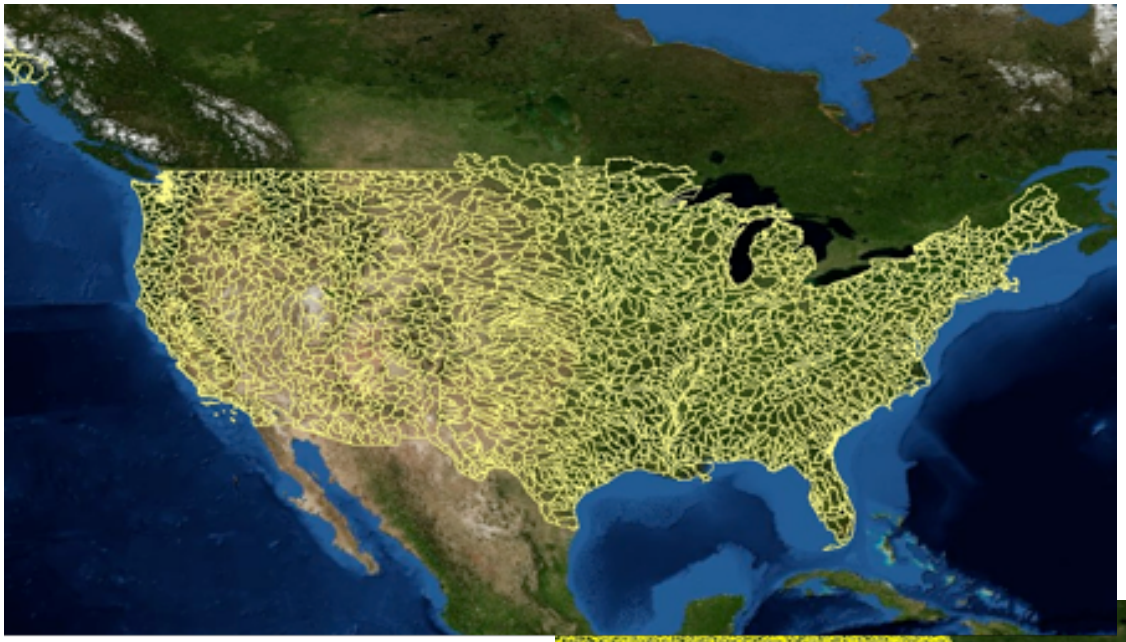
2. Accessing Geospatial Data

Essential Terrestrial Variables (ETVs)
for catchment modeling anywhere is CONUS

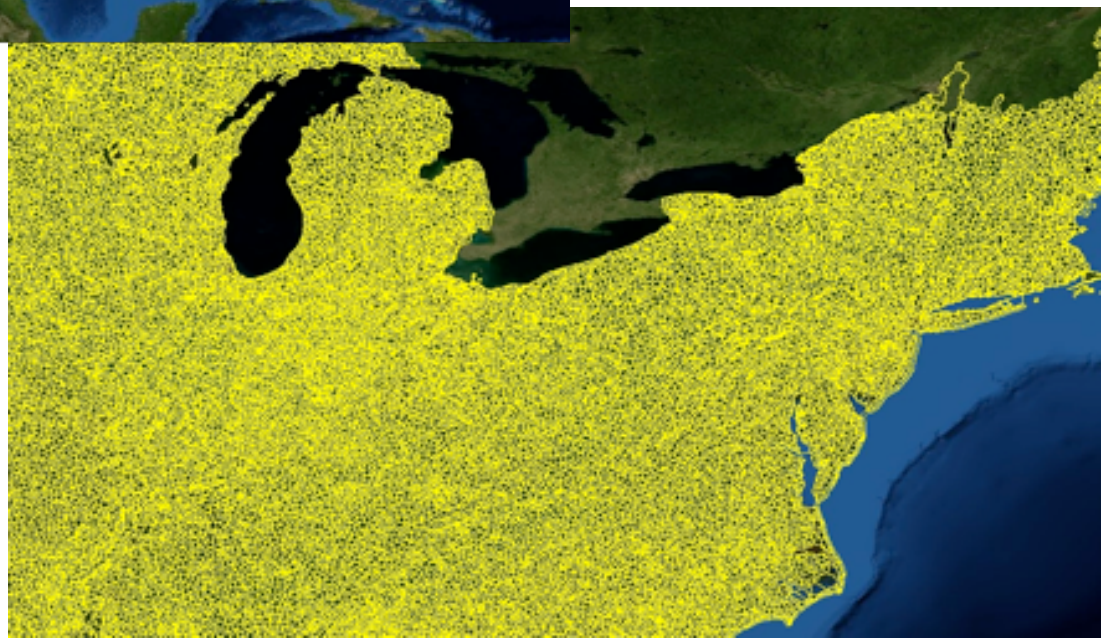
- Atmospheric Forcing (precipitation, snow cover, wind, relative humidity, temperature, net radiation, albedo, photosynthestic atmospheric radiation)
- Digital elevation models (30, 10, 3, 1m resolution)
- River/Stream discharge, stage, cross-section
- Soil (texture, C/N, organic, hydrologic & thermal properties)
- Groundwater (levels, extent, hydrogeologic properties, 3D Architecture)
- Land Cover (biomass/leaf area index, phenology,…….)
- Land Use (human infrastructure, demography, ecosystem disturbance, property & political boundaries)
- Environmental Tracers- stable isotopes
- Water Use and Water Transfers
- Lake/Reservoir/Diversion (levels, extent, discharge, operating rules)
- … and more …

Lorne and Duffy 2013

The Hydrologic Unit Code (HUC) as a basis for Catchment Model-Data Sharing



2,268 USGS HUC 8 watersheds



103,444 USGS HUC 12 watersheds

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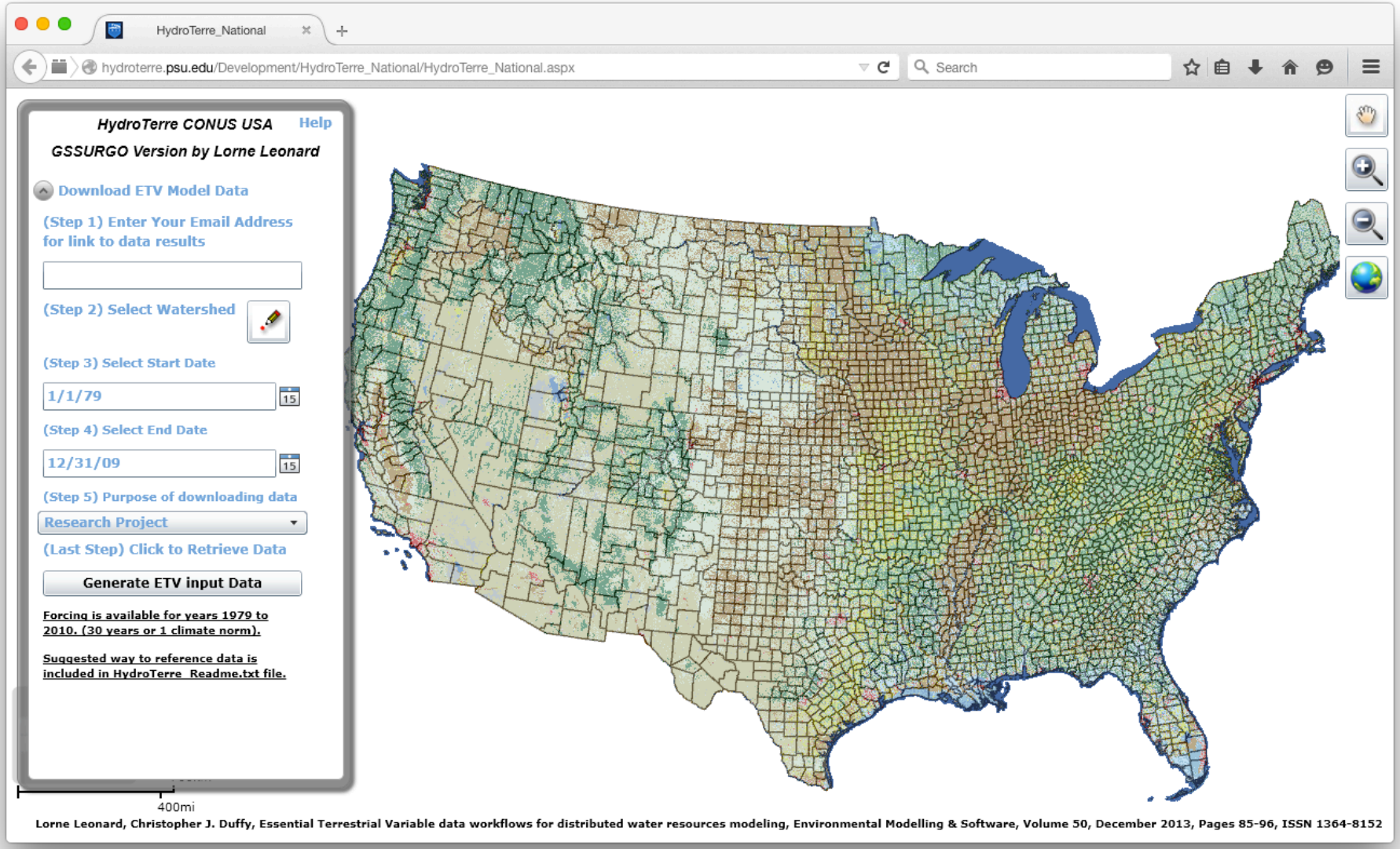
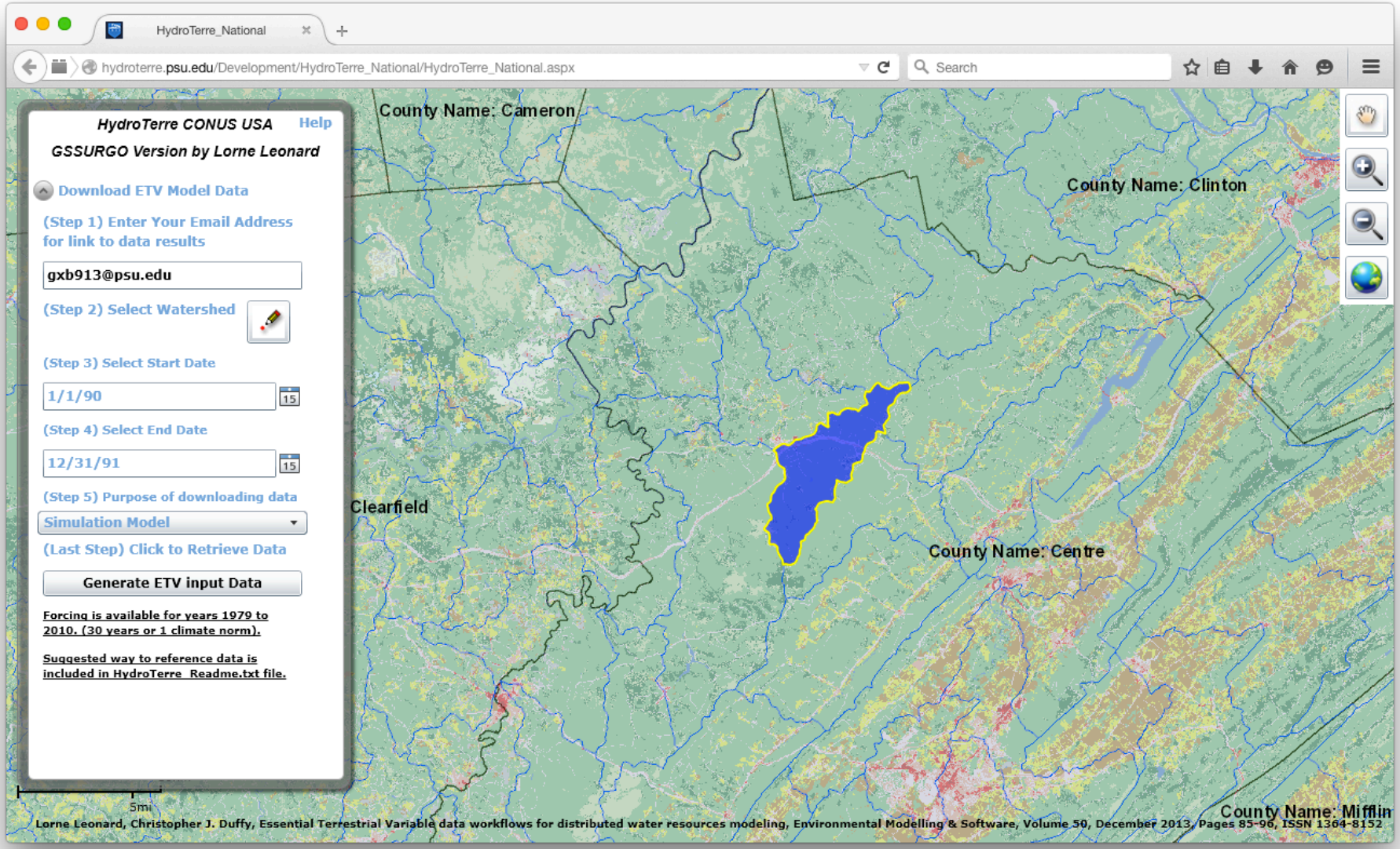
HydroTerre: **http://hydroterre.psu.edu/**



