THE CATHOLIC UNIVERSITY of AMERICA

Catchment-Scale Evaluation of Stormwater Green Infrastructure Using a Flexible Surface-Subsurface Interaction Model

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We All Live Downstream

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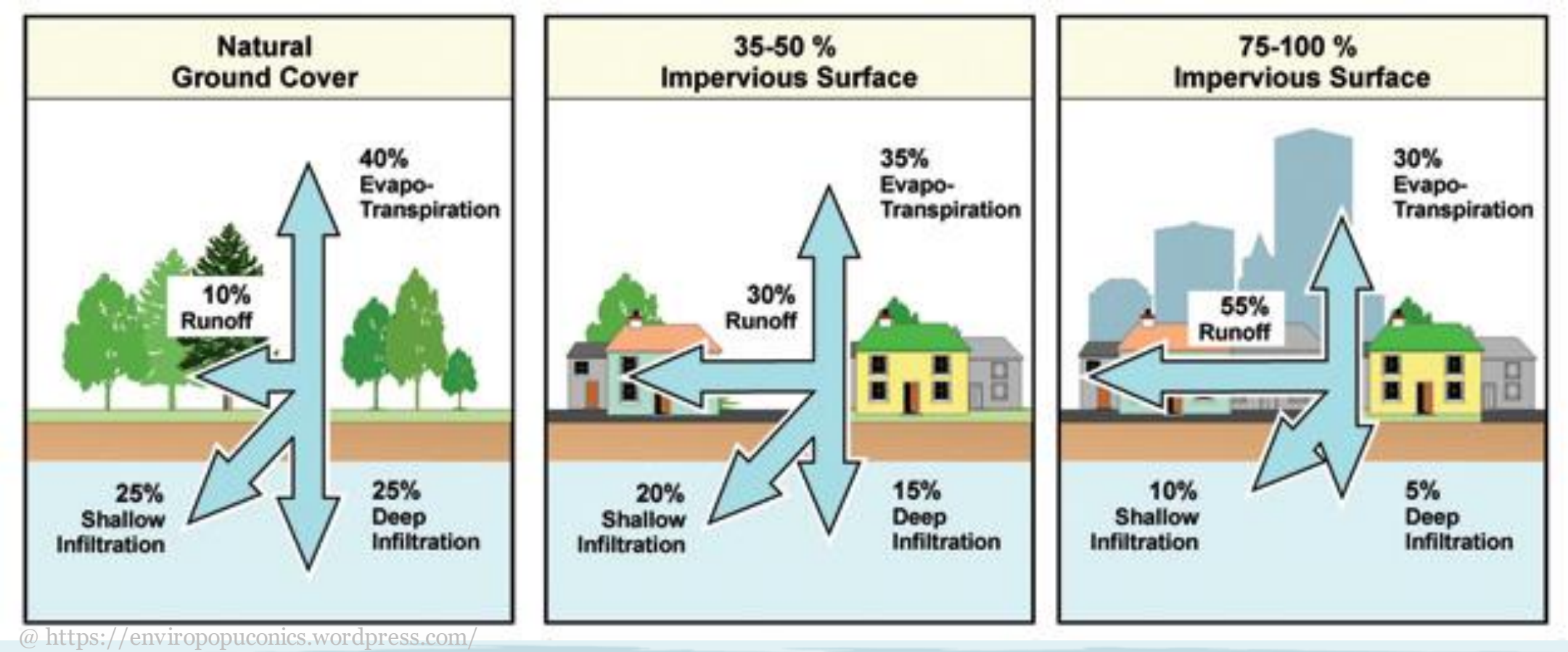
Content Layout

- Background
  - Urbanization and natural system
  - Storm water
  - GI and modeling
- Problem statement
  - Complexity of the natural system
  - GI modeling limitation
- Research Objective
- Methodology
  - Site selection: Sligo Creek details
  - Geospatial model GIS
  - Data process & preparation
  - GIFMod Model
- Conclusion

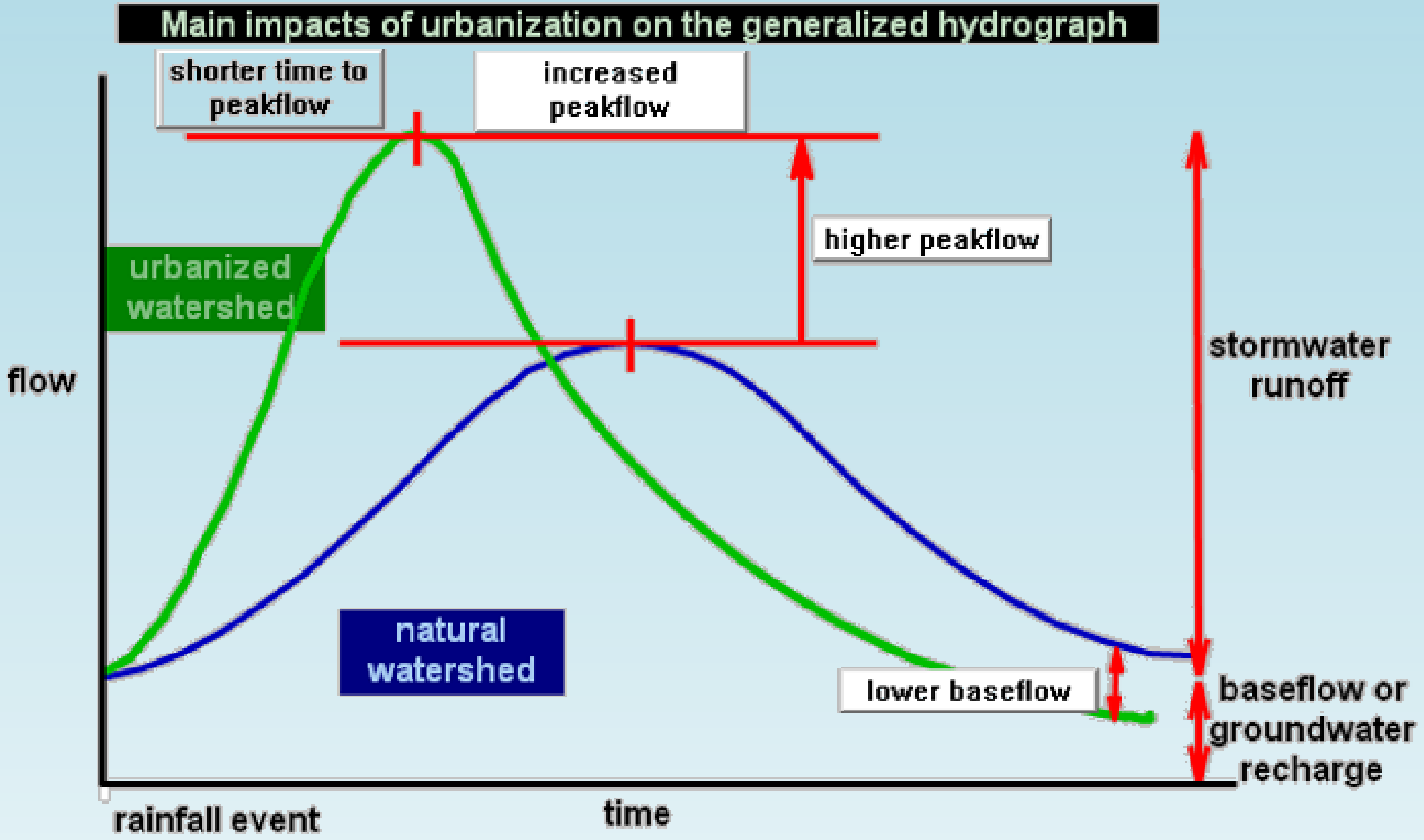
The urbanization changes the nature of the land

Negative impacts: impervious surfaces ++ (buildings, rooftops, roads, parking lots, sidewalks)



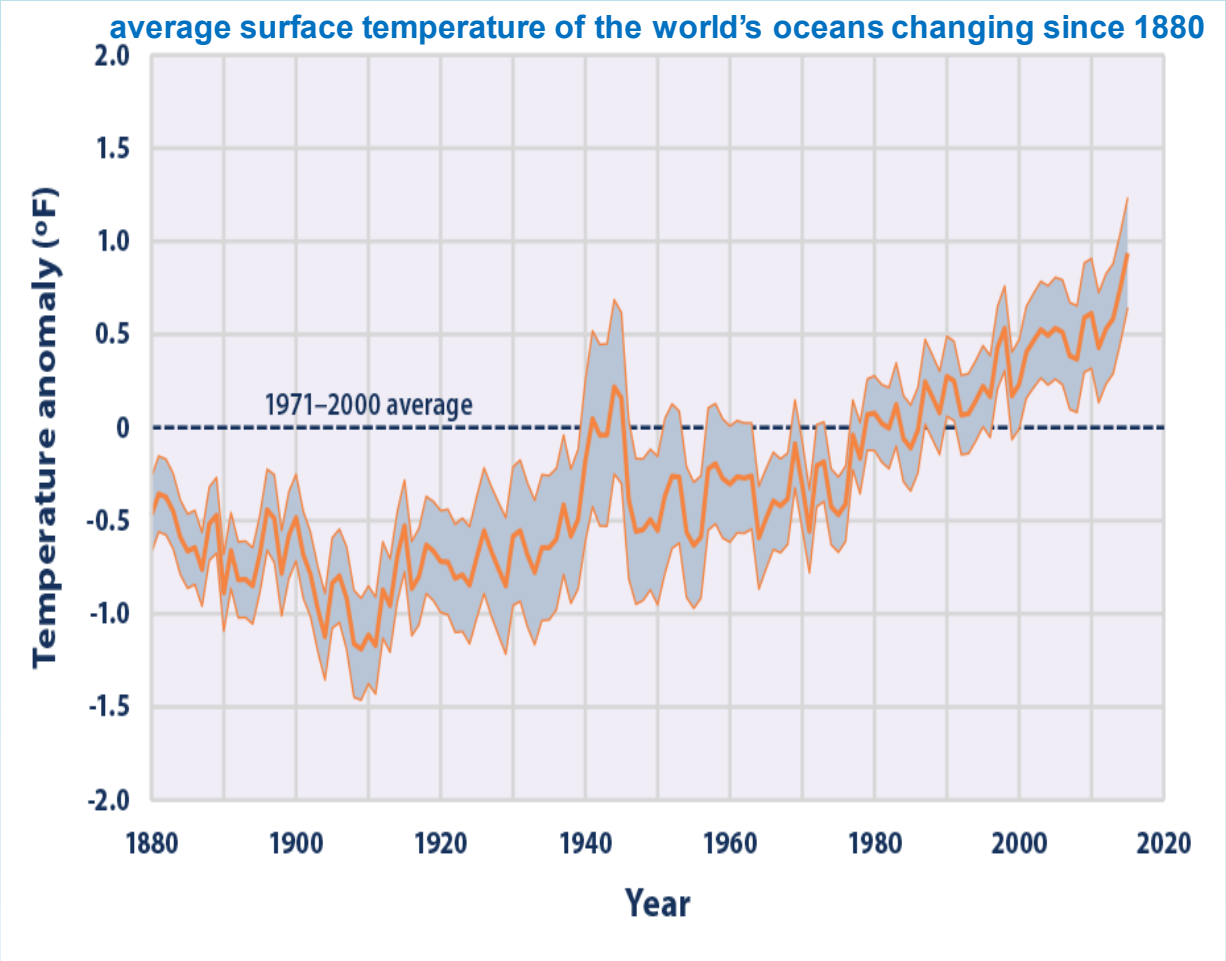
@ https://enviropopuconics.wordpress.com/

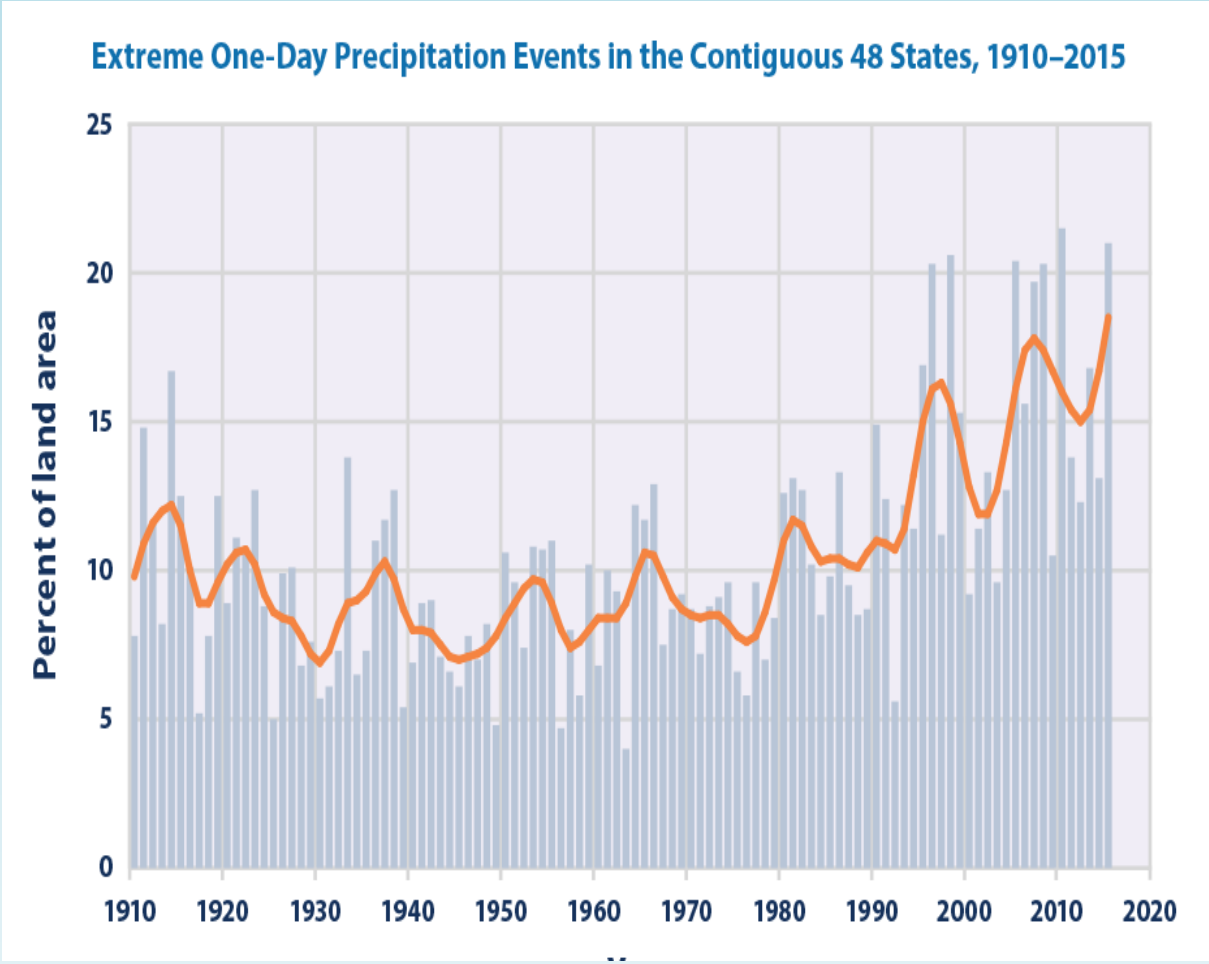
preventing water to infiltrate and recharge - high stormwater peak flows – flooding – erosion – enormous pollutant



Earth's climate is changing

Temperatures are rising **precipitation patterns are shifting** **more extreme climate events**





Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. U.S. Climate Extremes Index.

2nd largest

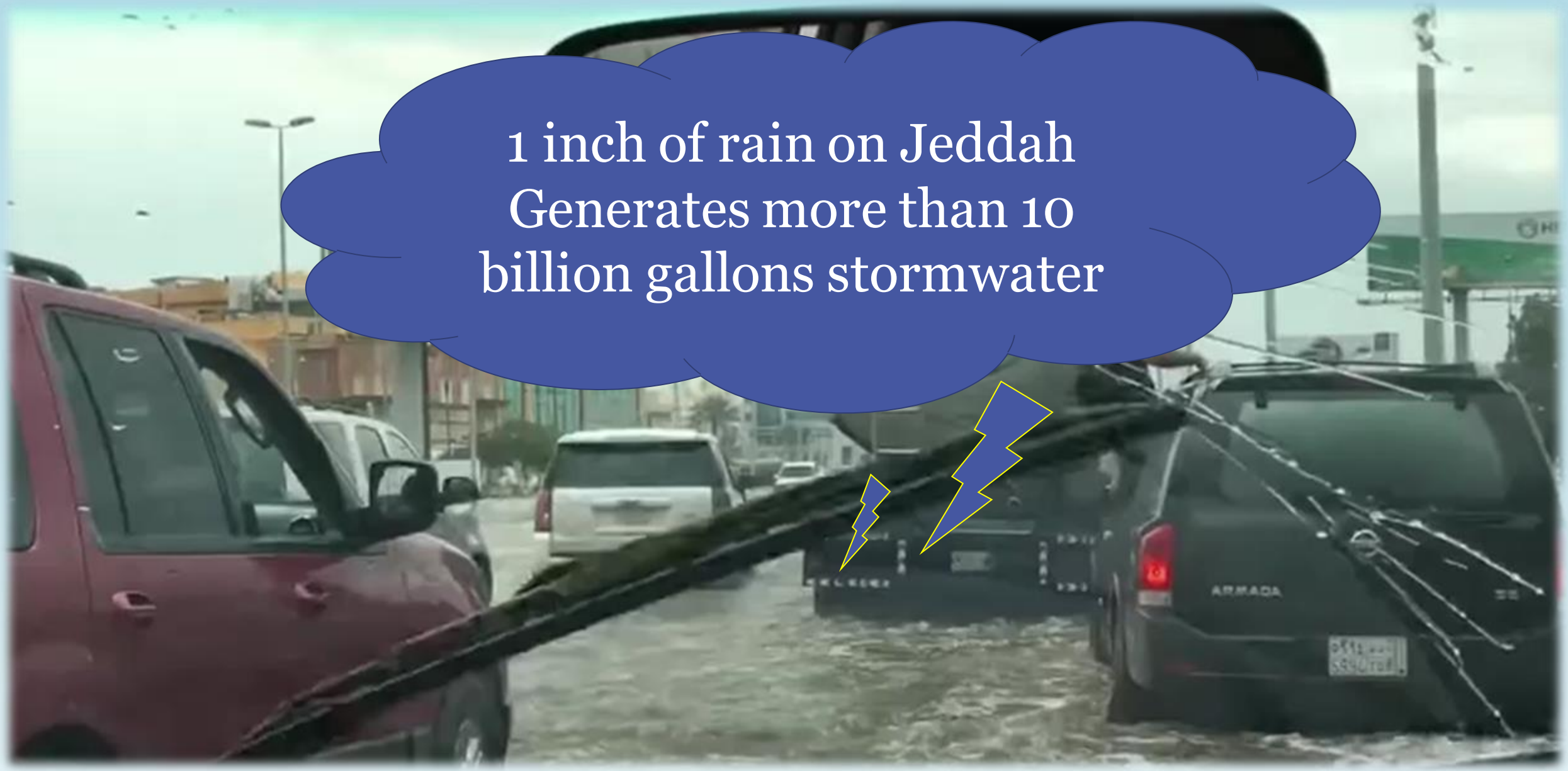
4m people

Saudi Arabia's commercial capital

600 sq mi

More than $1 billion in last 2-3 years

For 100s km of stormwater drainage systen



618 sqmi
4m people

Rain event +/- 30 in
450 killed & missing

Billions are spent for 100s km
of stormwater drainage system

Conventional Drainage system

Urbanization

Climate change

High flooding pea degrading watershed

to address

deficits in drainage system

climate change impacts

Green Infrastructure

Green Infrastructure

- GI is a sustainable method of Best Management Practices (BMP) to manage stormwater referred to as low impact development (LID) practices.
- maintaining the site hydrology patterns close to the predevelopment condition.
- GI treats runoff close to where it is generated.
- decreasing runoff volume and peaks, reduce pollution and other impacts.
- GI is designed to promote retention of water and infiltration into the ground.

