‘age’ of water:

a physics based, fully coupled, distributed model for watershed assessment

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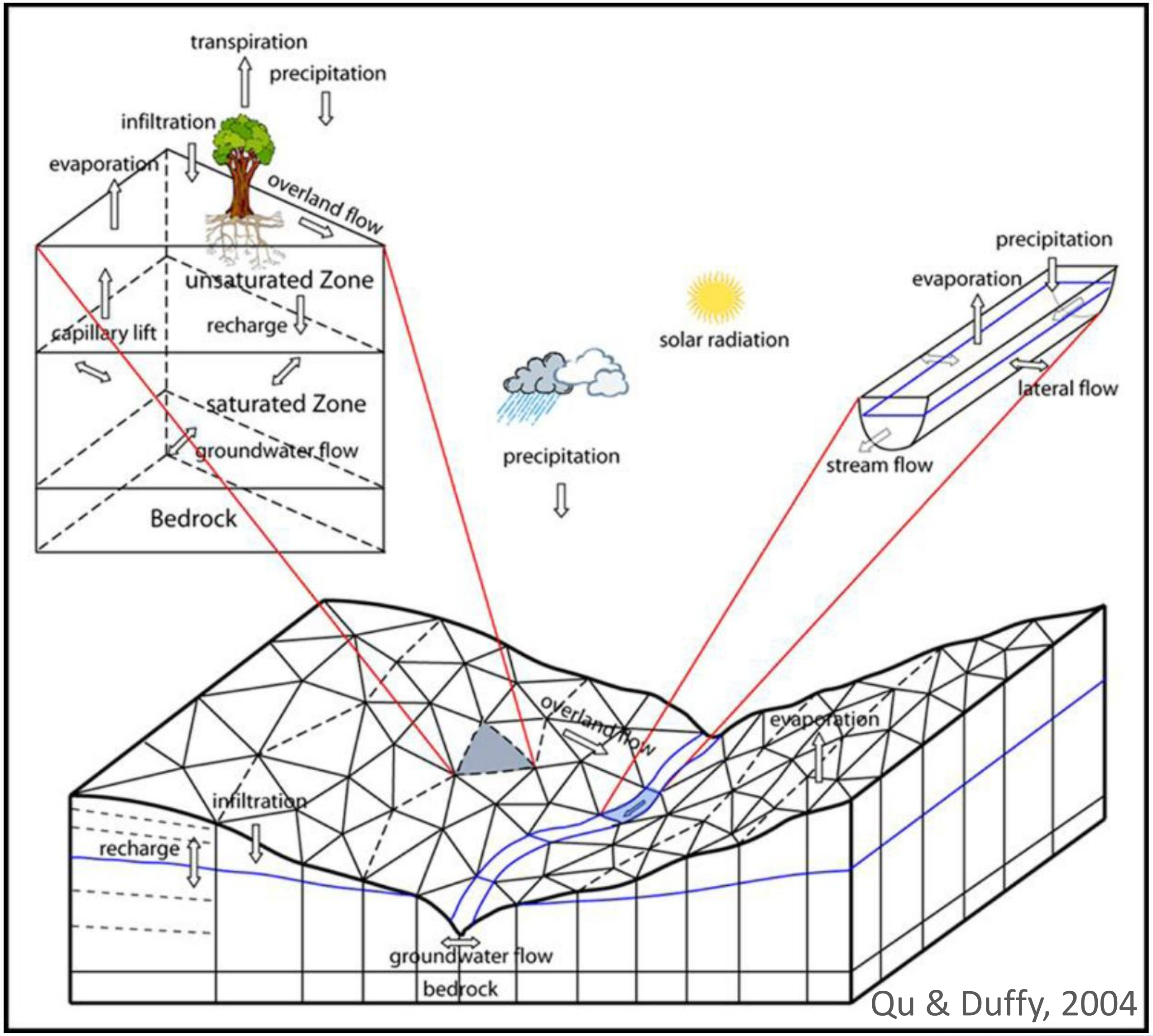
Penn State Integrated Hydrologic Modeling System

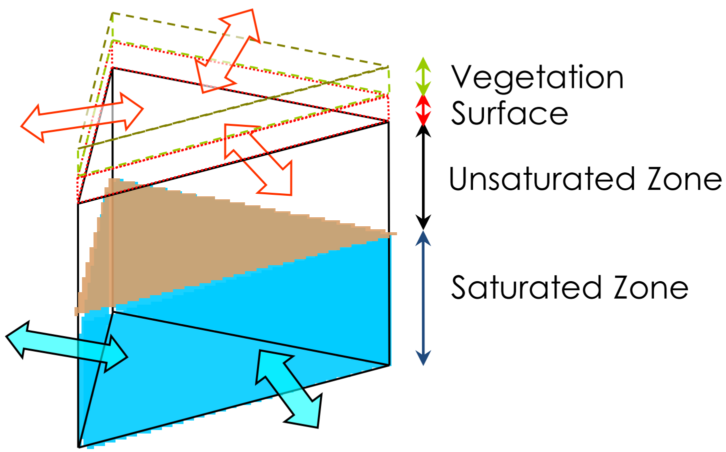


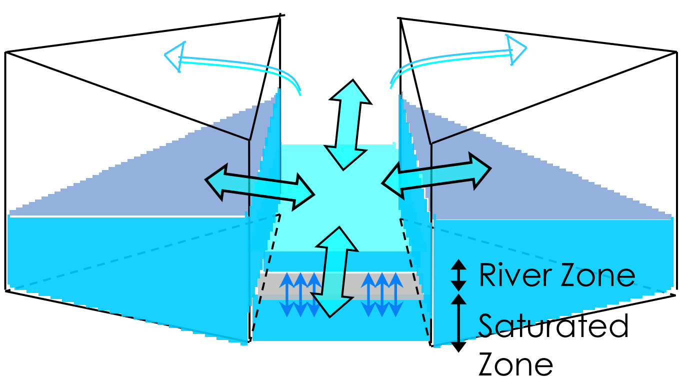
Qu & Duffy, 2004

Penn State Integrated Hydrologic Modeling System

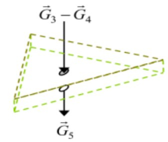
Source code: www.pihm.psu.edu

- 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.



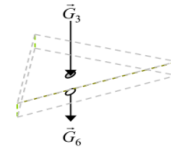


Interception



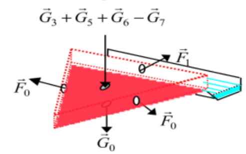
$$\frac{dy_0}{dt} = G_3 - G_4 - G_5$$

Snow Melt



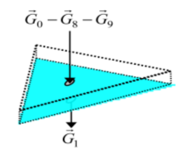
$$\frac{dy_1}{dt} = G_3 - G_6$$

Overland Flow



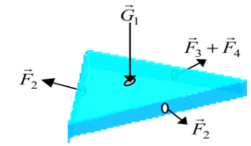
$$\frac{dy_2}{dt} = G_3 + G_5 + G_6 + G_7 - G_0 + F_0 + \|F_1\|$$

Unsaturated Zone



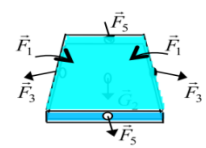
$$\frac{dy_3}{dt} = G_0 - G_1 - G_8 - G_9$$

Saturated Zone



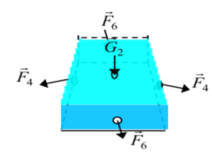
$$\frac{dy_4}{dt} = G_1 + F_2 + \|F_3\| + \|F_4\|$$

Channel



$$\frac{dy_5}{dt} = G_3 - G_2 - G_7 + F_1 + F_5 + \|F_3\|$$

Sub-Channel Aquifer



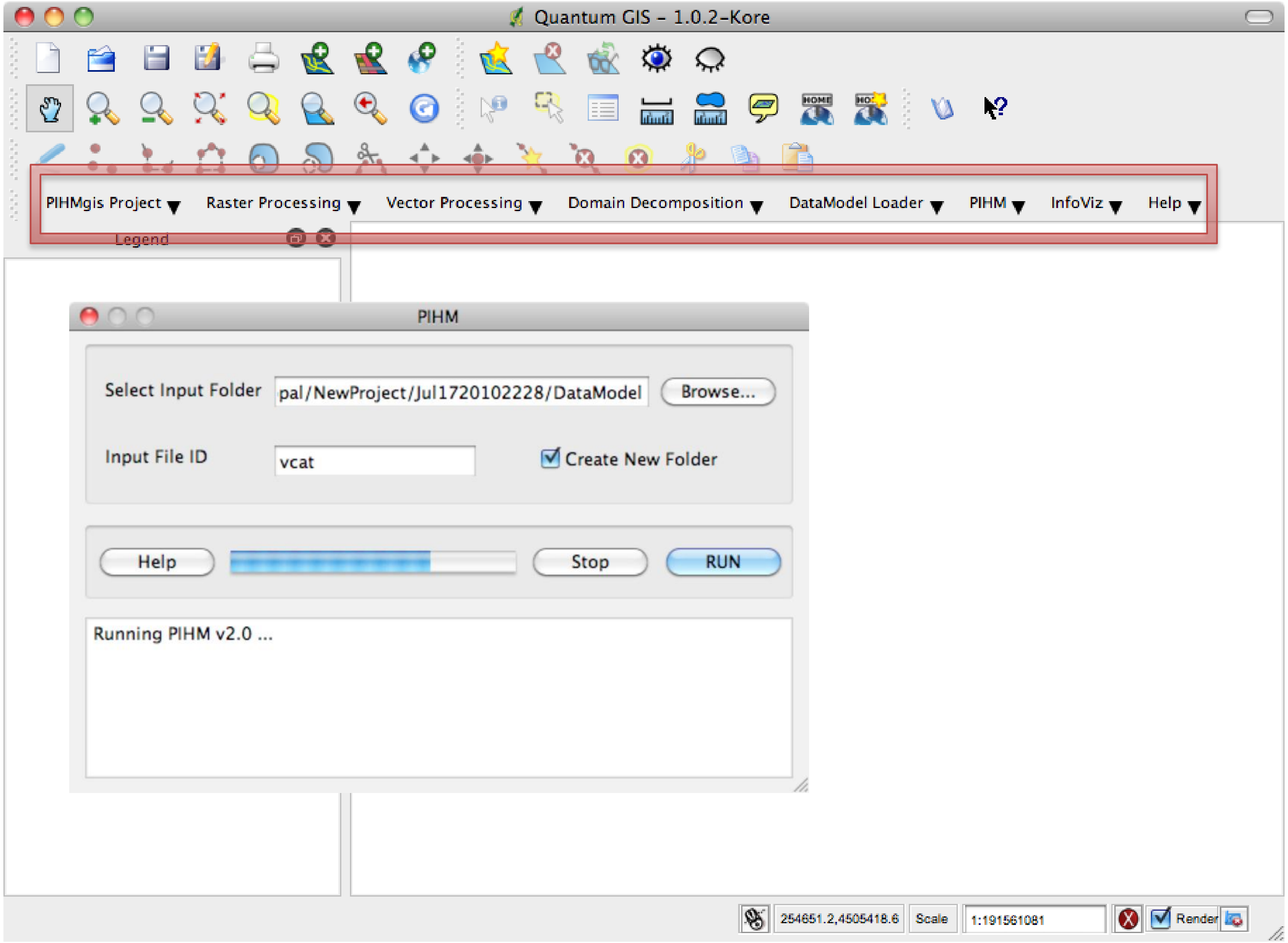
$$\frac{dy_6}{dt} = G_2 + F_4$$

Kumar et. al., 2009

The system of ODEs is solved using state-of-the-art solver with adaptive time steps