HydroTerre: **http://hydroterre.psu.edu/**



HydroTerre: High Resolution ETVs

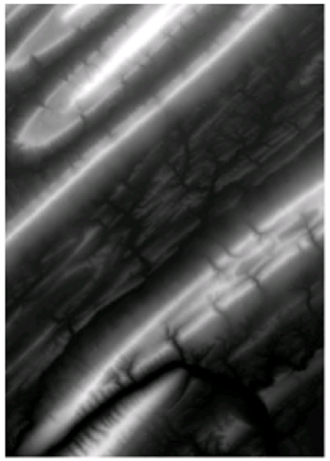
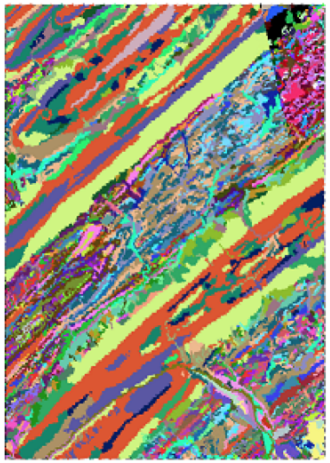
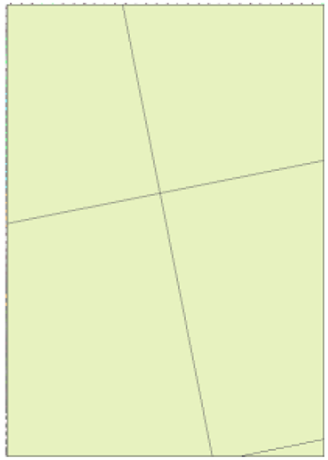
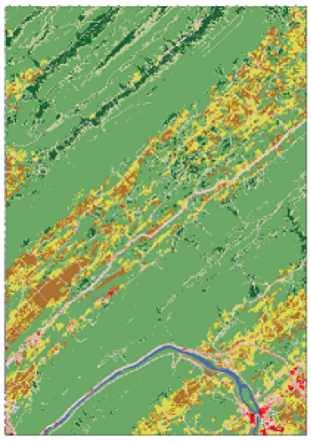
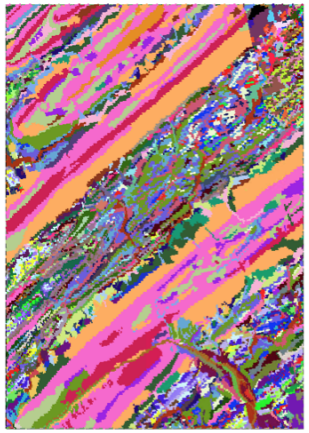
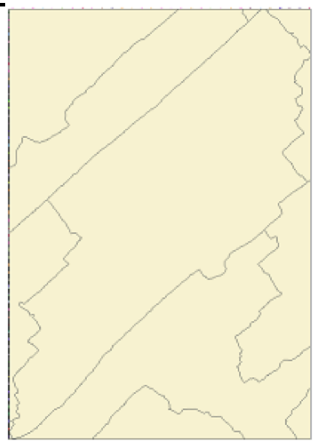
NED Elevation from USGS	Soils using SSURGO from USDA	Soils from Statsgo from USDA	NLDAS Climate Forcing Variables from NASA
			
National Land Cover (NLCD) from USGS	**Geology based on Soils from USDA**	**NHD HUC12 from USGS**	**NHD Streams from USGS**
			

Figure 1: HydroTerre Essential Terrestrial Variables data and data sources

HydroTerre Data Conversion Tool

http://www.pihm.psu.edu/HydroTerre-demo.pdf

An open source JAVA and Shell Script tool

(1) Convert the raster data in GeoTiff to ARC ASCII Grid File.

(2) Parse forcing data from XML format to PIHM support format

(3) Compute Leaf Area Index (LAI) and Roughness length (RL) time series.

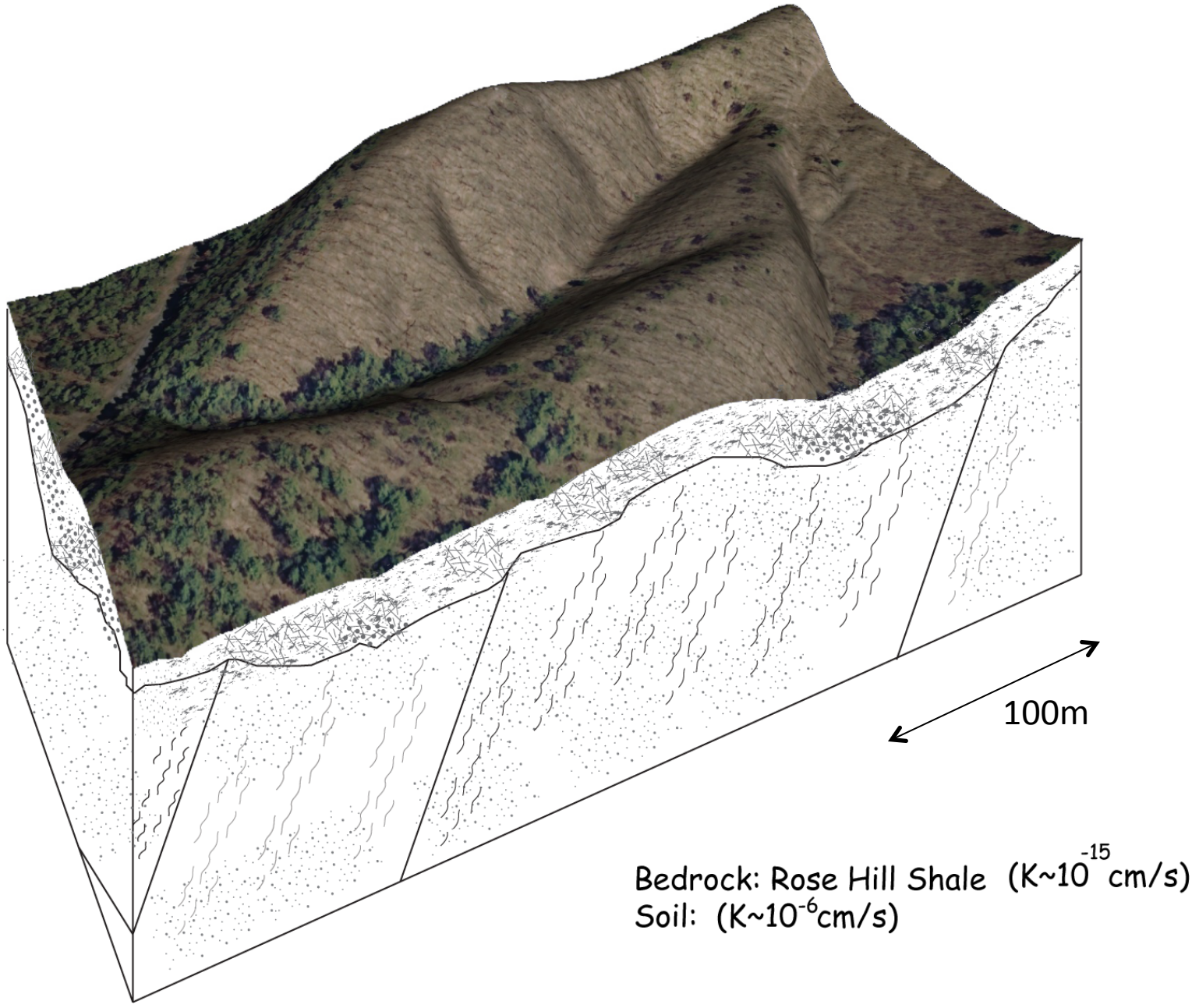
- Download & Install PIHMgis* and GIS Software

- PIHMgis Workflow
  - setup the model for a catchment
  - run the model simulation
  - analyze the model results

