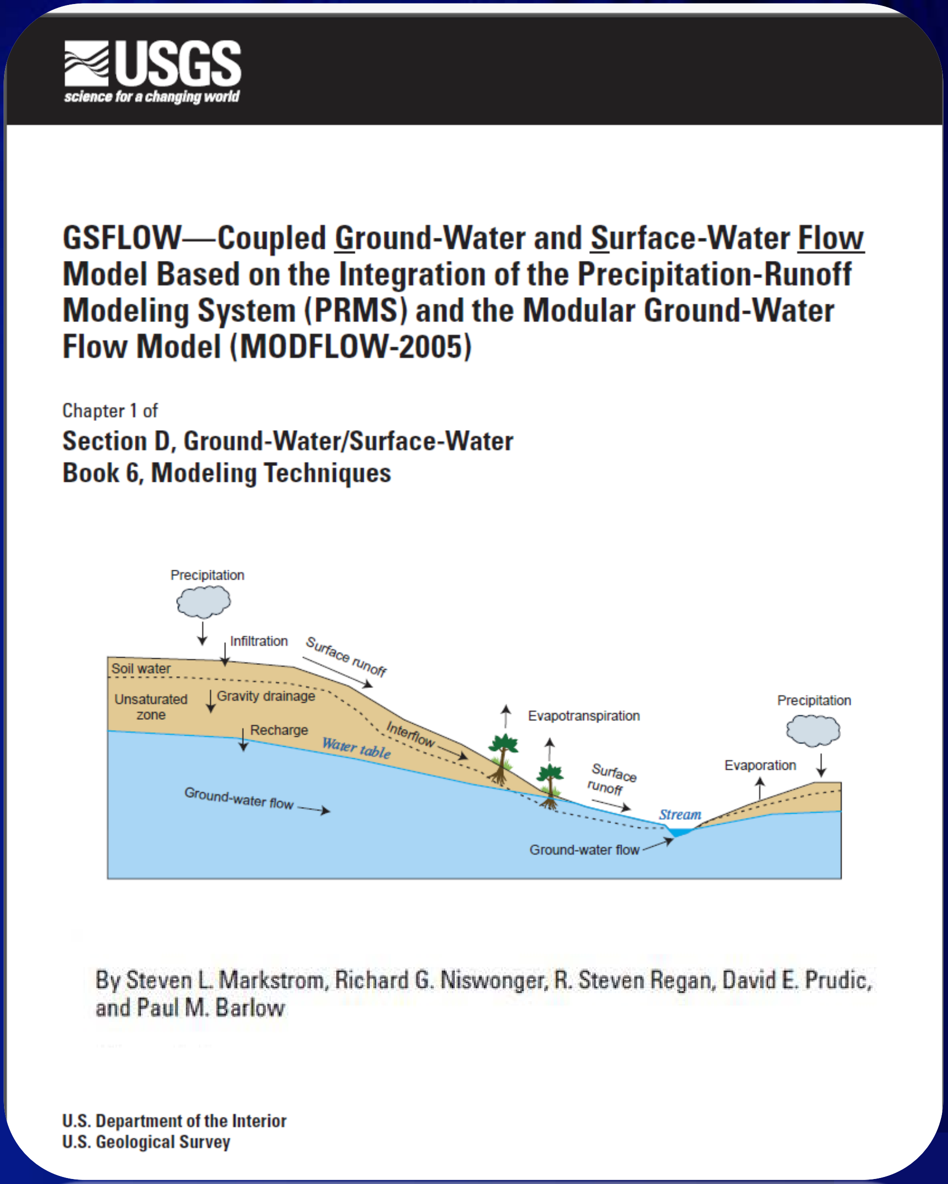
SECTION 1: GSFLOW OVERVIEW

GSFLOW

- Integrated hydrologic model
- Supply limited and demand driven water use
- More than just reproducing the past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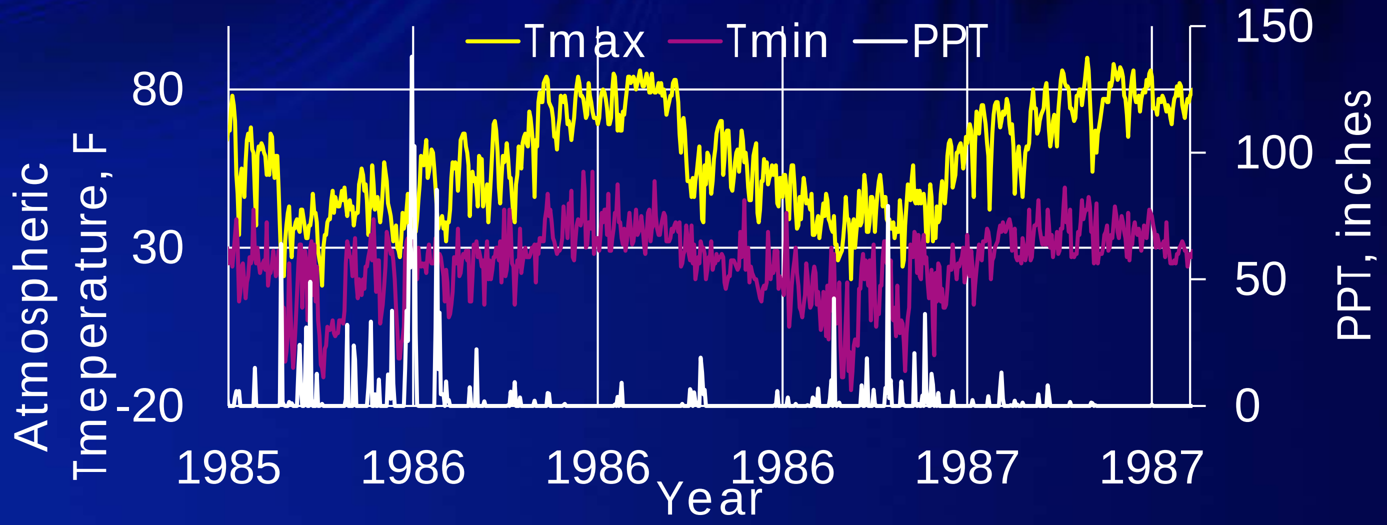
GSFLOW—Coupled Ground-Water and Surface-Water Flow Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005)

Chapter 1 of
Section D, Ground-Water/Surface-Water
Book 6, Modeling Techniques

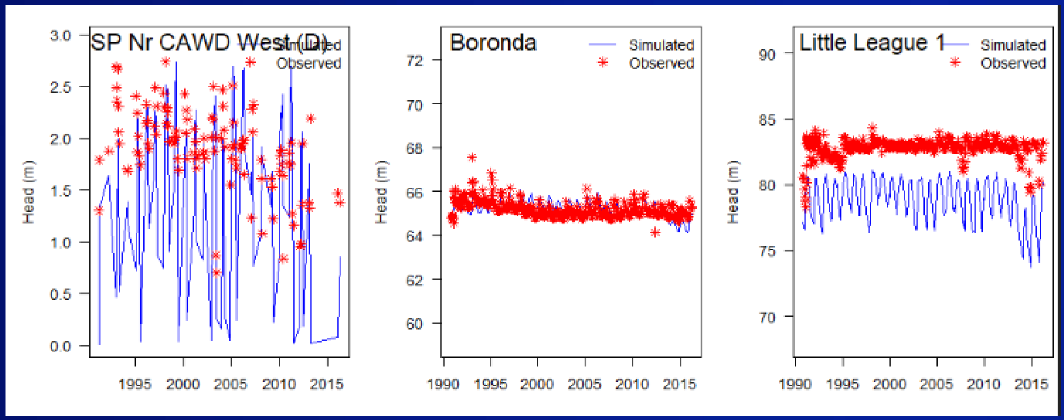
By Steven L. Markstrom, Richard G. Niswonger, R. Steven Regan, David E. Prudic, and Paul M. Barlow

U.S. Department of the Interior
U.S. Geological Survey

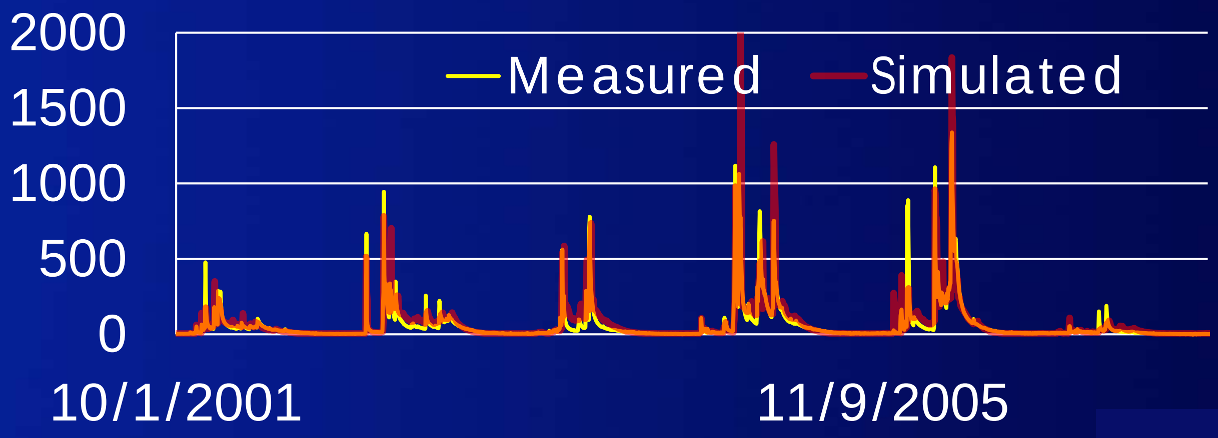
WHAT IS AN INTEGRATED MODEL?



GW heads



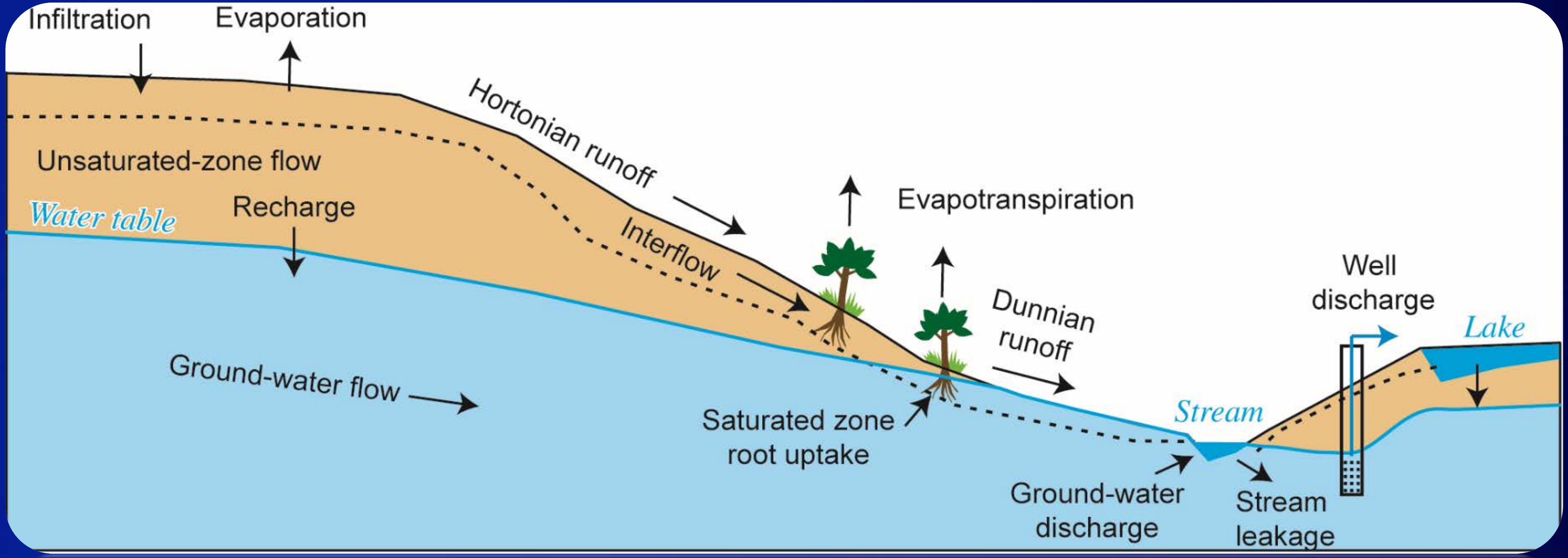
River flow



GSFLOW

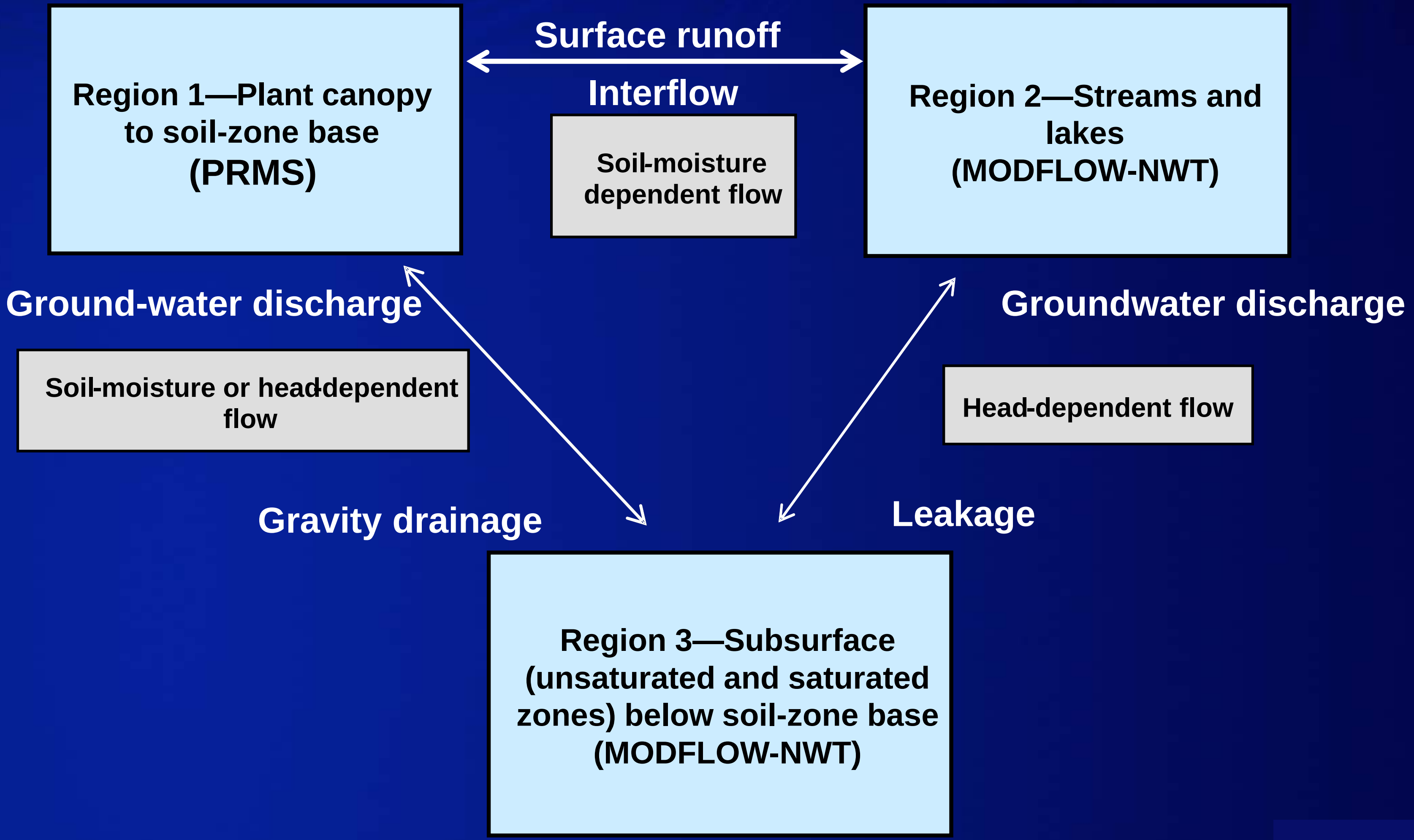
- Simulates all major hydrologic processes

