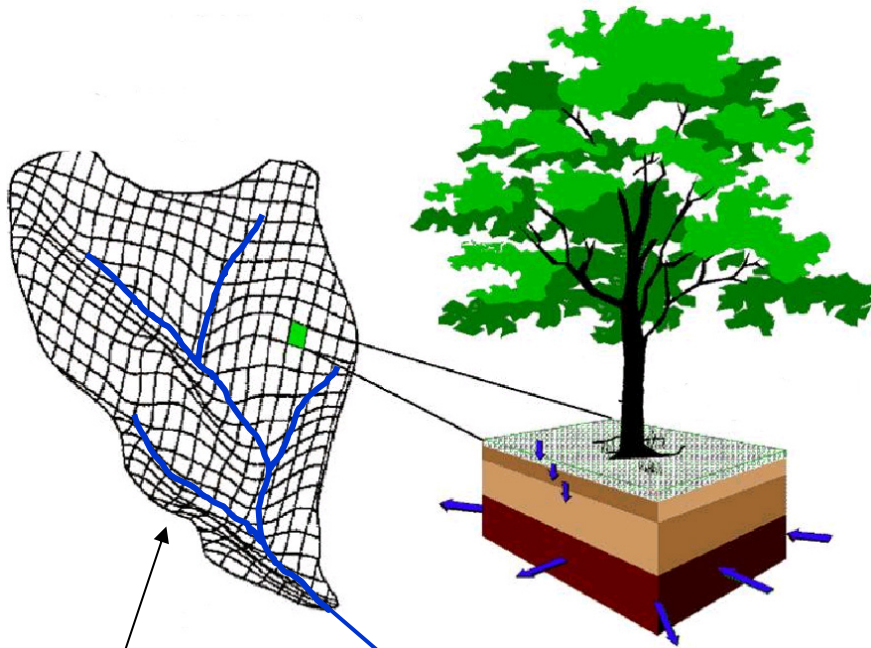


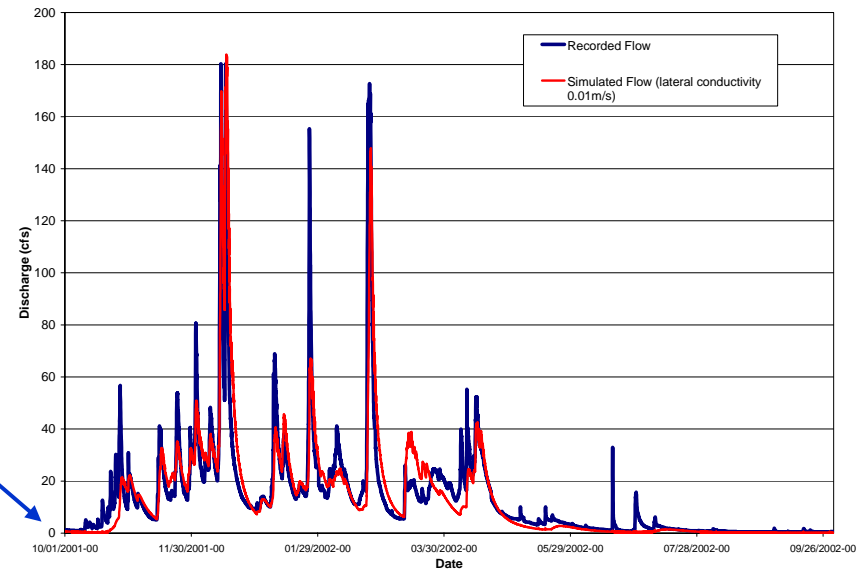
# Hydrologic Modeling with the Distributed-Hydrology- Soils- Vegetation Model (DHSVM)

DHSVM was developed by researchers at the University of Washington and the Pacific Northwest National Lab

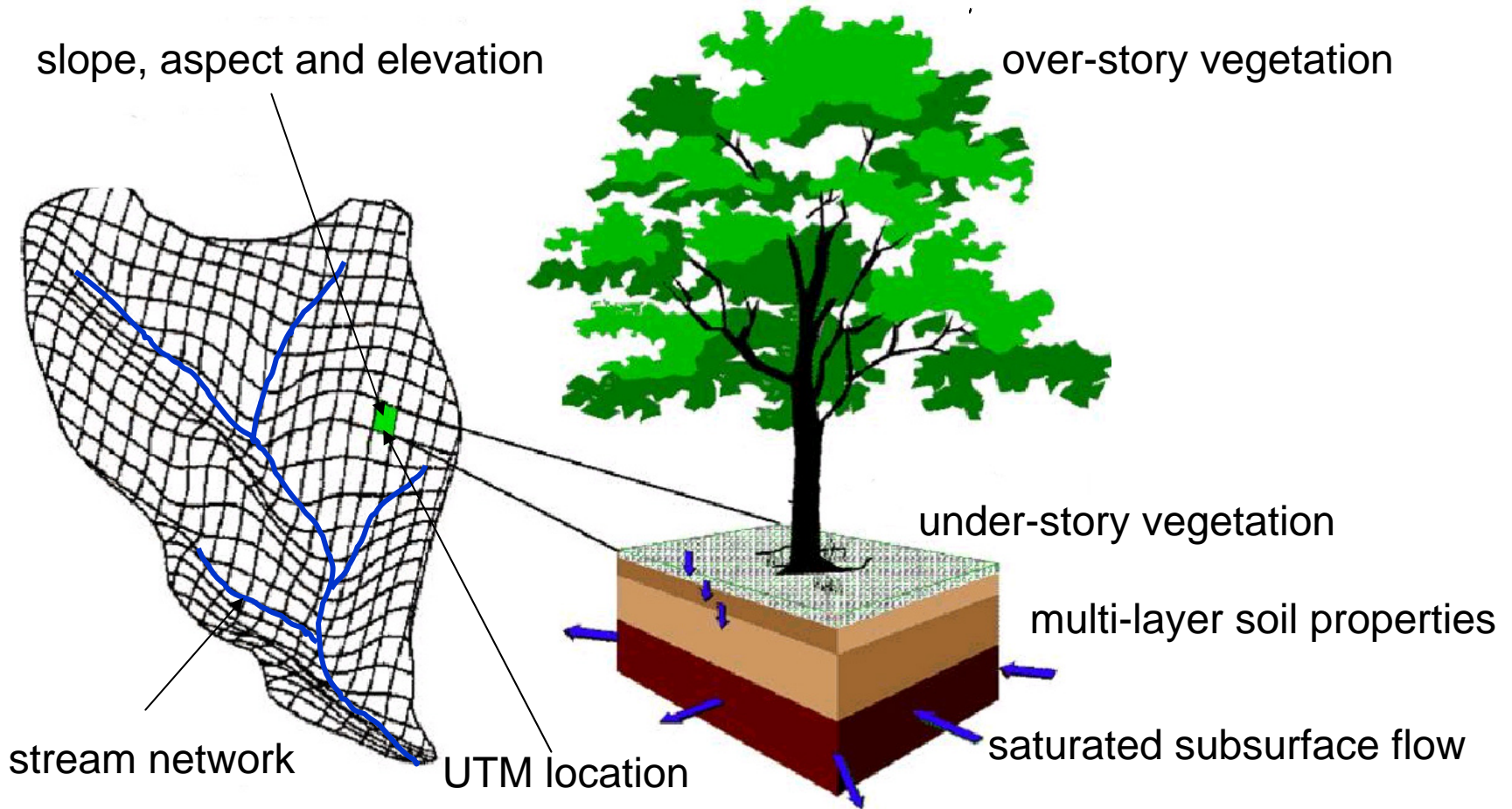


GIS grid-based representation  
(30 m x 30 m)

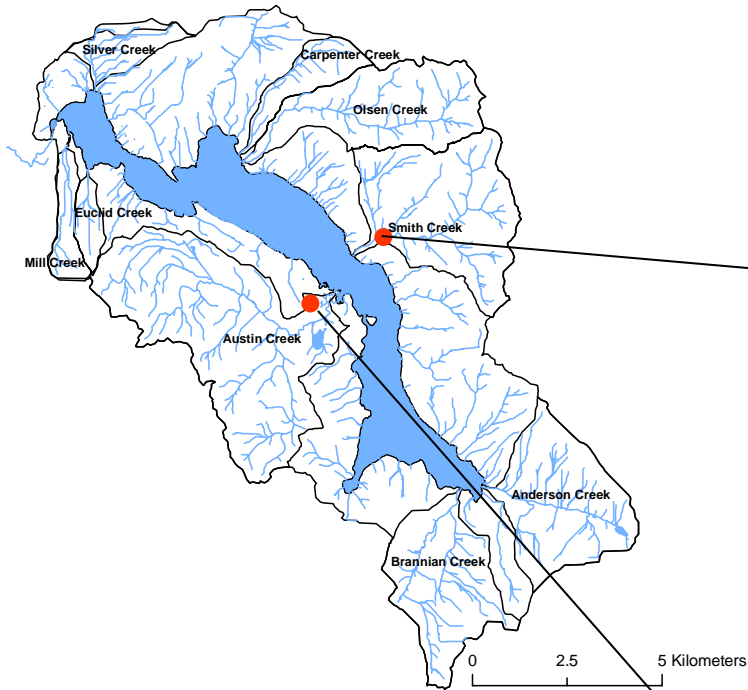
### Simulated versus Measured Discharge



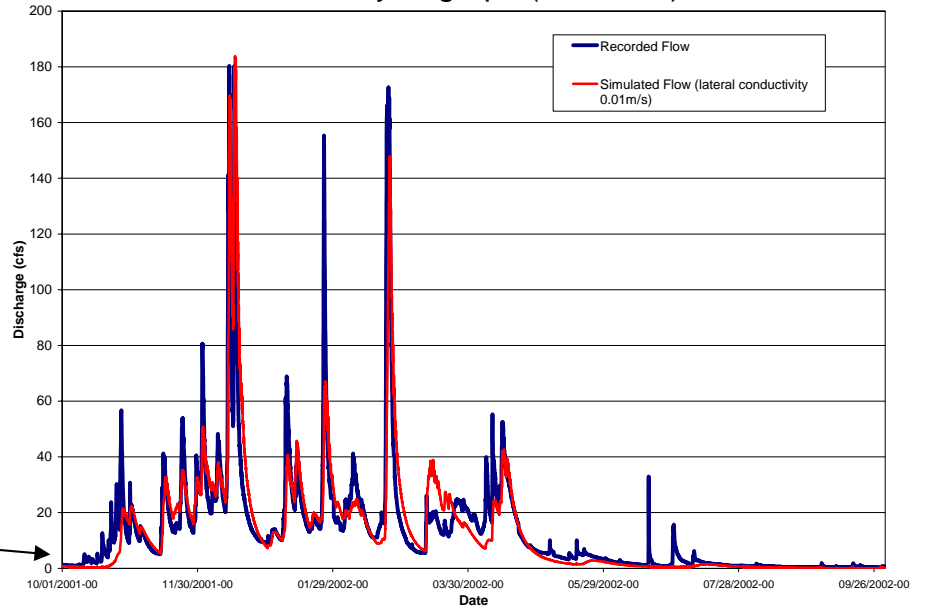
Each 30 x 30 meter grid contains information about the



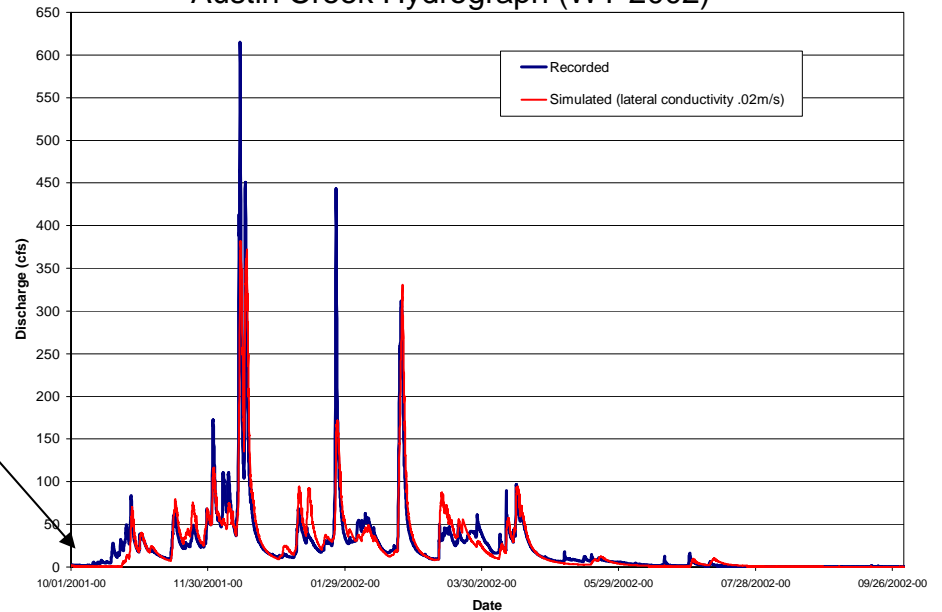
# Thesis results of Katie Kelleher, Geology (2006)



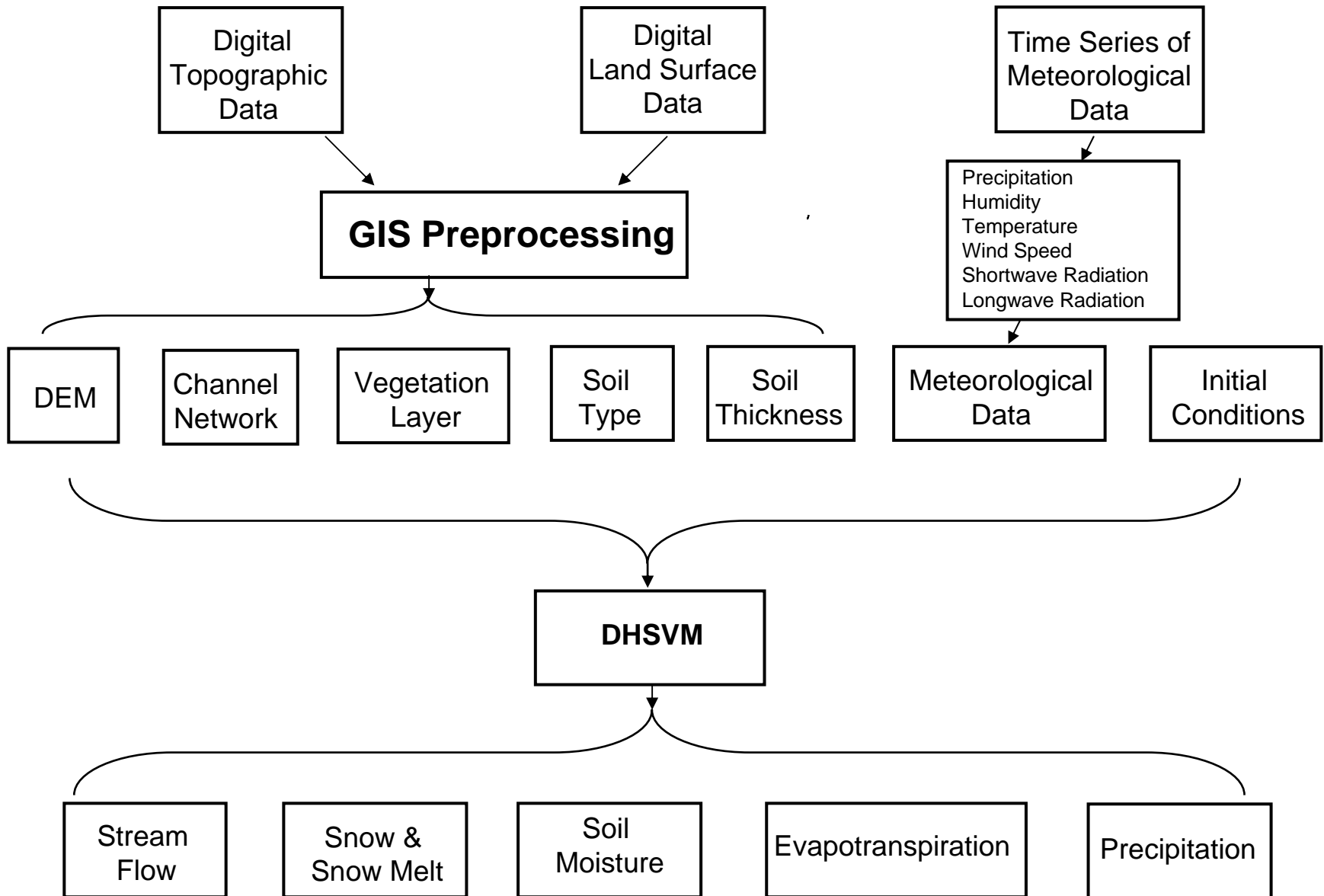
## Smith Creek Hydrograph (WY 2002)



