Distributed Catchment Modeling

PENNSTATE
1855

Topics

- Essential Terrestrial Variables
- Automating the Model Workflow
- National Geospatial Data
- Hydrologic Basis for Earth System Models
- PIHM development
- Climate Reanalysis & IPCC Projections
- Detecting Decadal Ecosystem Change

Christopher Duffy, Penn State University

National CZO Program

CSDMS
COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

CUAHSI HIS
Sharing hydrologic data

NSF

Why High Resolution Distributed Catchment Modeling?

All flood, drought and water supply impacts are local

Hydrologic Basis for Earth System Modeling (e.g. CZO's)

Cyberinfrastructure for Virtual Data-Model Sharing

Climate reanalysis and future scenario reconstructions

Scaling up from HUC-12 to River Basin Scales

Motivating the Need for Water-Cycle Models

Essential Terrestrial Variables Necessary for Catchment Modeling Anywhere in 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)
- …to be cont'd……..??

ETV's -> National Data Supporting Catchment Models

National (continental) geospatial data for catchments is served by multiple nations/ federal agencies/organizations

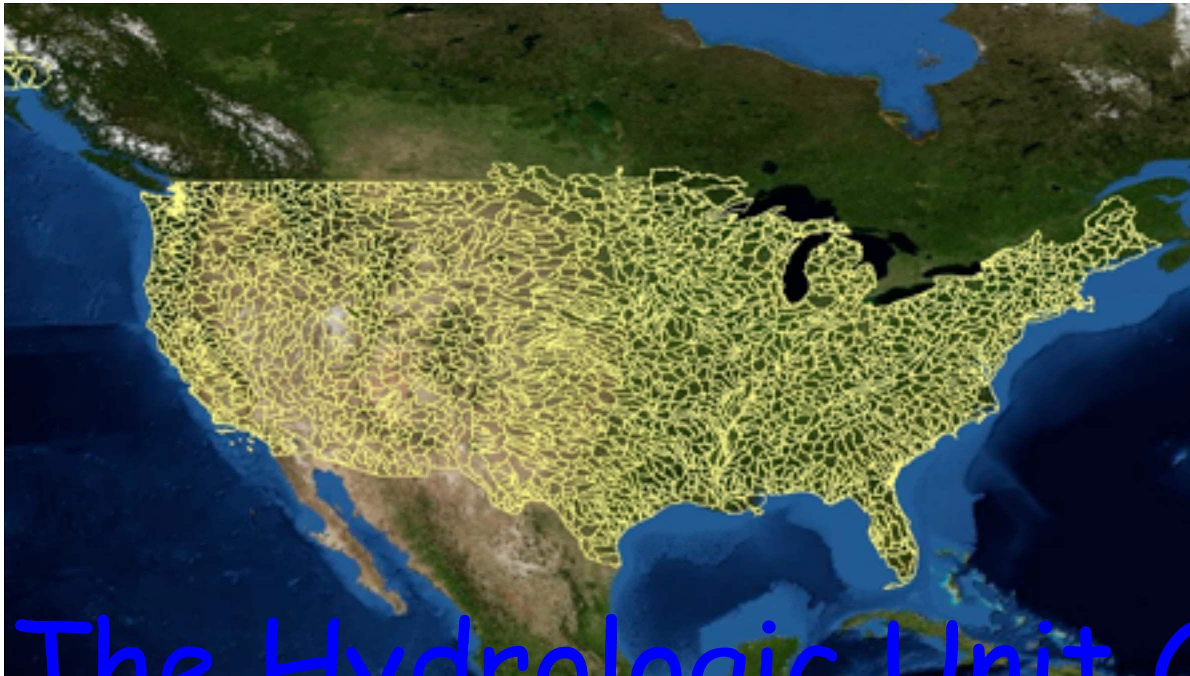
Fast access to high resolution data is a requirement for model development at relevant scales

Detection and attribution of change for climate, landuse and ecosystem impacts is critical for resource management and policy

A community-driven exercise in developing a high resolution data and models

The Hydrologic Unit Code (HUC)

A Basis For Catchment Model-Data Sharing



2,268 USGS
HUC 8
watersheds

103,444 USGS
HUC 12
watersheds

An Initial ETV Bundle

Category	Variables	Nat. Products	Reference	Size/Resolution
Atmospheric Forcing	precipitation, snow cover wind speed/direction relative humidity temperature atmospheric radiation albedo photosynthetic radiation	NLDAS II, NAAR	Bailey, 2004 NARR, 2011	8km, hourly, 5 TB per year .
Digital Terrain	DEM, DTM, Lidar	NHD+	NHD, 2013	30m, 10TB
River/Stream	Discharge, stage	USGS Gauging	USGS, 2011	100 GB
Soil	class, hydrologic properties	SSURGO STATSGO	SSURGO, 2011 STATSGO, 2011	1 TB
Groundwater	Hydrogeological formations Hydrogeological properties Water Levels		NHD, 2011 ** USGS, 2013	
Surface Water Bodies	Lake/Reservoir Geometry Operating Rules Volume/Area/Level	USGS US COE US Bur Rec	USGS, 2013 NHD, 2013	
Land Cover	Leaf area index human infrastructure surface roughness	NLCD, MODIS	MODIS, 2011, NLDAS, 2011	30m, 5TB
Water Use	Wells diversions municipal supply storm flow/sewer networks irrigation drainage	USGS	USGS, 2013 NHD, 2013** ** ** ** **	
				Approximately 185 TB

HydroTerre: High Resolution ETV

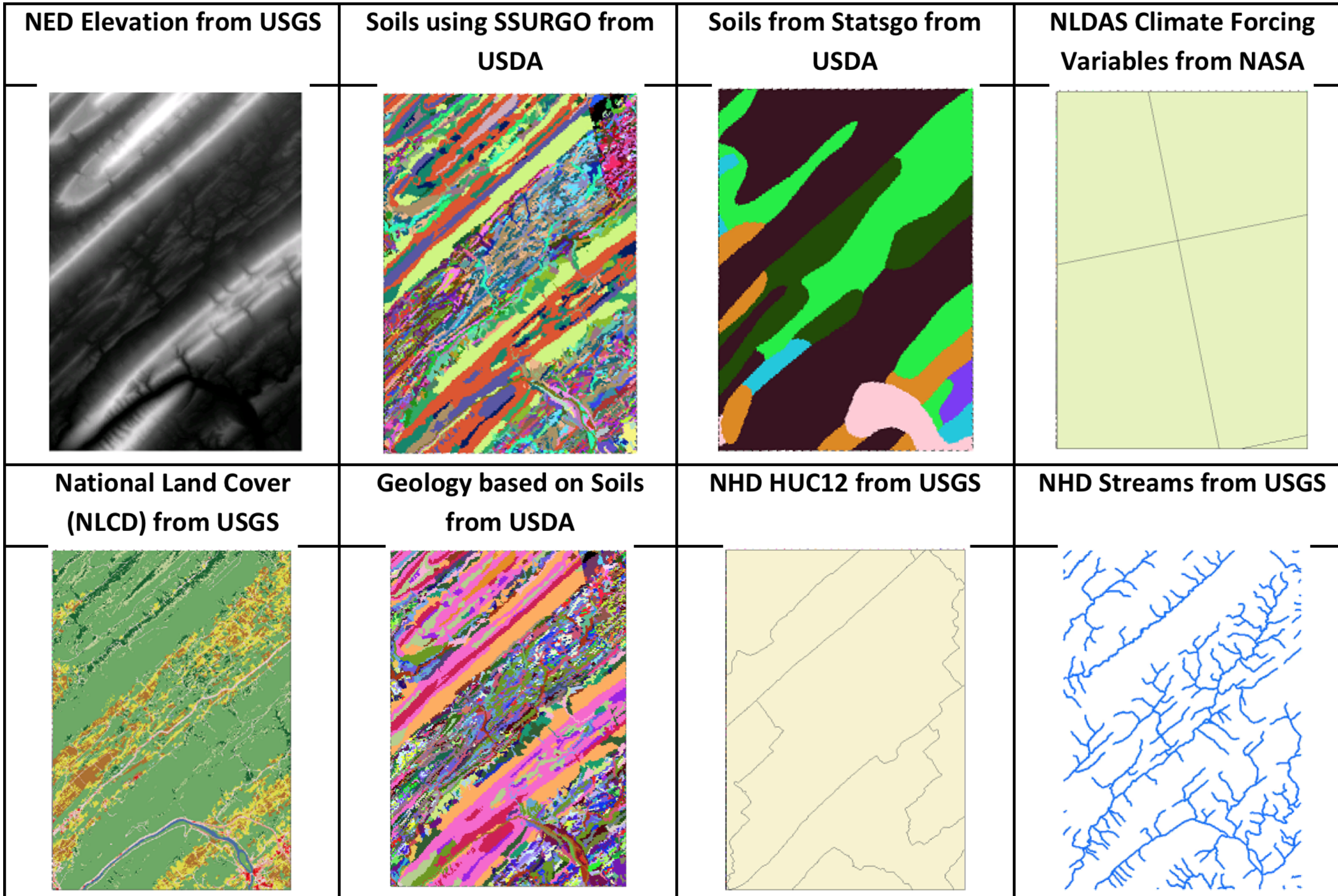
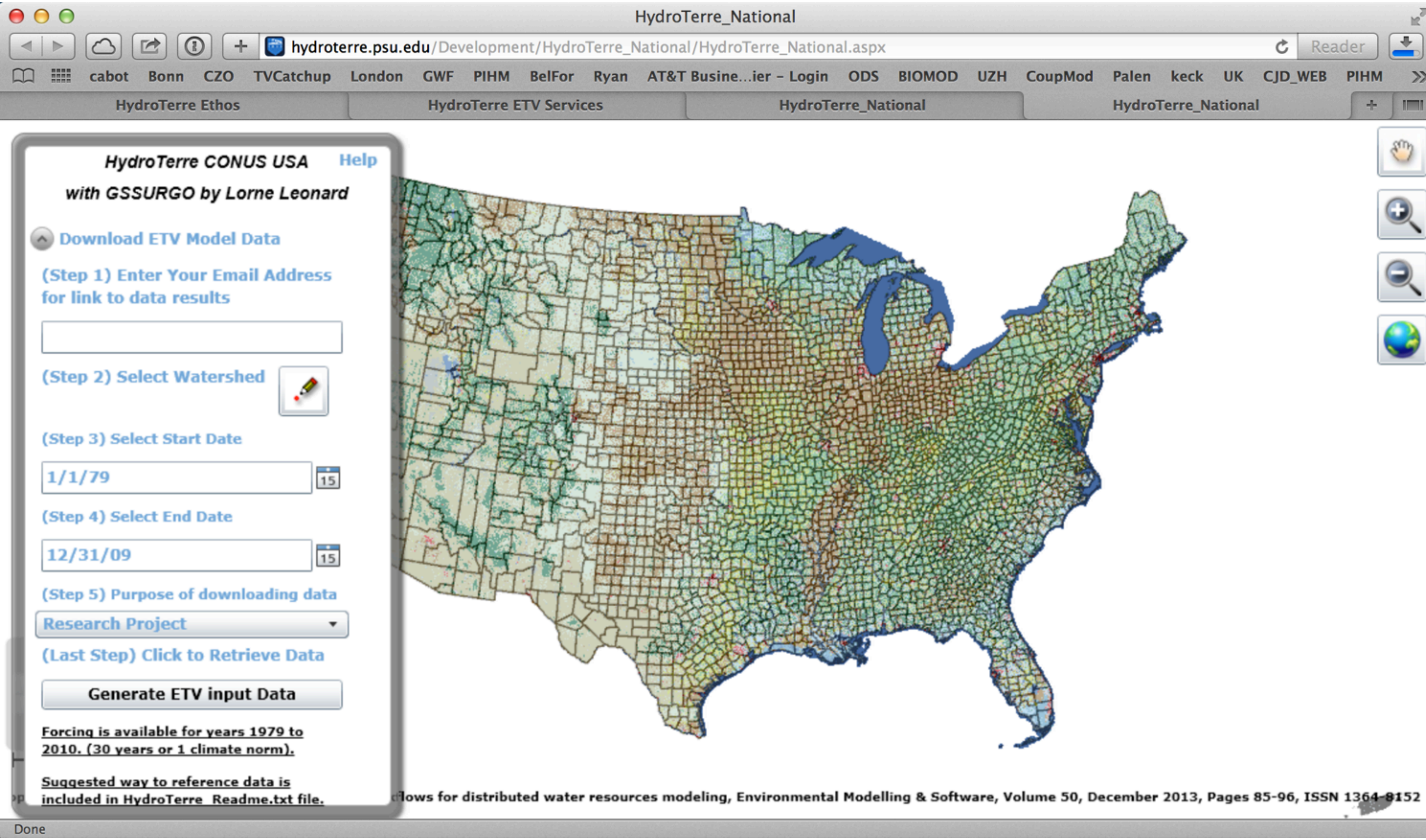


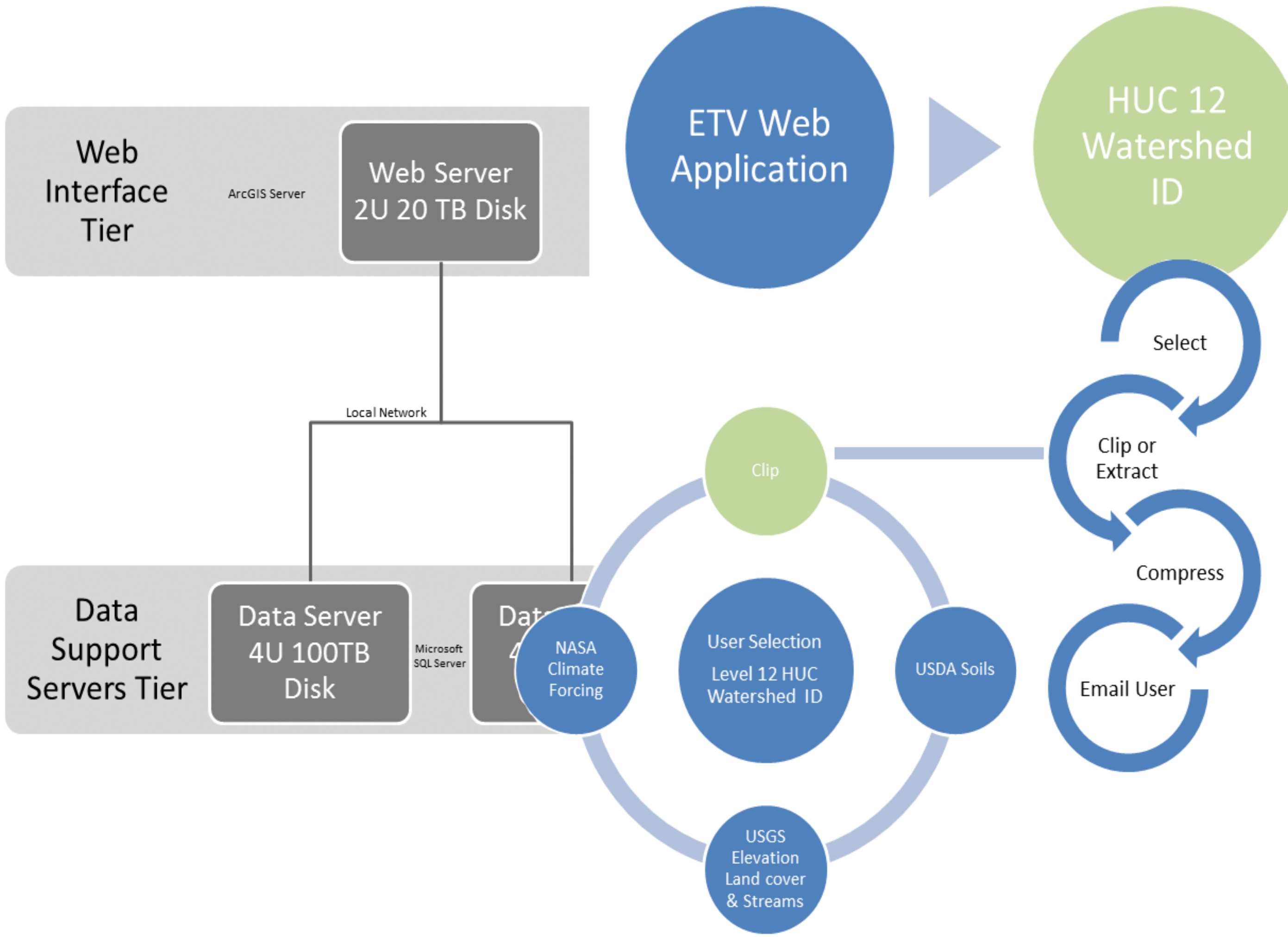
Figure 1: HydroTerre Essential Terrestrial Variables data and data sources


HydroTerre_National
hydroterre.psu.edu/Development/HydroTerre_National/HydroTerre_National.aspx
Reader
cabot Bonn CZO TVCatchup London GWF PIHM BelFor Ryan AT&T Busine...ier – Login ODS BIOMOD UZH CoupMod Palen keck UK CJD_WEB PIHM
HydroTerre Ethos
HydroTerre ETV Services
HydroTerre_National
HydroTerre_National
HydroTerre CONUS USA
Help
with GSSURGO by Lorne Leonard
Download ETV Model Data
(Step 1) Enter Your Email Address for link to data results
(Step 2) Select Watershed
(Step 3) Select Start Date
1/1/79
(Step 4) Select End Date
12/31/09
(Step 5) Purpose of downloading data
Research Project
(Last Step) Click to Retrieve Data
Generate ETV input Data
Forcing is available for years 1979 to 2010. (30 years or 1 climate norm).
Suggested way to reference data is included in HydroTerre_Readme.txt file.
lows for distributed water resources modeling, Environmental Modelling & Software, Volume 50, December 2013, Pages 85-96, ISSN 1364-8152
Done

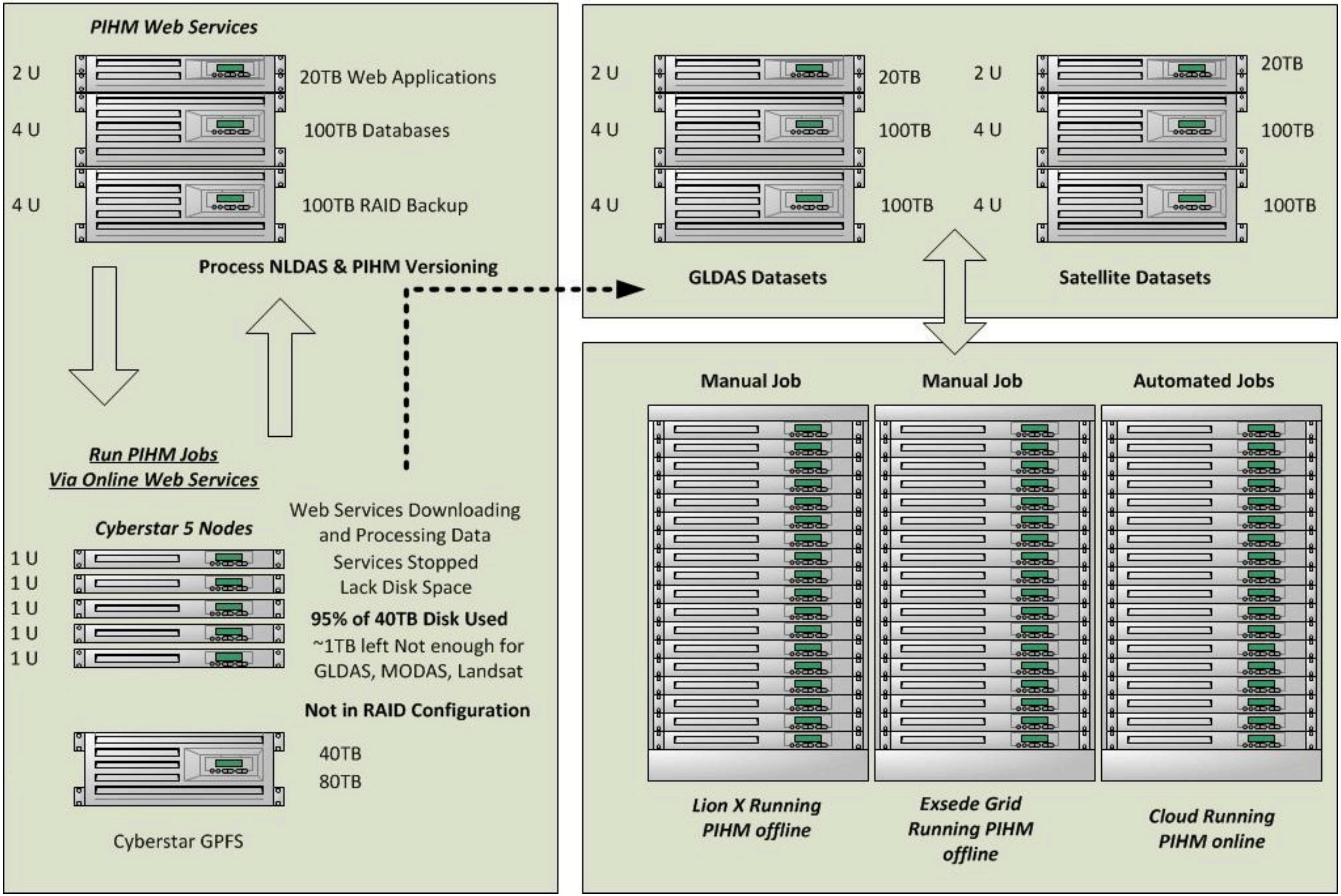
HydroTerre: A Prototype for Model-Data Access

Land Parcel Data; NHD: Stream, Lake, HUC'; USDA: Soils/Crops; NLCD: LU_LC;

HydroTerre: A Prototype Model-Data Workflow



HydroTerre Prototype: Data and Modeling Hardware



A Time Line for the Penn State Model PIHM

1998-04 SAHRA NSF Science & Technology Center
- Duffy sabbatical at Los Alamos
- Yizhong Qu first PhD & early architect
- Finite volume model first steps

2006-08 NSF Waters/CUAHSI Project
- Duffy and Reed
- Mukesh Kumar-redesign PIHM, Data-Model
- Gopal Bhatt, PIHMgis
- Shuangcai Li, PIHM_hydro

2008-13 NSF Critical Zone Observatory
- Duffy, Brantley, and CZO teams
- Kumar-PIHM_3D
- Gopal Bhatt/Duffy- Solute, Age Modeling
- Yuning Shi, Ken Davis Flux_PIHM
- Lorne Leonard: Hydroterre
- Soil TrEC European Community funding

2013-16 NSF EarthCube GeoSoft BB
- NSF INSPIRE Project Lake-Catchment Age of Water

Why & How of Integrated Models

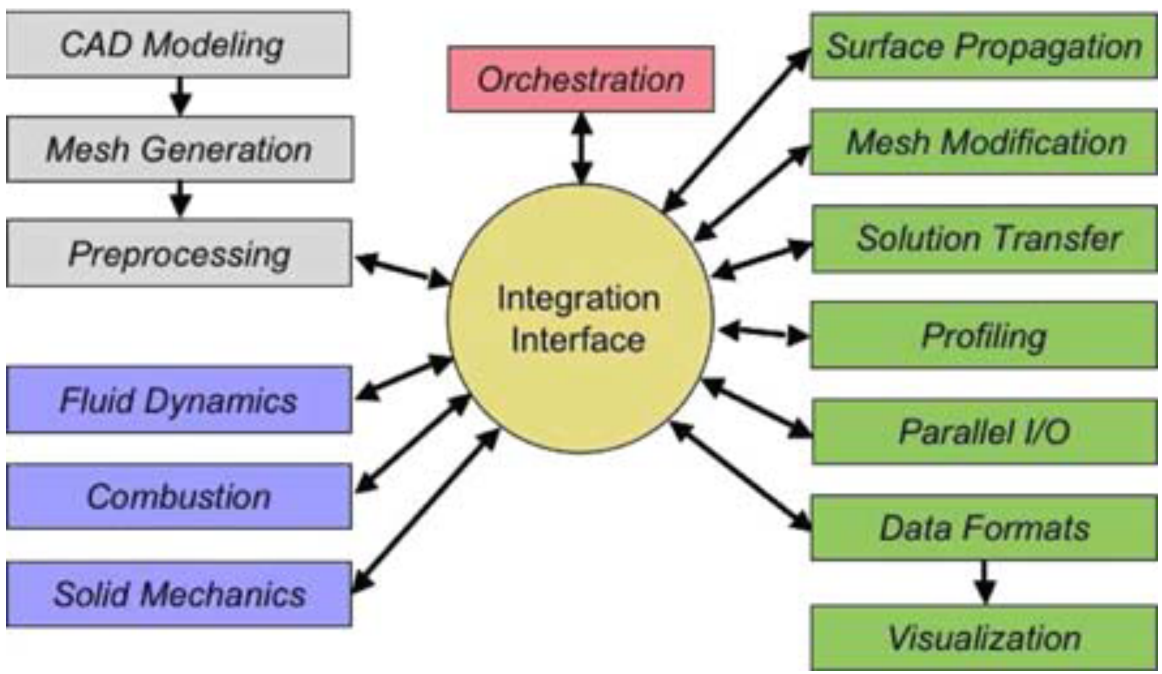
Multiphysics analysis is a unifying modeling strategy that allow
scientists and engineers to explore
fully-coupled effects of complex
physical phenomena

New sensors, communication networks, and characterization tools
have made it possible to examine spatial and temporal
phenomena over an unprecedented
range of scales

Goal: to develop an evolvable approach to hydrologic simulation,
to advance predictive understanding &
to develop the next generation
of environmental forecasting tools

Architecture for Multiphysics Modeling

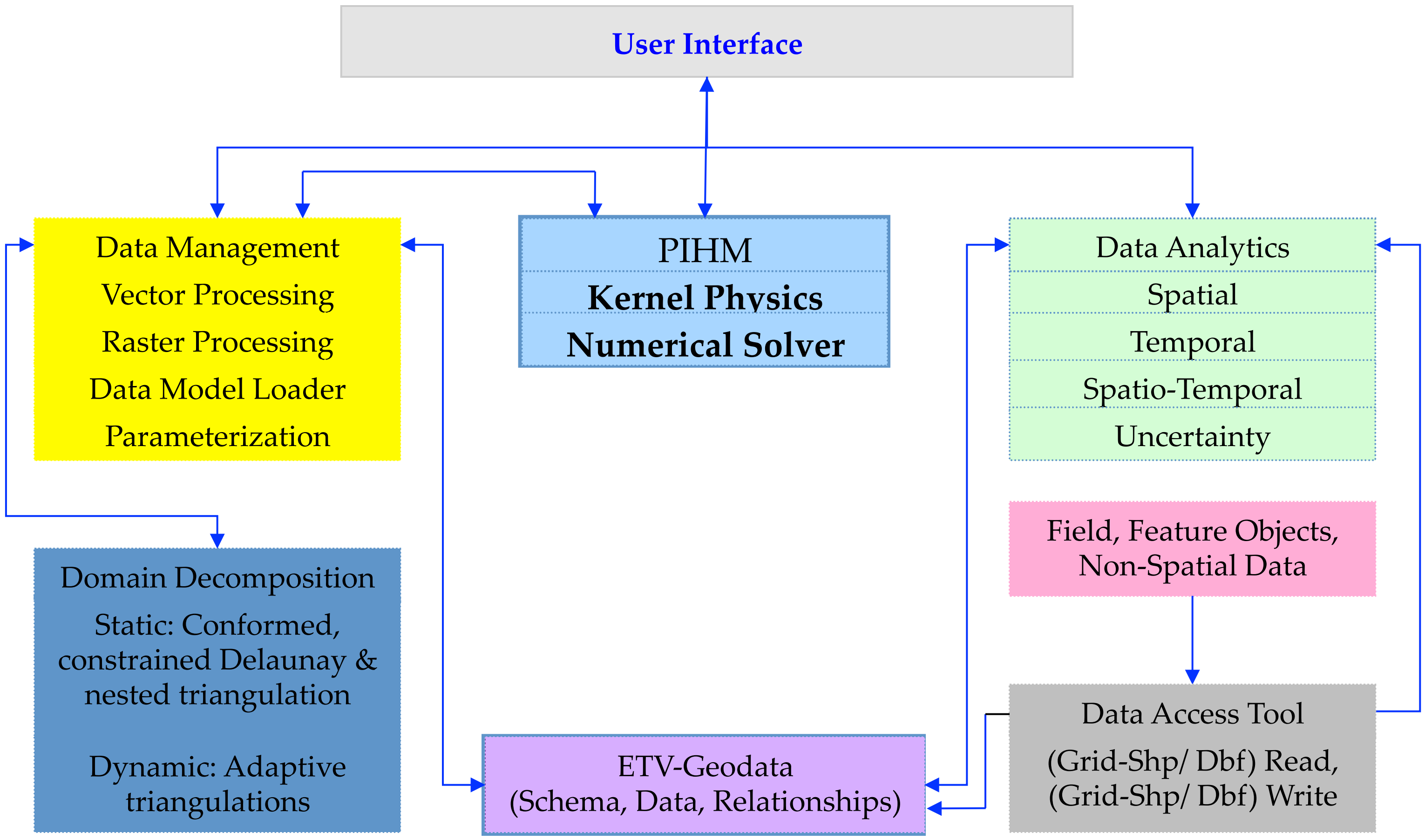
Sequential Coupling Approach one process or field is partially solved and then passed to the next physics field to form an initial solution. The iteration process continues until a final solution is achieved. The integration interface provides the services for subsystem interaction, data handling, mesh generation, parallel I/O, visualization, etc.



Mike Heath UIUC, 2008

Architecture for Multiphysics Modeling

Direct Coupling assembles all the physics equations in one matrix and solves all equations together. In this example an open-source GIS and Geodatabase is used for data management, mesh generation, space-time data analysis, and interface to the system solver and visualization.