*** http://tiny.cc/pihmgis**

3. Catchment Modeling using PIHM/PIHMgis

The Shale Hills Critical Zone Observatory



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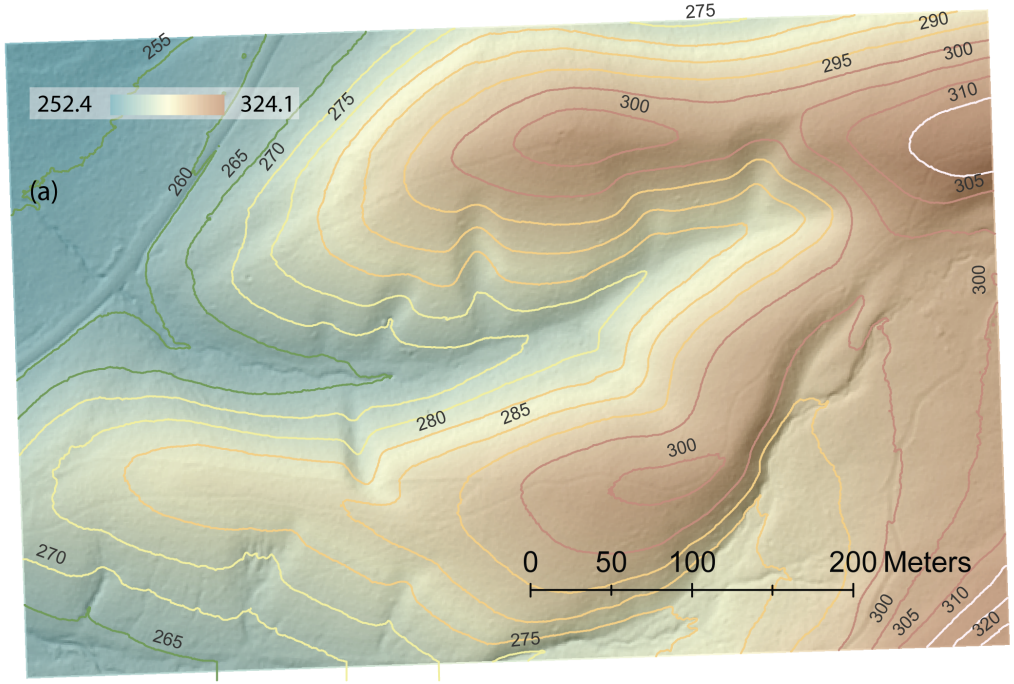
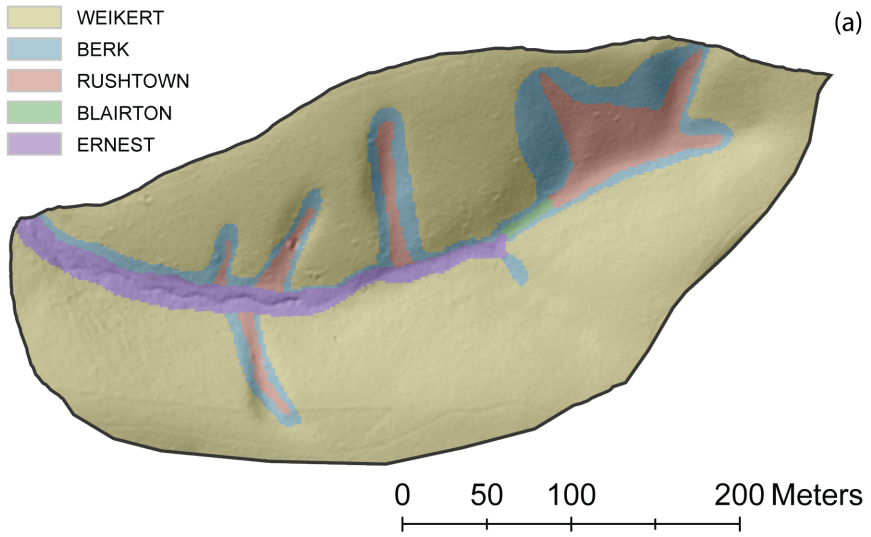
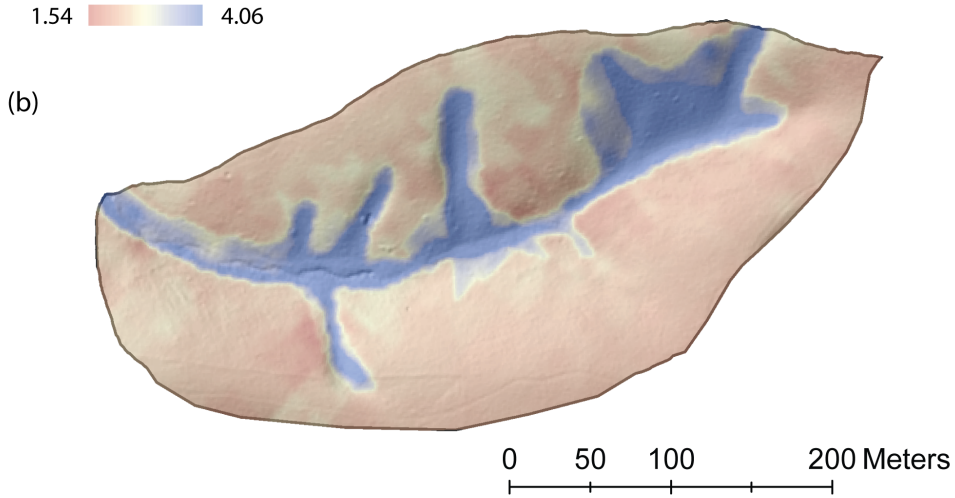
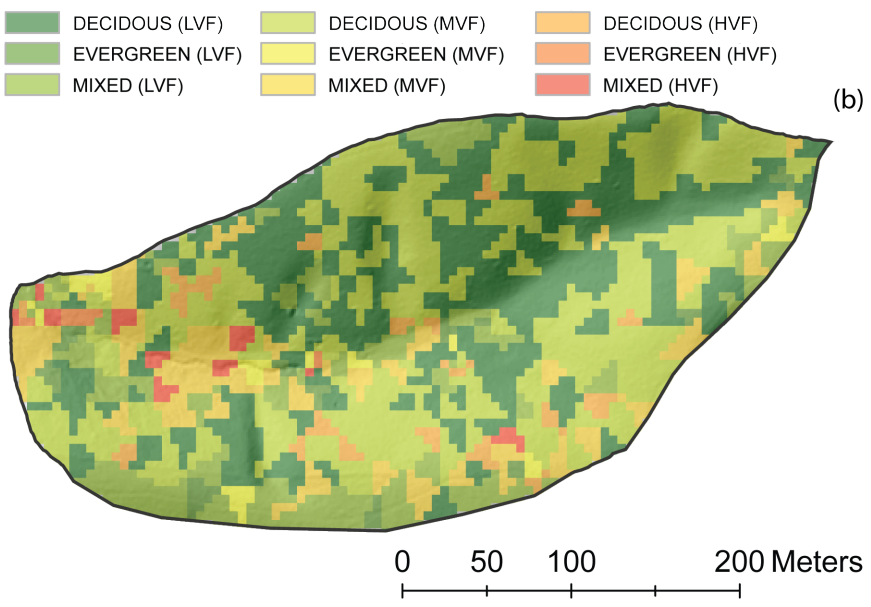
Geospatial Dataset (Input)