## Austin Creek Hydrograph (WY 2002)

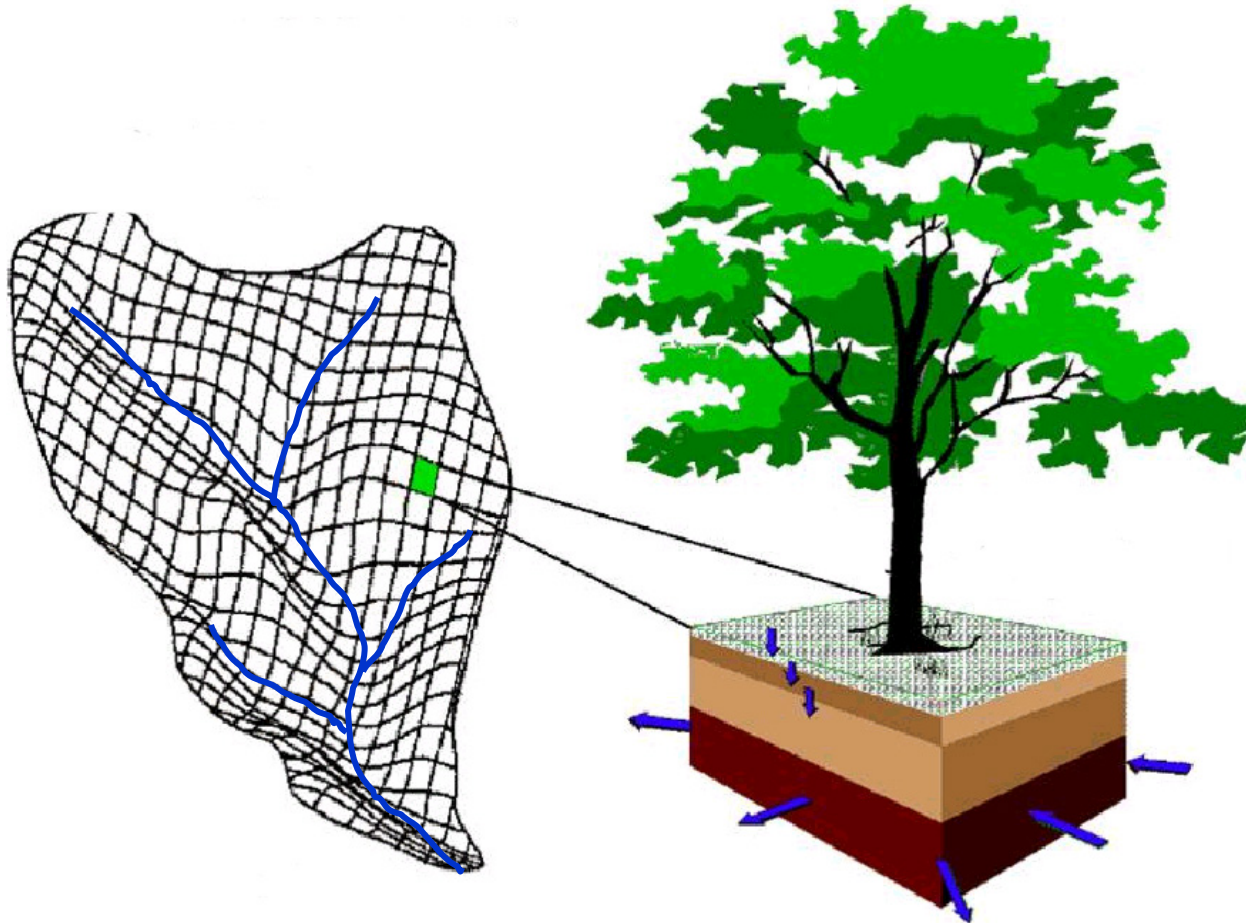


# DHSVM Modeling Inputs and Outputs



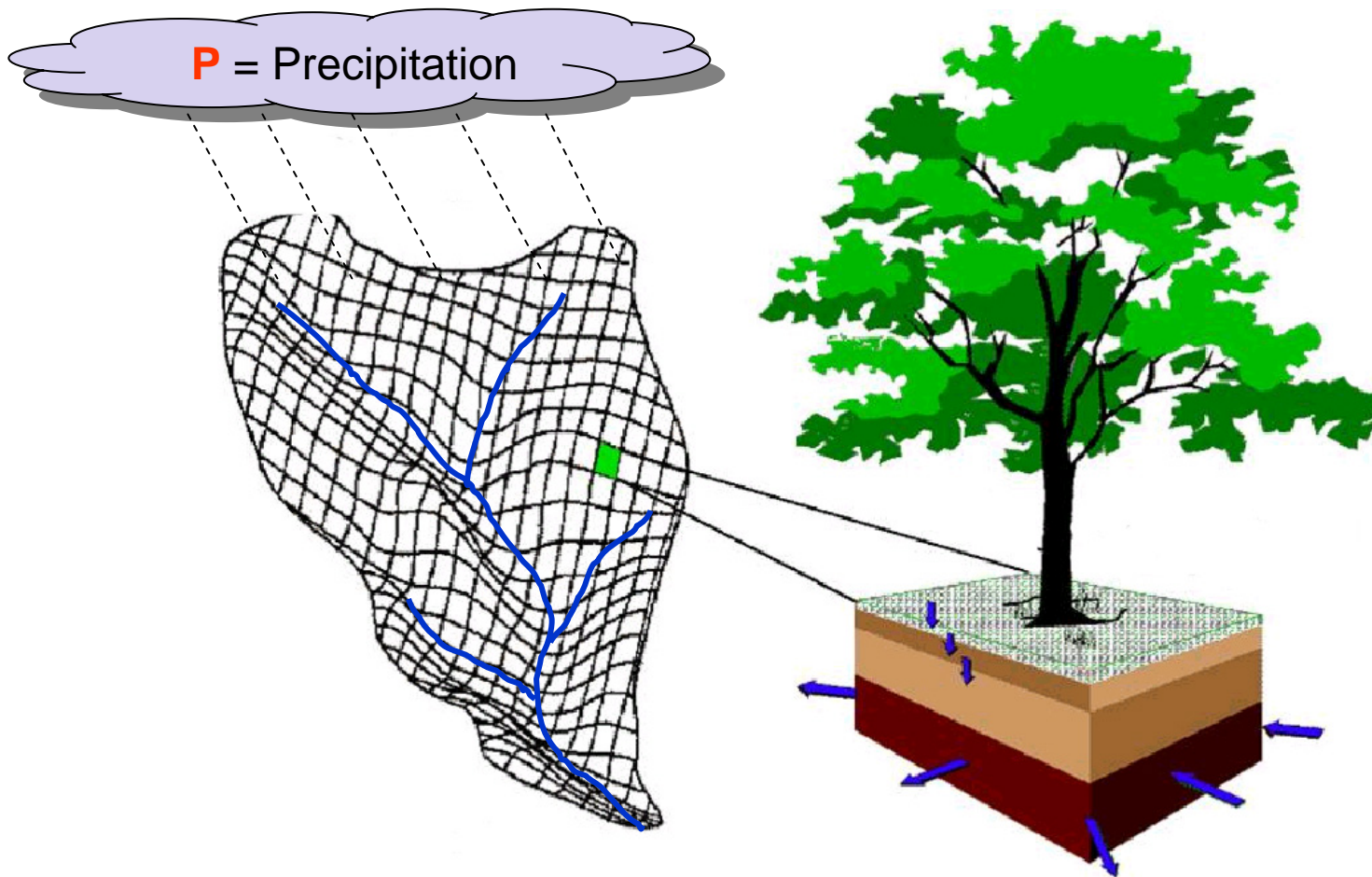
DHSVM calculates a water and energy budget on each grid cell for each time step

inputs - outputs = change in storage

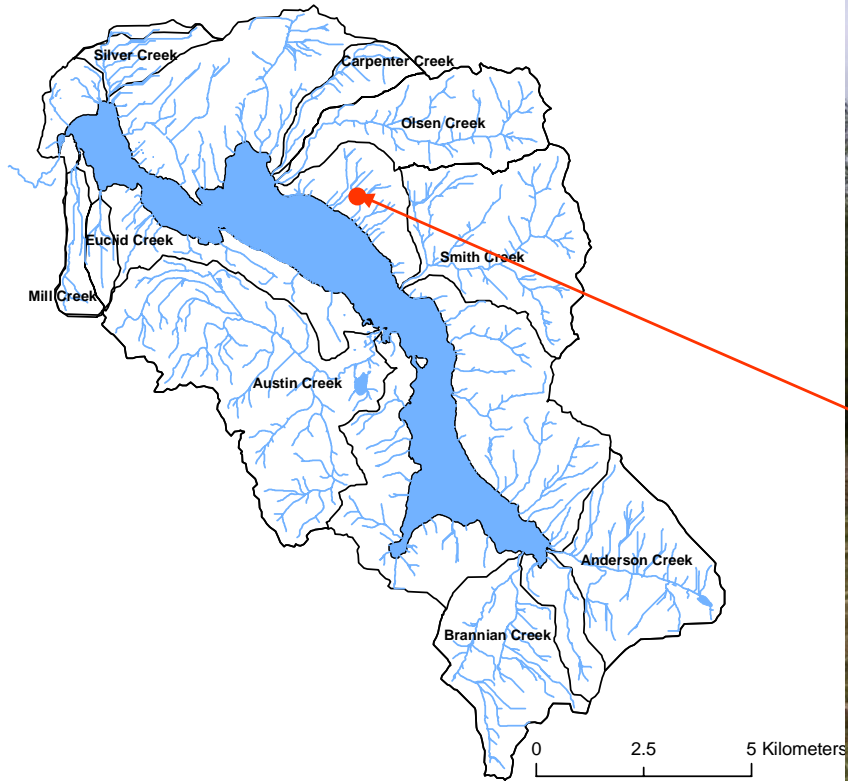


Inputs - Outputs = Change in Storage

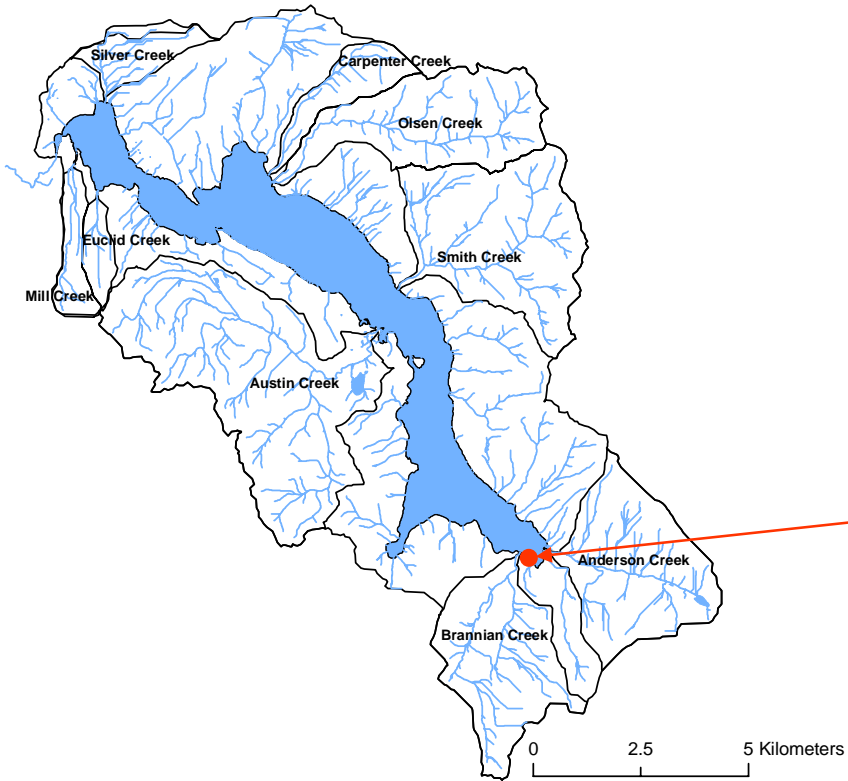
$$P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W$$



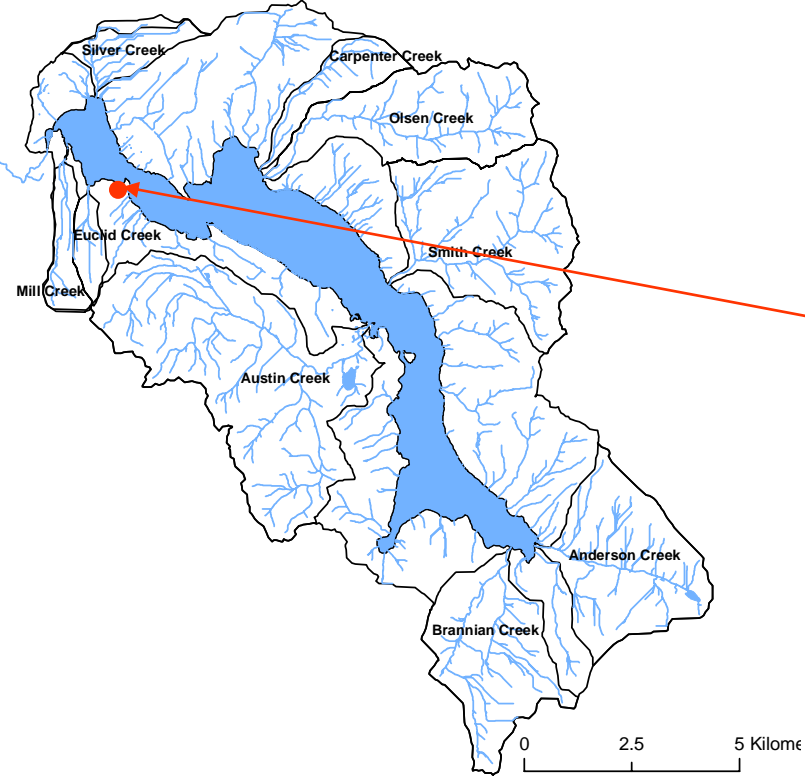
# North Shore Meteorological (MET) Station



## Brannian Creek Rain Gauge



# Geneva Rain Gauge

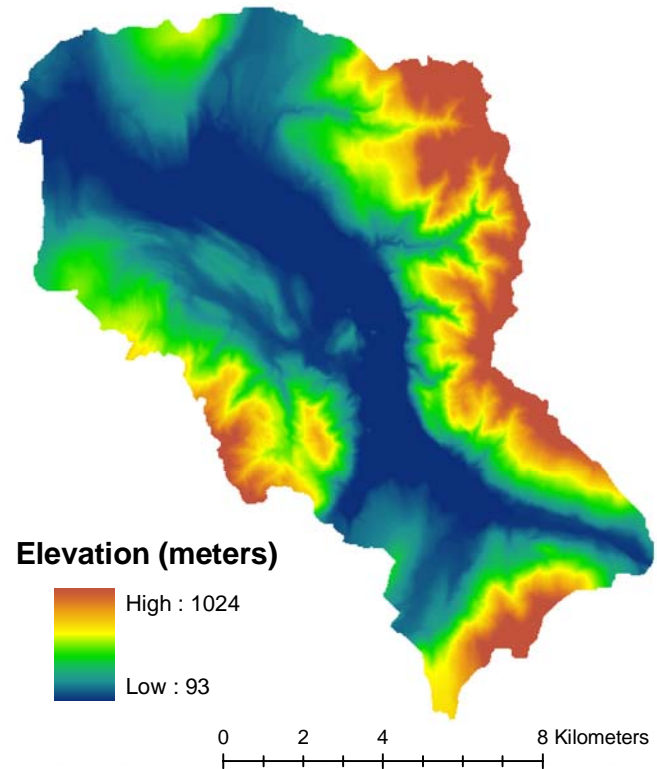
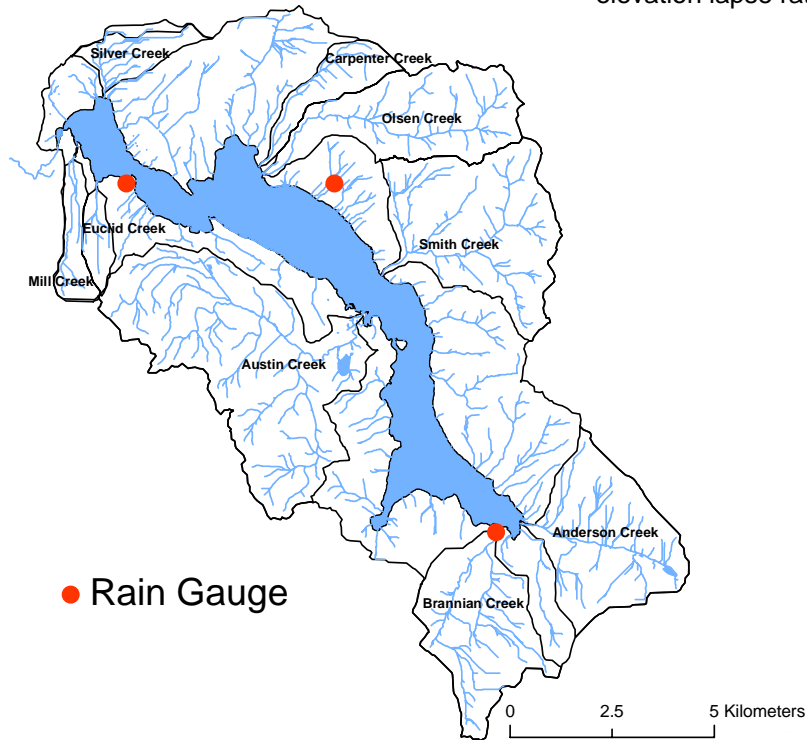


# Rainfall (or snow) is distributed over the DEM

Point Measurements

inverse distance  
elevation lapse rate

Distributed Rainfall (162,669 grid cells)

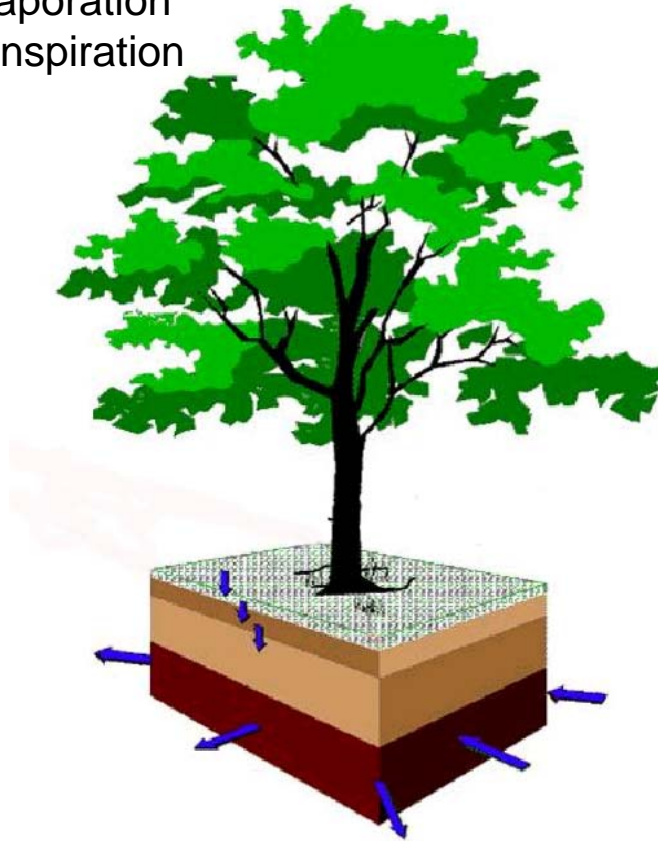


Inputs - **Outputs** = Change in Storage

$$P - \mathbf{E_{io}} - \mathbf{E_{iu}} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W$$

$E_{io}$  = overstory evaporation

$E_{to}$  = overstory transpiration

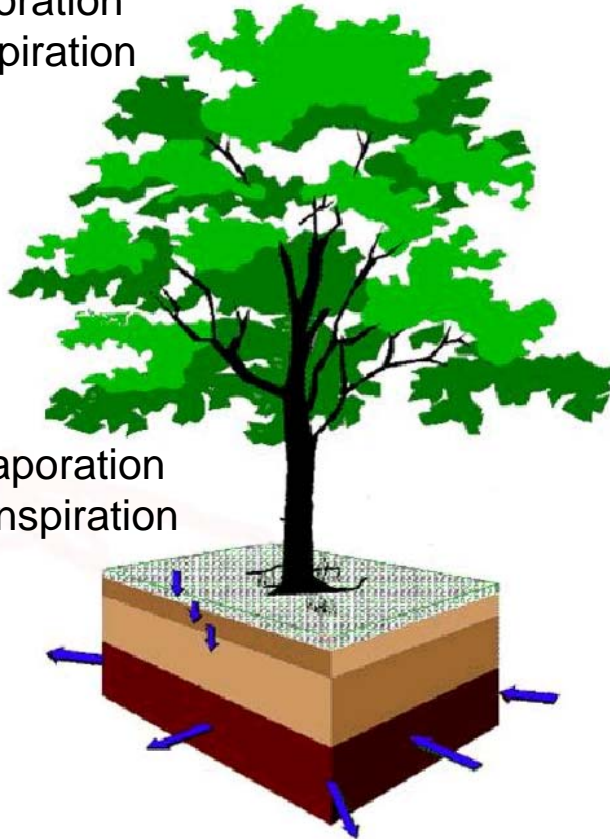


Inputs - **Outputs** = Change in Storage

$$P - E_{io} - E_{iu} - E_s - \mathbf{E_{to}} - \mathbf{E_{tu}} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W$$