Re-connecting the pervious surfaces

Hydrological Modeling

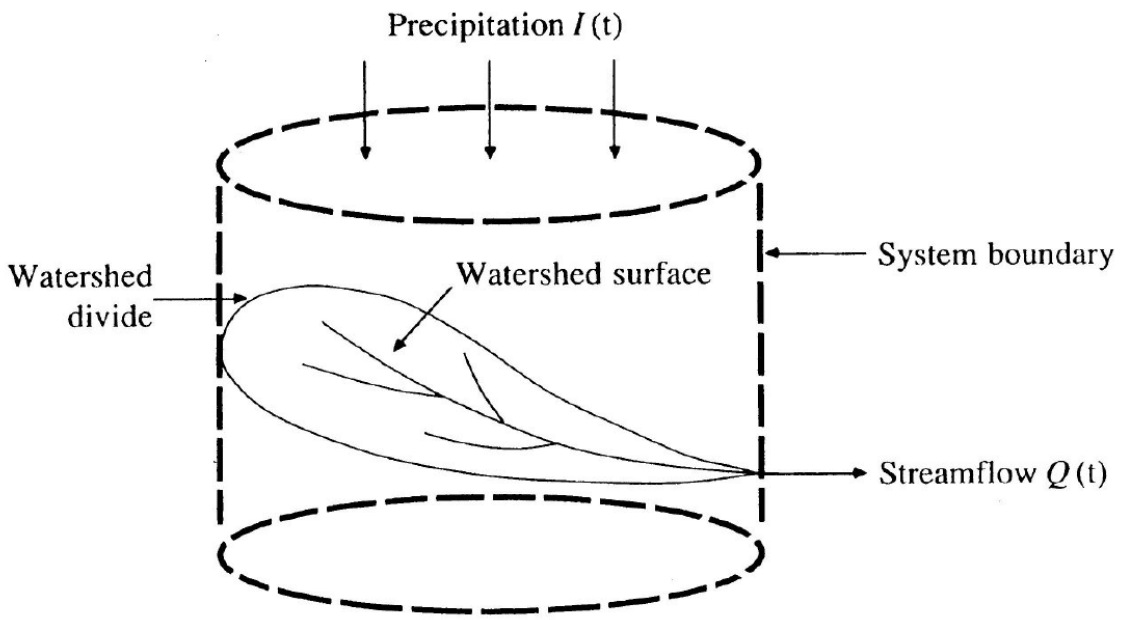


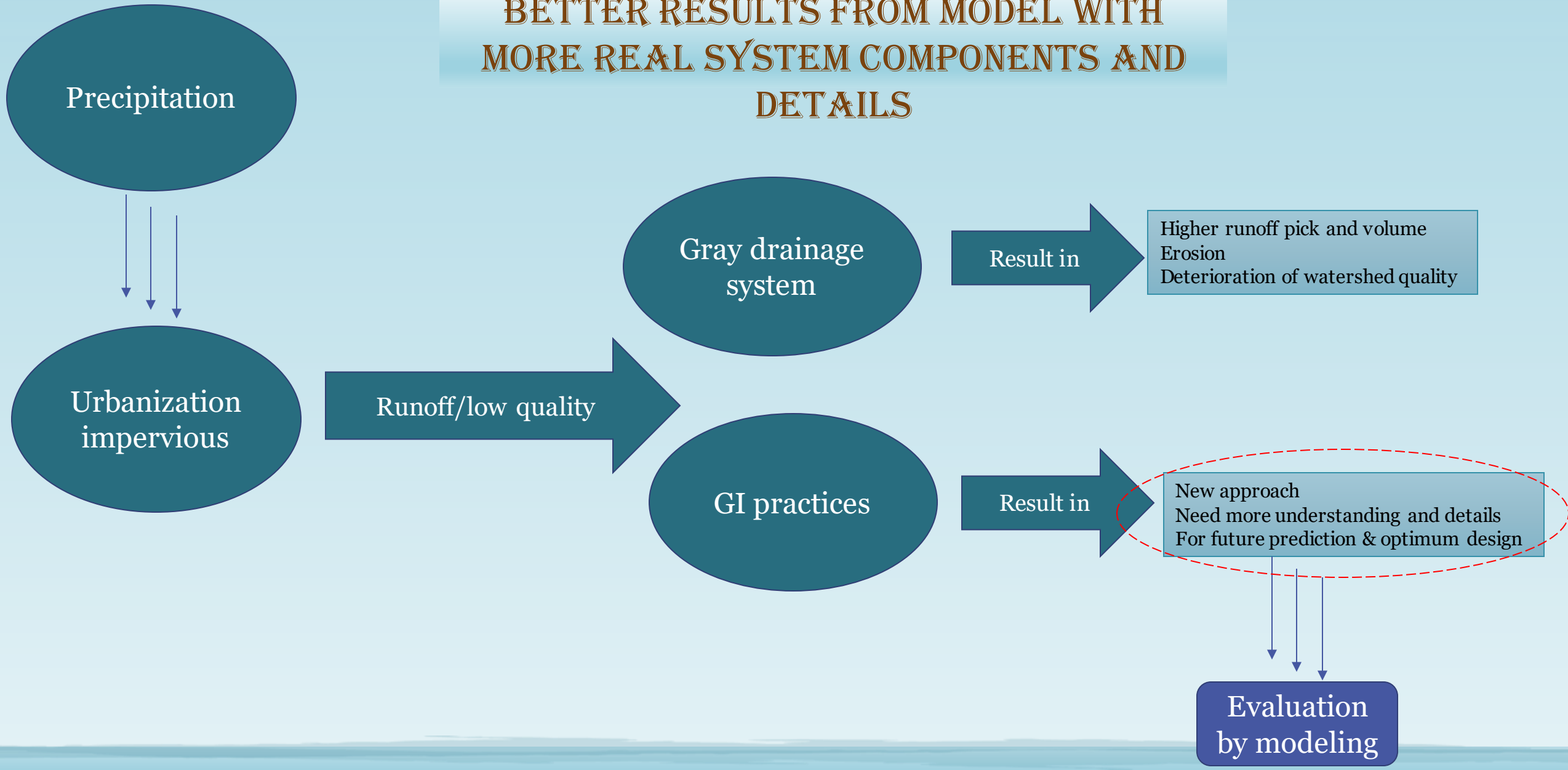
Fig.1.1 The watershed as a hydrologic system (from Chow et al, 1988)

mathematical conceptualization of a real world water system

Why

to be similar but simpler contracture

Better results from model with more real system components and details



Research Goal

Evaluation the long-term effects of GI in Catchment-scale

Subobjectives:

- Building a new comprehensive model
- Simulate GIs mechanism & interaction with different media including:

✧generation of runoff;

✧interaction between surface and groundwater;

✧Contaminants transport and fate

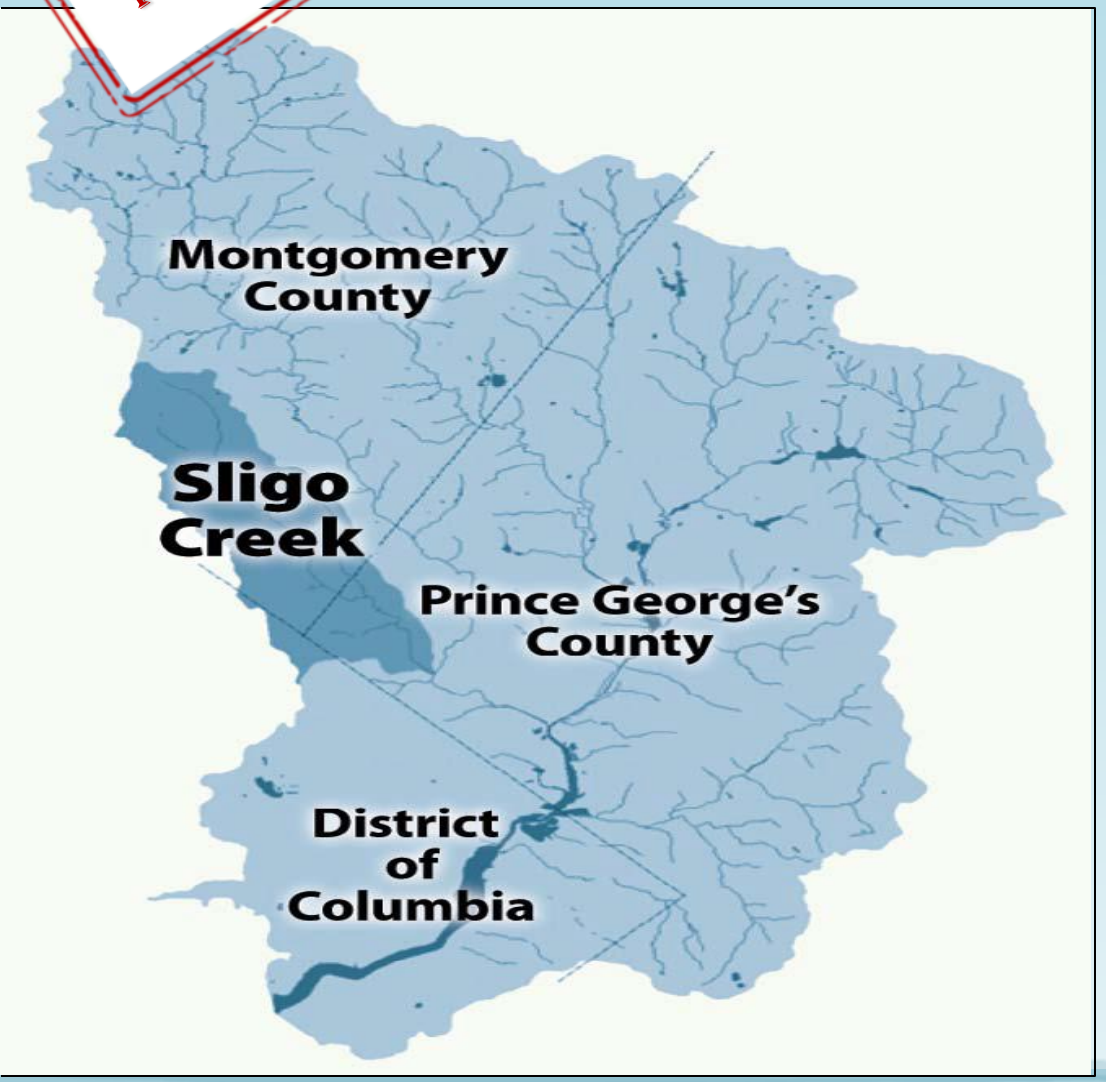
Methodology

Building 3 framework models

1	2	3
Pre Development Land	After Development Surfaces	Post GI Implement

Site selection & Characteristics

PHASE 1



Sligo Creek,

MD

tributary of the Anacostia river

drainage area is 11.1 square miles

length 9.1 miles

137 -11 m height

precip. 40 inch

water temp. s 0°– 25°C

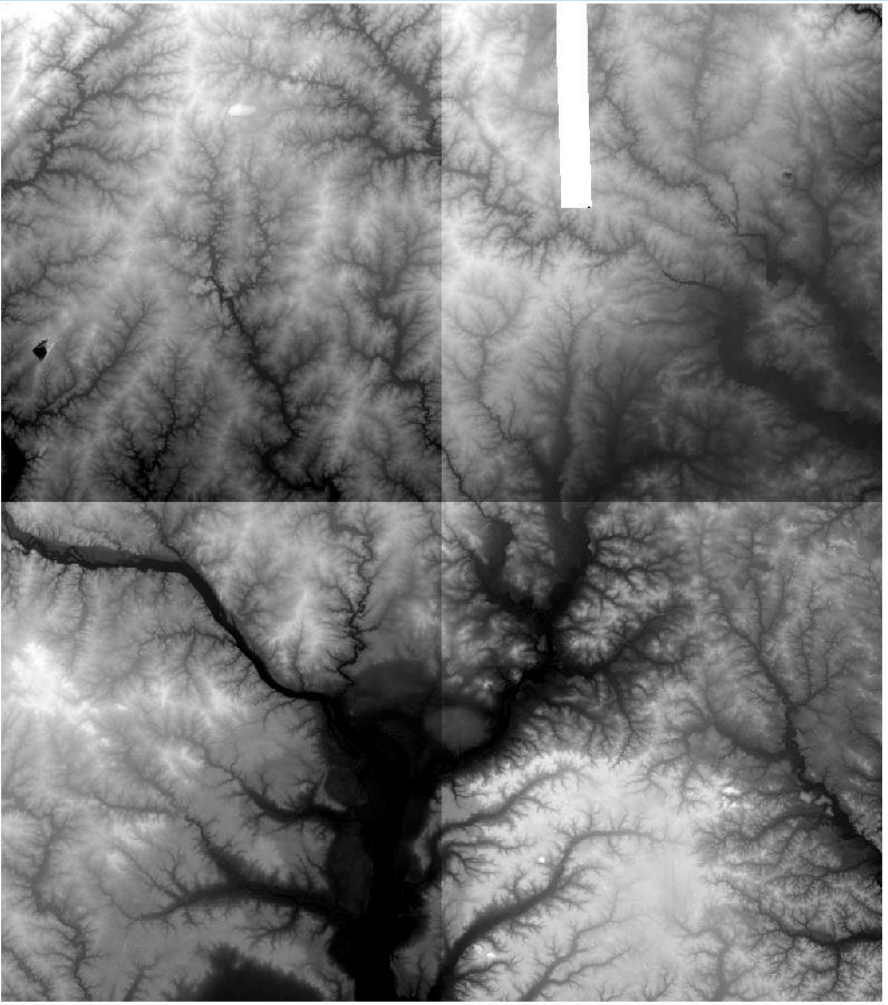
impervious % 34

PHASE 2

Geospatial model (GIS)

Representing digital model parameters (raster/vector):

topography, vegetative, land use/cover, soils and impervious areas and derivative