Kumar, Bhatt, Duffy, 2008; Bhatt, Kumar, Duffy, 2014; Leonard and Duffy, 2014

Open Source Programming Tools

QGIS

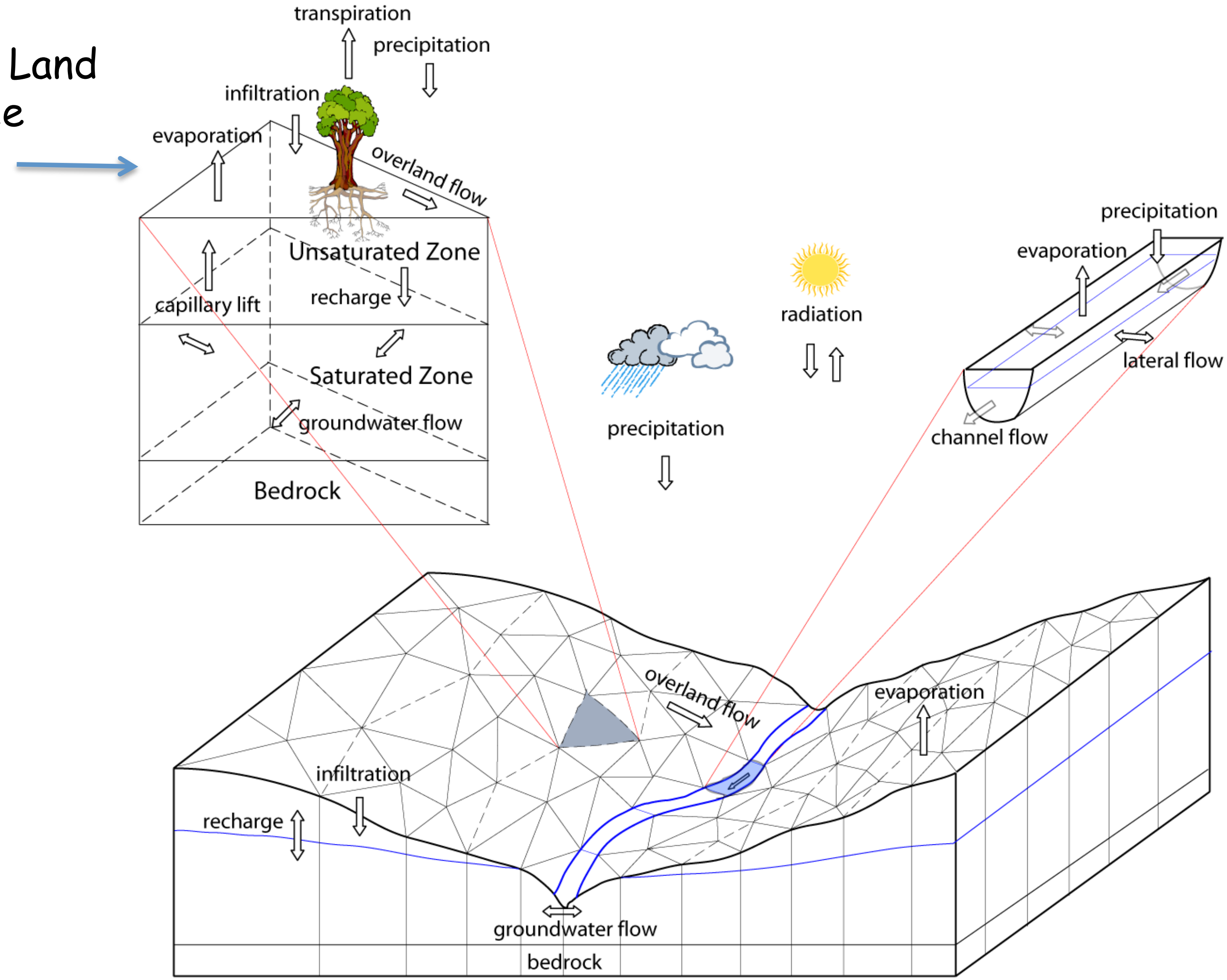
- an open source and free "Programmable Geographic Information System"
- a mapping tool, a GIS modeling system, and a GIS application programming interface (API) all in one
- a platform independent Open Source Geographic Information System that runs on Linux, Unix, Mac OSX, and Windows
- libraries for raster and vector geospatial formats
- Object relational database is handled using PostgreSQL
- GRASS compatible

Qt/C++

- tools for programming the interface and visualization

Fully coupled processes but with reduced physics (ASAP)

NOAH Land Surface Model



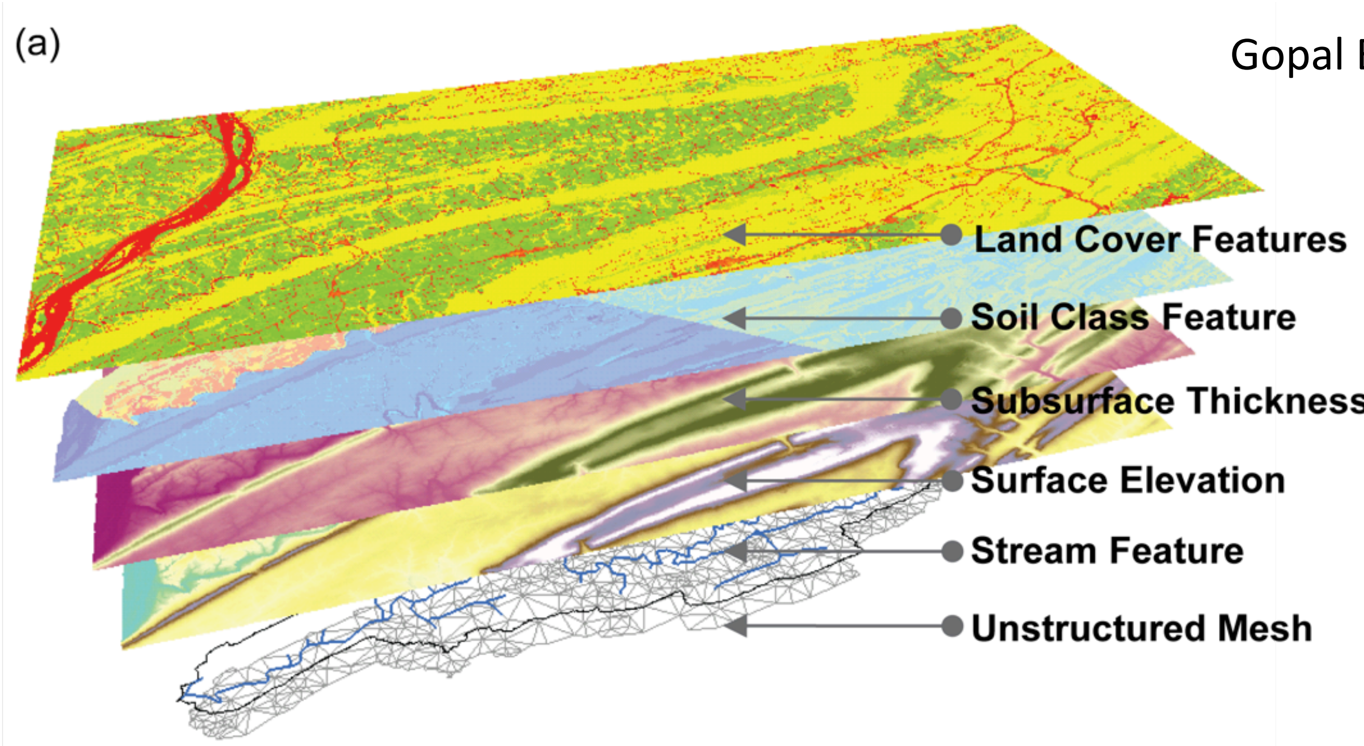
Qu and Duffy 2007. Kumar, Bhatt, Duffy 2009

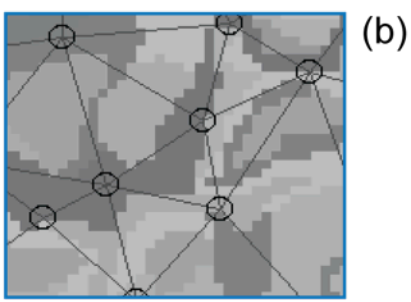
Semi-Discrete Finite Volume Formulation

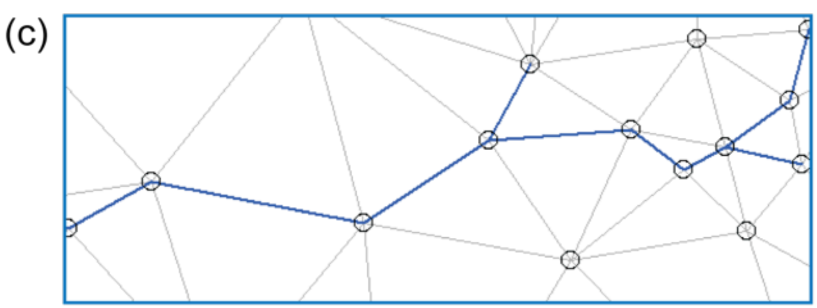
Process	Governing equation/model	Original governing equations	Semi-discrete form
Channel Flow	St. Venant Equation	$\frac{\partial h}{\partial t}+\frac{\partial (uh)}{\partial x}=q$	$\left(\frac{d\varsigma}{dt}=P_c-\sum Q_{gc}+\sum Q_{oc}+Q_{in}-Q_{out}-E_c\right)_i$ [1]
Overland Flow		$\frac{\partial h}{\partial t}+\frac{\partial (uh)}{\partial x}+\frac{\partial (vh)}{\partial y}=q$	$\left(\frac{\partial h}{\partial t}=P_o-I-E_o-Q_{oc}+\sum_{j=1}^{3}Q_s^{ij}\right)_i$ [1]
Unsaturated Flow	Richard Equation	$C(\psi)\frac{\partial \psi}{\partial t}=\nabla\cdot(K(\psi)\nabla(\psi+Z)$	$\left(\frac{d\xi}{dt}=I-q^0-ET_s\right)_i$ [2]
Groundwater Flow		$C(\psi)\frac{\partial \psi}{\partial t}=\nabla\cdot(K(\psi)\nabla(\psi+Z)$	$\left(\frac{d\zeta}{dt}=q^0+\sum_{j=1}^{3}Q_g^{ij}-Q_l+Q_{gc}\right)_i$ [3]
Interception	Bucket Model	$\frac{dS_I}{dt}=P-E_I-P_o$	$\left(\frac{dS_I}{dt}=P-E_I-P_o\right)_i$
Snowmelt	Temperature Index Model	$\frac{dS_{snow}}{dt}=P-E_{snow}-\Delta w$	$\left(\frac{dS_{snow}}{dt}=P-E_{snow}-\Delta w\right)_i$
Evapotranspiration	Pennman-Monteith Method	$ET_0=\frac{\Delta(R_n-G)+\rho_a C_p\frac{(e_s-e_a)}{r_a}}{\Delta+\gamma(1+\frac{r_s}{r_a})}$	$\left(ET_0=\frac{\Delta(R_n-G)+\rho_a C_p\frac{(e_s-e_a)}{r_a}}{\Delta+\gamma(1+\frac{r_s}{r_a})}\right)_i$

Desktop Data-Model Workflow

Gopal Bhatt author



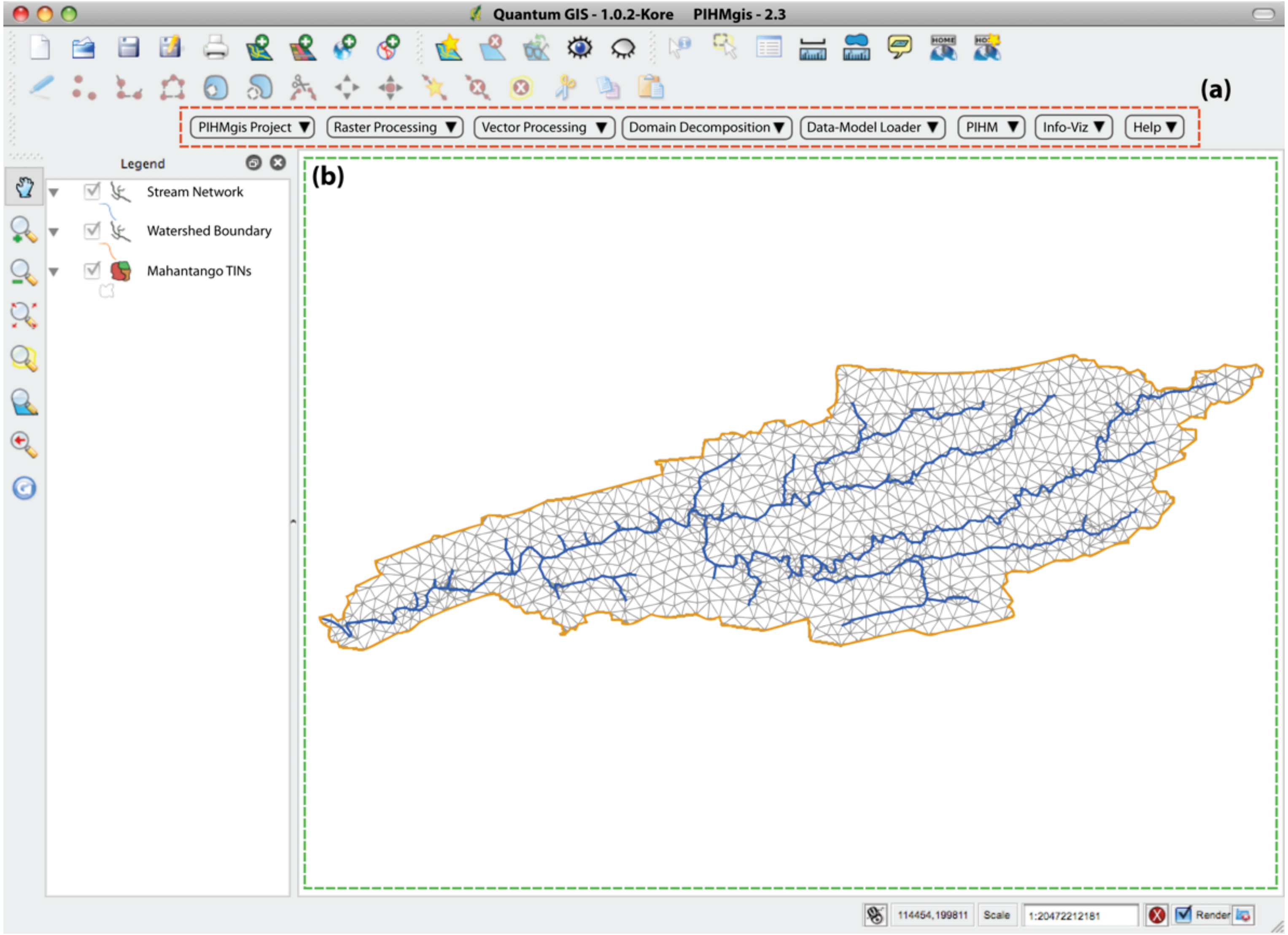




Data Parameterization: defined by representative parameter value of each data layer for each element

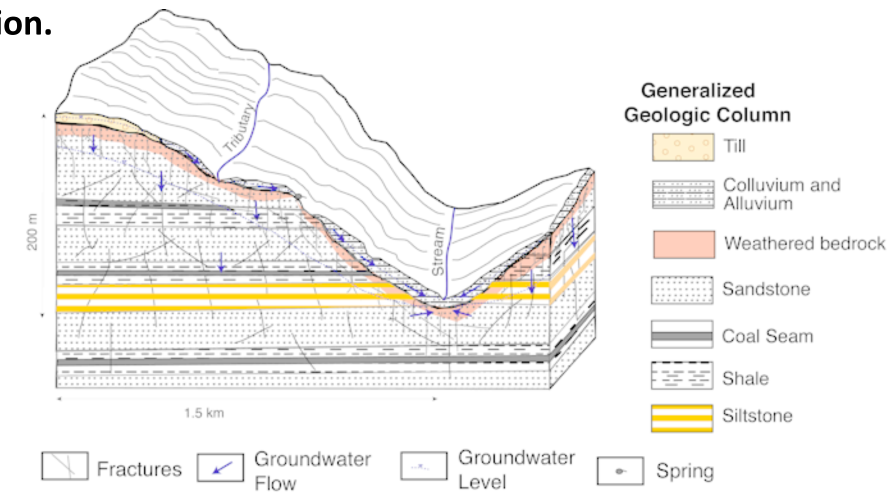
Topology for channel segments: defined by From Node, To Node, Upstream Segment, Downstream segment, Left TIN element, Right TIN element

PIHM GIS: Open Source tool for Desktop Model Setup with Tools for A-Priori Parameters



Conceptual Model + ETV data = A Priori Parameters

Conceptual Model Groundwater flow in the Allegheny Plateau Section.

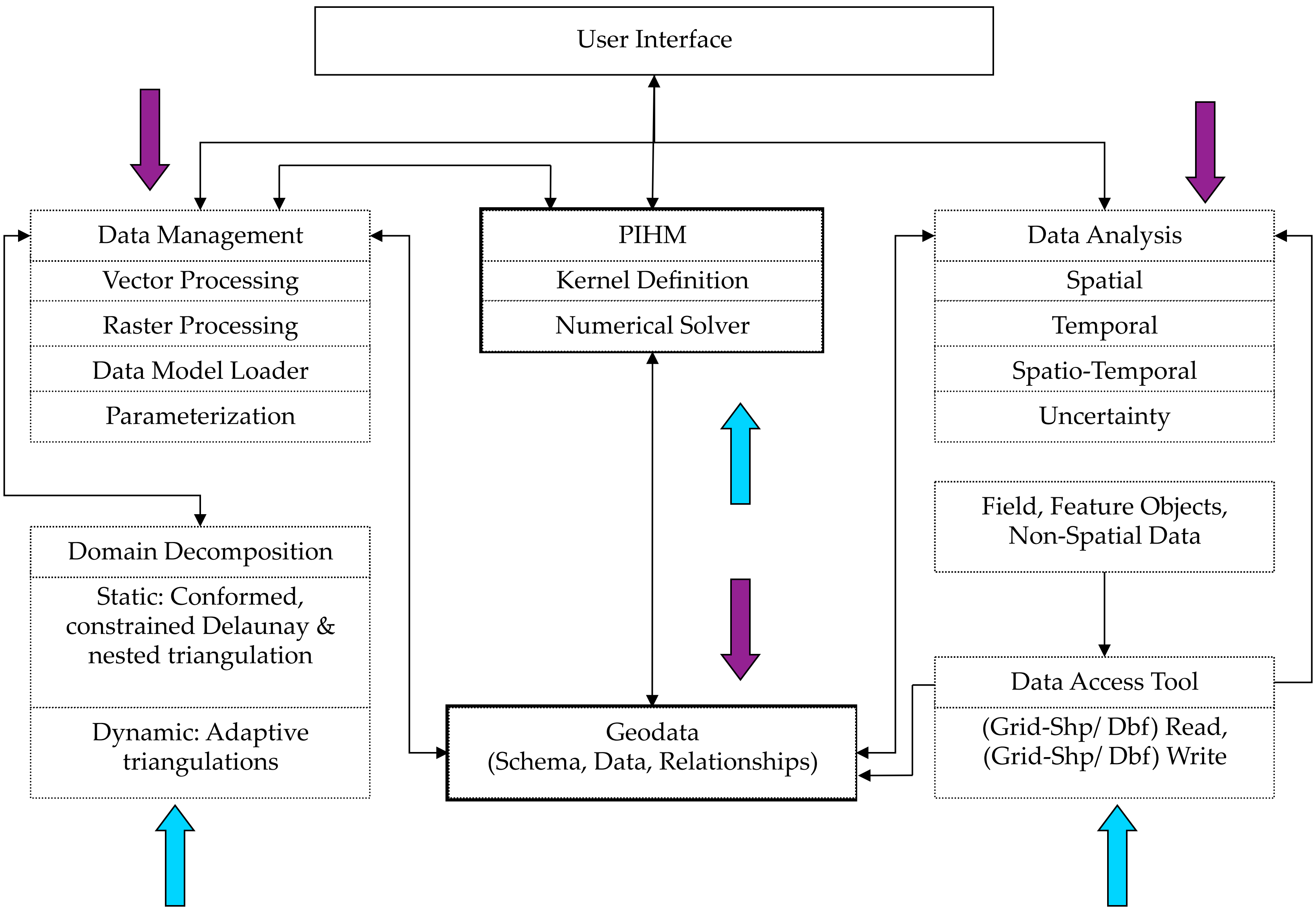


Example of the GIS for the surface geology coverage.

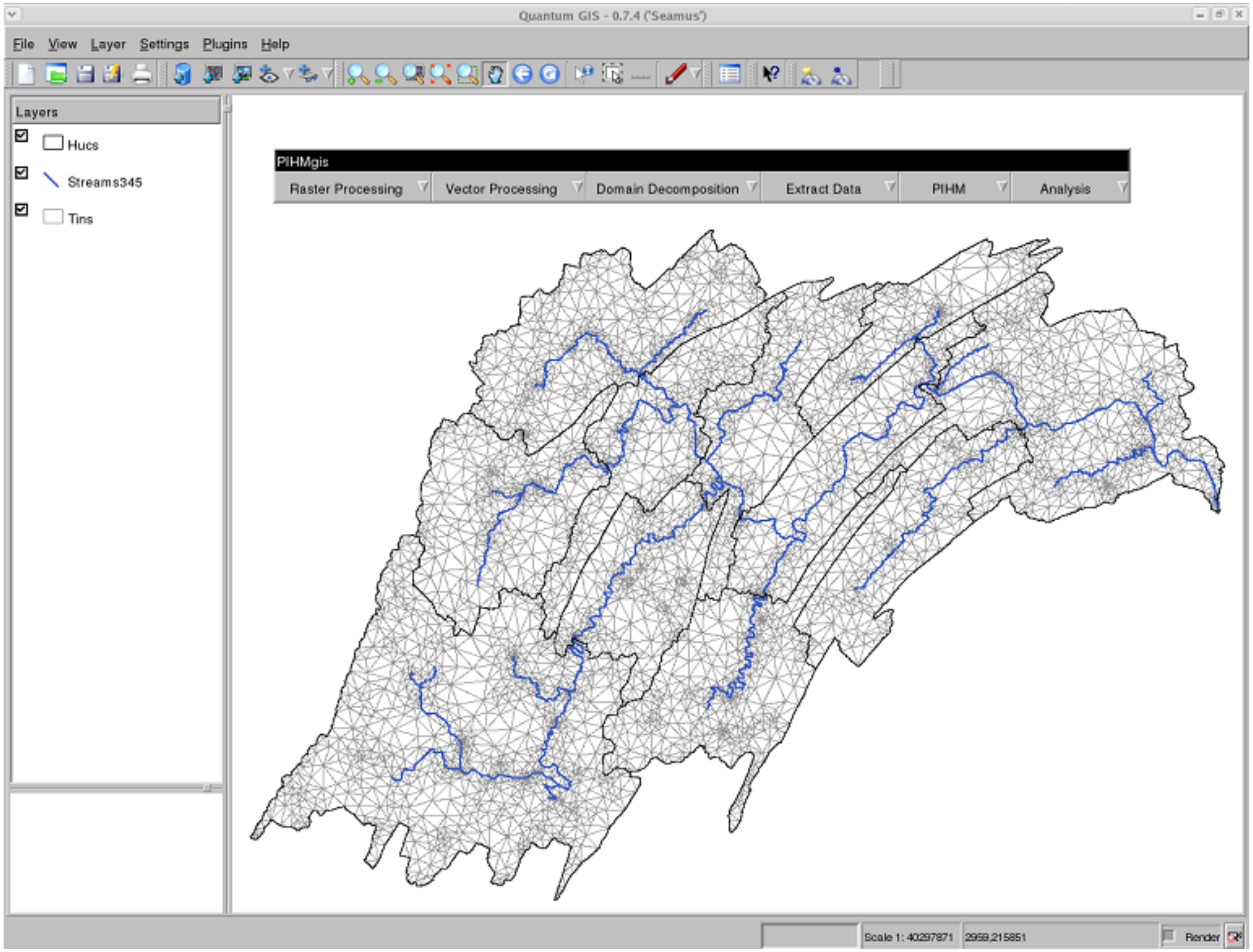
	A	B	C	D	E	F	G	H	I
1	CODE	SECTION_NA	FM	NAME	ROCK_TYPE	AQ_THICK	HYD_COND	AREA	PERIMETER
2	EL	Eastern_Lake	Dne	Northeast Shale	Shale	415	1.3012048	159203525.302	174535.706
3	GPiP	Glaciated_Pittsburgh_Plateau	Dne	Northeast Shale	Shale	415	1.3012048		
4	EL	Eastern_Lake	Dne	Northeast Shale	Shale	415	1.3012048	5993884.600	16754.859
5	EL	Eastern_Lake	Dne	Northeast Shale	Shale	415	1.3012048	120027.339	1849.084
6	EL	Eastern_Lake	Dne	Northeast Shale	Shale	415	1.3012048	9446.560	667.284
7	EL	Eastern_Lake	Dne	Northeast Shale	Shale	415	1.3012048	3573.466	283.214
8	EL	Eastern_Lake	Dg	Girard Shale	Shale	125	0.7200000	275408393.809	274812.341
9	GPiP	Glaciated_Pittsburgh_Plateau	Dg	Girard Shale	Shale	125	0.7200000		
10	EL	Eastern_Lake	Dg	Girard Shale	Shale	125	0.7200000	107654.879	1901.998
11	GPiP	Glaciated_Pittsburgh_Plateau	Dg	Girard Shale	Shale	125	0.7200000		
12	EL	Eastern_Lake	Dg	Girard Shale	Shale	125	0.7200000	74075.937	1947.983
13	GPiP	Glaciated_Pittsburgh_Plateau	Dg	Girard Shale	Shale	125	0.7200000		
14	EL	Eastern_Lake	Dch	Chadakoin Fm	Interbedded Sedimentary	300	0.7000000	94654007.747	87141.494
15	GPiP	Glaciated_Pittsburgh_Plateau	Dch	Chadakoin Fm	Interbedded Sedimentary	300	0.9333333		
16	EL	Eastern_Lake	Dch	Chadakoin Fm	Interbedded Sedimentary	300	0.7000000	785682.607	5240.580
17	GPiP	Glaciated_Pittsburgh_Plateau	Dch	Chadakoin Fm	Interbedded Sedimentary	300	0.9333333		
18	EL	Eastern_Lake	Dch	Chadakoin Fm	Interbedded Sedimentary	300	0.7000000	92957.507	1423.608
19	GPiP	Glaciated_Pittsburgh_Plateau	Dch	Chadakoin Fm	Interbedded Sedimentary	300	0.9333333		
20	EL	Eastern_Lake	Dch	Chadakoin Fm	Interbedded Sedimentary	300	0.7000000	345884.828	2488.304