$E_{io}$  = overstory evaporation

$E_{to}$  = overstory transpiration



$E_{iu}$  = understory evaporation

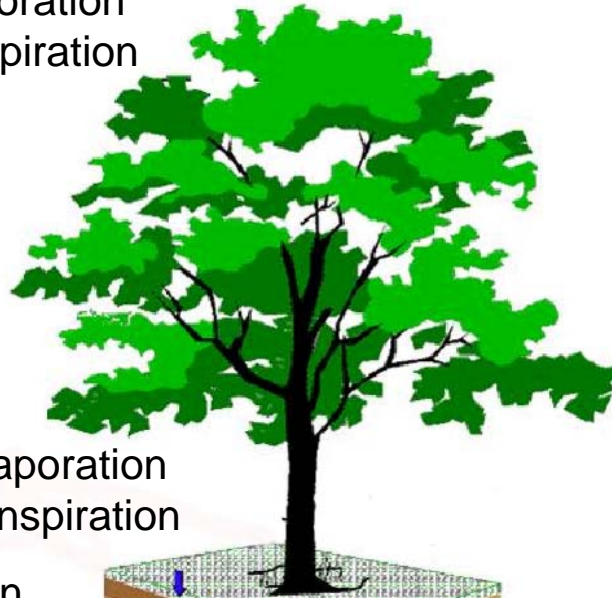
$E_{tu}$  = understory transpiration

Inputs - **Outputs** = Change in Storage

$$P - E_{io} - E_{iu} - \mathbf{E}_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W$$

$E_{io}$  = overstory evaporation

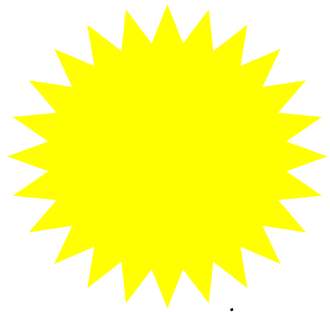
$E_{to}$  = overstory transpiration



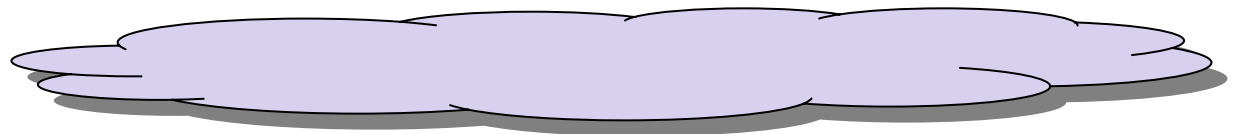
$E_{iu}$  = understory evaporation

$E_{tu}$  = understory transpiration

$\mathbf{E}_s$  = soil evaporation



Incoming shortwave radiation

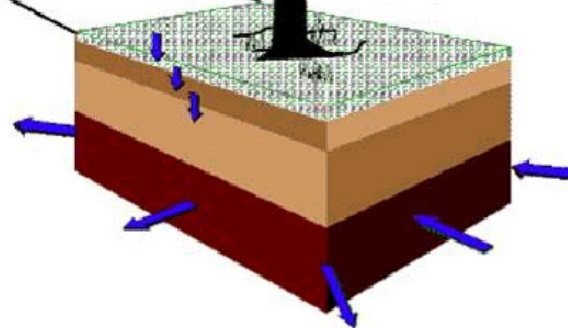
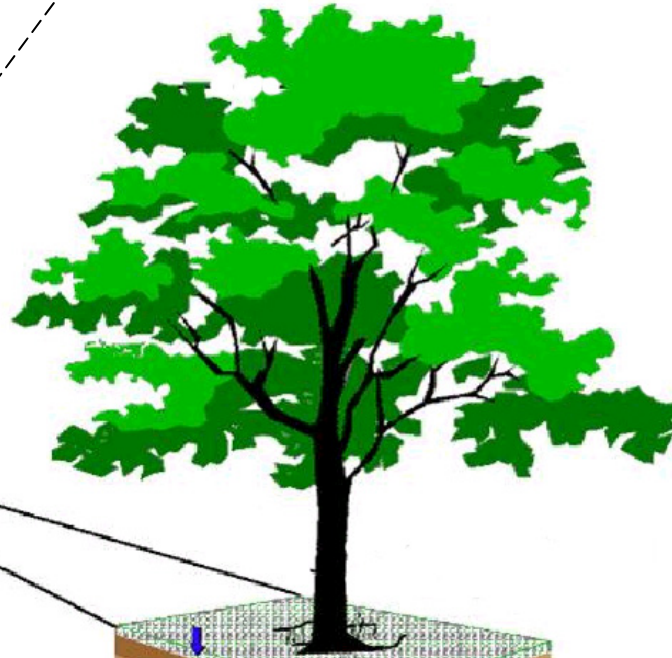
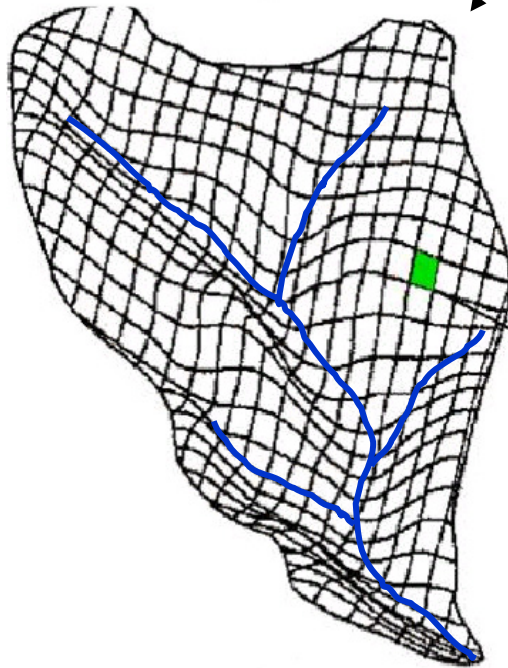


Incoming longwave radiation

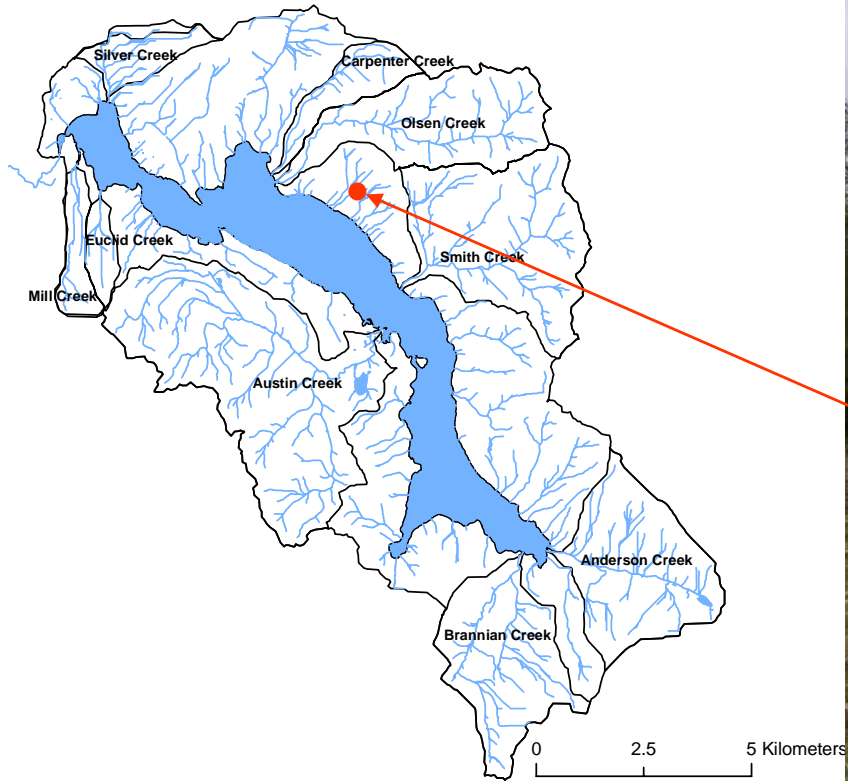
Air Temperature

Humidity

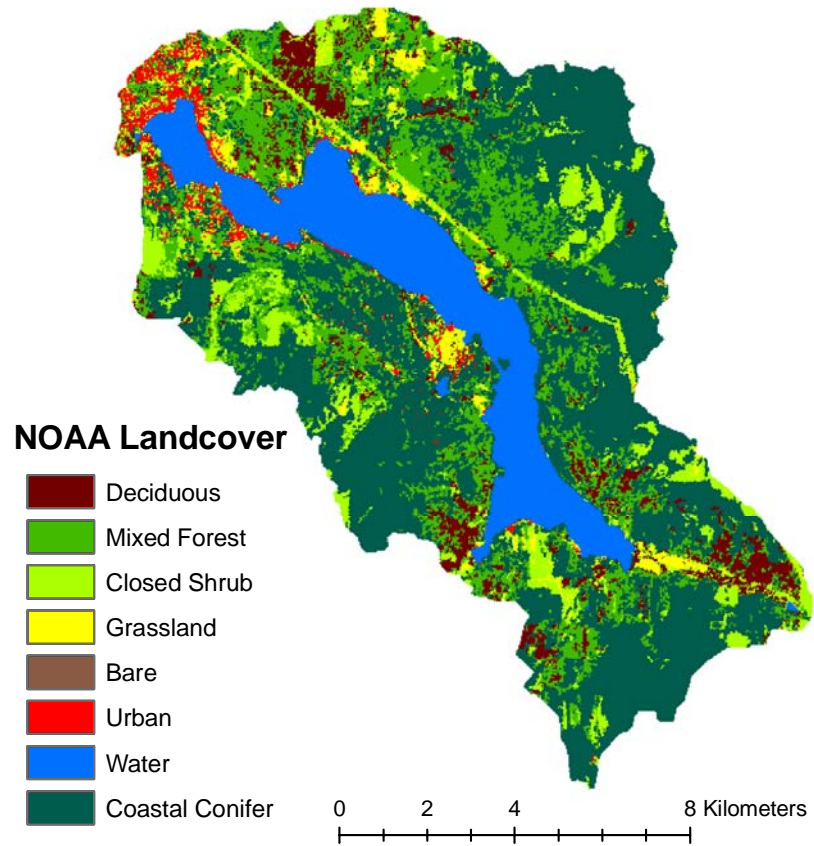
Wind speed



# North Shore MET Station



# Vegetation and Landcover Grid

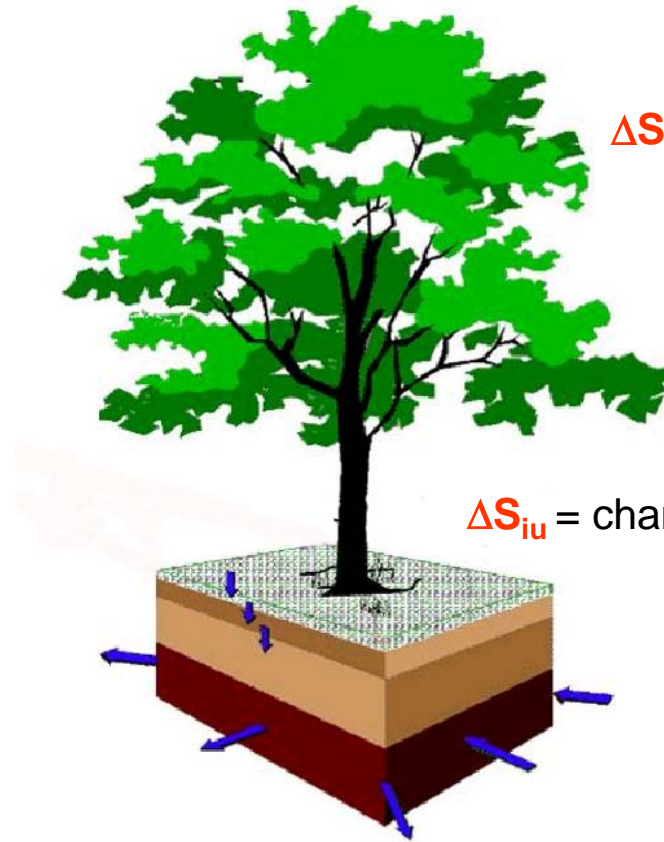


- 1 Evergreen Needleleaf
- 2 Evergreen Broadleaf
- 3 Deciduous Needleleaf
- 4 Deciduous Broadleaf
- 5 Mixed Forest
- 6 Woodland
- 7 Wooded Grassland
- 8 Closed Shrub
- 9 Open Shrub
- 10 Grassland
- 11 Cropland
- 12 Bare
- 13 Urban
- 14 Water
- 15 Coastal Conifer Forest**
- 16 Xeric Conif Forest (Dry)
- 17 Mesic Conif Forest (Wet)
- 18 Subalpine Conif Forest
- 19 Alpine Meadow
- 20 Ice
- 21 Wetland

Vegetation Description	15 = <b>Coastal Conifer Forest</b>
Impervious Fraction	15 = 0.0
Overstory Present	15 = TRUE
Understory Present	15 = TRUE
Fractional Coverage	15 = 0.9
Hemi Fract Coverage	15 = 0.9
Trunk Space	15 = .5
Aerodynamic Attenuation	15 = 2.0
Radiation Attenuation	15 = 0.15
Max Snow Int Capacity	15 = 0.040
Snow Interception Eff	15 = 0.6
Mass Release Drip Ratio	15 = 0.4
Height	15 = 50.0 0.5
Overstory Monthly LAI	15 = 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0
Understory Monthly LAI	15 = 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
Maximum Resistance	15 = 5000.0 3000.0
Minimum Resistance	15 = 666.6 200.0
Moisture Threshold	15 = 0.33 0.13
Vapor Pressure Deficit	15 = 4000 4000
Rpc	15 = .108 .108
Overstory Monthly Alb	15 = 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18
Understory Monthly Alb	15 = 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18
Number of Root Zones	15 = 3
Root Zone Depths	15 = 0.10 0.25 0.40
Overstory Root Fraction	15 = 0.20 0.40 0.40
Understory Root Fraction	15 = 0.40 0.60 0.00

Inputs - Outputs = Change in Storage

$$P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W$$

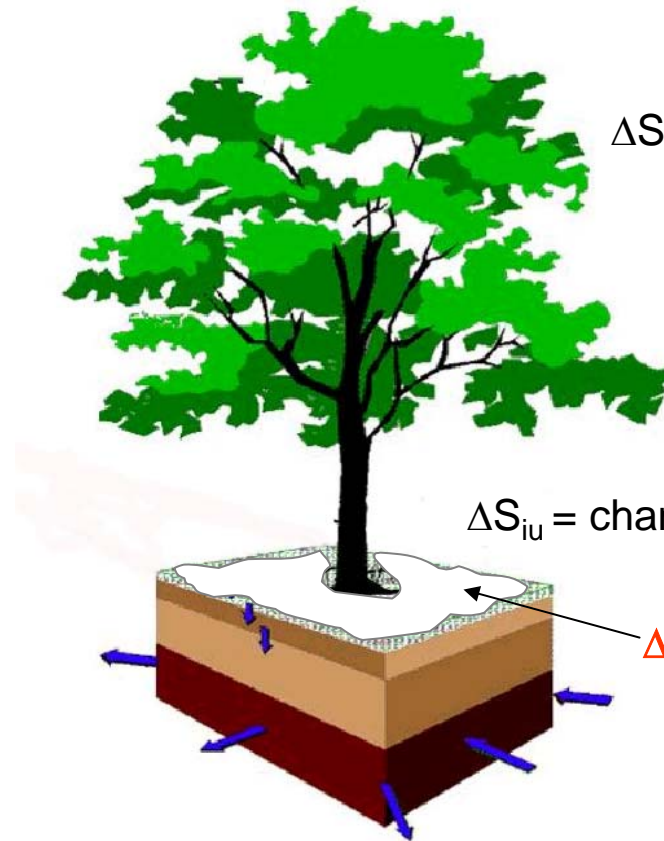


$\Delta S_{io}$  = change in overstory interception storage

$\Delta S_{iu}$  = change in understory interception storage

Inputs - Outputs = **Change in Storage**

$$P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W$$



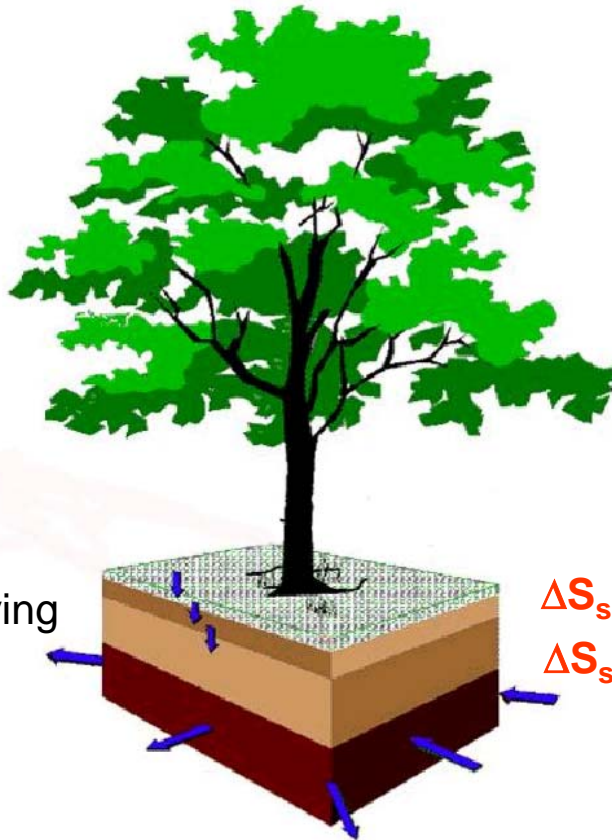
$\Delta S_{io}$  = change in overstory interception storage

$\Delta S_{iu}$  = change in understory interception storage

$\Delta W$  = change in snow-water equivalent

Inputs - Outputs = Change in Storage

$$P - E_{io} - E_{iu} - E_s - E_{to} - E_{tu} - Q_s = \Delta S_{s1} + \Delta S_{s2} + \Delta S_{io} + \Delta S_{iu} + \Delta W$$