DEM maps

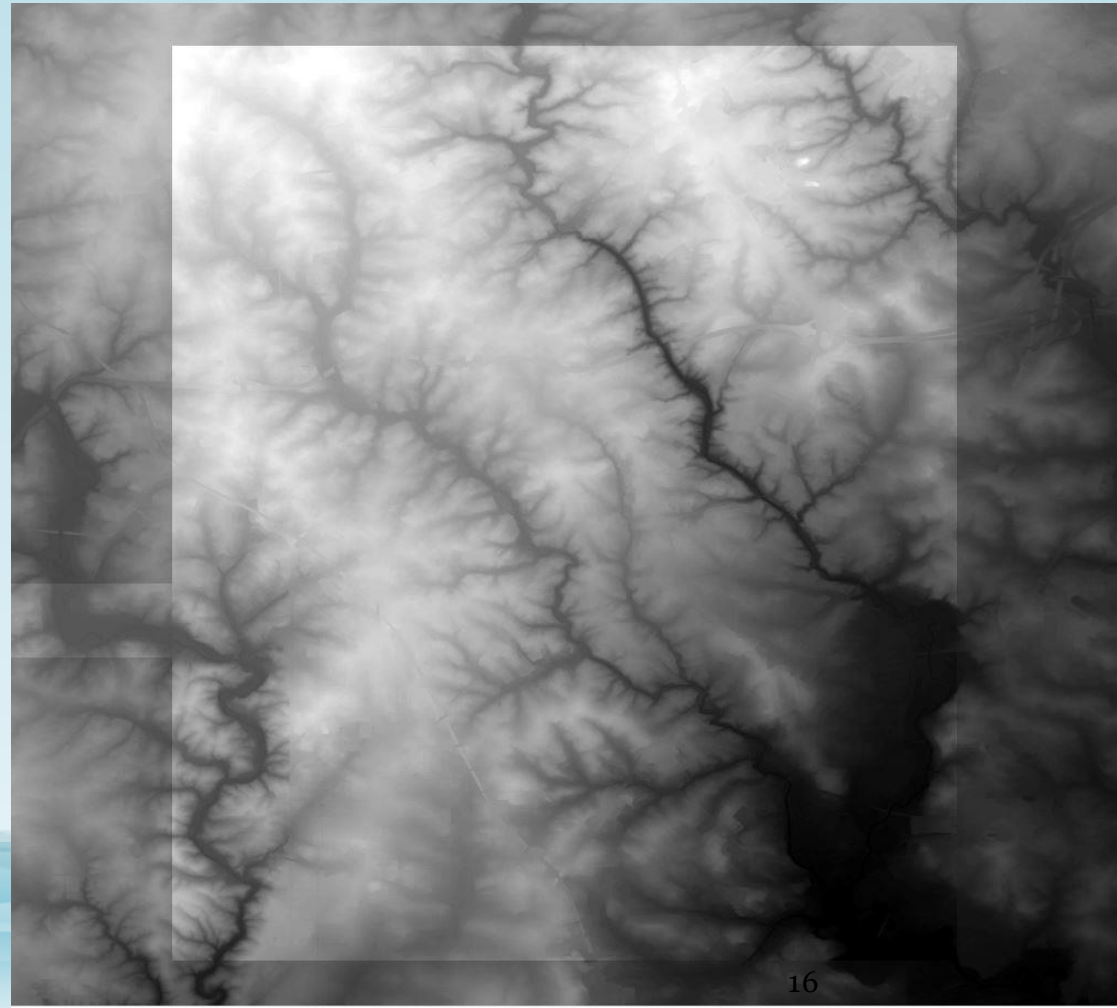
Download Satellite images

High resolution

Unify units

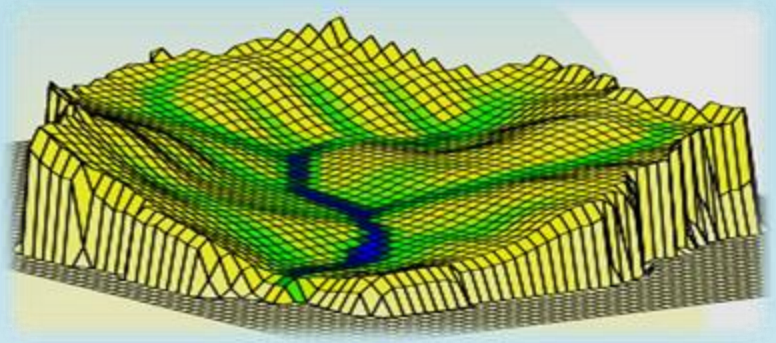
Combine different image

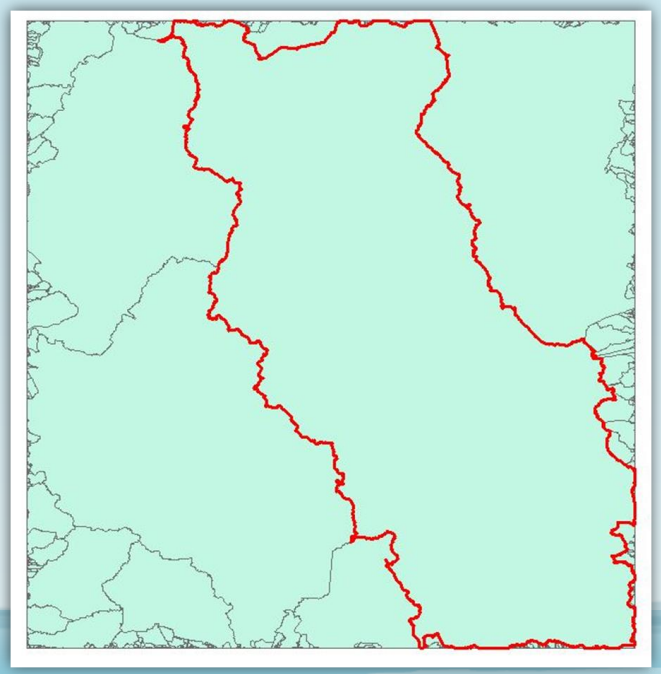
Extract the targeted area



PHASE 2

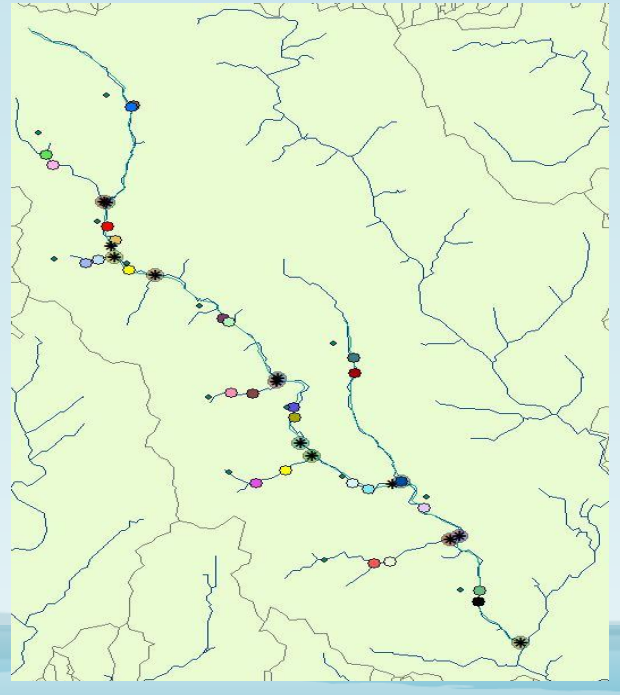
Watershed Delineation





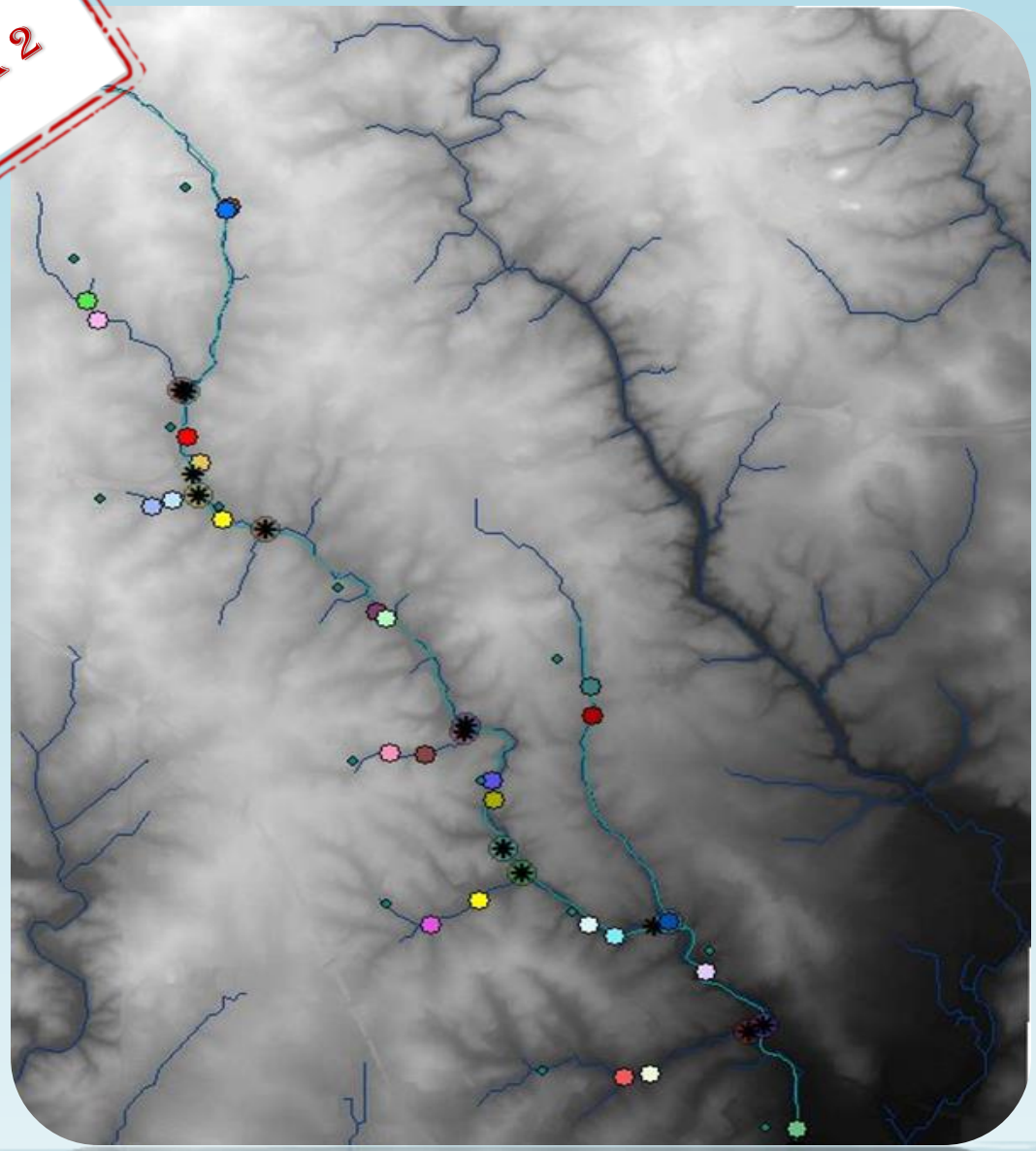
Fill & sink

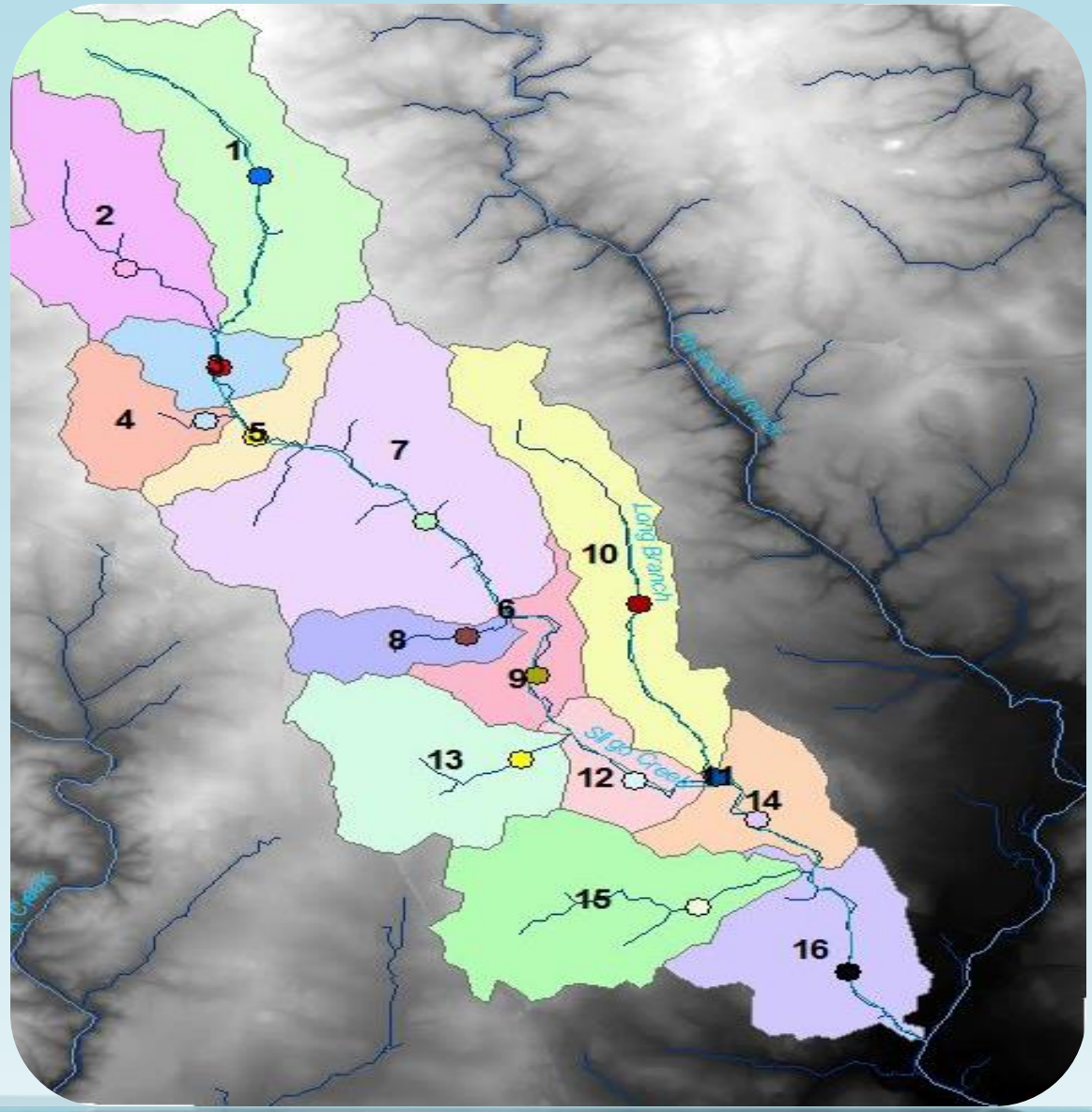
Flow direction



Flow accumulation

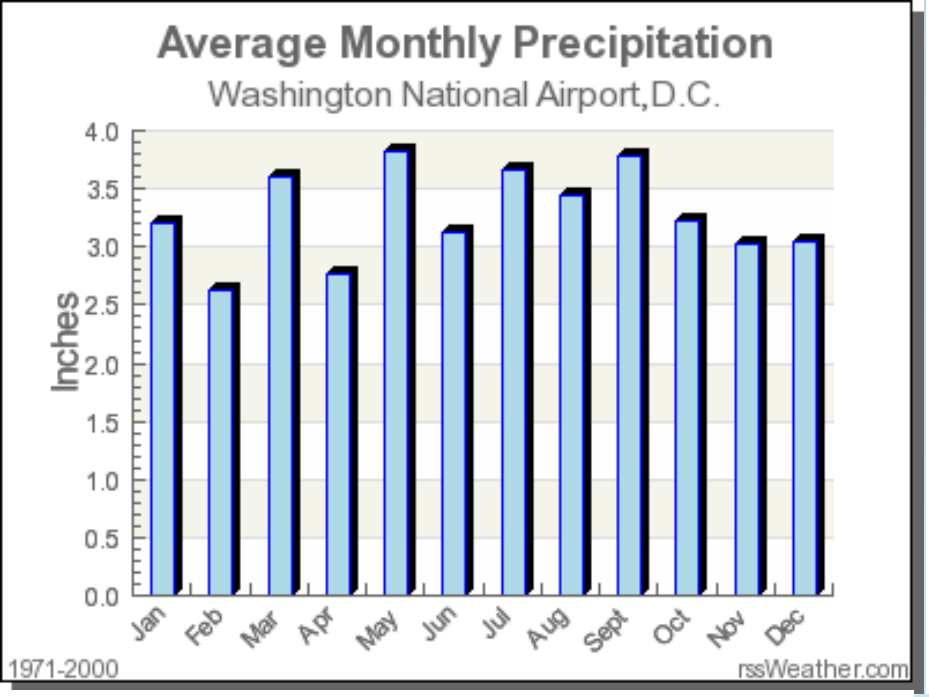
PHASE 2

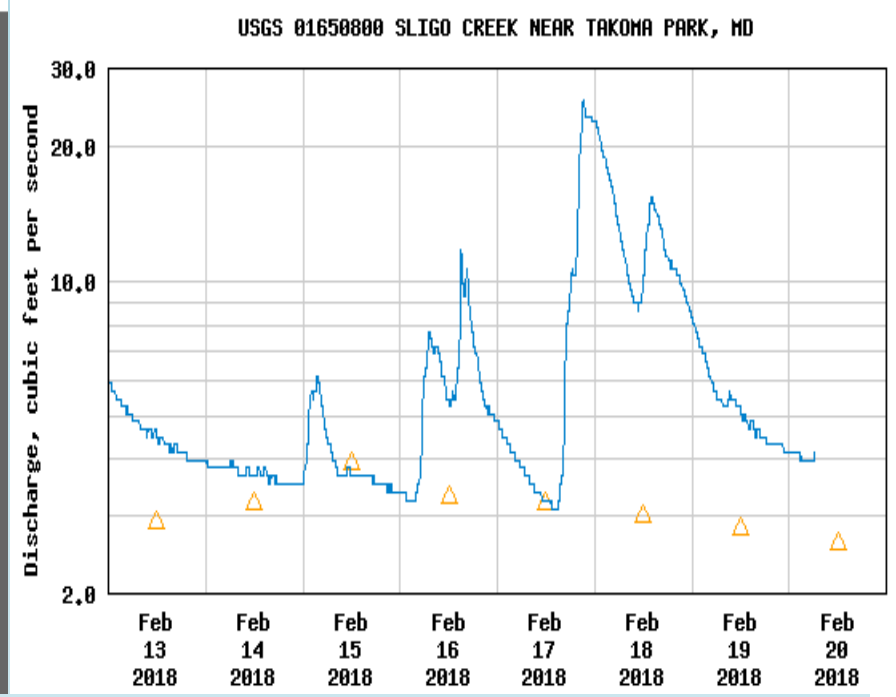


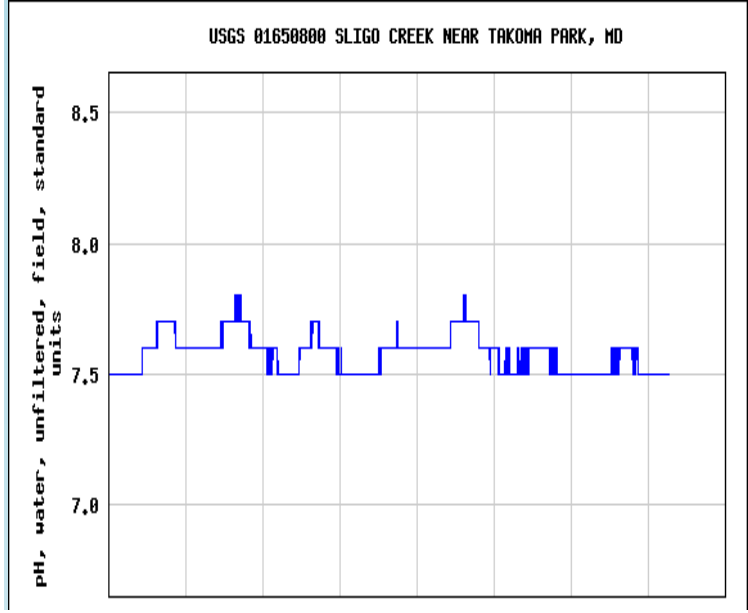


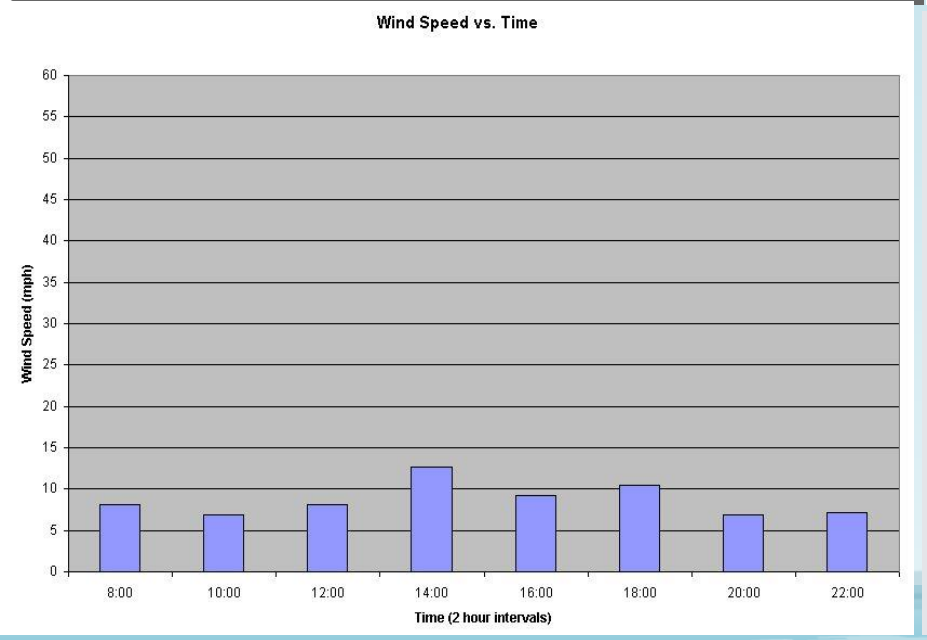
- Delineate the watershed
- Discretize to sub-watersheds

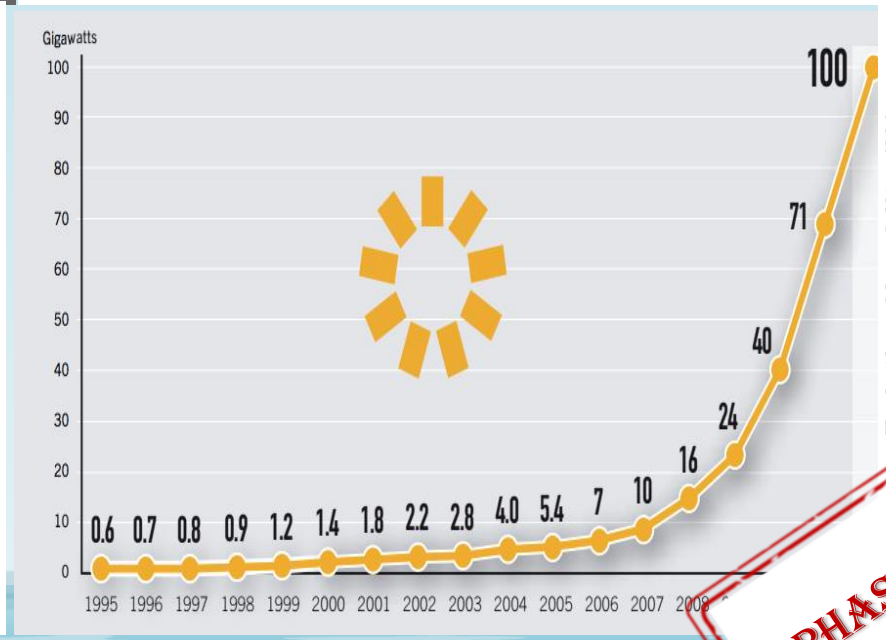

Elevations
Streams segment length
Centroid and gages
Areas (total/ imp/perv)
Interface area











Temperature (°F)

Relative Humidity (%)

	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
		93	100	108	117	127										
			103	112	121	132										

PHASE 3

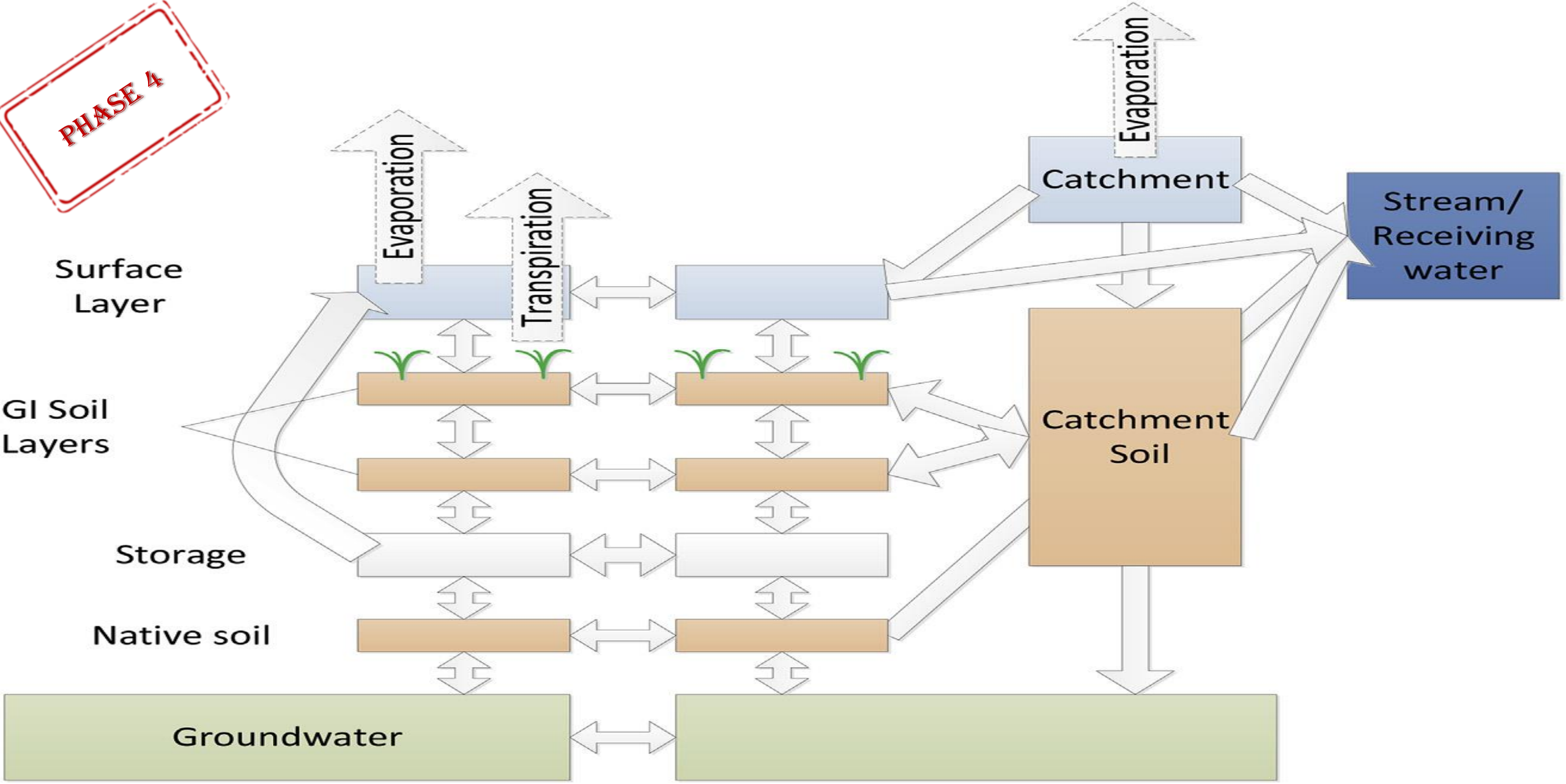
Data process: accept format – convert units – create time series

PHASE 4

Conceptual model GIFMod

- GIFMod : flexible framework for modeling
- Multi-dimensional hydro/quality within GI practices (with level of complexity)
- Using scripts/graphical interface
- Conceptualize spatial/temporal features (hydrology/water quality)
- Using blocks to represent these features
- Connecters between blocks :

Saturated/non-saturated soil – Pond – catchment – stream – ground water – storage - manhole – pipe – pressure/free-surface flow …all media.