- Flows are not specified, they are simulated



MODEL COUPLING

- Nonlinear feedbacks
- Not a single matrix



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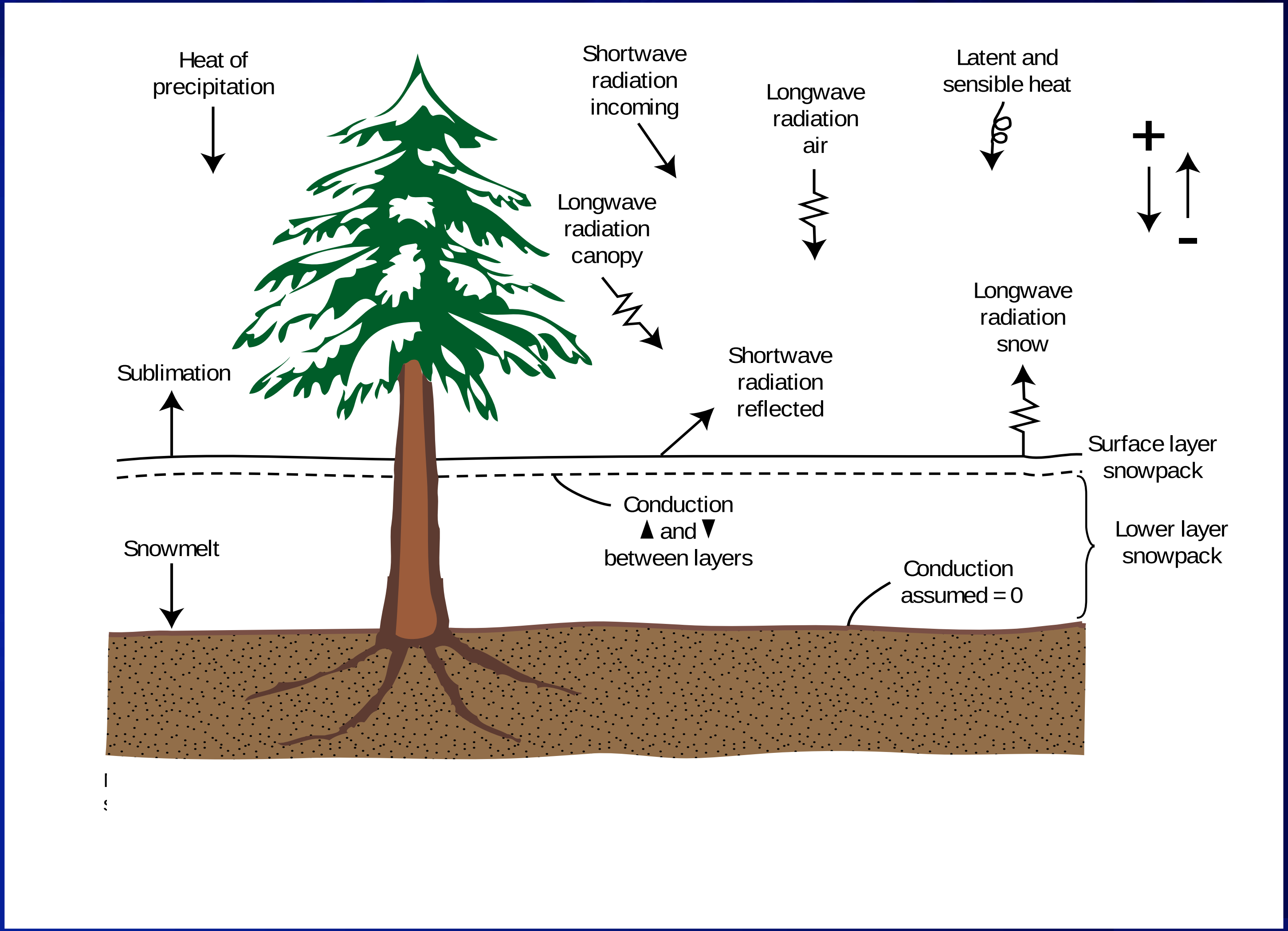
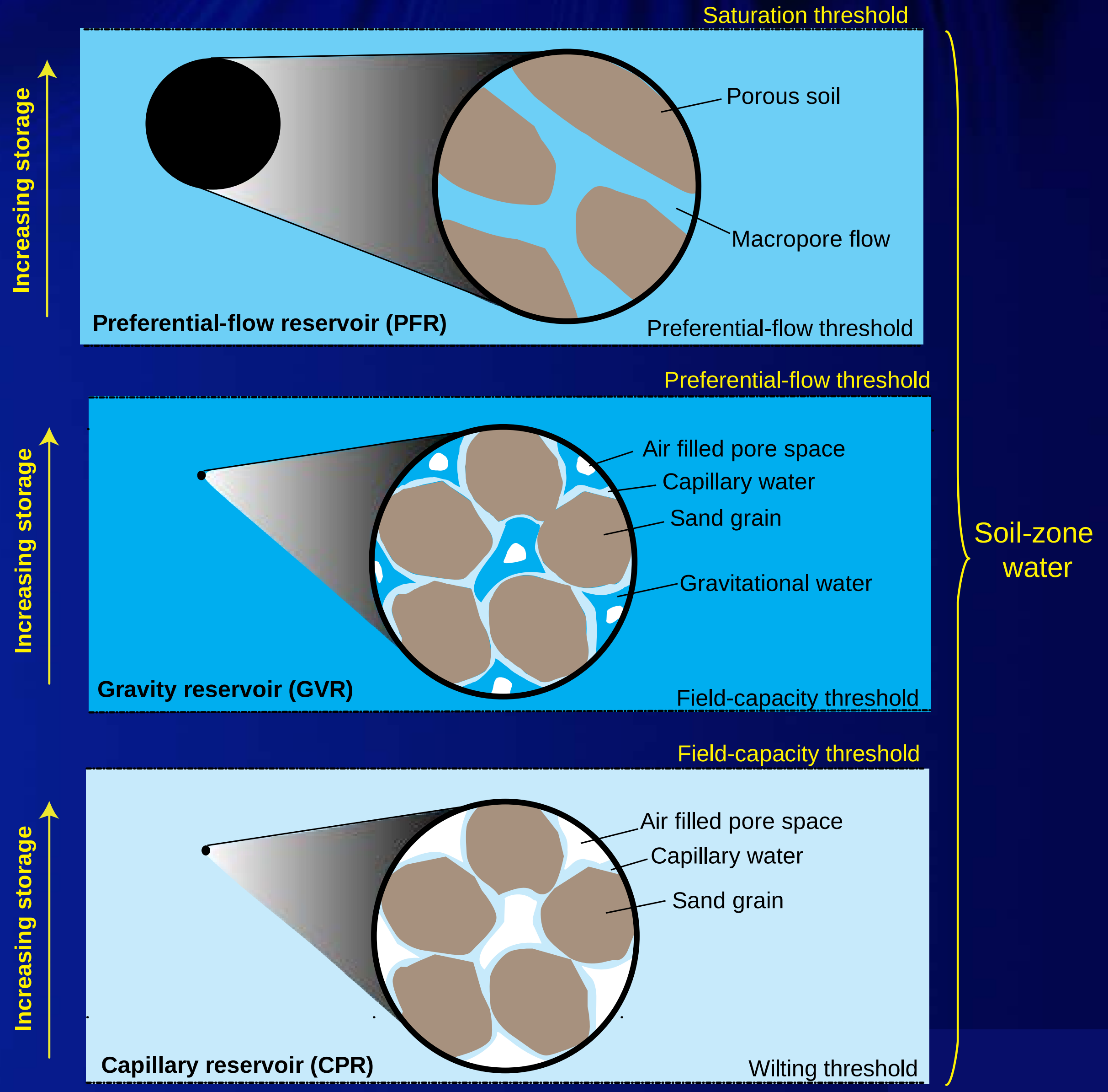
SNOW

- Snow accumulation and depletion processes
- Energy-budget approach for each cell/HRU



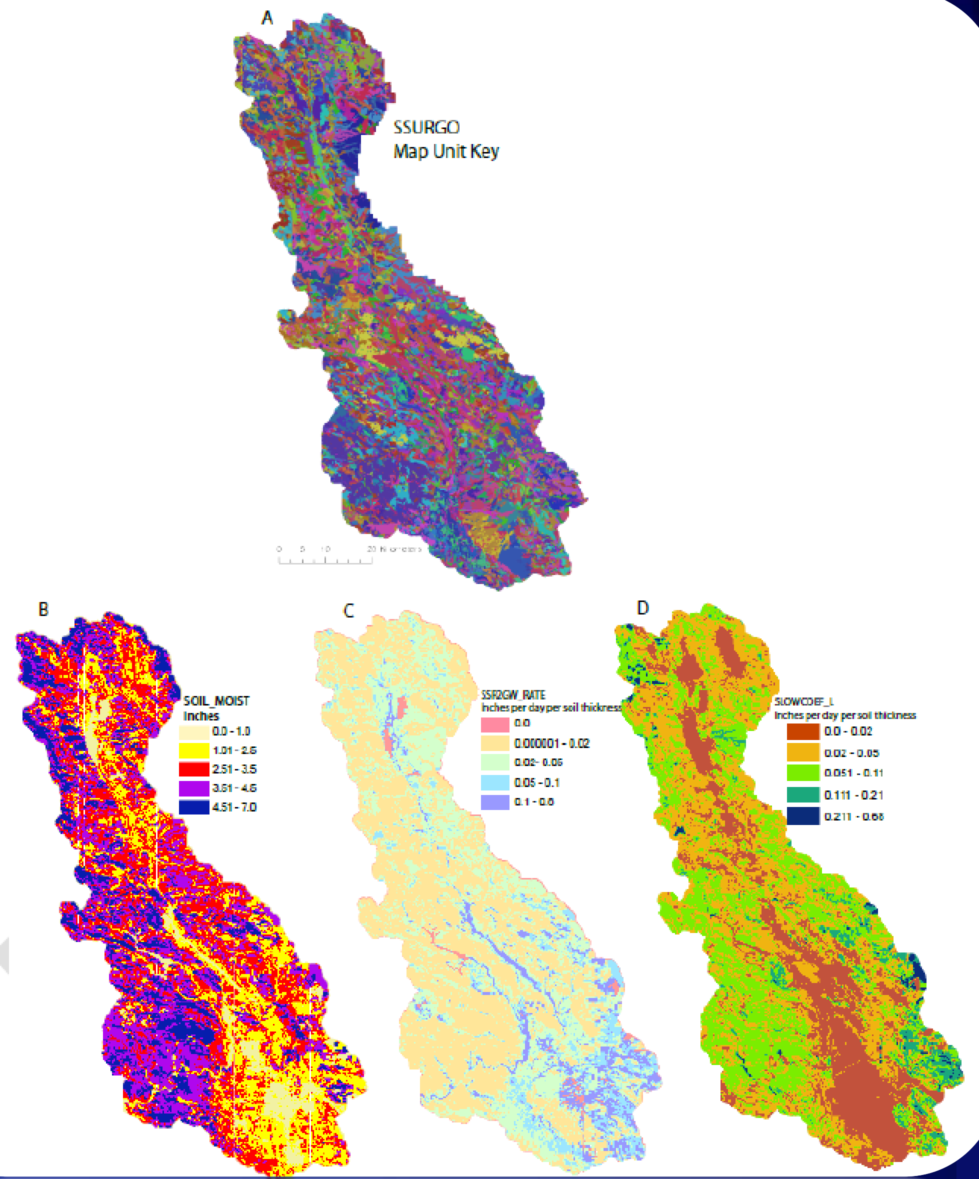
CONCEPTUAL/ PHYSICAL SOIL ZONE

- Soils represented using conceptual model
- Storm flow through soils dominated by macro-pore flow
- Streamflow often dominated by stormflow through soils



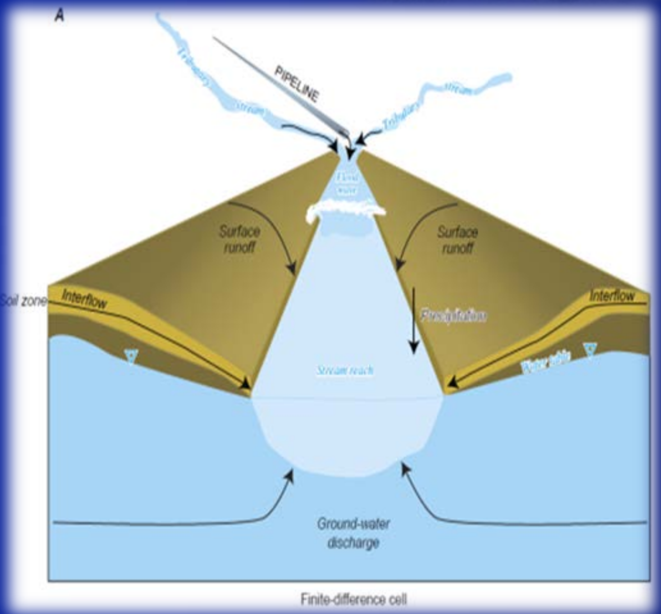
SOIL HYDRAULIC PROPERTIES

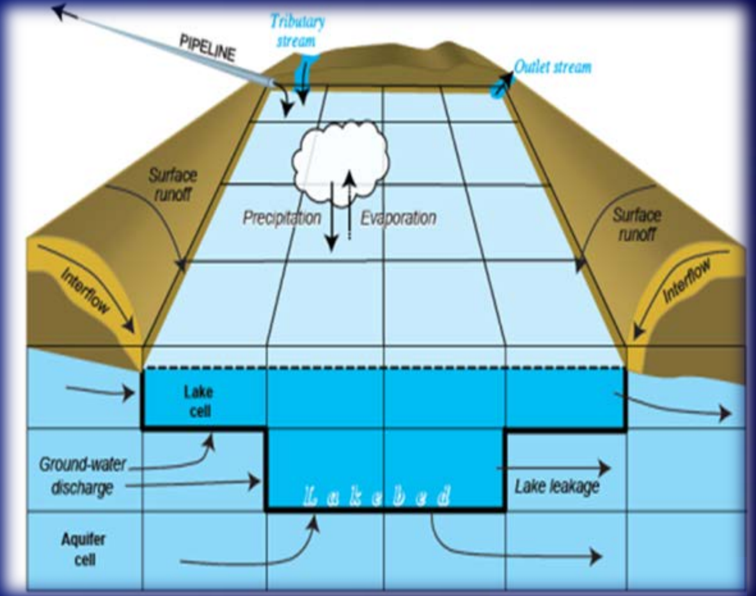
- Extremely important for controlling hydrologic cycle



SURFACE WATER BODIES

- Streams represented at sub-grid resolution
- Lakes represented at sub-grid or grid resolution





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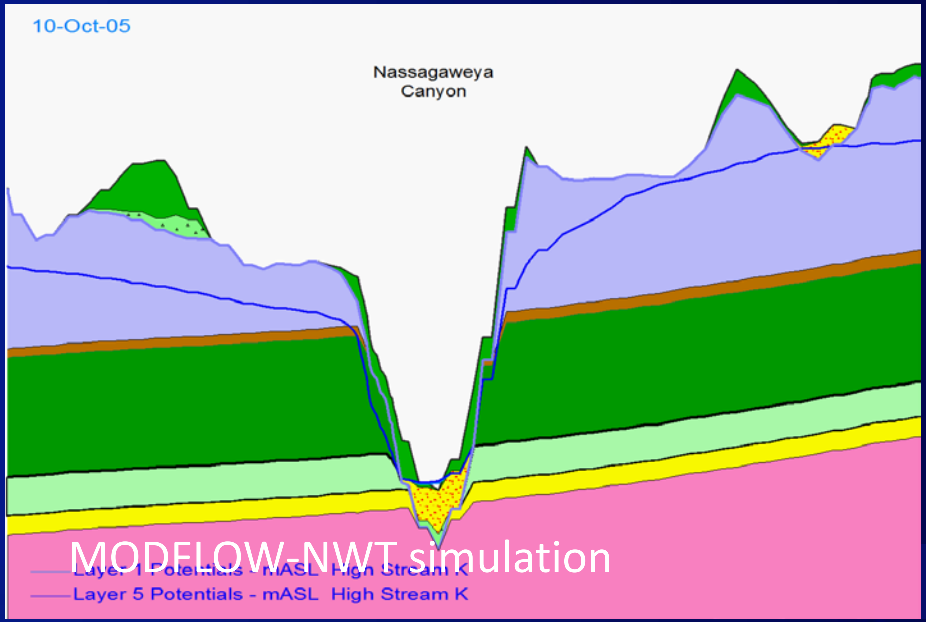
ROBUST GROUNDWATER SIMULATION

- Large contrasts in hydraulic conductivity, recharge, and runoff
- Steep topography, large hydraulic gradients
- Springs, seepage faces
- Discontinuous aquifers (wet-dry issues)