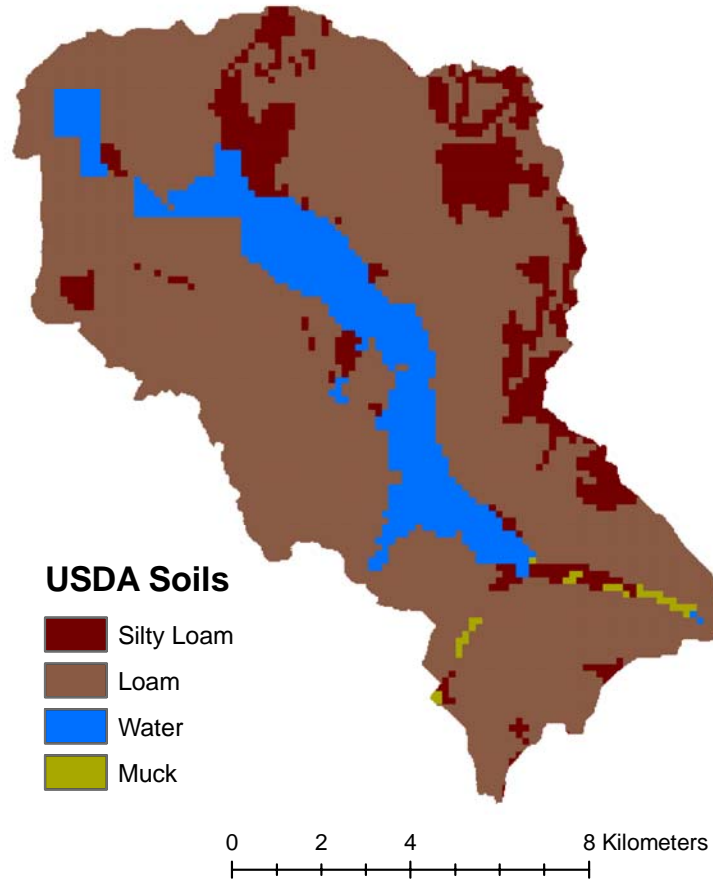


$Q_s$  = discharge leaving the lower soil

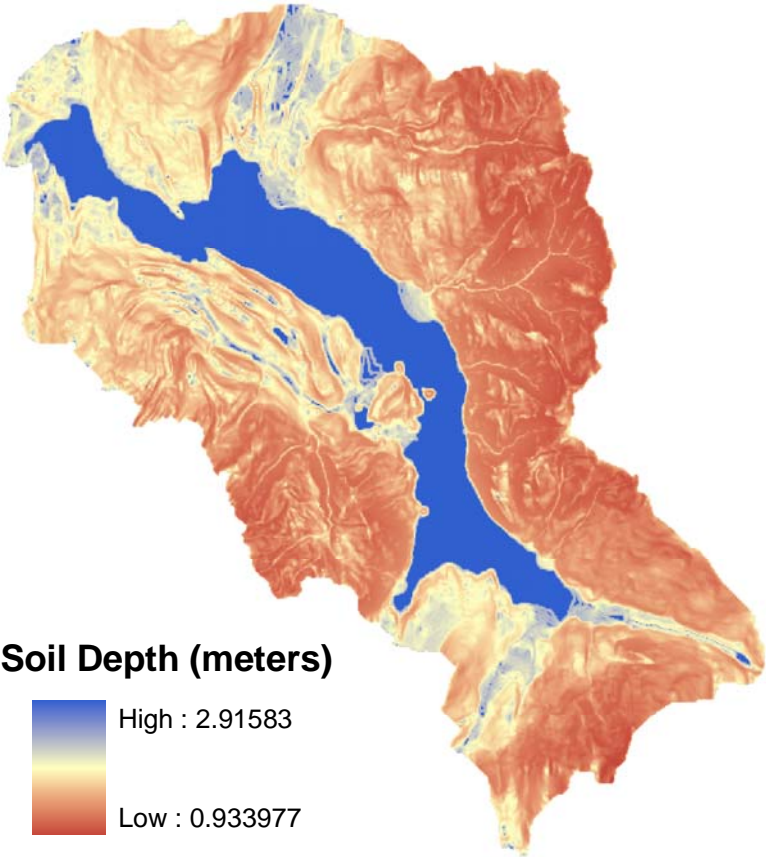
$\Delta S_{s1}$  = change in upper soil storage

$\Delta S_{s2}$  = change in lower soil storage

# Soil Coverage (USDA)



# Soil Depth (estimated)



**Soil Depth (meters)**

High : 2.91583  
Low : 0.933977

0 2 4 8 Kilometers

# USDA Soil Classifications

1 = SAND

2 = LOAMY SAND

3 = SANDY LOAM

4 = SILTY LOAM

5 = SILT

**6 = LOAM**

7 = SANDY CLAY LOAM

8 = SILTY CLAY LOAM

9 = CLAY LOAM

10 = SANDY CLAY

11 = SILTY CLAY

12 = CLAY

13 = ORGANIC (as loam)

14 = WATER (as clay)

15 = BEDROCK

16 = OTHER (as SCL)

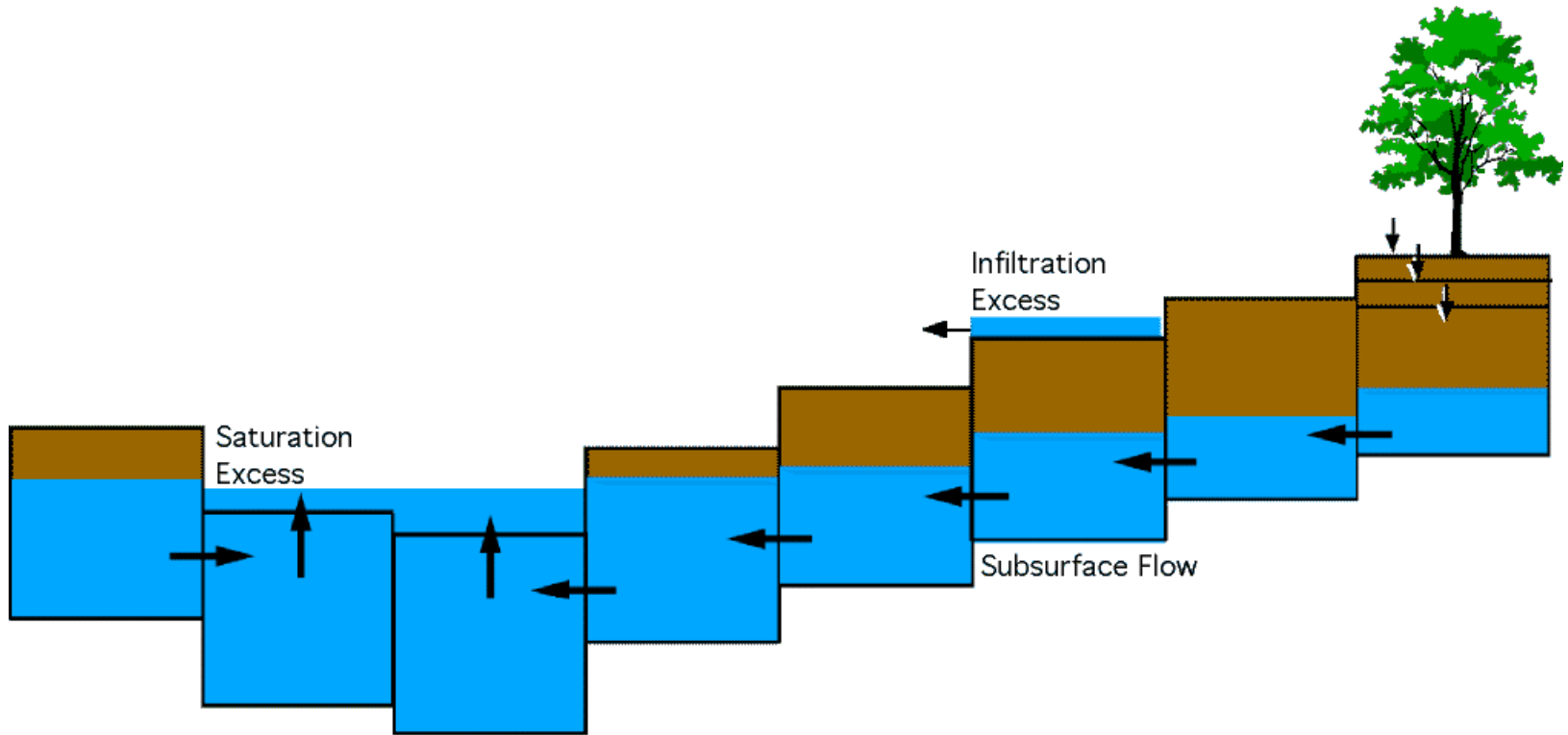
17 = MUCK

18 = TALUS

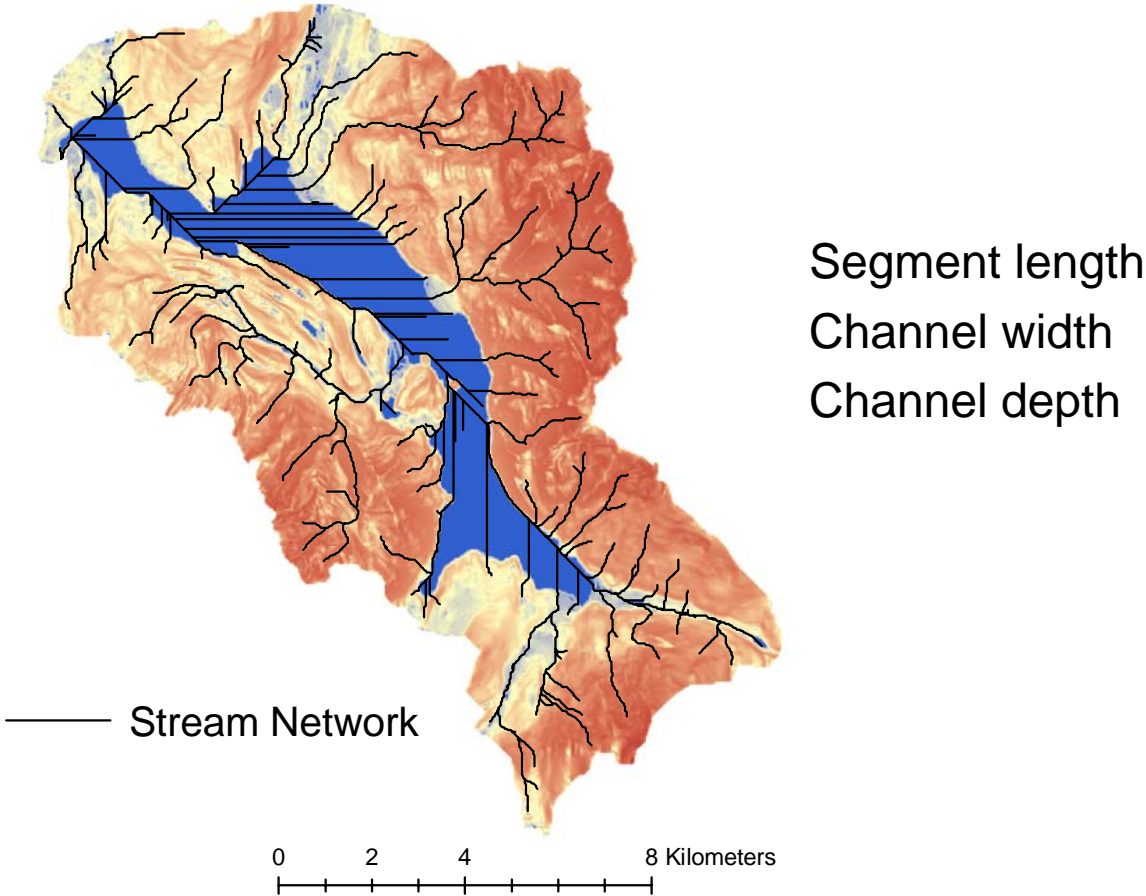
## SOIL 6

Soil Description	<b>6 = LOAM</b>
Lateral Conductivity	6 = 0.01
Exponential Decrease	6 = 3.0
Maximum Infiltration	6 = 1e-5
Surface Albedo	6 = 0.1
Number of Soil Layers	6 = 3
Porosity	6 = .43 .43 .43
Pore Size Distribution	6 = .19 .19 .19
Bubbling Pressure	6 = .11 .11 .11
Field Capacity	6 = .29 .29 .29
Wilting Point	6 = .14 .14 .14
Bulk Density	6 = 1485. 1485. 1485.
Vertical Conductivity	6 = 0.01 0.01 0.01
Thermal Conductivity	6 = 7.114 6.923 7.0
Thermal Capacity	6 = 1.4e6 1.4e6 1.4e6