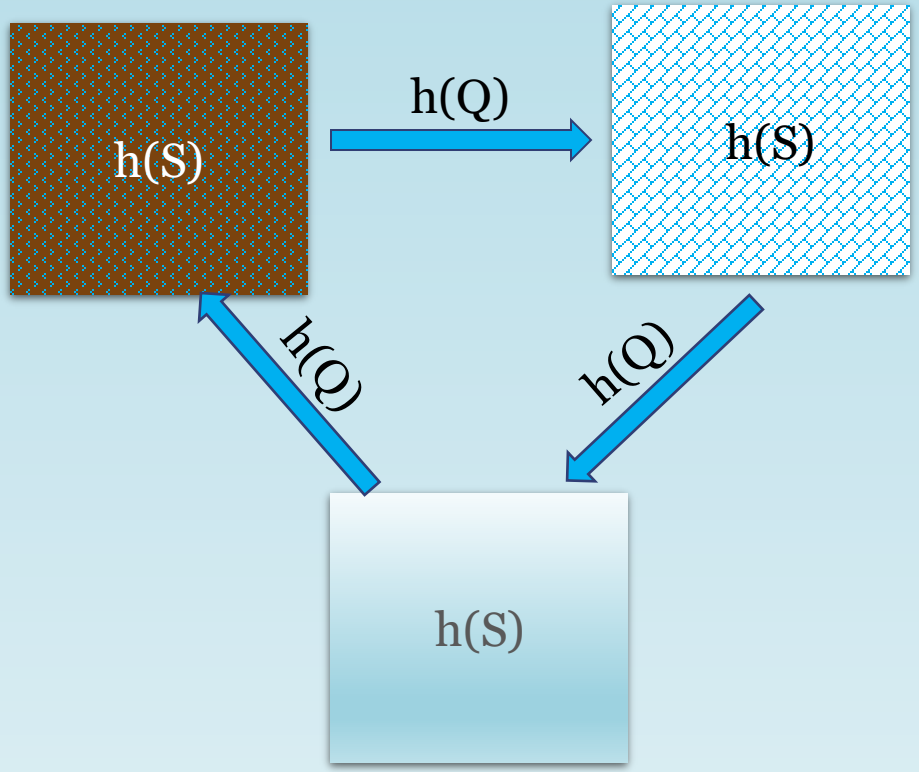
How the model work?

Hydraulic water balance equations

- Using equation that express **Head** relationships:

For blocks: head-storage

For connectors: head-flow



PHASE 4

Mathematical concepts

$$\frac{dS_i}{dt} = -\sum_{j=1}^{nj} Q_{w,ij} - \sum_{j=1}^{nj} Q_{ev,ij} + \sum_{j}^{ns} Q_{Si,j}$$

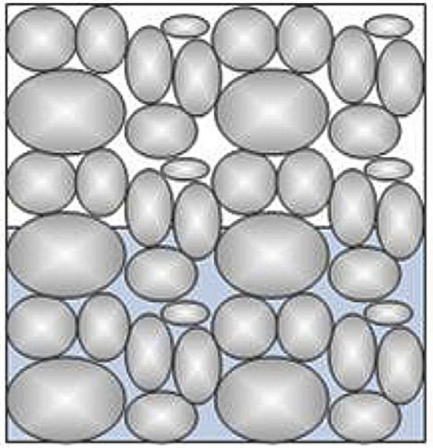
The equations:

- Van Genutchten-Maulem for unsaturated media
- Darcy for saturated porous media & storage
- Diffusive wave (DW) for surface water components including streams, ponds and overland flow

Calculating (evaporation and evapotranspiration) :

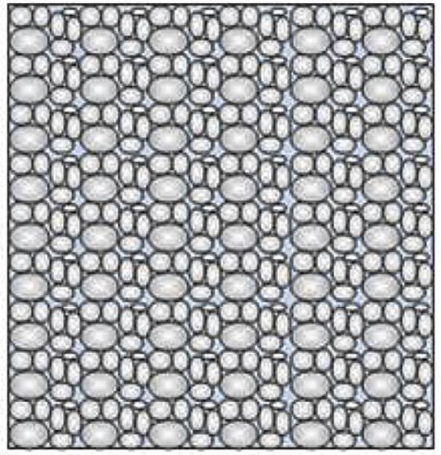
- Penman model
- Priestly-Taylor model
- Aerodynamic model
- Assign new equation (function of moisture content, light intensity, temperature, wind and humidity

PHASE 4



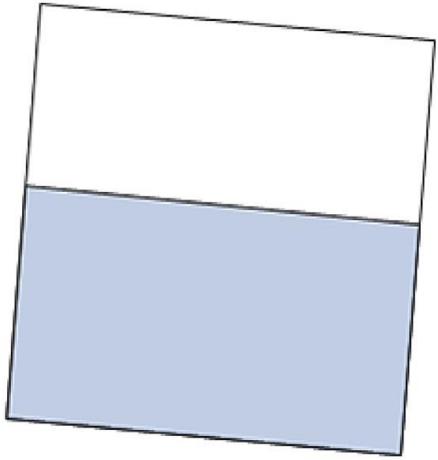
Storage

$$h = \frac{S}{A_s \theta_s} - \frac{\varepsilon}{s_e^{n_s}} + \frac{pos(\theta - \theta_s)}{S_s}$$



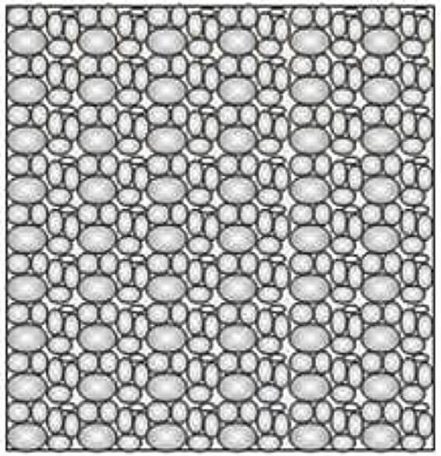
Saturated soil

$$h = h_0 + \frac{\theta - \theta_s}{S_s}$$



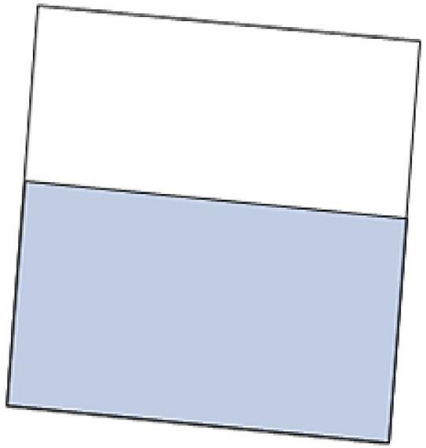
Pond

$$h = z_0 + \frac{S}{A_s}$$



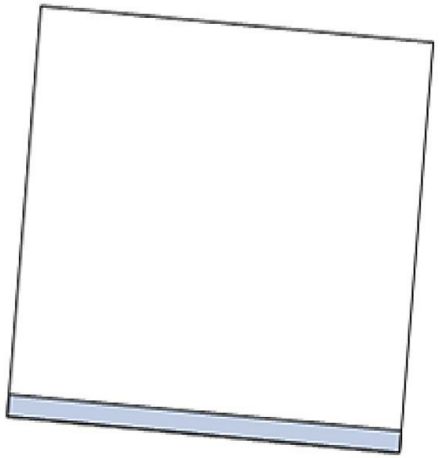
Unsaturated Soil

$$h = z_0 - \frac{H(\theta_s - \theta)}{\alpha}\left(s_e^{n/(1-n)} - 1\right)^{1/n} + \frac{pos(\theta - \theta_s)}{S_s}$$