PIHMgis: a coupled GIS-Modeling System

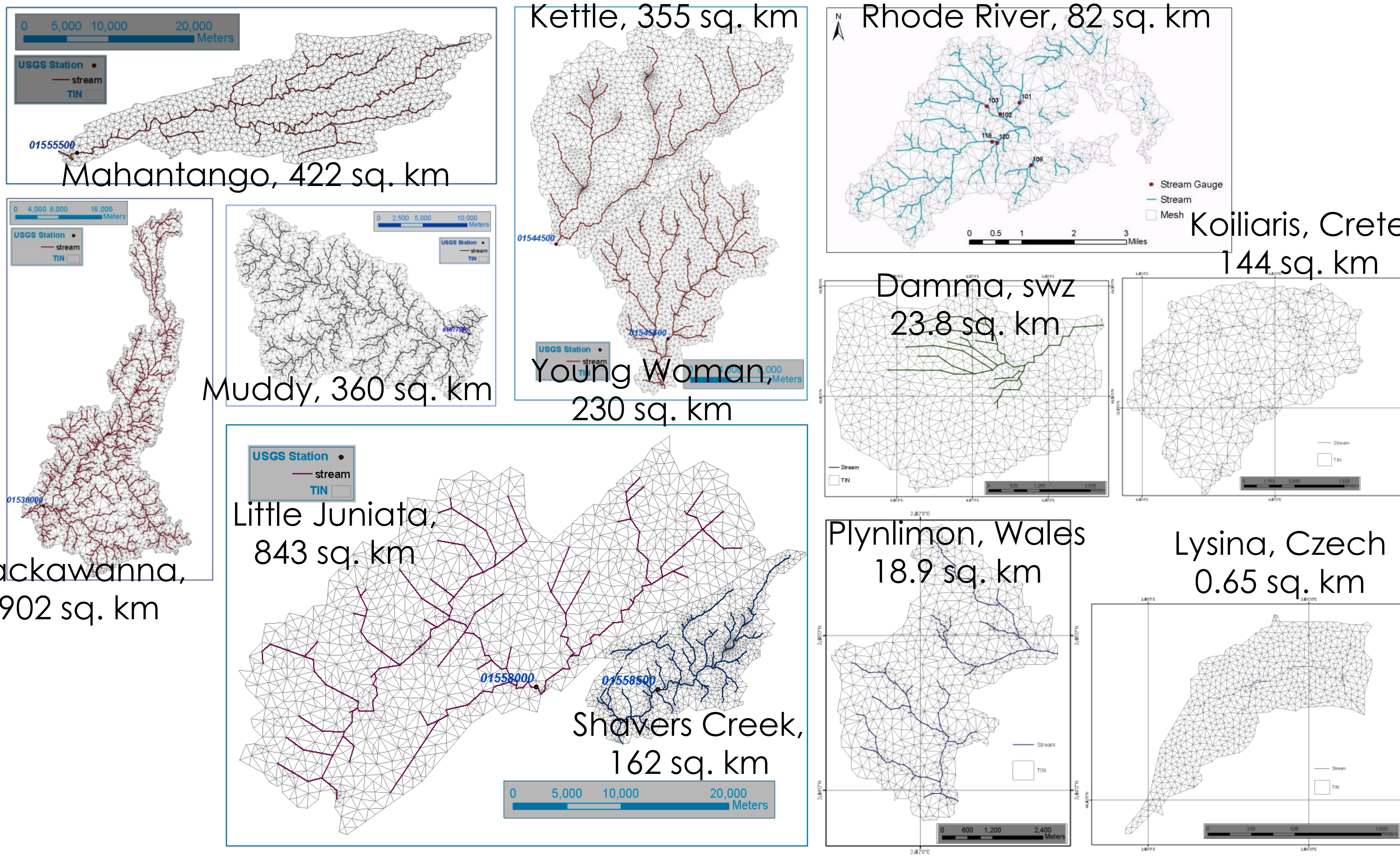
Source code: www.pihm.psu.edu



Open Source, **Platform Independent**, C/C++ Qt, QGIS, GDAL, OGR, SUNDIALS

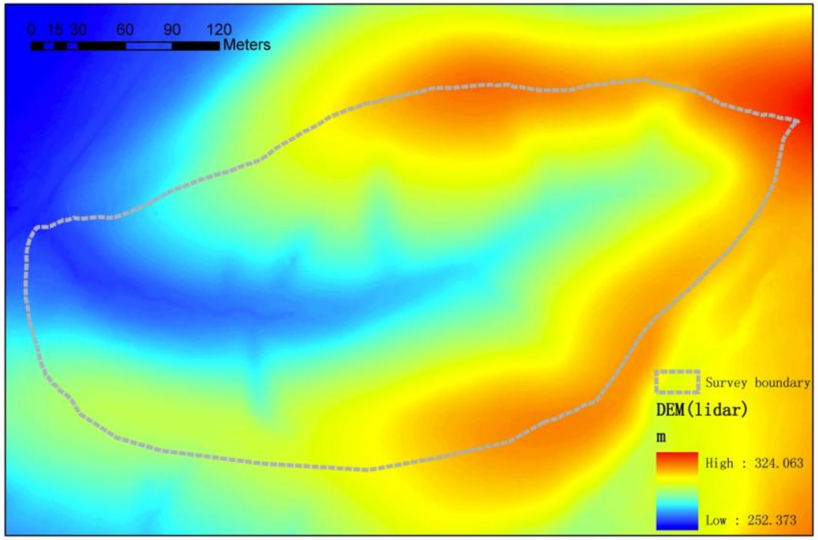
Multi-scale Applications

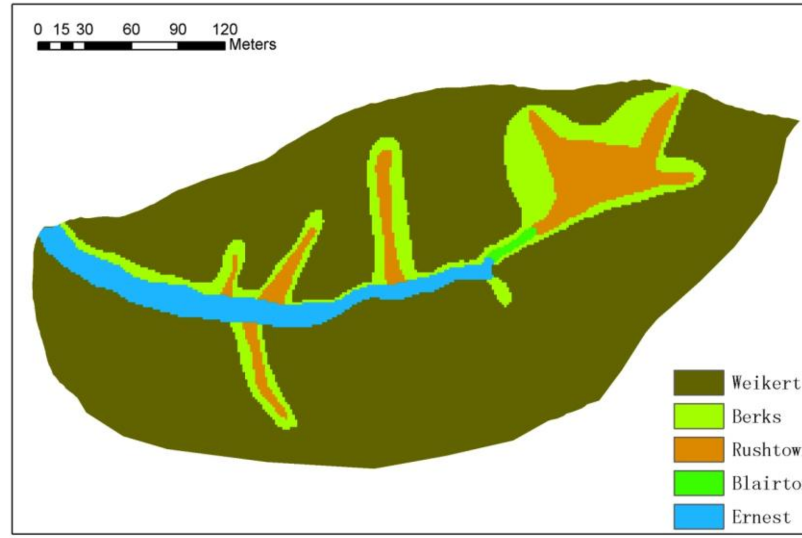
www.pihm.psu.edu :: Applications

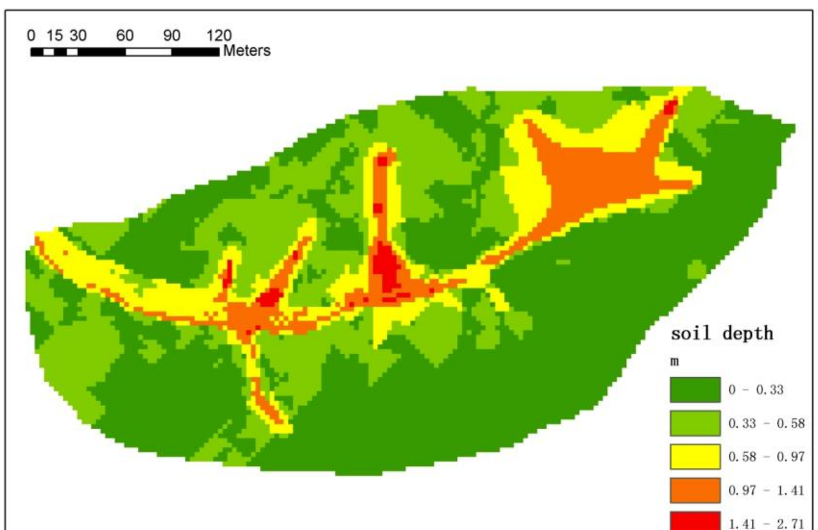


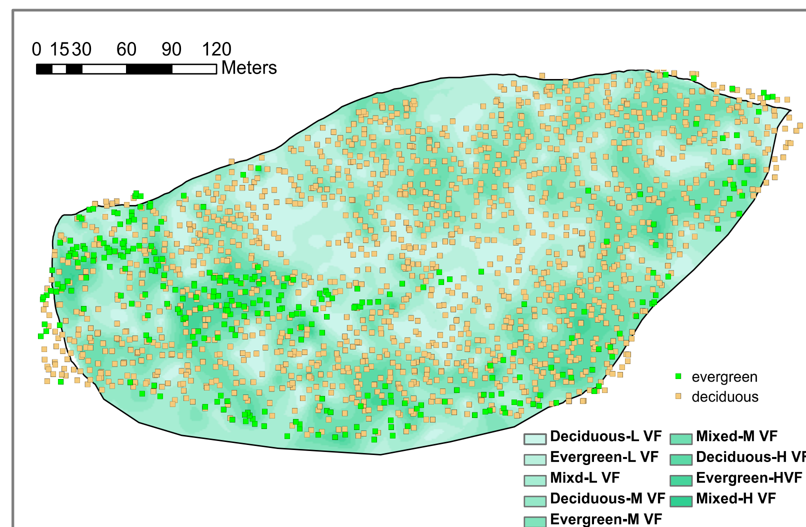
Shale Hills – Susquehanna Critical Zone Observatory

0.084 sq. km





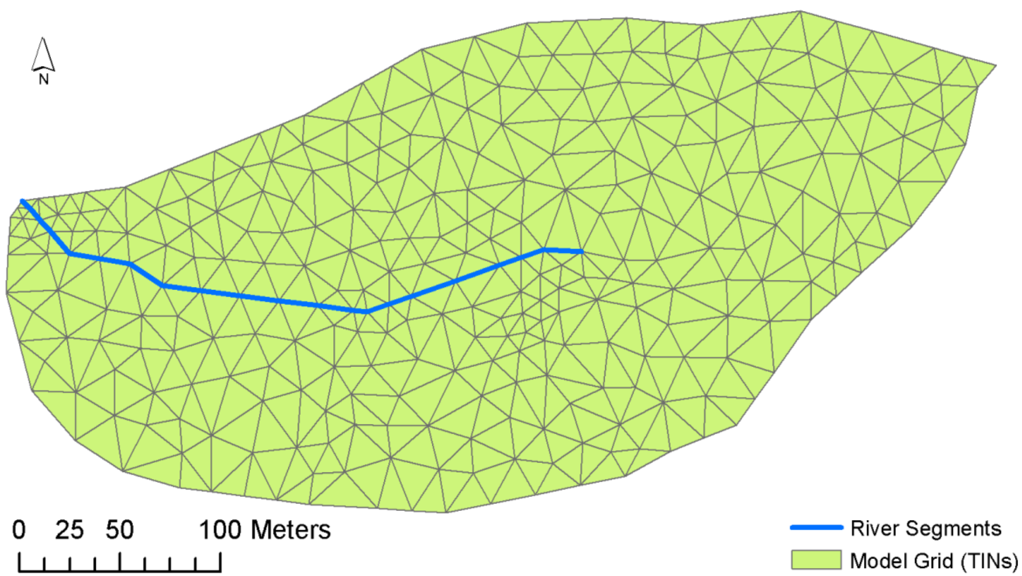




Shale Hills – Susquehanna Critical Zone Observatory

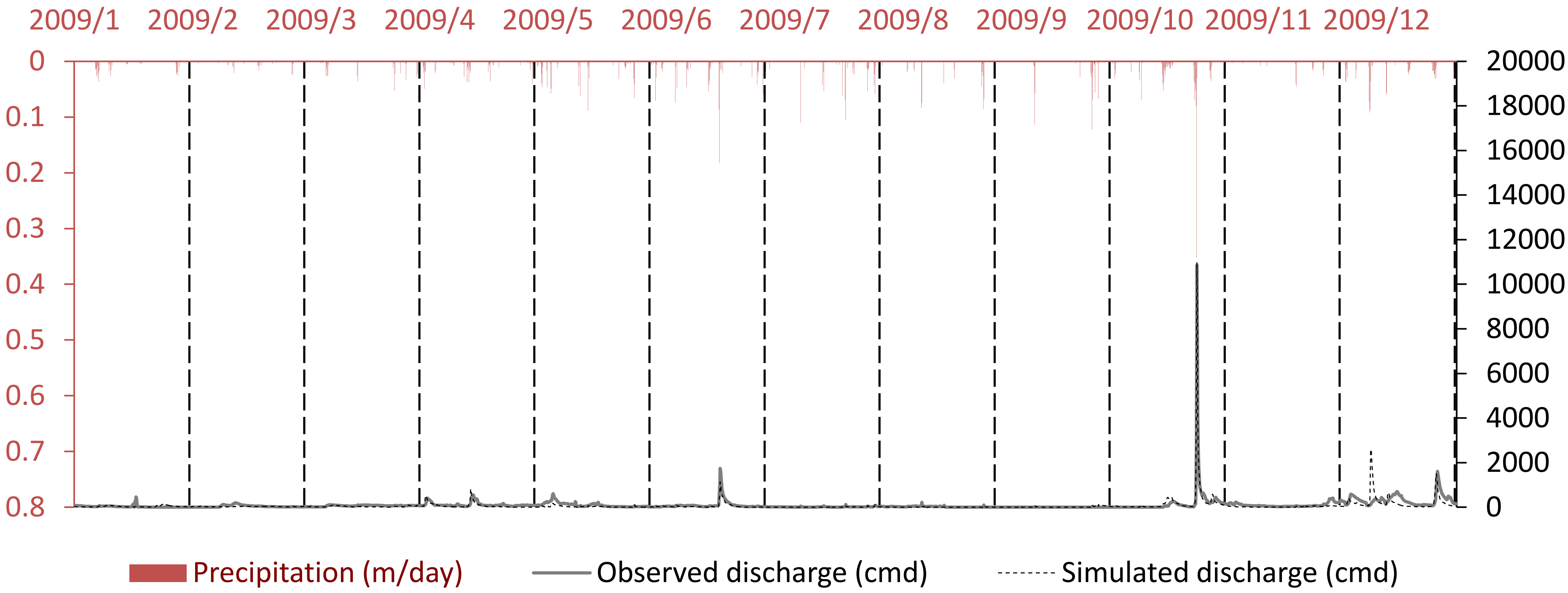
- Yu et. al. (2011) performed PIHM v2.1 hydrologic reanalysis simulation (1979 – 2010) with improved CZO data products for better numerical representation of the model domain
  - (a) Soil Classification (Lin et. al.);
  - (b) Land Cover classification (Eissenstat et. al.);
  - (c) LiDAR DEM
  - (d) Leaf Area Index