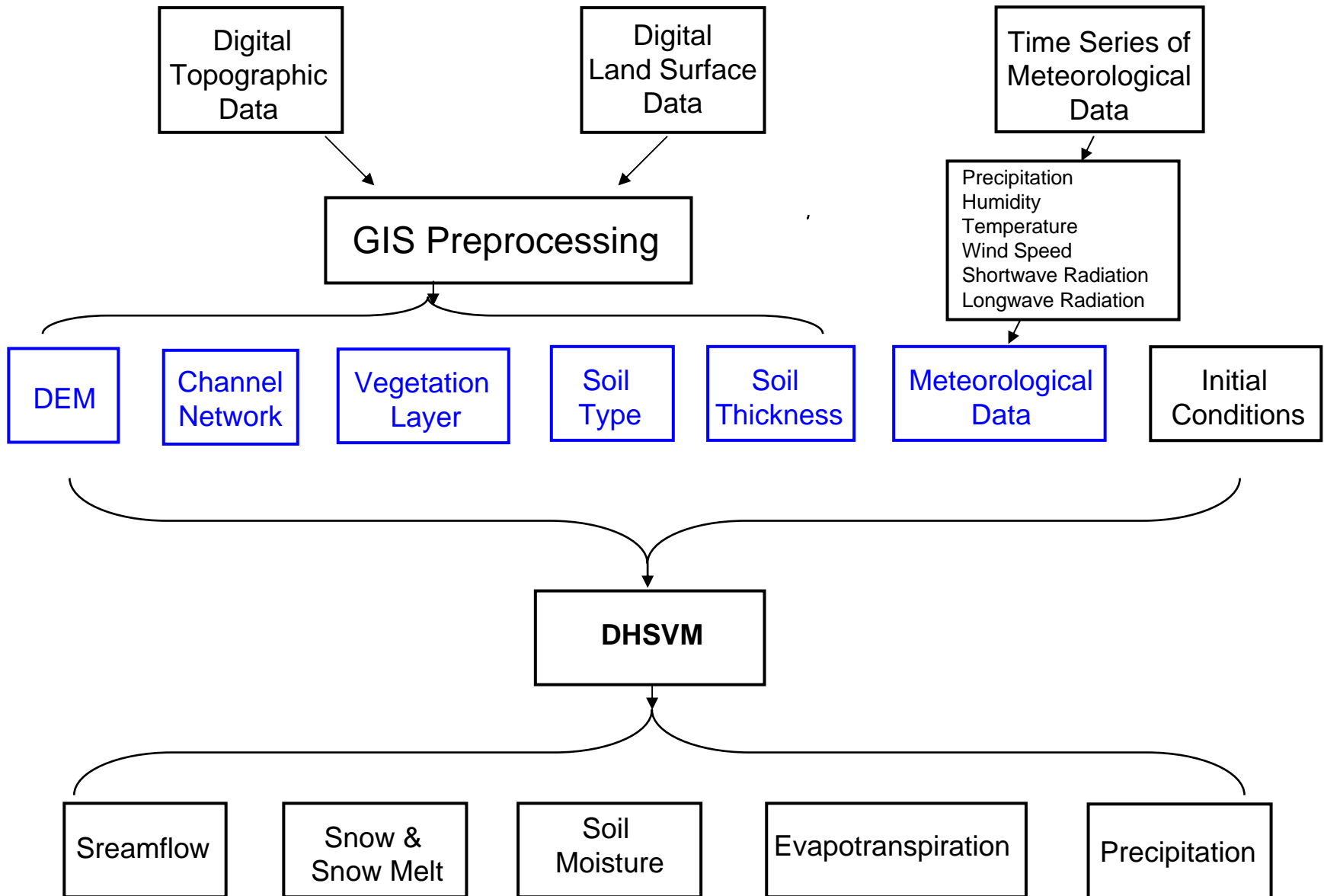
# Surface and Subsurface Flow



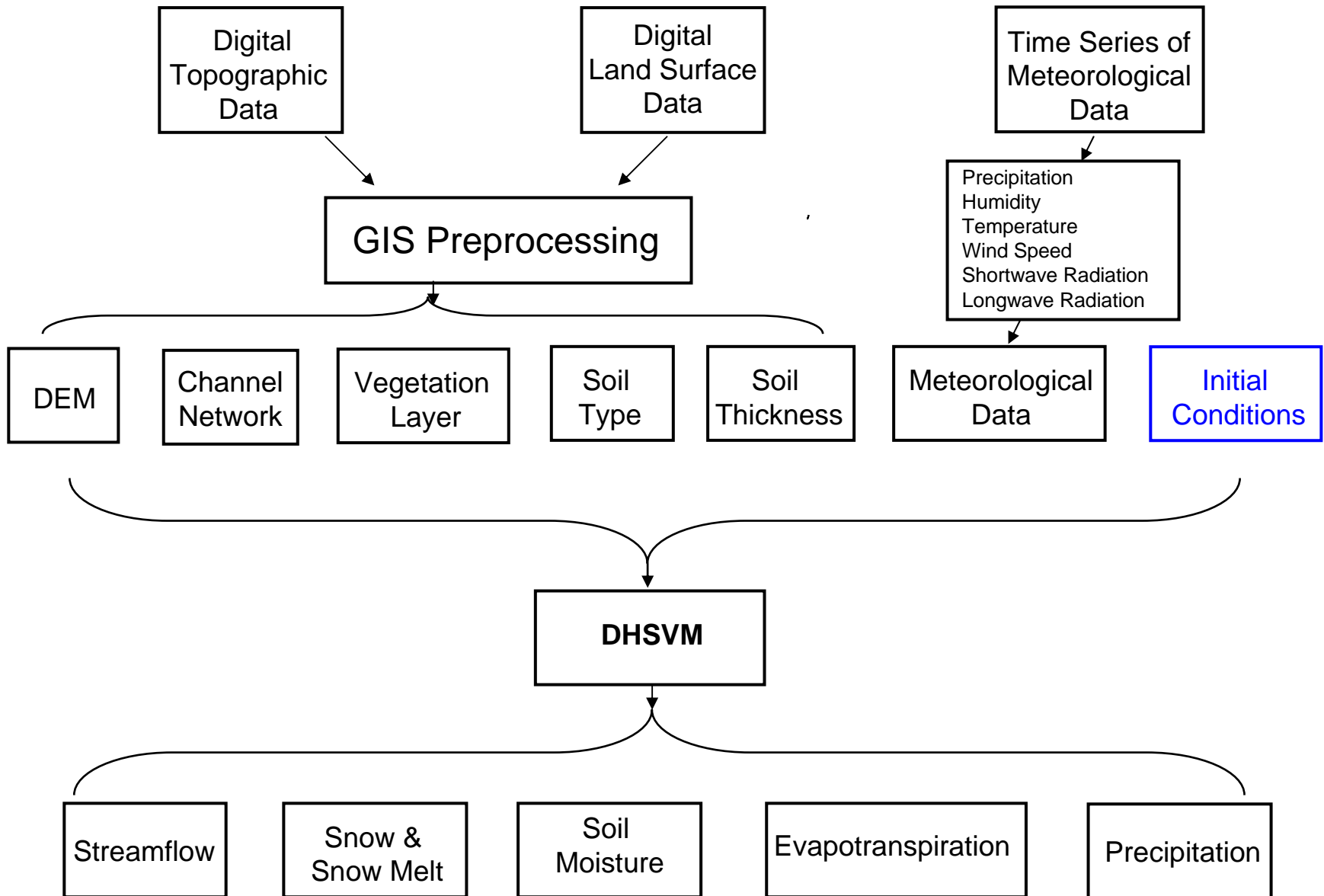
# Stream Network



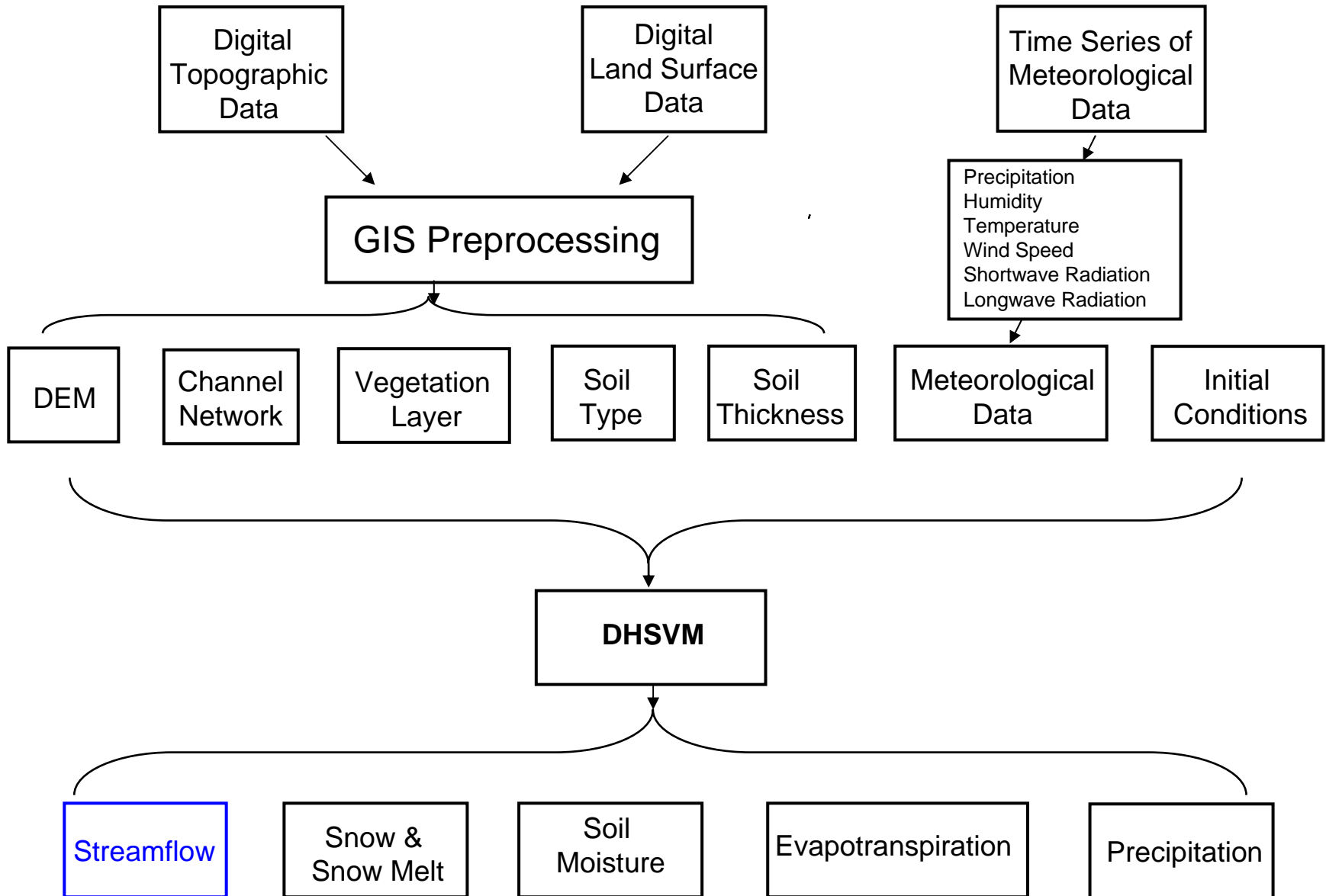
# DHSVM Modeling Inputs and Outputs



# DHSVM Modeling Inputs and Outputs



# DHSVM Modeling Inputs and Outputs



## Modeling Methods

- Collect and format MET and spatial data
- Calibrate the model to recorded streamflow
- Validate the model

# Modeling Assumptions

- Recorded streamflow adequately captures actual streamflow.
- Recorded MET data provide an adequate representation of MET conditions in the basin.
- Model parameters, other than calibration parameters, provide an acceptable physical representation of the basin.

Simulations were performed on a Dell Precision having two, 3-GHz processors, 2 GB of RAM and a Linux platform.

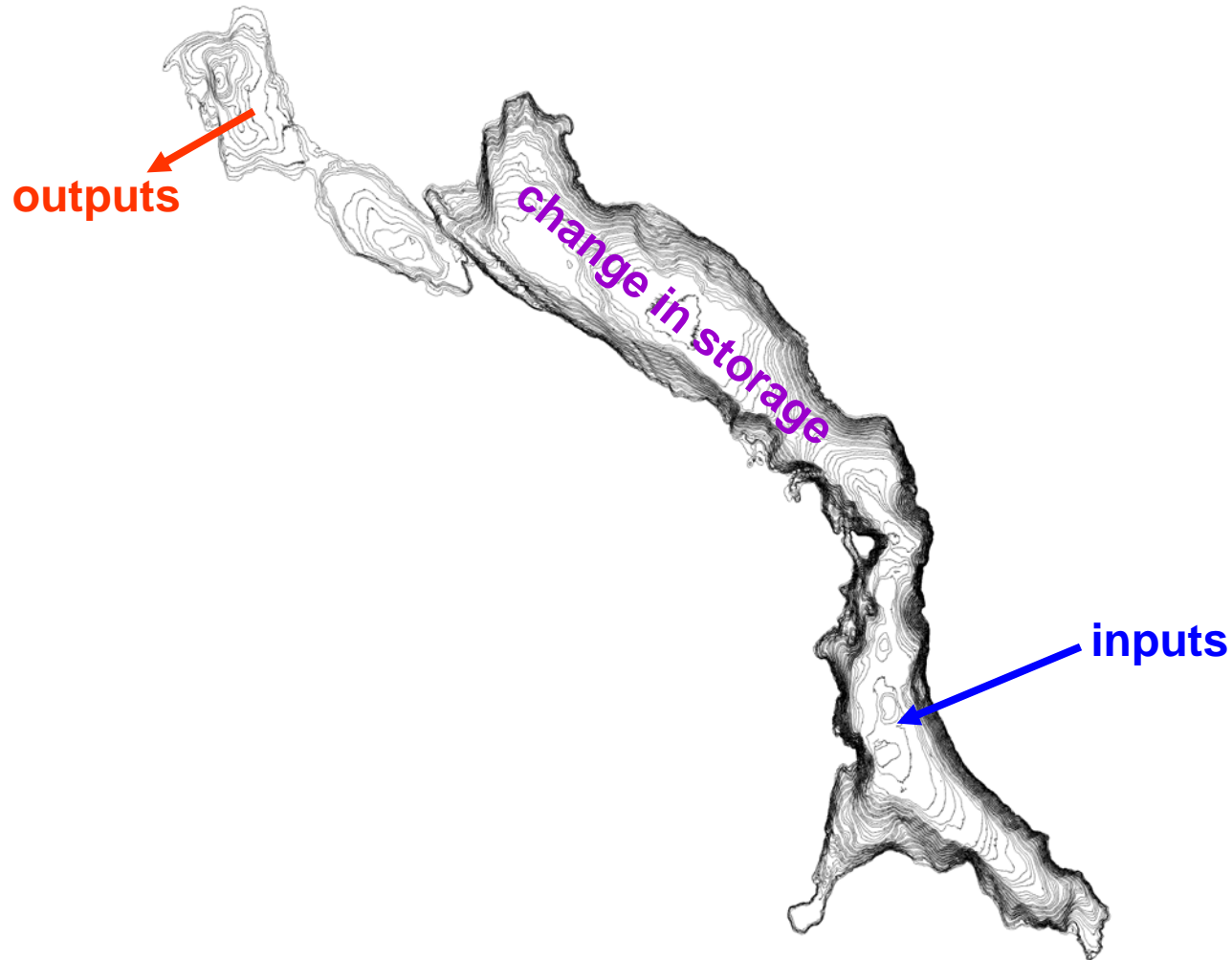
# Model Calibration

Alter model parameters until there is a sufficient match between the simulated streamflow and recorded streamflow. The most influential parameters are the:

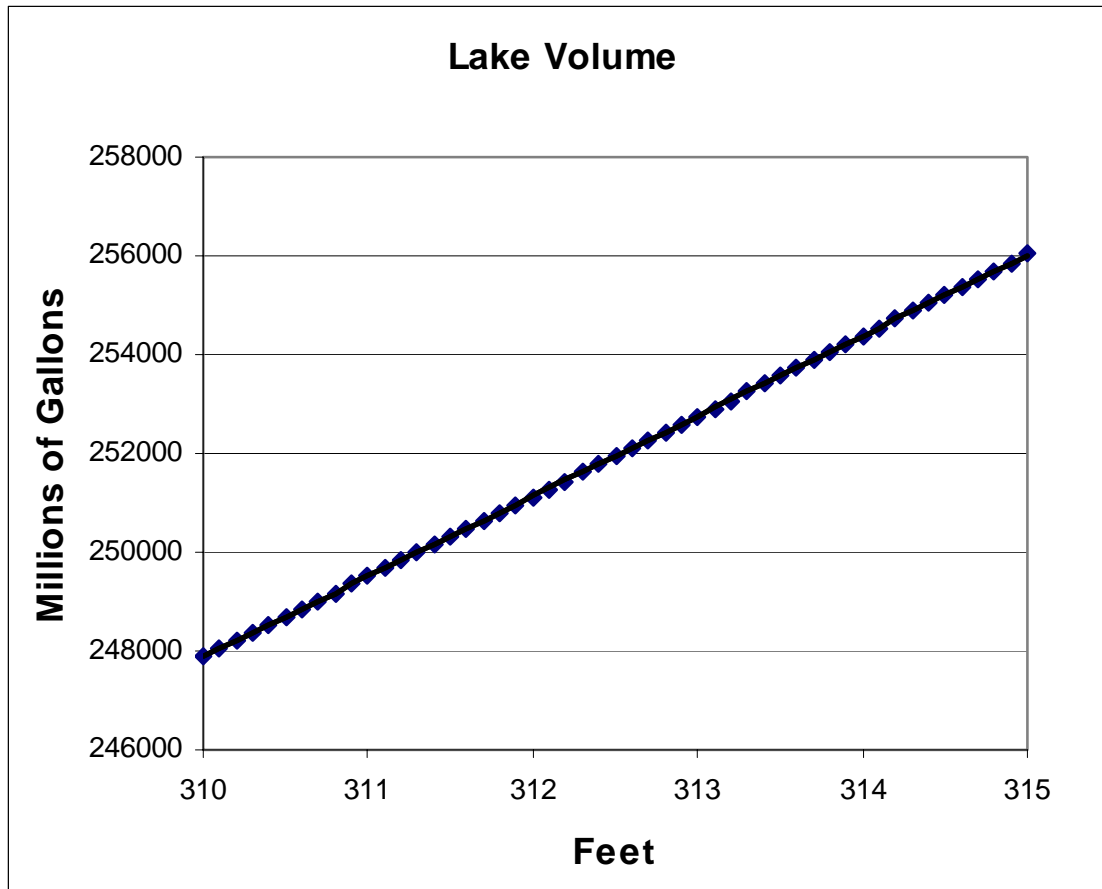
- precipitation lapse rate
- soil thicknesses
- lateral hydraulic conductivity

# Runoff Estimate: Lake Whatcom Water Budget Method

$$\text{inputs} - \text{outputs} = \text{change in storage}$$



Rating curve generated from the lake level -capacity data developed by Ferrari and Nuanes (2001)



# Water Budget Runoff Estimate

**inputs** – **outputs** = **change in storage**

## Water Budget for water year (WY) 2003-2004

<b>Inputs</b>	Volume (MG)	% of total
Direct Precipitation	7612	18.6
Diversion	5095	12.4
Runoff	28288	69.0
 <b>Outputs</b>		
Whatcom Creek	26948	71.2
Hatchery	1278	3.4
Georgia Pacific	2053	5.4
City of Bellingham	4449	11.8
Water District 10	204	0.5
Evaporation	2924	7.7
 <b>Change in Storage</b>	 +3139	

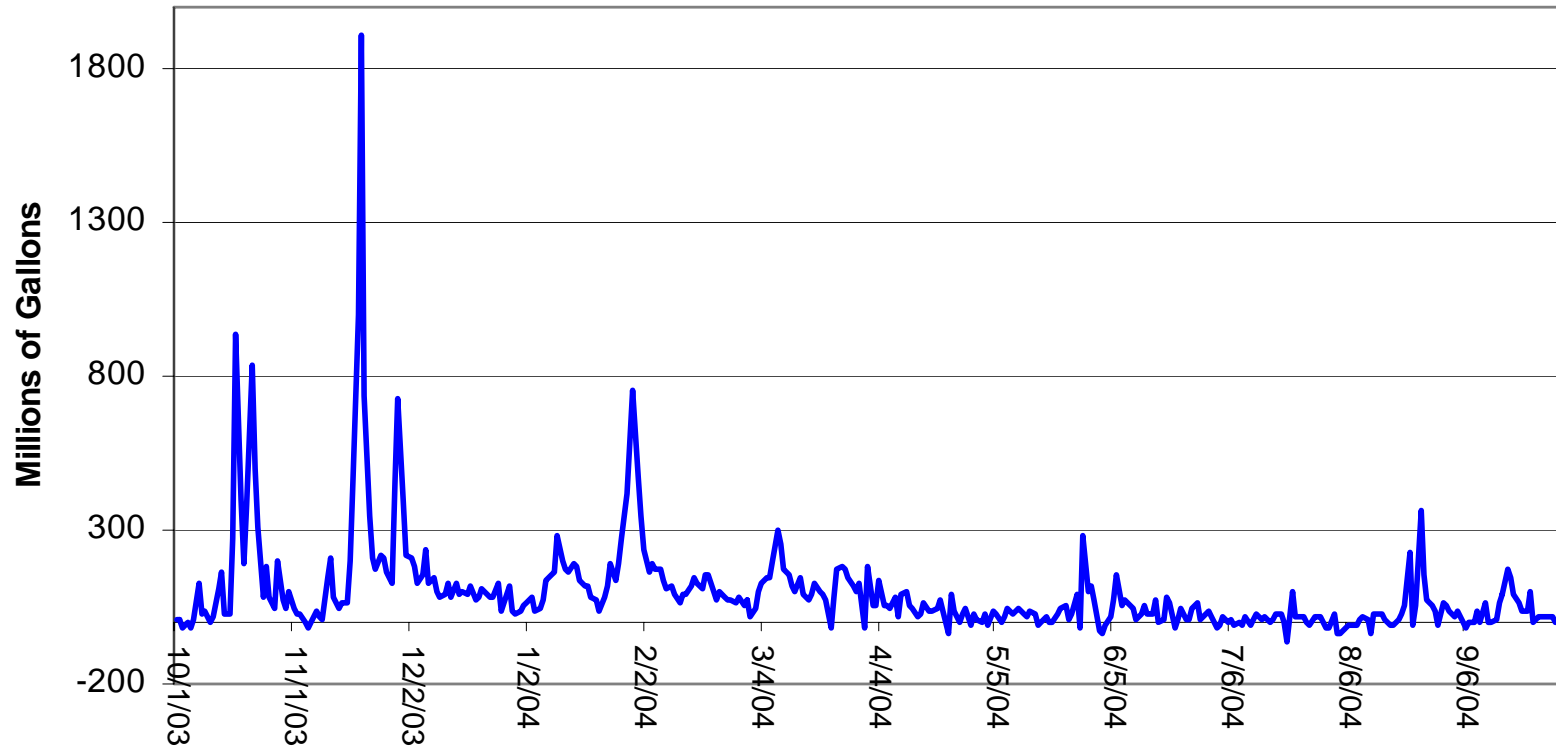
# Water Budget Runoff Estimate

**Runoff** = change in storage + outputs – direct precipitation – diversion flow

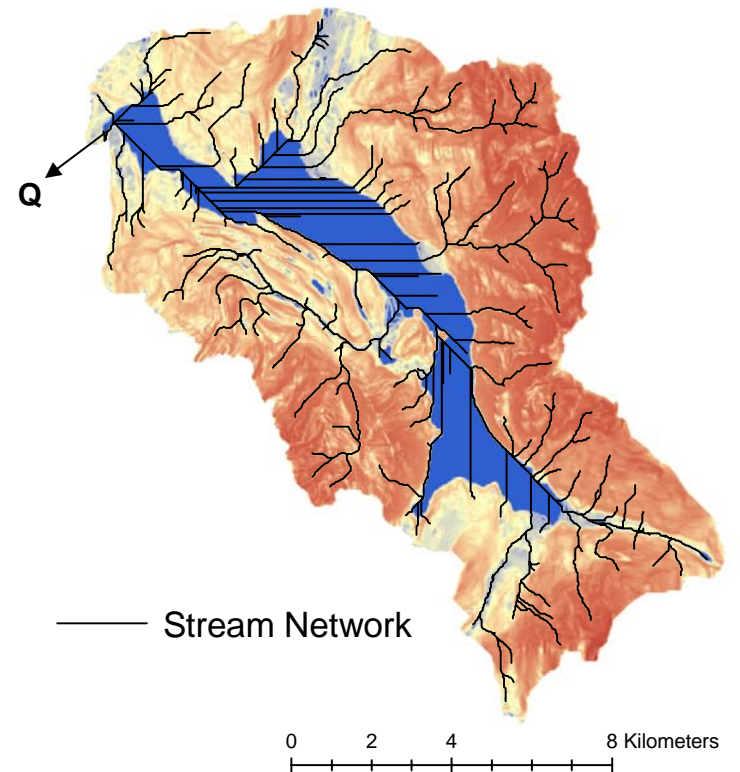
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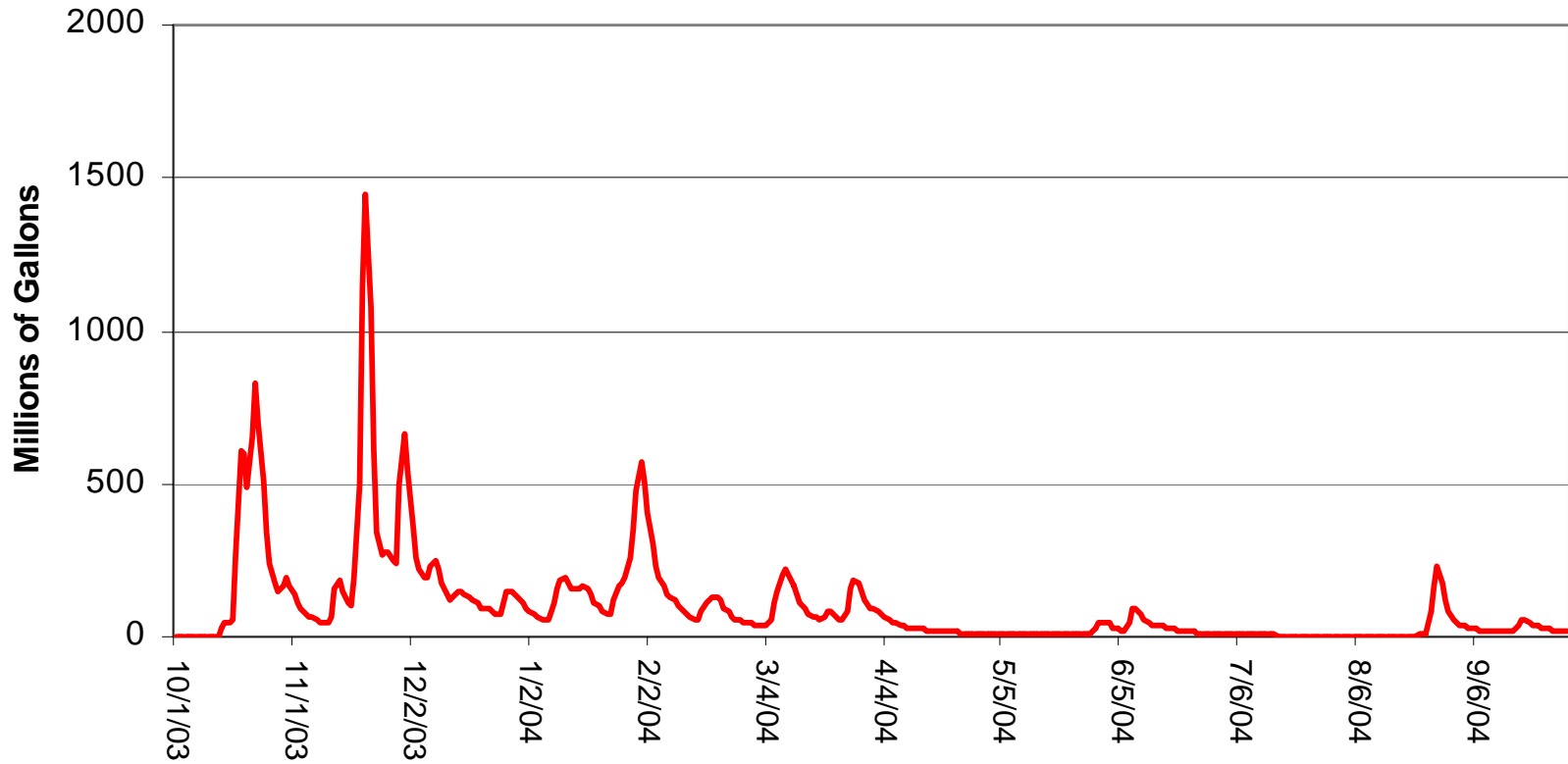
## Runoff: Water Budget Approach