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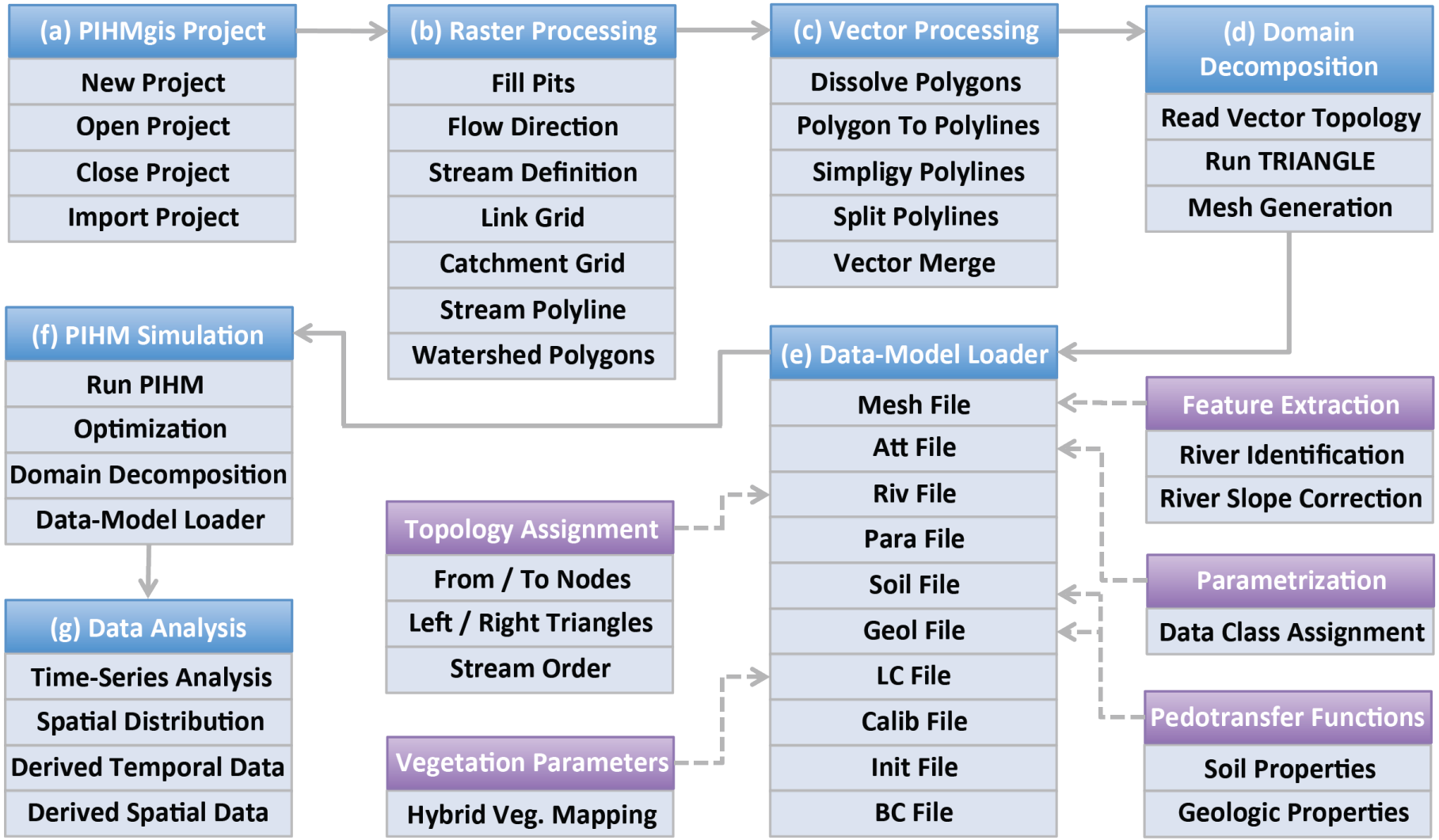
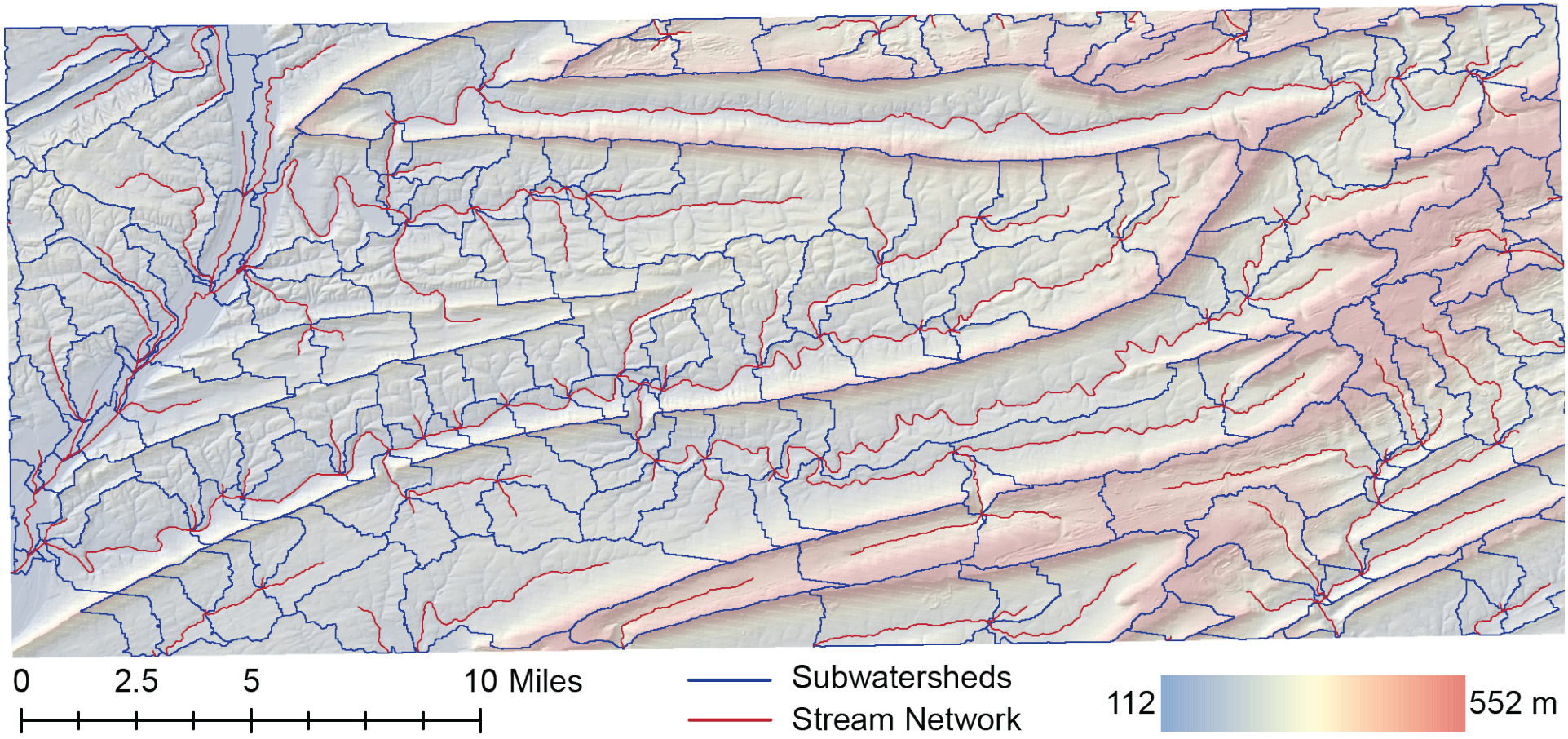
http://www.pihm.psu.edu/announcement_20150526.html

PIHMgis Procedural Workflow



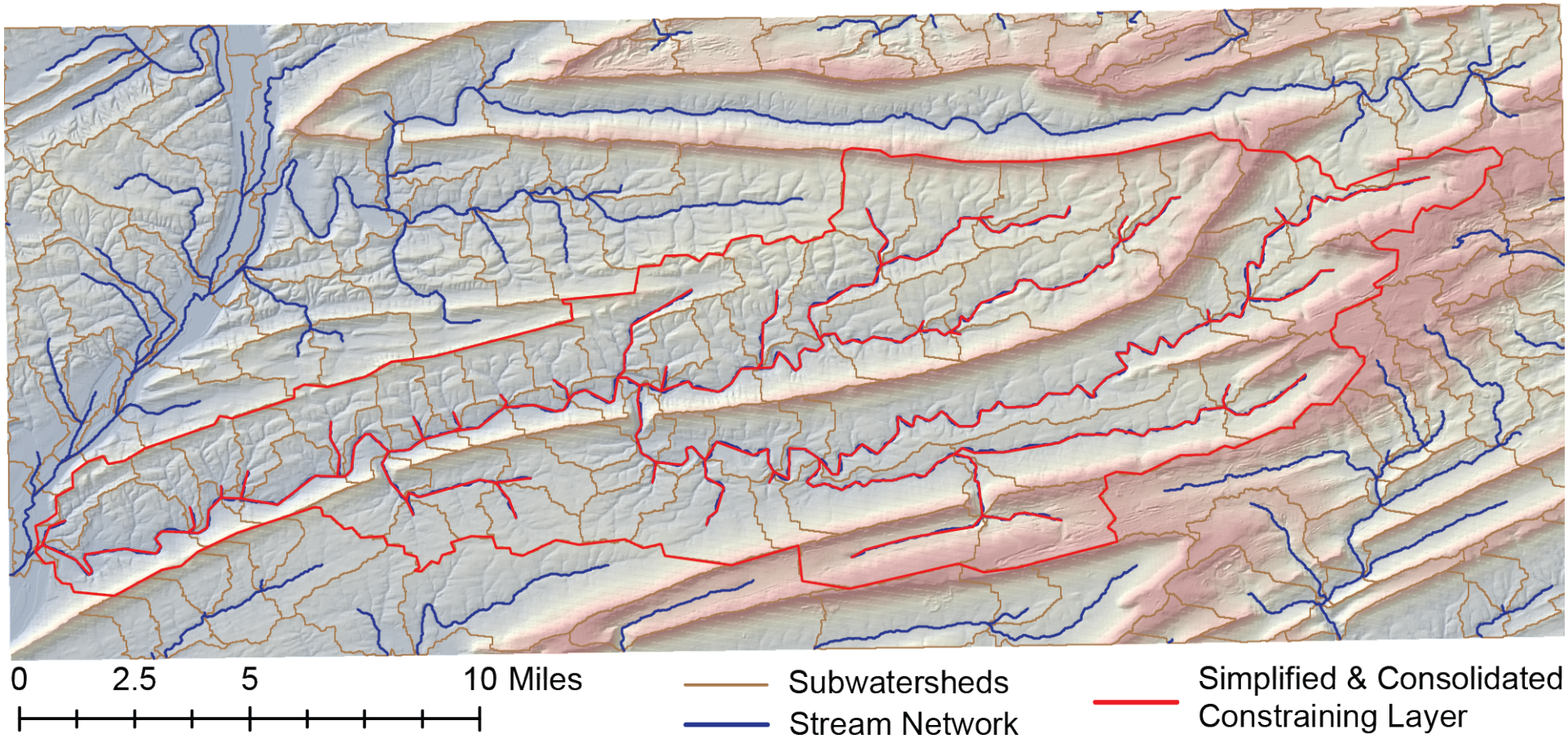
RASTER PROCESSING

A set of seven tools that is used for watershed delineation and stream definition from gridded topographic data.



VECTOR PROCESSING

A set of five tools provides flexibility to consolidate multiple geospatial layers (e.g., streams, watershed boundary) in form of line or point feature type.