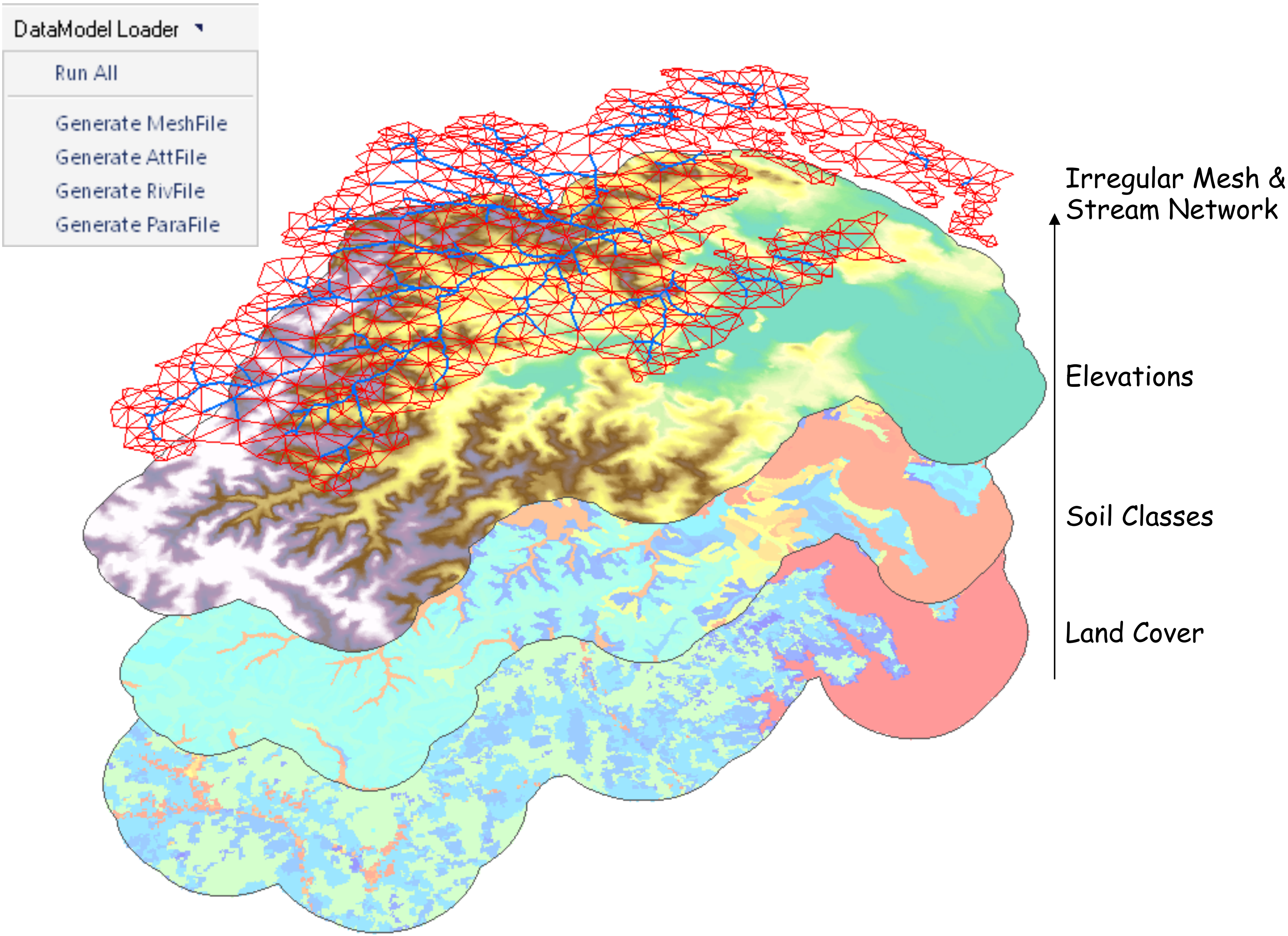
geolphys

PIHM GIS Framework

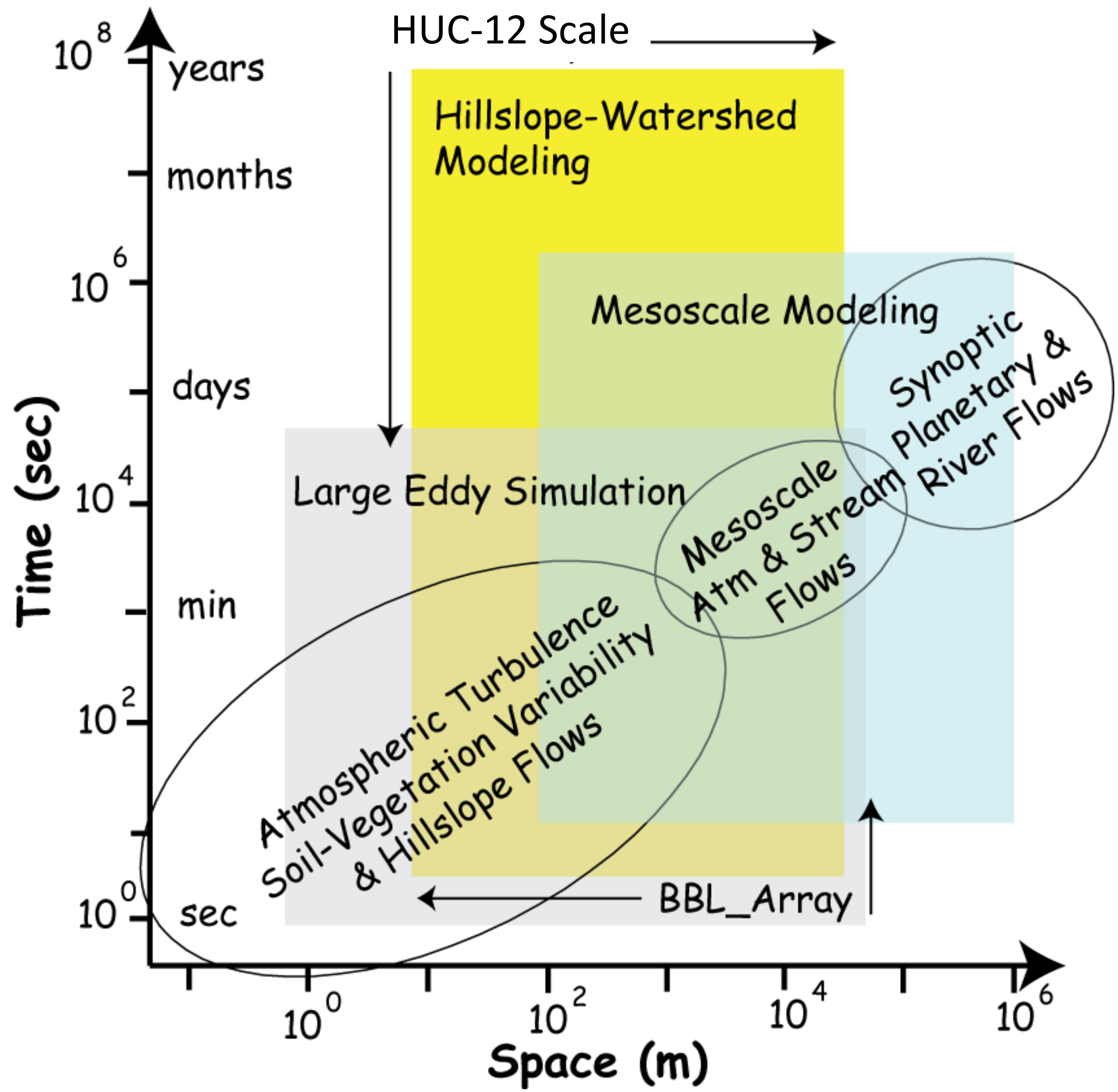


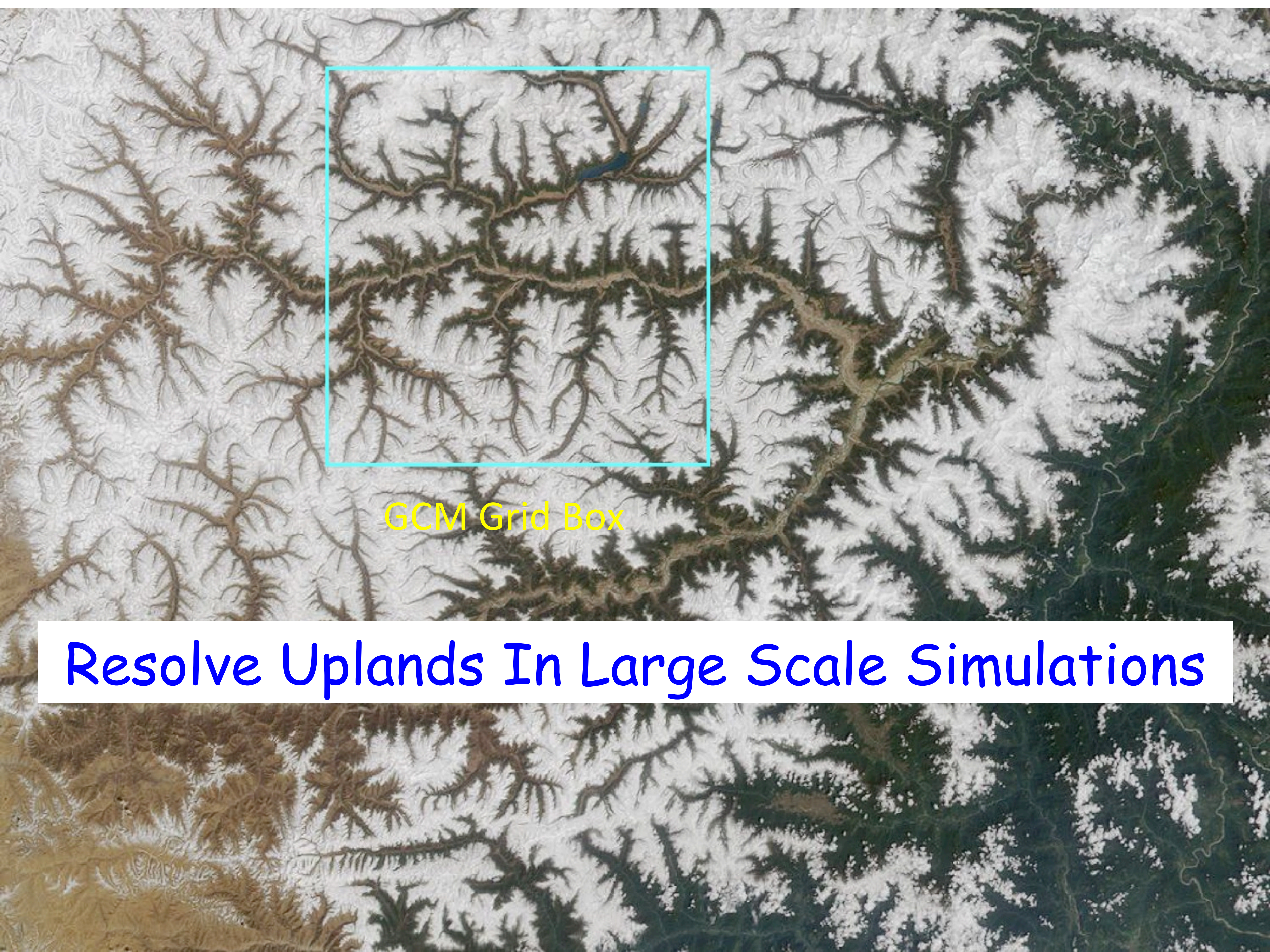
PIHM GIS Interface: Domain Decomposition

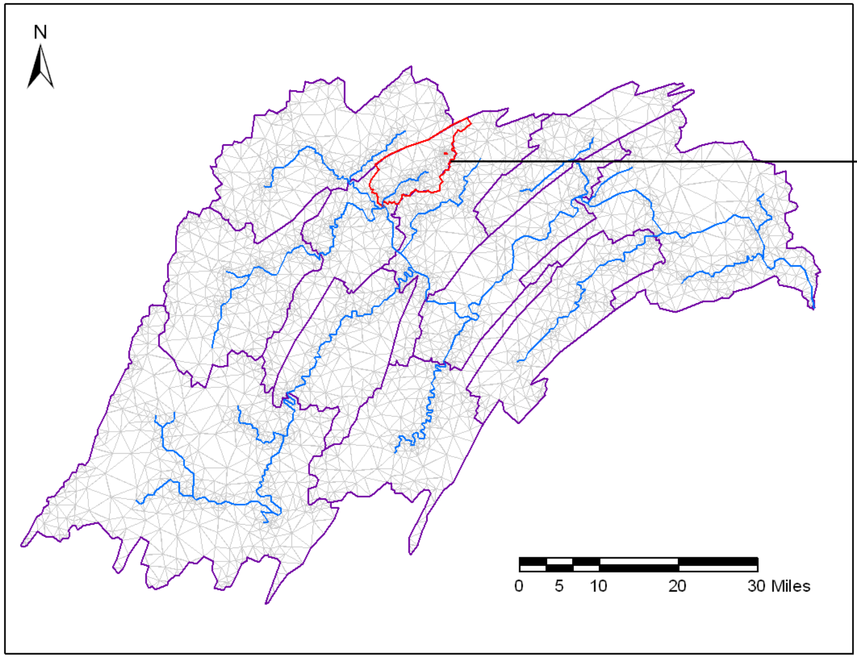


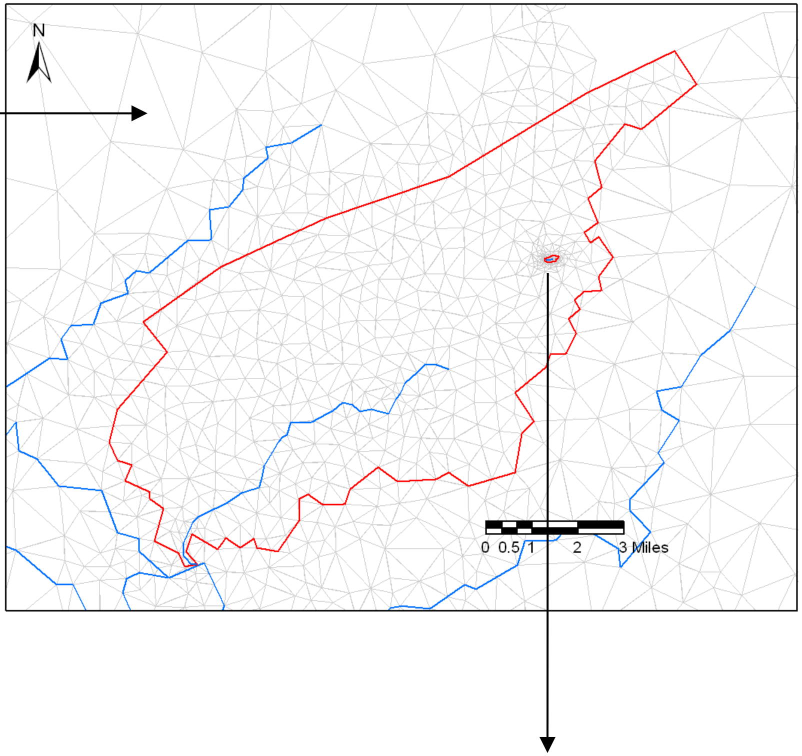

DataModel Loader
Run All
Generate MeshFile
Generate AttFile
Generate RivFile
Generate ParaFile
Irregular Mesh &
Stream Network
Elevations
Soil Classes
Land Cover

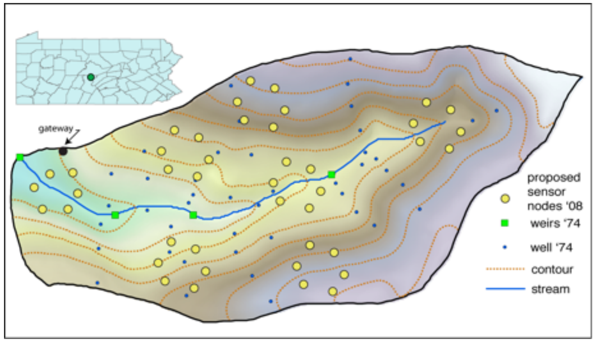
Hydroclimatic Process Scales




GCM Grid Box
Resolve Uplands In Large Scale Simulations

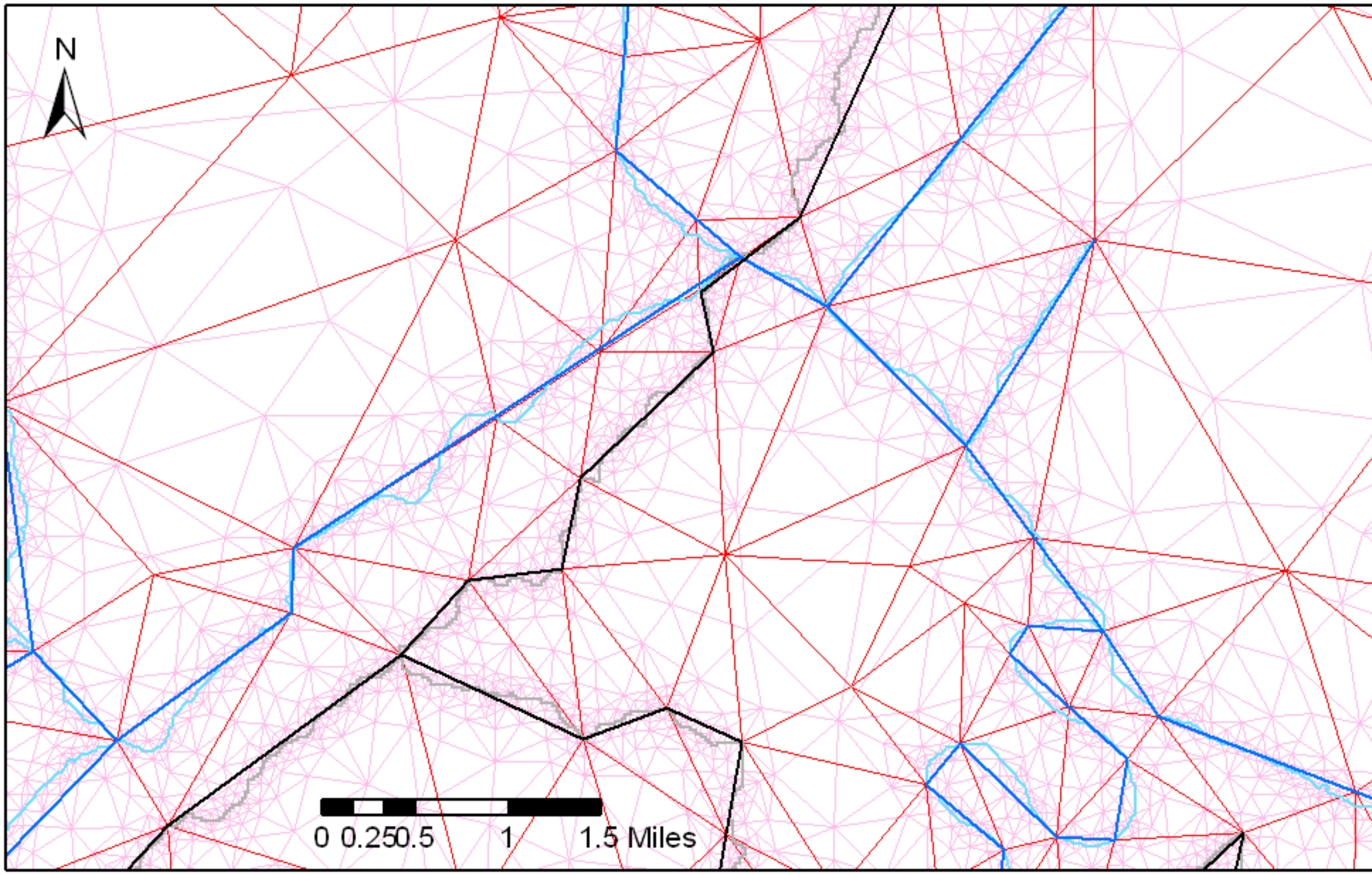






Unfolding A Multi-Scale Experiment

Generating Grids: resolution depends on purpose



National CZO Program

Advancing interdisciplinary studies of earth surface processes

Model Development & Testing
The Shale Hills/Susquehanna Critical Zone Observatory

PENNSTATE 1855

NSF

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Sue Brantley
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Ken Davis
Kamini Singha
Laura Toran
Pat Reed
Karen Salvage
Eric Kirby
Tim White
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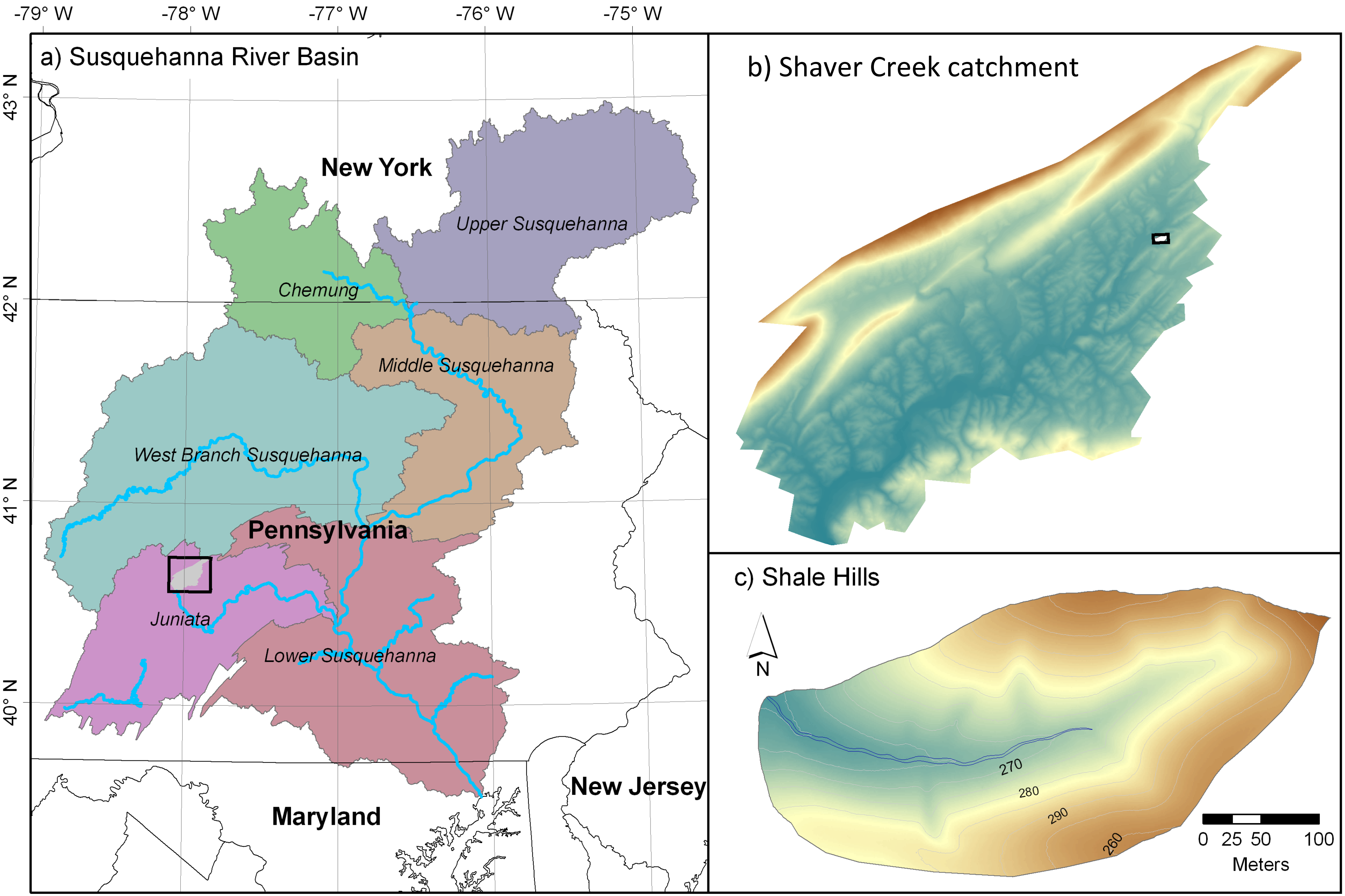
Ray Fletcher
Michelle Tuttle
Paul Bierman
Peter Lichtner
Carl Steefel
Rich April
Ryan Mather
David Harbor
Larry McKay
Teferi Tsegaye
HernanSantos
Evan Thomas
Xuan Yu
Yu Zhang
Ryan Jones
Beth Boyer

CZEN

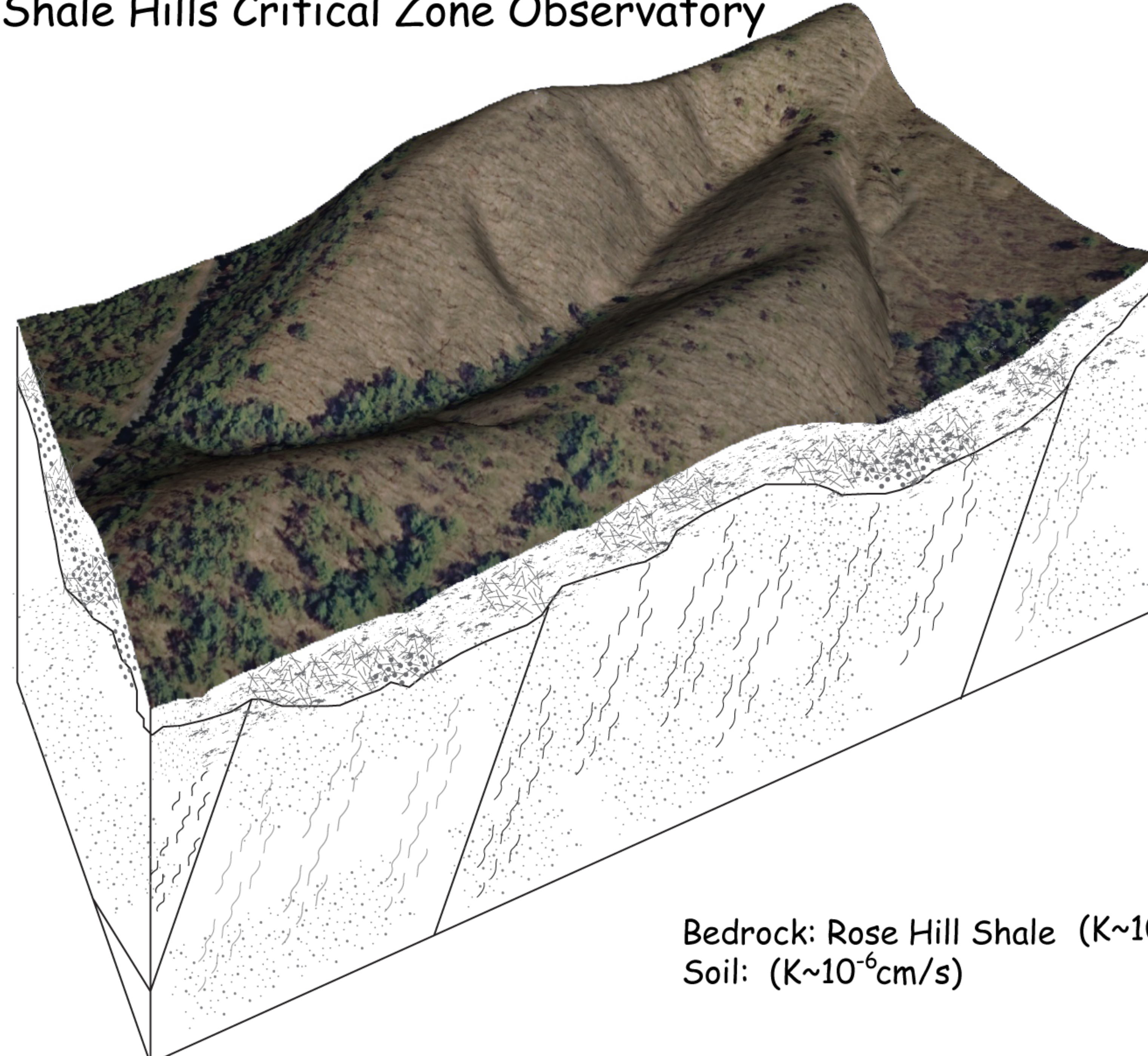
CUAHSI
universities allied for water research

CSDMS
COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

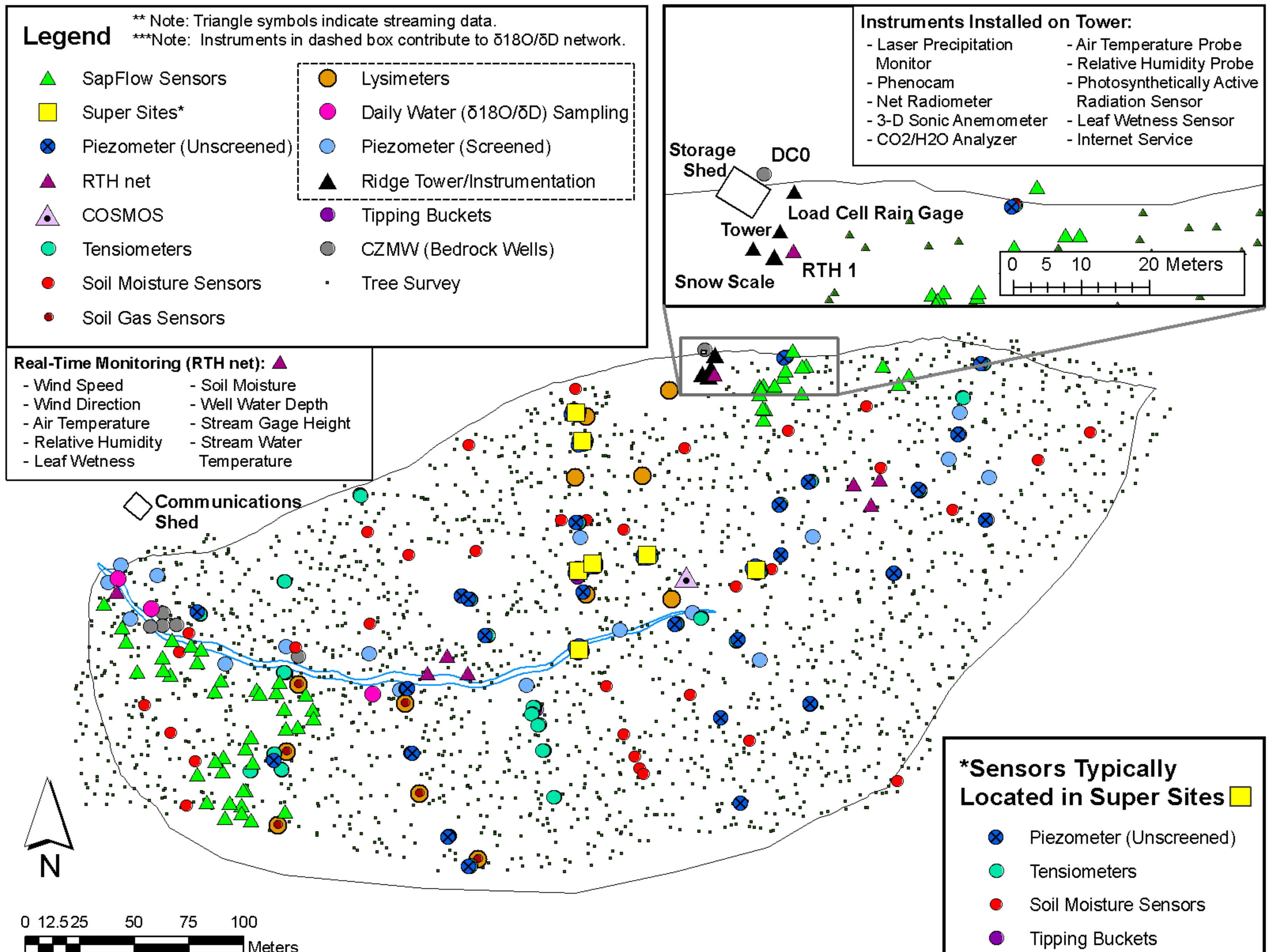


-79° W
-78° W
-77° W
-76° W
-75° W
43° N
42° N
41° N
40° N
a) Susquehanna River Basin
New York
Upper Susquehanna
Chemung
Middle Susquehanna
West Branch Susquehanna
Pennsylvania
Juniata
Lower Susquehanna
New Jersey
Maryland
b) Shaver Creek catchment
c) Shale Hills
N
270
280
290
260
0 25 50 100
Meters