MODFLOW-NWT simulation

DESIGN CONCEPTS

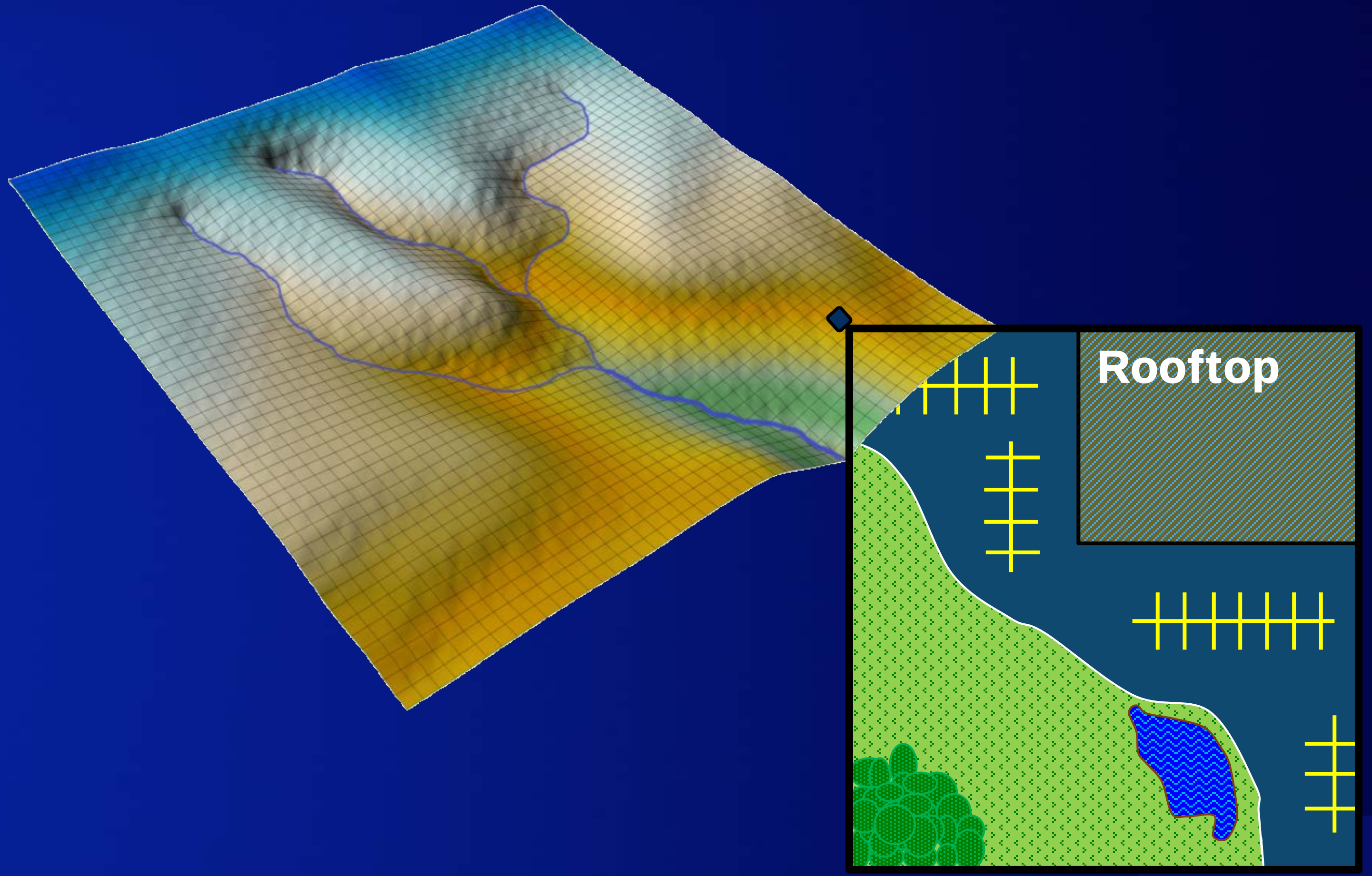
Sub-grid features

- Retention ponds
- Bioswales
- Rain barrels
- Green Roof




LAND USE/PERVIOUS/IMPERVIOUS

- Percentages of cells/HRUs are attributed different properties, e.g., impervious, detention.



PART 2: HYDROLOGIC CONCEPTUALIZATION

SHALLOW LATERAL FLOW

- Anderson and Burt, 1978
- Converging (“hollow”) verses diverging (“Spur”) flow

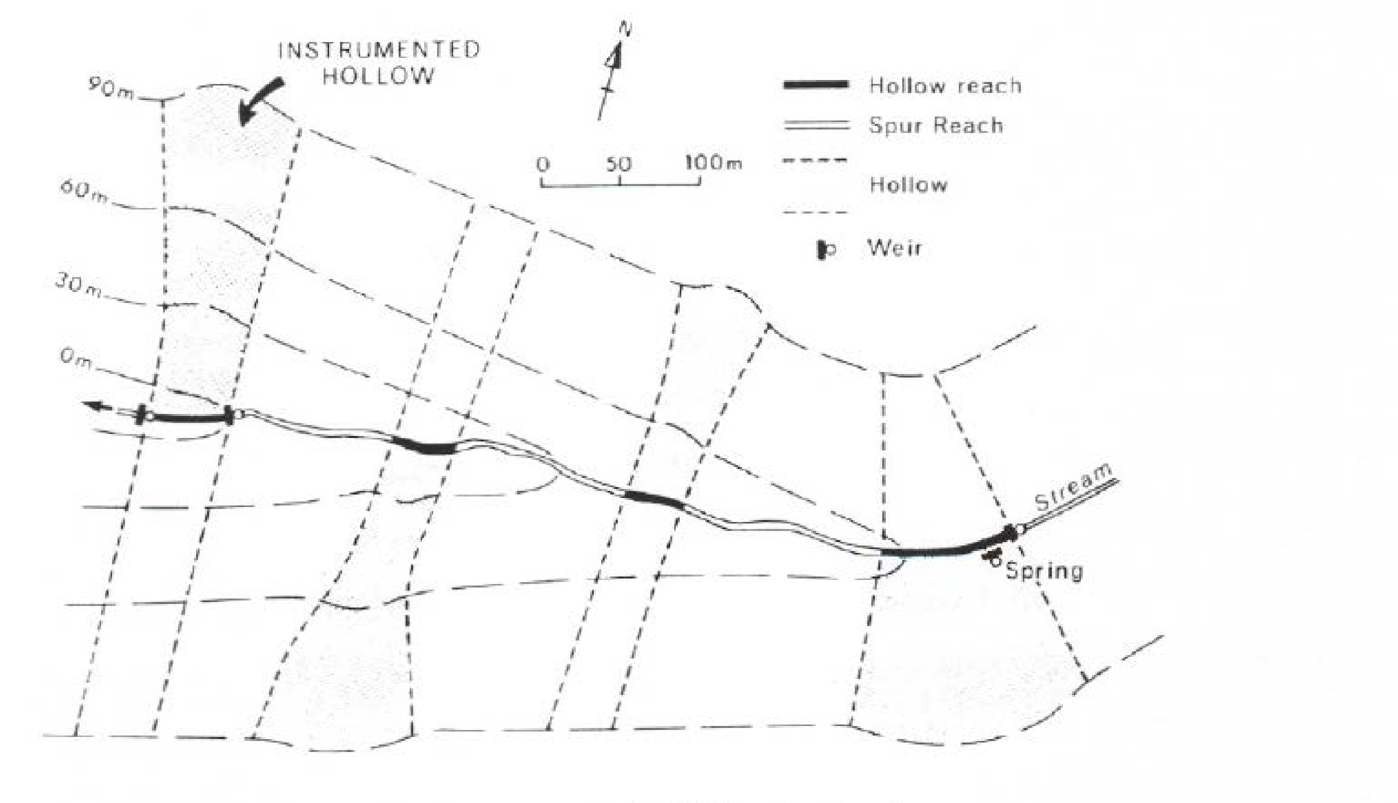


Figure 9. Map of catchment subunits of hollow and spur reaches

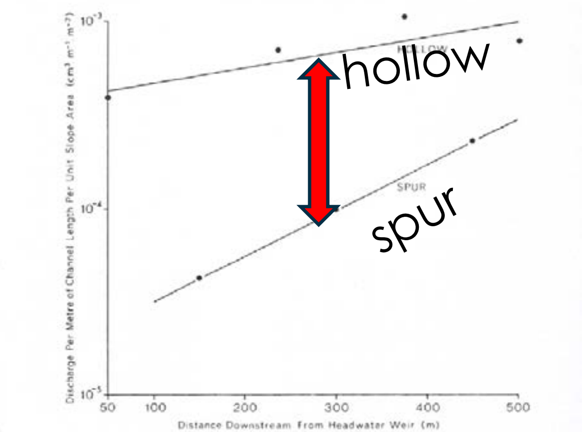
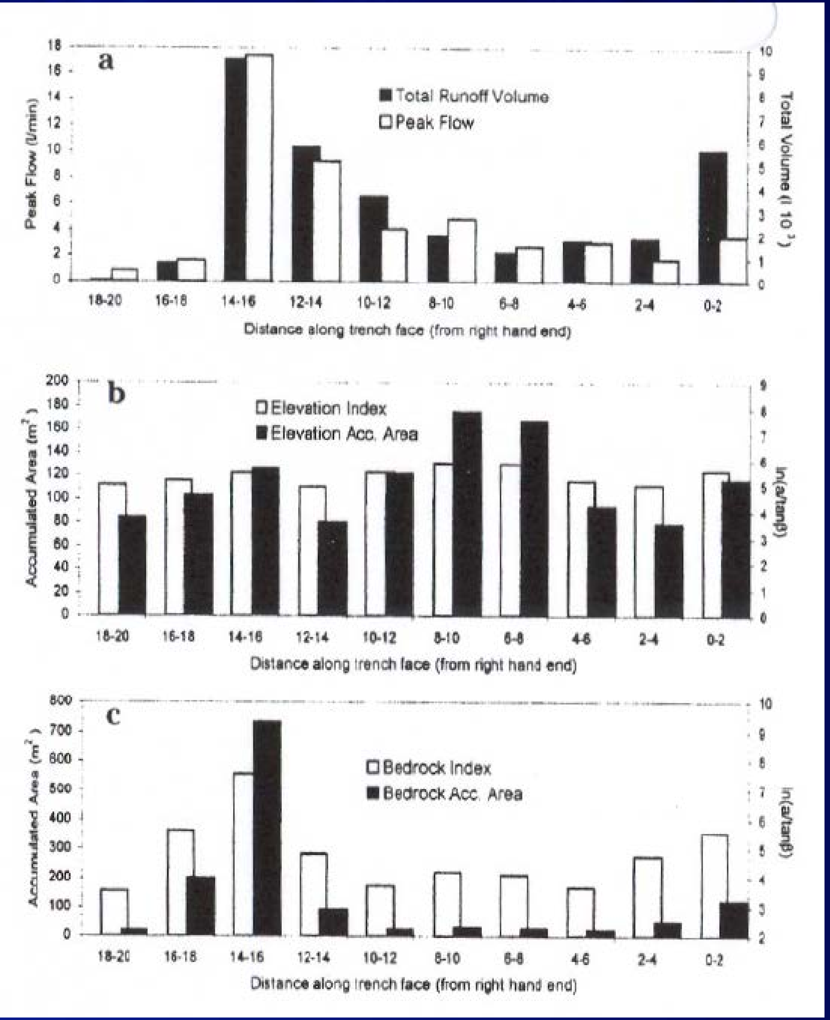


Figure 10. Hollow and spur reach discharge inputs over 550 m channel length – discharge per metre of channel length per square metre of drained area

TOPOGRAPHY

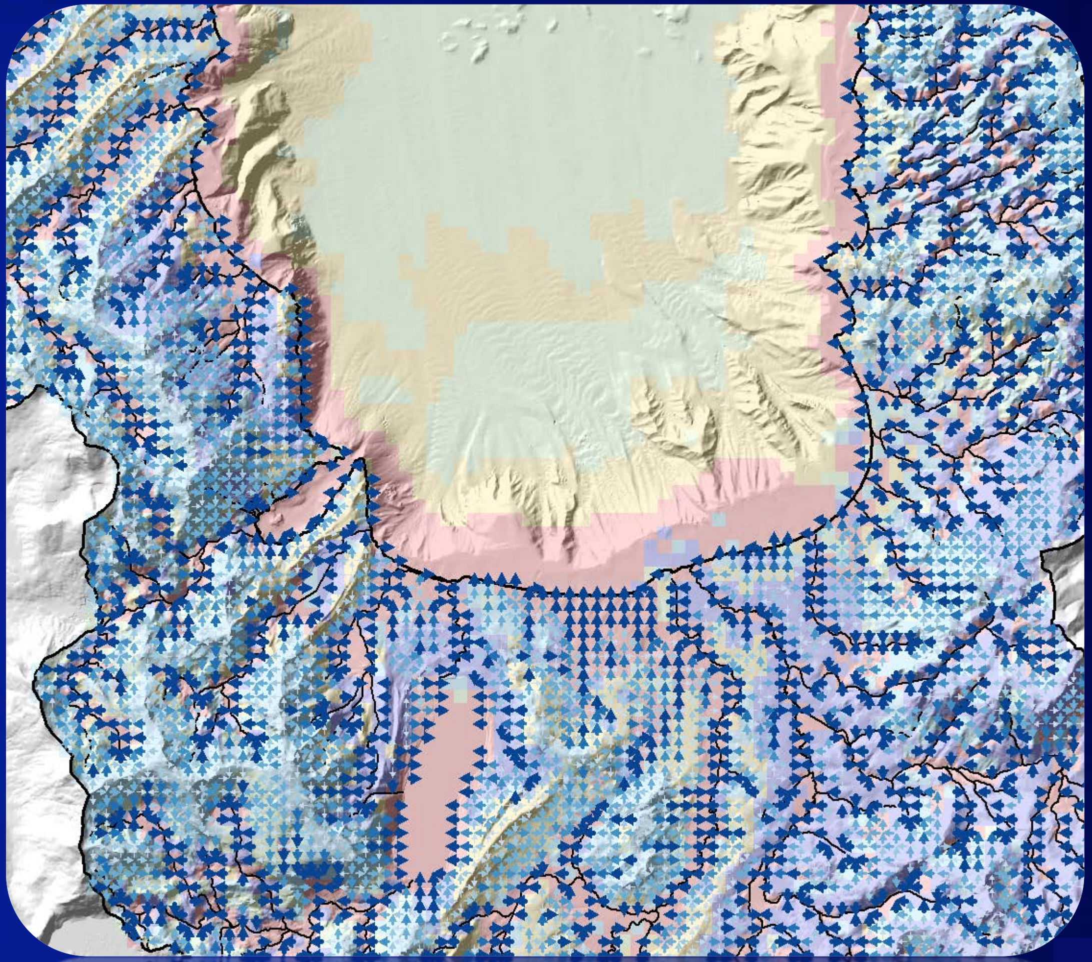
- McDonnell et al., 1996
- Surface topography and bedrock topography



