

**Impacts on the Terrestrial Water Cycle**  
**from Climate Change of Precipitation**  
**Magnitude, Pattern, Timing, & Intensity**

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Qualifying Exam  
March 12, 2010

**“My interest is in the future because I am going to spend the rest of my life there.” -Charles Kettering**

# Rationale

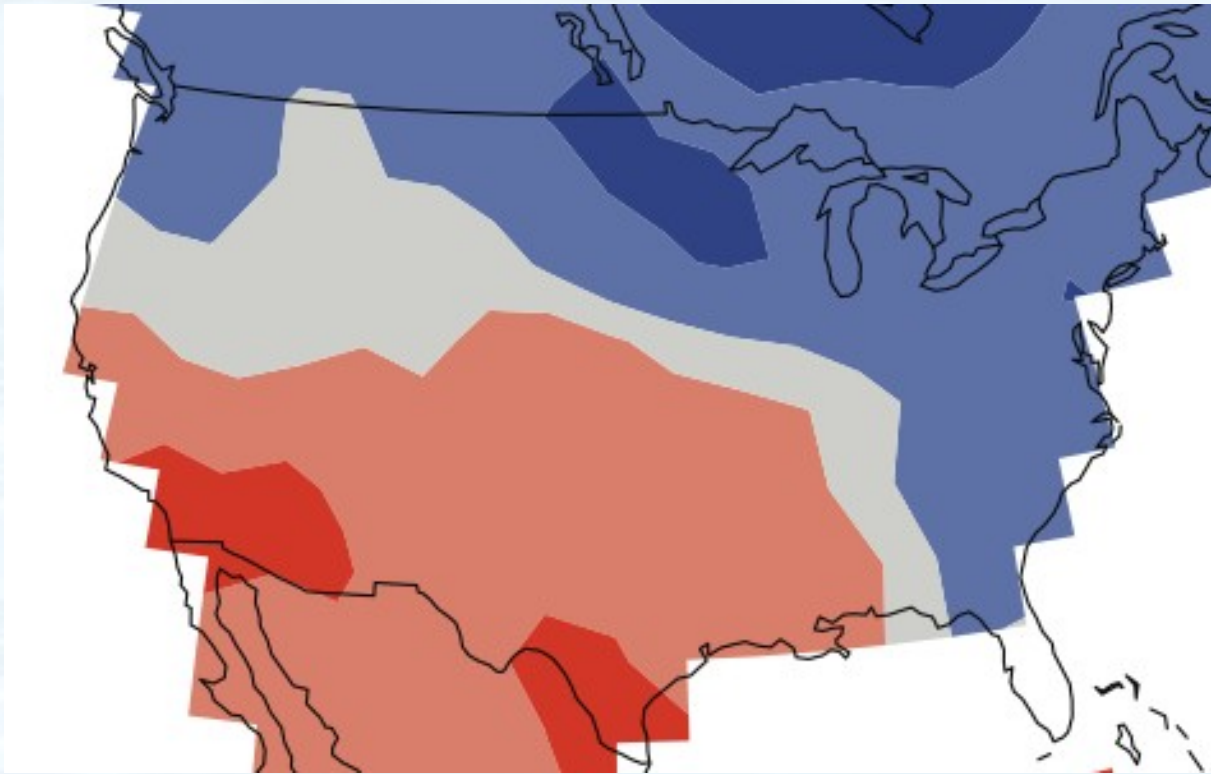
- Climate Change Most Impacts on **Water**  
*“Water is the primary way that climate change will impact people, society and ecosystems.” (WWF 2009)*
- Precipitation Estimates *“Wildly Diverging”*
- Understand Climate (Precipitation) Connections to the Hydrological Cycle
  - Water Sensitivity to Precipitation Change
  - Benefit Climate Model Development and Comparisons

**“It’s tough to make predictions, especially about the future.” - Yogi Berra**

# Thesis

- Total Annual Amount is Inadequate as Sole Metric for Precipitation
  - Other Characteristics Important  
e.g. intensity, duration, & seasonality
- Watershed Drainage is Inadequate as Sole Metric for Hydrology
  - Other Components Important  
e.g. ET, baseflow, groundwater recharge
- Impact of all Precipitation on all Hydrology

# U.S. Precipitation Estimates



Scenario  
IPCC A1B

1990-2030

Ensemble  
models

(U.S. CCSP, 2008)

NCAR/DOE Climate Change Prediction Group:

[www.cgd.ucar.edu/ccr/ccp](http://www.cgd.ucar.edu/ccr/ccp)