The Shale Hills Critical Zone Observatory

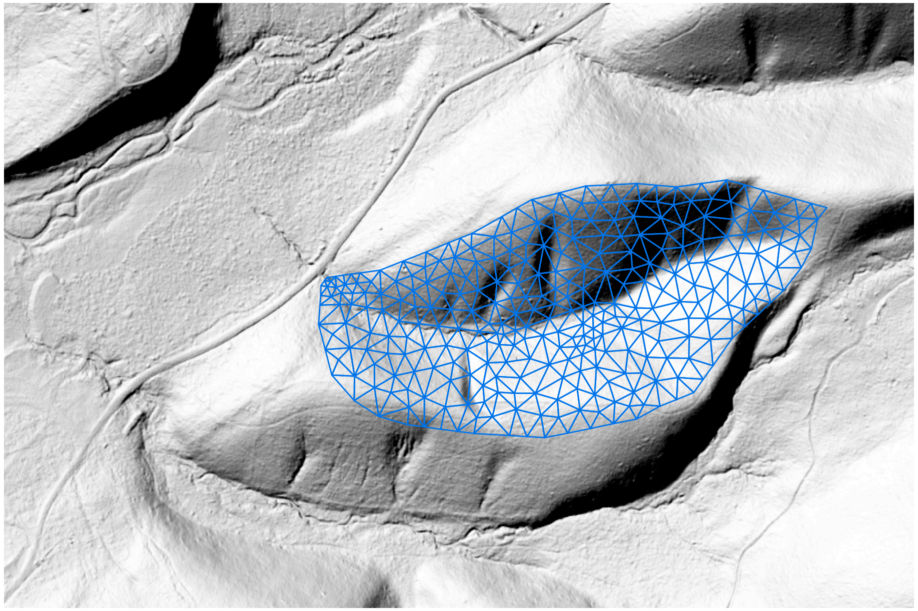


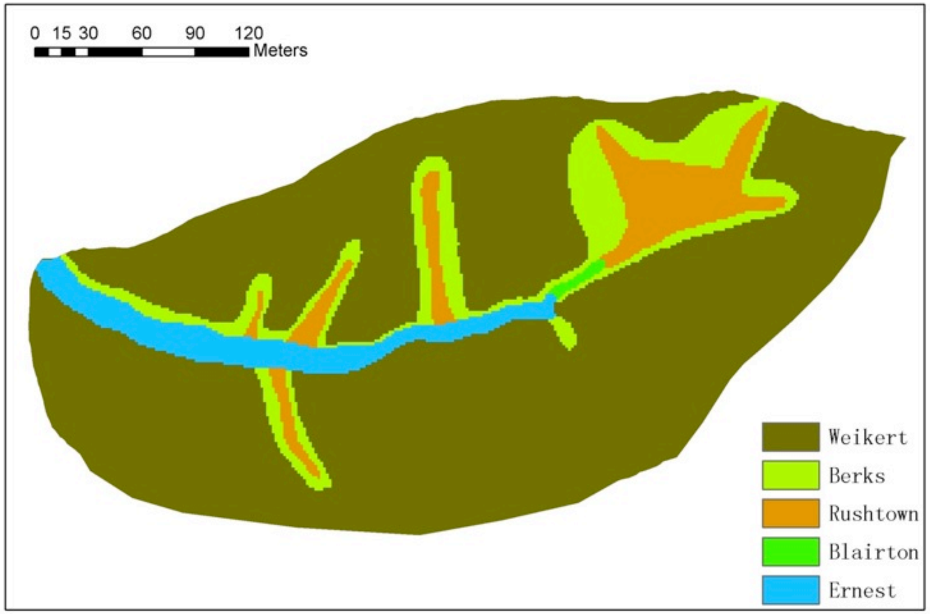
Bedrock: Rose Hill Shale (K~10^{-15} cm/s)
Soil: (K~10^{-6}cm/s)

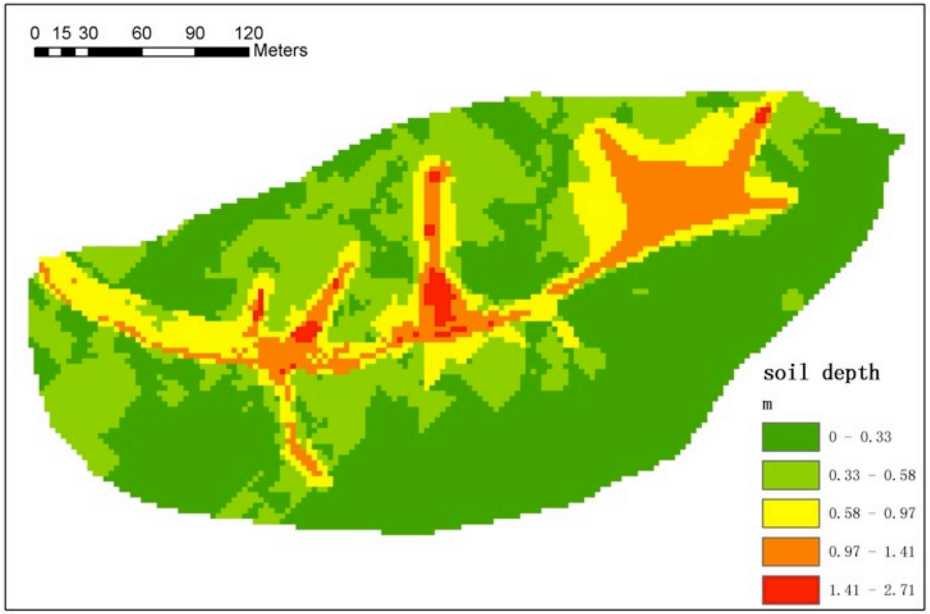


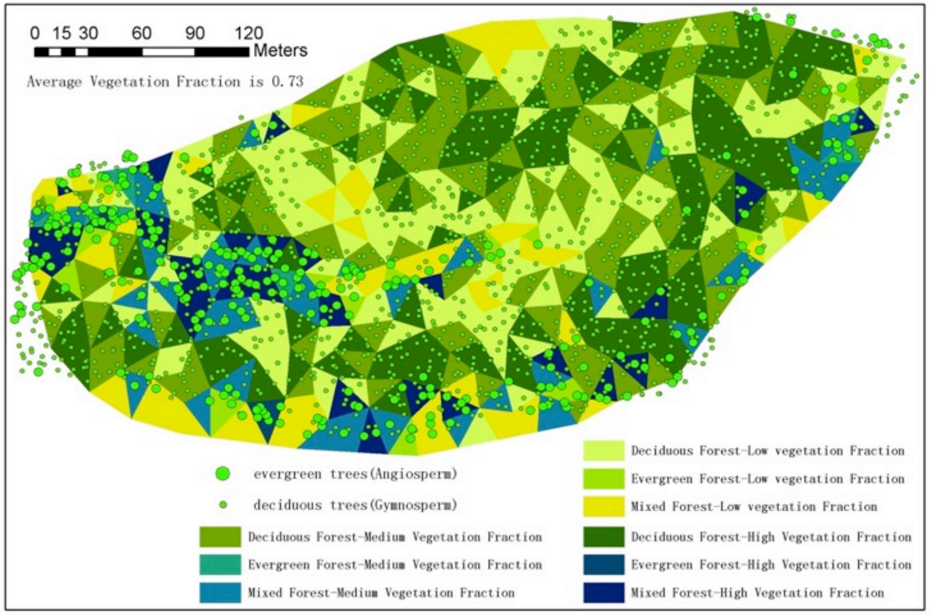
Legend
** Note: Triangle symbols indicate streaming data.
***Note: Instruments in dashed box contribute to δ18O/δD network.
SapFlow Sensors
Super Sites*
Piezometer (Unscreened)
RTH net
COSMOS
Tensiometers
Soil Moisture Sensors
Soil Gas Sensors
Lysimeters
Daily Water (δ18O/δD) Sampling
Piezometer (Screened)
Ridge Tower/Instrumentation
Tipping Buckets
CZMW (Bedrock Wells)
Tree Survey
Real-Time Monitoring (RTH net):
- Wind Speed
- Wind Direction
- Air Temperature
- Relative Humidity
- Leaf Wetness
- Soil Moisture
- Well Water Depth
- Stream Gage Height
- Stream Water Temperature
Instruments Installed on Tower:
- Laser Precipitation Monitor
- Phenocam
- Net Radiometer
- 3-D Sonic Anemometer
- CO2/H2O Analyzer
- Air Temperature Probe
- Relative Humidity Probe
- Photosynthetically Active Radiation Sensor
- Leaf Wetness Sensor
- Internet Service
Storage Shed
DC0
Load Cell Rain Gage
Tower
RTH 1
Snow Scale
0 5 10 20 Meters
Communications Shed
N
0 12.5 25 50 75 100 Meters
*Sensors Typically Located in Super Sites
Piezometer (Unscreened)
Tensiometers
Soil Moisture Sensors
Tipping Buckets

CZO Data ->lidar, Soil, Regolith,Veg

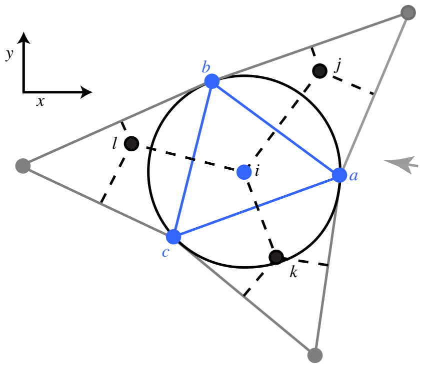


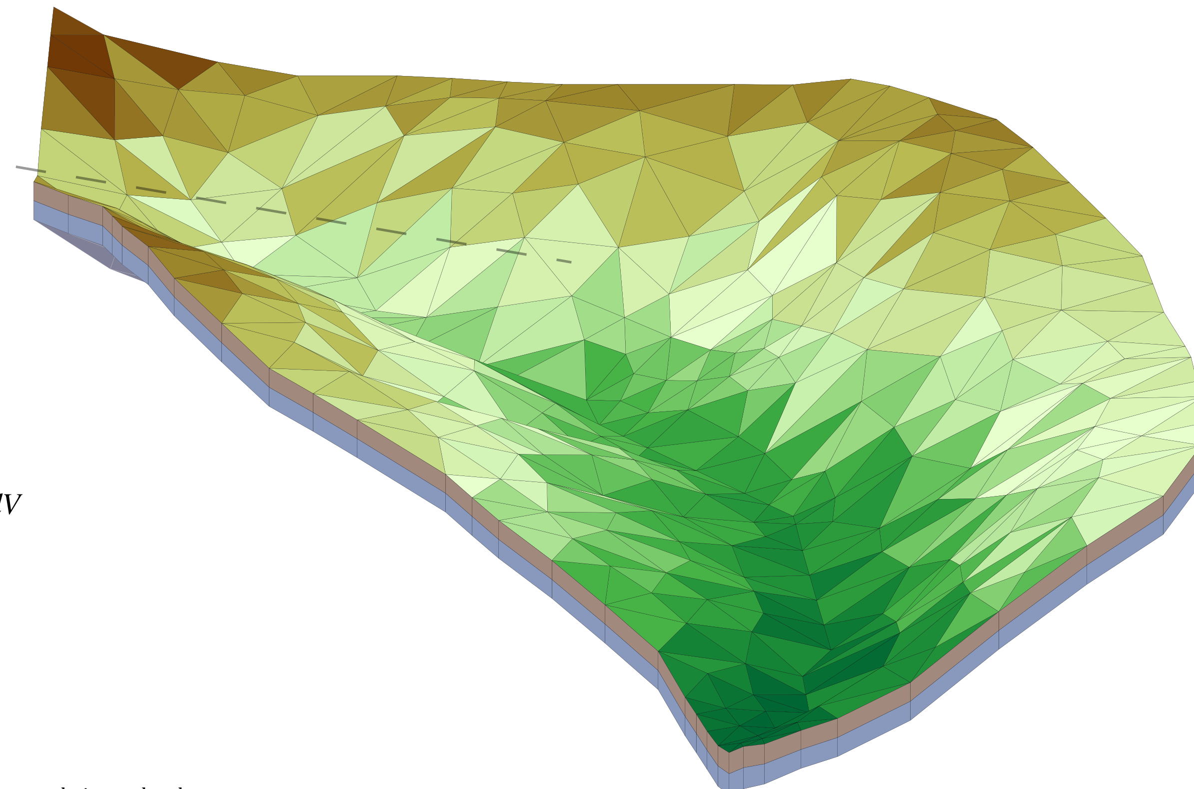






PIHM

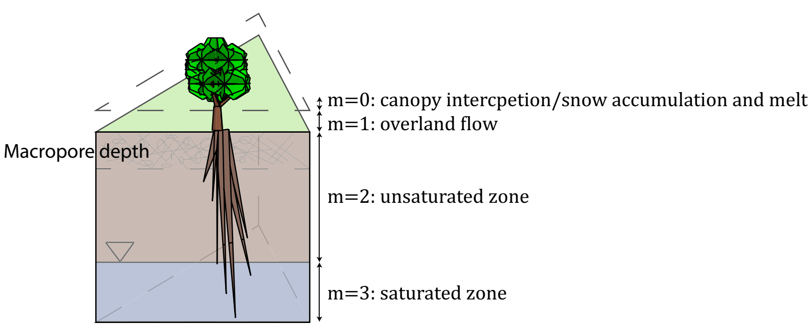


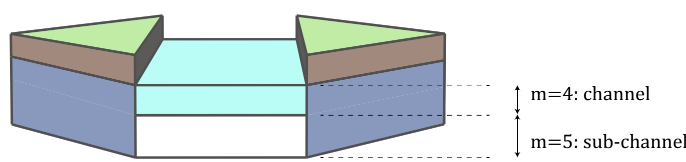


$$\frac{\partial \varphi}{\partial t} = \nabla\cdot(\varphi U) + \nabla\cdot(\Gamma\nabla\varphi) + Q_{ss}$$

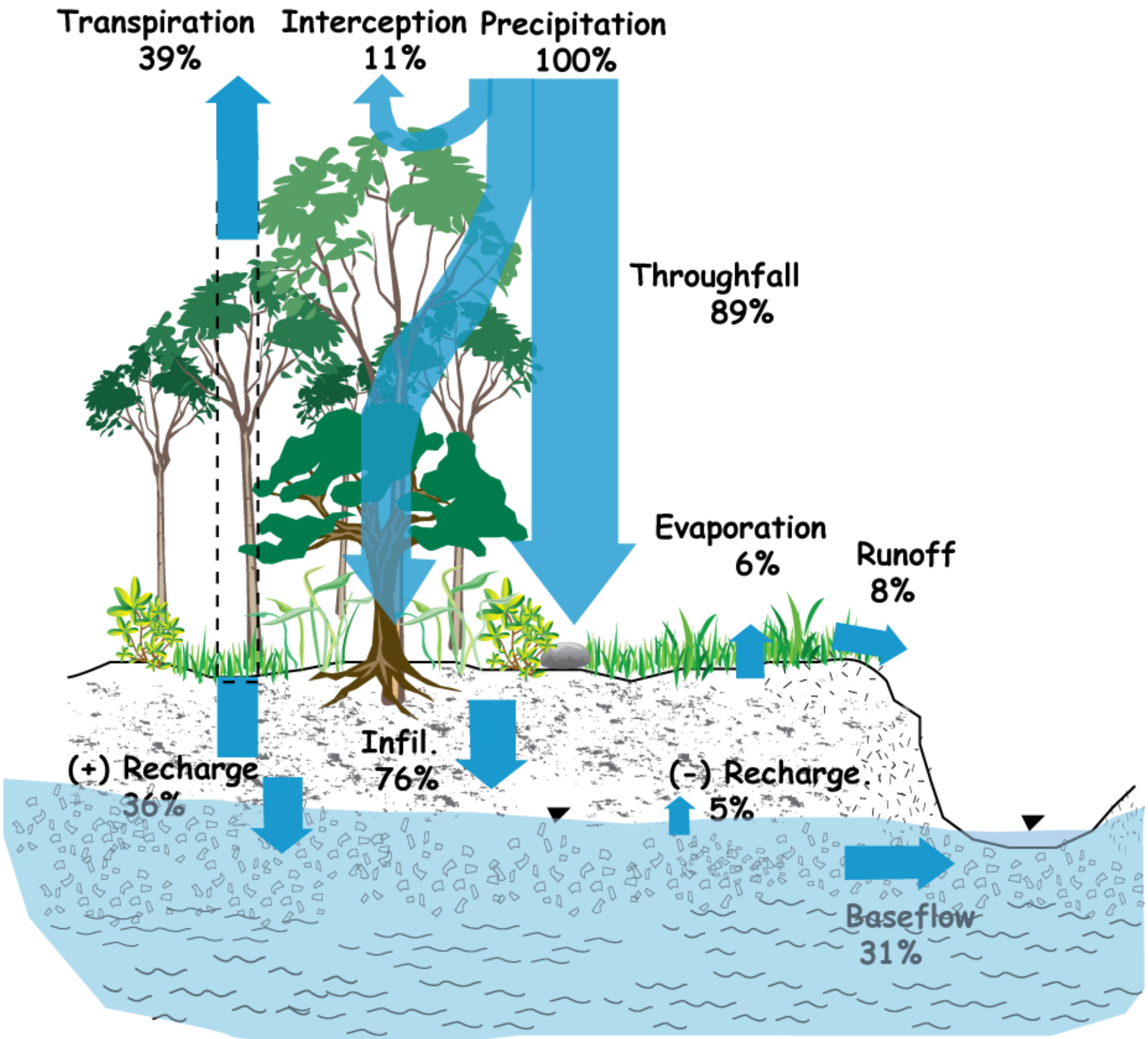
$$\frac{\partial}{\partial t}\int_{V_i}\varphi\, dV = \int_{A_{ij}} \vec{n}\cdot(\varphi U)dA + \int_{A_{ij}}\vec{n}\cdot(\Gamma\nabla\varphi)dA + \int_{V_i} Q_{ss}\, dV$$

$$\left.\left\{A_i\frac{d\bar{\phi}}{dt} = \sum_j \vec{n}\cdot\bar{C}A_{ij} + \sum_j \vec{n}\cdot\bar{D}A_{ij} + \bar{Q}_{ss}V_i\right\}\right|_{m=0,1,\ldots,5}$$

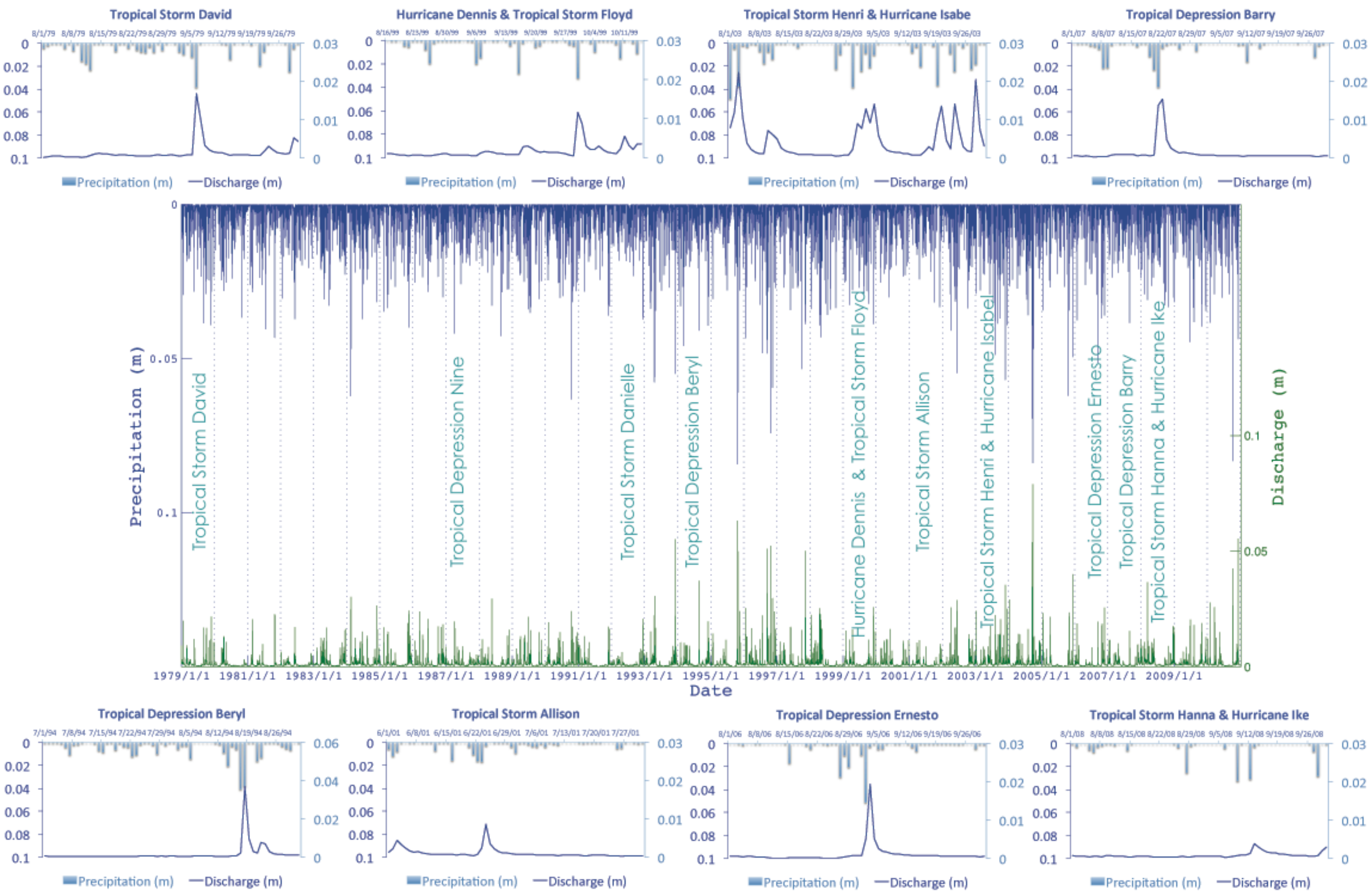




Basic Output: Water balance

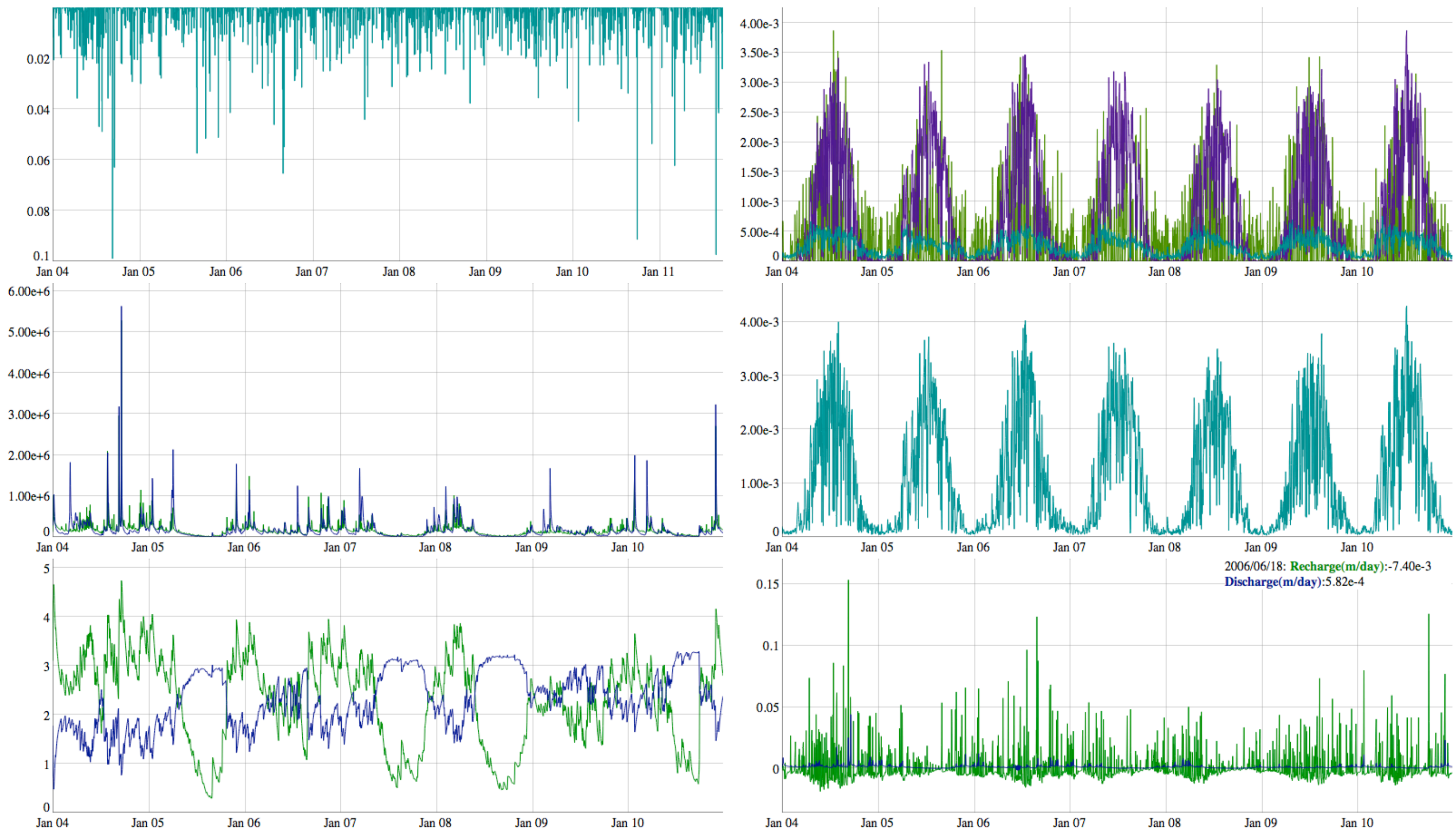


Shale Hills CZO: 1979-2010 Reanalysis Storm Library



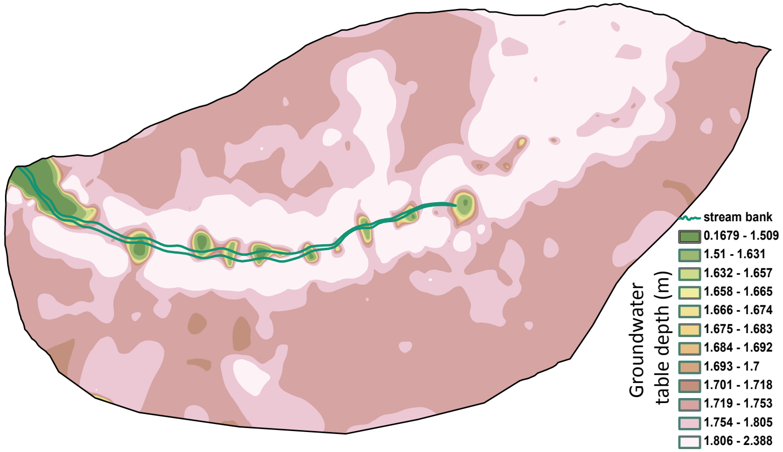
http://www.pihm.psu.edu/applications.html

CZO Catchment Reanalysis time series: 1979-Present

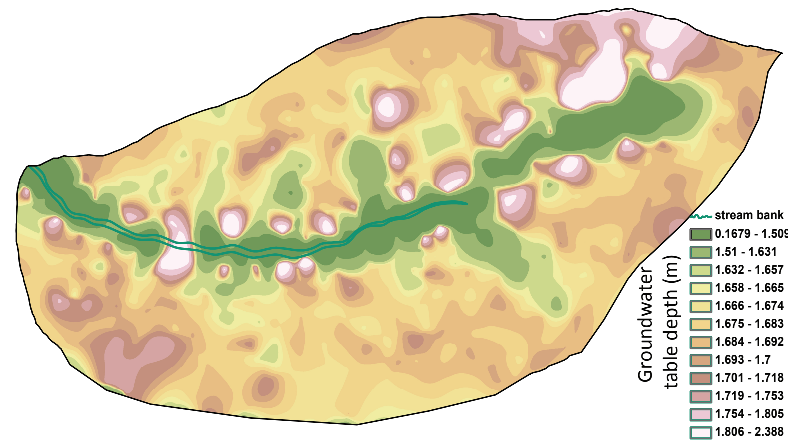


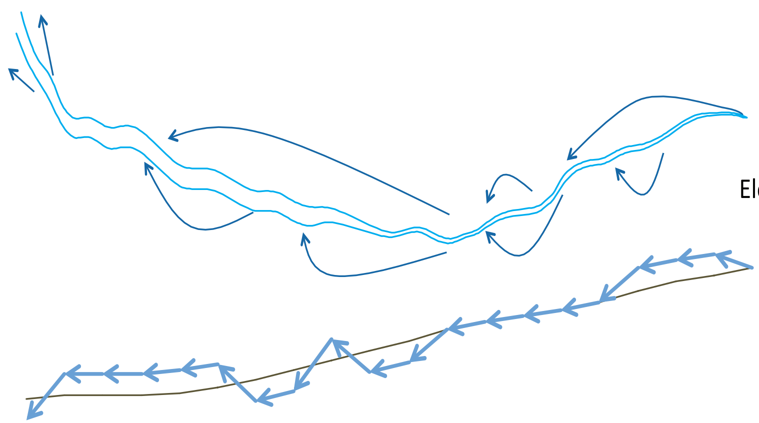
Stream-Groundwater Interaction

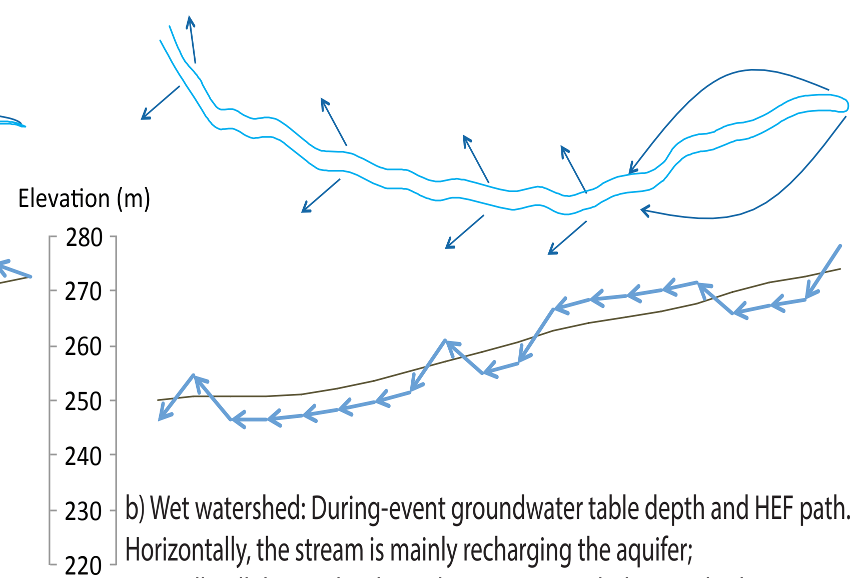
T=2009/10/23 00:00:00 before precipitation



T=2009/10/24 00:00:00 during precipitation







a) Dry watershed: Pre-event groundwater table depth and HEF path.
Horizontally, HEF vaies (gaining/losing) 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.