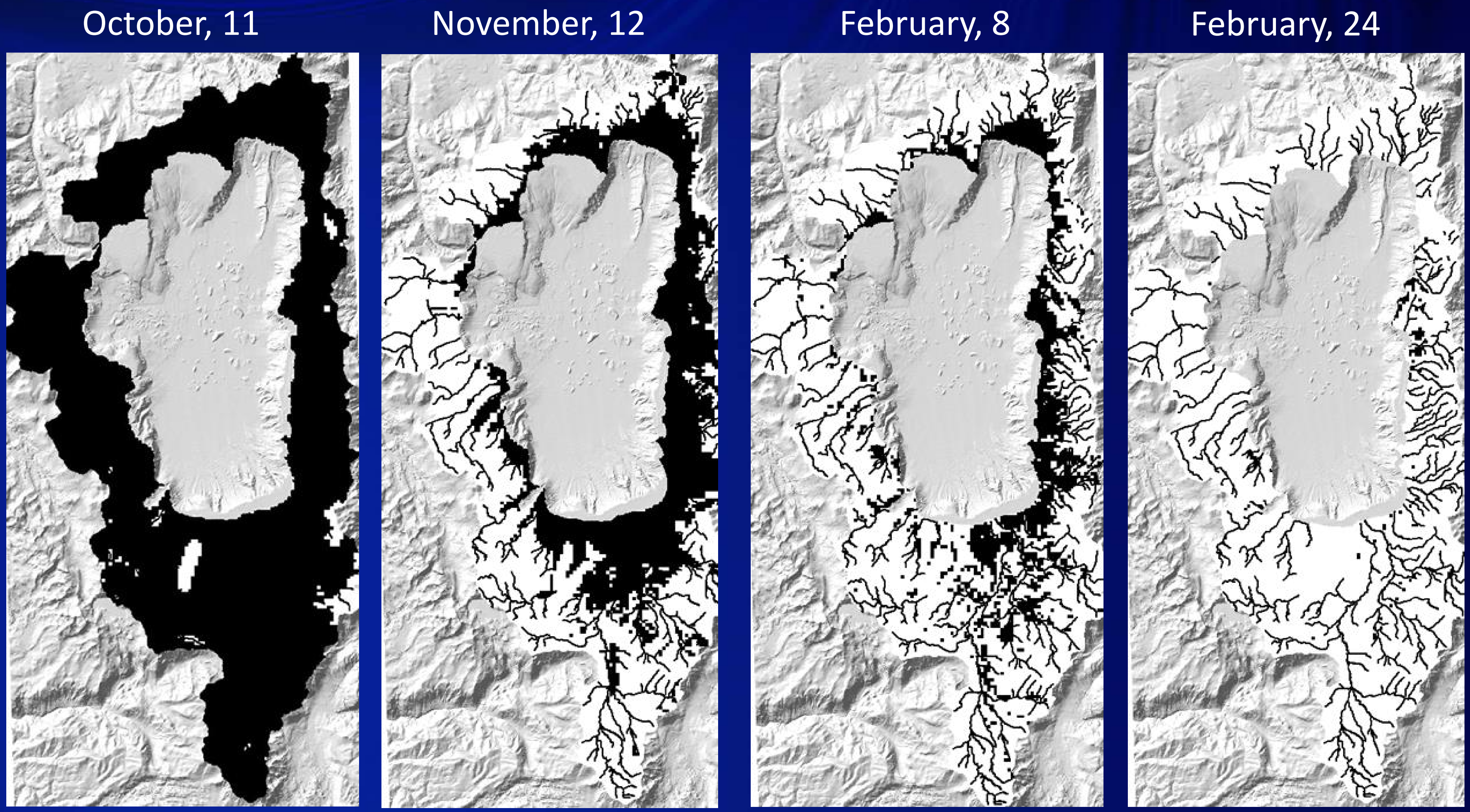
CASCADES

- Lateral flows routed according to topography and topology

- Cascades determined using Cascade Routing Tool (Henson and others, 2013)



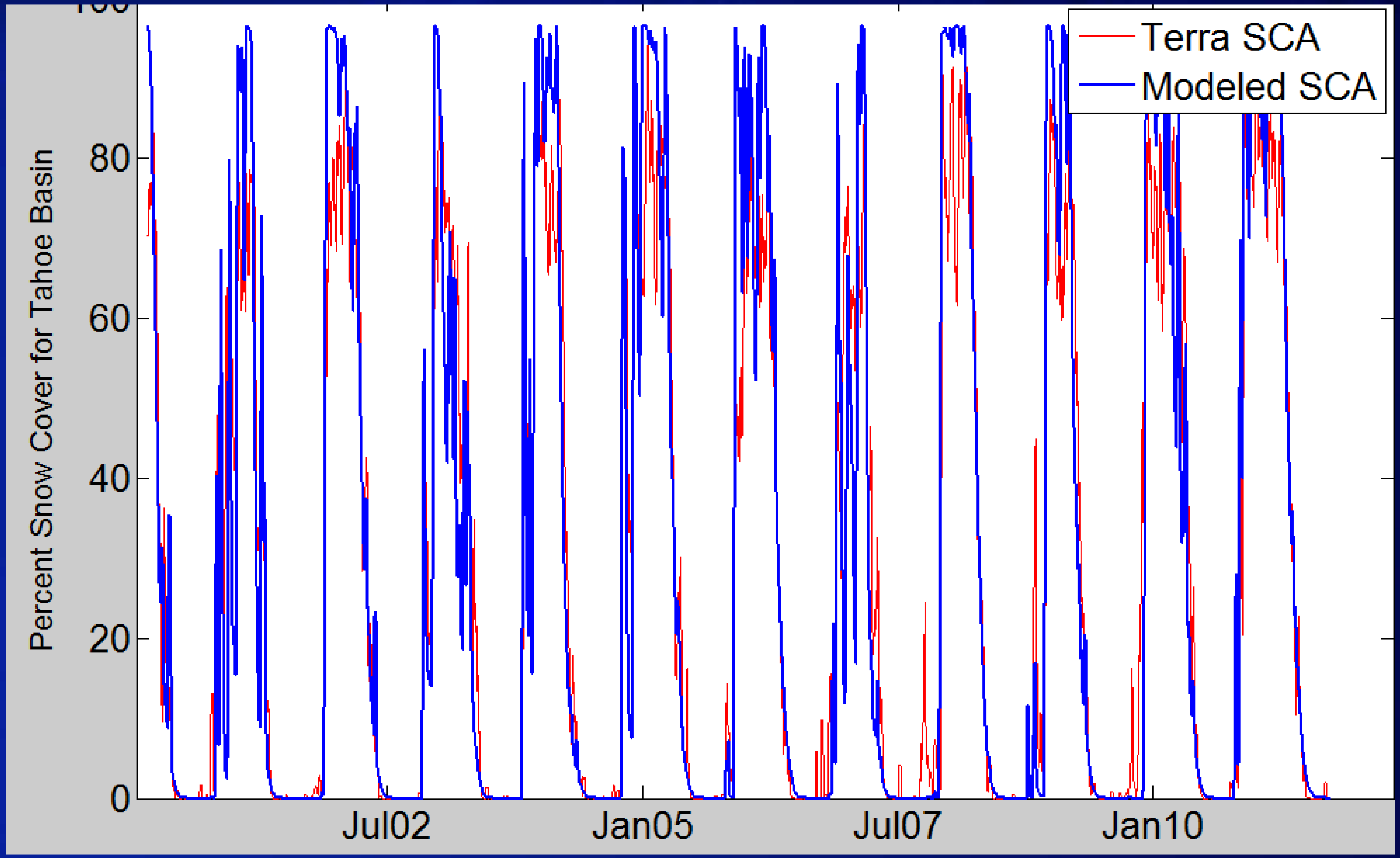
SEASONAL SCA PROVIDES INFORMATION ABOUT REGIONAL EFFECTS ON PRECIPITATION



SNOWPACK

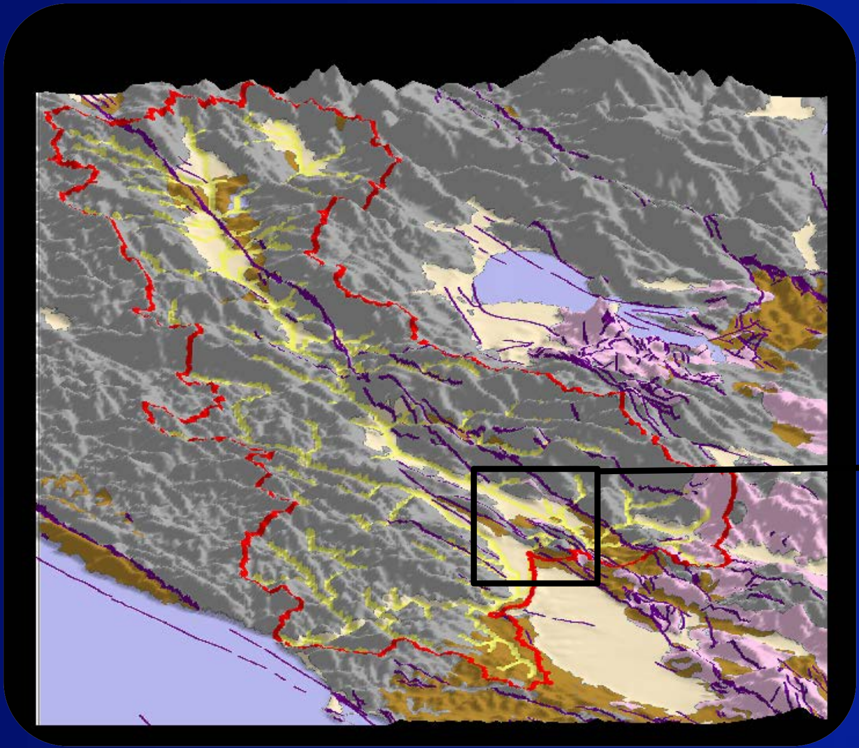
- SNOW COVERED AREA IS MEASURED FROM SATELLITES

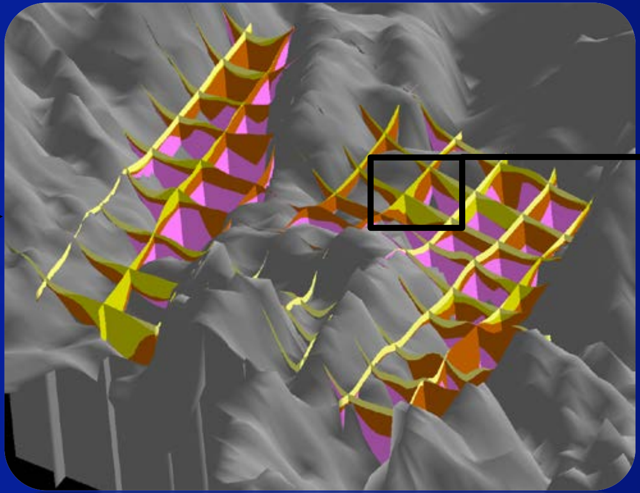
  USEFUL FOR MODEL CALIBRATION

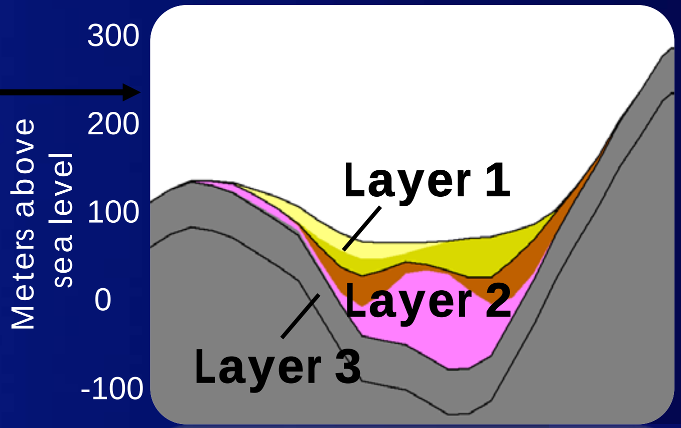


HYDROGEOLOGIC FRAMEWORK

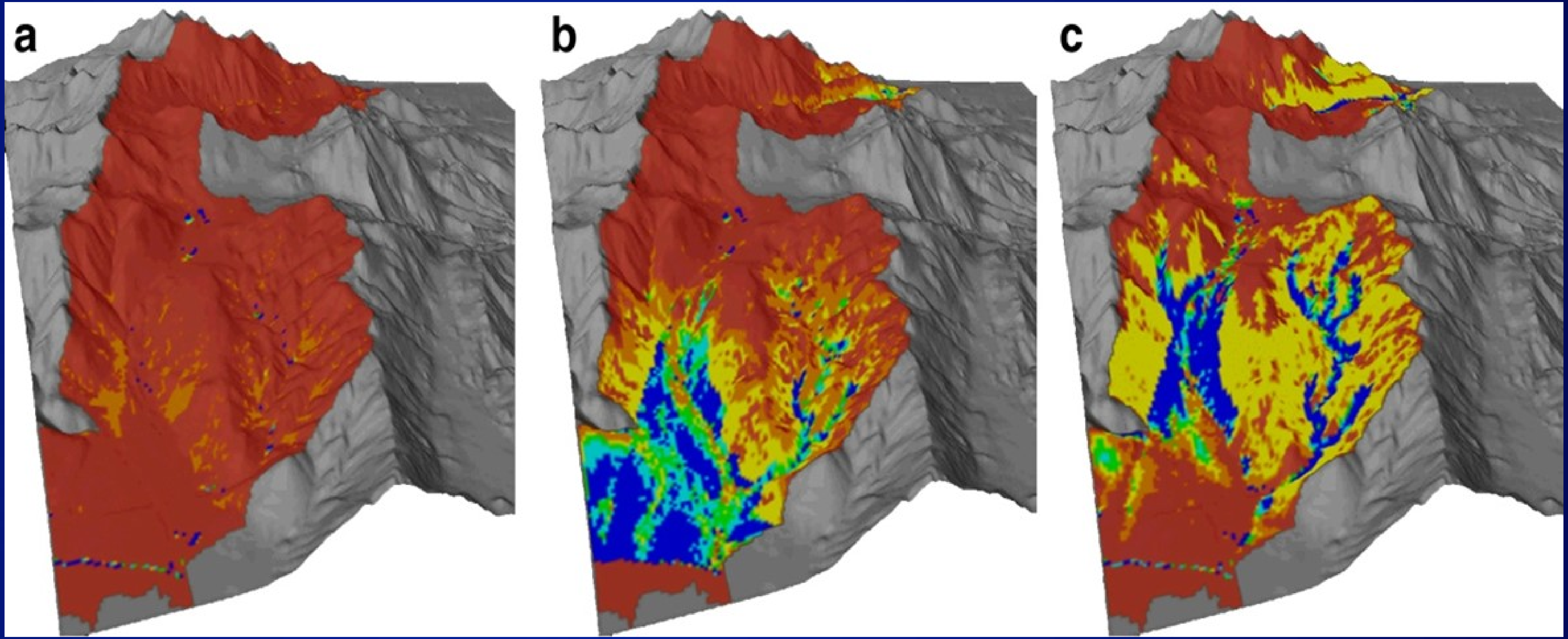
Channel Alluvium
Unconsolidated sediment
Consolidated sediment
Sonoma Volcanics
Franciscan Basement







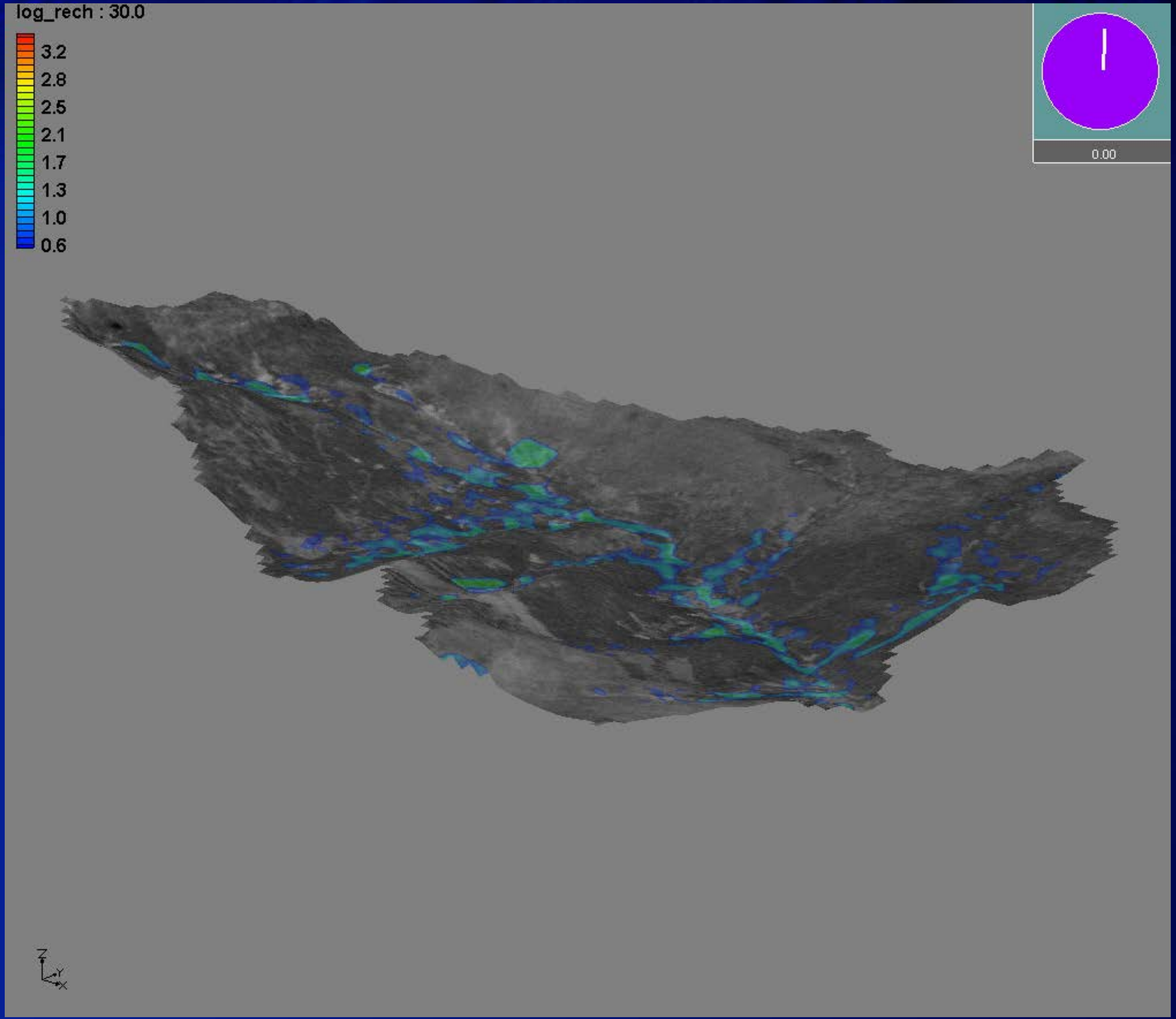
REALISTIC RECHARGE AND NOT JUST A FACTOR OF PRECIPITATION