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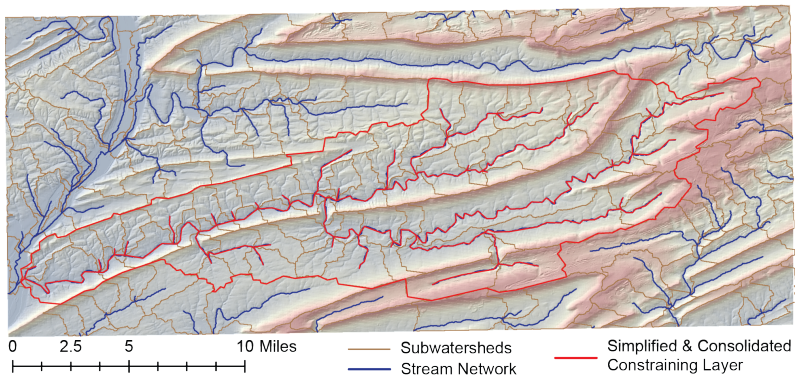
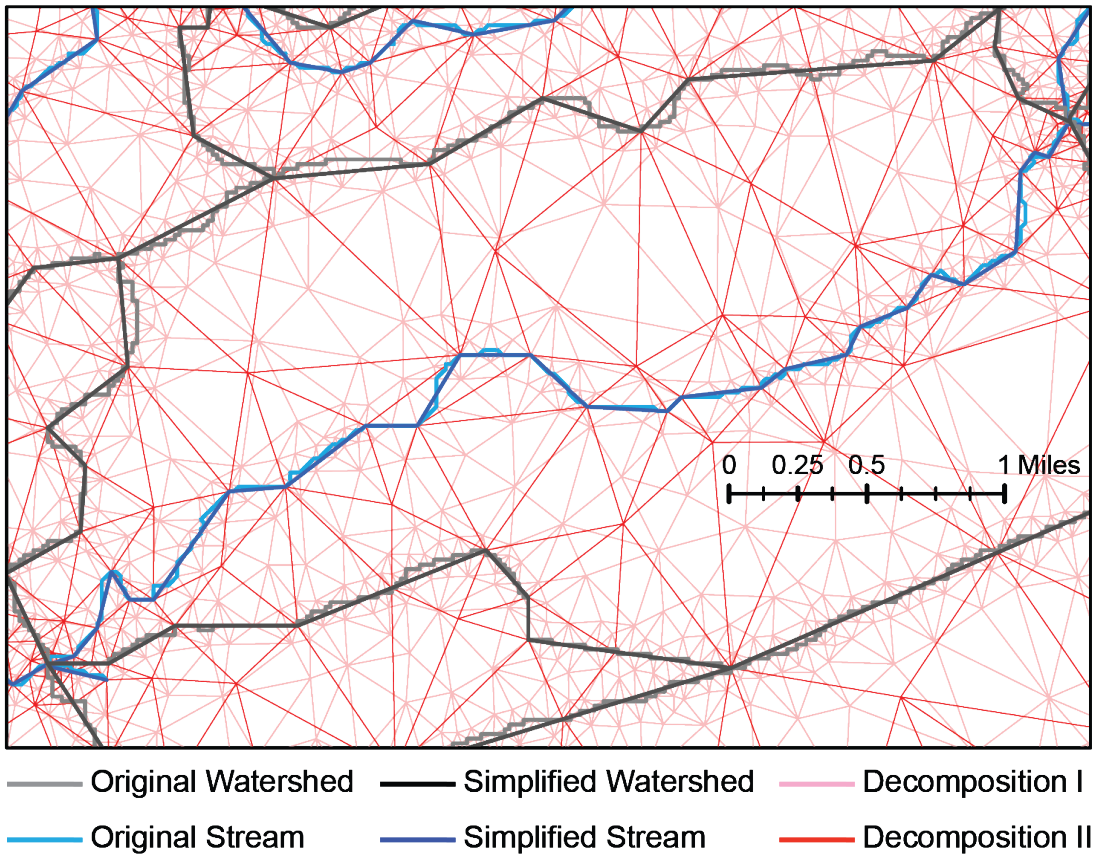
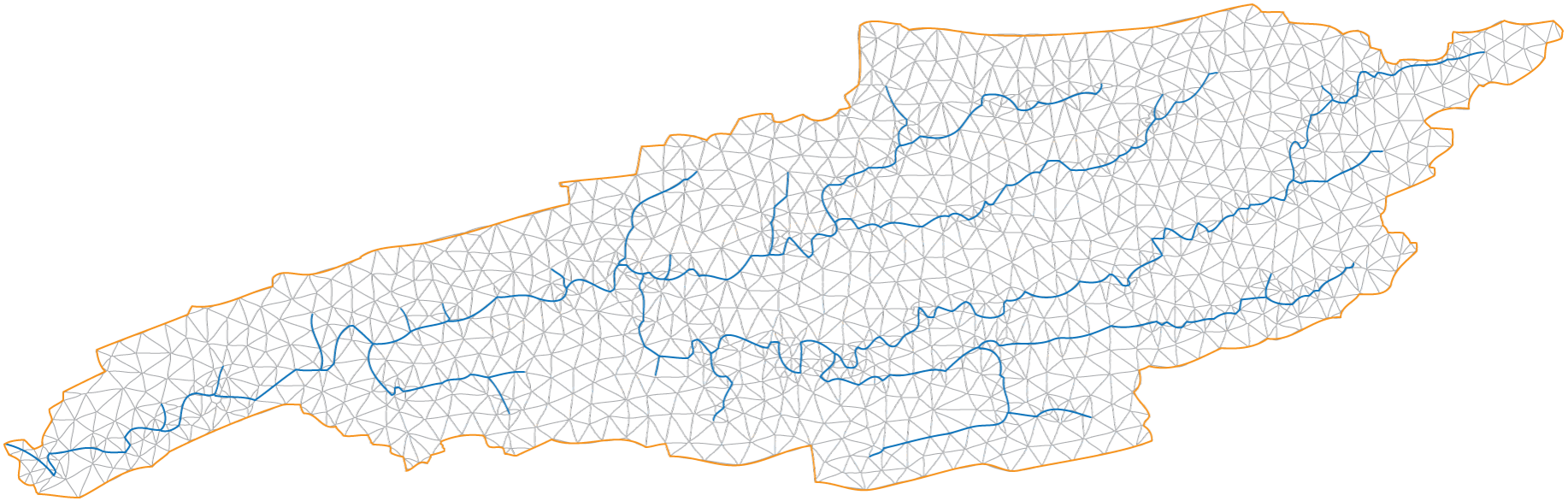




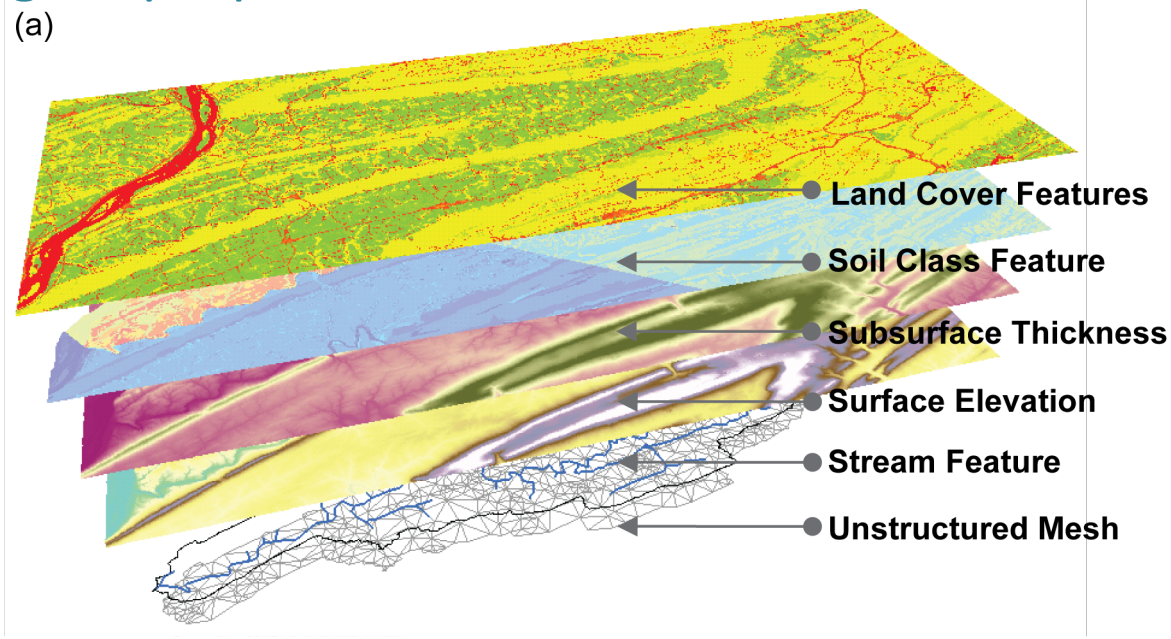
DOMAIN DECOMPOSITION

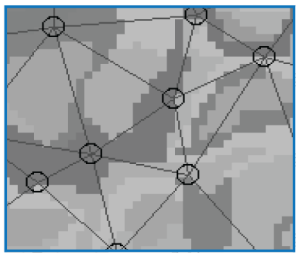
A set of three tools to produce quality triangular mesh network.



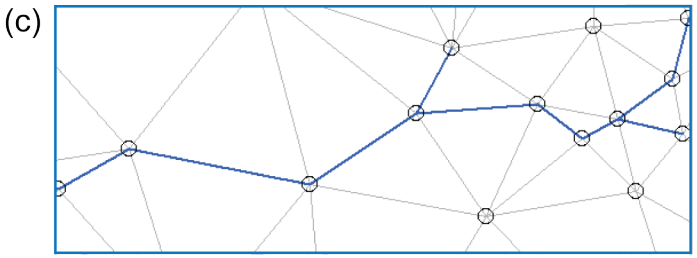
DATA MODEL LOADER

A set of ten tools for automated assignment of topology information and for mapping spatio-temporal watershed and climatological properties to mesh elements and river reaches.





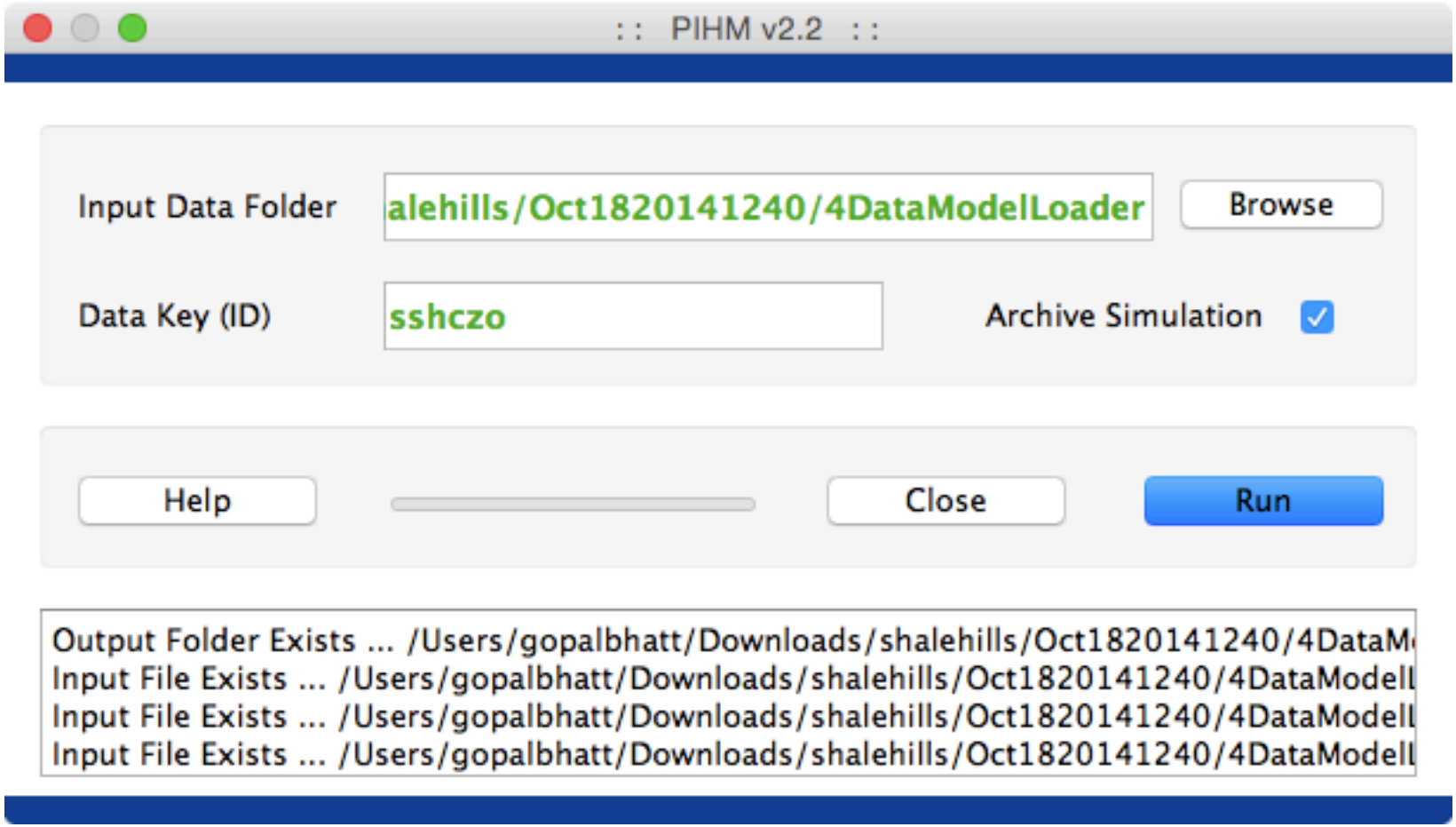
Data Parameterization: defined by representative parameter value of each data layer for each element