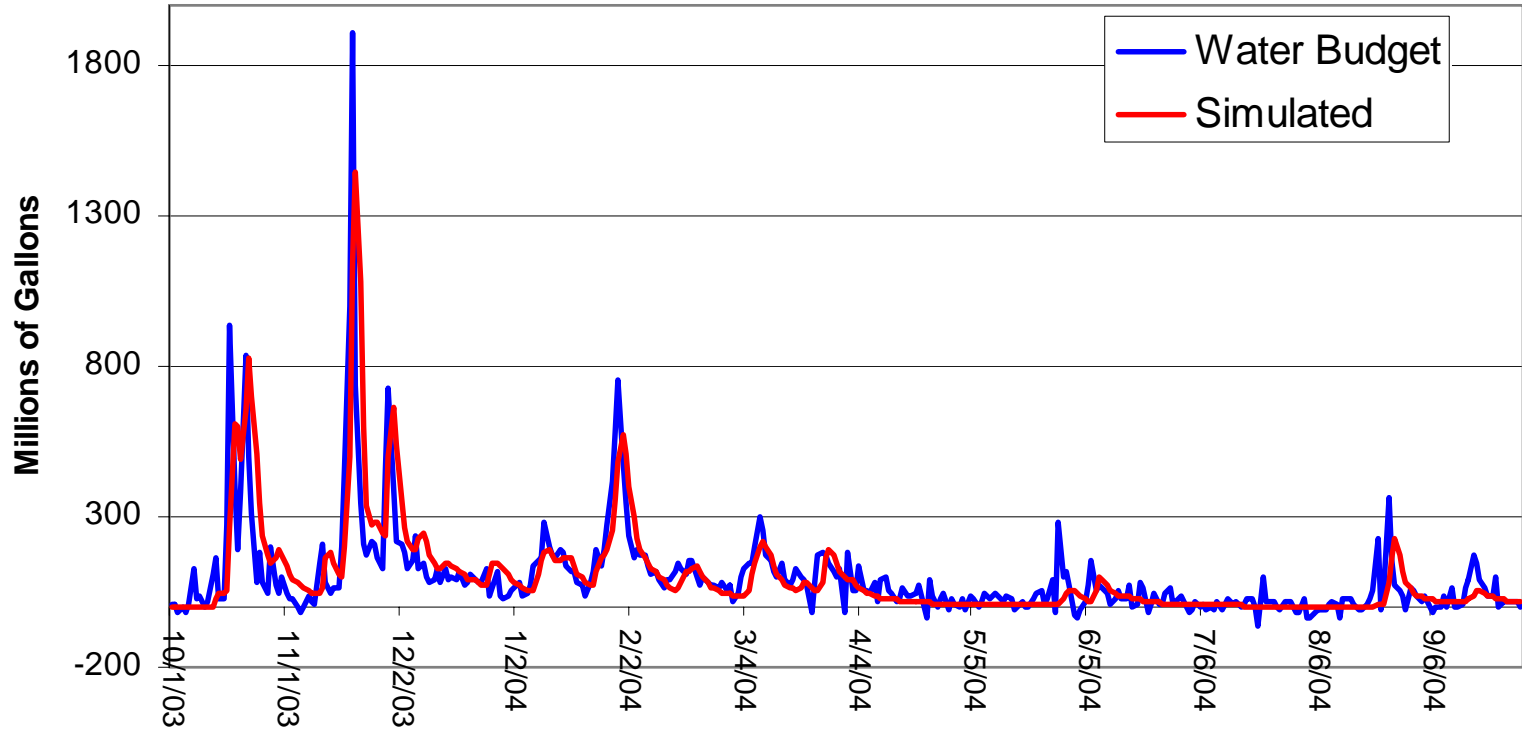
# Simulated Whatcom Creek Outflow



## Runoff: Simulated



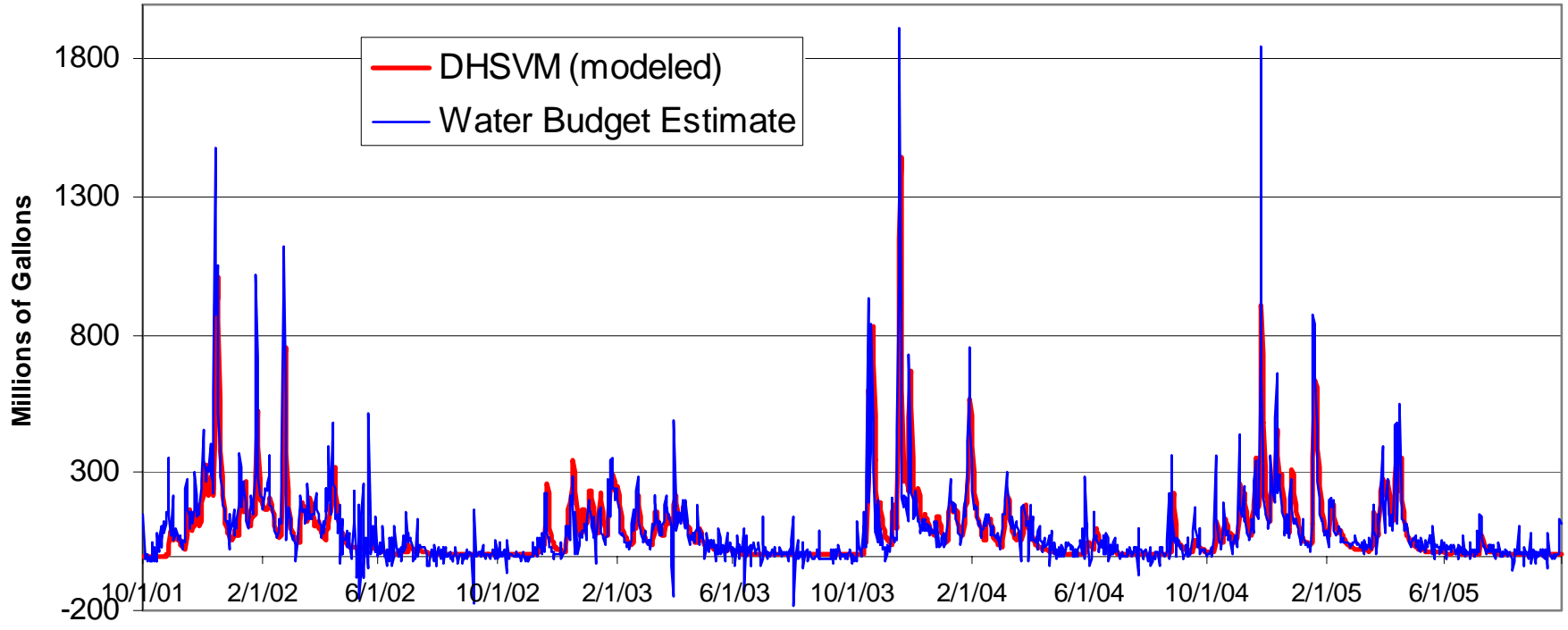
### Runoff: Water Budget versus Simulated



## **Model Validation**

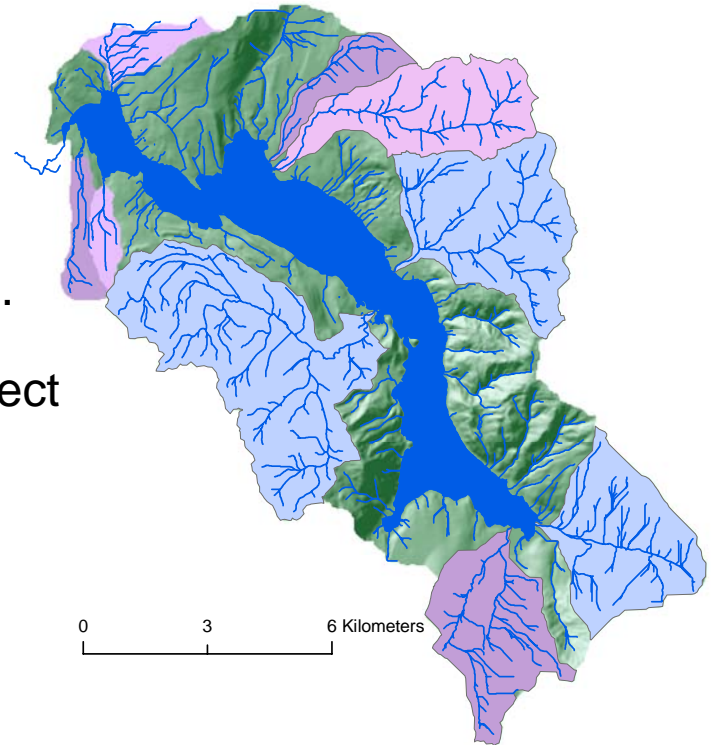
If the model is calibrated, it should adequately simulate streamflow for a different water year (e.g., different MET and recorded streamflow).

### Runoff into Lake Whatcom (WY2001 to 2005)

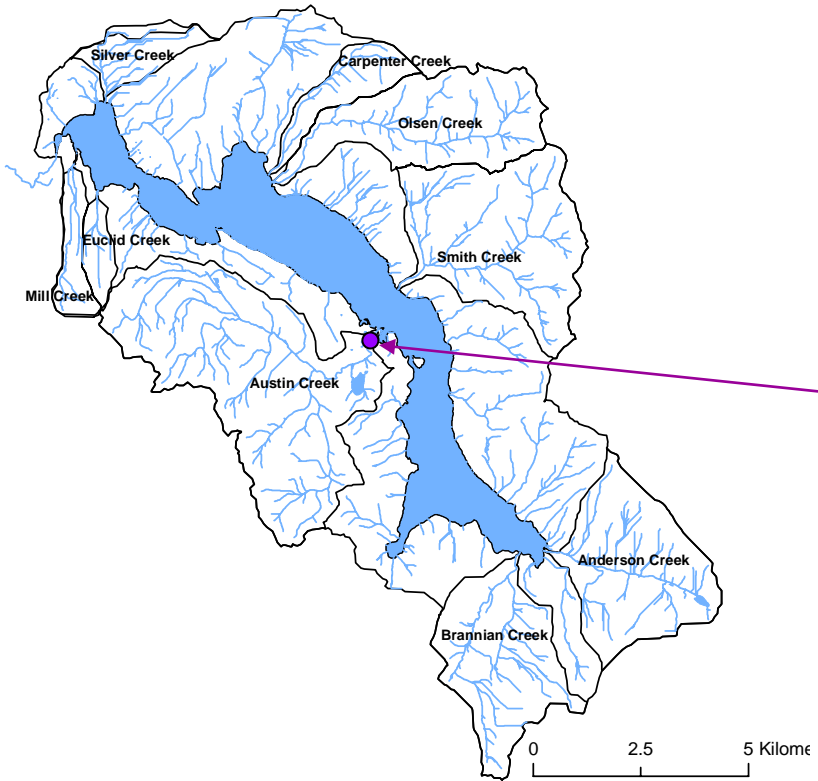


# What next?

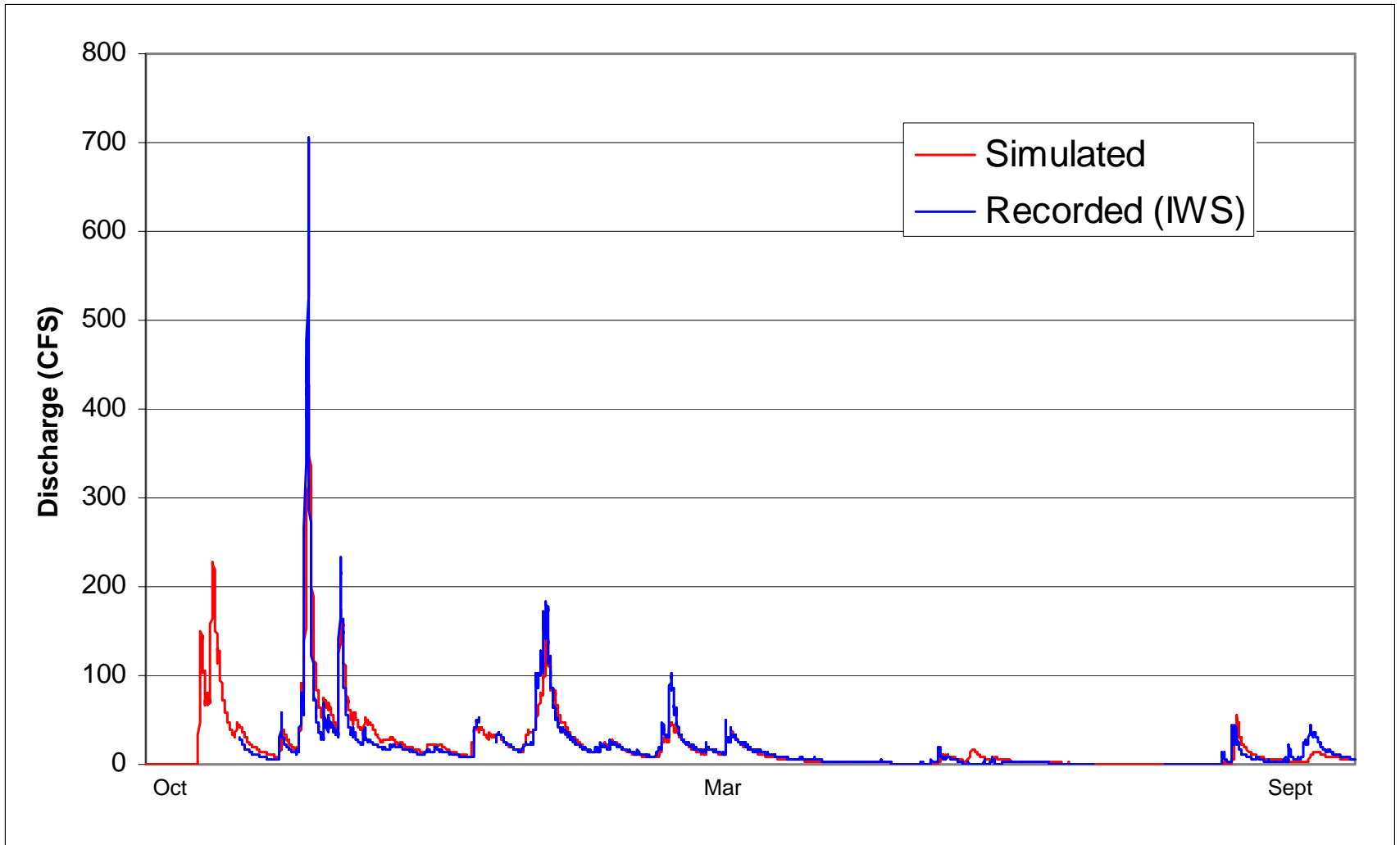
- Constant model refinement.
- Determine the groundwater input to the lake.
- Focus on specific basins and include the effect of roads and impervious services.
- Examine sediment inputs to streams.
- Model the effect of glacial recession on diversion magnitudes.
- Simulate drought influences.