Area = 84170 m^2
TINs = 535
Strs = 20

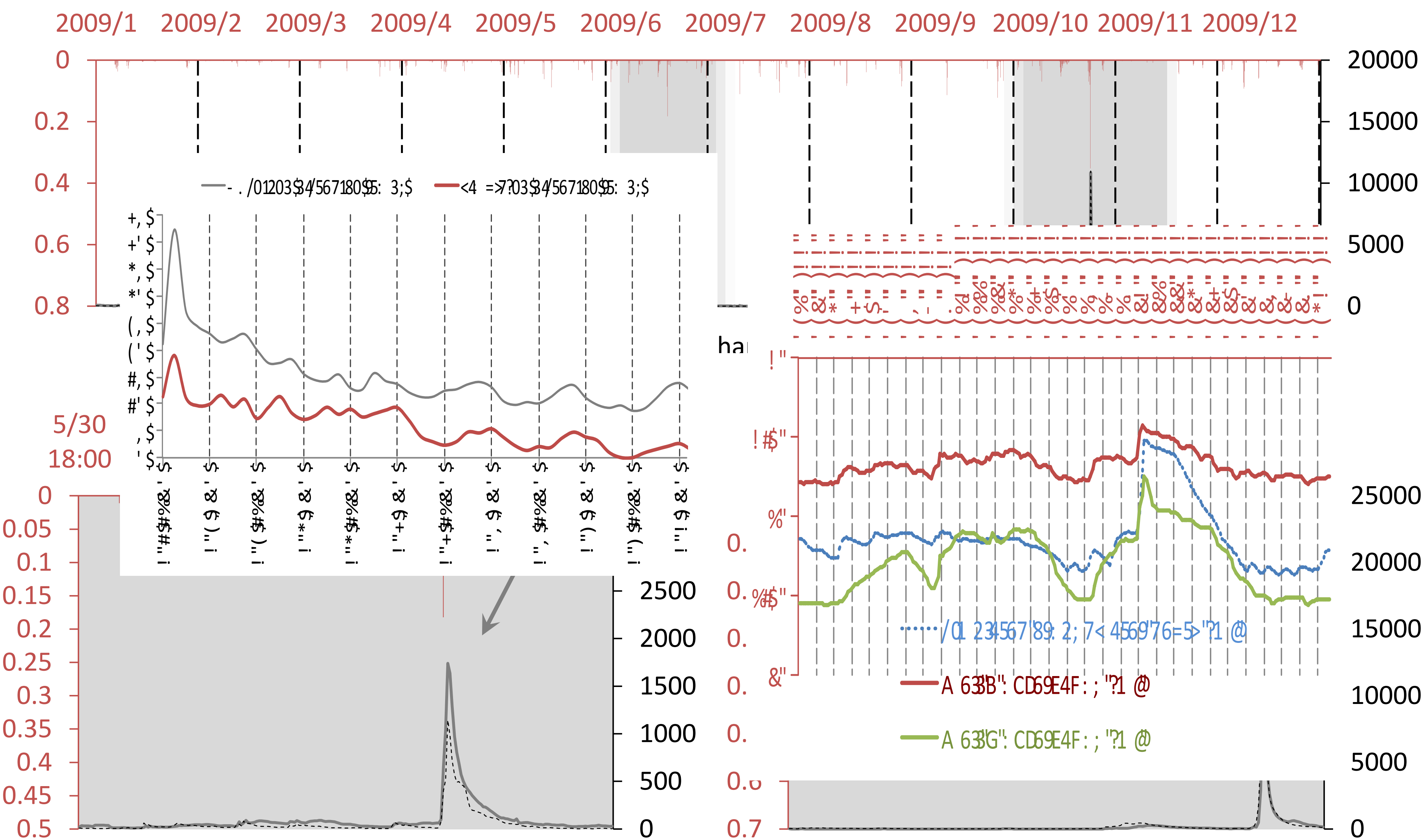


Multistate Validation of the Watershed Response

STREAMFLOW:

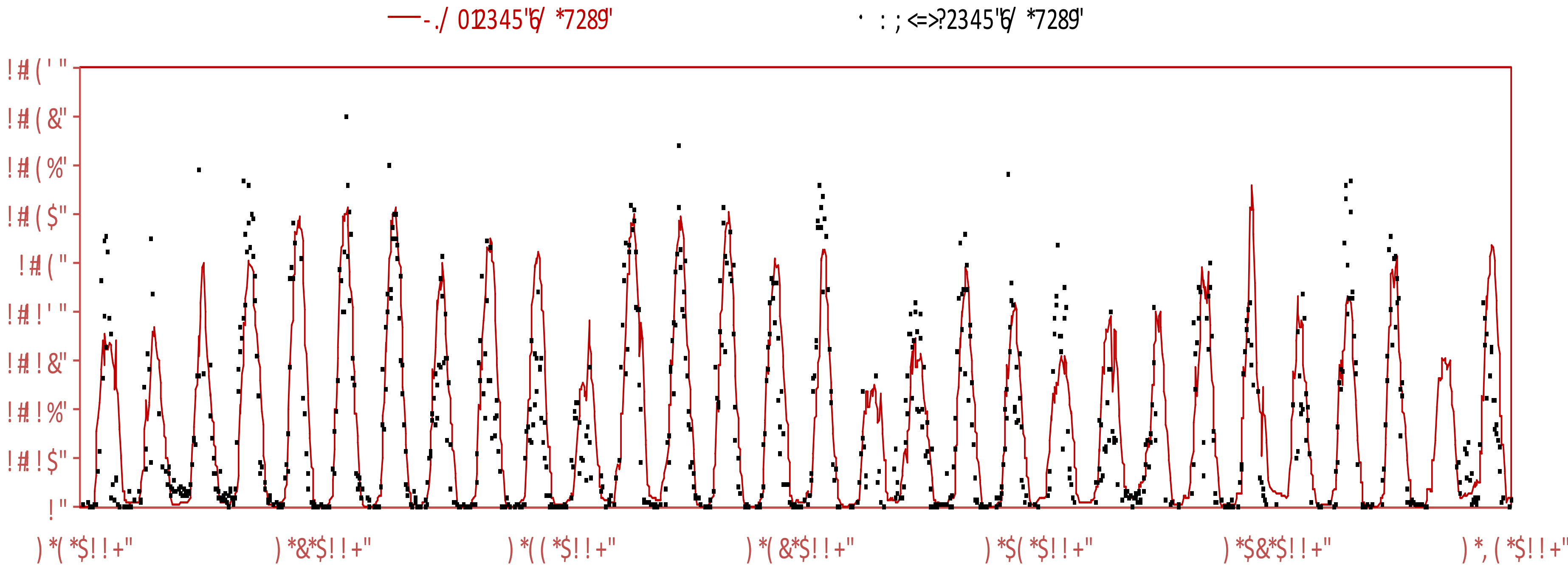


Multistate Validation of the Watershed Response



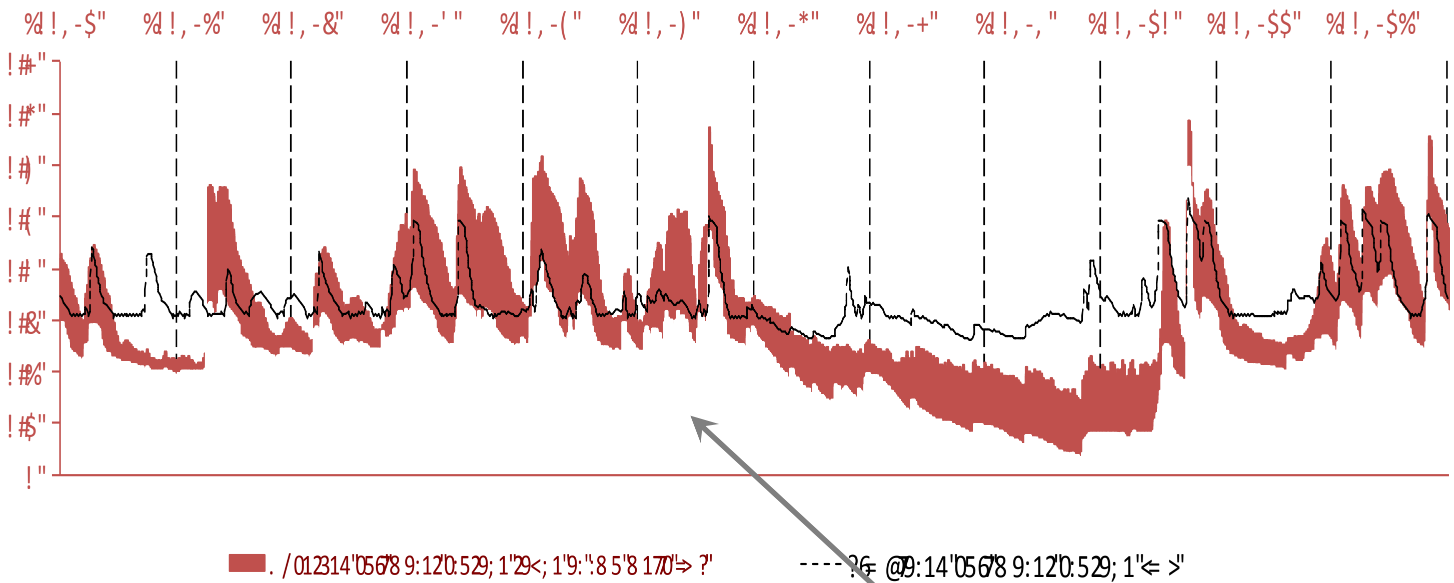
Multistate Validation of the Watershed Response

EVAPOTRANSPIRATION:

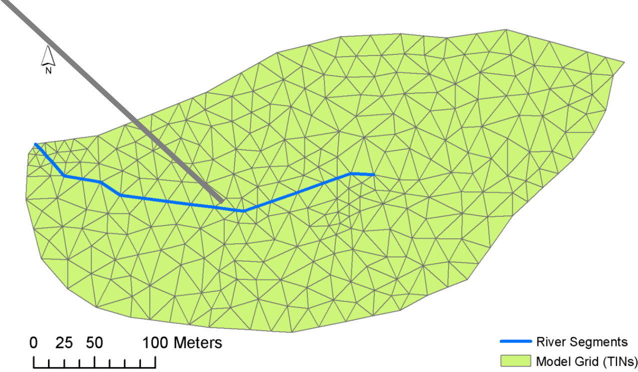


Multistate Validation of the Watershed Response

SOIL MOISTURE:

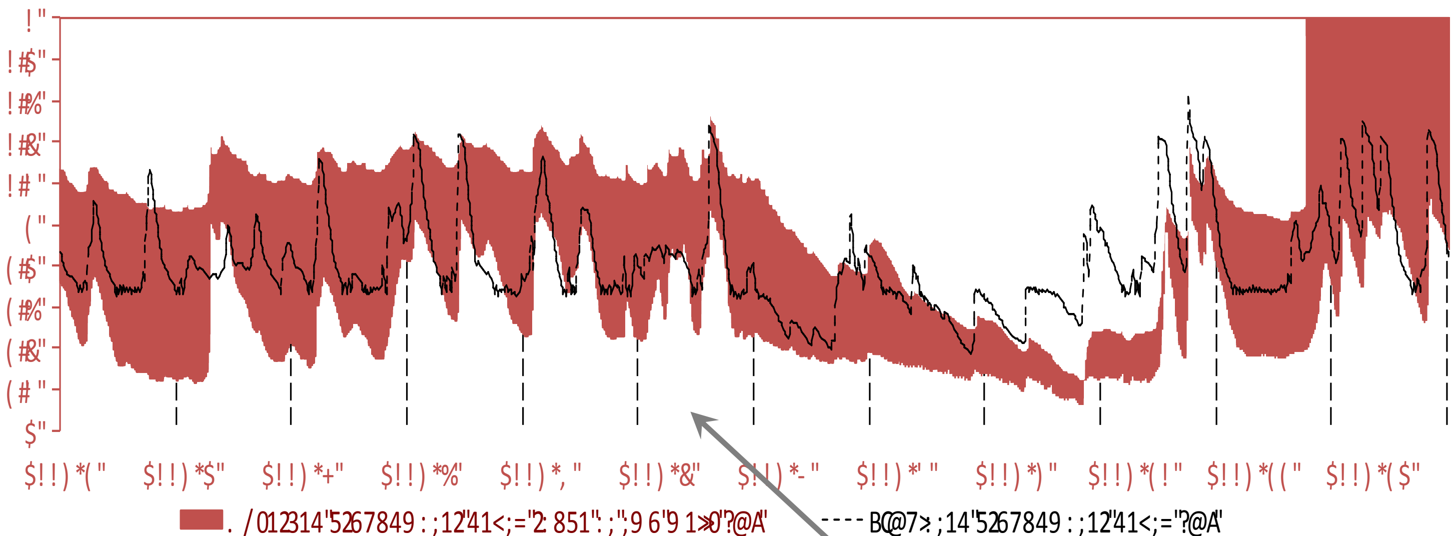


The two observation gauges are located on a single model grid adjacent to the stream segment



Multistate Validation of the Watershed Response

GROUNDWATER:



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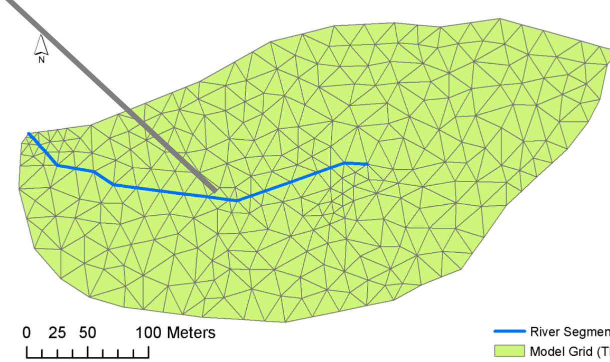
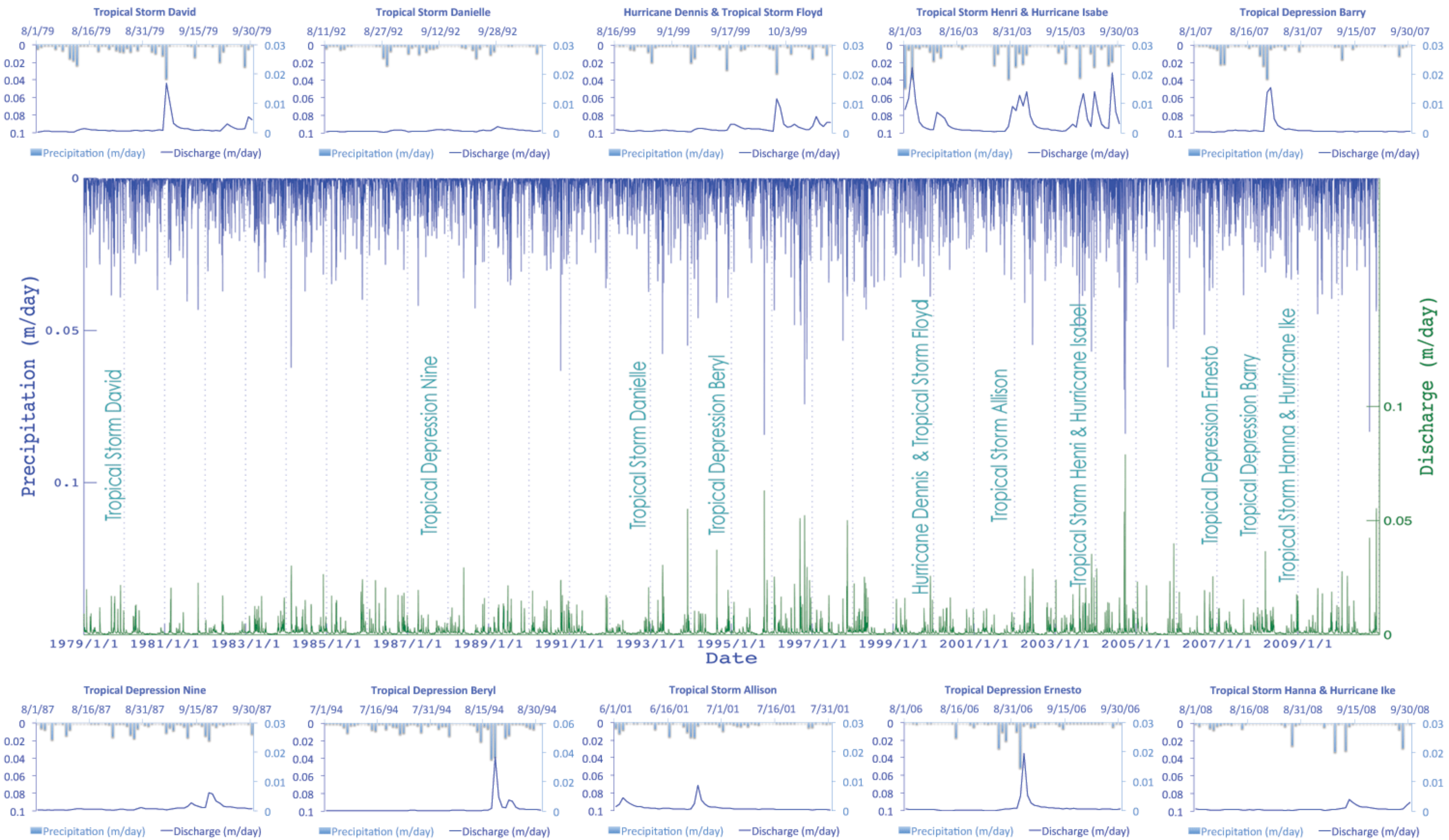
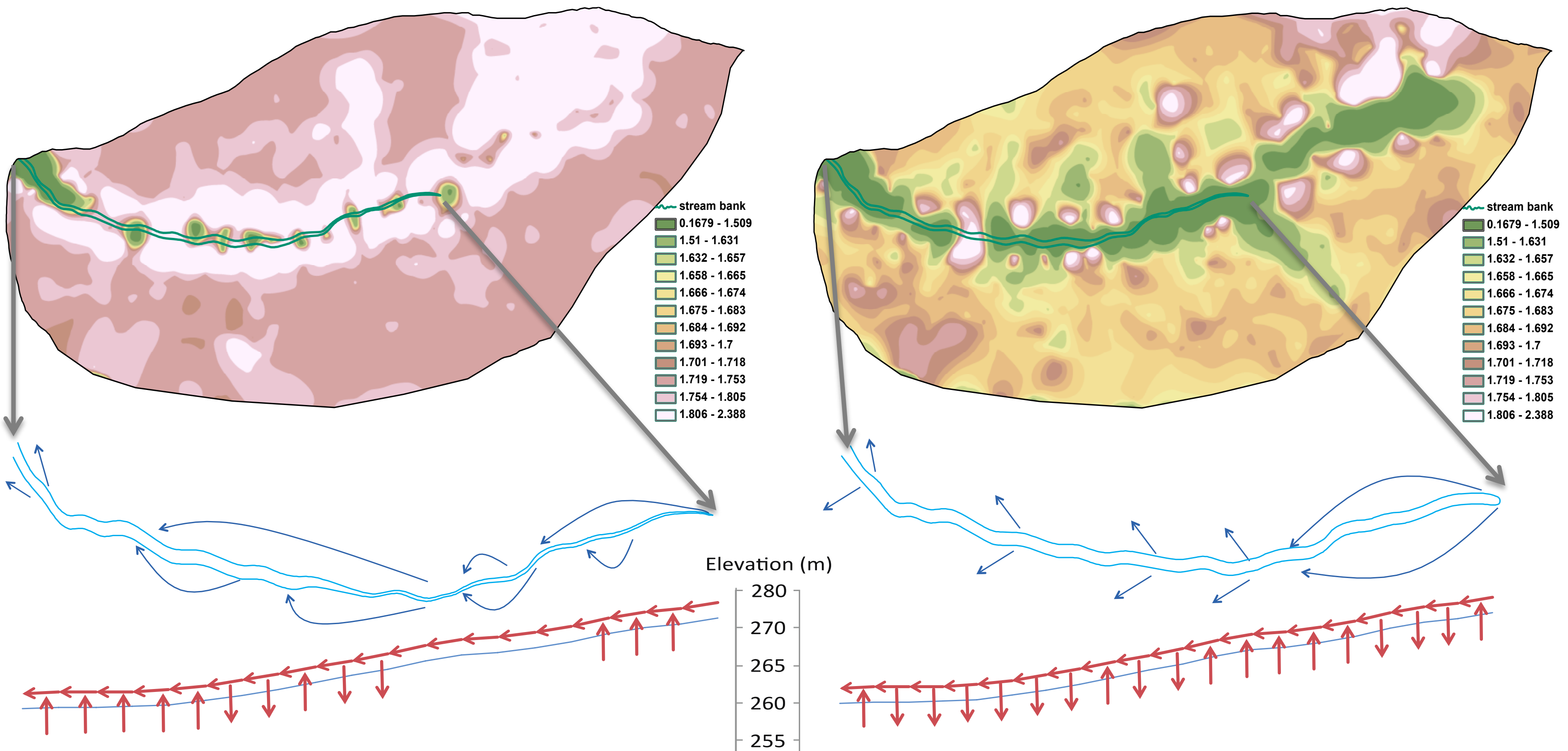


Multistate Validation of the Watershed Response



1st Generation of 32 Year (1979 – 2010) Watershed Reanalysis Product

Hyporheic Exchange Flow (HEF)



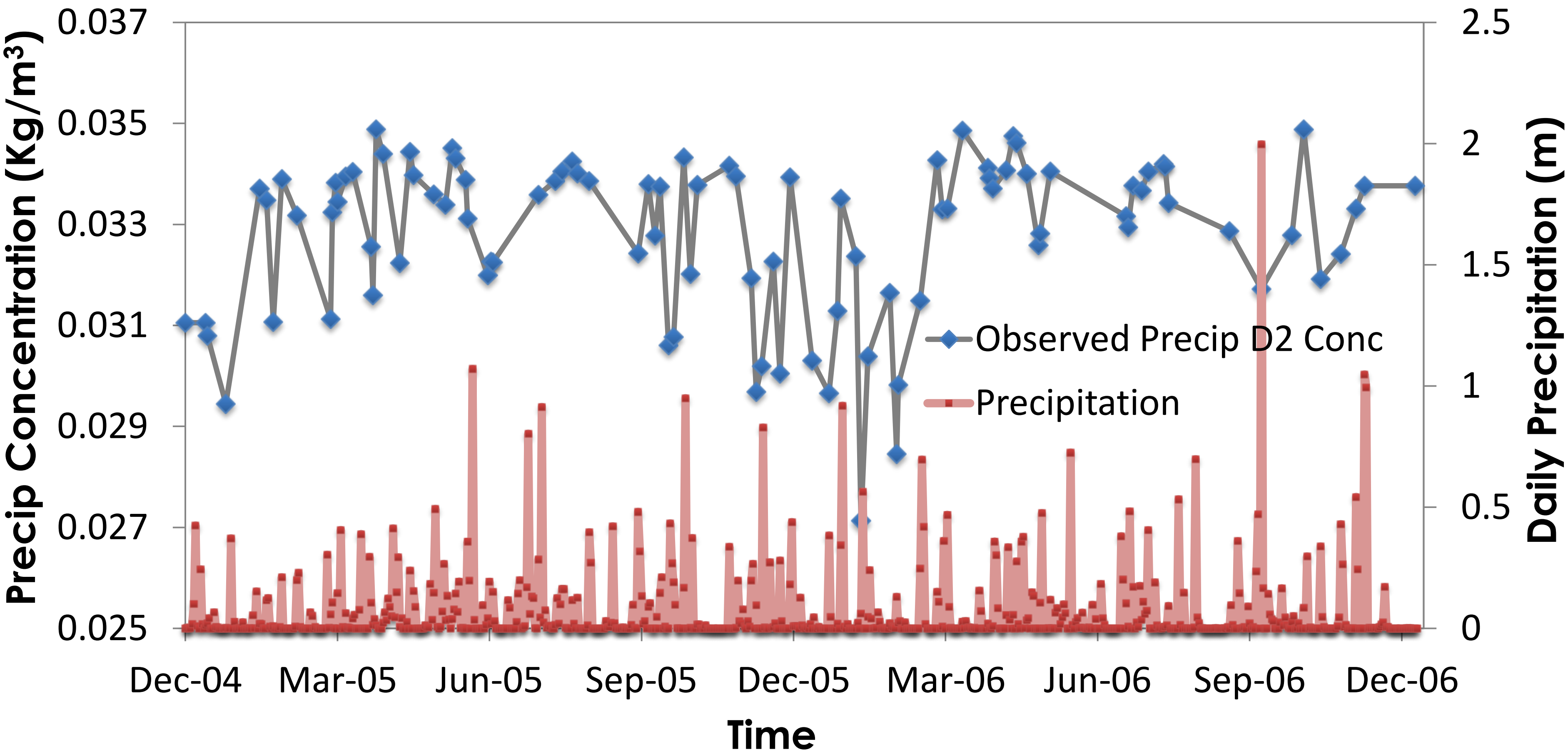
a) Dry watershed: Pre-event groundwater table depth and HEF path.
Horizontally, HEF vaies (gaining/loosing) with stream reaches.
Vertically, some reaches have no exchange with the river beds.

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.