Topology for channel segments: defined by From Node, To Node, Upstream Segment, Downstream segment, Left TIN element, Right TIN element

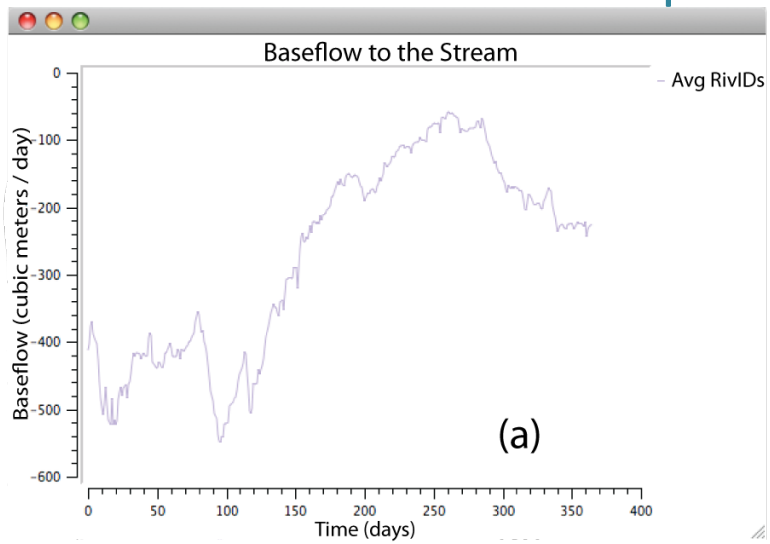
RUN PIHM SIMULATION

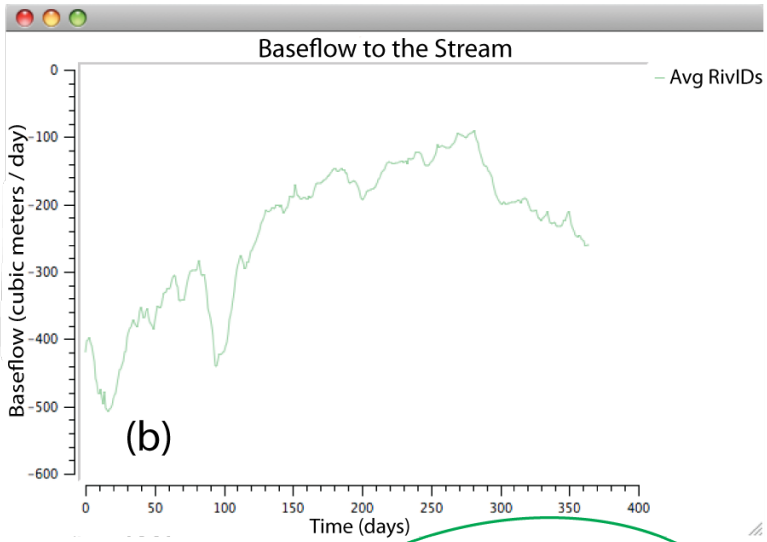
This tool provides ability to perform concurrent executions of multiple instances of PIHM simulations.

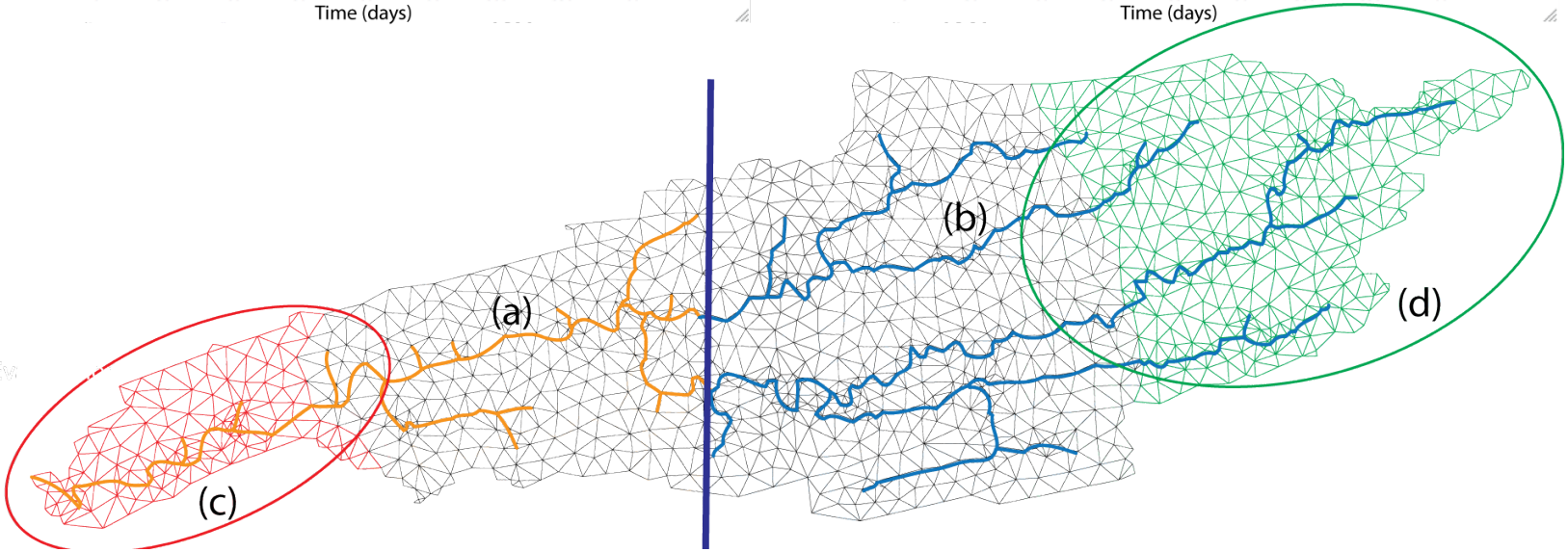


VISUAL ANALYTICS: ***TEMPORAL***

Data analysis toolset provides the ability to visualize simulated outputs for a user-selected group of triangular or linear mesh element over the simulation period.

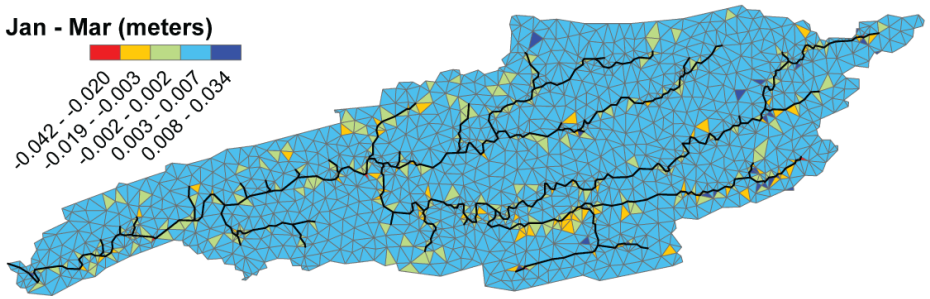


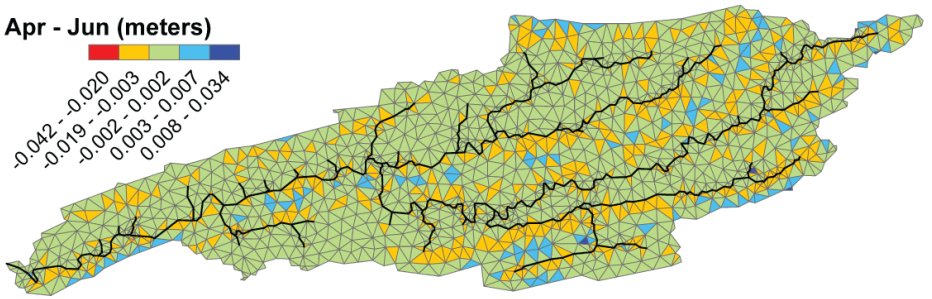


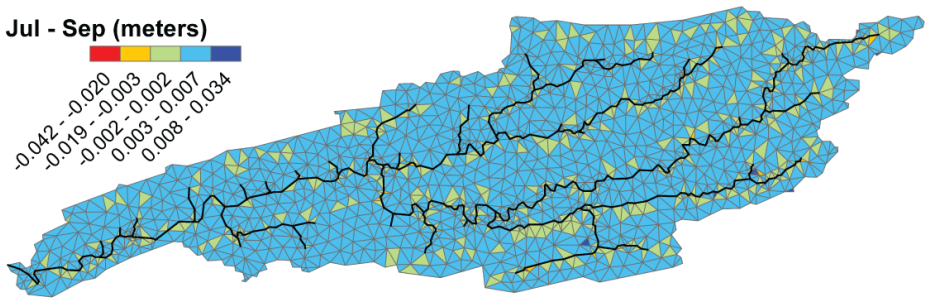


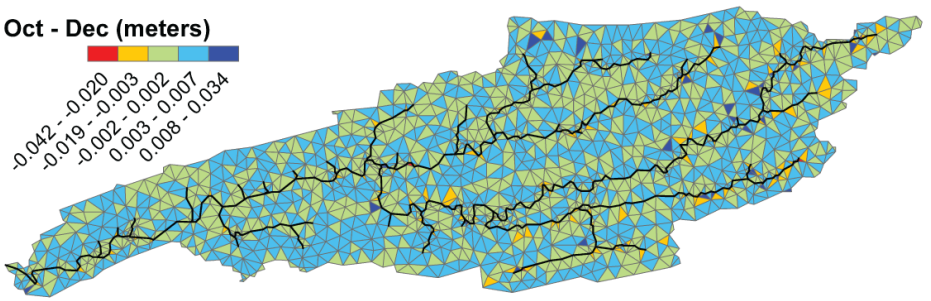
VISUAL ANALYTICS: ***SPATIAL***

Data analysis toolset provides the ability to visualize simulated outputs for a user-selected group of triangular or linear mesh element over the simulation period.