TWO FACES OF RECHARGE

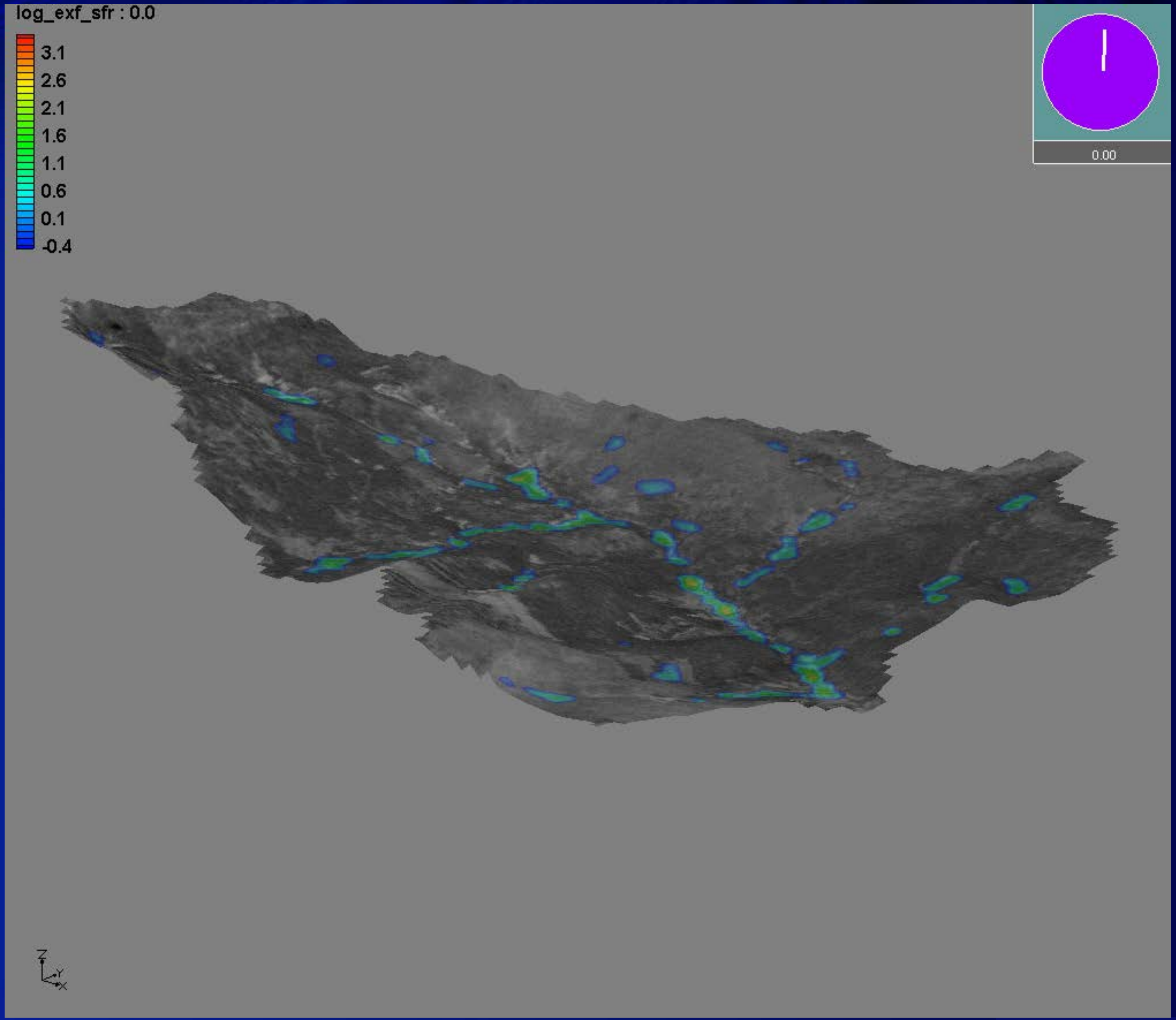
1. Thin UZ: abrupt, flashy, high rates of short duration

2. Thick UZ: diffuse, steady, low rates



GROUNDWATER DISCHARGE

- Important runoff mechanism
- Constrains hillslope aquifer properties



CONJUNCTIVE USE OF SW AND GW FOR AGRICULTURE

1. Water diverted from stream to canal/pipe delivered to fields
2. Groundwater pumped and delivered to fields
3. Conjunctive use/supplementary groundwater pumping

OPTIONS FOR REPRESENTING AGRICULTURAL WATER USE

1. Model calculates Net Irrigation Water Requirement
2. User specified NIWR

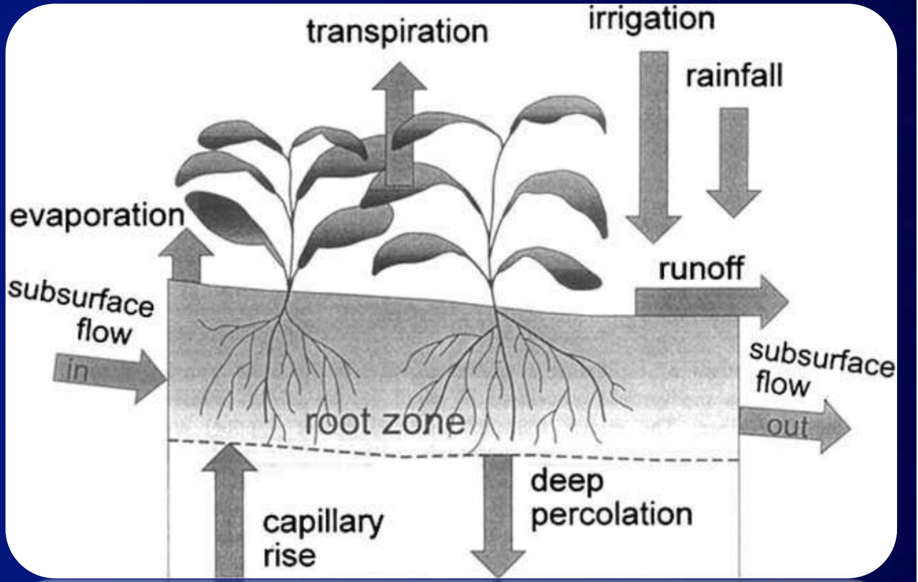
NIWR CALCULATOR

- Model determines amount of irrigation required to minimize the ET deficit

- Actual ET (ET_a) is calculated by model using soil-water balance (UZF or PRMS)

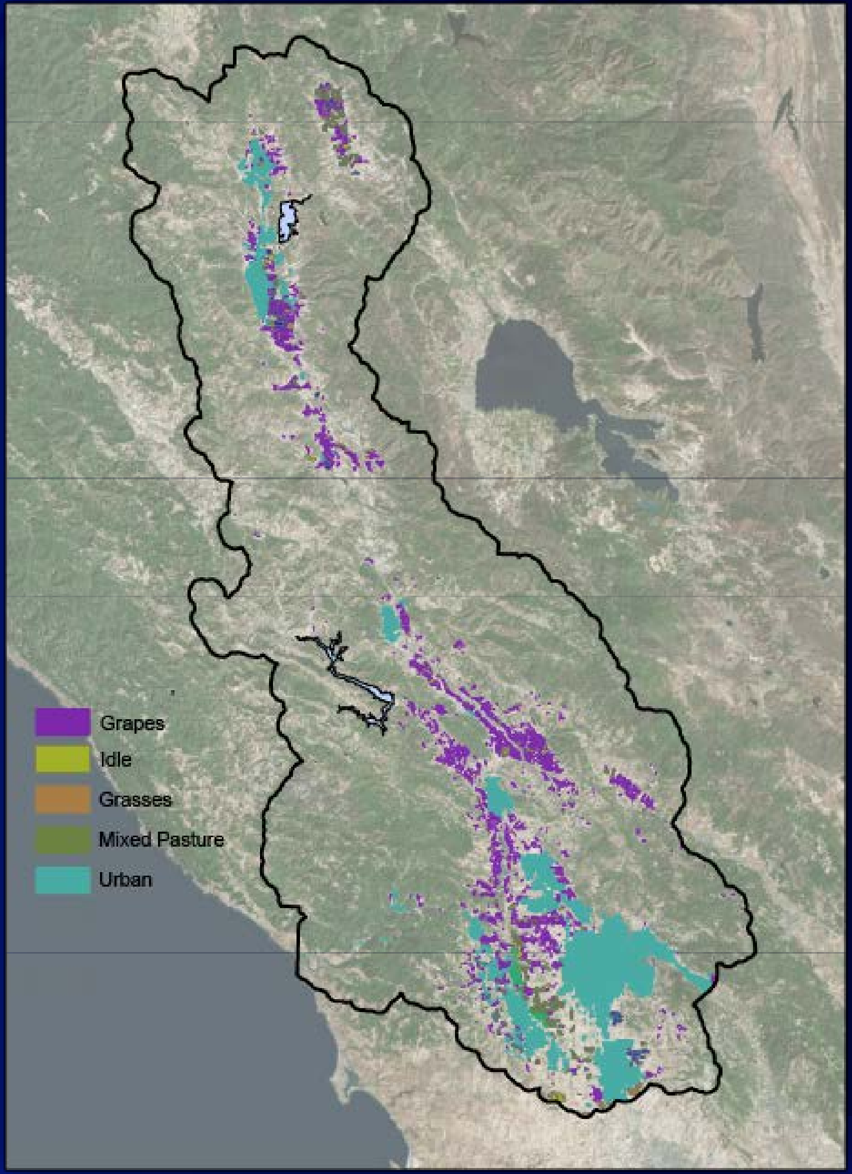
$$min[ET_{def}] = ET_{ww} - ET_a$$

ET_{ww} is crop ET under well-watered conditions



LAND USE/CROP COEFFICIENTS

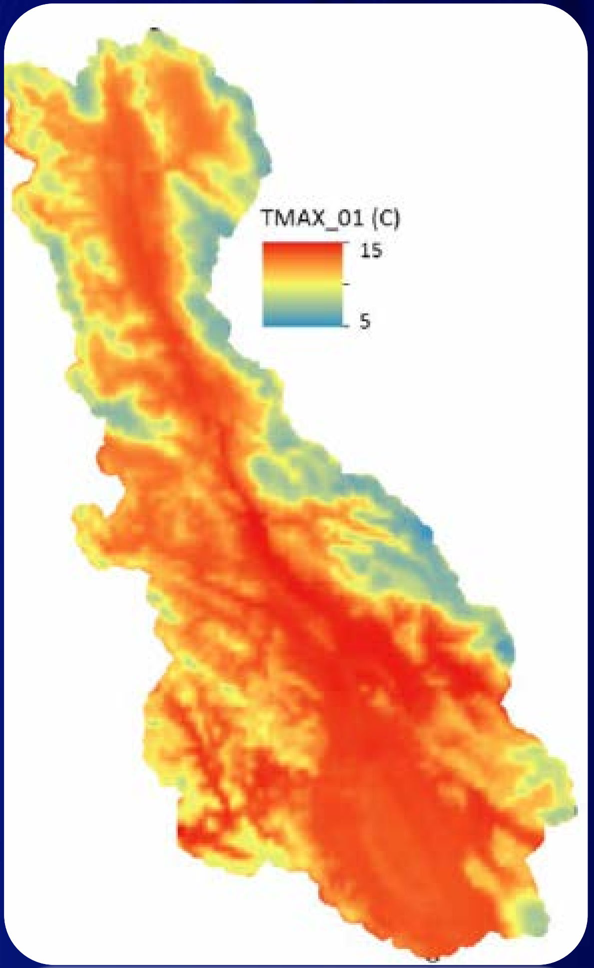
- Land use maps provide crop coefficient by cell combined with GSFLOW climate for PET



CROP WATER DEMANDS

- NIWR is dependent on potential ET: $ET_{ww} = K_c * PET_{HRU}$

- Several options in GSFLOW for calculating PET:
  1. Penman-Monteith
  2. Jensen-Haise
  3. Priestley-Taylor
  4. Hamon
  5. others

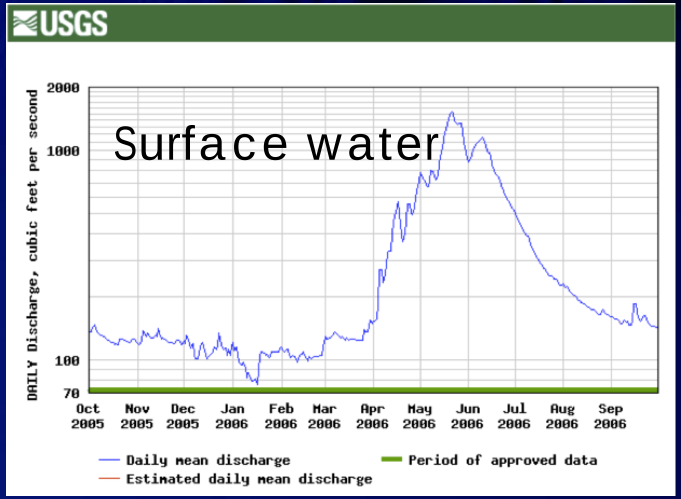


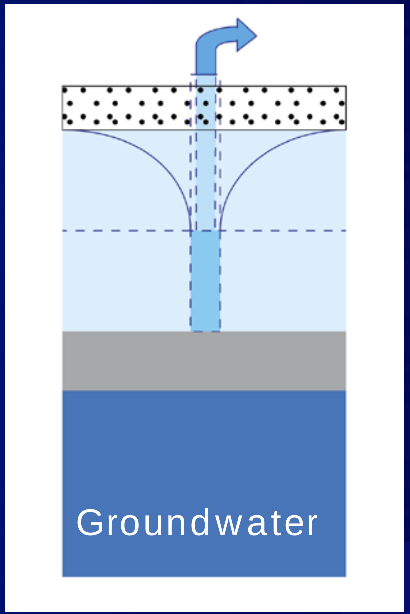
NIWR CALCULATOR

- For conjunctive-use supplementary groundwater is automatically pumped to meet the shortfall

- Irrigation is supply limited

$$Q_{GW,i+1} = PCT_{SUP} \left[Q_{NIWR,i+1} - Q_{SW,i+1}\right]$$





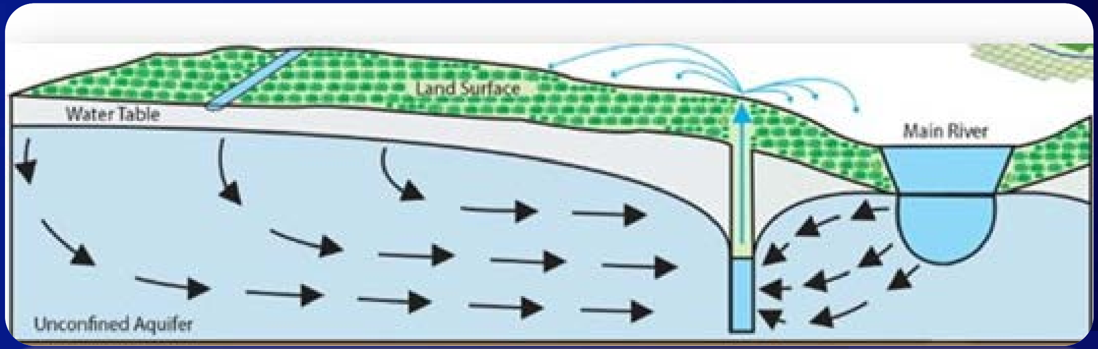
SPECIFIED NIWR

```
0 4
2.63E+06 22
5.26E+06 42
7.88E+06 77
1.05E+07 28
1.31E+07 99
1.58E+07 63
1.84E+07 35
2.10E+07 21
2.37E+07 7
2.63E+07 3.5
2.89E+07 3.3
3.15E+07 3.1
3.42E+07 10.5
3.68E+07 21
3.94E+07 98
4.20E+07 35
4.47E+07 63
4.73E+07 28
4.99E+07 14
5.26E+07 7
5.52E+07 3.5
5.78E+07 3.2
6.04E+07 3.5
6.31E+07 3.5
6.57E+07 14
```