Observed D (^2H) Conc. at Shale Hills

(Holmes et. al. 2011)

- δ representations were converted to standard concentration units [Dewitt et. al. 1980]



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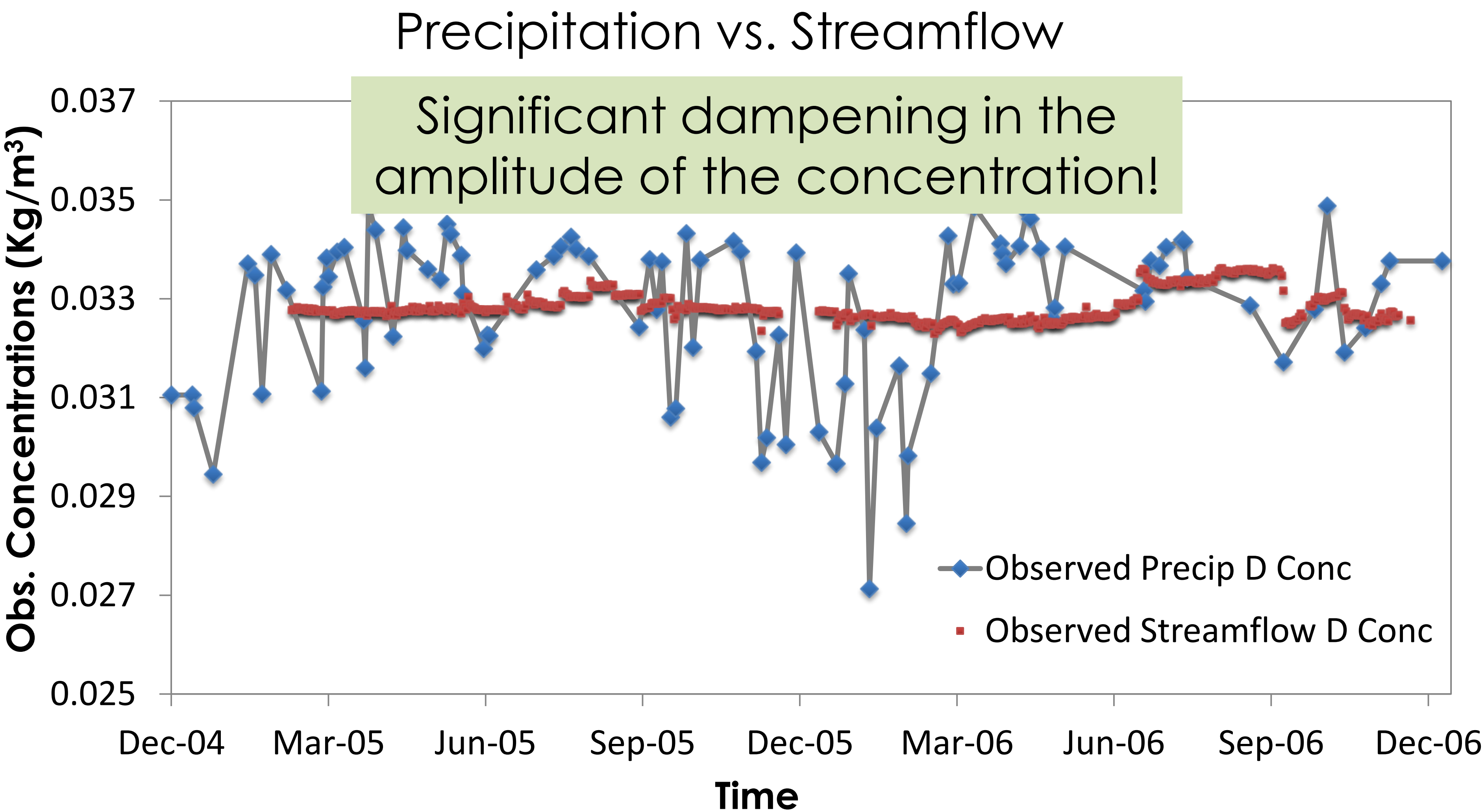
Observed D (^2H) Conc. at Shale Hills

(Holmes et. al. 2011)



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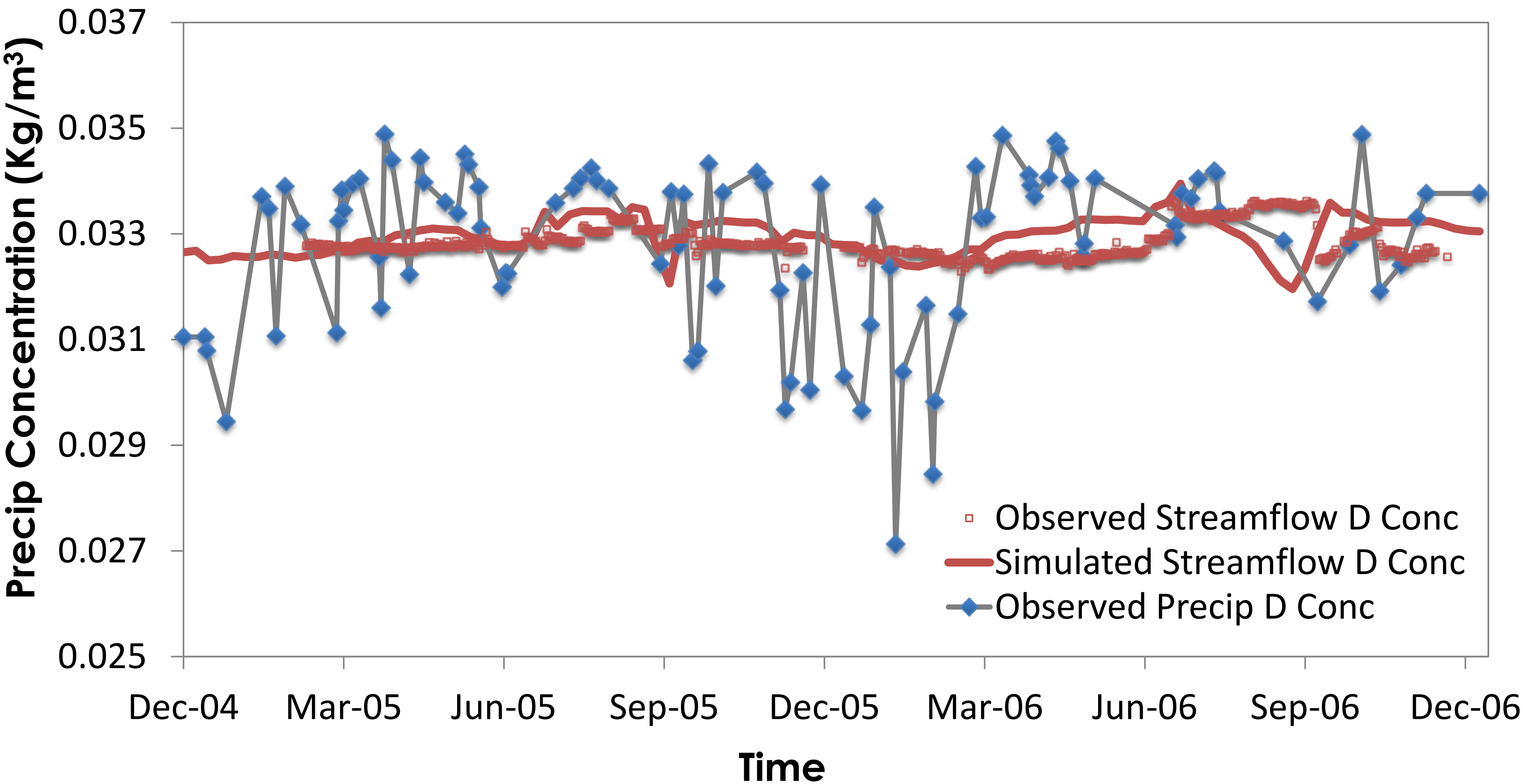
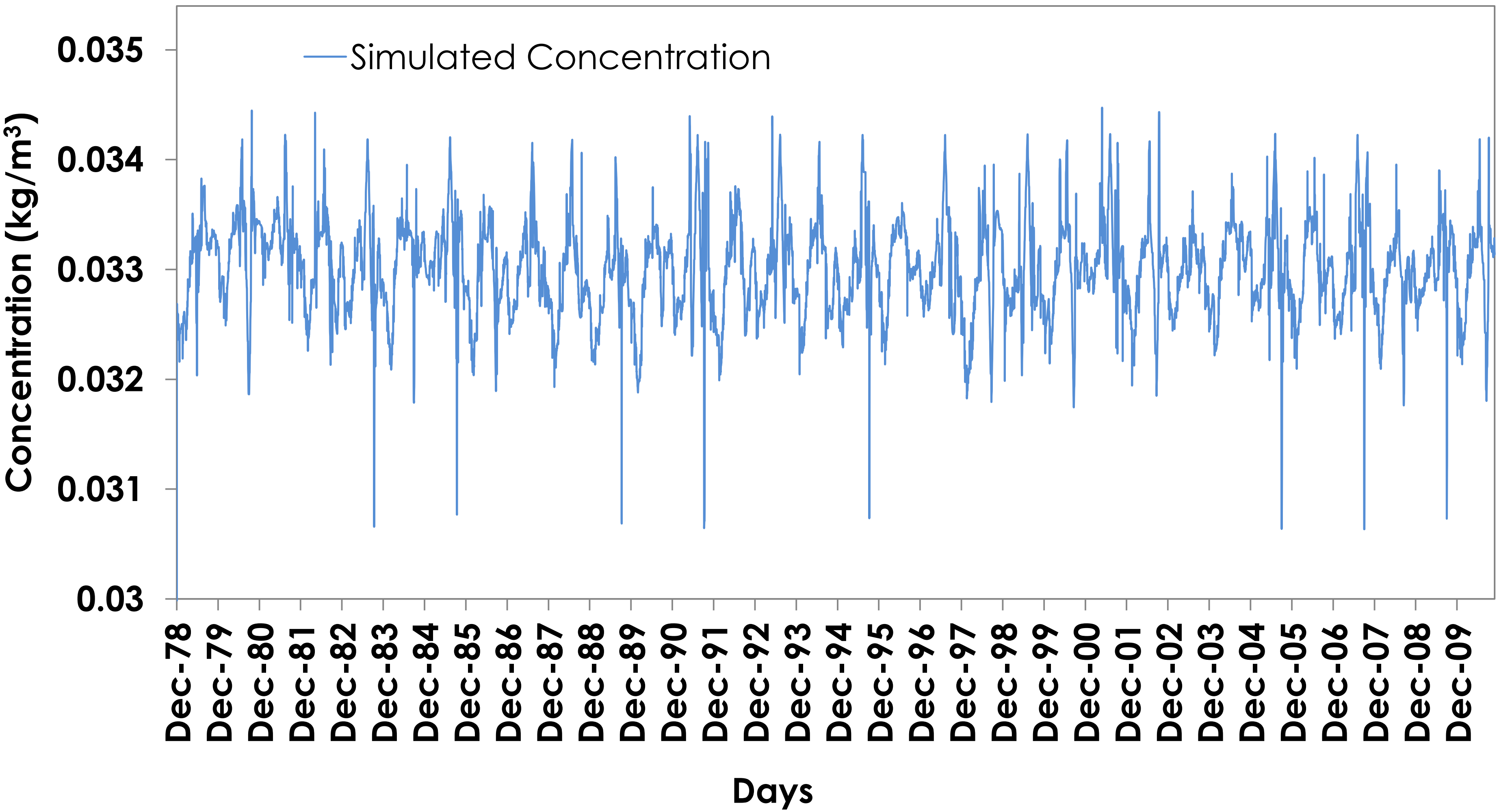
Simulated Streamflow D Conc.



Model is able to Simulate the Dampening of the Concentration Signal

Reconstructed D Concentration



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Theoretical Considerations

We extended the numerical formulation of conservative solute transport (concentration) to define 'age' Concentration.

$$A = aC$$

$$where,$$

$$C = Solute\ Concentration$$

$$a = age$$

$$A = Age\ Concentration$$

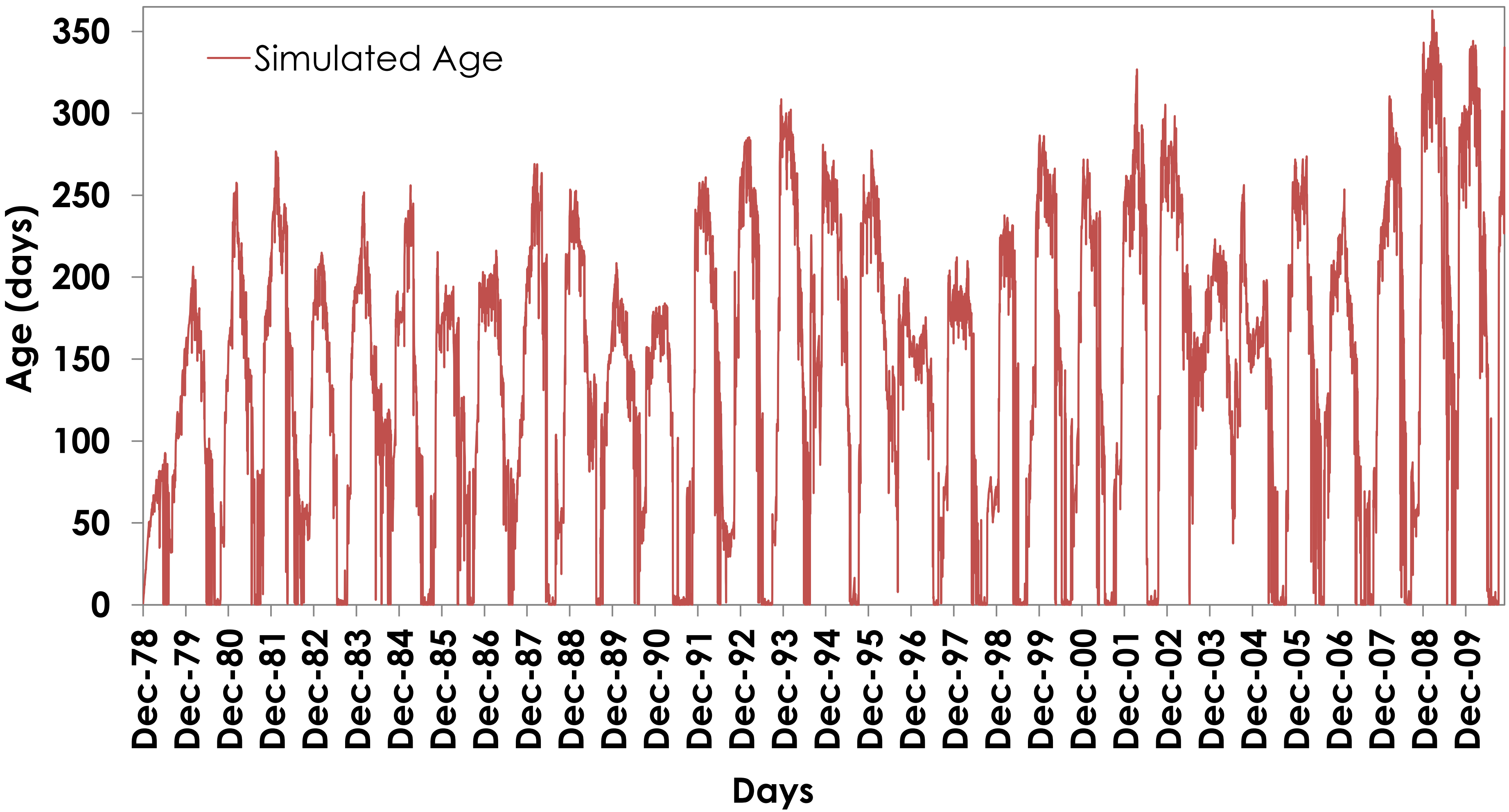
$$Use\ ODE\ below\ on\ each\ numerical\ FV\ element:$$