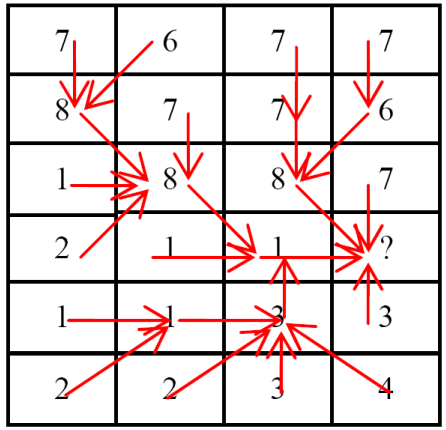


- open forum

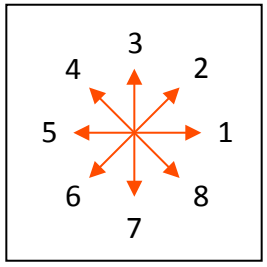
4. Discussion

FLOW DIRECTION & ACCUMULATION

52	51	50	39
35	40	37	38
39	34	32	34
41	54	29	10
51	35	30	35
49	43	49	40



0	0	0	0
2	0	1	1
0	6	4	0
0	0	15	23
0	2	6	0
0	0	0	0



d8 Algorithm

STREAM GRID DEFINITION

0	0	0	0
2	0	1	1
0	6	4	0
0	0	15	23
0	2	6	0
0	0	0	0

Threshold = 2 →

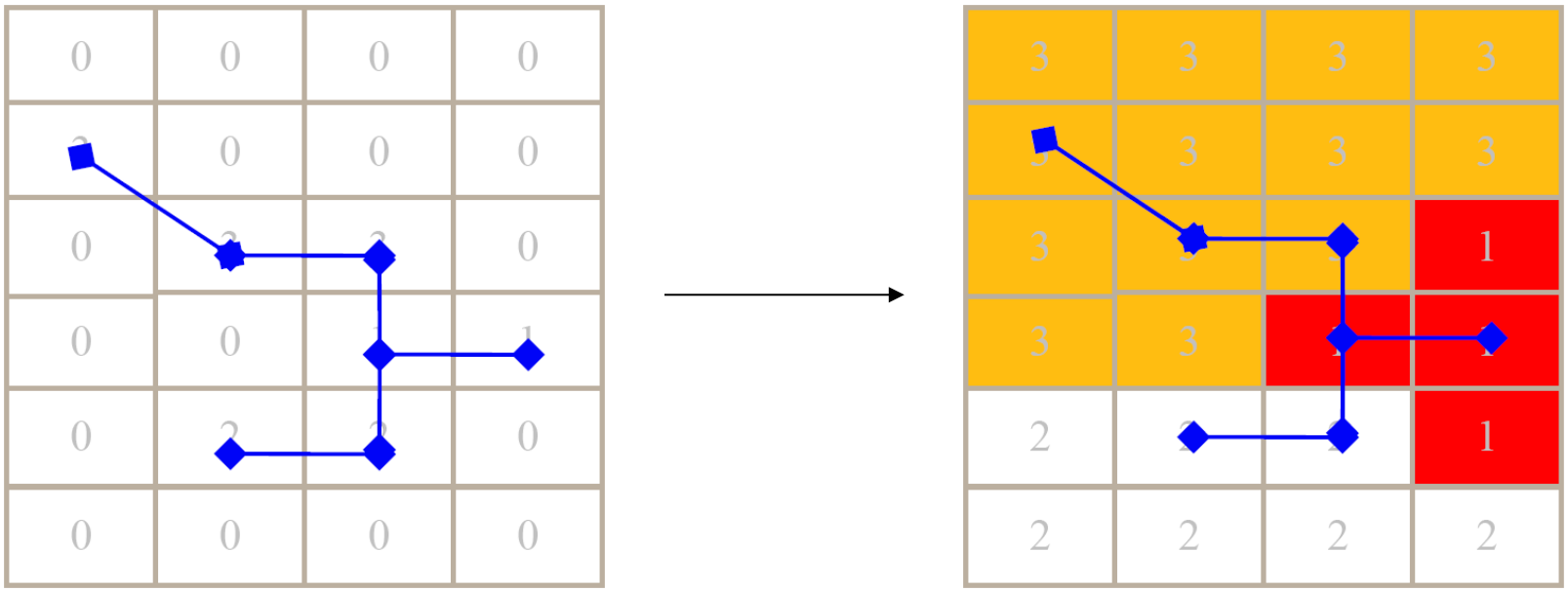
0	0	0	0
1	0	0	0
0	1	1	0
0	0	1	1
0	1	1	0
0	0	0	0

LINK GRIDS

0	0	0	0
1	0	0	0
0	1	1	0
0	0	1	1
0	1	1	0
0	0	0	0

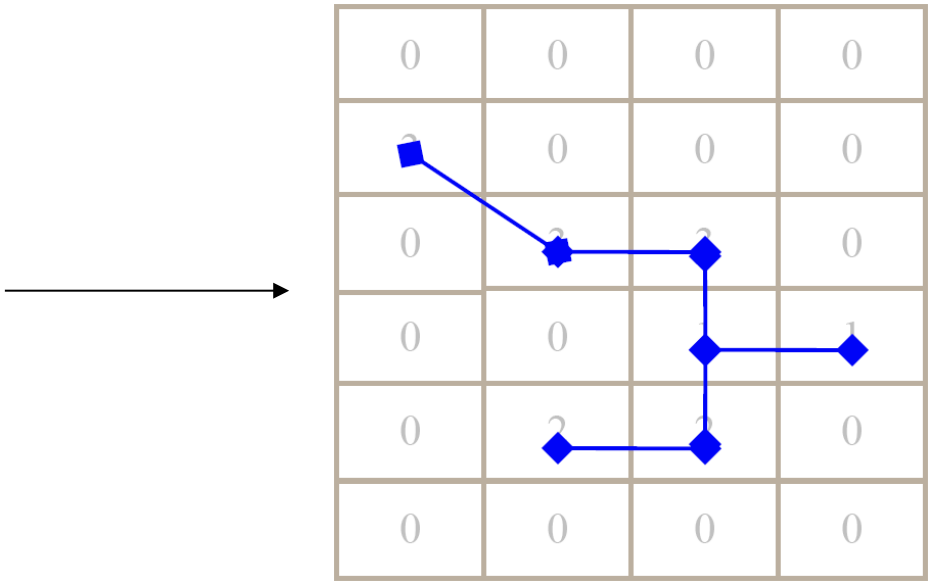
0	0	0	0
3	0	0	0
0	3	3	0
0	0	1	1
0	2	2	0
0	0	0	0