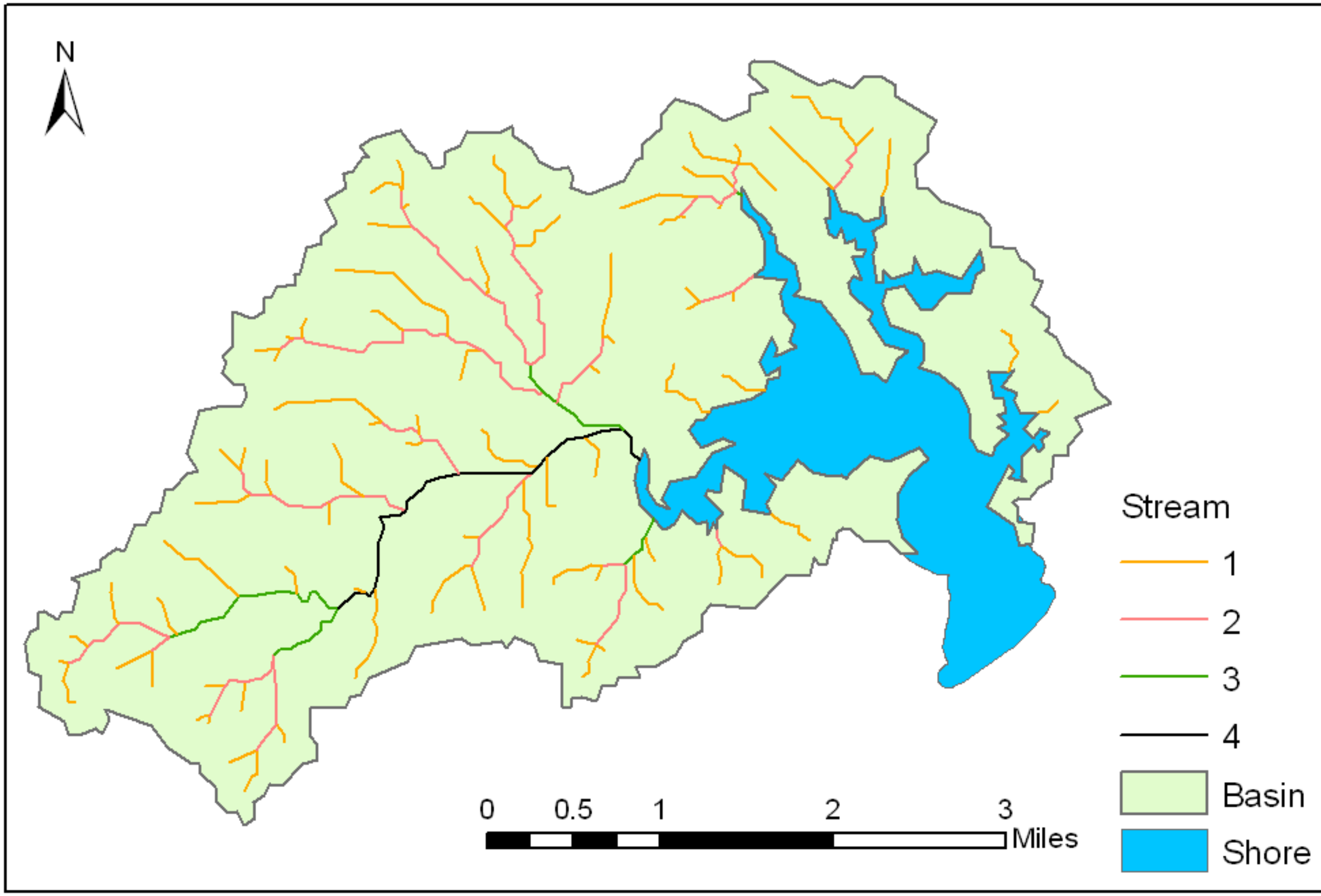
30 km^2 Meso-Scale Experiment

Integrated Modeling in a Coastal Watershed

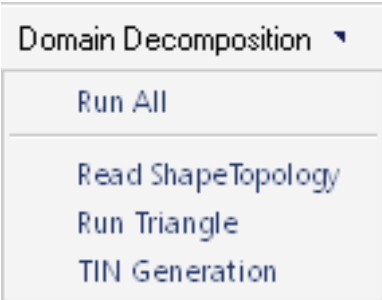
Freshwater Discharge: Groundwater or Surface Water?

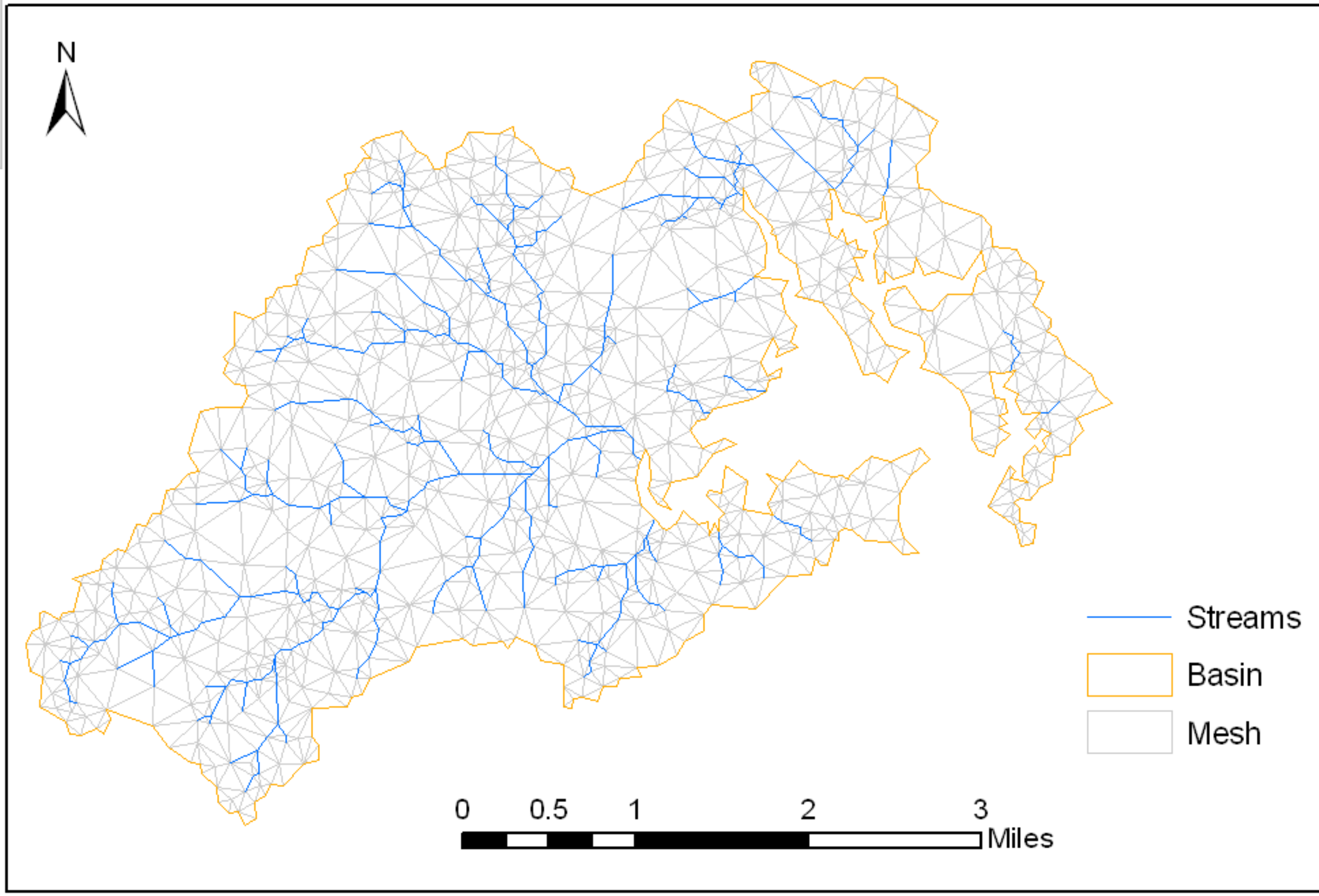
Gopal Bhatt

In cooperation with the Smithsonian
Environmental Research Center

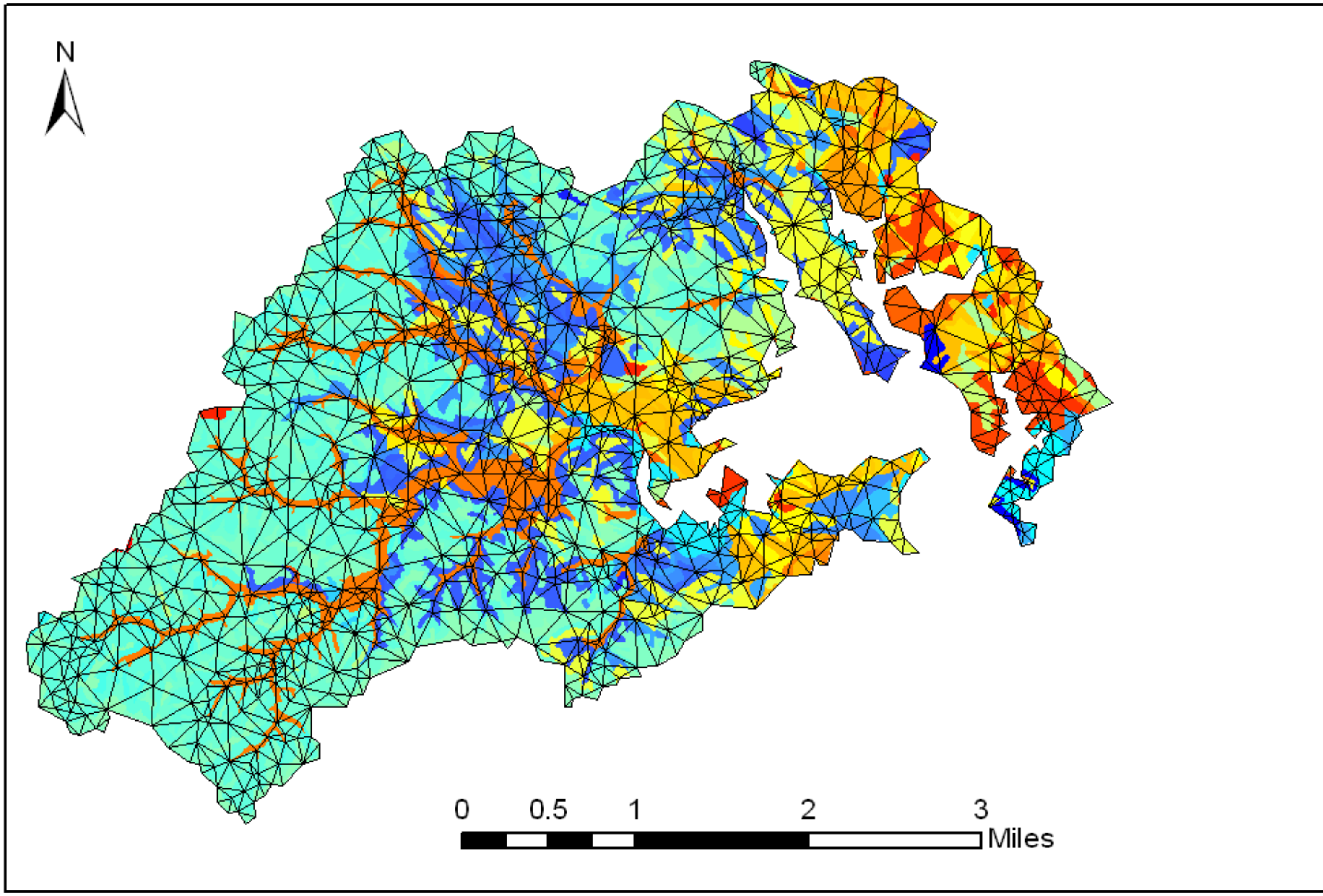


Domain used in decomposition

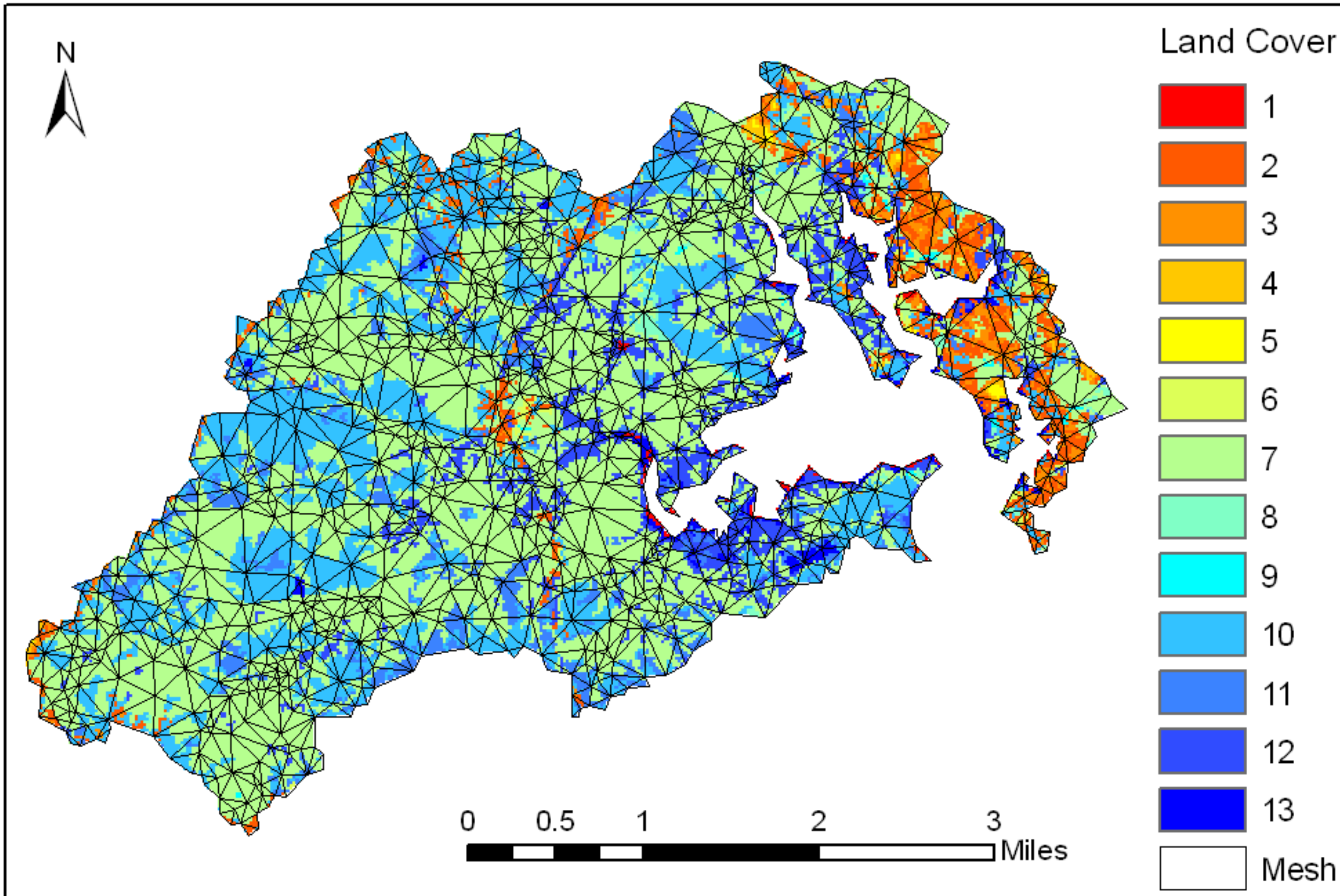




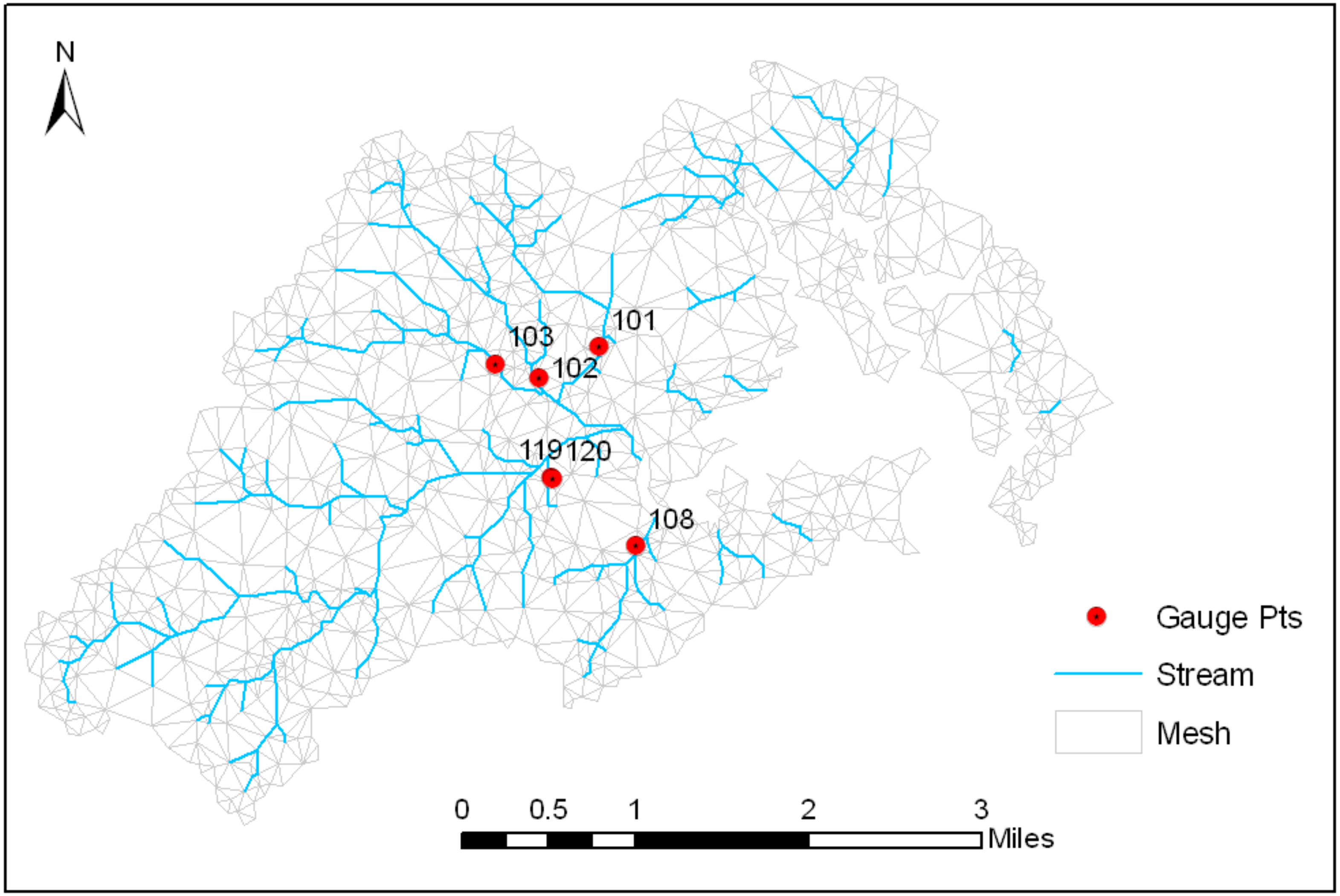
Triangular Irregular Mesh
(Number of Mesh = 1862)



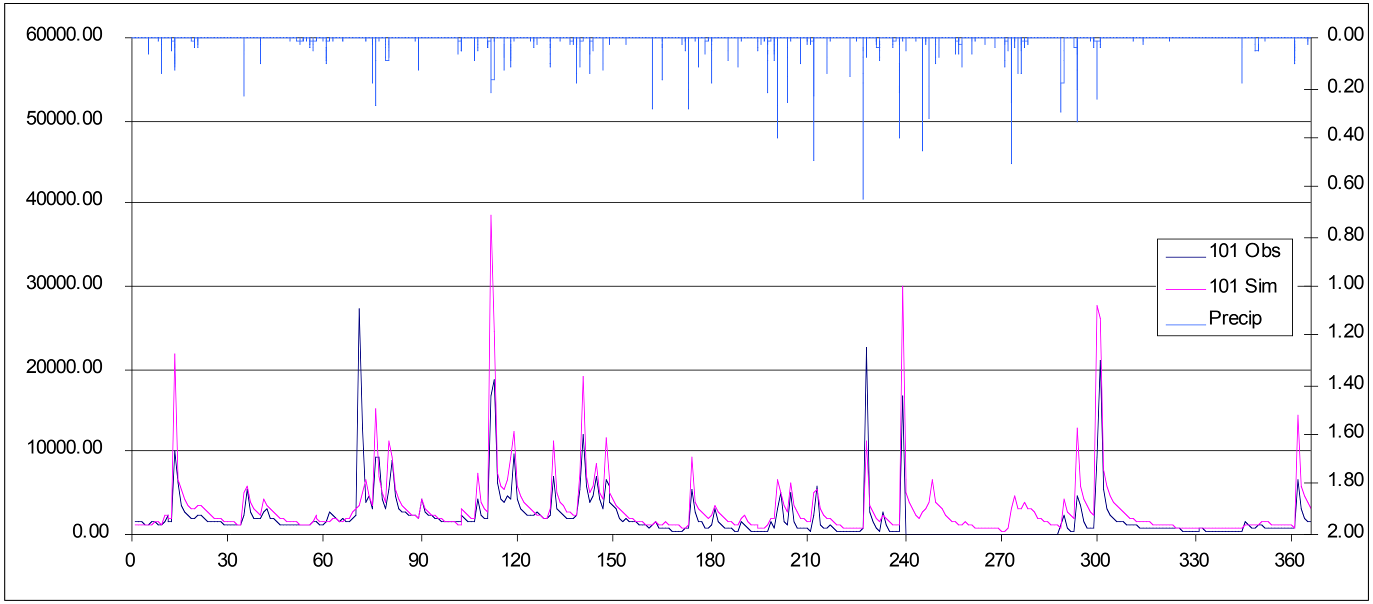
SSURGO Soil Classification

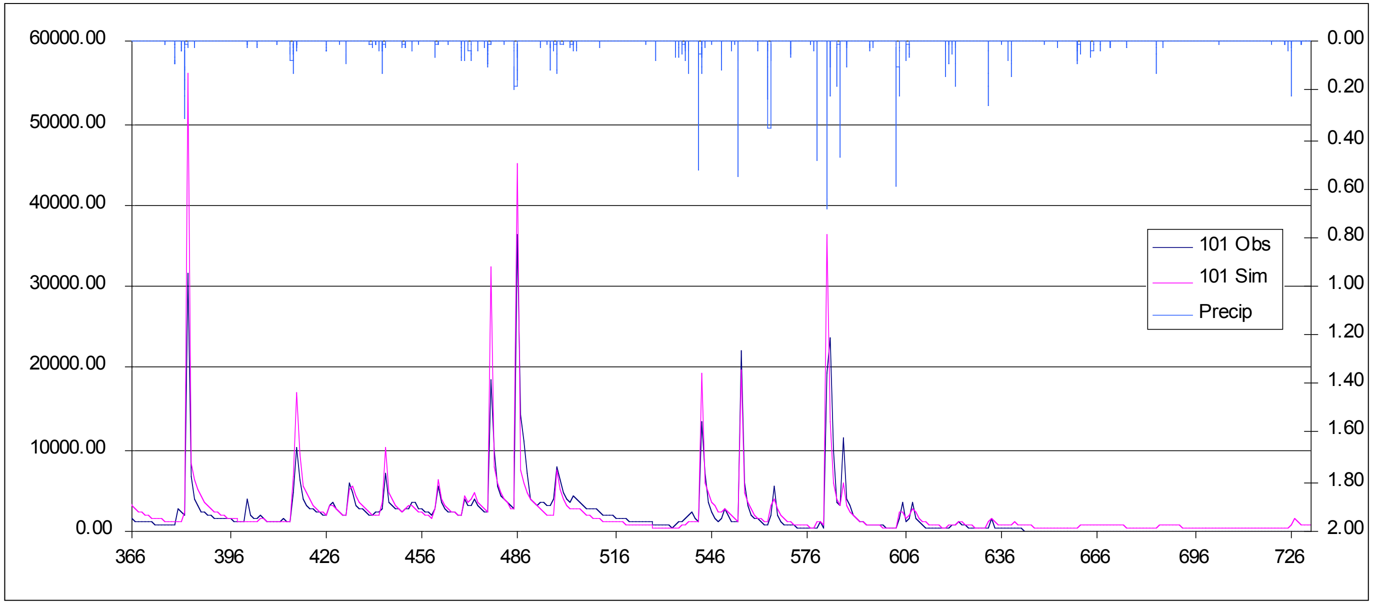


30m NLCD Data

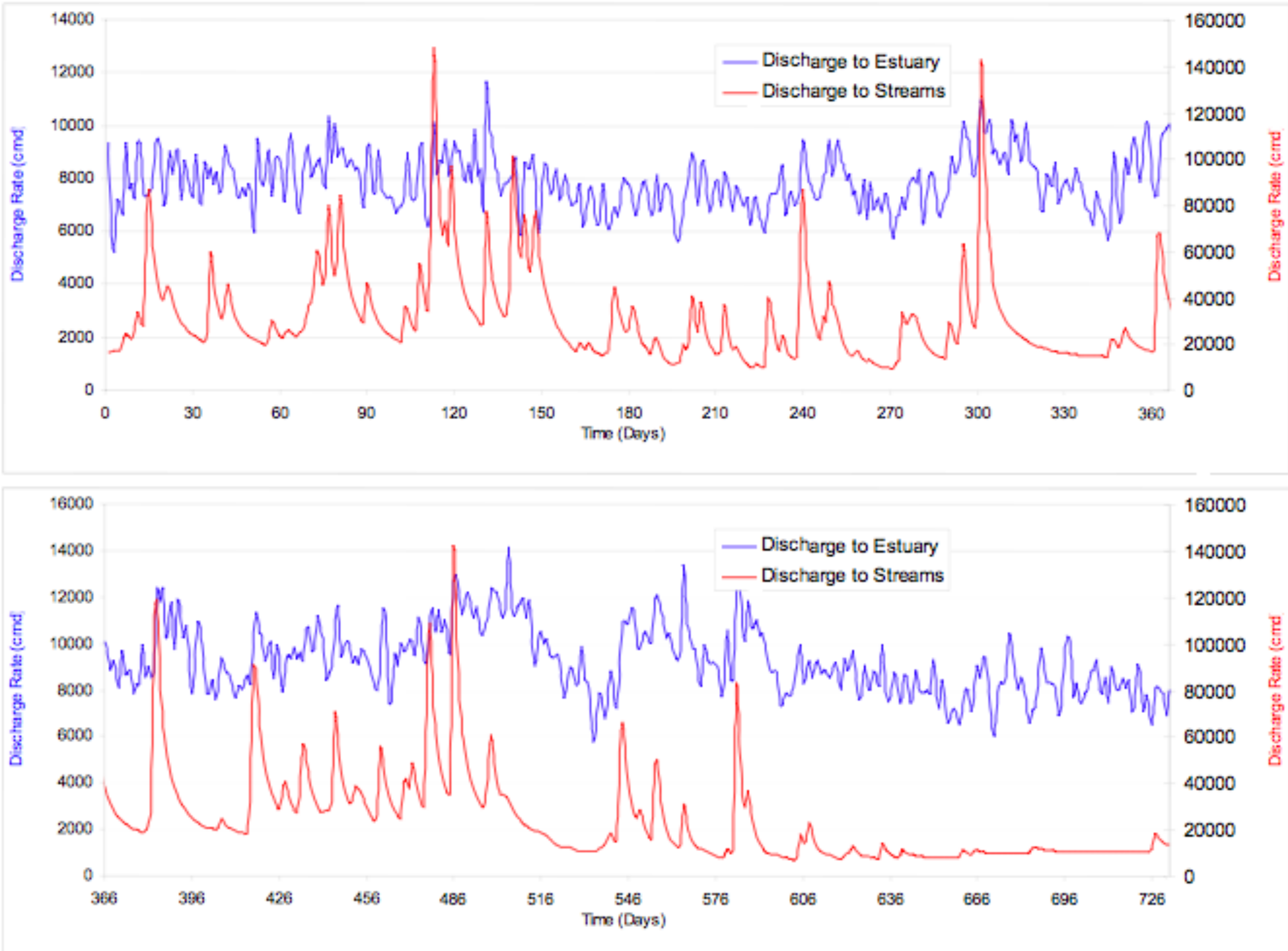


Stream Gauge Locations


60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
0
30
60
90
120
150
180
210
240
270
300
330
360
101 Obs
101 Sim
Precip


60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
366
396
426
456
486
516
546
576
606
636
666
696
726
101 Obs
101 Sim
Precip