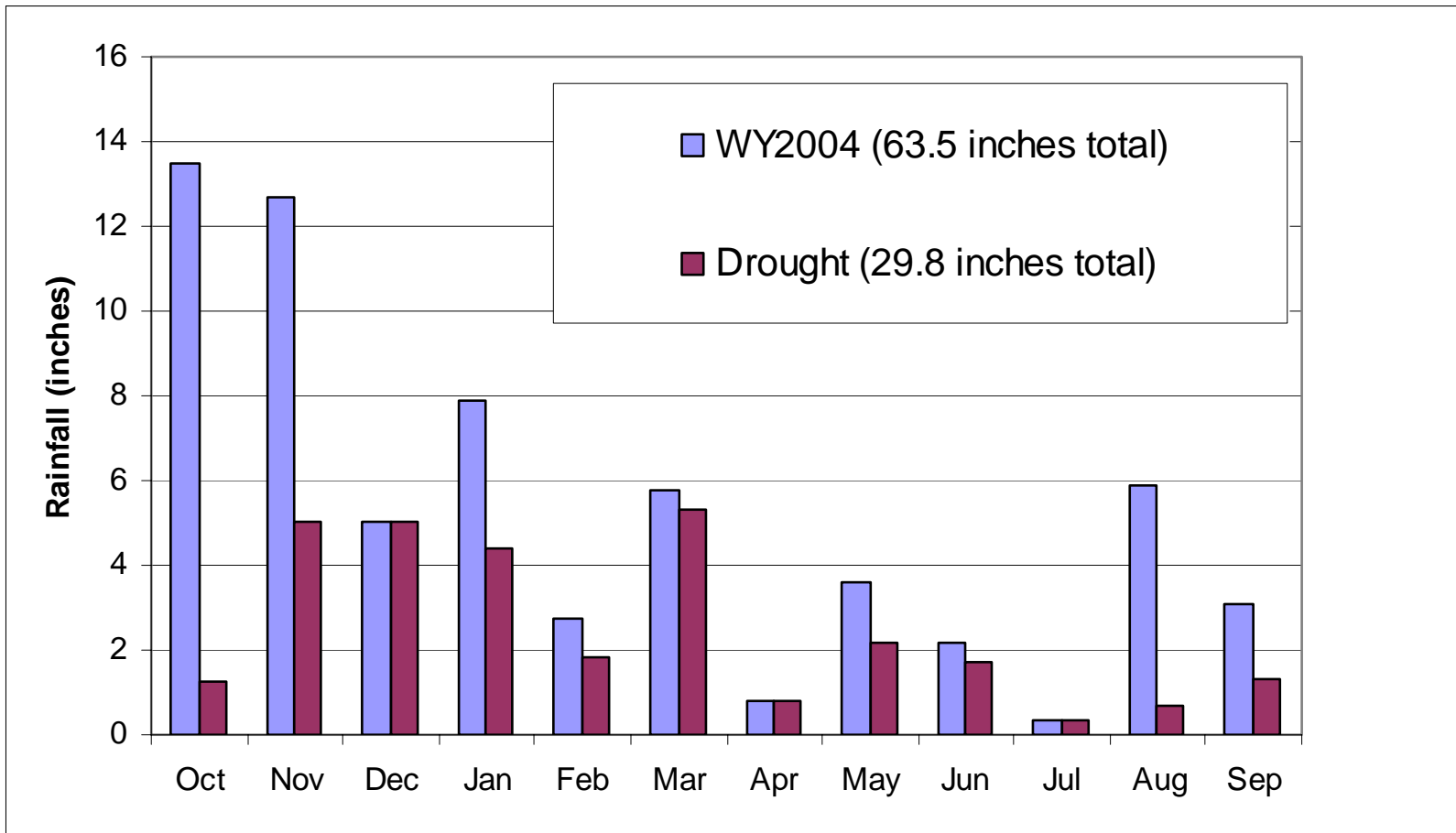


## Austin Creek Stream Gauge (IWS)

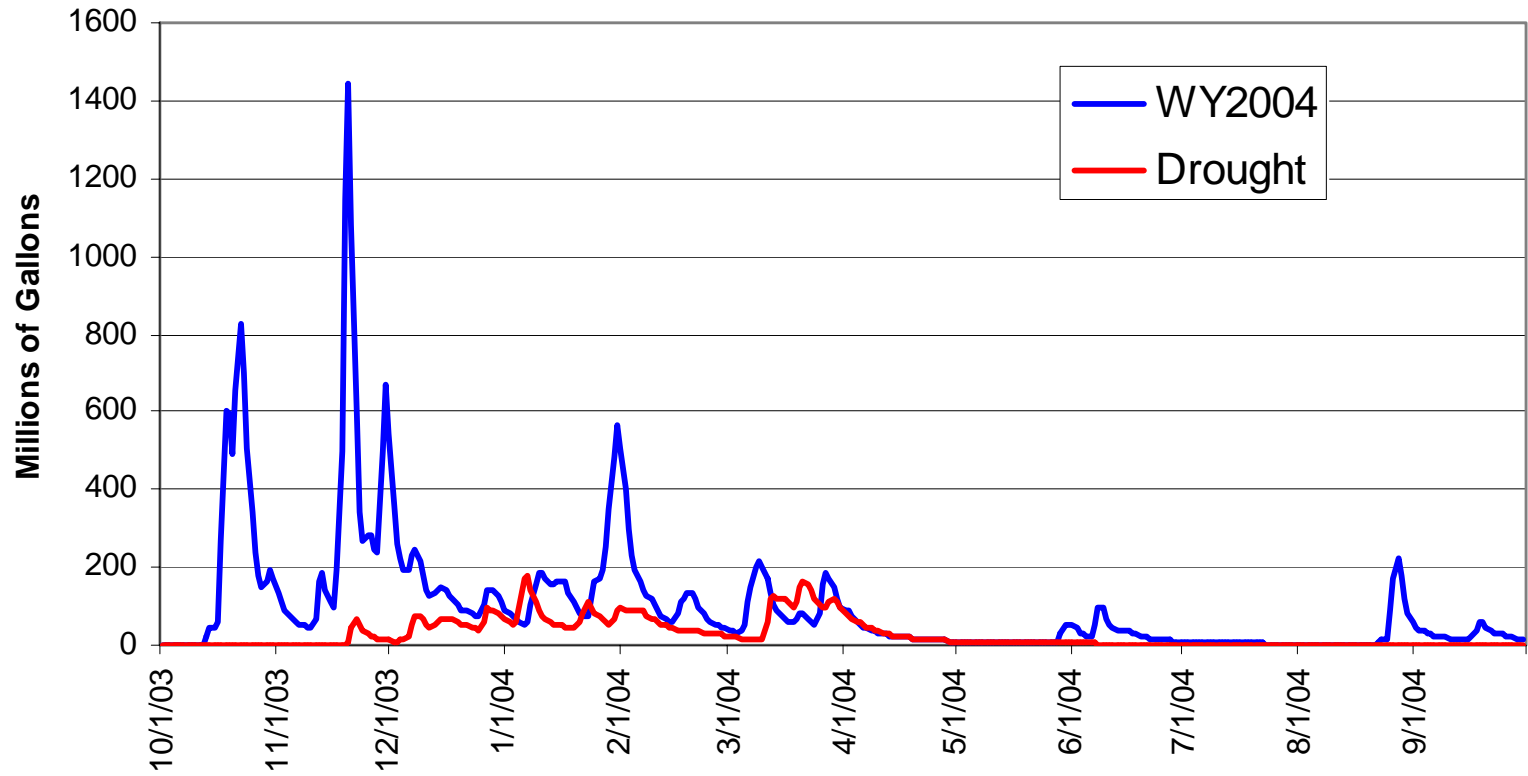


# Austin Creek Sreamflow: WY 2004

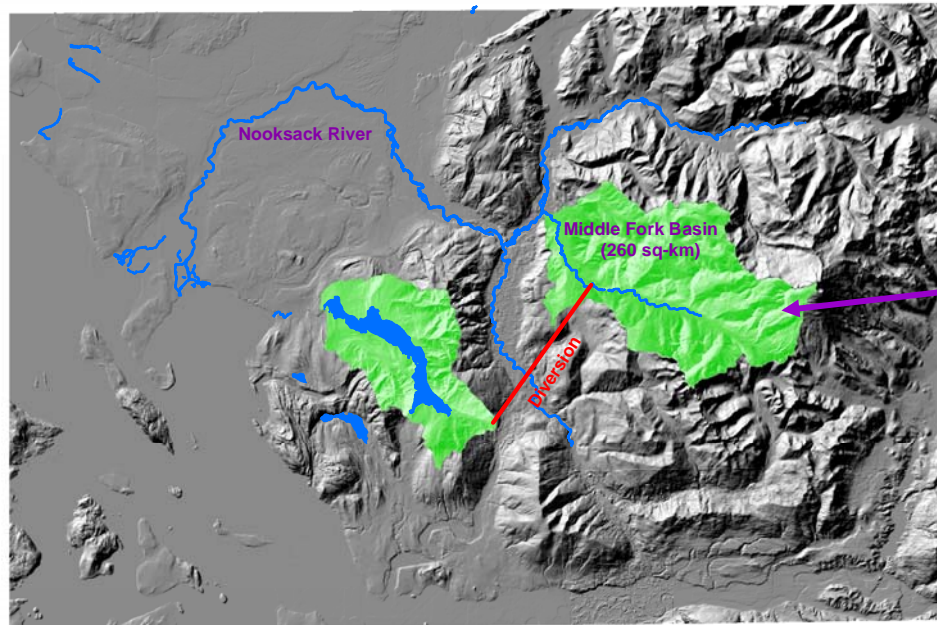




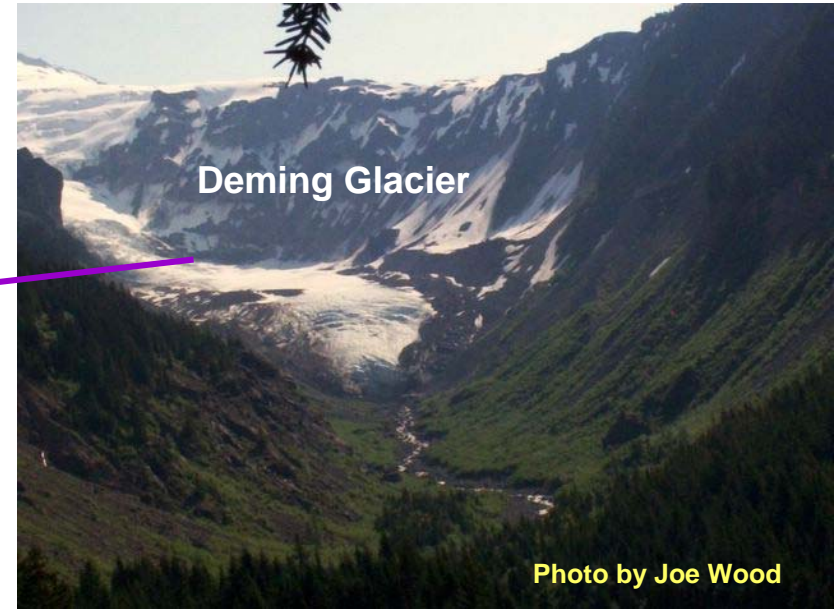
# Drought Year



# Deming glacier is shrinking!



0 5 10 20 Kilometers

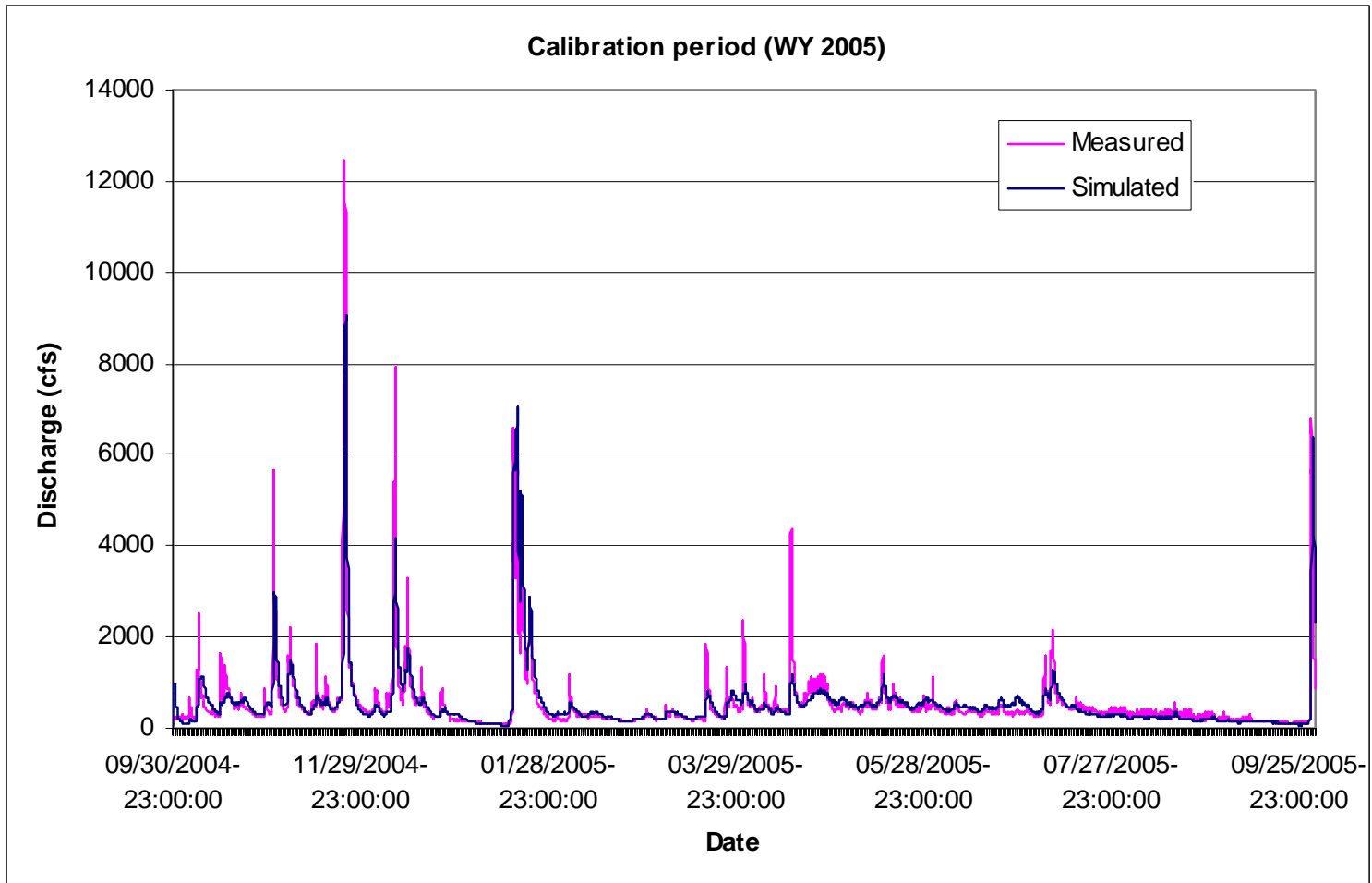


Geology graduate student Carrie Donnell is using DHSVM to predict how Deming glacier recession changes Middle Fork streamflow.



Photo by Joe Wood

# Middle Fork Nooksack calibration results: 2005 water year

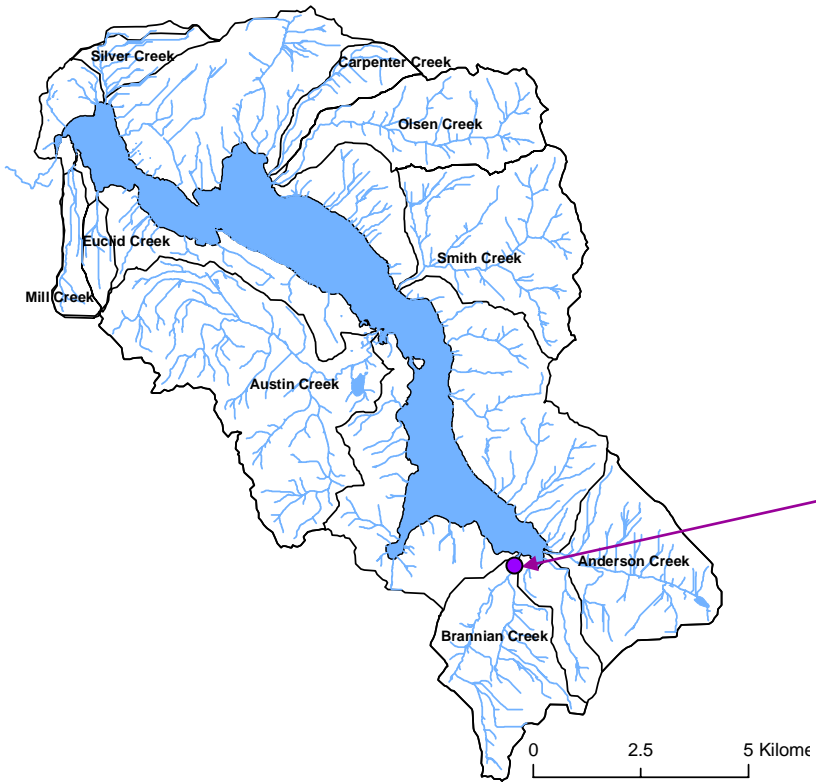


**Questions?**

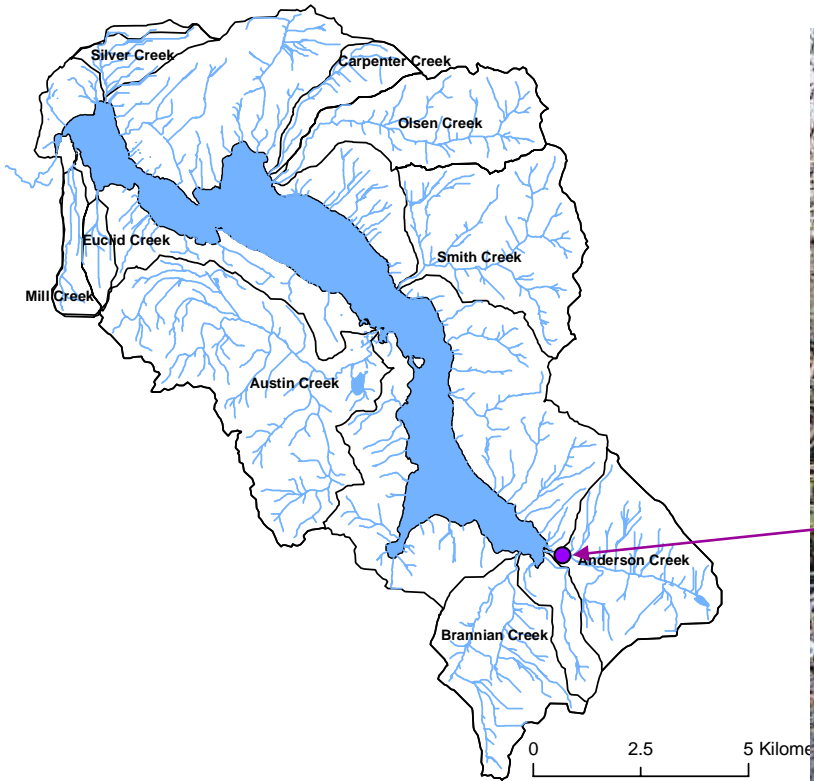
**Lake Whatcom looking west toward the Puget Sound**

**Photo by Margaret Landis**

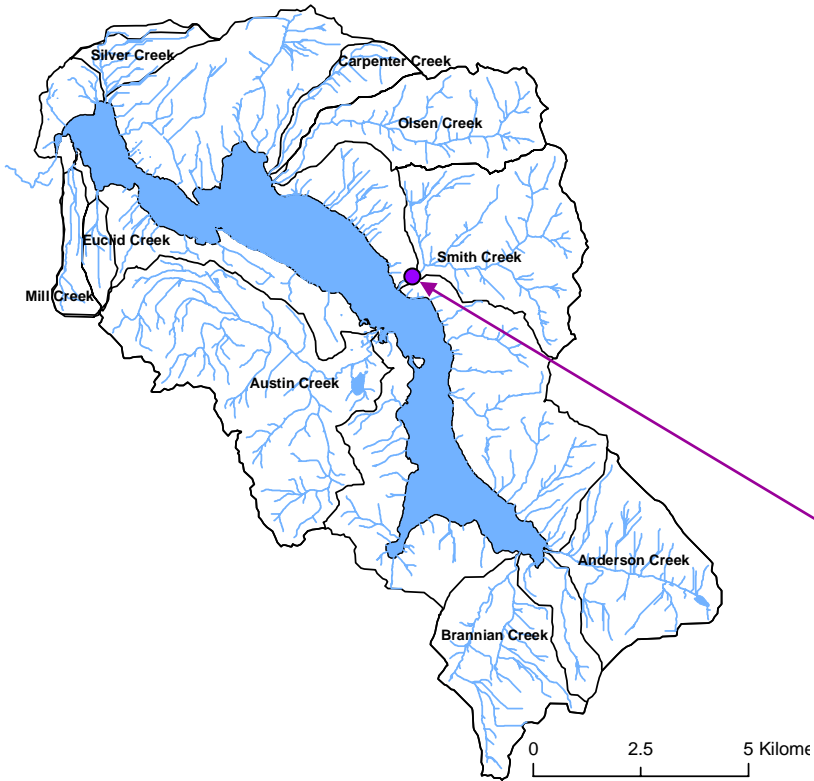
## Brannian Creek Stream Gauge (USGS)