- NIWR is specified as time series of stream diversions for SW or conjunctive use

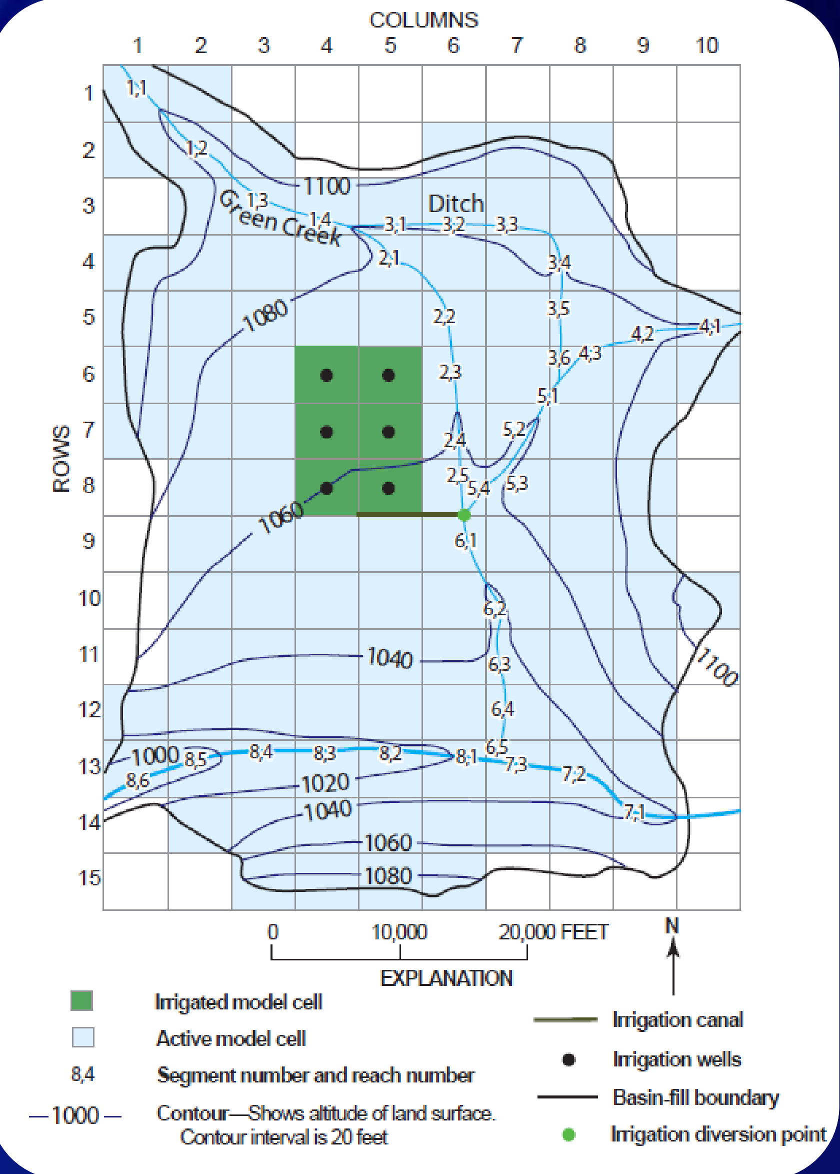
or

- NIWR is specified as time series pumping rates for GW only irrigation



EXAMPLE 2 FROM SFR

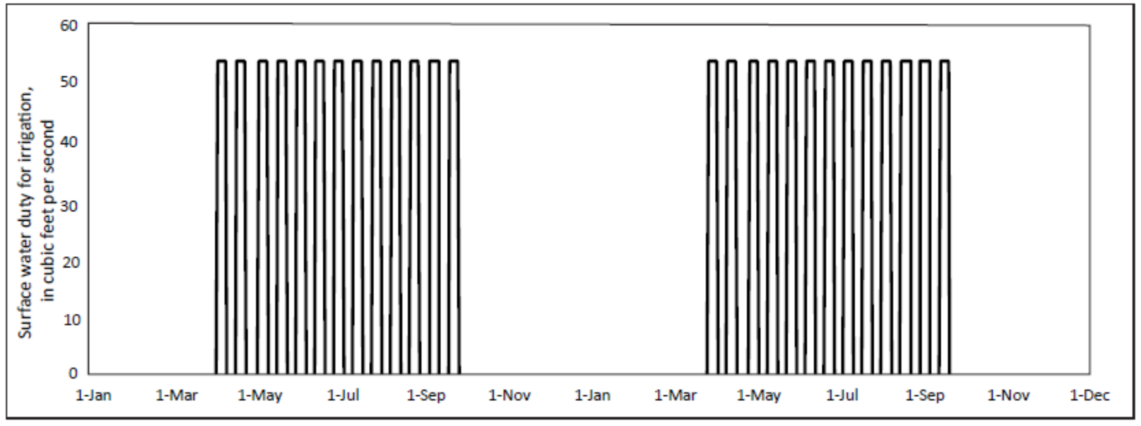
- Simple model provides illustration of capabilities
- Conjunctive use
- Uses NIWR calculator option



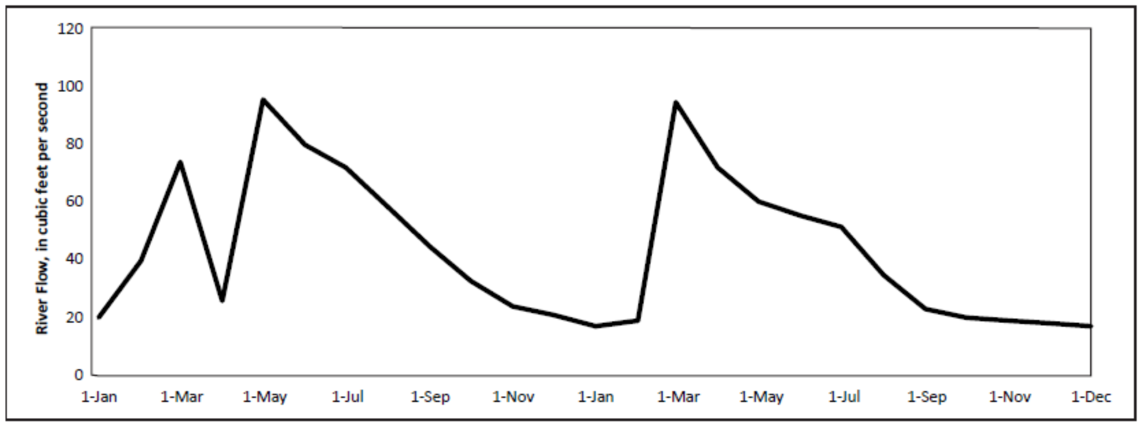
WATER SUPPLY IMPACTS ON IRRIGATION

- Simple model provides illustration of capabilities
- Conjunctive use
- Uses NIWR calculator option

Irrigation schedule



River flow

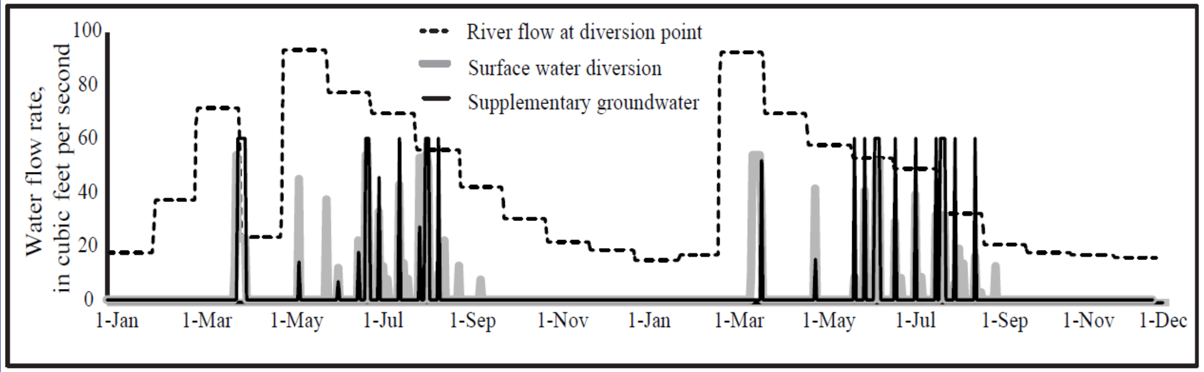


IRRIGATION AND CROP CONSUMPTION

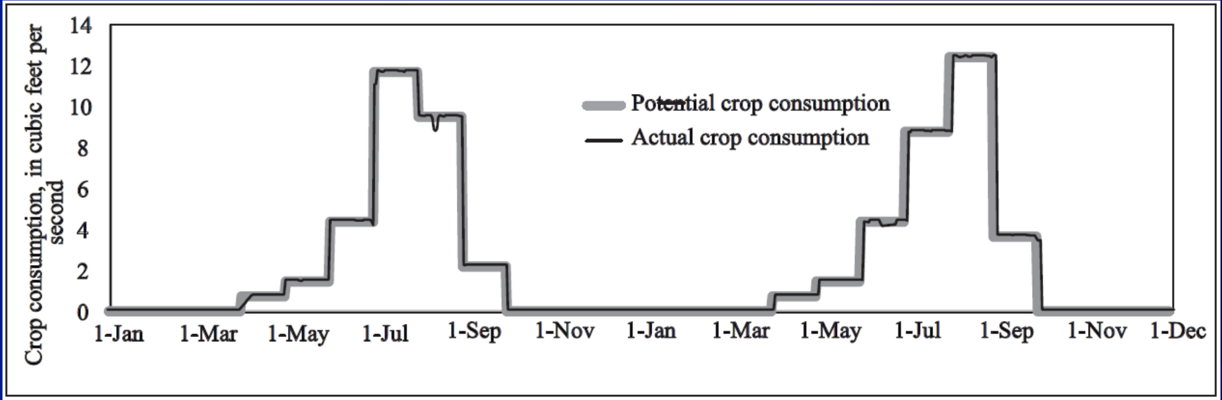
- Irrigation constrained by available surface water and pumping capacity

- Difference between well watered ET and actual ET minimized

Calculated irrigation



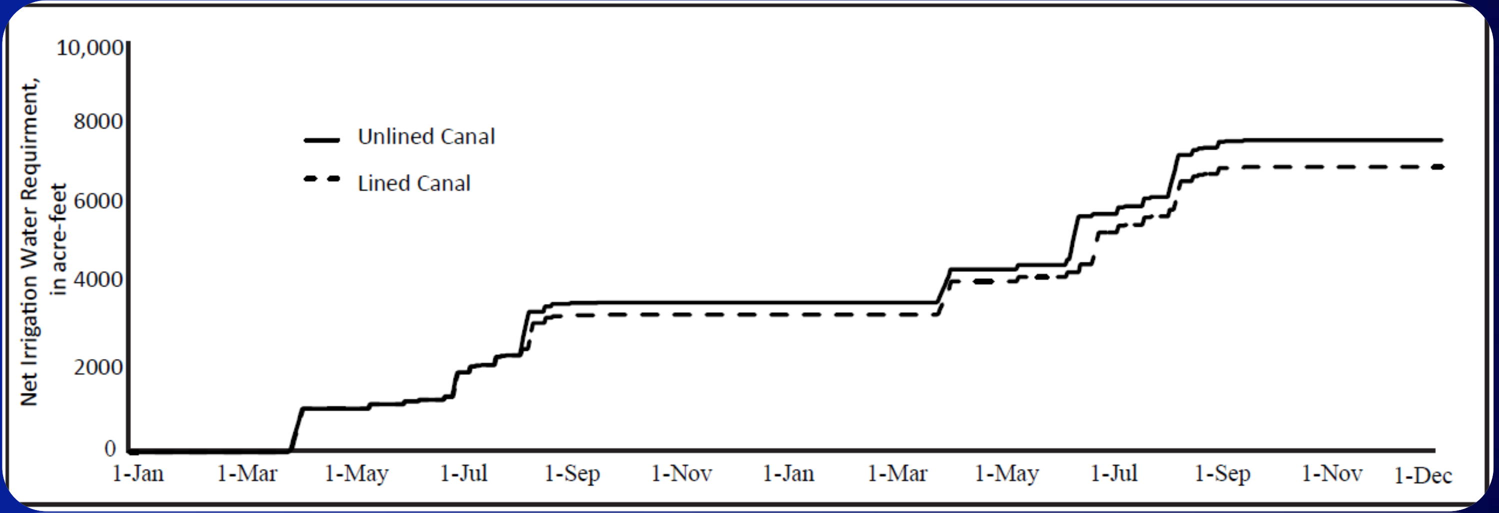
Actual and crop ET



EXAMPLE SIMULATION

- System losses and return flows are calculated by hydrology model
- Model determines impacts of infrastructure on NIWR

Impacts of canal lining on NIWR

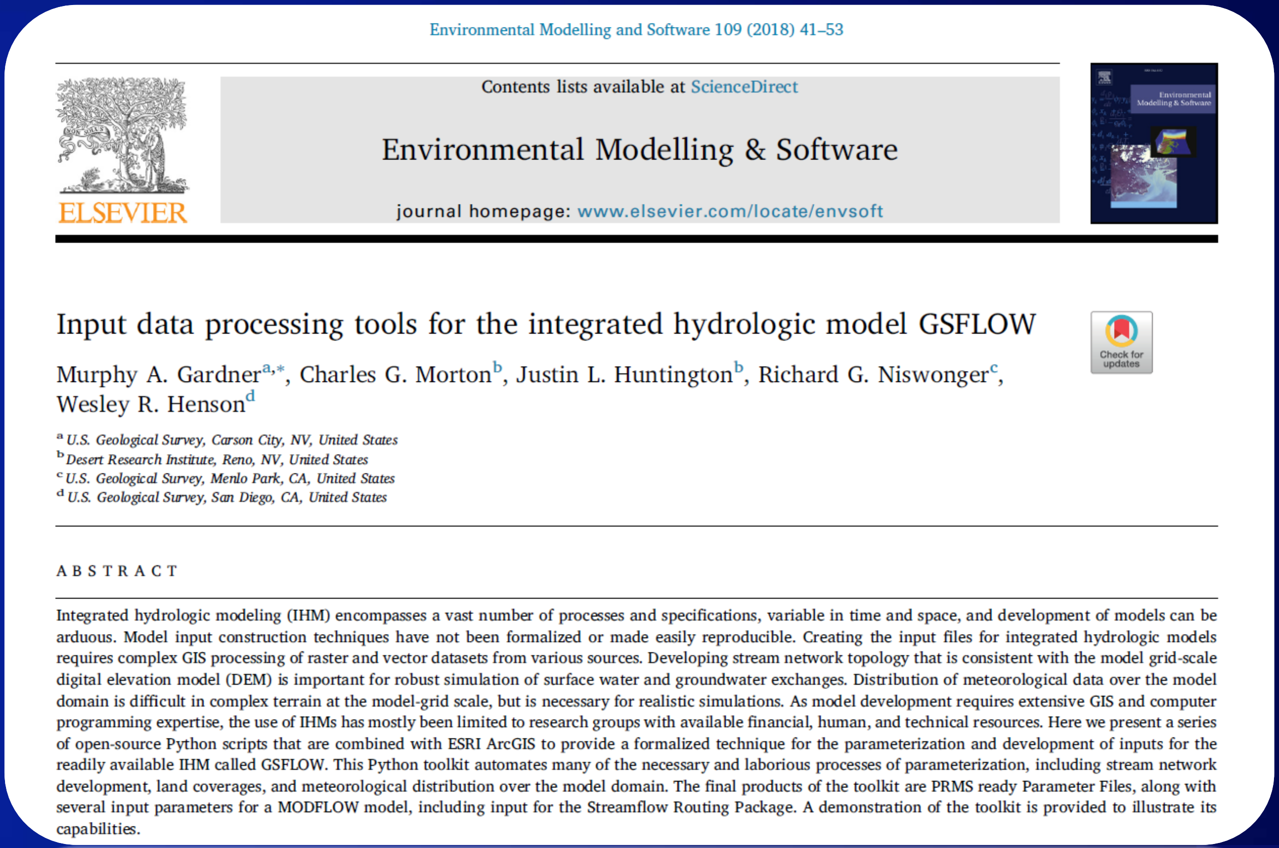


SECTION 3: BUILDING INPUT FILES FOR GSFLOW

BUILDING A GSFLOW MODEL

- Techniques for creating GSFLOW models developed over the last decade have been distilled into python scripts

- Scripts provide reproducible approach



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Input data processing tools for the integrated hydrologic model GSFLOW

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[c] U.S. Geological Survey, Menlo Park, CA, United States
[d] U.S. Geological Survey, San Diego, CA, United States

ABSTRACT

Integrated hydrologic modeling (IHM) encompasses a vast number of processes and specifications, variable in time and space, and development of models can be arduous. Model input construction techniques have not been formalized or made easily reproducible. Creating the input files for integrated hydrologic models requires complex GIS processing of raster and vector datasets from various sources. Developing stream network topology that is consistent with the model grid-scale digital elevation model (DEM) is important for robust simulation of surface water and groundwater exchanges. Distribution of meteorological data over the model domain is difficult in complex terrain at the model-grid scale, but is necessary for realistic simulations. As model development requires extensive GIS and computer programming expertise, the use of IHMs has mostly been limited to research groups with available financial, human, and technical resources. Here we present a series of open-source Python scripts that are combined with ESRI ArcGIS to provide a formalized technique for the parameterization and development of inputs for the readily available IHM called GSFLOW. This Python toolkit automates many of the necessary and laborious processes of parameterization, including stream network development, land coverages, and meteorological distribution over the model domain. The final products of the toolkit are PRMS ready Parameter Files, along with several input parameters for a MODFLOW model, including input for the Streamflow Routing Package. A demonstration of the toolkit is provided to illustrate its capabilities.