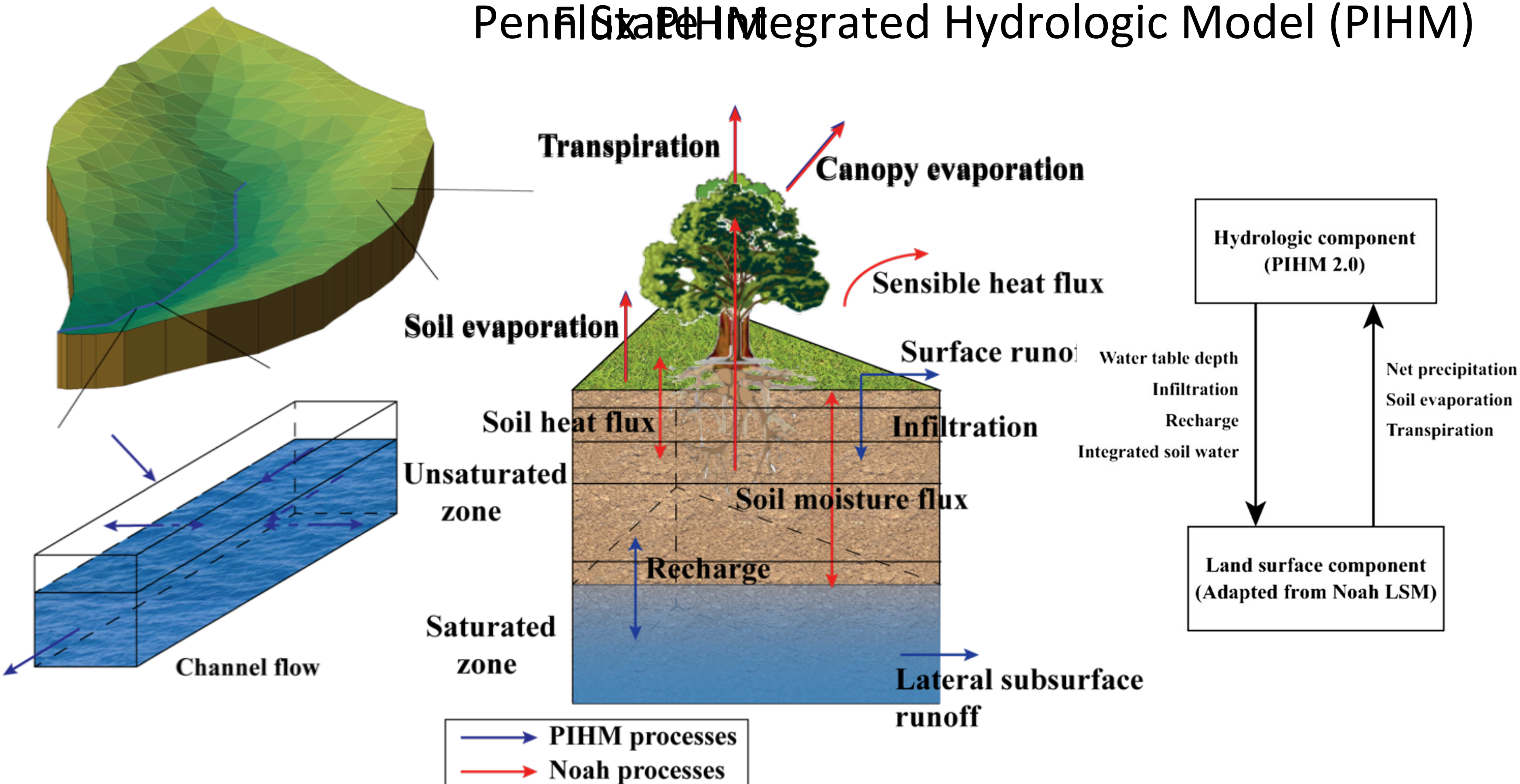
Freshwater Discharge to the Chesapeake



Physically-based land surface hydrologic model: Flux-PIHM

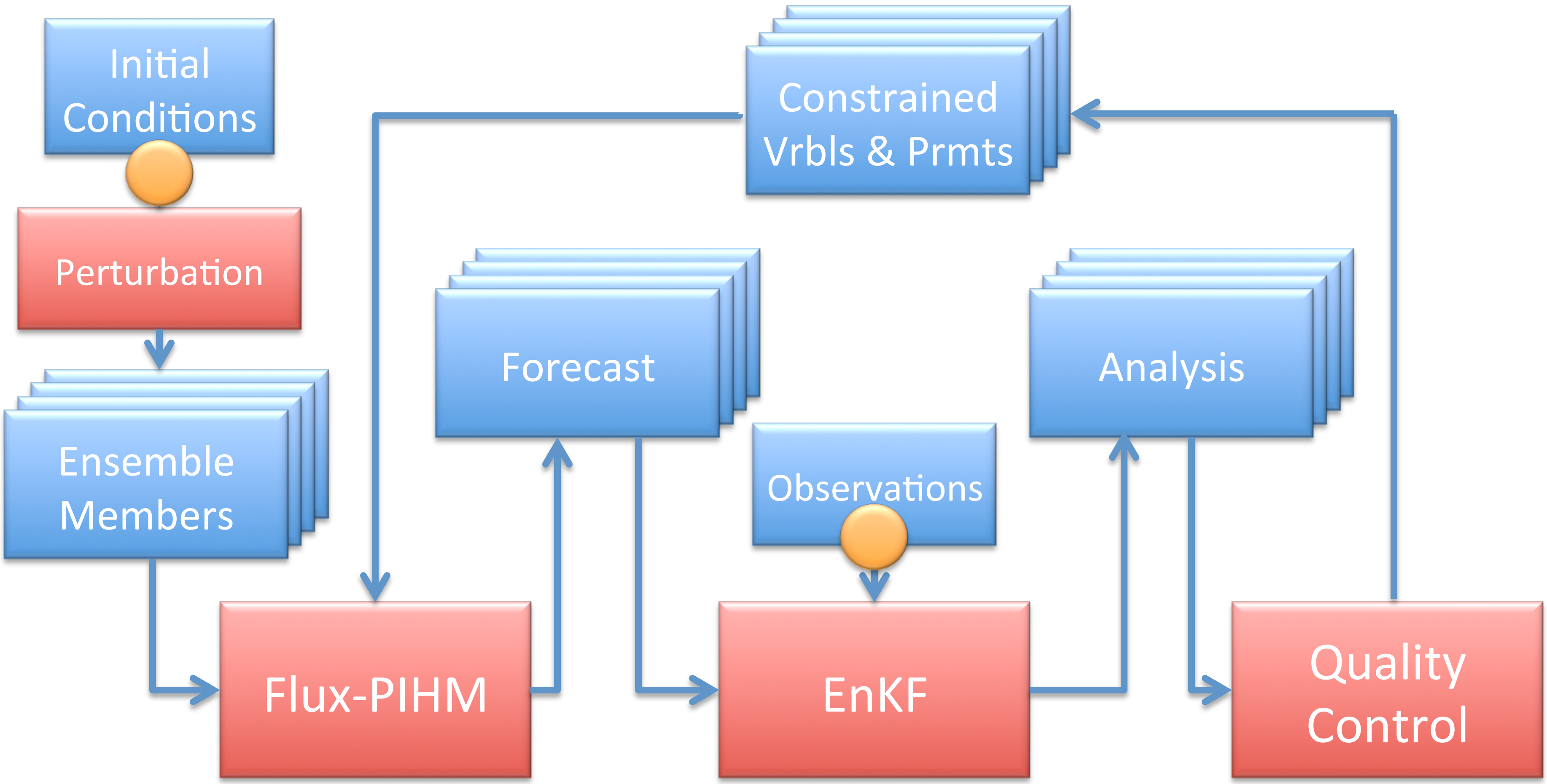
Penn State Integrated Hydrologic Model (PIHM)

Flux-PIHM



Shi et al. 2013 Hydrometeorology

Flux-PIHM data assimilation system

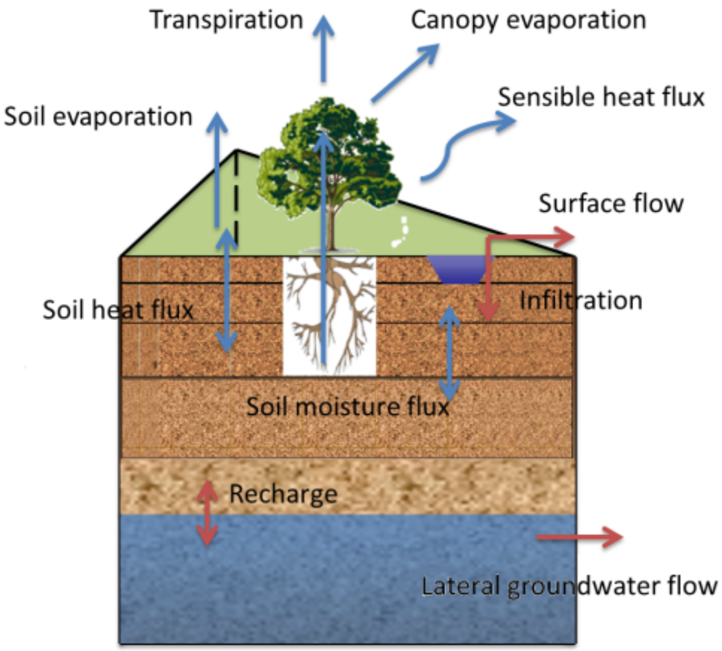


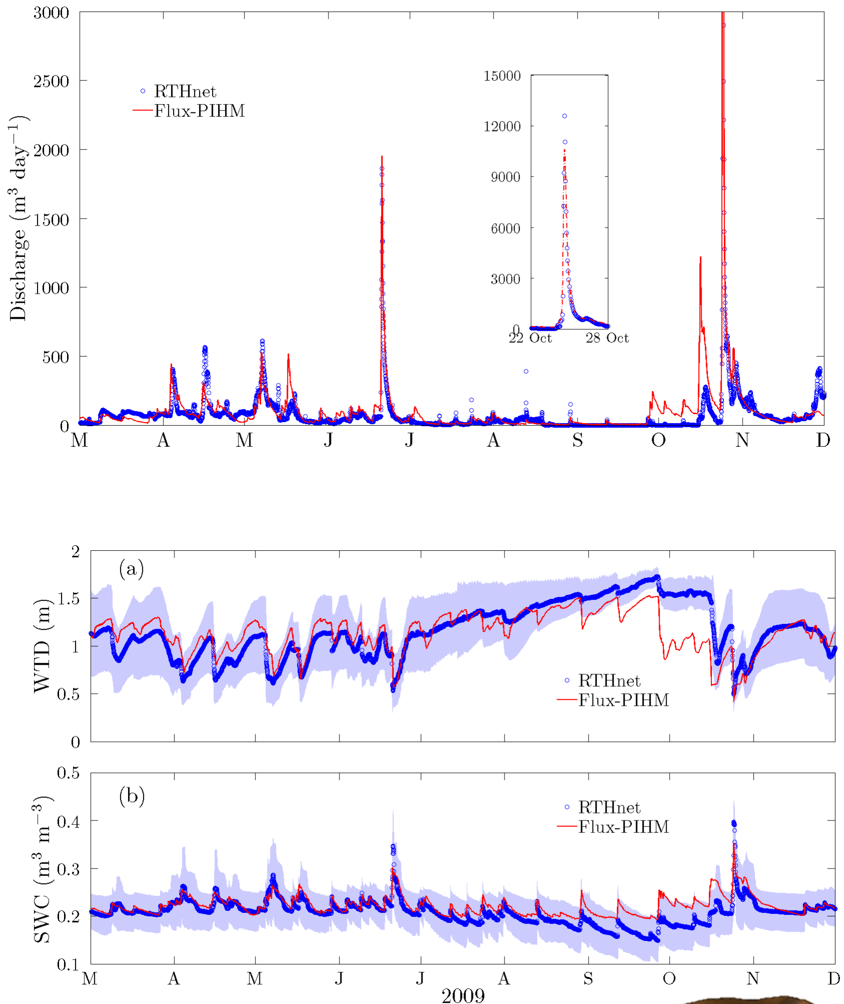
Shi et al. 2014 WRR

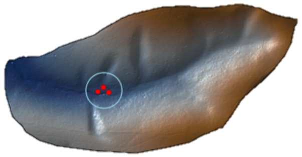
Flux-PIHM

Coupled land surface hydrologic model

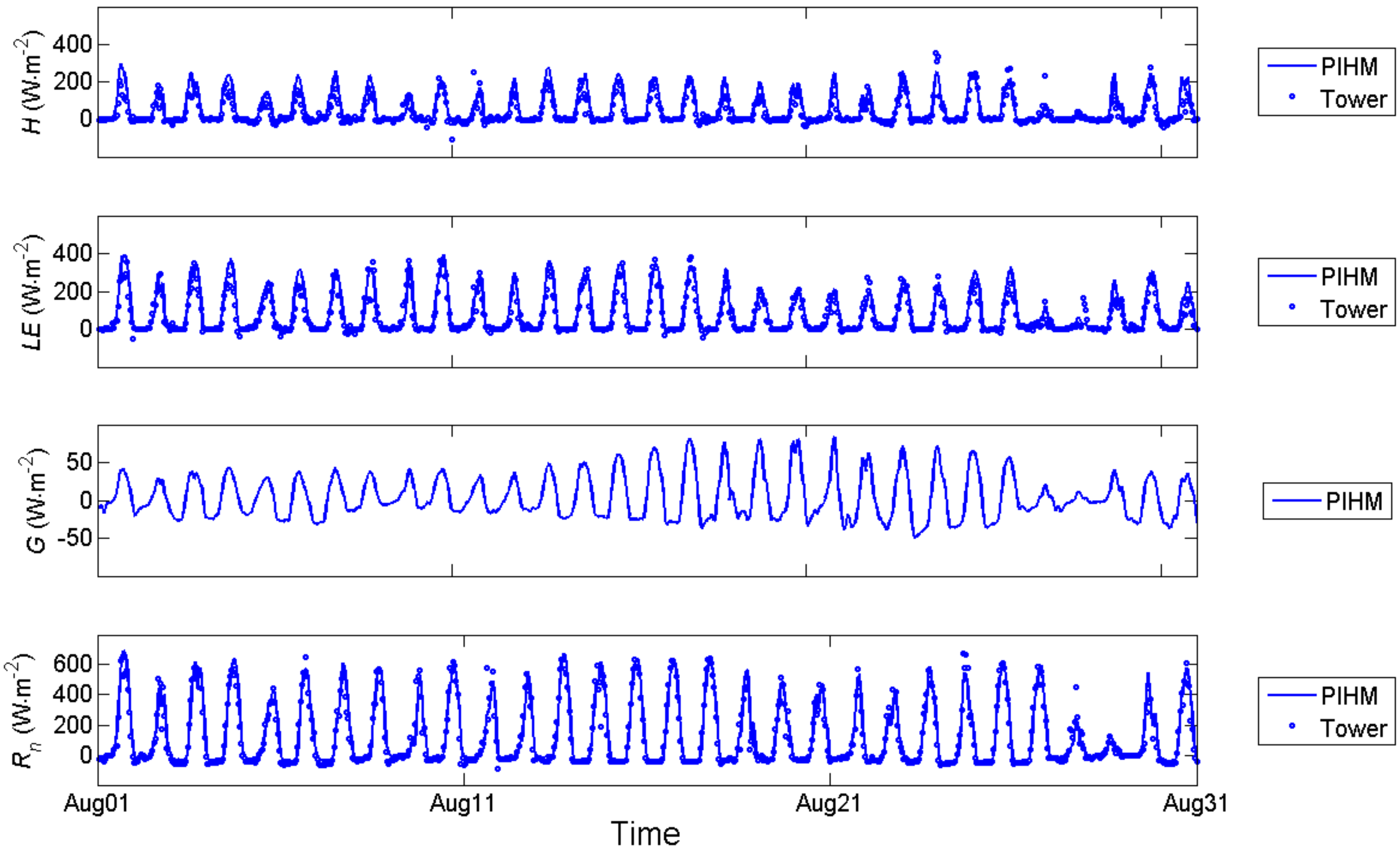
- Noah land surface + PIHM hydrology
- Physically-based
- Spatially-distributed



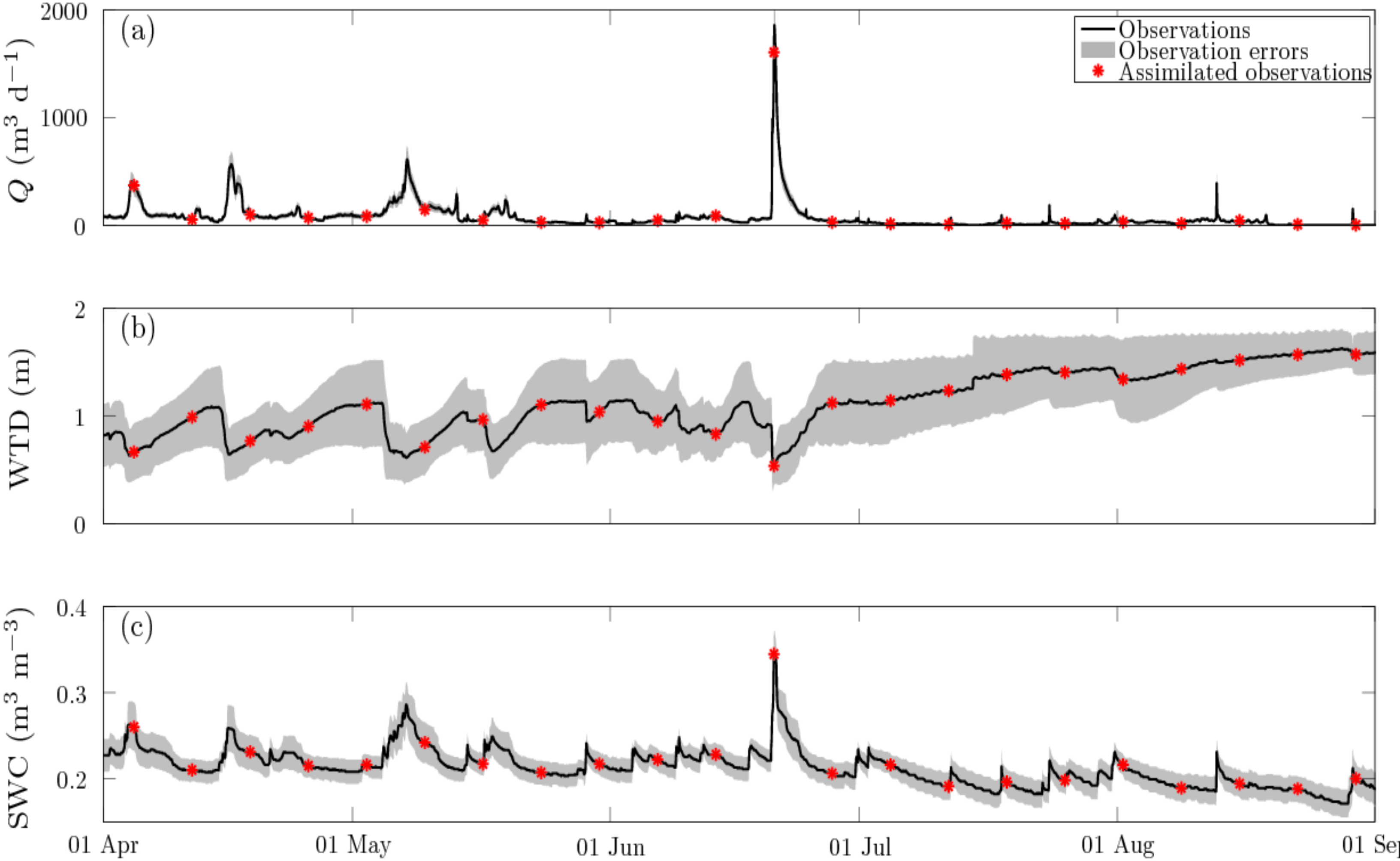




Shi et al. 2013 Hydrometeorology

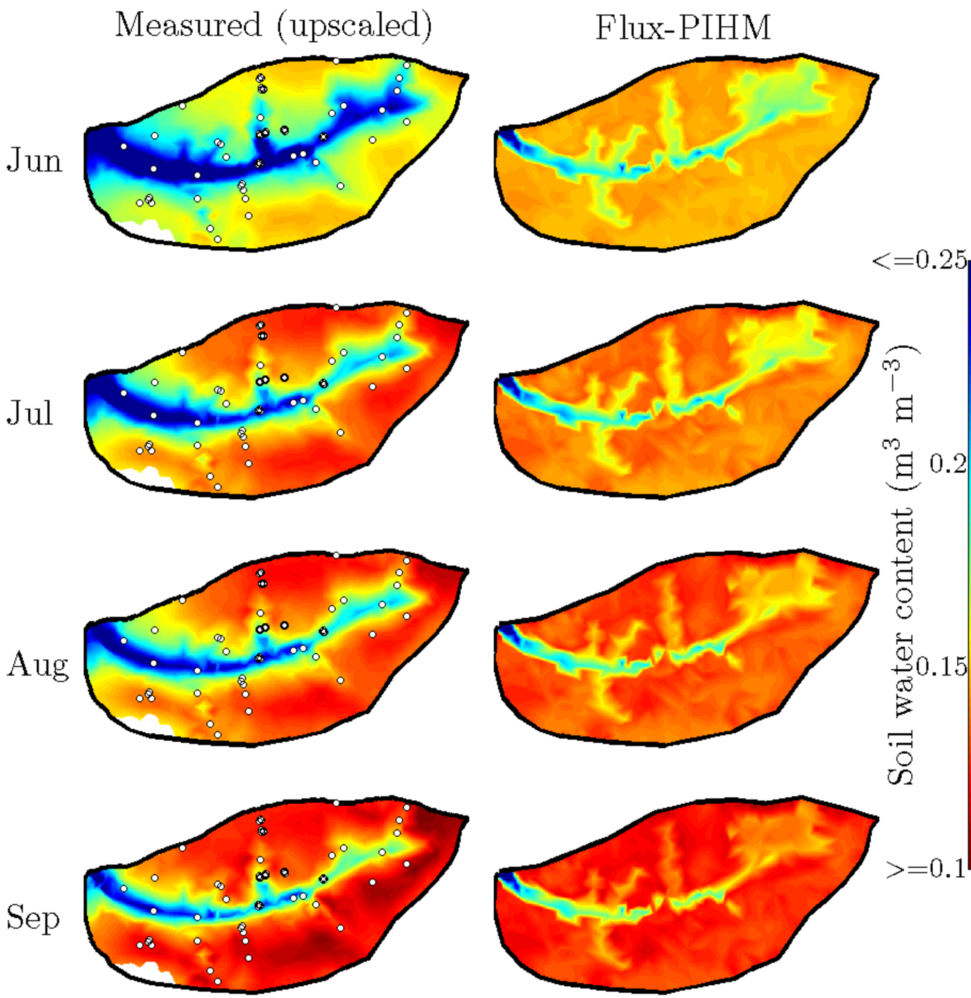


H (W.m-2)
400
200
0
PIHM
Tower
LE (W.m-2)
400
200
0
PIHM
Tower
G (W.m-2)
50
0
-50
PIHM
Rn (W.m-2)
600
400
200
0
PIHM
Tower
Aug01
Aug11
Aug21
Aug31
Time



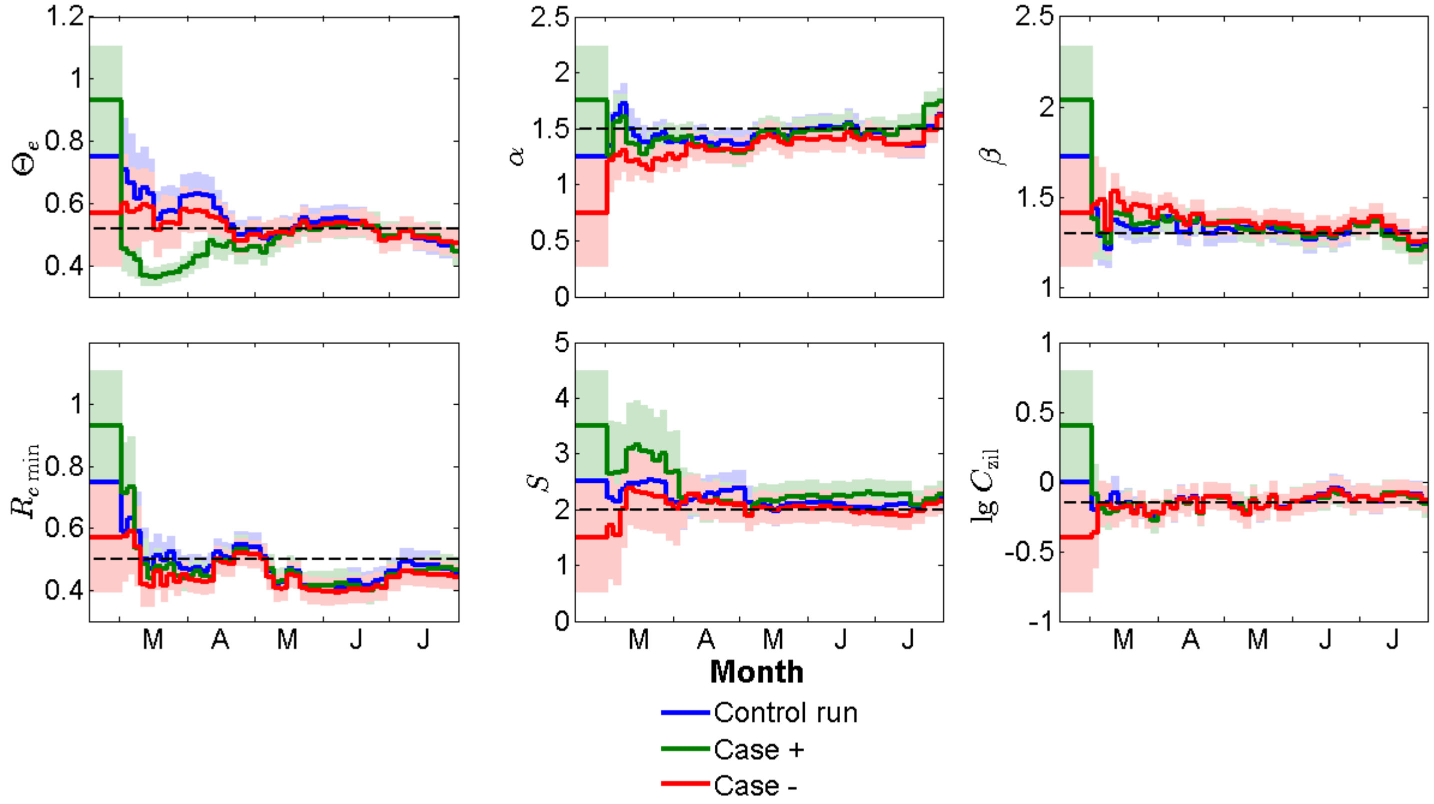
(a)
Q (m3 d−1)
2000
1000
0
Observations
Observation errors
Assimilated observations
(b)
WTD (m)
2
1
0
(c)
SWC (m3 m−3)
0.4
0.3
0.2
01 Apr
01 May
01 Jun
01 Jul
01 Aug
01 Sep

Spatial pattern of soil water content



Calibrated only using outlet discharge and SWC and WTD at one location, and driven by spatially uniform forcing data

Flux-PIHM DA system for parameter estimation



Shi et al. 2014 WRR

Flux-PIHM

- Flux-PIHM provides accurate predictions of water and energy fluxes both in time and space
- It is now being coupled with different models to explore watershed processes:
  - Weathering models (Flux-PIHM-WITCH)
  - Reactive transport models (RT-Flux-PIHM)
  - Biogeochemistry models (Flux-PIHM-BBGC)
  - …

Sullivan et al. in prep., Bao et al. in prep., Shi et al. in prep.