CATCHMENT GRID

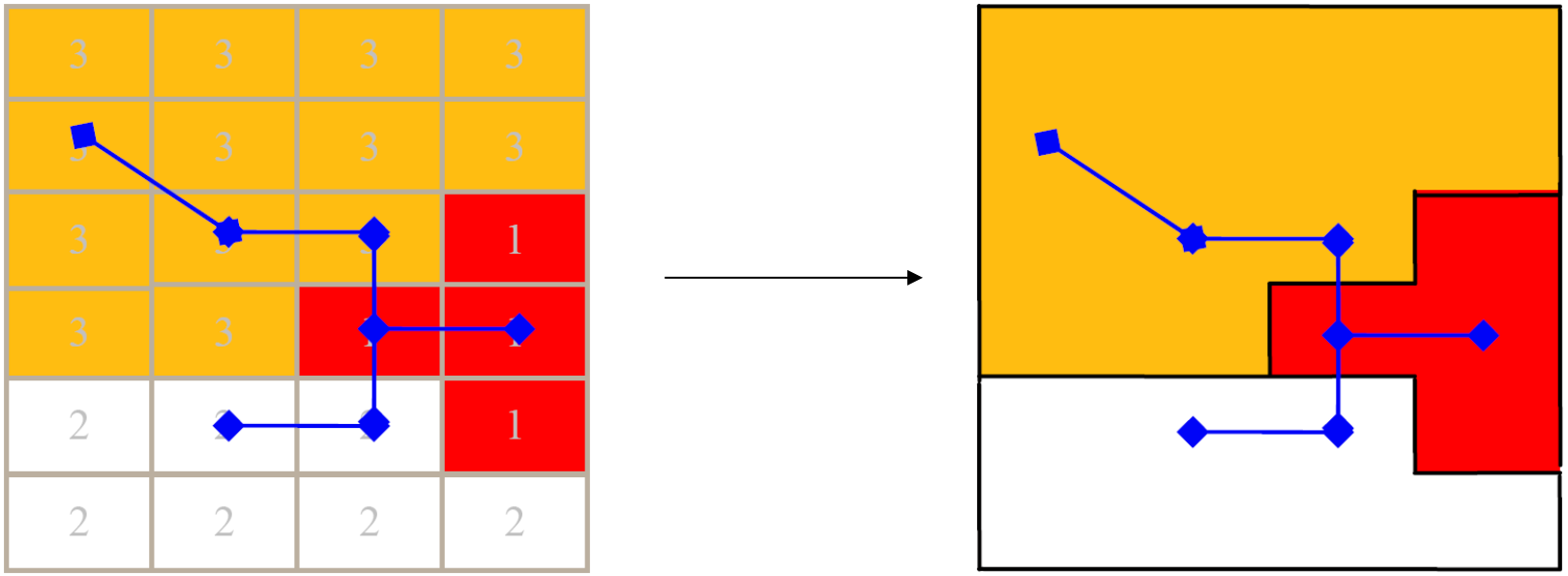


STREAM POLYLINES

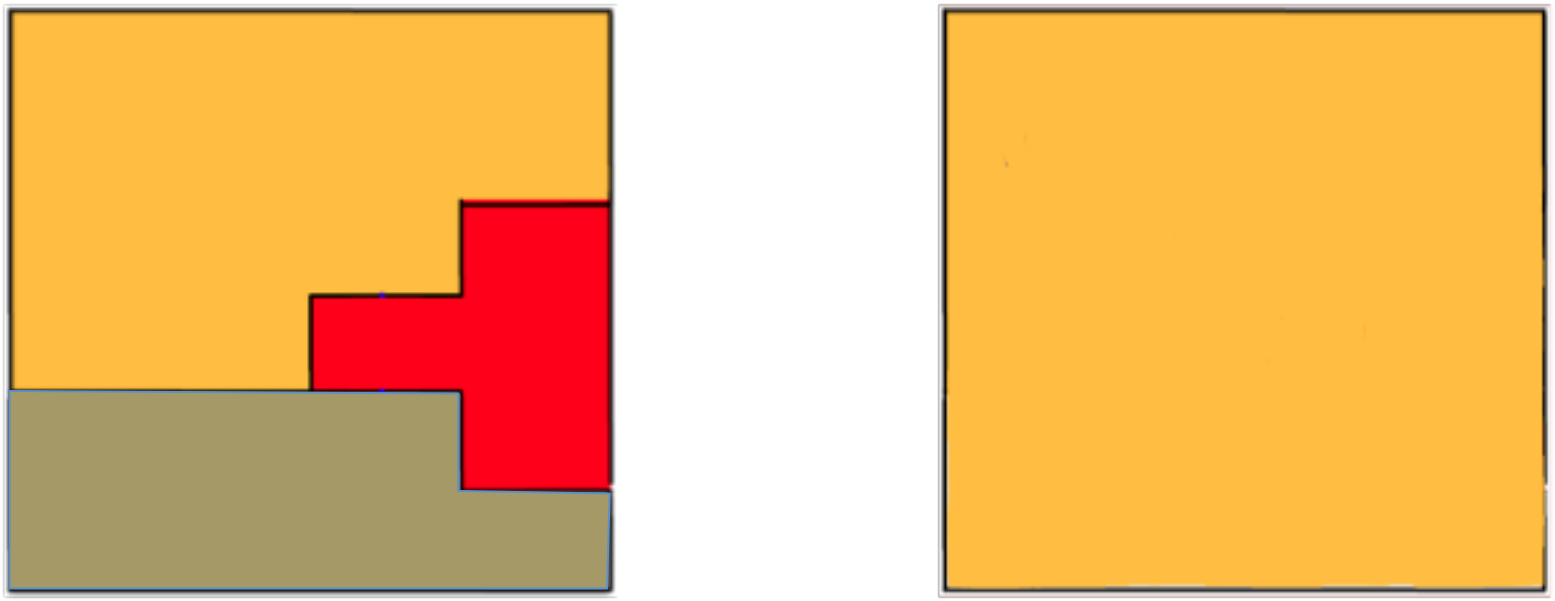
0	0	0	0
3	0	0	0
0	3	3	0
0	0	1	1
0	2	2	0
0	0	0	0



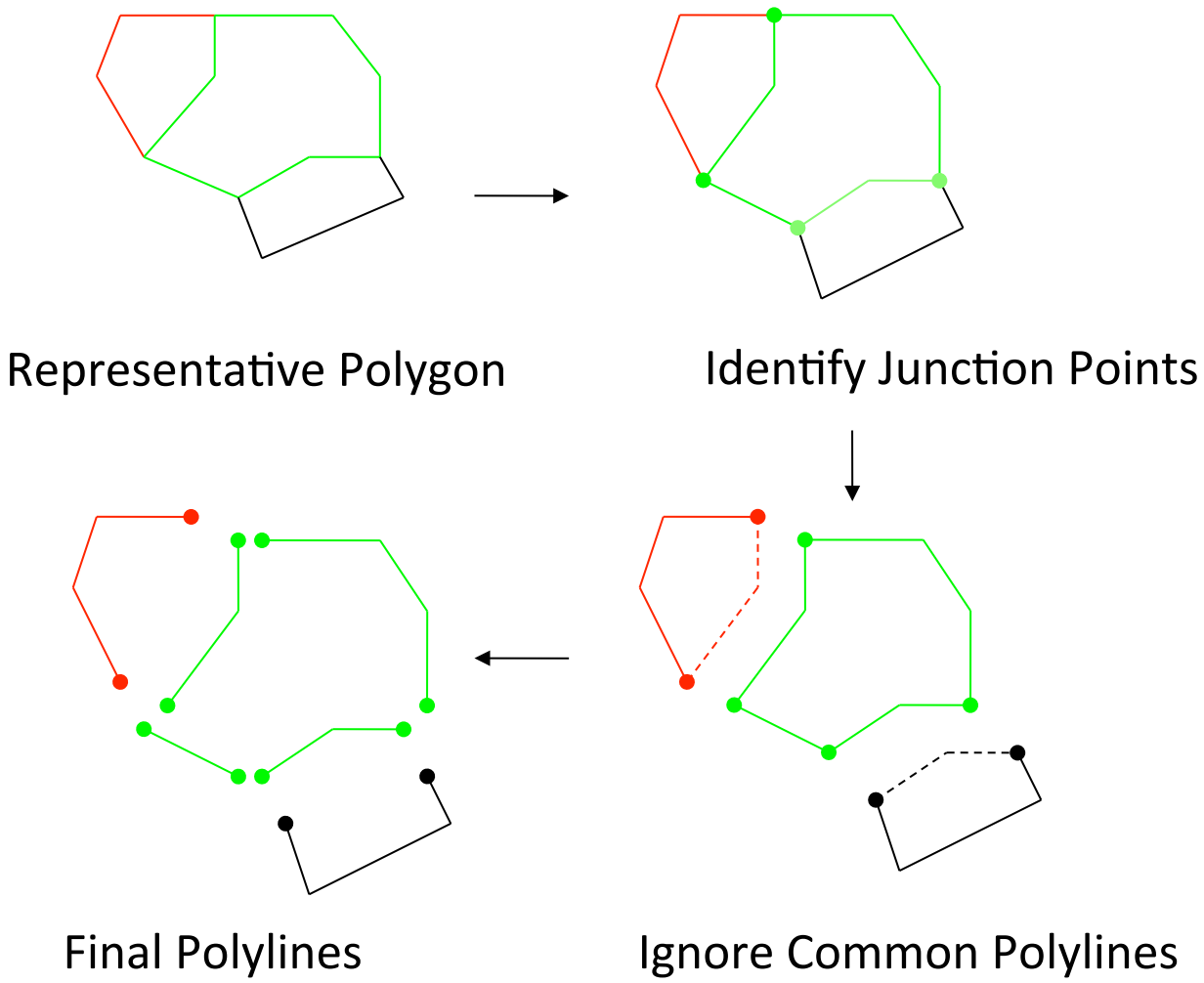
CATCHMENT POLYGONS



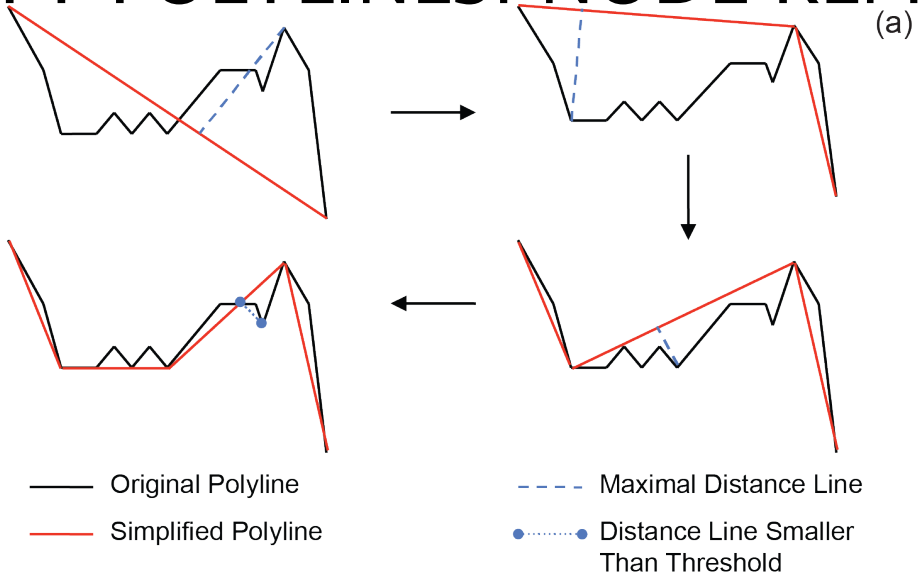
DISSOLVE POLYGONS

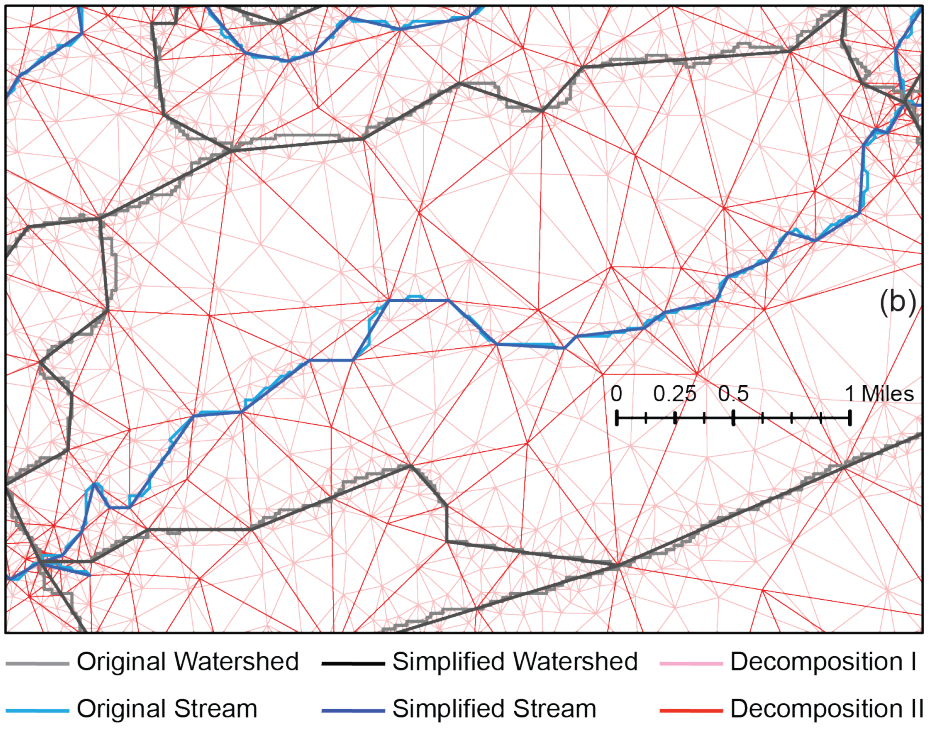


POLYGONS TO POLYLINES



SIMPLIFY POLYLINES: NODE REMOVAL





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