$$\frac{dA}{dt} = a\frac{dC}{dt} + C$$

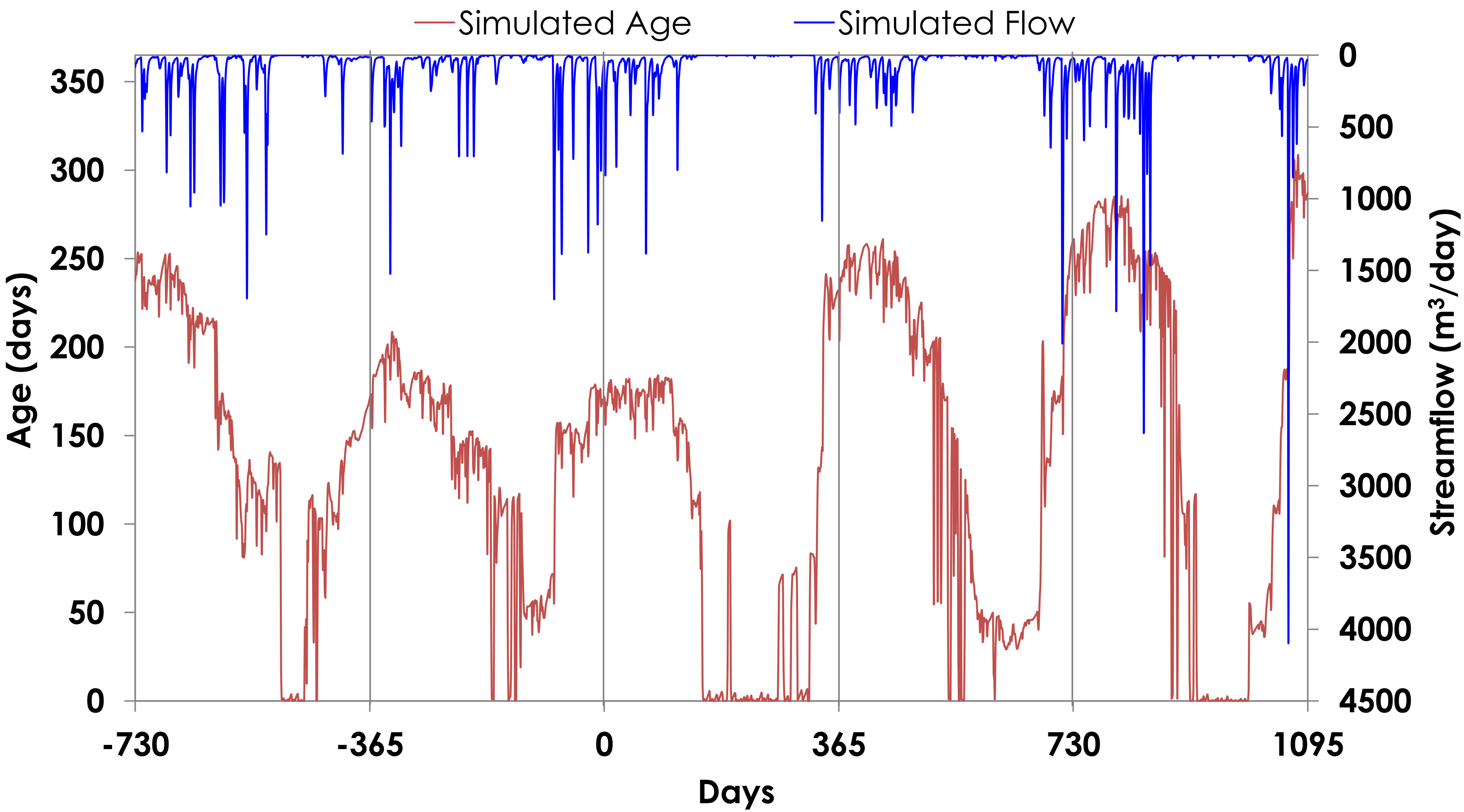
$$Calculate\ Age$$

$$a = A / C$$

Simulated 'age' of Streamflow



Simulated 'age' of Streamflow



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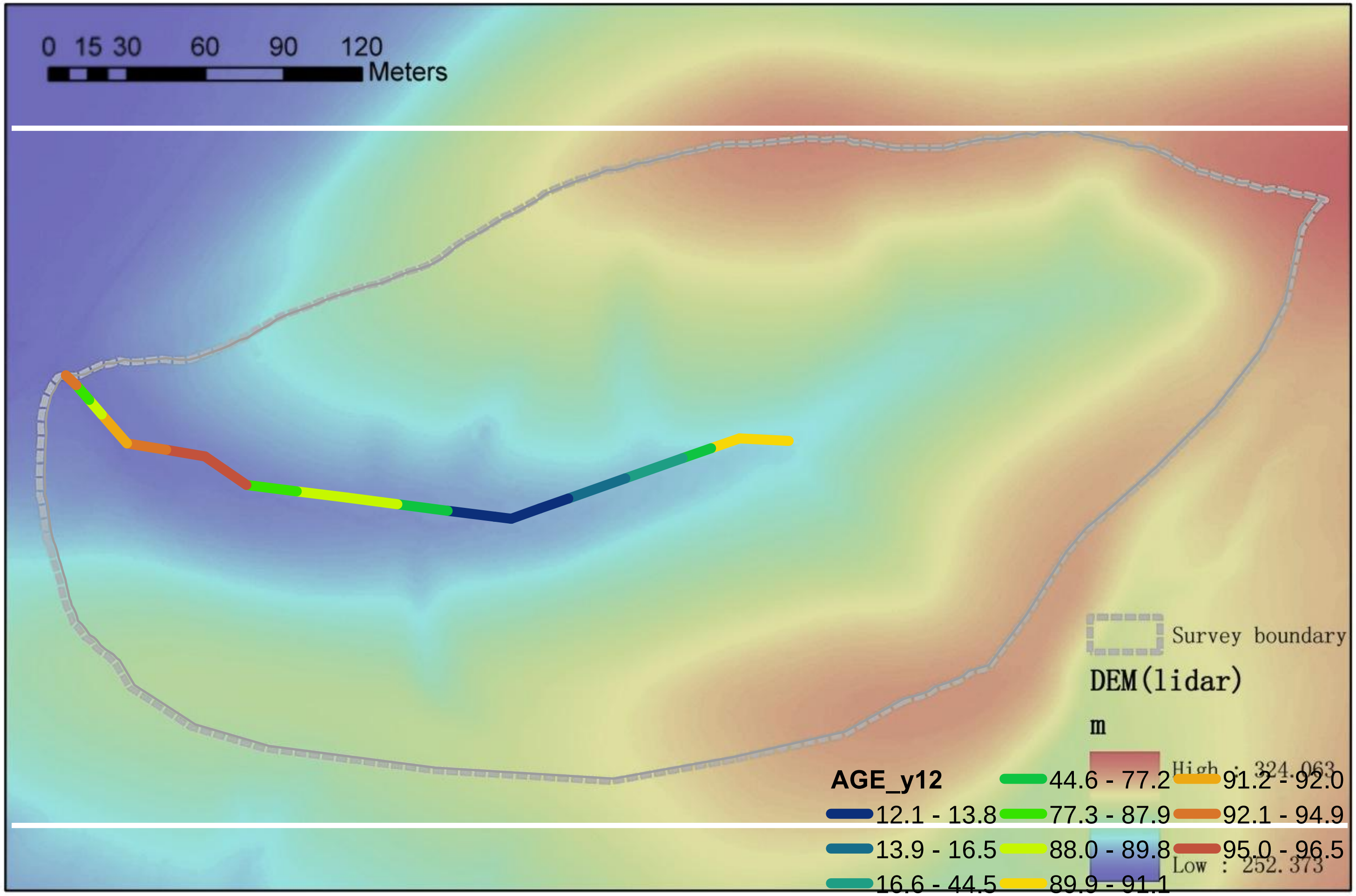
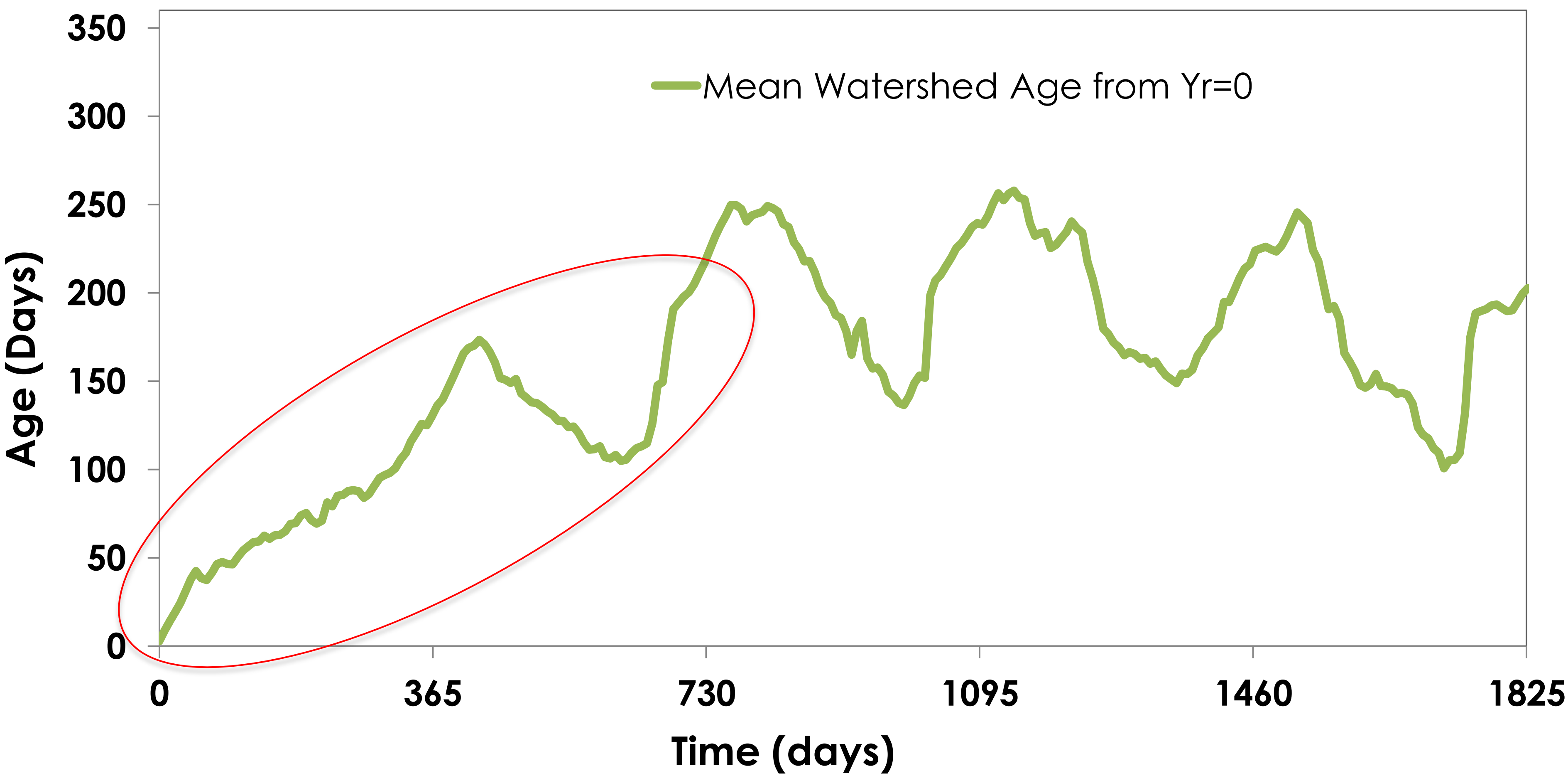
Simulated 'age' of Streamflow