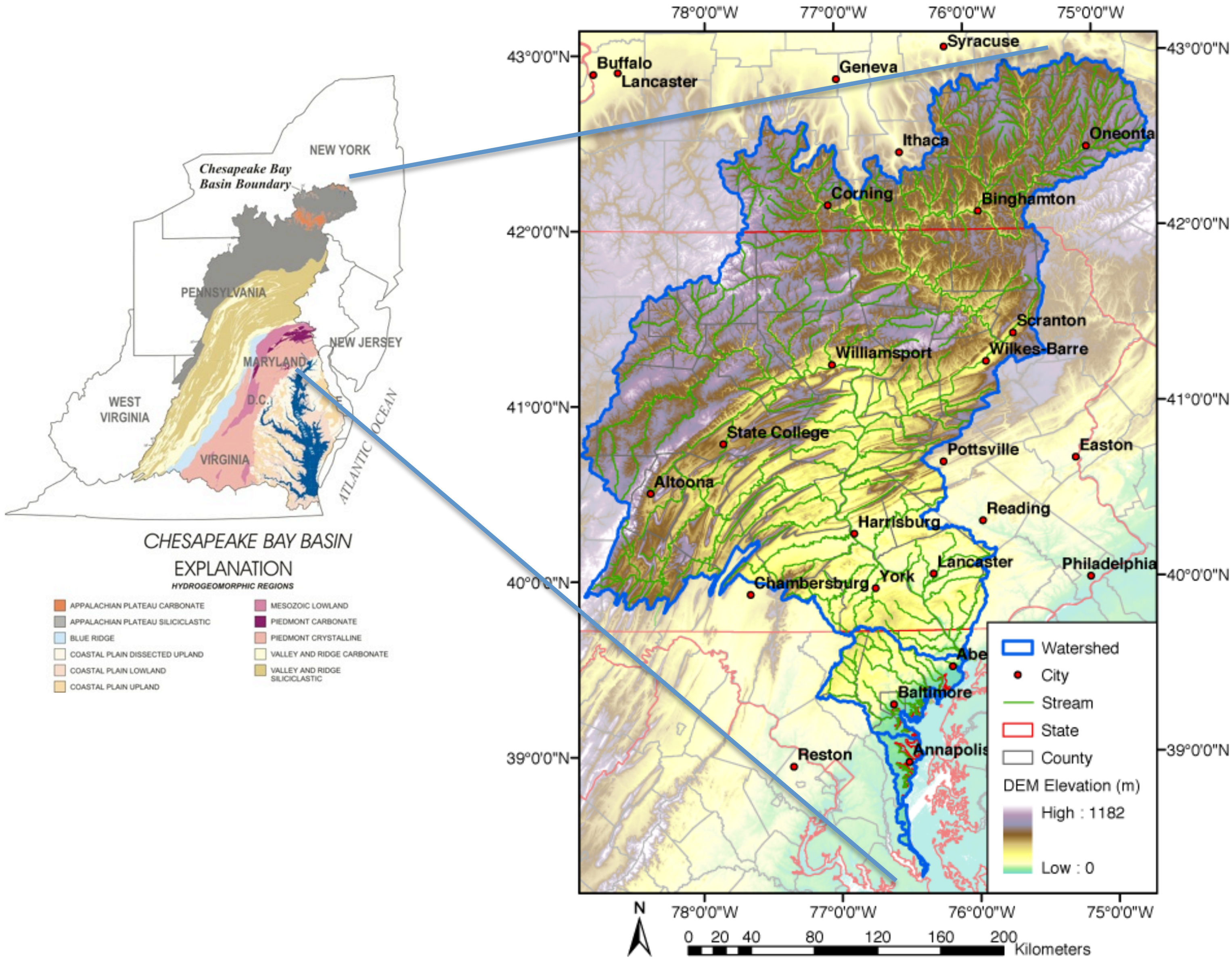
Wetland Vulnerability to Climate Change

Team
Chris Duffy
Xuan Yu
Gopal Bhatt
Ray Najaar
Michael Nassry
Denice Wardrop

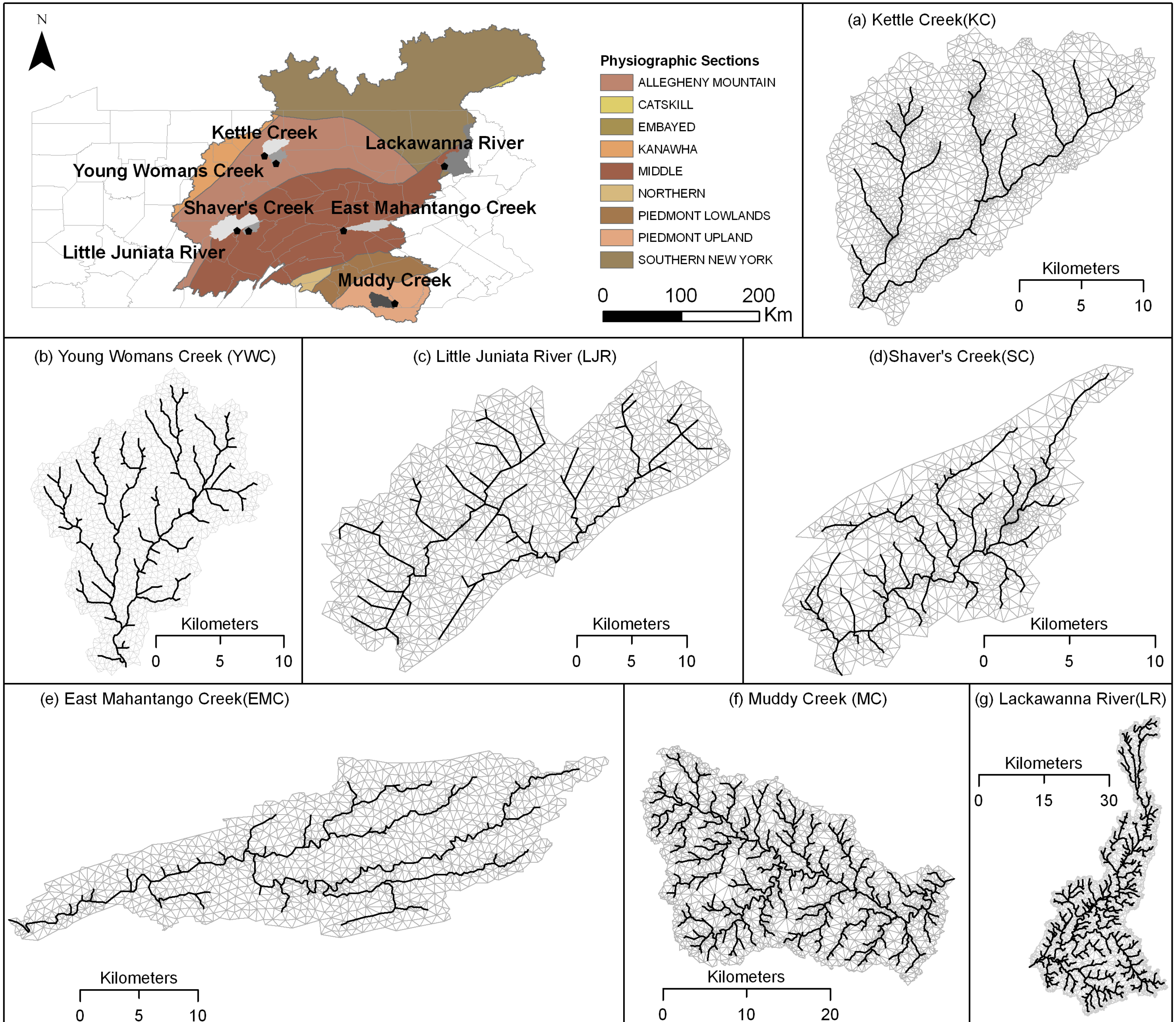
Ecoregions (4)
Ridge and Valley
Piedmont
Unglaciated Plateau
Glaciated Plateau

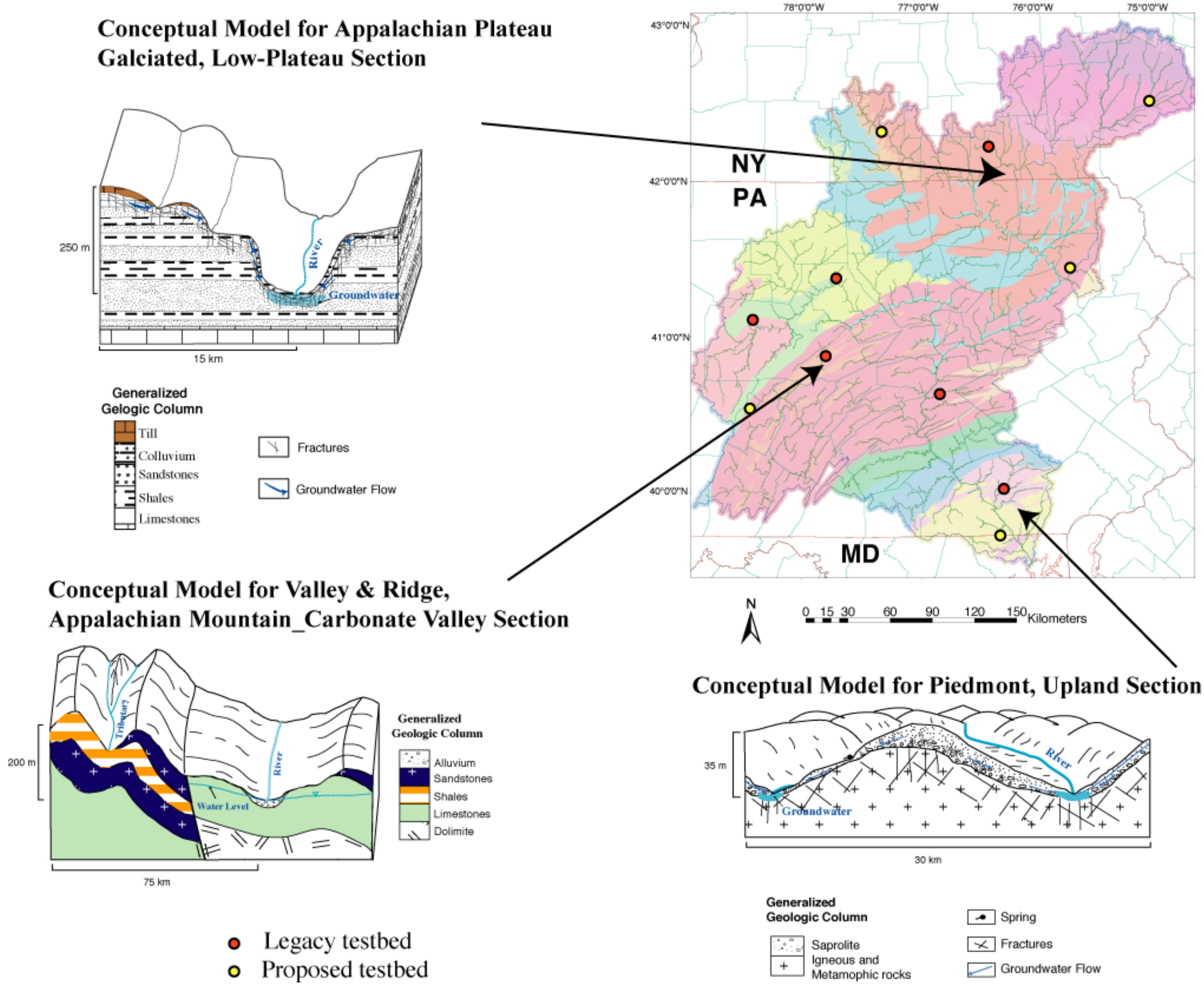
Watersheds (7)
Muddy Creek
Kettle Creek
Shaver's Creek
Young Womans Creek
East Mahantango Creek
Little Juniata River
Lackawanna River

20-Year Climate Scenarios (2)
Historical: 1979 - 1998
Future: 2046 - 2065



NEW YORK
Chesapeake Bay Basin Boundary
PENNSYLVANIA
NEW JERSEY
MARYLAND
D.C.
WEST VIRGINIA
VIRGINIA
ATLANTIC OCEAN
CHESAPEAKE BAY BASIN
EXPLANATION
HYDROGEOMORPHIC REGIONS
APPALACHIAN PLATEAU CARBONATE
APPALACHIAN PLATEAU SILICICLASTIC
BLUE RIDGE
COASTAL PLAIN DISSECTED UPLAND
COASTAL PLAIN LOWLAND
COASTAL PLAIN UPLAND
MESOZOIC LOWLAND
PIEDMONT CARBONATE
PIEDMONT CRYSTALLINE
VALLEY AND RIDGE CARBONATE
VALLEY AND RIDGE SILICICLASTIC
78°0'0"W
77°0'0"W
76°0'0"W
75°0'0"W
43°0'0"N
42°0'0"N
41°0'0"N
40°0'0"N
39°0'0"N
Syracuse
Buffalo
Lancaster
Geneva
Ithaca
Oneonta
Corning
Binghamton
Scranton
Wilkes-Barre
Williamsport
State College
Pottsville
Easton
Altoona
Reading
Harrisburg
Lancaster
Philadelphia
Chambersburg
York
Baltimore
Annapolis
Reston
Watershed
City
Stream
State
County
DEM Elevation (m)
High : 1182
Low : 0
N
0 20 40 80 120 160 200
Kilometers


N
Kettle Creek
Lackawanna River
Young Womans Creek
Shaver's Creek
East Mahantango Creek
Little Juniata River
Muddy Creek
Physiographic Sections
ALLEGHENY MOUNTAIN
CATSKILL
EMBAYED
KANAWHA
MIDDLE
NORTHERN
PIEDMONT LOWLANDS
PIEDMONT UPLAND
SOUTHERN NEW YORK
0 100 200
Km
(a) Kettle Creek(KC)
Kilometers
0 5 10
(b) Young Womans Creek (YWC)
Kilometers
0 5 10
(c) Little Juniata River (LJR)
Kilometers
0 5 10
(d)Shaver's Creek(SC)
Kilometers
0 5 10
(e) East Mahantango Creek(EMC)
Kilometers
0 5 10
(f) Muddy Creek (MC)
Kilometers
0 10 20
(g) Lackawanna River(LR)
Kilometers
0 15 30


Conceptual Model for Appalachian Plateau
Galciated, Low-Plateau Section
250 m
River
Groundwater
15 km
Generalized
Gelogic Column
Till
Colluvium
Sandstones
Shales
Limestones
Fractures
Groundwater Flow
78°0'0"W
77°0'0"W
76°0'0"W
75°0'0"W
43°0'0"N
42°0'0"N
41°0'0"N
40°0'0"N
NY
PA
MD
N
0 15 30 60 90 120 150 Kilometers
Conceptual Model for Valley & Ridge,
Appalachian Mountain_Carbonate Valley Section
200 m
Tributary
River
Water Level
75 km
Generalized
Geologic Column
Alluvium
Sandstones
Shales
Limestones
Dolimite
Conceptual Model for Piedmont, Upland Section
35 m
River
Groundwater
30 km
Generalized
Geologic Column
Saprolite
Igneous and
Metamophic rocks
Spring
Fractures
Groundwater Flow
Legacy testbed
Proposed testbed

Workflow

Set up models using HydroTerre data

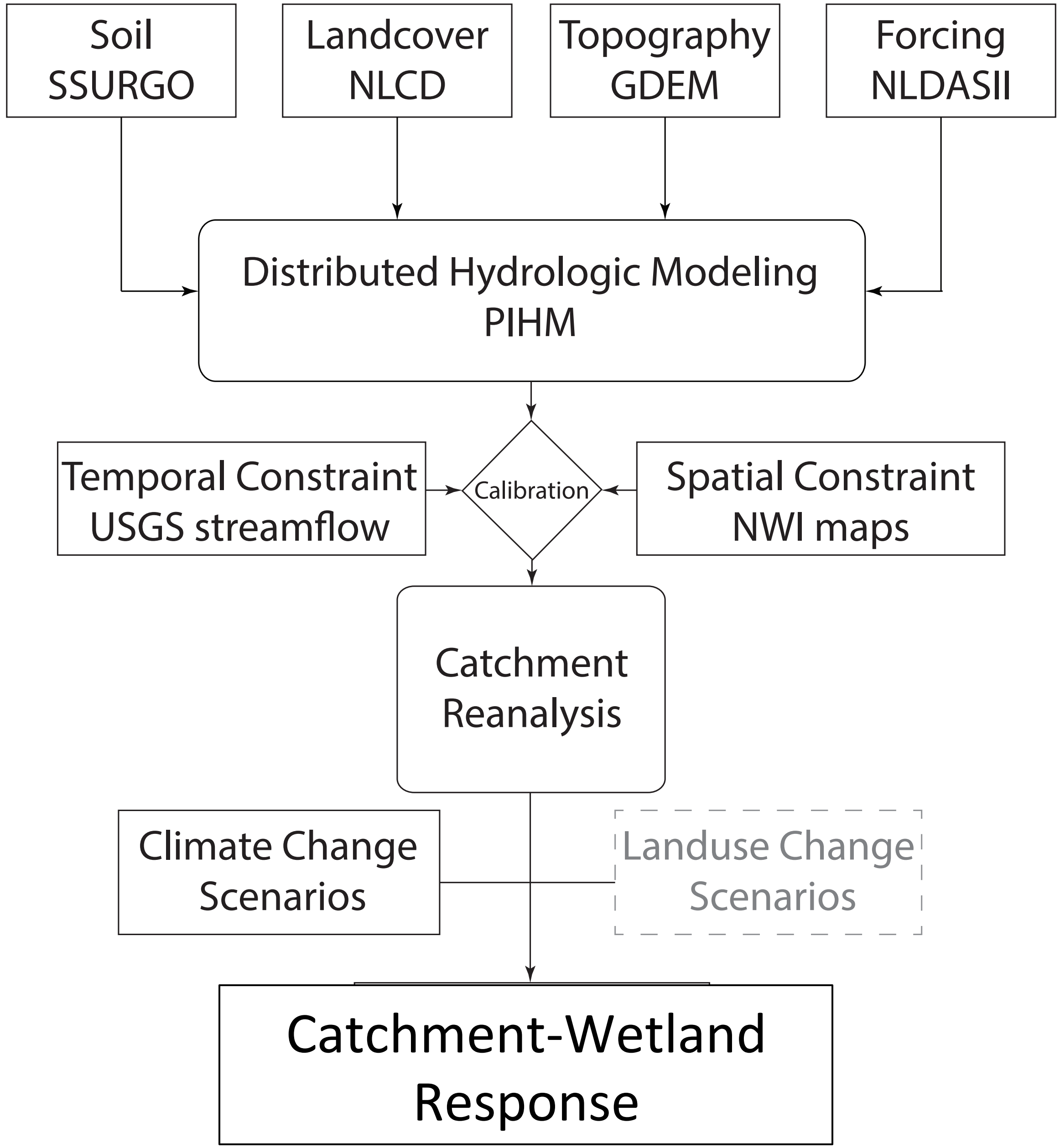
Calibrate catchments on historic data (1979-1998)

HydroGeoMorphic (HGM) classification of wetlands

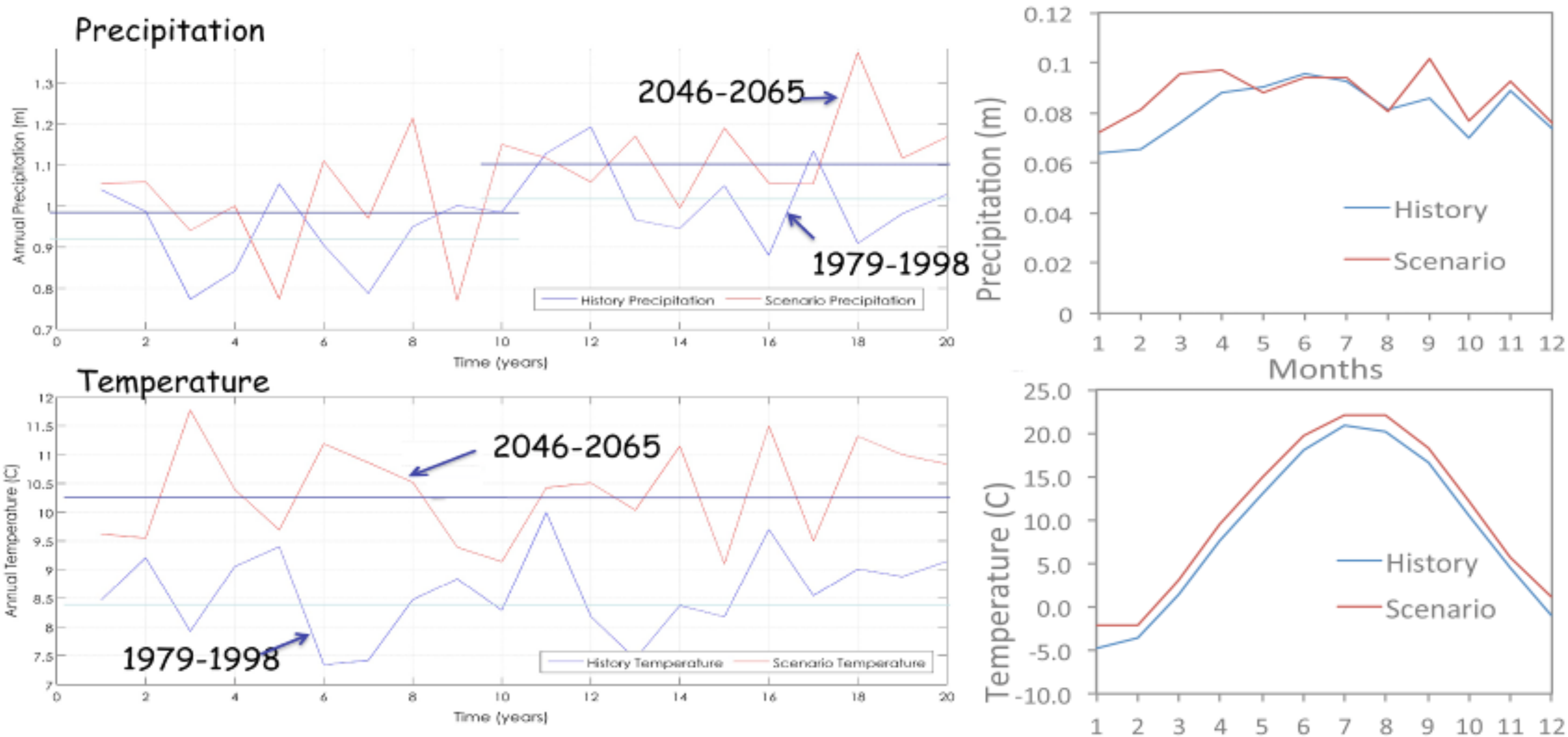
- Riverine
- Slope
- Depression

Run IPCC future climate scenario (2046-2065)

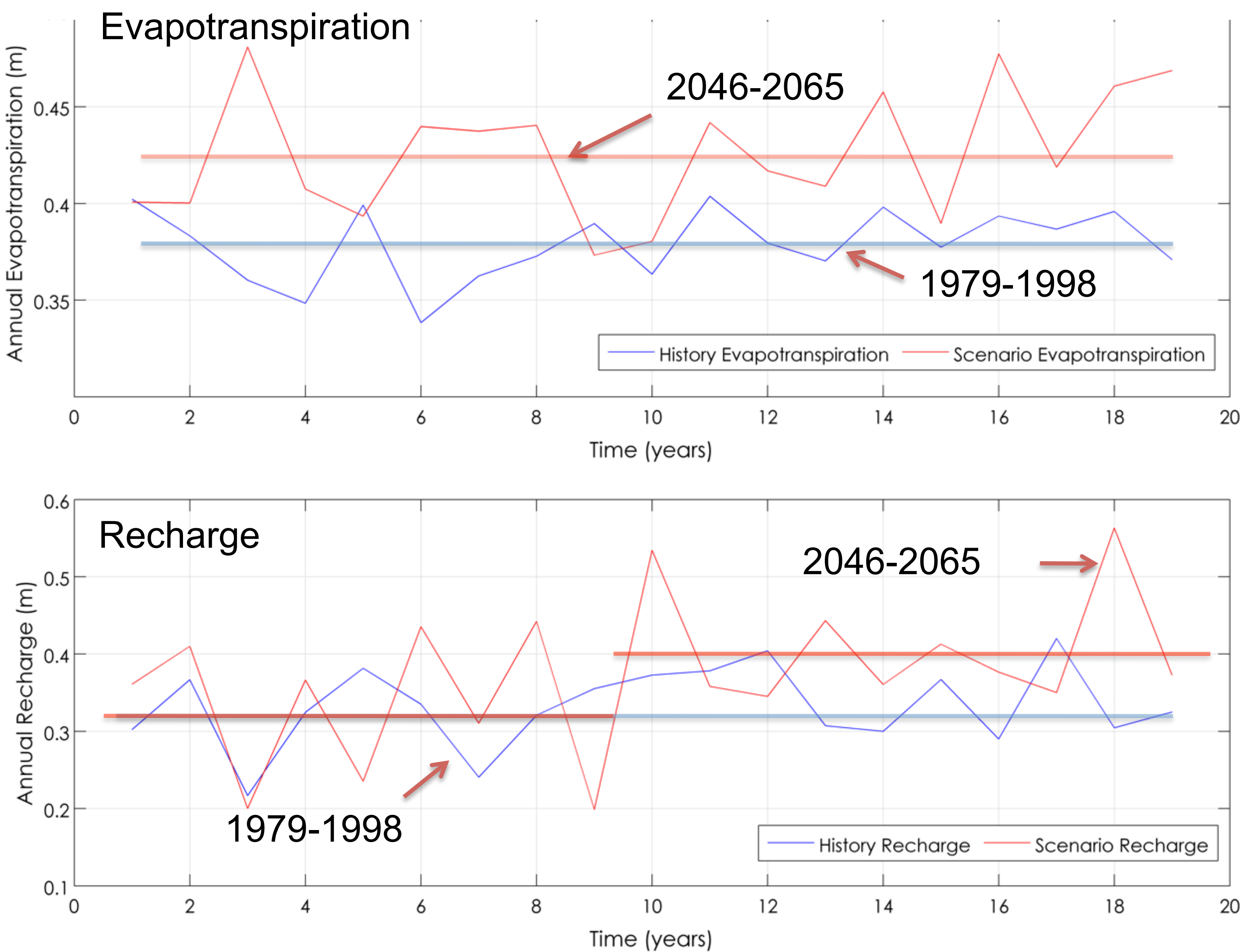
Use relative *gwl* change to measure wetland vulnerability

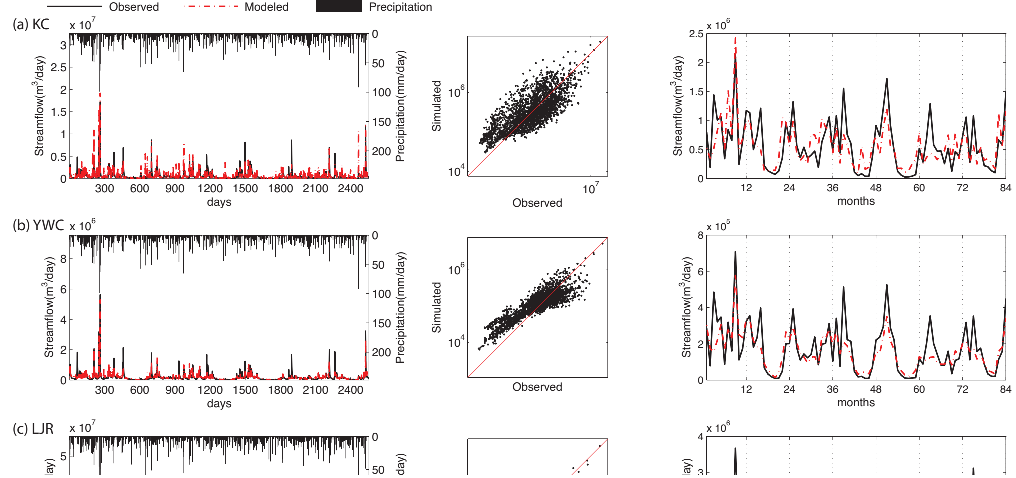

Soil
SSURGO
Landcover
NLCD
Topography
GDEM
Forcing
NLDASII
Distributed Hydrologic Modeling
PIHM
Temporal Constraint
USGS streamflow
Calibration
Spatial Constraint
NWI maps
Catchment
Reanalysis
Climate Change
Scenarios
Landuse Change
Scenarios
Catchment-Wetland
Response