Stream segment

$$h = z_0 + \frac{S}{A_s}$$



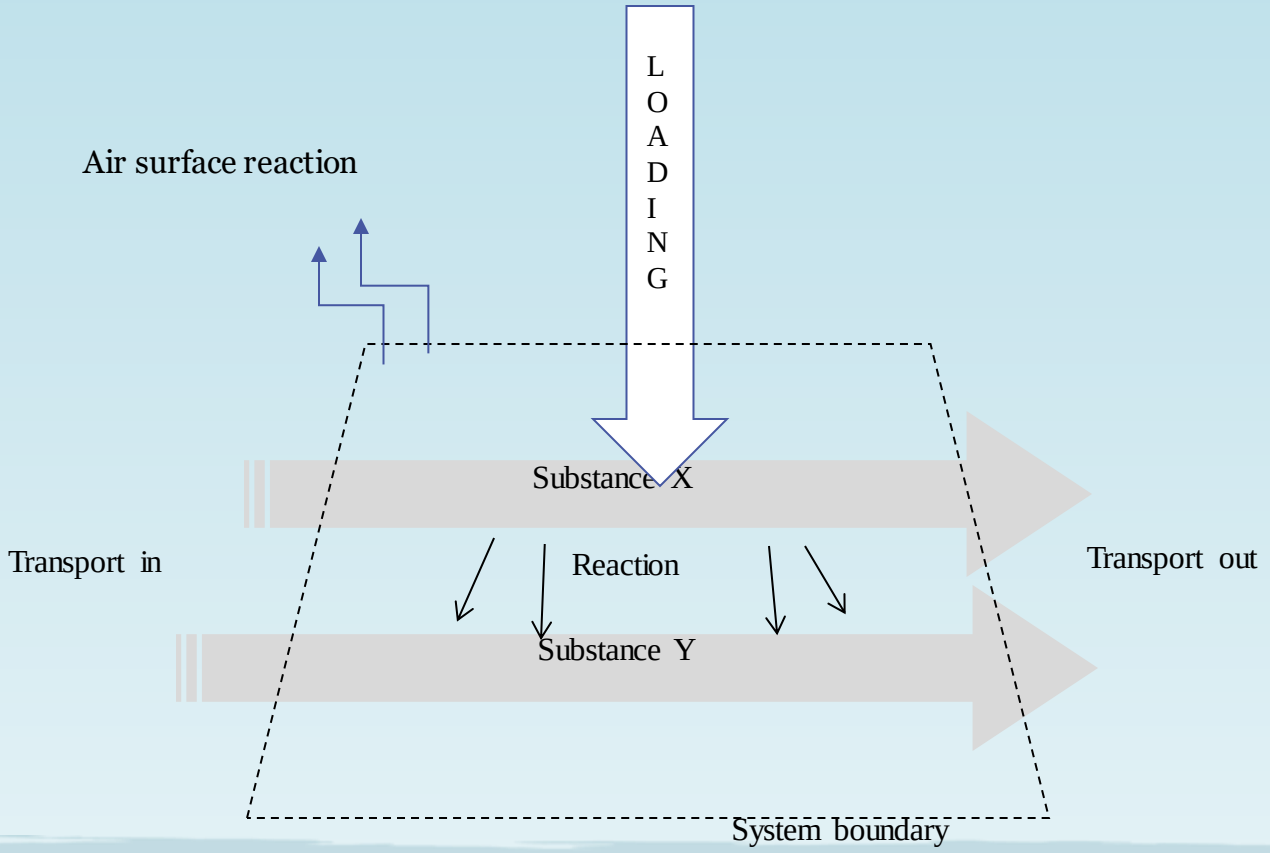
Overland flow

$$h = z_0 + \frac{S}{A_s}$$

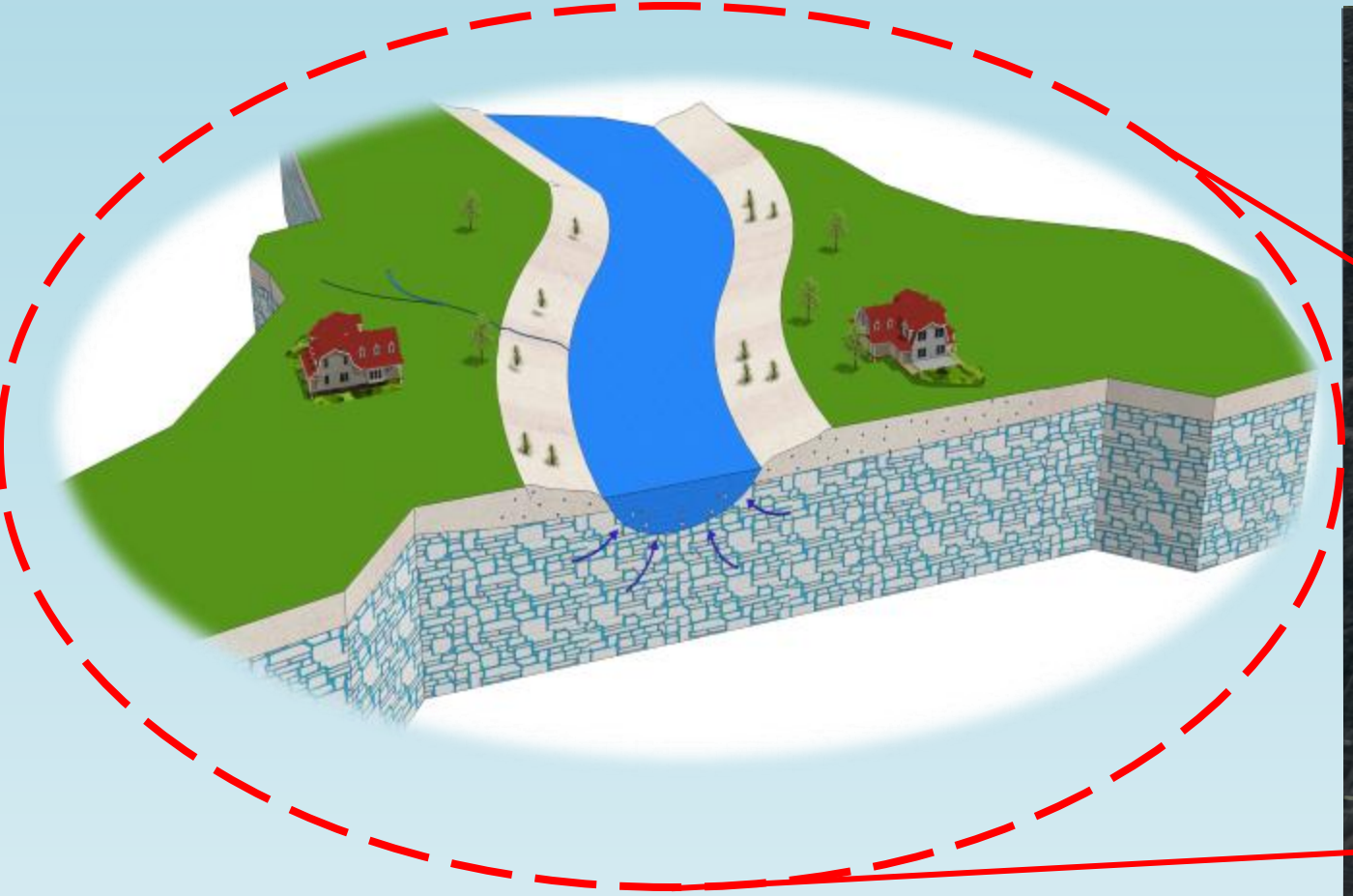
PHASE 4

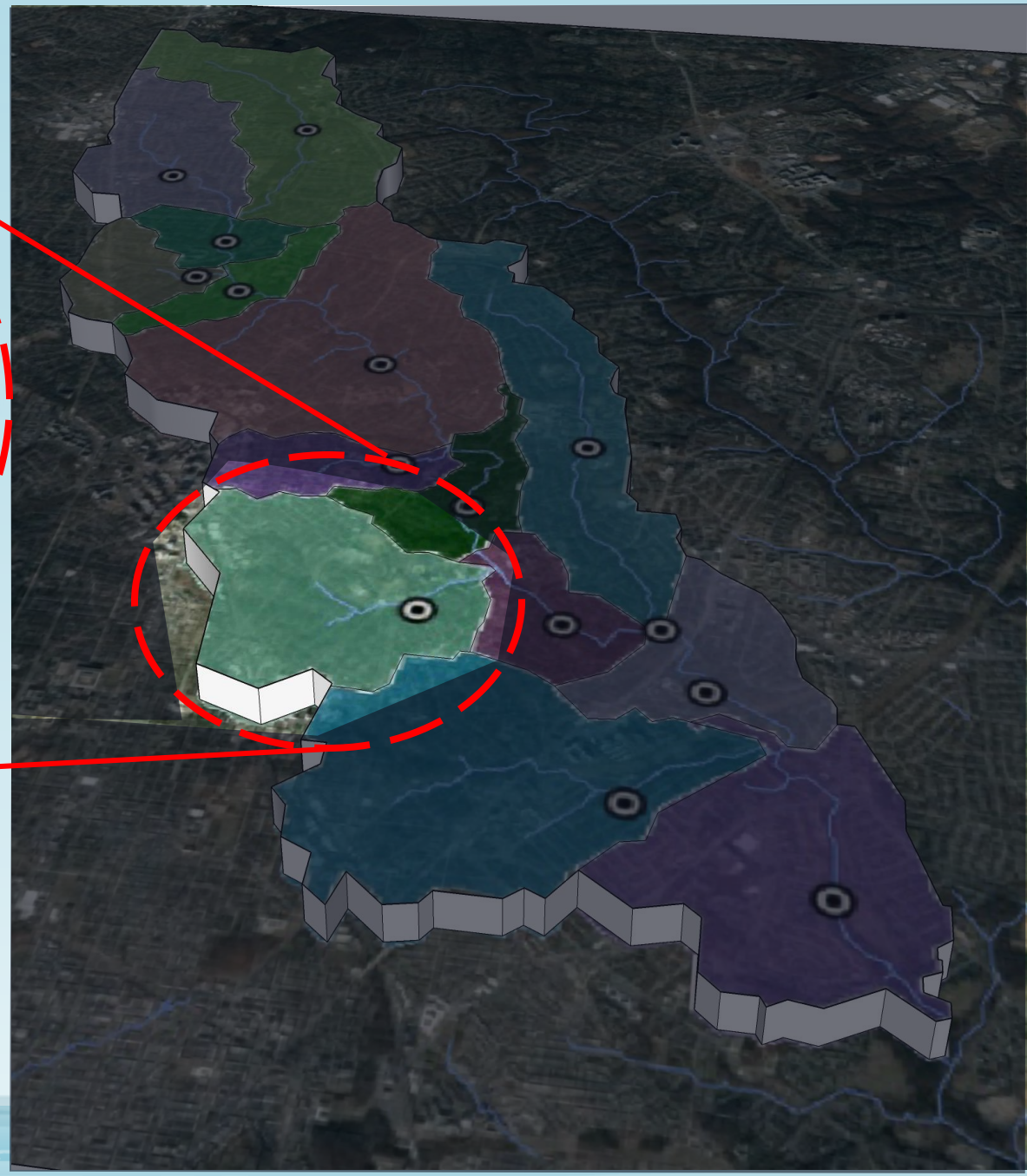
Water Quality

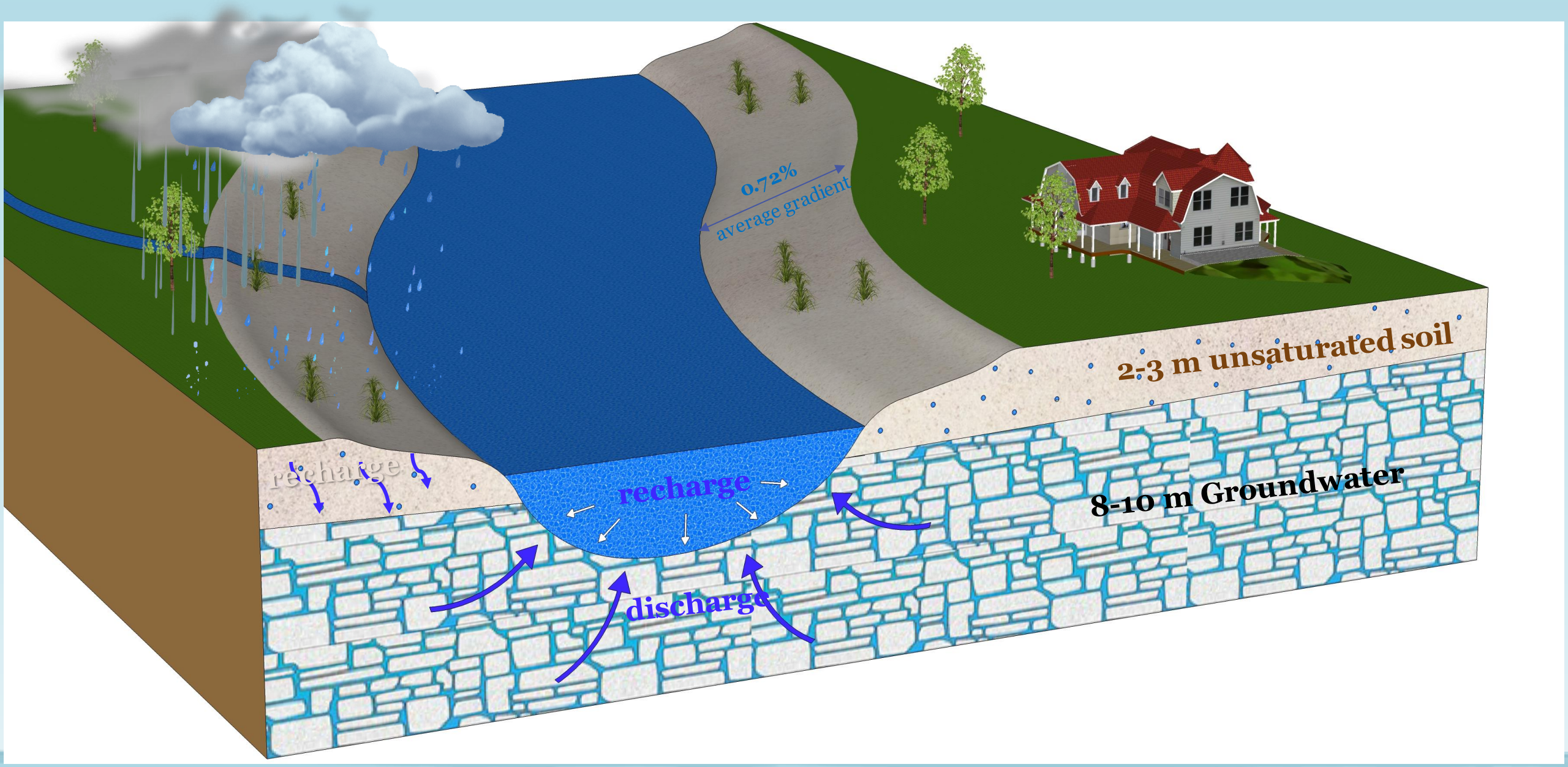
Reaction fundamental: Chemical balance equation



Total concentration rate = Rate income – Rate outcome +/- source/sinks






0.72%
average gradient
2-3 m unsaturated soil
recharge
recharge
8-10 m Groundwater
discharge

Green Infrastructure Flexible Model (GIFMod)*

File Edit View Model Preferences Post Processing Help

All experiments

Model Space

Pond (1), z0=0 (m)

Plant (1), z0=0 (m)

Catchment (1), z0=0 (m)

Stream (1), z0=0 (m)

Storage (1), z0=0 (m)

Soil (1), z0=96.5 (m)

Soil (2), z0=0 (m)

Darcy (1), z0=0 (m)

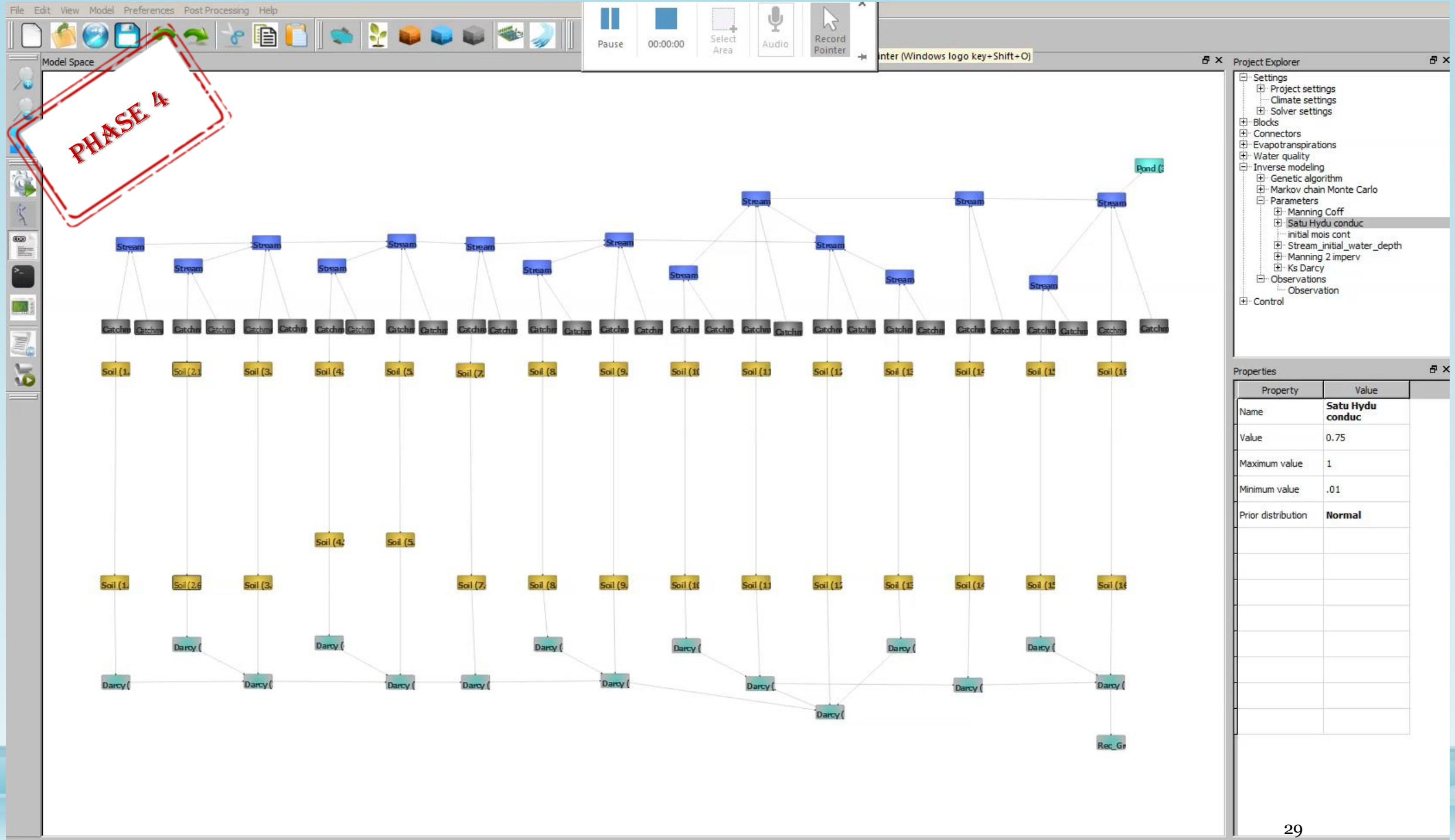
Project Explorer

- Project settings
- Climate settings
- Solver settings
- Blocks
- Connectors
- Evapotranspirations
- Water quality
- Inverse modeling

Properties

Property	Value
Name	**Soil (1)**
Type	**Soil**
SubType	**Clay loam**
Bottom area	236120 (m²)
Bottom elevation	96.5 (m)
Build-up	
Bulk density	**1500 (kg/m³)**
Constituent initial concentration	...
External flux	
Head-storage relationship	
Inflow time series	
moisture content (θ)	**0.2**
Depth	**0 (m)**
Particle initial concentration	...
Precipitation	**No**
x	729
y	951
Vapor diffusion coefficient	**0 (m²/day)**

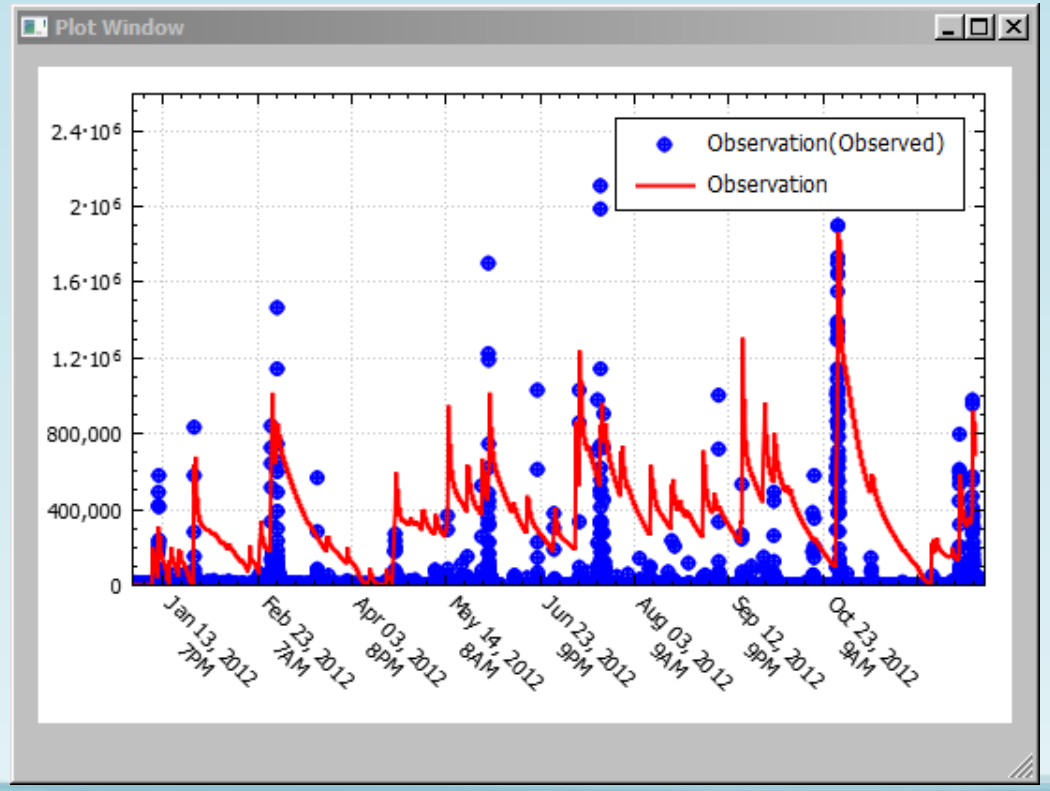
X = 560 , Y = 1345

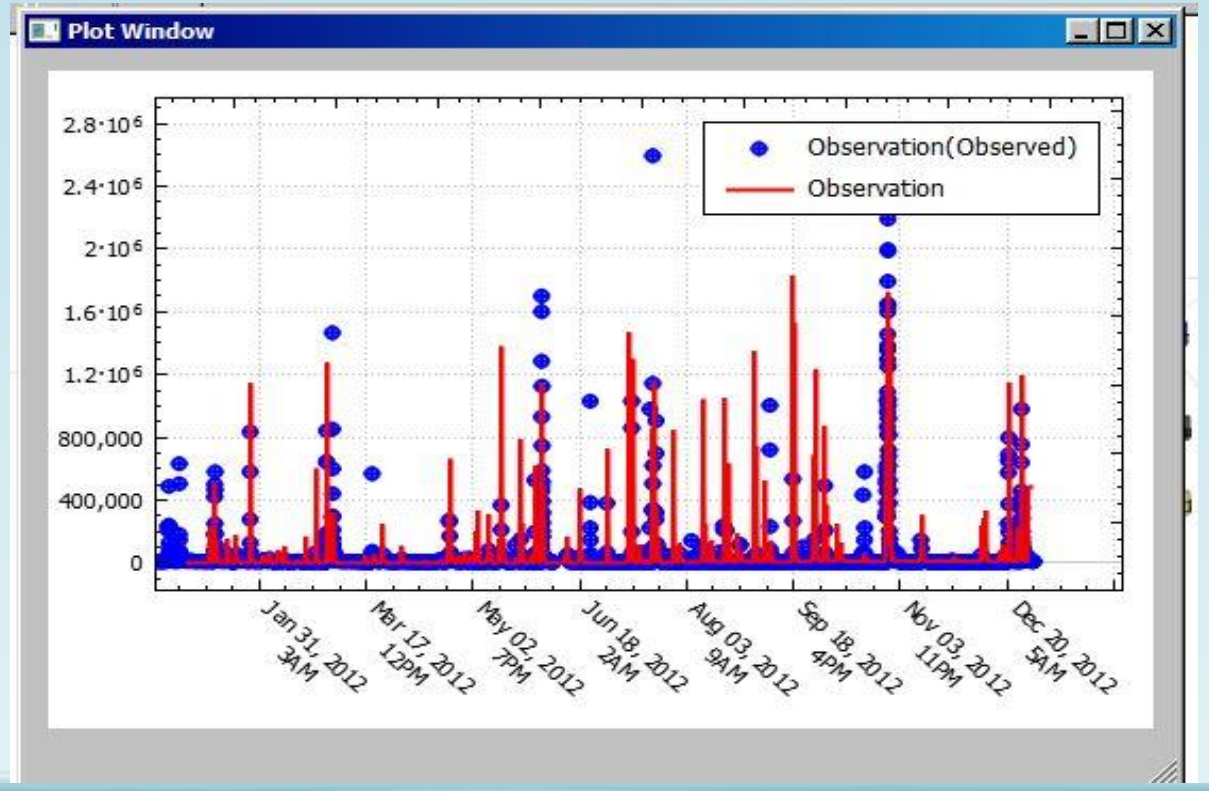

PHASE 4
File Edit View Model Preferences Post Processing Help
Pause
00:00:00
Select Area
Audio
Record Pointer
Model Space
Project Explorer
Settings
Project settings
Climate settings
Solver settings
Blocks
Connectors
Evapotranspirations
Water quality
Inverse modeling
Genetic algorithm
Markov chain Monte Carlo
Parameters
Manning Coff
Satu Hydu conduc
initial mois cont
Stream_initial_water_depth
Manning 2 imperv
Ks Darcy
Observations
Observation
Control
Properties
Property
Value
Name
Satu Hydu conduc
Value
0.75
Maximum value
1
Minimum value
.01
Prior distribution
Normal