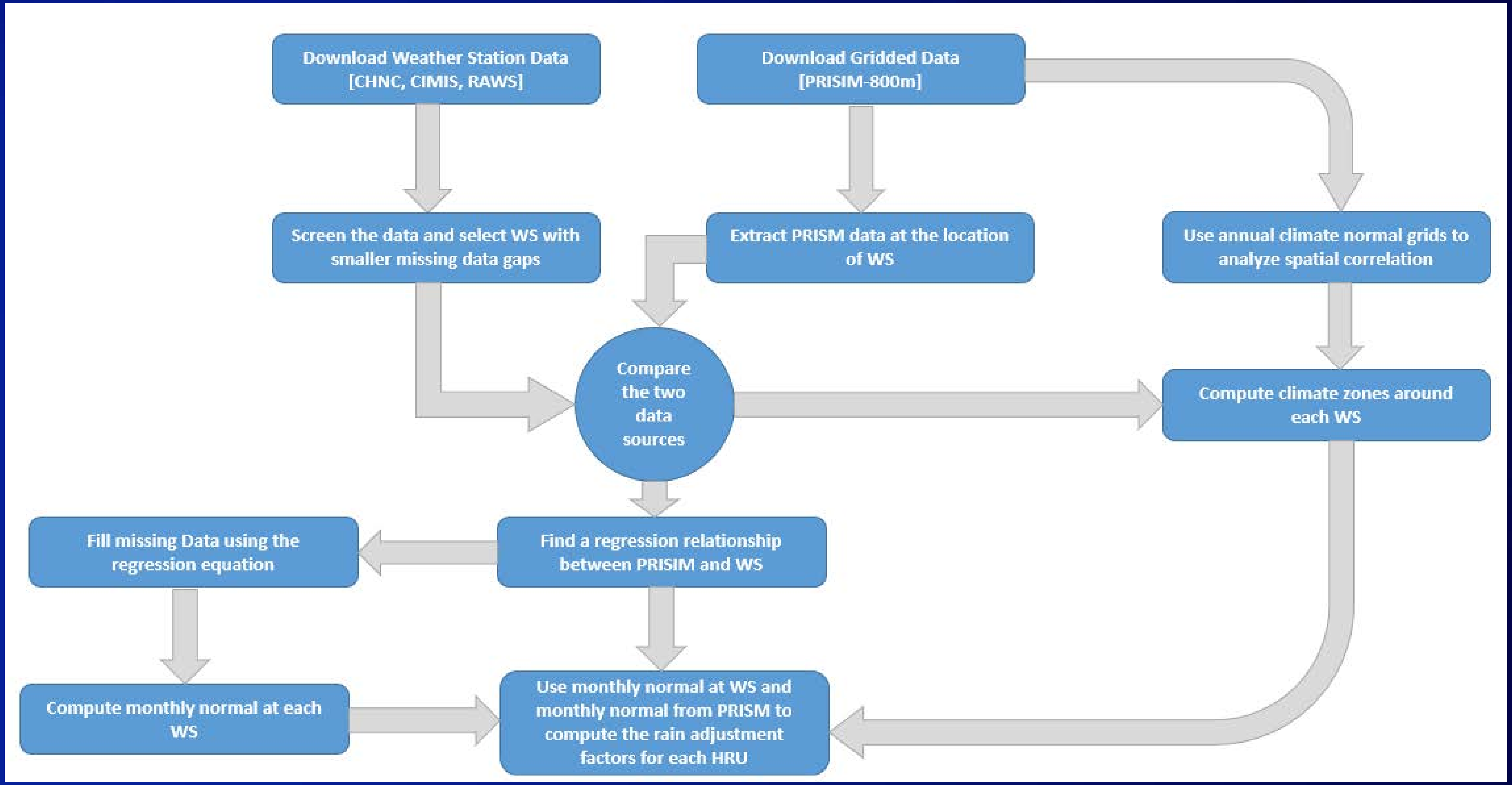
GEOSPATIAL DATA REQUIREMENTS

- Easy to acquire in the US through USDA Geospatial Data Gateway

1. DEM
2. Watershed boundary or outflow point
3. Vegetation
4. Soil
5. Geology
6. Impervious cover
7. Climate
8. NHD (guide)

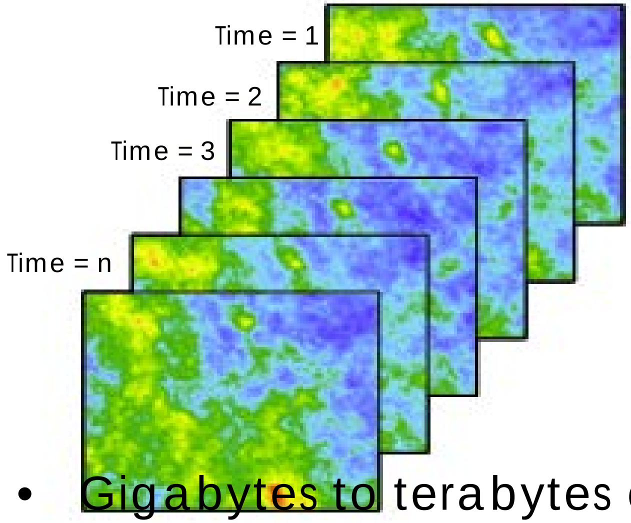
CLIMATE DISTRIBUTION

- Need to define daily climate (Tmin, Tmax, PPT) for each HRU in watershed



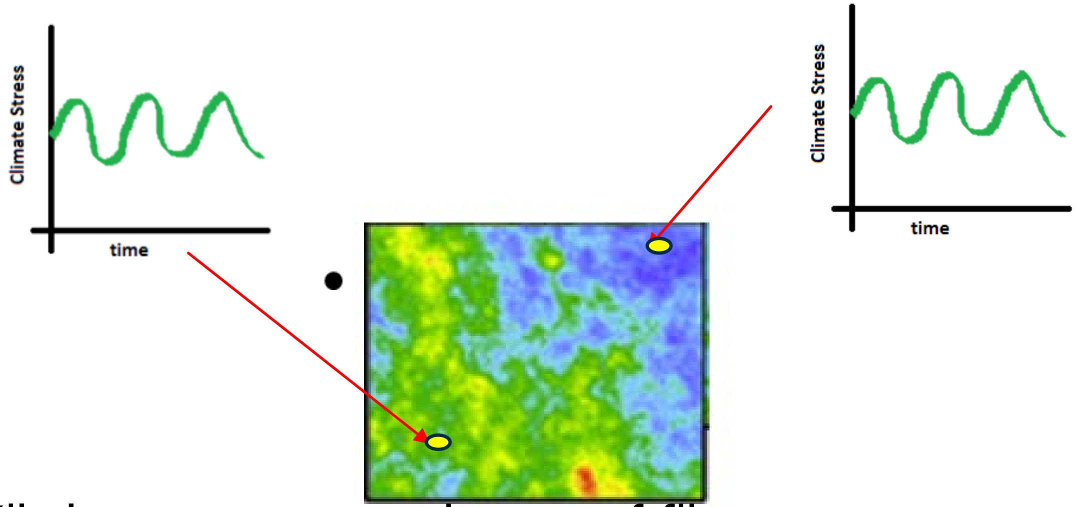
CLIMATE DISTRIBUTION

- Option 1: Read daily grids into model



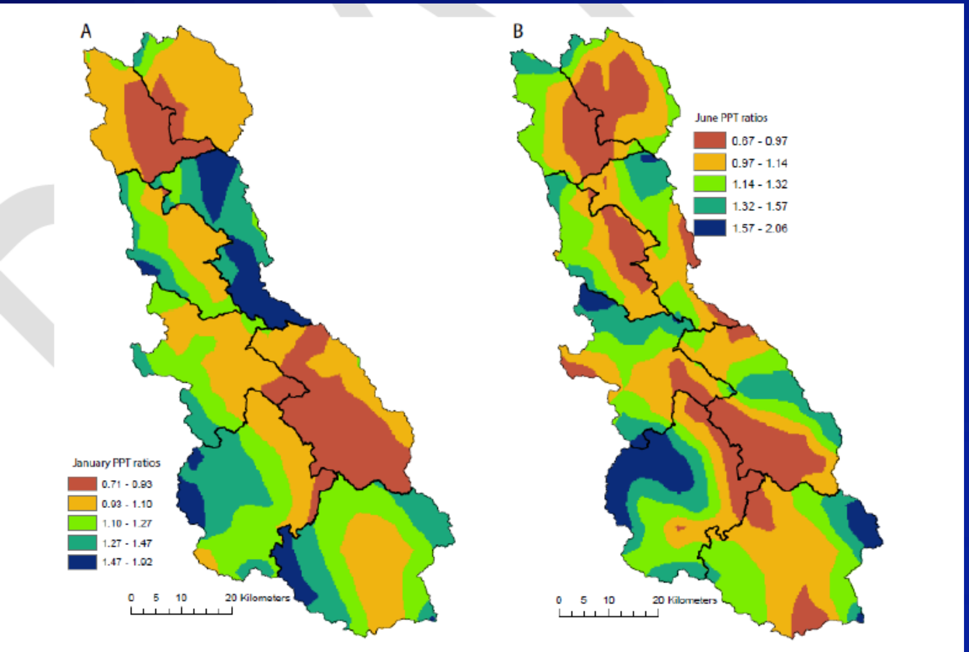
- Gigabytes to terabytes of file storage

- Option 2: Use PRISM monthly averages to distribute daily climate station to sub-basin HRUs/cells



- Kilobytes to megabytes of file storage

CLIMATE DISTRIBUTION

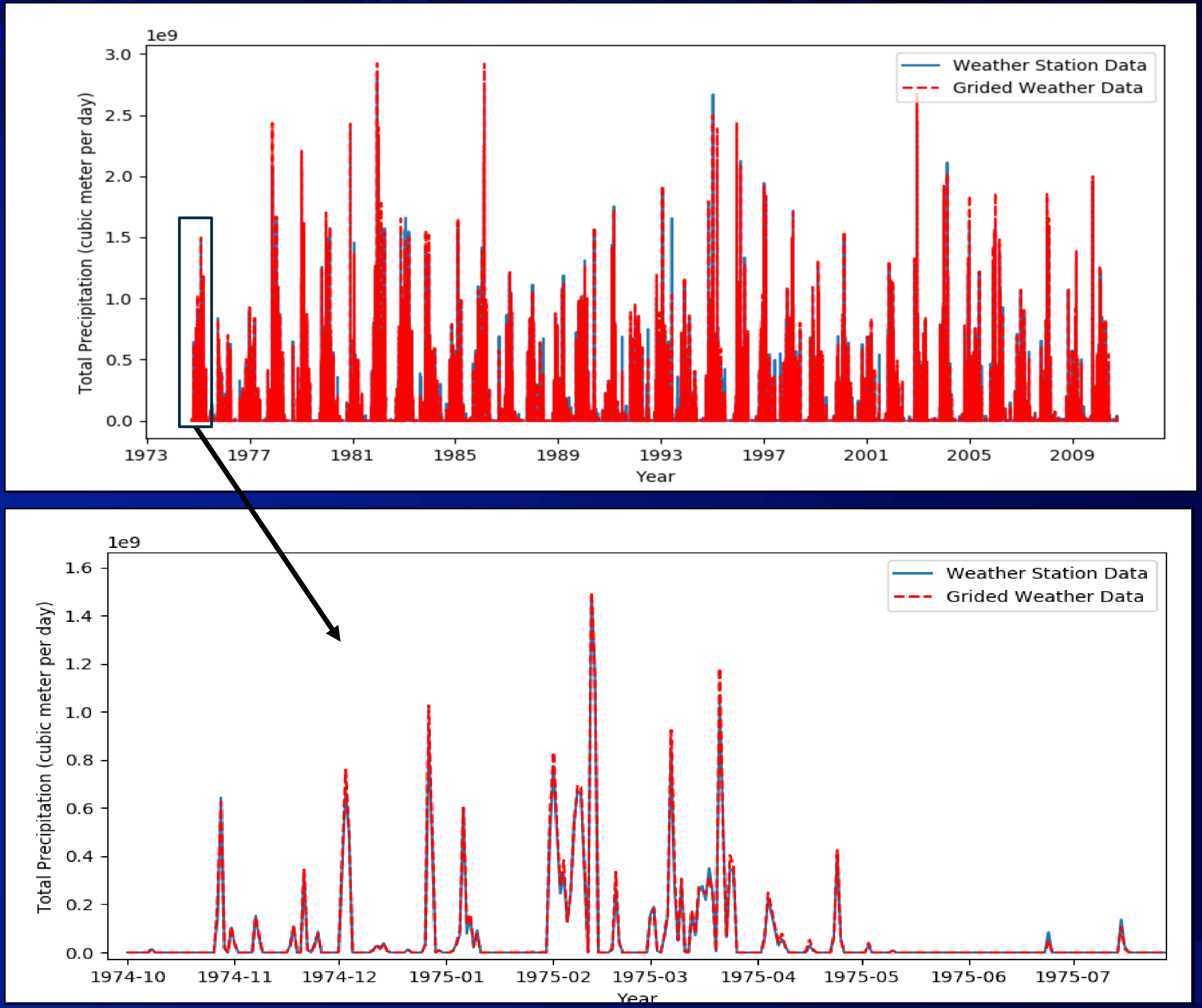


$$P^m_{HRU} = P^m_{sta} CF_{HRU}$$

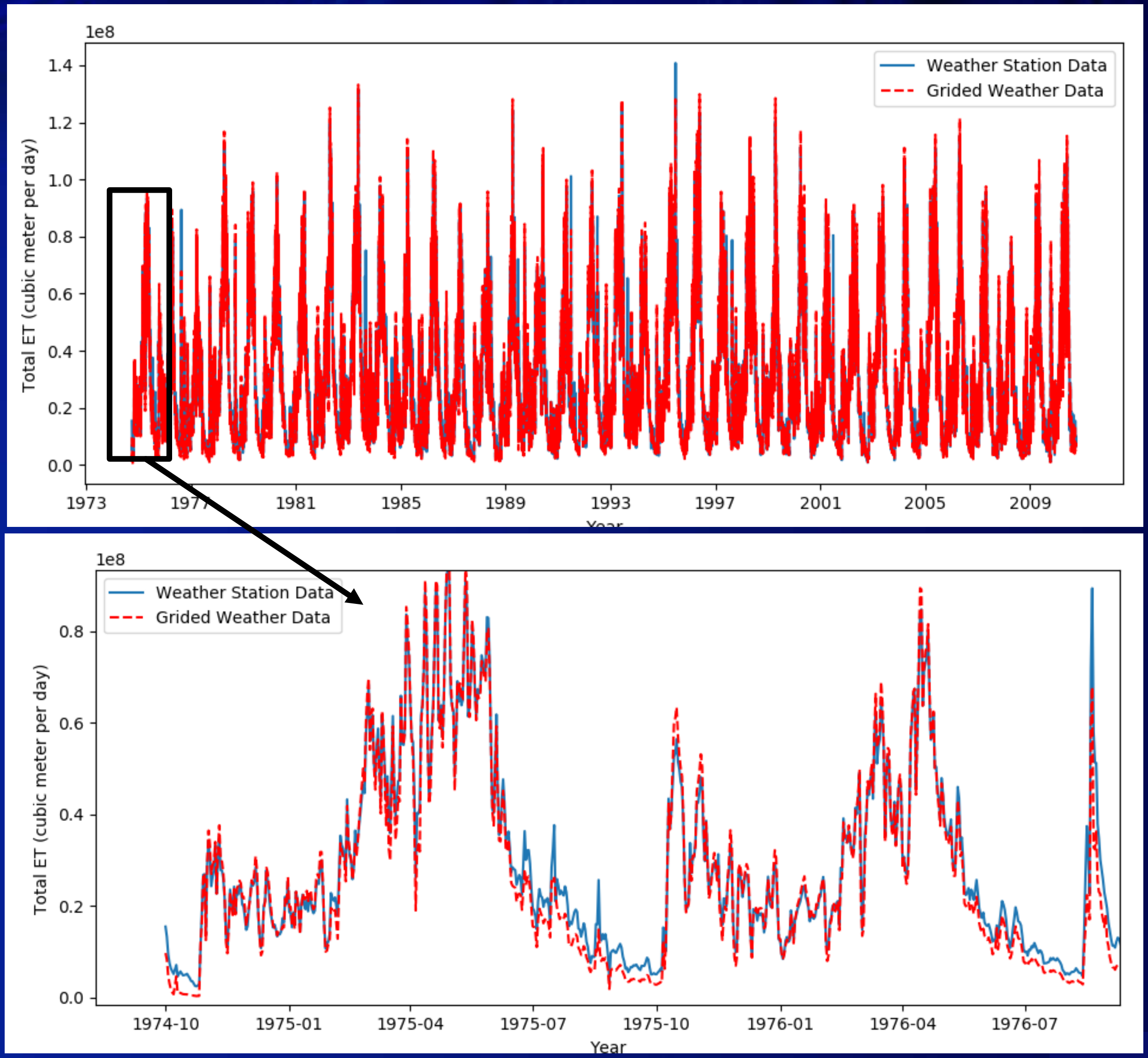
$$T^m_{HRU} = T^m_{sta} - b_{month}\left(\frac{Z_{HRU} - Z_{tsta}}{1000}\right) - taf_{HRU}$$