Historical - IPCC Precip-Temp

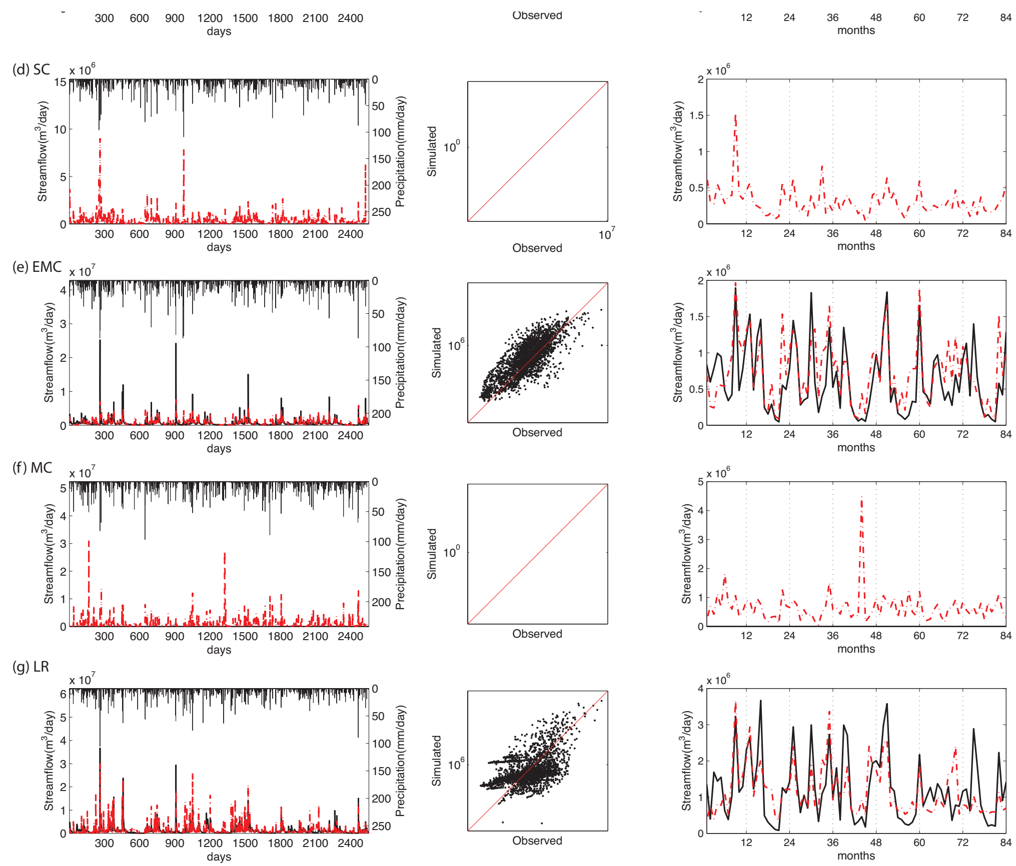


Historical vs IPCC Simulations

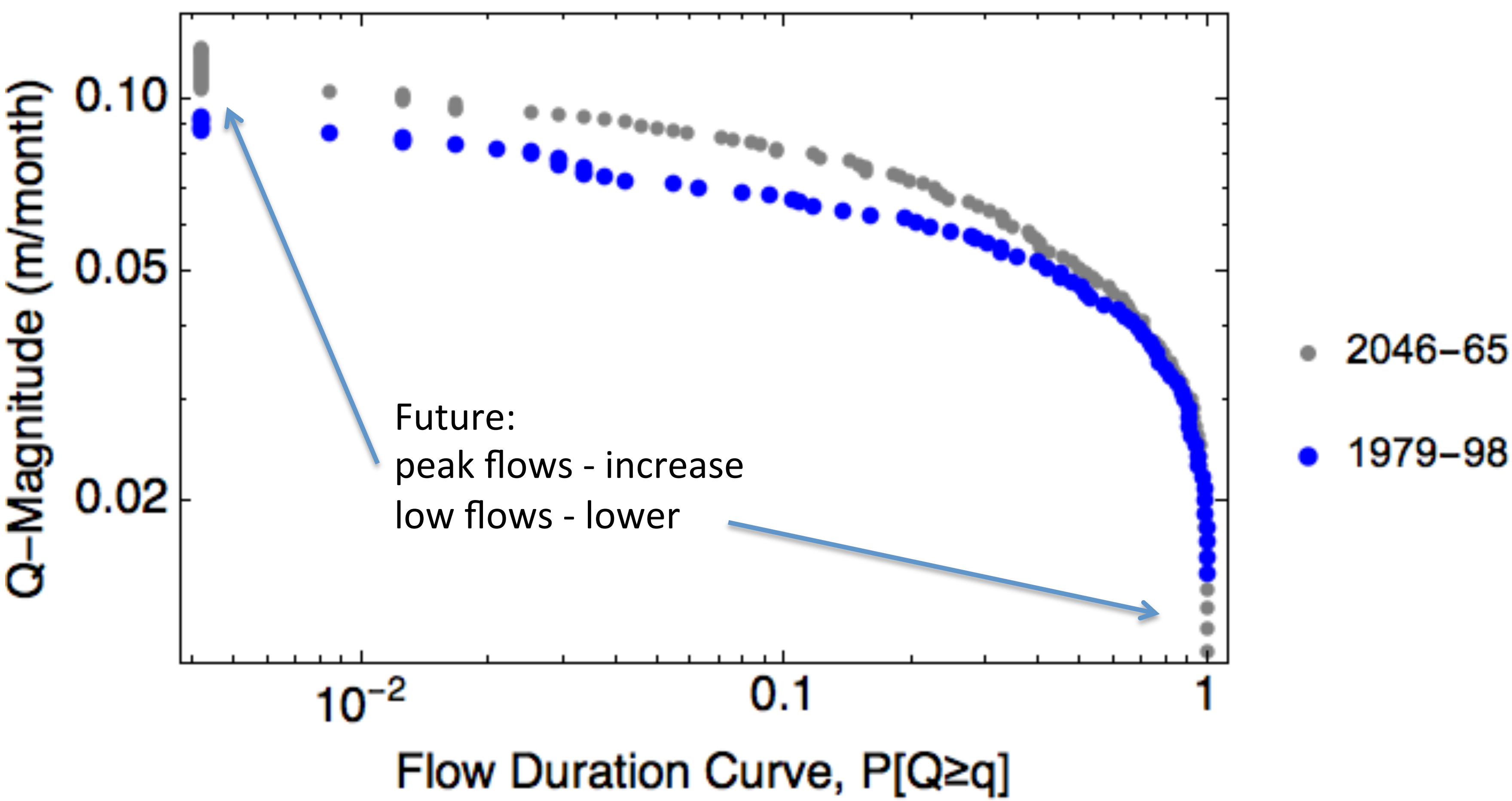




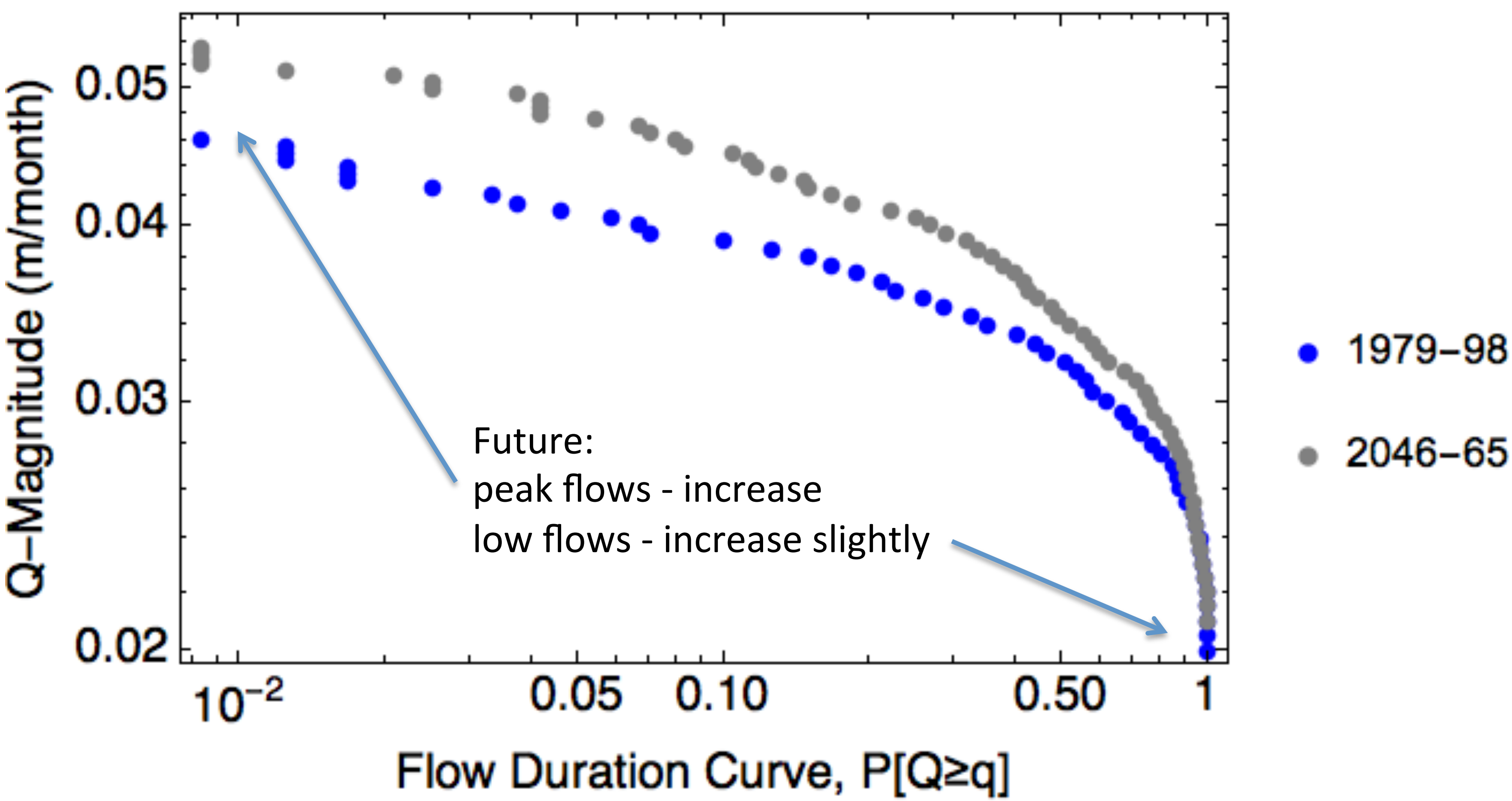
“Constrain” Model on Streamflow & NWI Wetlands



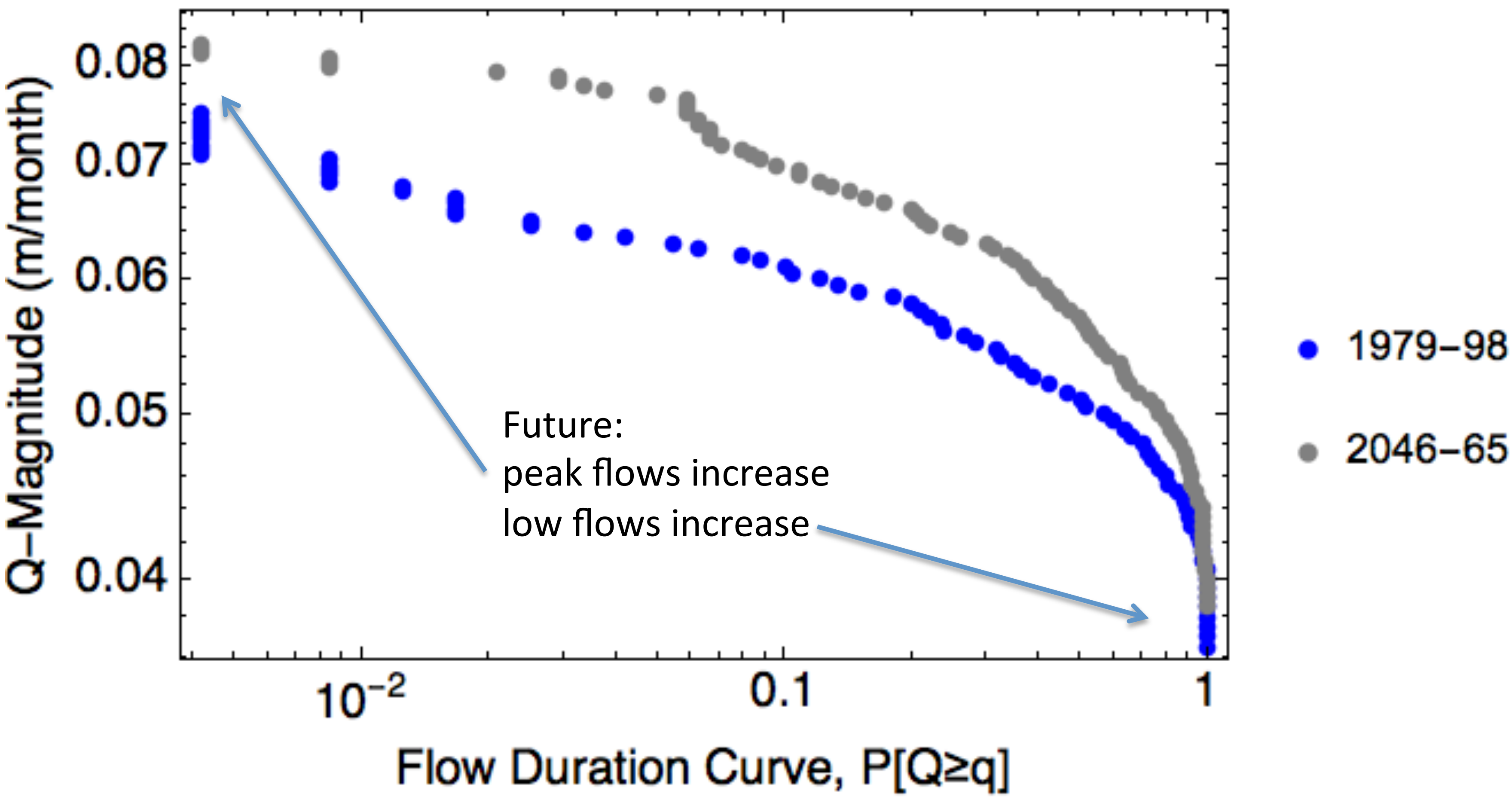
FDC Young Woman's Creek



FDC Shaver Creek

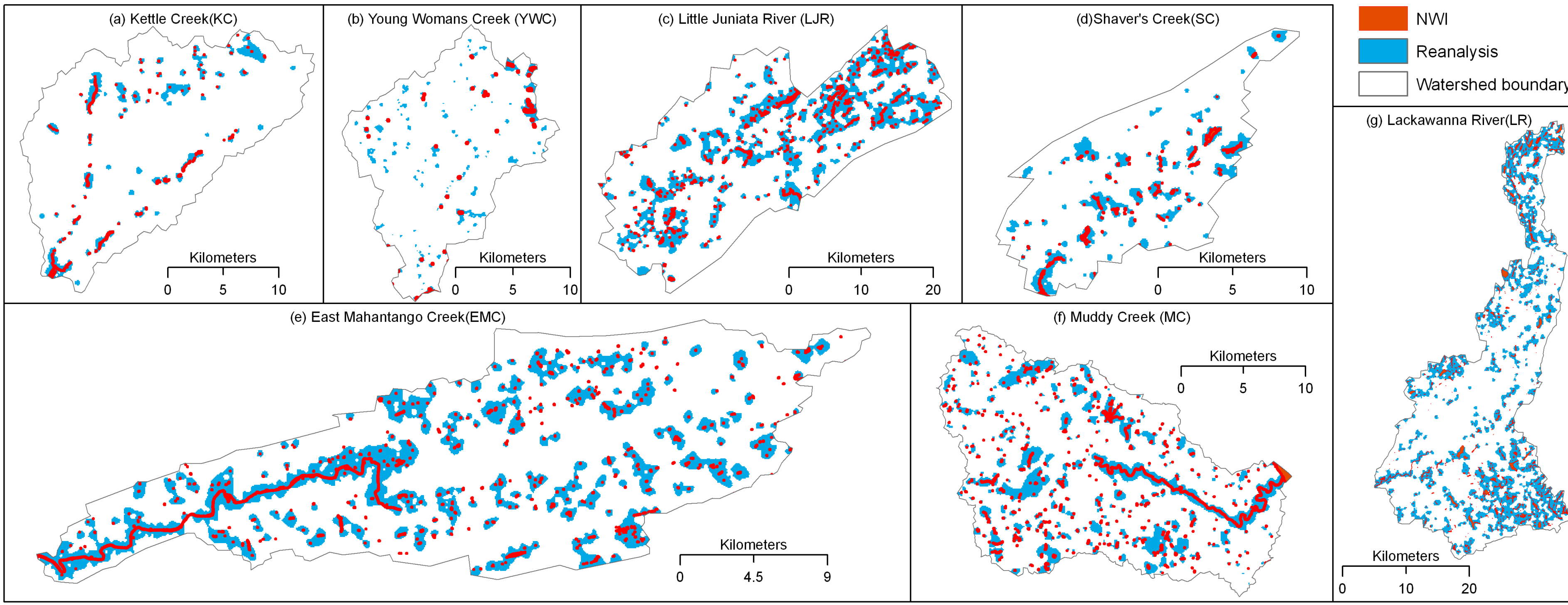


FDC Lackawanna

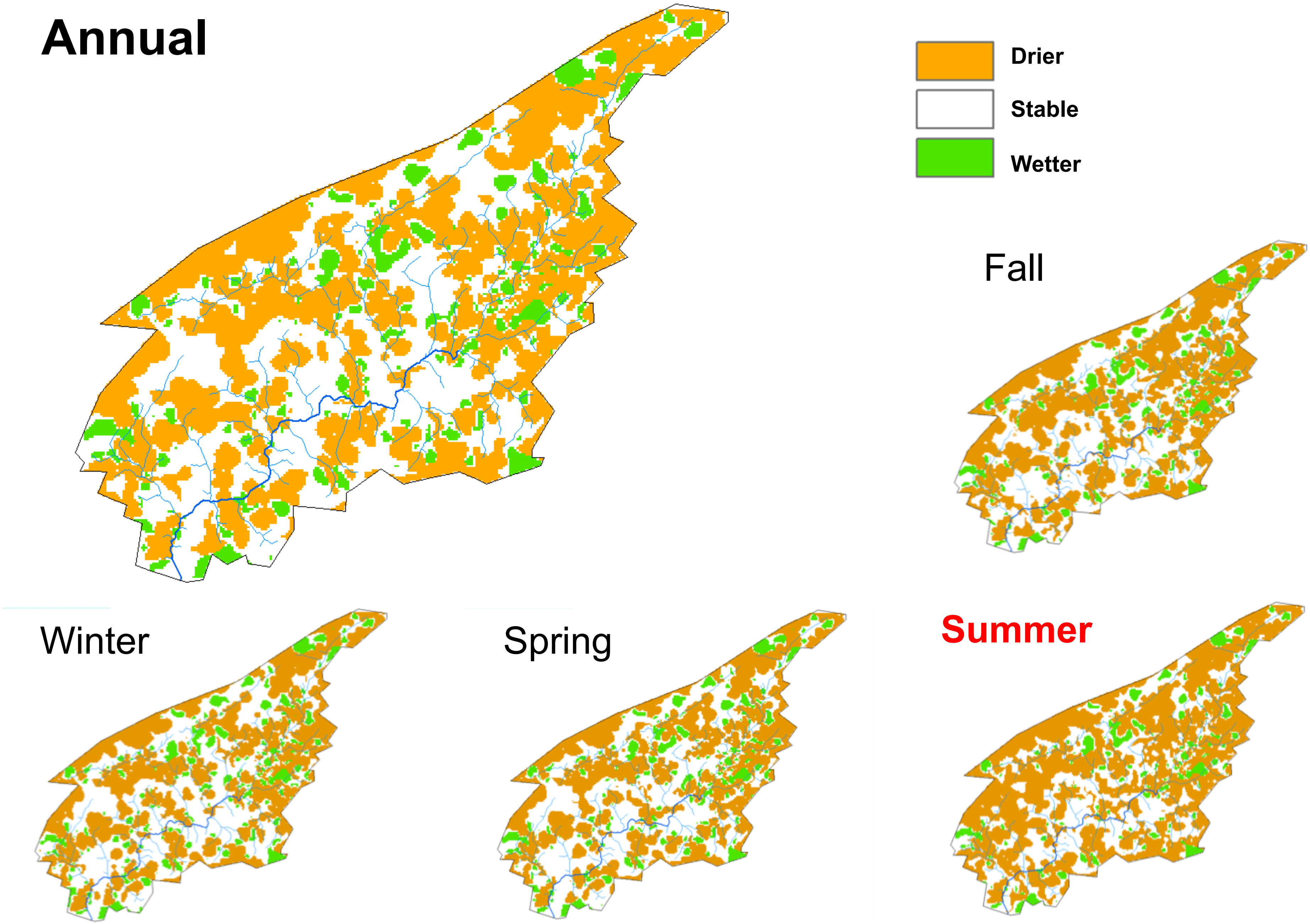


Simulated-Observed Wetlands

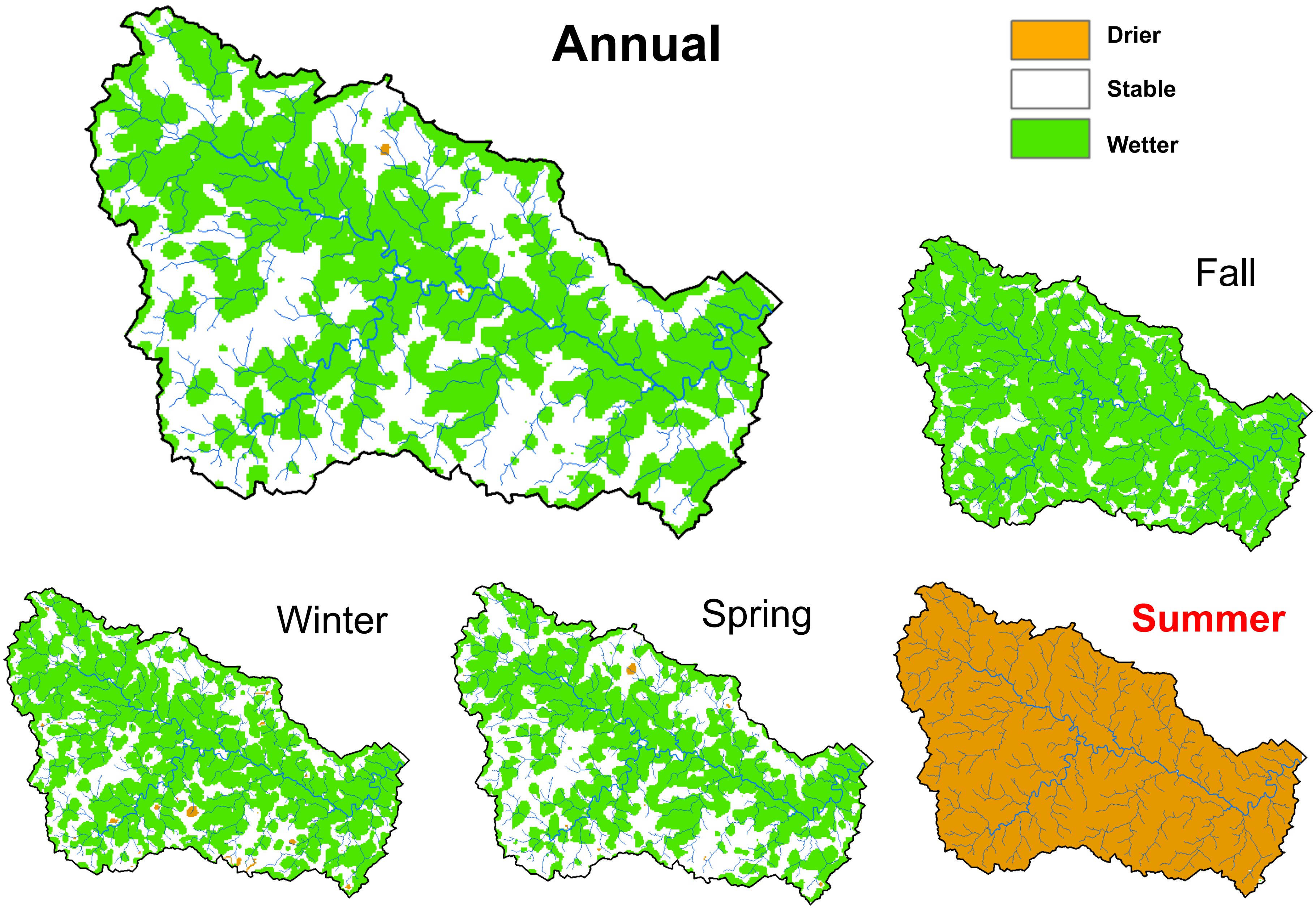
Working definition: wetland is defined as having a water table within 30 cm of the surface



Seasonal GW Change Anomaly Shavers Creek



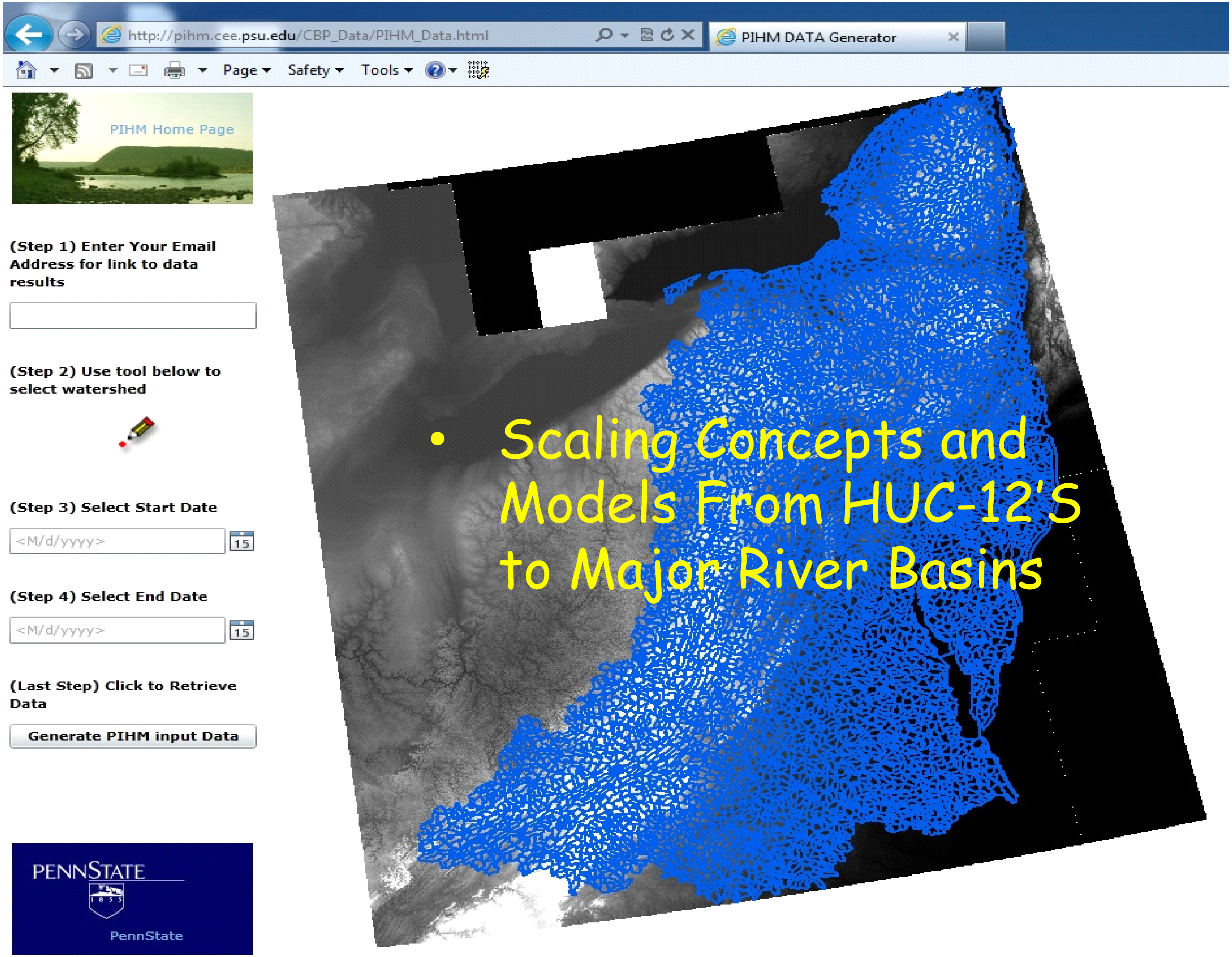
Seasonal GW Change Anomaly: Muddy Creek



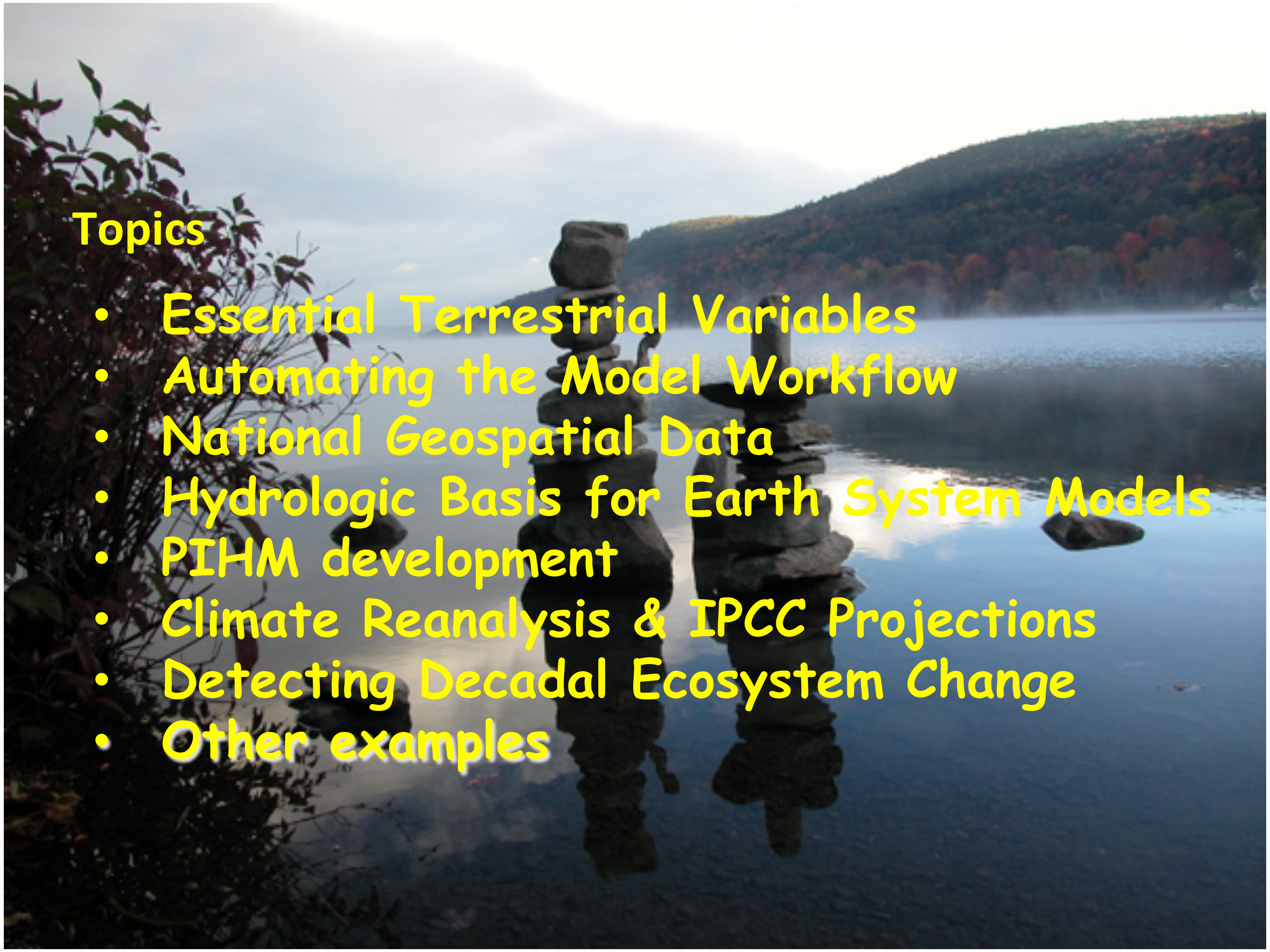
Catchment-Wide Results

	NWI Wetlands		PIHM Depression		
	Drier	**Wetter**	**Drier**	**Wetter**	**Ecoregion**
Lackawanna River	**74%**	**26%**	**71%**	**29%**	**Glaciated Plateau**
Young Womans Creek	62%	38%	63%	37%	Unglaciated Plateau
Kettle Creek	47%	53%	62%	38%	Unglaciated Plateau
East Mahantango Creek	40%	60%	50%	50%	Ridge and Valley
Shaver's Creek	**20%**	**80%**	**27%**	**73%**	**Ridge and Valley**
Little Juniata River	71%	29%	64%	36%	Ridge and Valley
Muddy Creek	35%	65%	35%	65%	Piedmont

Future Large Scale, High Resolution Model-Data Access & Scalability



- Scaling Concepts and Models From HUC-12'S to Major River Basins http://www.pihm.psu.edu/announcement_20141026.html



https://www.youtube.com/watch?v=1uRpMR6SpoI&feature=youtu.be