PHASE 4

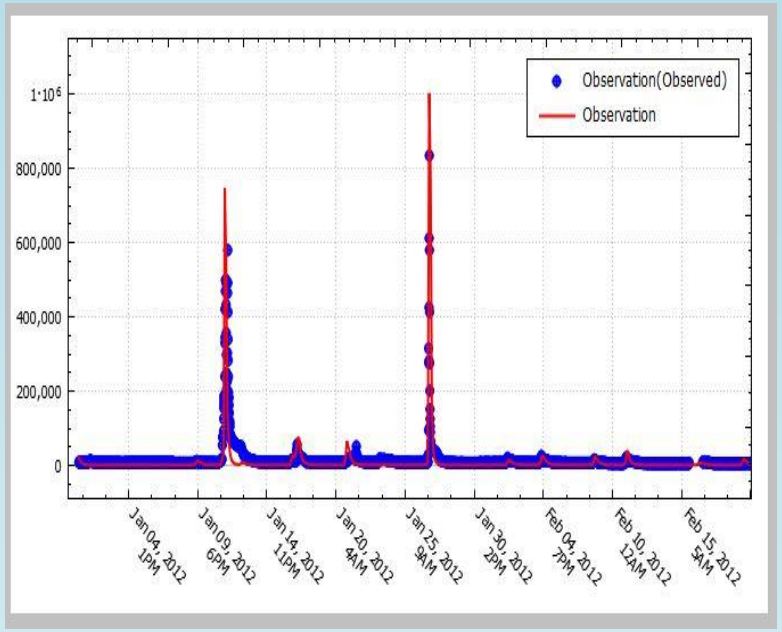
Calibration

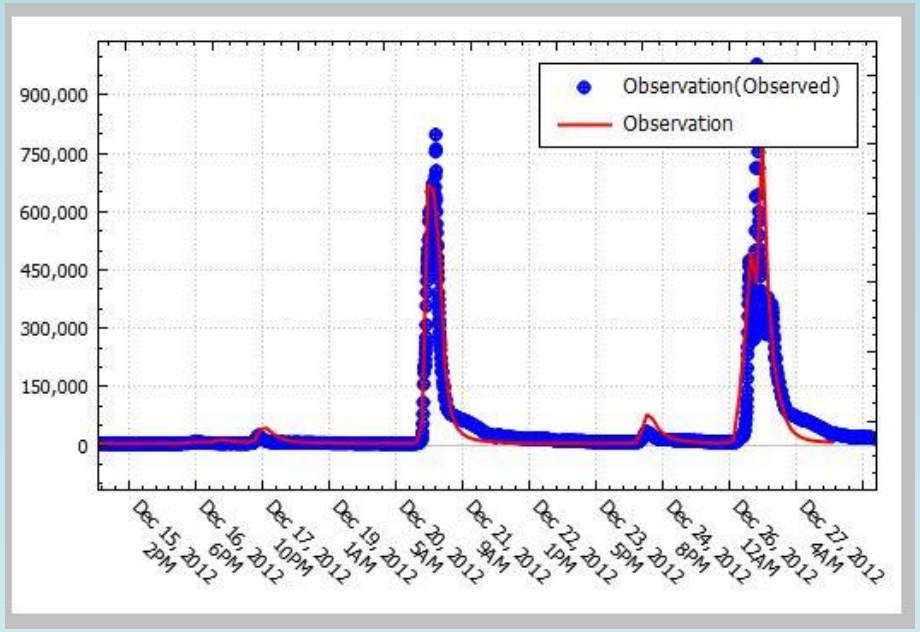
Observation Vs Observed

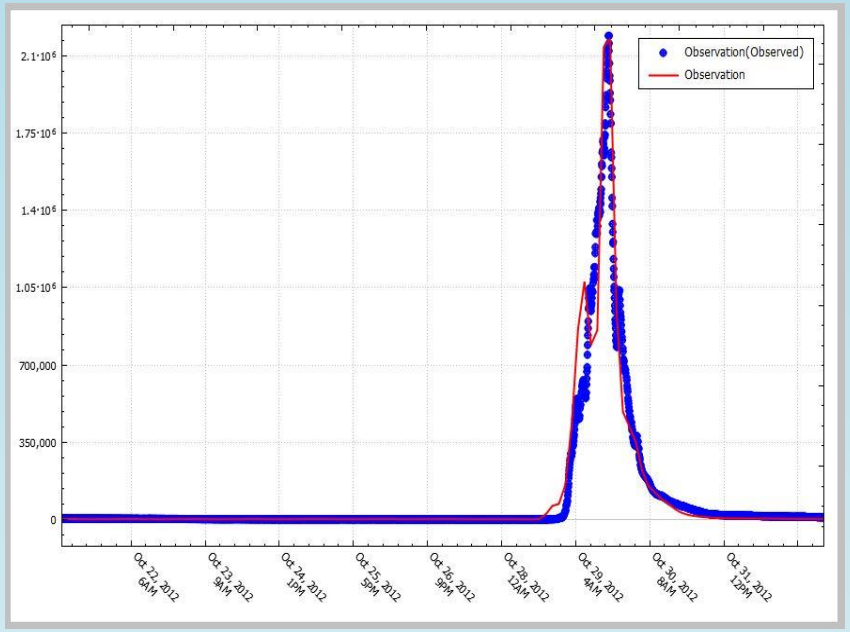


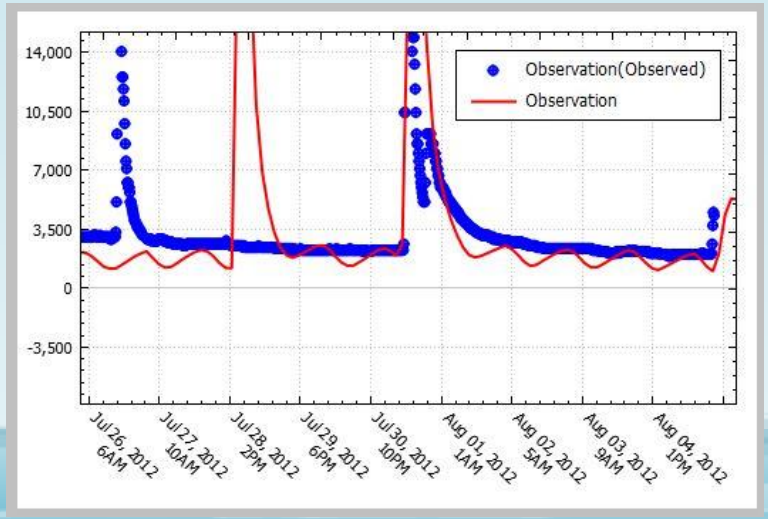


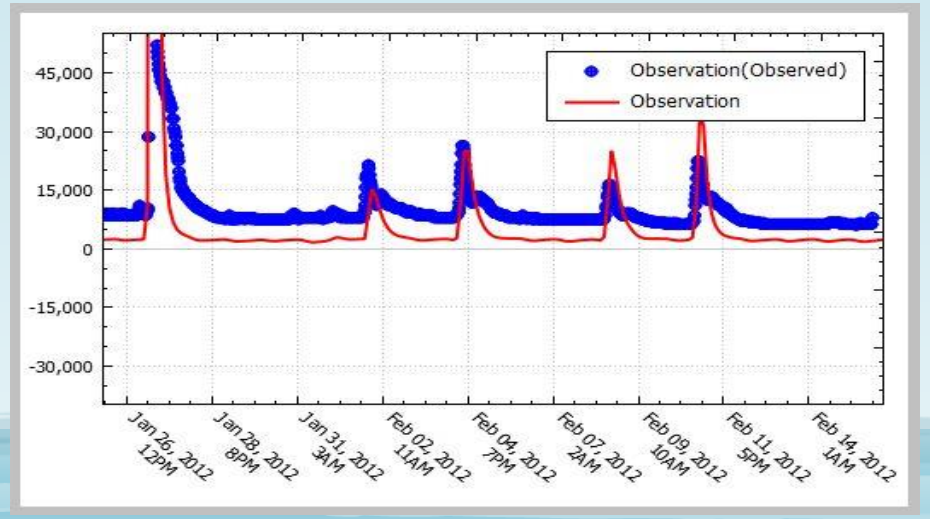
Calibration

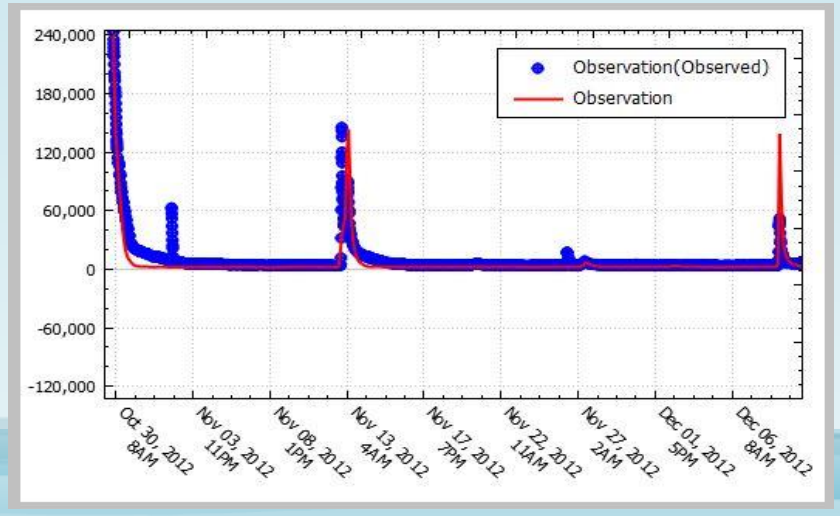




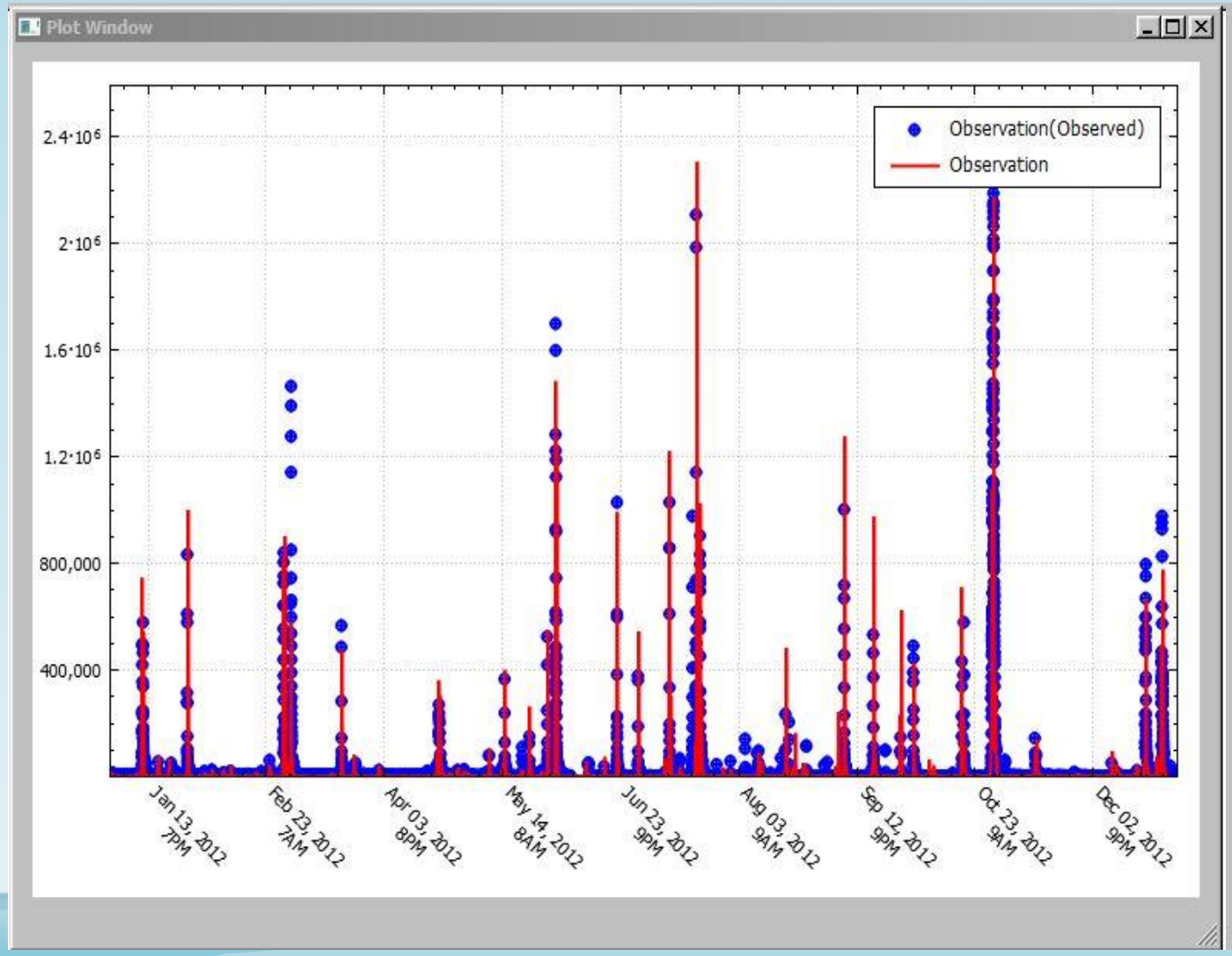


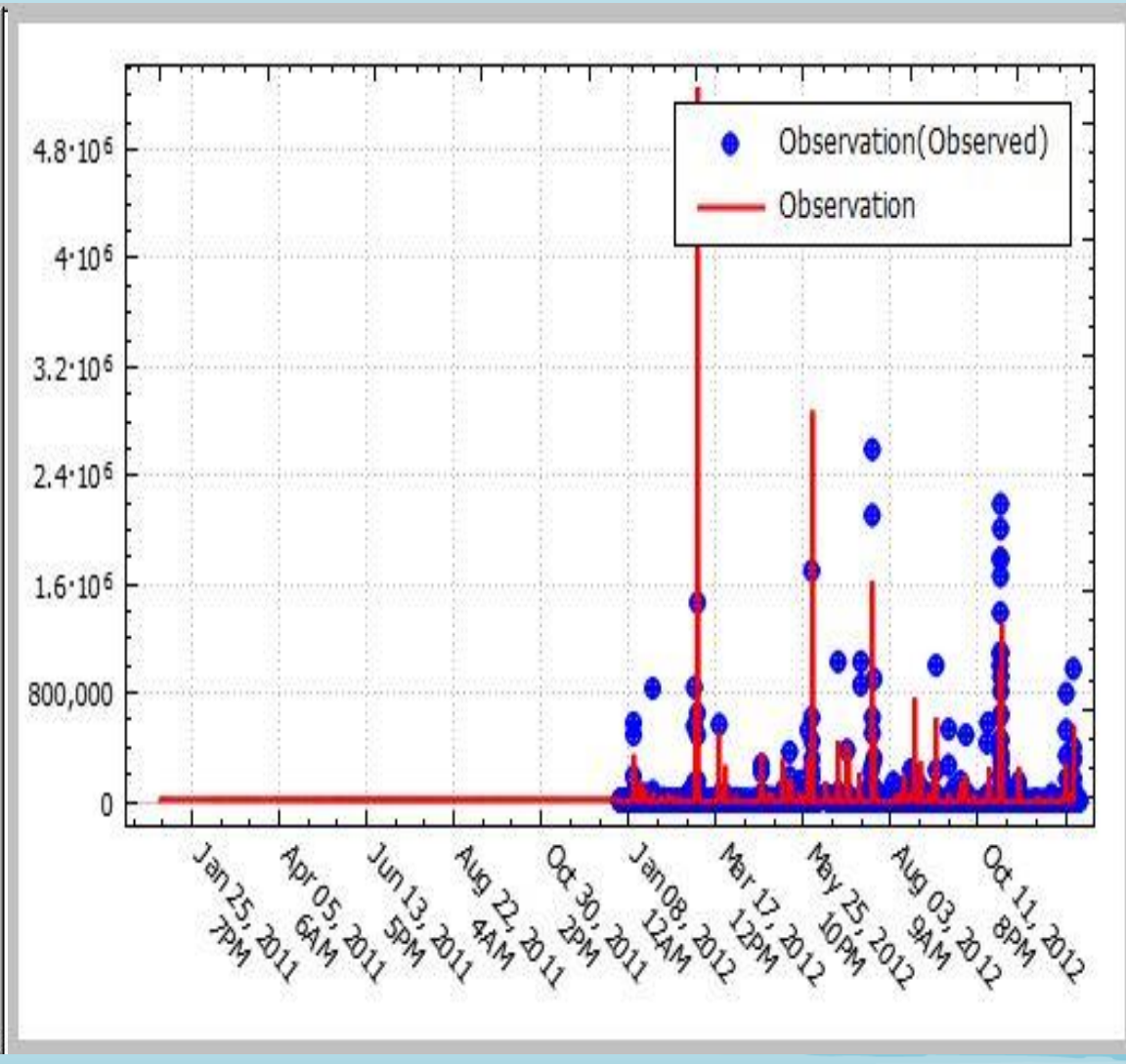






Validation

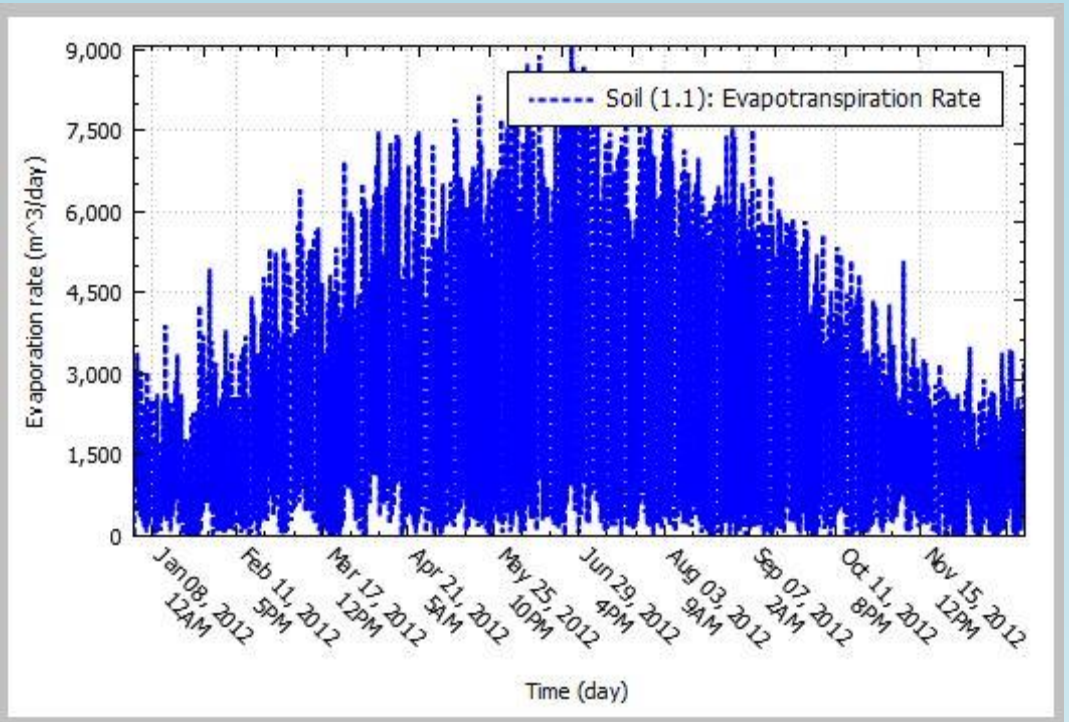

Plot Window
Observation(Observed)
Observation
2.4·10⁶
2·10⁶
1.6·10⁶
1.2·10⁶
800,000
400,000
Jan 13, 2012 7PM
Feb 23, 2012 7AM
Apr 03, 2012 8PM
May 14, 2012 8AM
Jun 23, 2012 9PM
Aug 03, 2012 9AM
Sep 12, 2012 9PM
Oct 23, 2012 9AM
Dec 02, 2012 9PM

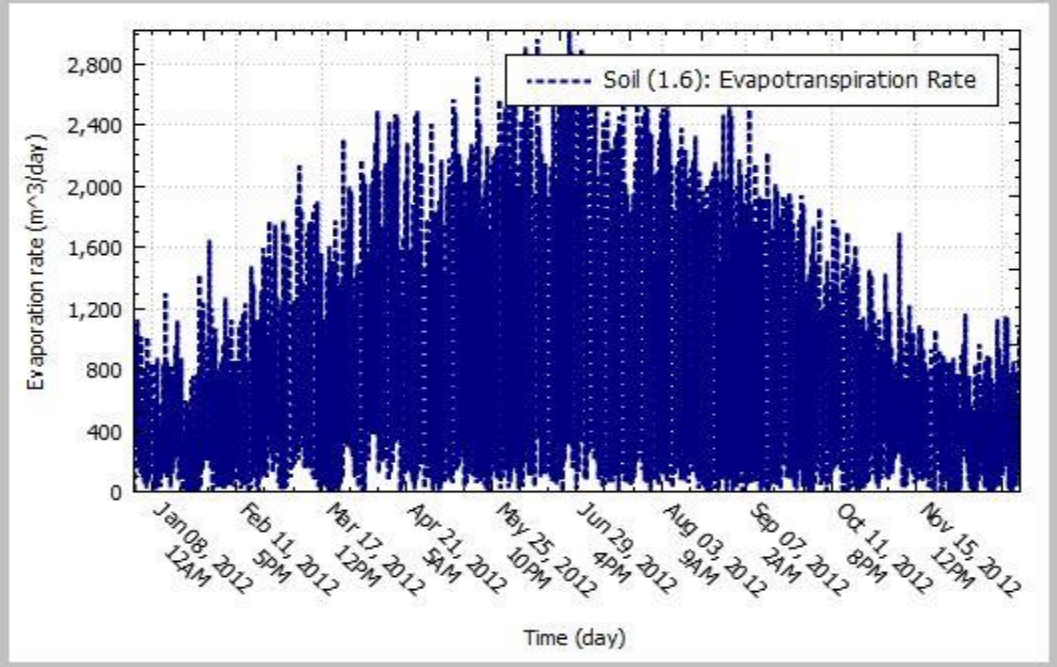

Observation(Observed)
Observation
4.8·10⁶
4·10⁶
3.2·10⁶
2.4·10⁶
1.6·10⁶
800,000
0
Jan 25, 2011 7PM
Apr 05, 2011 6AM
Jun 13, 2011 5PM
Aug 22, 2011 4AM
Oct 30, 2011 2PM
Jan 08, 2012 12AM
Mar 17, 2012 12PM
May 25, 2012 10PM
Aug 03, 2012 9AM
Oct 11, 2012 8PM

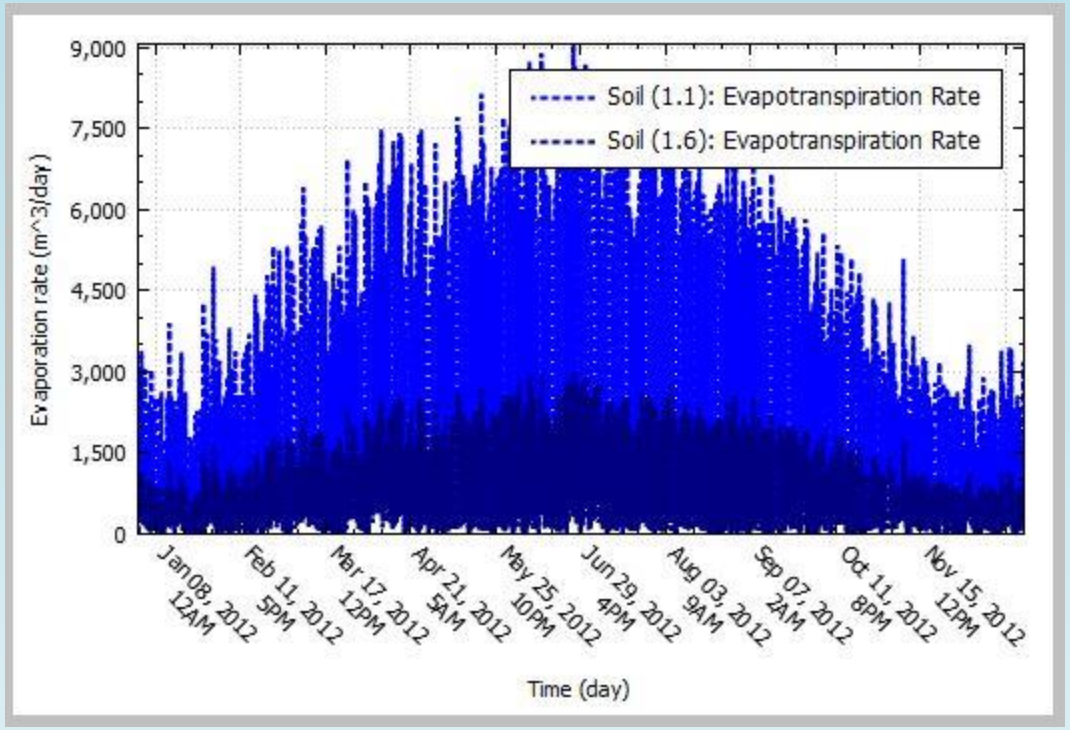
calibration/validation - annual flow and correlation coefficients