Evolution of Age of the Watershed

from <u>Zero-Age</u> Initial Condition



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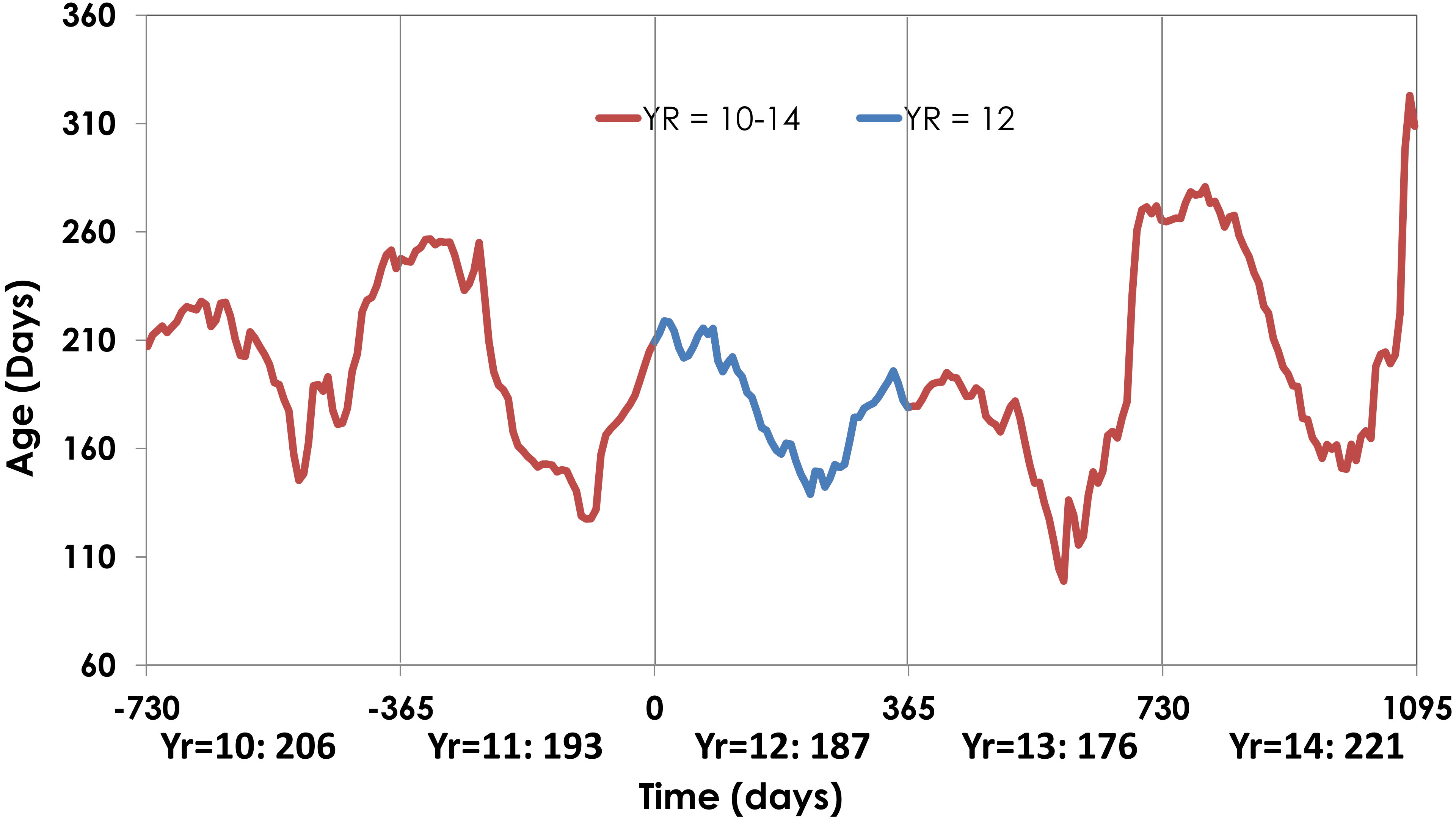
Watershed Age



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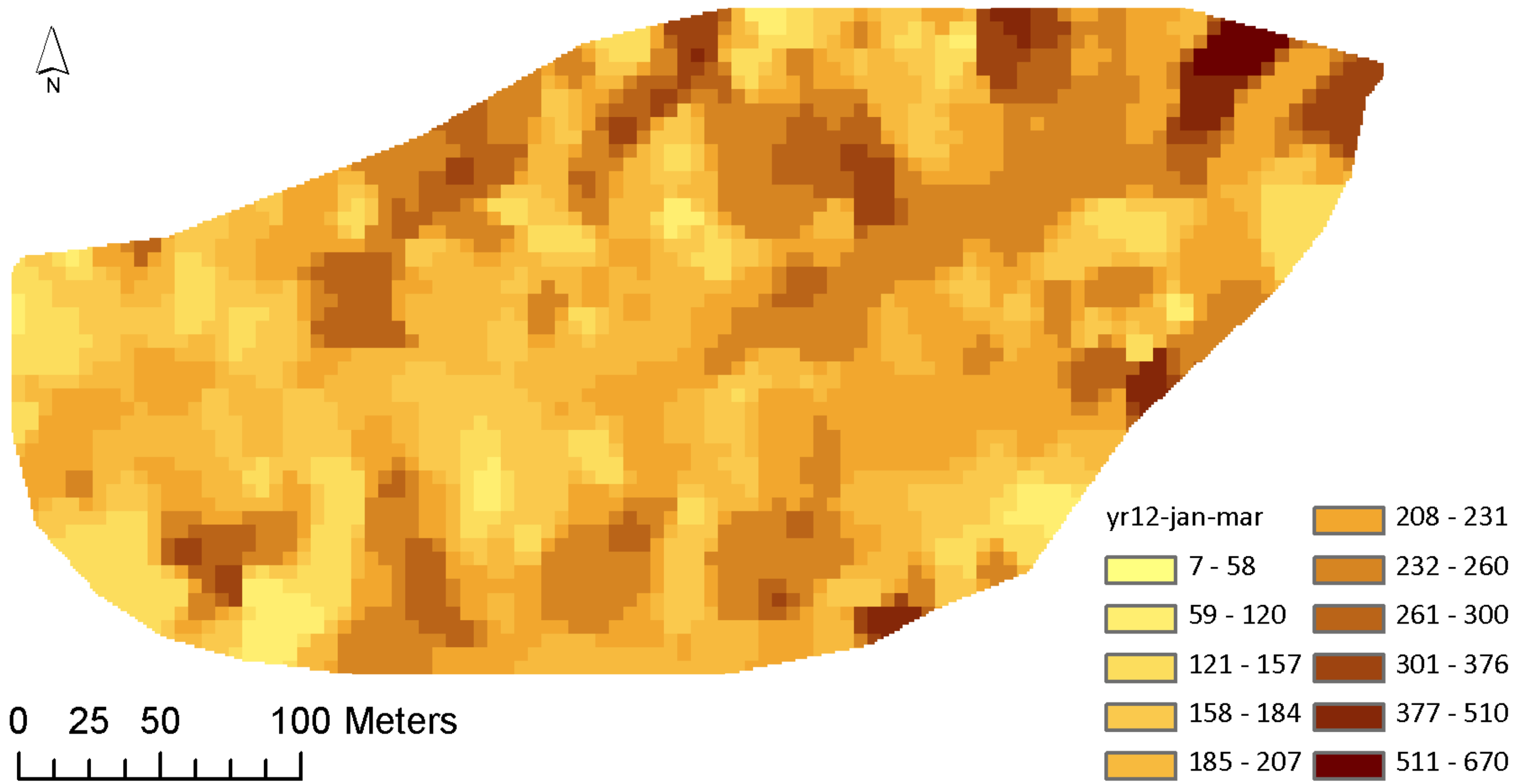
JAN – MAR

Mean Watershed Age = 210.9 days



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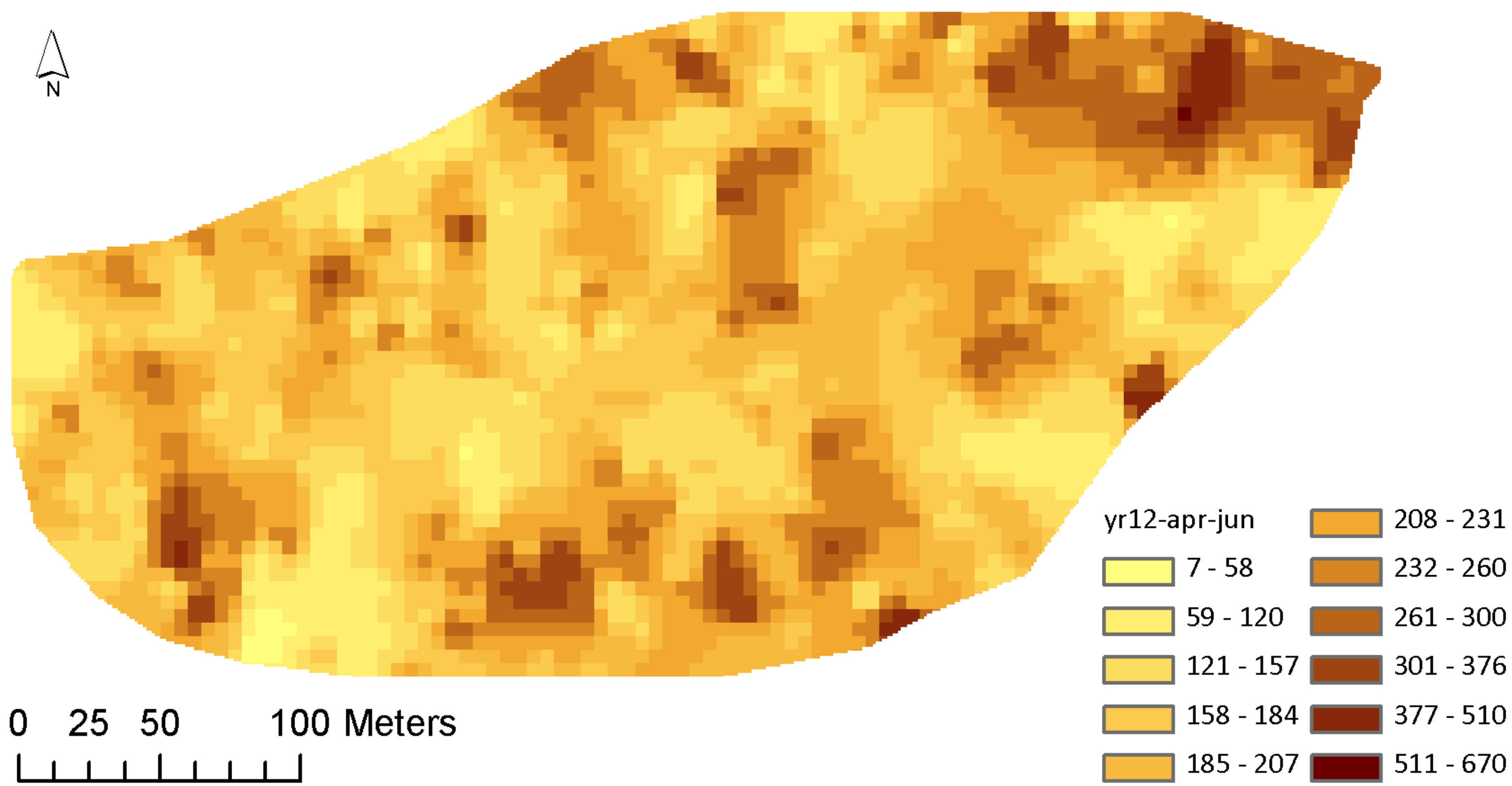
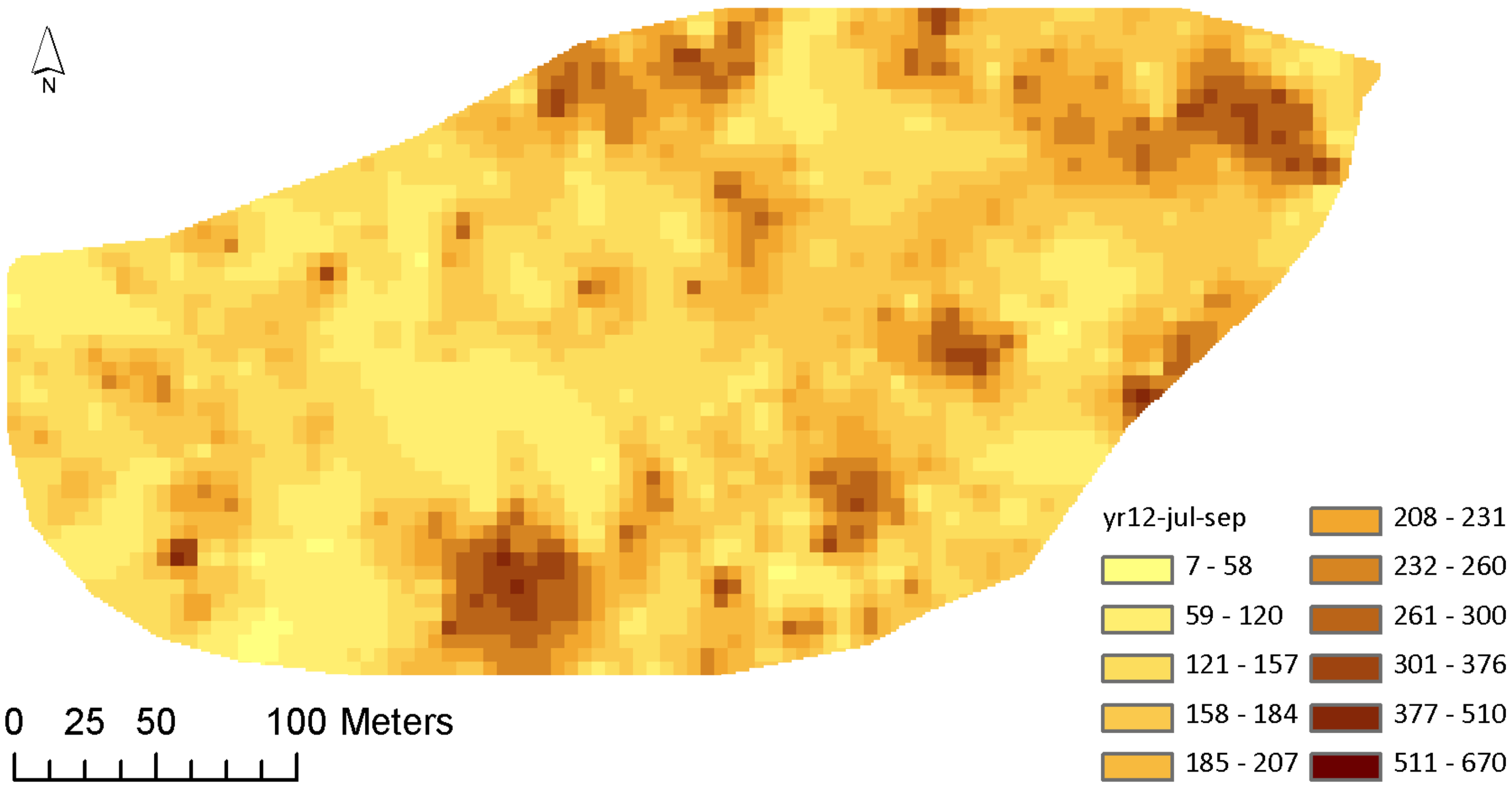
APR – JUN