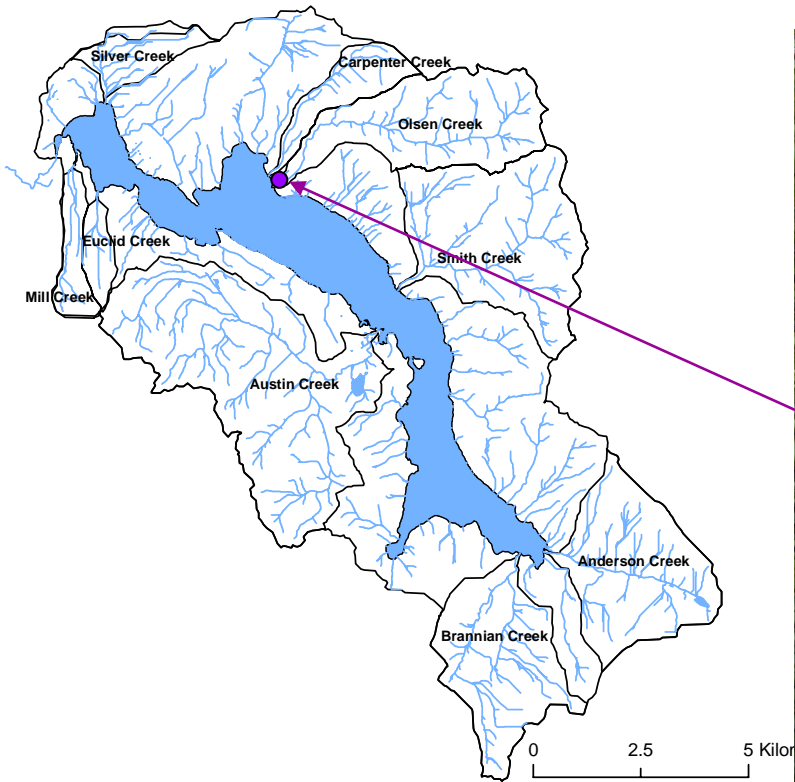
## Anderson Creek Stream Gauge (IWS)



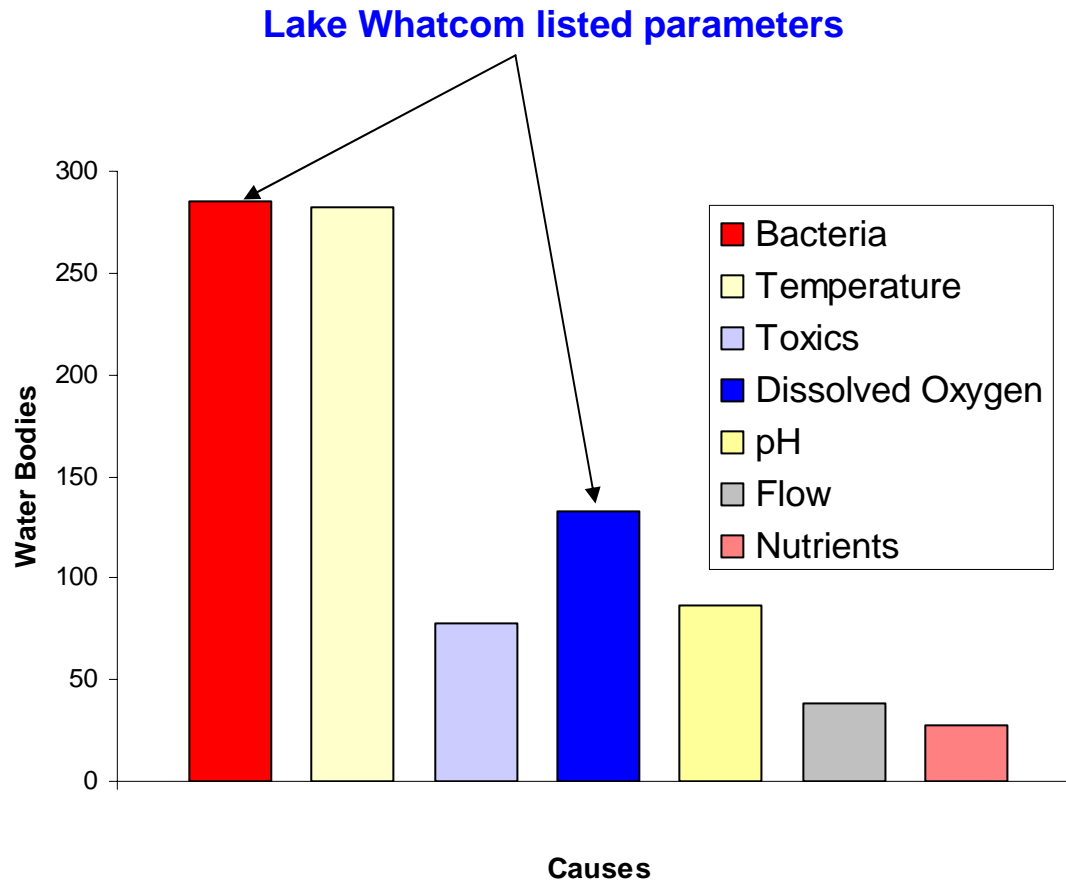
# Smith Creek Stream Gauge (IWS)



## Olsen Creek Stream Gauge (USGS)



# Major causes for water degradation in Washington



# Development of the Lake Whatcom TMDL

The objectives of Ecology and researchers at Portland State are to:

- 1) Develop and calibrate a hydrodynamic and water quality model of Lake Whatcom using CE-QUAL-W2
- 2) Use the model to evaluate strategies for water quality improvement

# Development of the Lake Whatcom TMDL

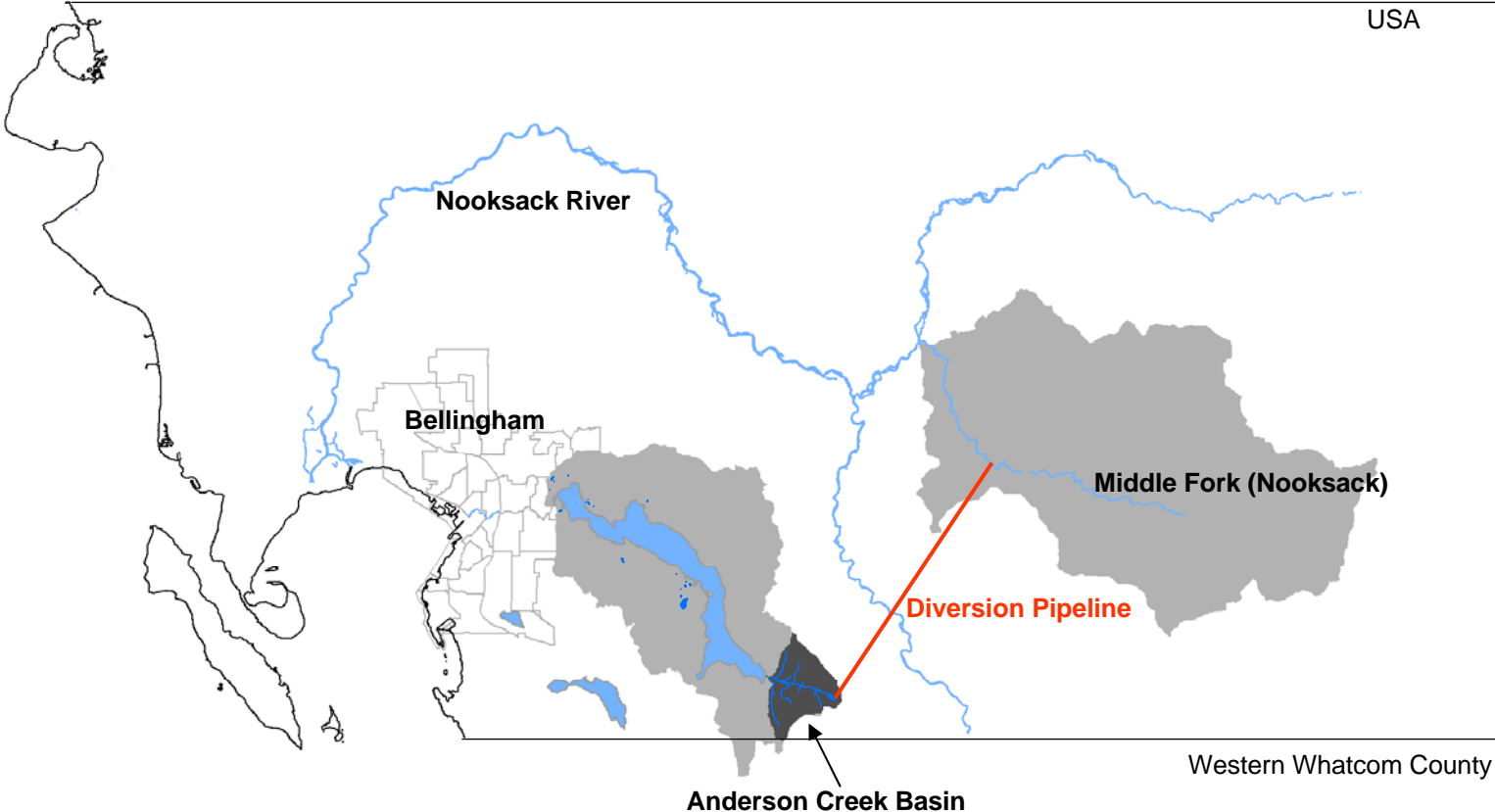
The objectives of Ecology and researchers at Portland State are to:

- 1) Develop and calibrate a hydrodynamic and water quality model of Lake Whatcom using CE-QUAL-W2
- 2) Use the model to evaluate strategies for water quality improvement

**runoff magnitudes are required inputs to the model**

# Middle Fork Diversion

Canada  
USA



Anderson Creek Basin

Western Whatcom County

Diversion Off

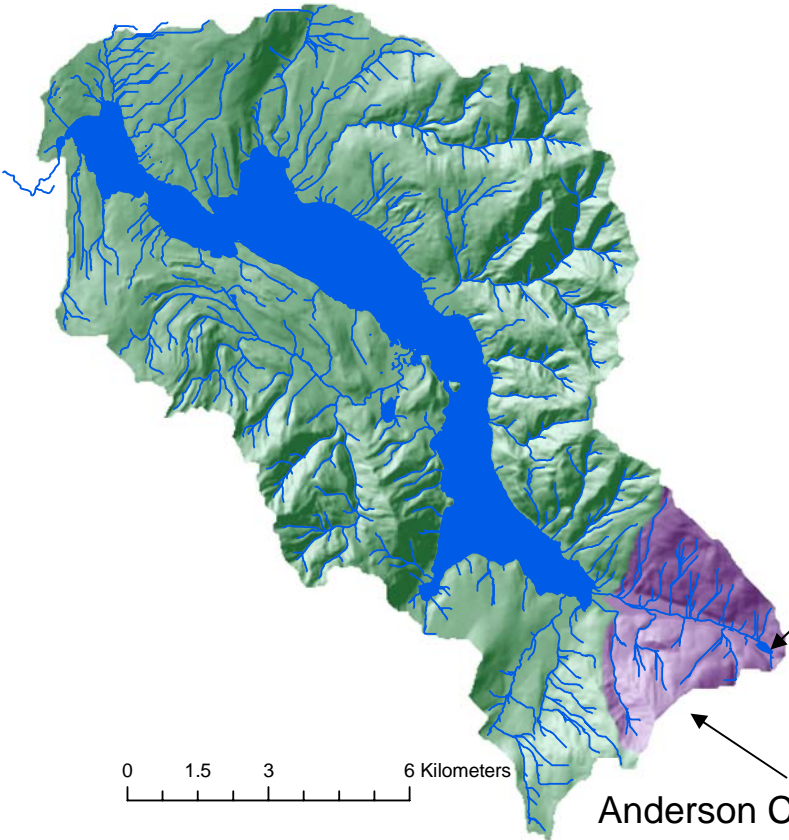


Diversion On (max of 65 cfs)



# Diversion Flow into Mirror Lake

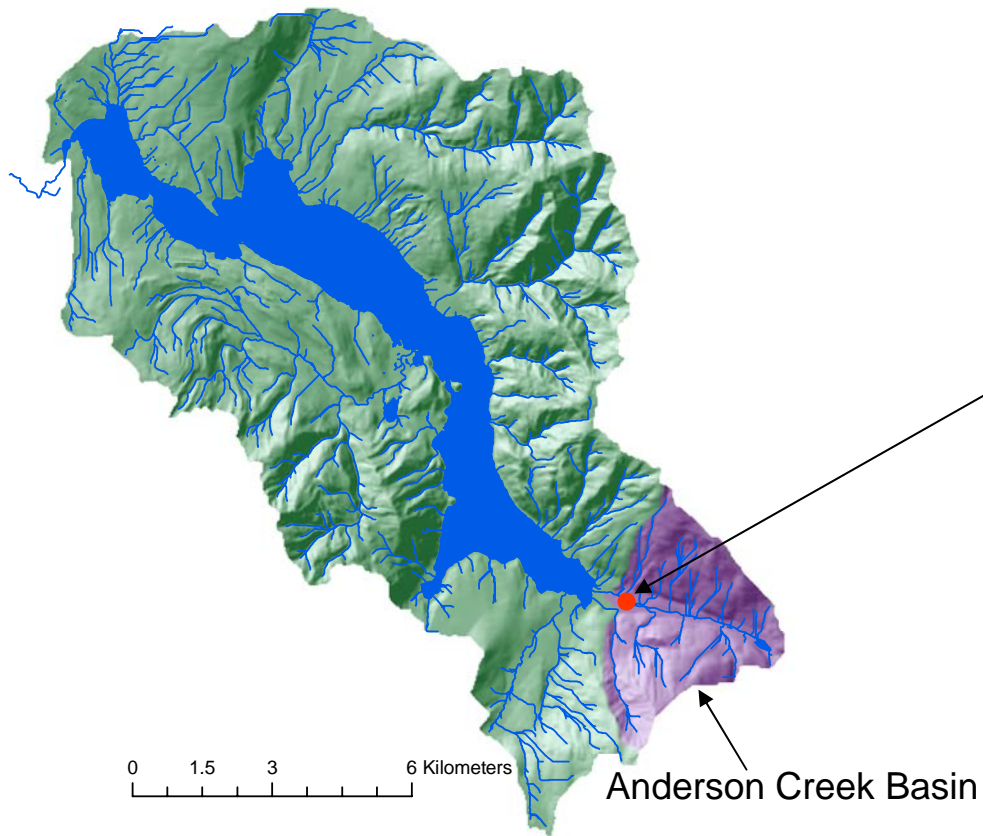
Mirror Lake



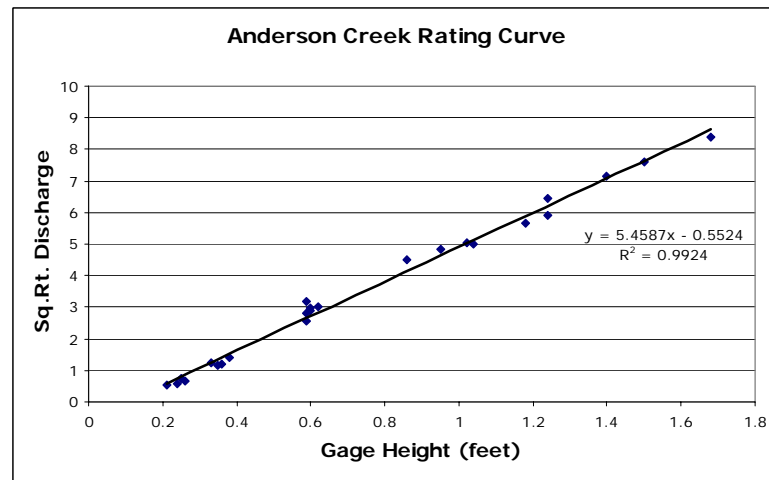
0 1.5 3 6 Kilometers

Anderson Creek Basin

# Recorded Streamflow



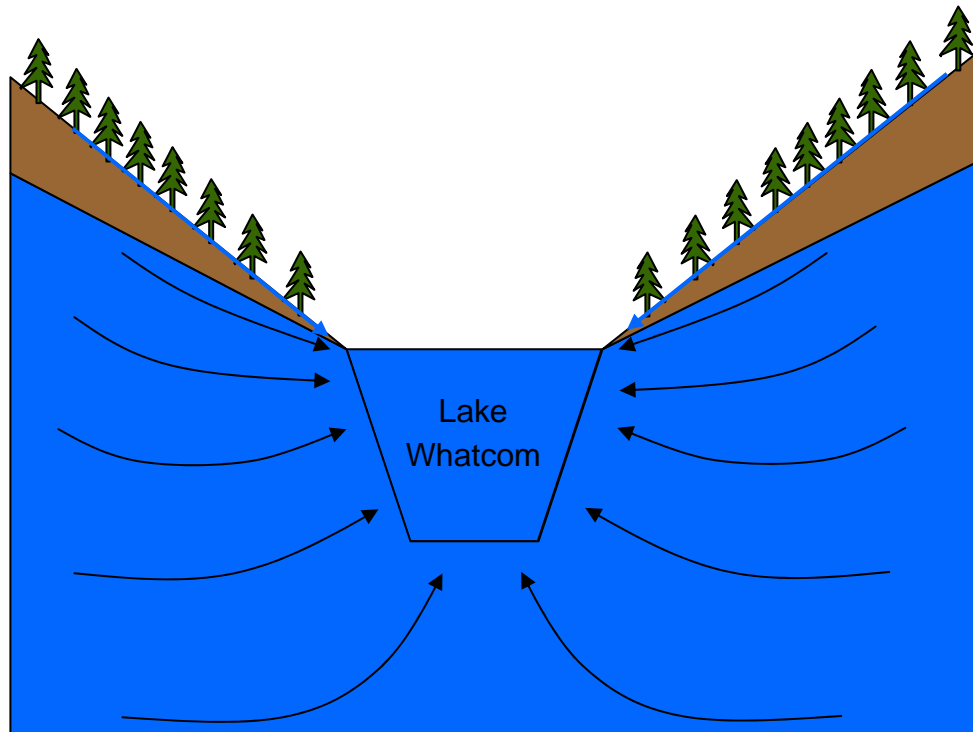
## Anderson Creek Stream Gauge



# Motivation

- 1) The lake serves as Bellingham's drinking water supply.
- 2) Runoff is the largest input to the lake.

Runoff = streamflow and groundwater discharge to the lake



20 to 30% of the total runoff is groundwater (Pitz, 2005)