Mean Observed Annual Flow (inches)	Mean Simulated Annual Flow (inches)	R Average Daily	R Average Monthly	Mean Observed Annual Flow (inches)	Mean Simulated Annual Flow (inches)	R Average Daily	R Average Monthly
23.6	24.4	0.83	0.92	26.3	25.8	0.79	0.92
26.3	26.4	0.82	0.94	29.0	28.3	0.71	0.91
21.4	21.7	0.84	0.93	25.9	25.2	0.75	0.91
23.8	23.6	0.82	0.93	27.2	24.7	0.86	0.95
26.2	26.0	0.85	0.92	26.2	29.1	0.87	0.94
31.7	31.9	0.88	0.98	34.6	31.5	0.87	0.96

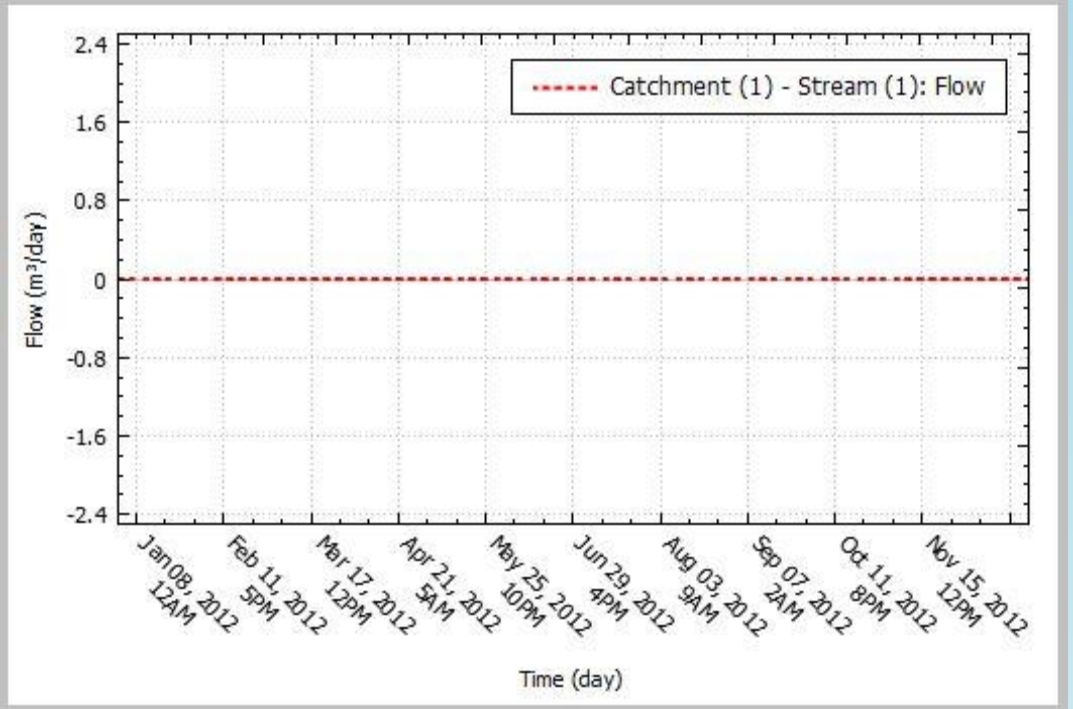
Evapotranspiration

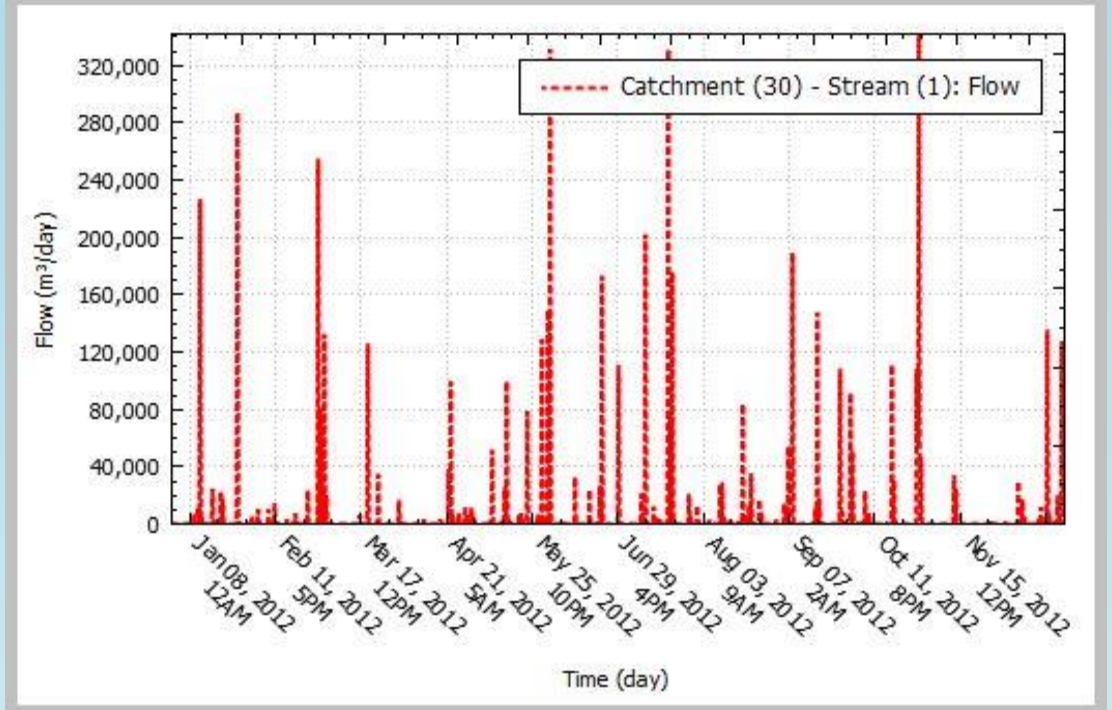


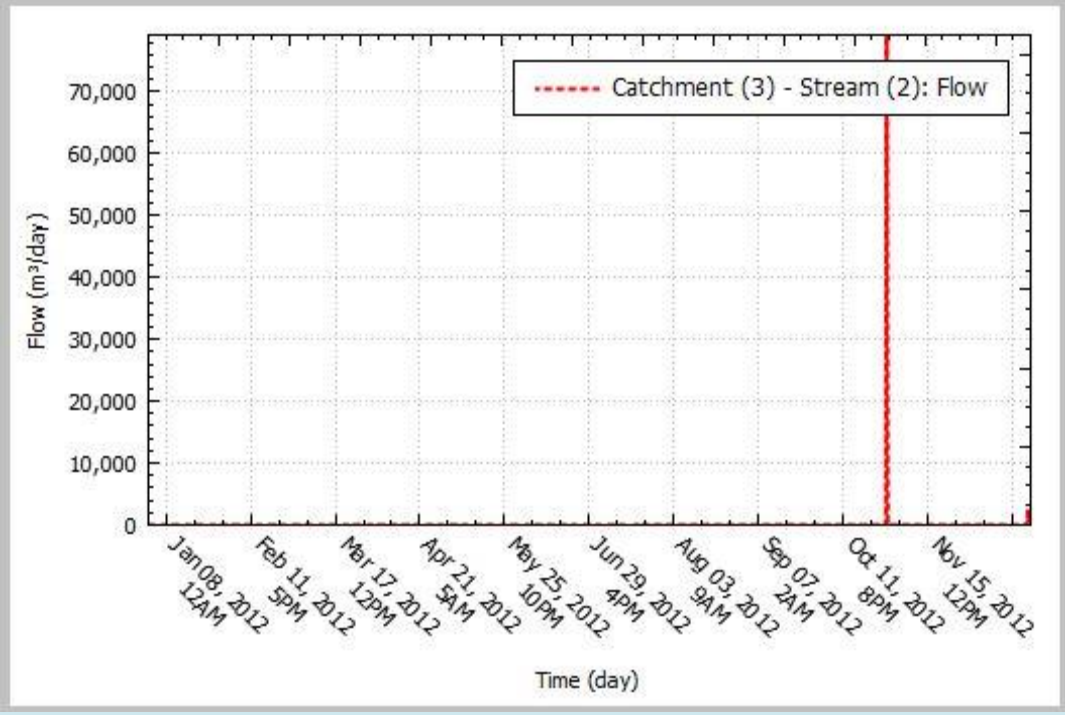


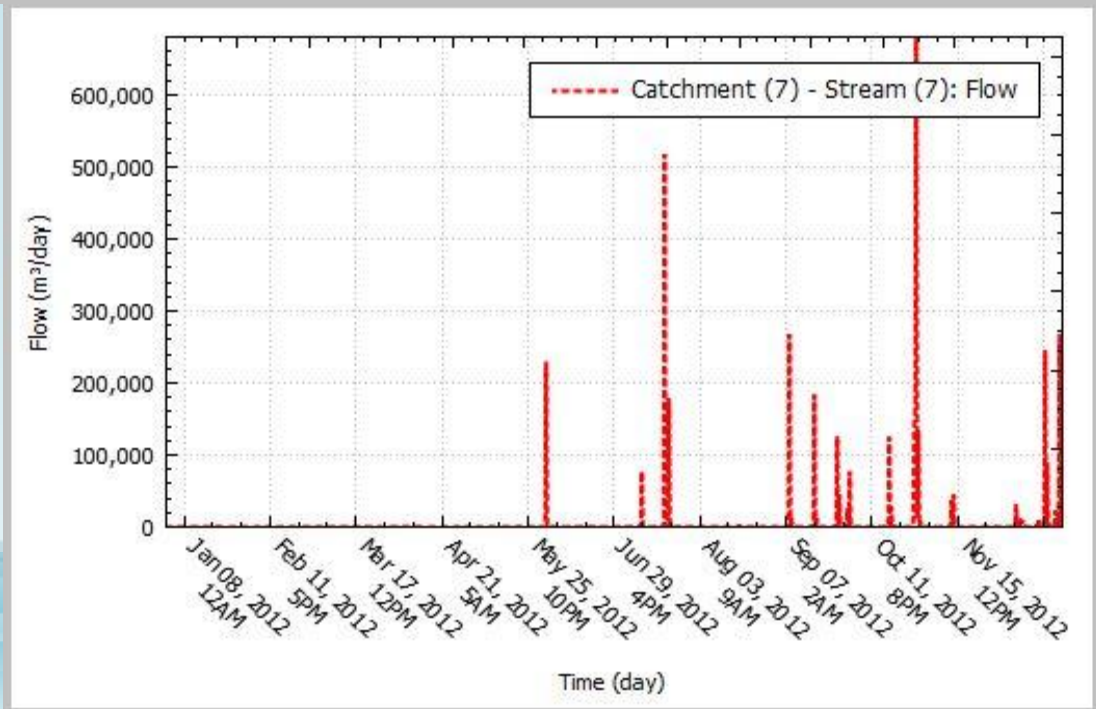


Flow Catch-stream

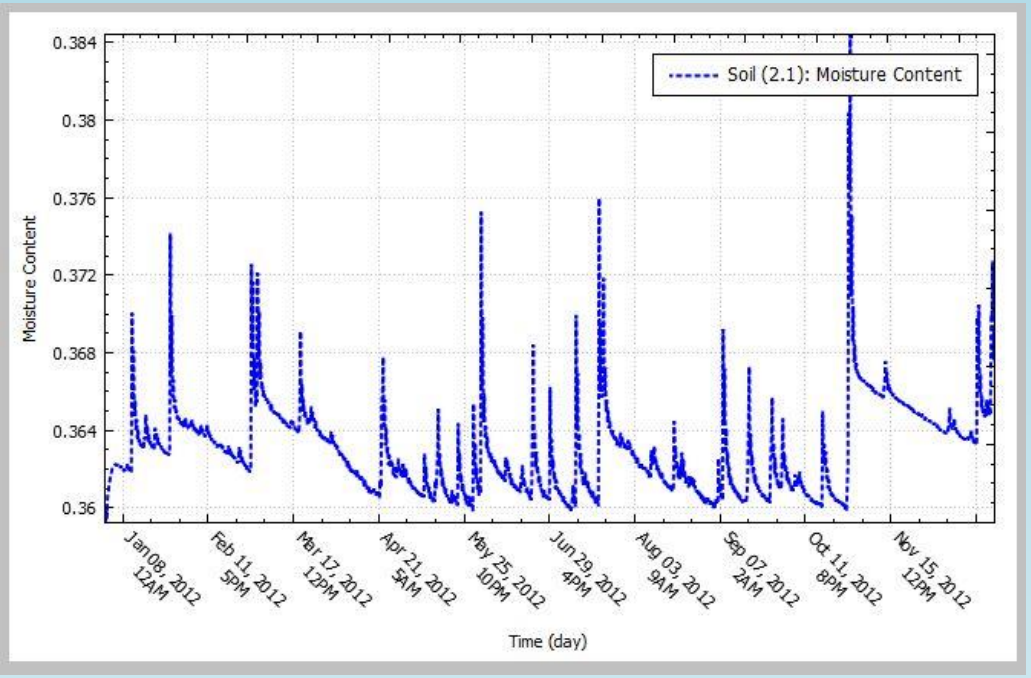


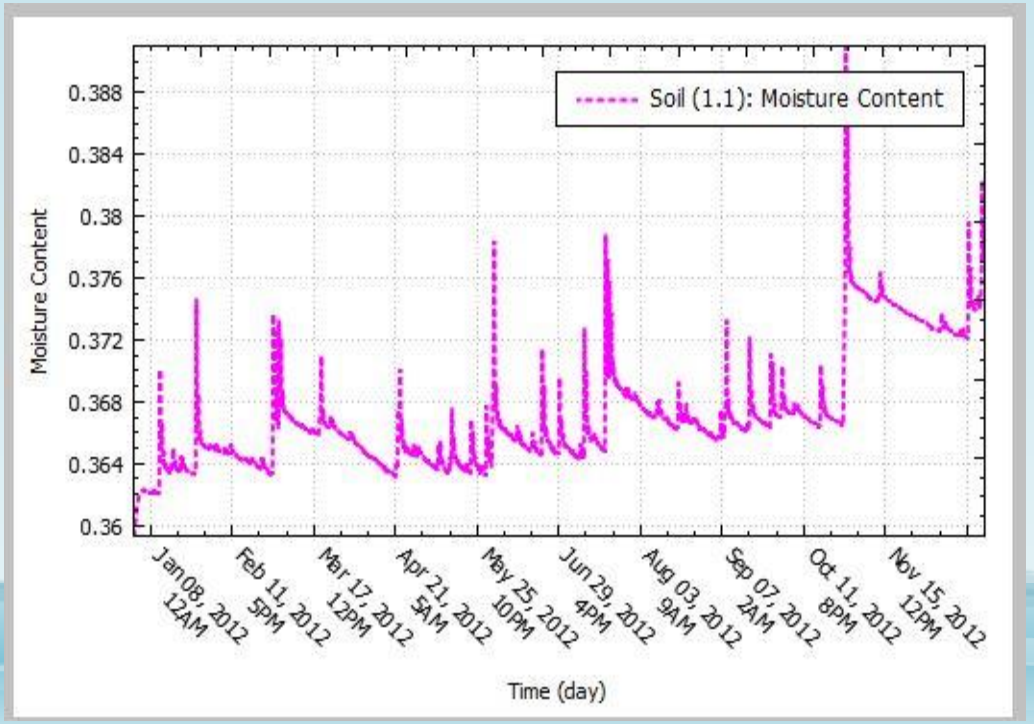


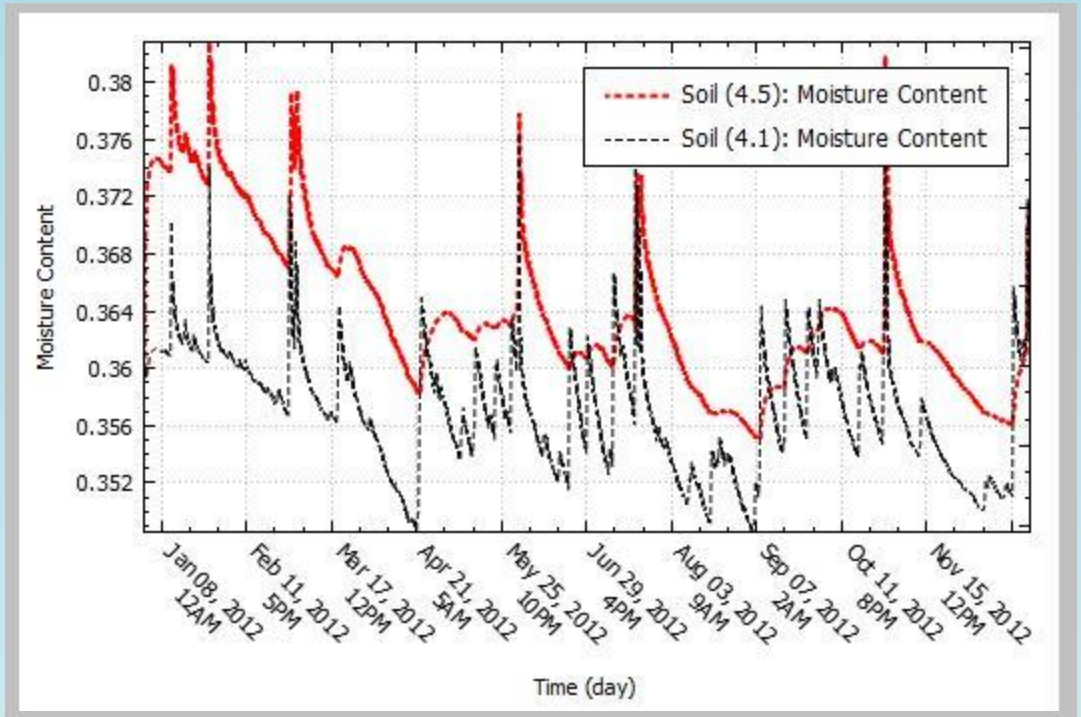


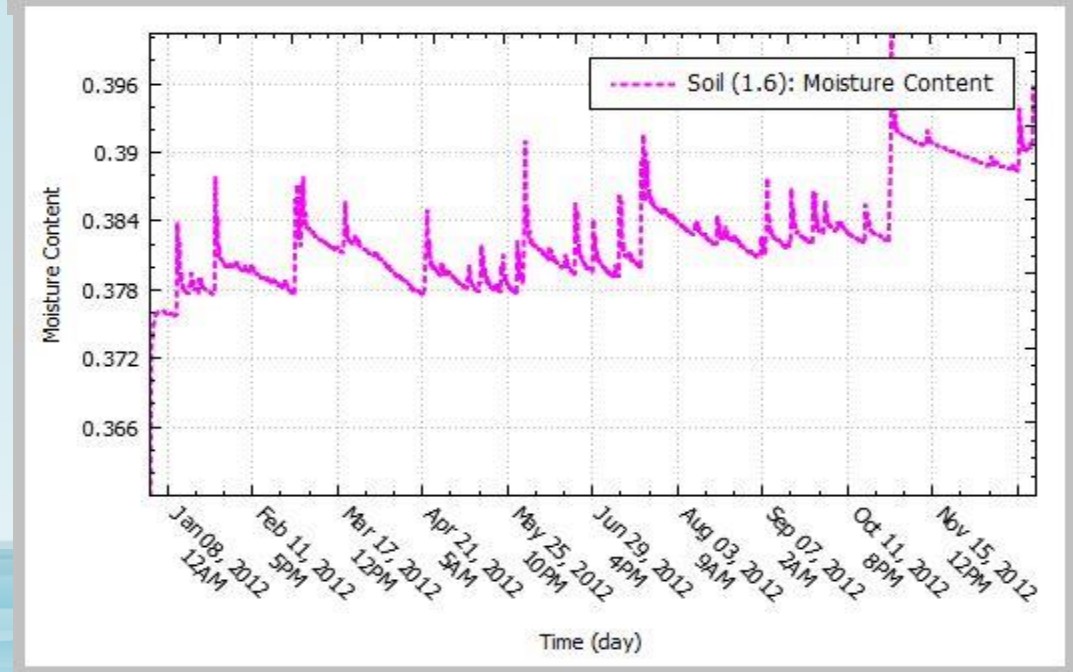


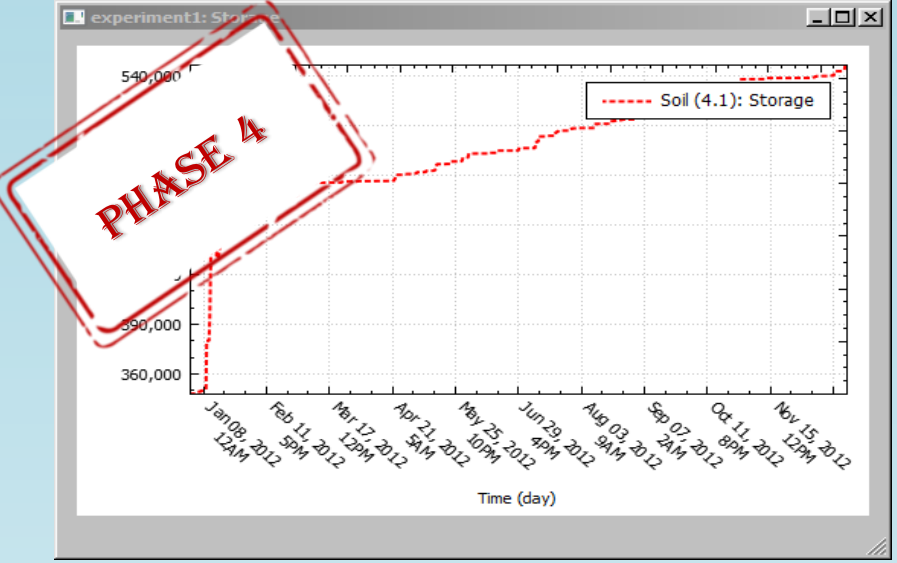
Soil Moisture Content

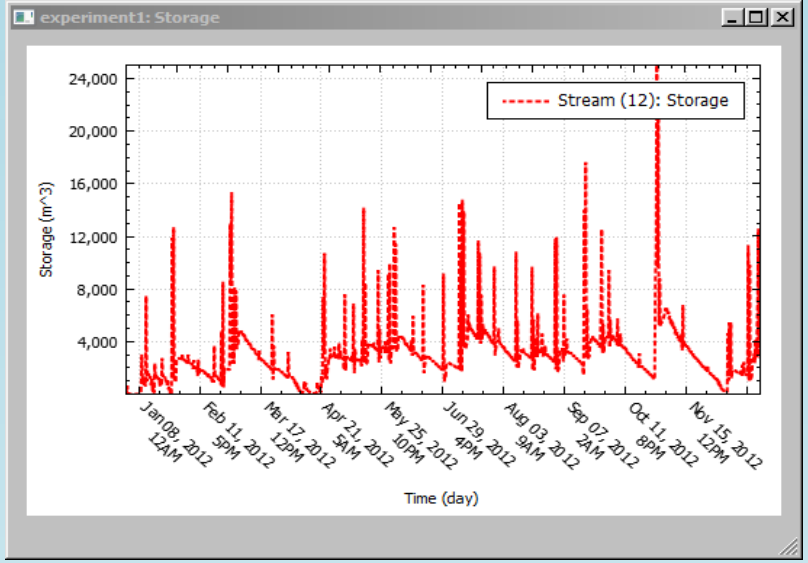


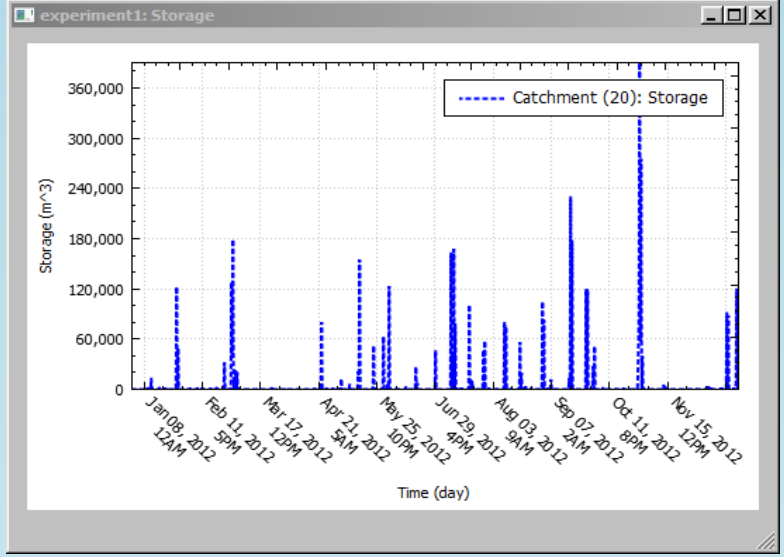


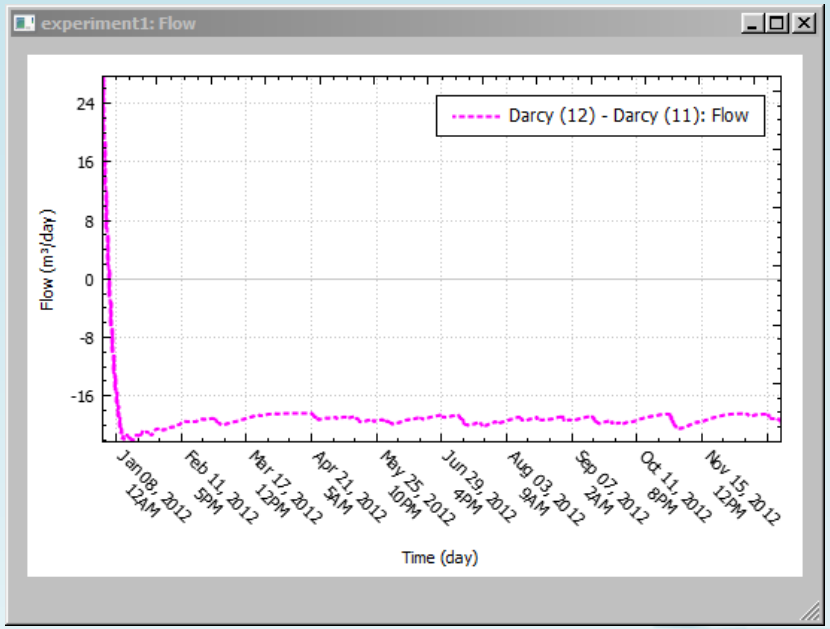


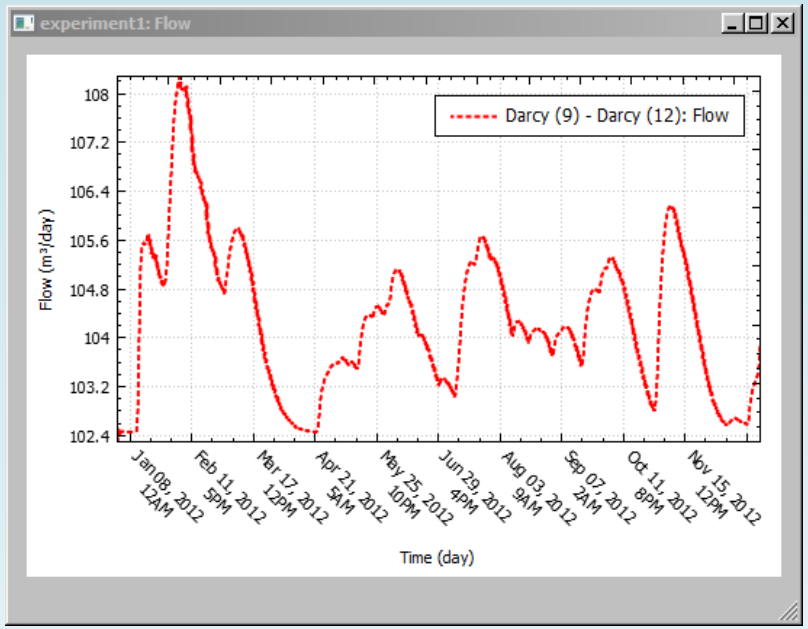


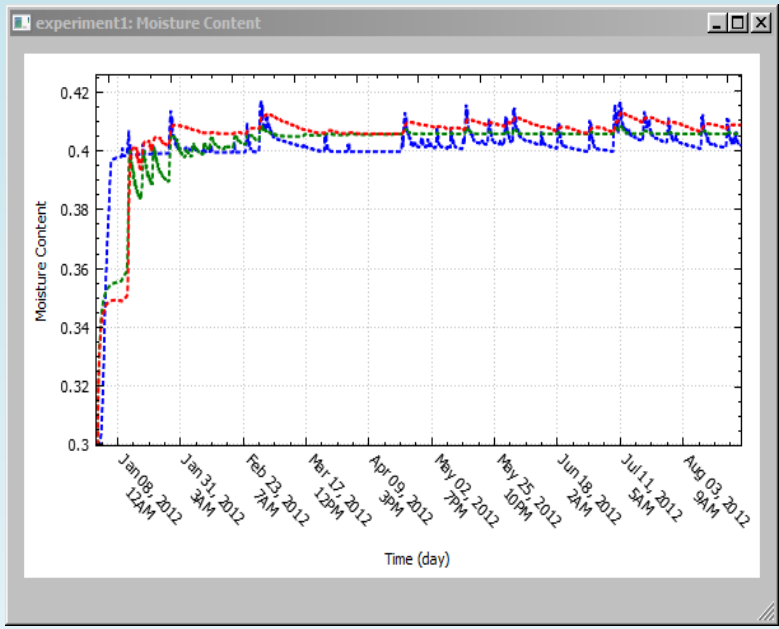




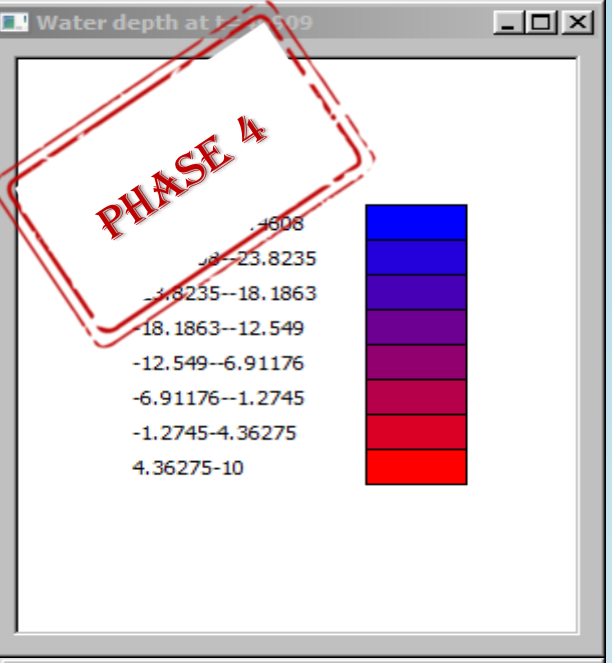


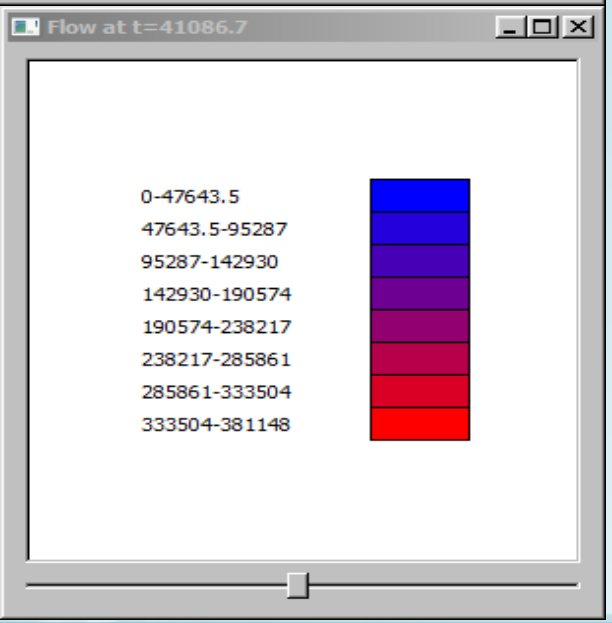


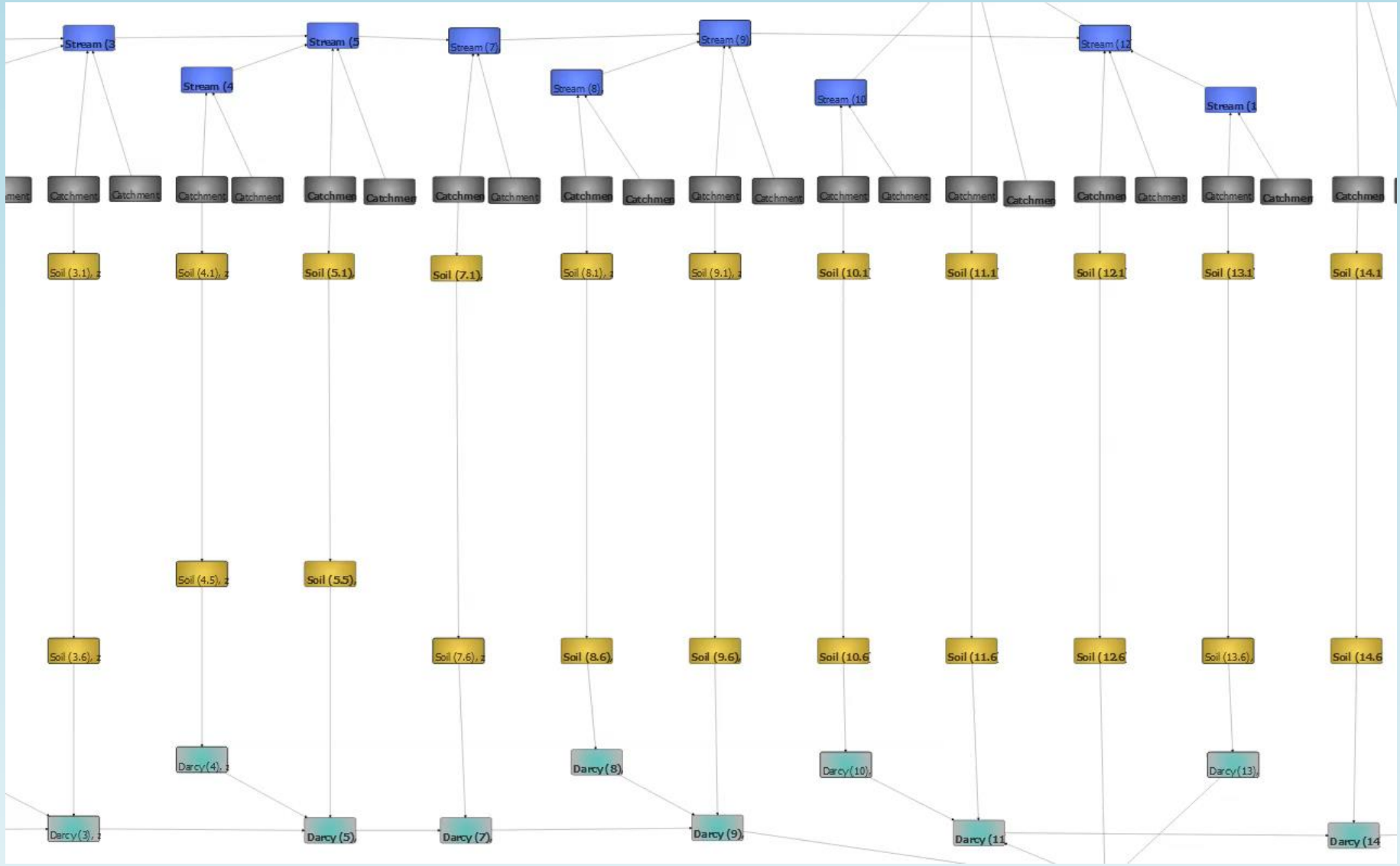




Running results







Results interpretation

PHASE 4

Invers modeling

- For best parameters estimation
- Using Genetic Algorithms =========> point estimate
- Using Markov Chain Monte-Carlo ===>Probabilistic

Auto Calibration

Future work

- ~~Site selection~~
- ~~Geospatial model~~
- ~~Data process~~
- ~~Crete the Model~~