Mean Watershed Age = 188.7 days



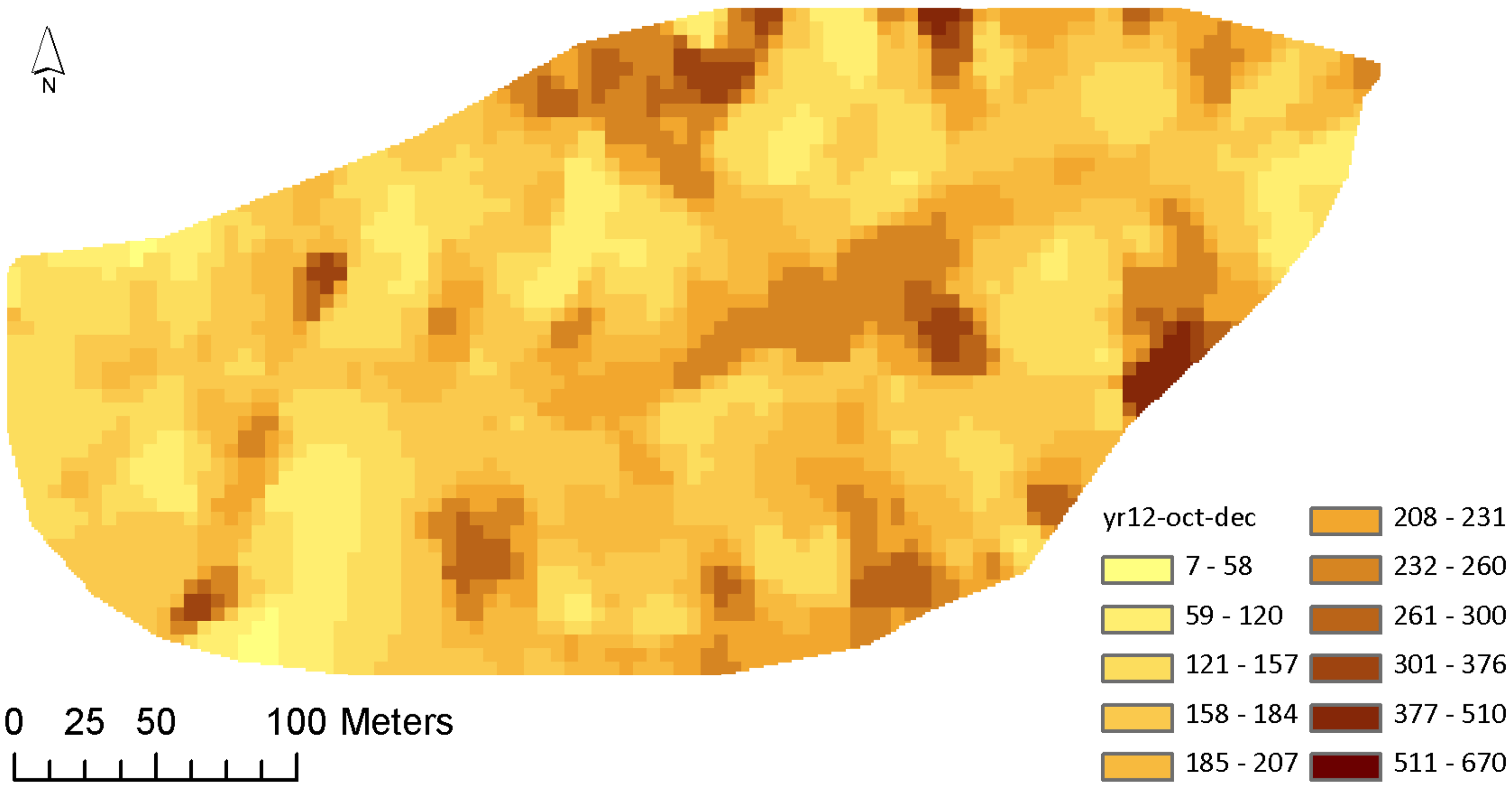
JUL – SEP

Mean Watershed Age = 161.6 days

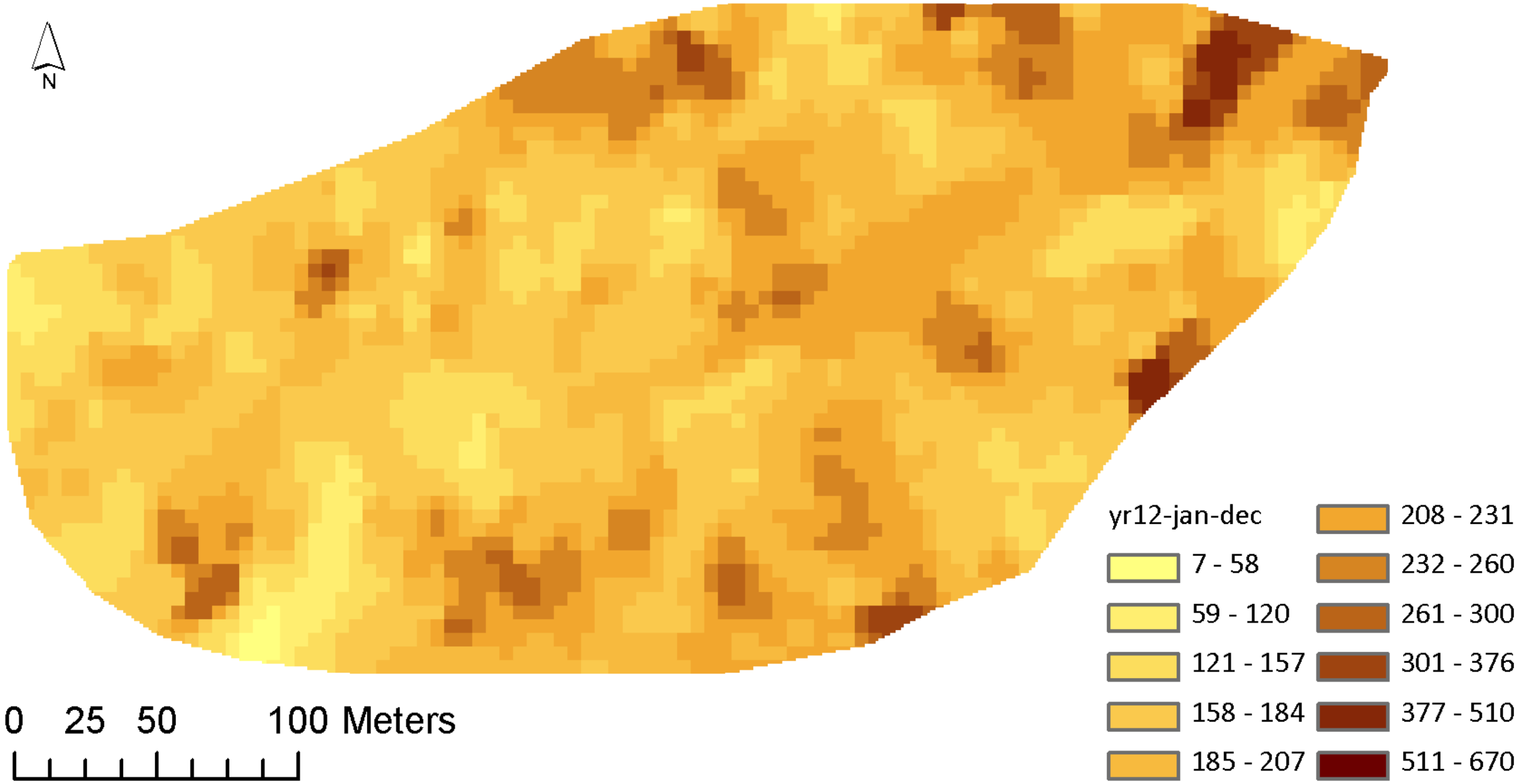


OCT – DEC

Mean Watershed Age = 180.1 days

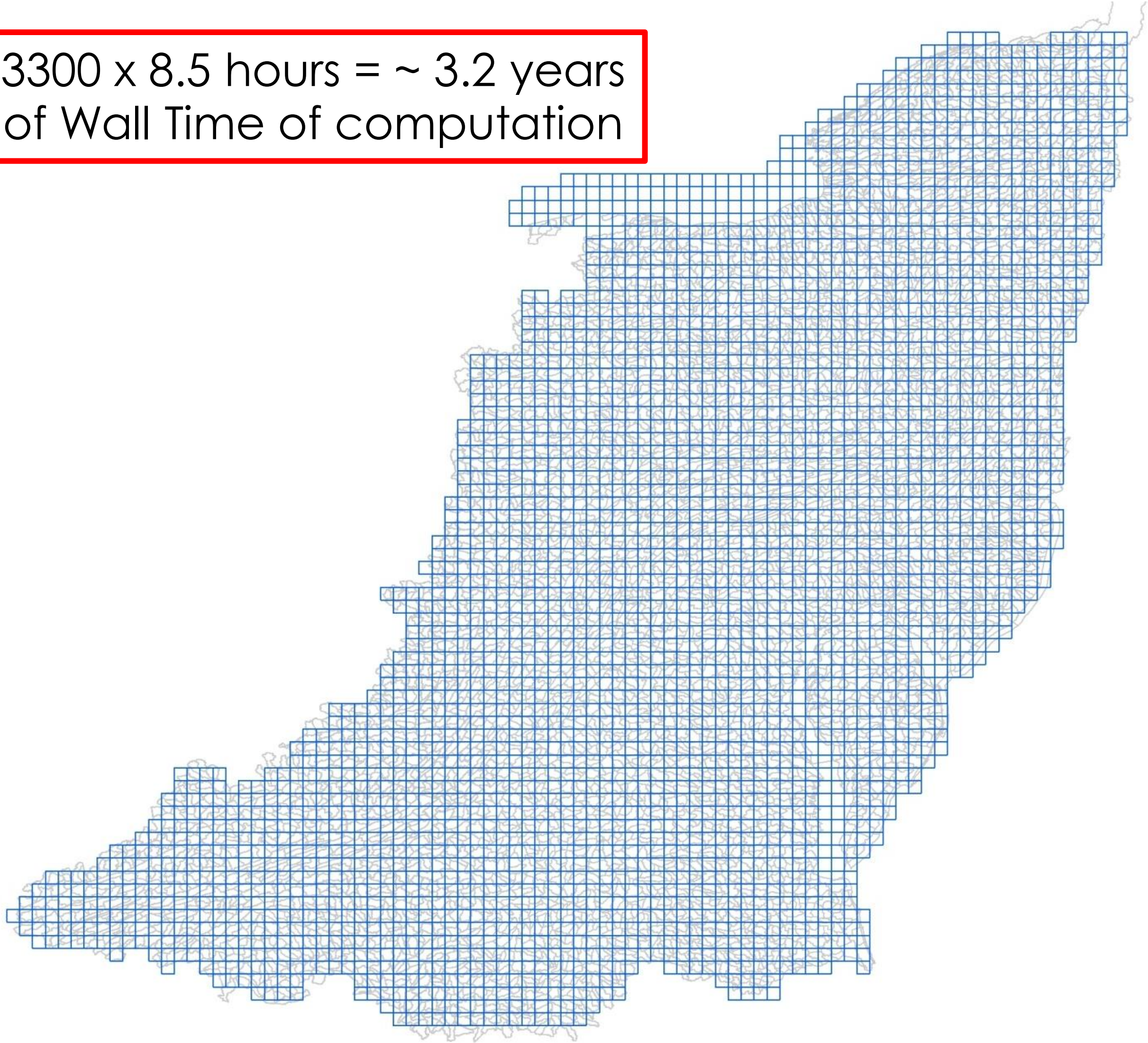


Average Age of the Watershed = **187 days**



Data :: Climate :: NLDAS v2 (1979 – 2011)

3300 x 8.5 hours = ~ 3.2 years of Wall Time of computation



<u>8km **Hourly** time-series</u>

1. Precipitation
2. Temperature
3. Solar Radiation
4. Vapor Pressure
5. Relative Humidity
6. Wind Speed

We have developed tools that extracts forcing variables (from NLDAS-2 grib2 data) and formats all above mentioned variables according to PIHM data structure

~3300 Climate Grids or Time-series Data for each climate variables!