- Option 2: Use PRISM monthly averages to distribute daily climate station to sub-basin HRUs/cells
- P and T are distributed internally within memory for each time step; no need to store more than 1 day

COMPARISON BETWEEN INTERNALLY DISTRIBUTED AND SPECIFIED DAILY CLIMATE GRIDS

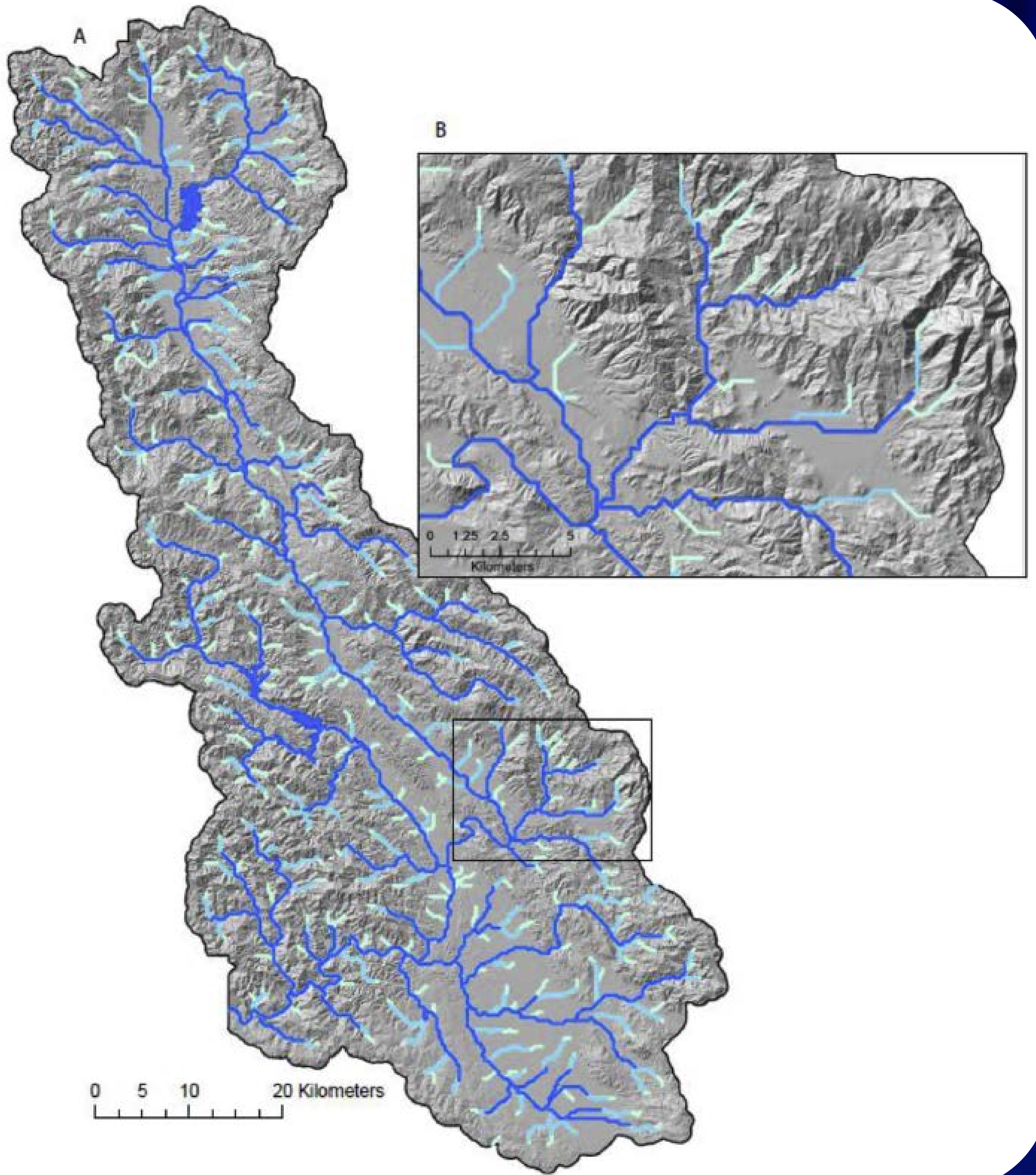


COMPARISON BETWEEN INTERNALLY DISTRIBUTED AND SPECIFIED DAILY CLIMATE GRIDS



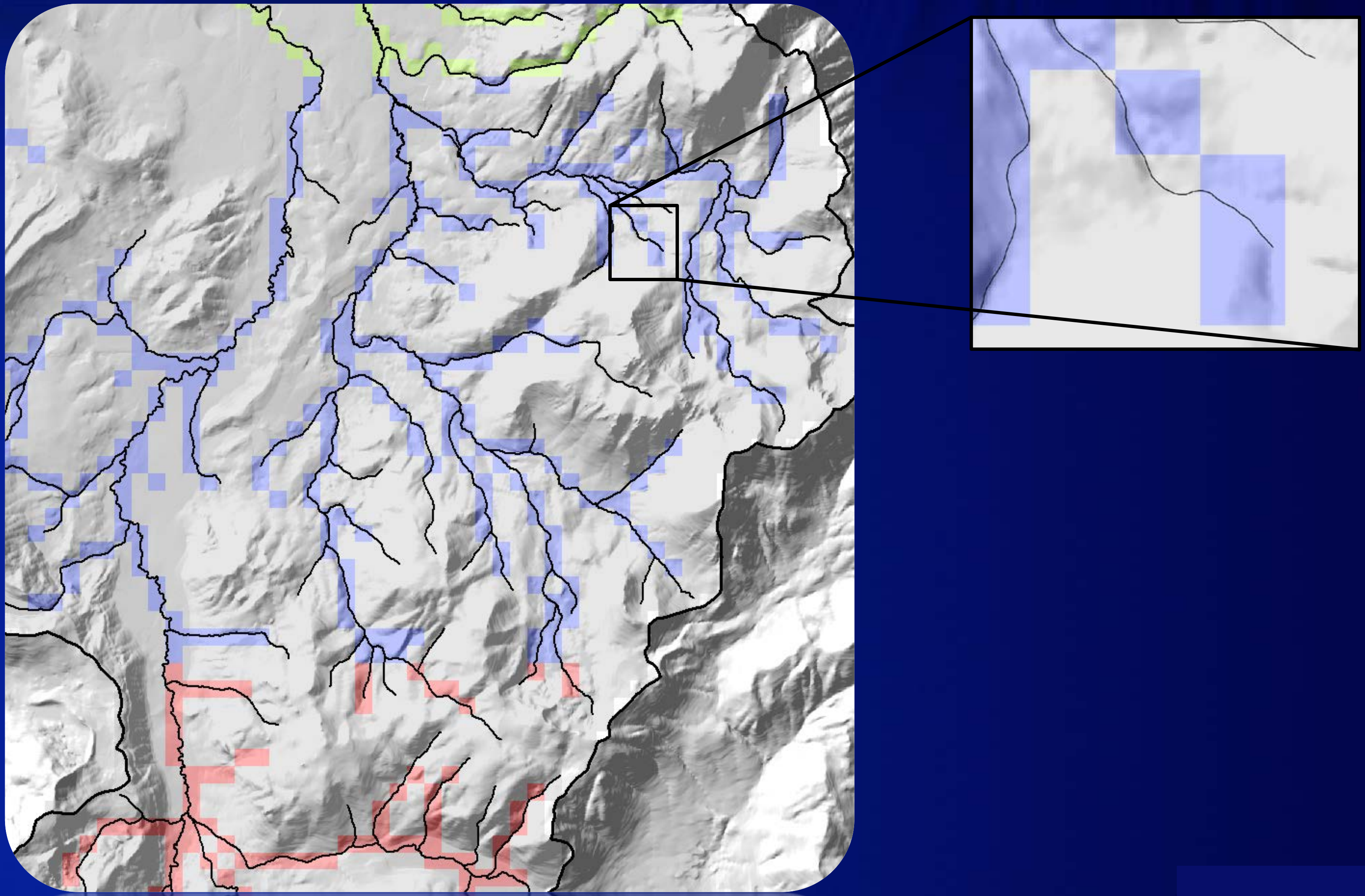
CREATING A STREAM NETWORK

- Important, must be done correctly for stable model, can't use NHD+, etc.



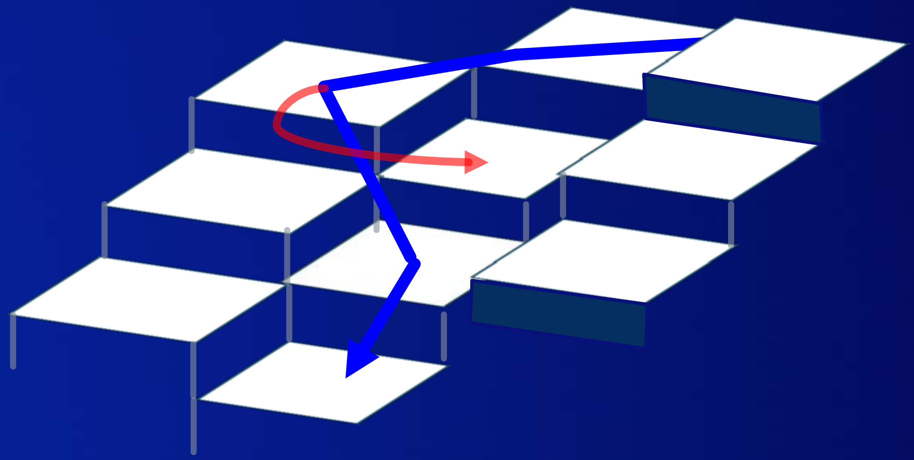
STREAM NETWORK

- NHD and stream networks generated using DEM scale smaller than model grid are problematic for SW-GW models



SPURIOUS SW-GW EXCHANGES

- Streams offset from stream canyons cause excessive spring discharge, resulting in slow/unstable models



GSFLOW-ARCPY

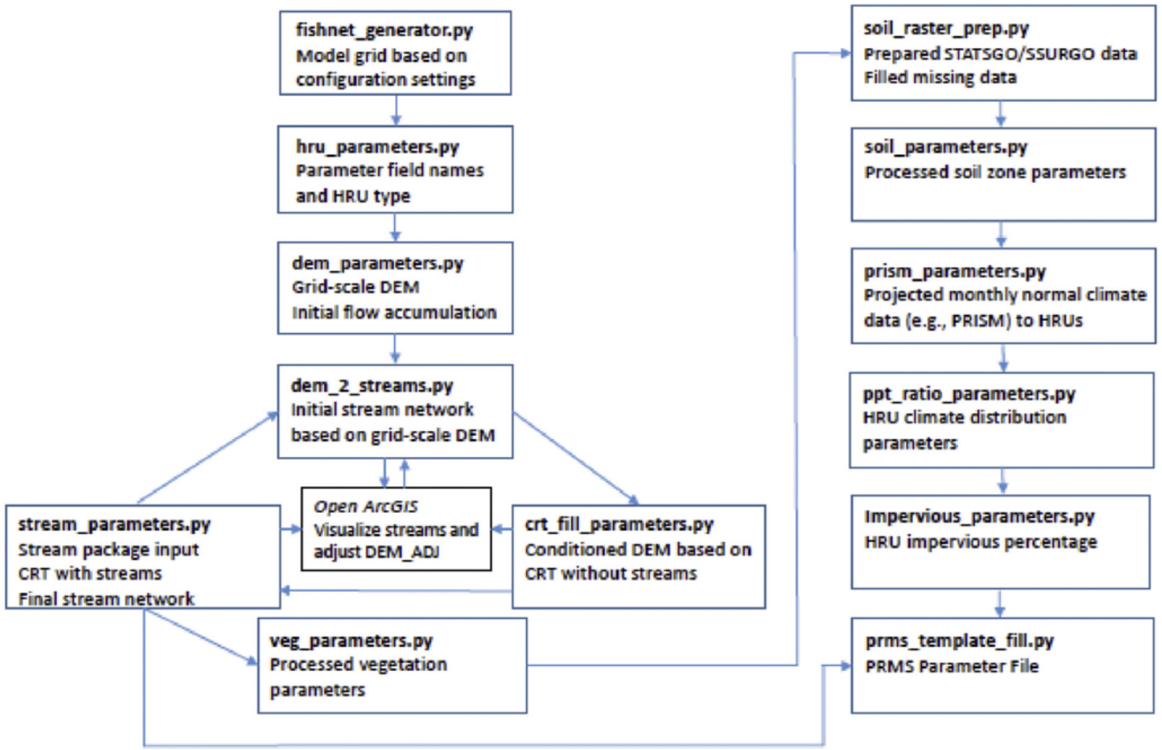


Fig. 1. Diagram illustrating the process flow for Gsflow-Arcpy and the 13 Python scripts that carry out the automated procedure for developing GSFLOW input datasets. The Cascade Routing Tool (CRT; Henson et al., 2013) is used by Gsflow-Arcpy.

GSFLOW-ARCPY CONFIGURATION AND REMAP FILES

- Config file (“.INI”) defines working directory
- Remap files define categorical variables

CLASS EXERCISE

1. Install Jupyter notebooks into Arcpy folder:
   - In Windows explorer navigate to C:\Python27\ArcGIS10.5\Scripts (#s in yellow vary)
   - type "cmd" in the folder address line
   - Type "pip install jupyter" (if this does not work follow instructions in readme file located gw3099_classrepo\exercises\GSFLOW\notebook

2. Install pyprms into Arcpy folder
   - Copy pyprms folder from .\gw3099_classrepo\exercises\GSFLOW\prmspy
   - Paste pyprms folder into C:\Python27\ArcGIS10.5\Lib\site-packages.

3. Change paths in configuration file.
   - Navigate to: .\gw3099_classrepo\exercises\GSFLOW\examples\sagehen.
   - Open "sagehen_parameters.ini" in text editor.
   - Replace first part of paths by globally replacing "C:\Users\rniswon\Documents\Data\Git\" using the correct path for your computer.

4. Open Jupyter Notebook
   - Navigate to .\ gw3099_classrepo\exercises\GSFLOW\notebook
   - Right click on "jupyter.bat" file and open in text editor.
   - In jupyter.bat change path "C:\Python27\ArcGIS10.5\Scripts\jupyter-notebook.exe" to be correct for your computer; save and close the file.
   - Double click jupyter.bat and the notebook should open.

5. Change paths in notebook to the correct paths for your computer
   - There are paths specified at the beginning and end of the notebook that need to be corrected for your computer.

6. Change paths in Sagehen_run.control
   - Navigate to gw3099_classrepo\exercises\GSFLOW\examples\sagehen\model\windows
   - Open sagehen_run.control
   - Do a global replace to correct paths for your computer.