- ~~Calibration~~
- ~~Validation~~
- Quality
- GI
- Evaluation

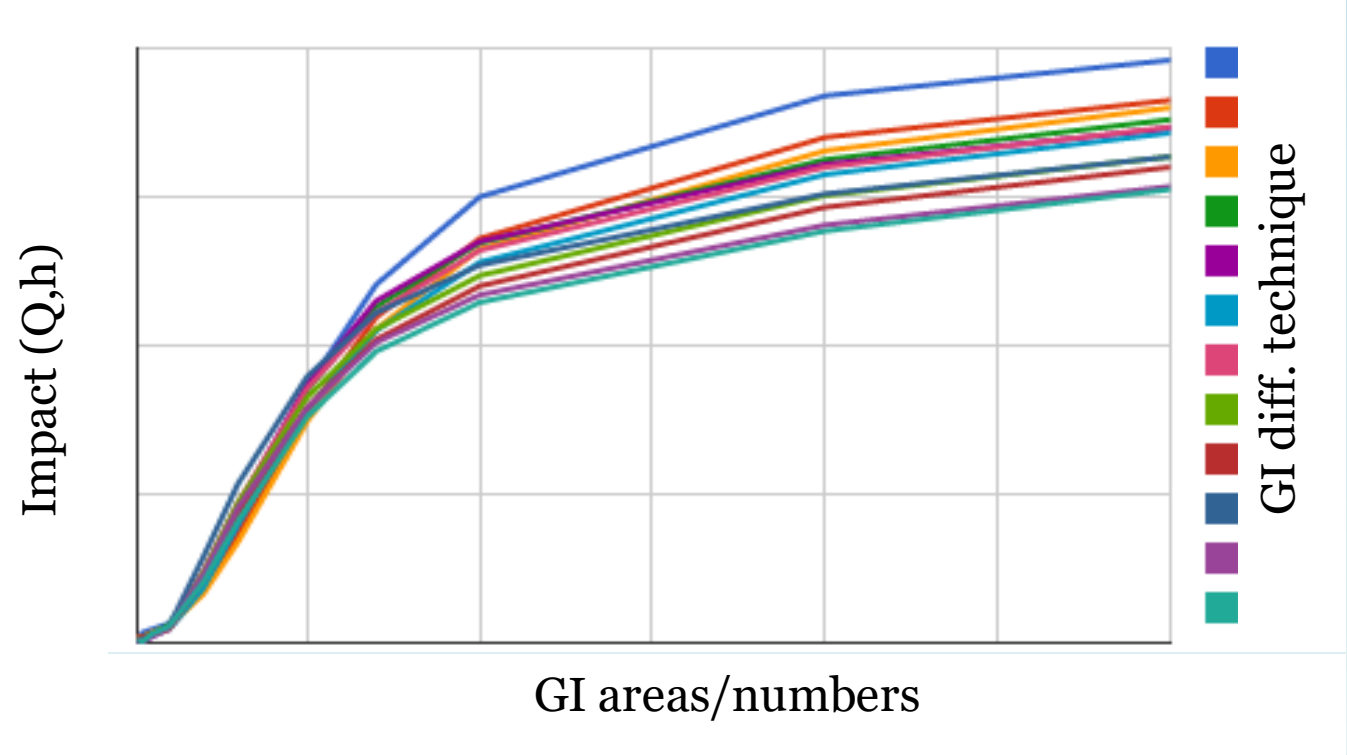
Green Infrastructures

- 1) The ones make water is diverted to/from impervious areas like, dry/wet ponds, bioretention, infiltration basin/trench; and
- 2) The ones turn impervious surface to pervious such as green roof and permeable pavement.
- 3) combination between techniques and numbers

Expected results & sensitive Interpretation

Selection of input variables that have the greatest impact on the outcomes of interest
quantify the range of likely outcomes, and likelihood of each outcome
Eliminating redundant uncertain inputs

Determination of parameters sensitivity $\frac{\text{\% change of output}}{\text{\% change of input}}$ $\frac{\text{\% change of Q}}{\text{\% change of Area}}$



aggregate measures :Comparing multi scenarios

output time series (peak, total volume, % quality, avg. concentration , loading, head .....)

Conclusion

- Enhance the understanding & predicting behavior of the GIs practices mechanisms
- Increasing the fidelity of the model by explicitly including important components
- Gaining better understanding of how GIs process interact with the watershed
- Evaluating GI performance for:

  - Hydraulic process

  - Contaminants transport and fate

First attempt of new model with noticeable features:

- hybrid between lumped and distributed model

- invers modeling and auto calibration

Capability to use the model for arid regions (Jeddah) depending how fast

,,,,Thank you ,,,,,

We All live Downstream