-10

-5

-1

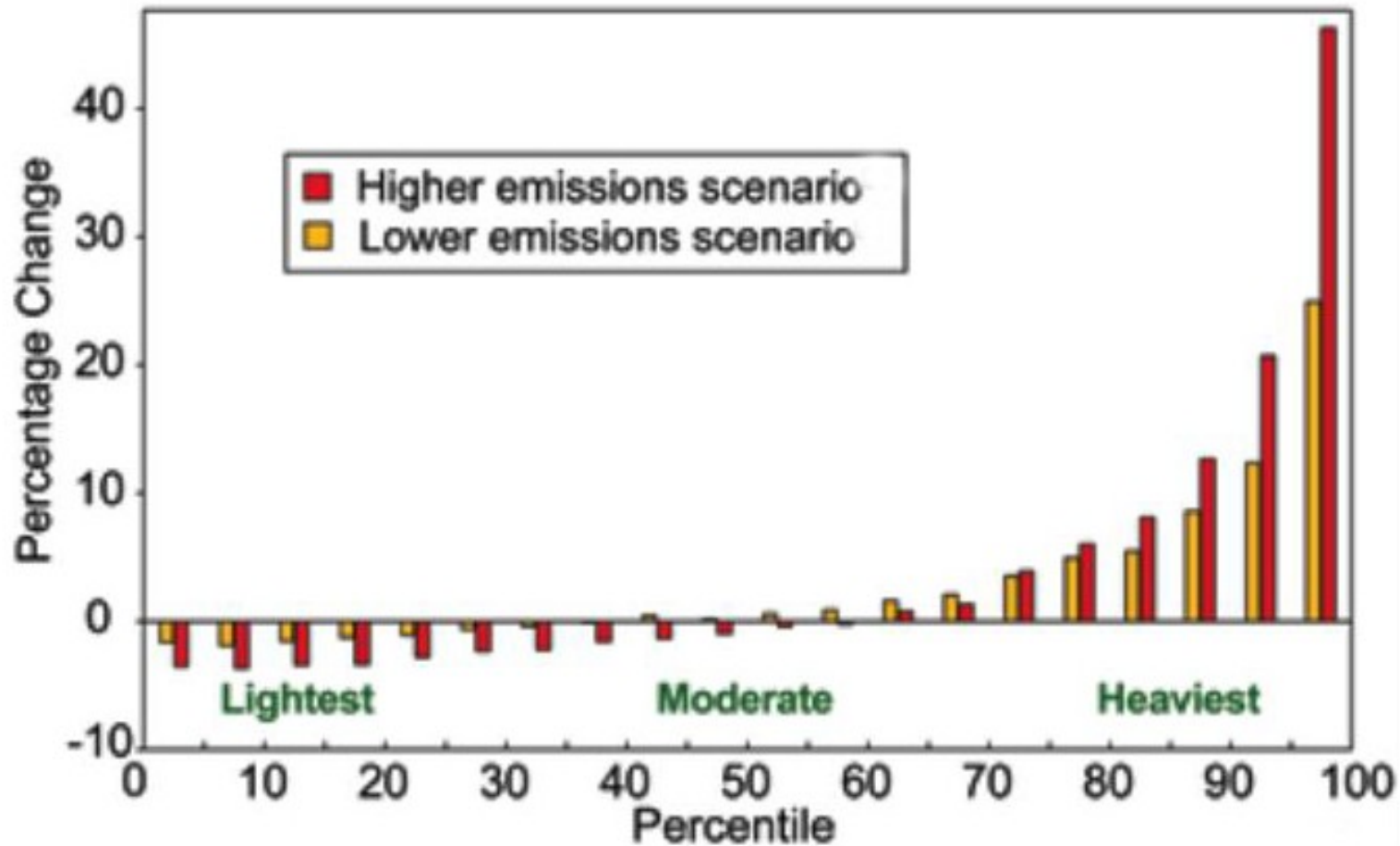
1

5

10

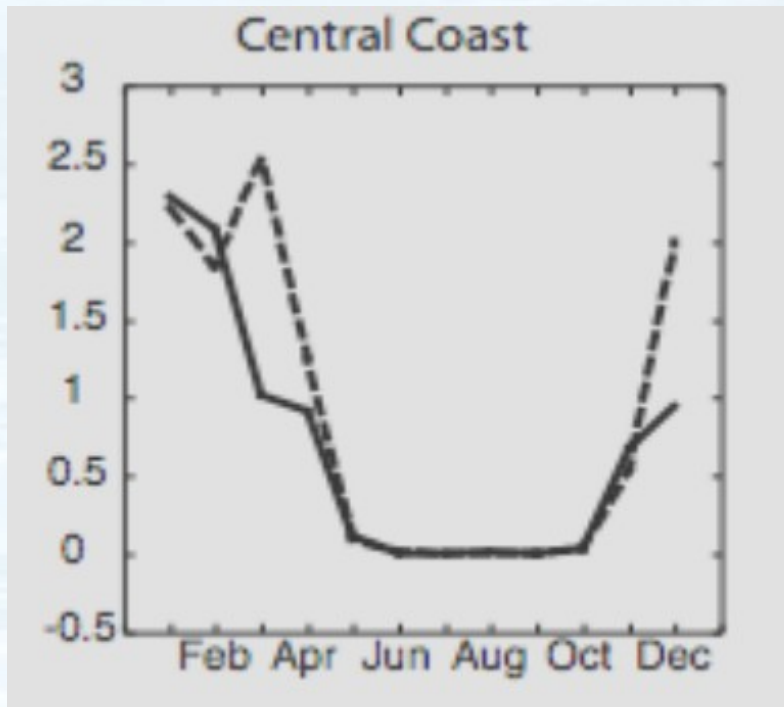
(%)

# Precipitation Event Intensity



Projected Changes in Light, Moderate, and Heavy Precipitation by 2090s (U.S. CCSP, 2008)

# Precipitation Season Decrease



## Rainfall Season

CO<sub>2</sub> 1X (280 ppm, preindustrial)

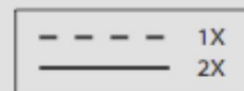
Dec. - Jan. - Feb. - Mar.

CO<sub>2</sub> 2X (560 ppm, year 2060?)

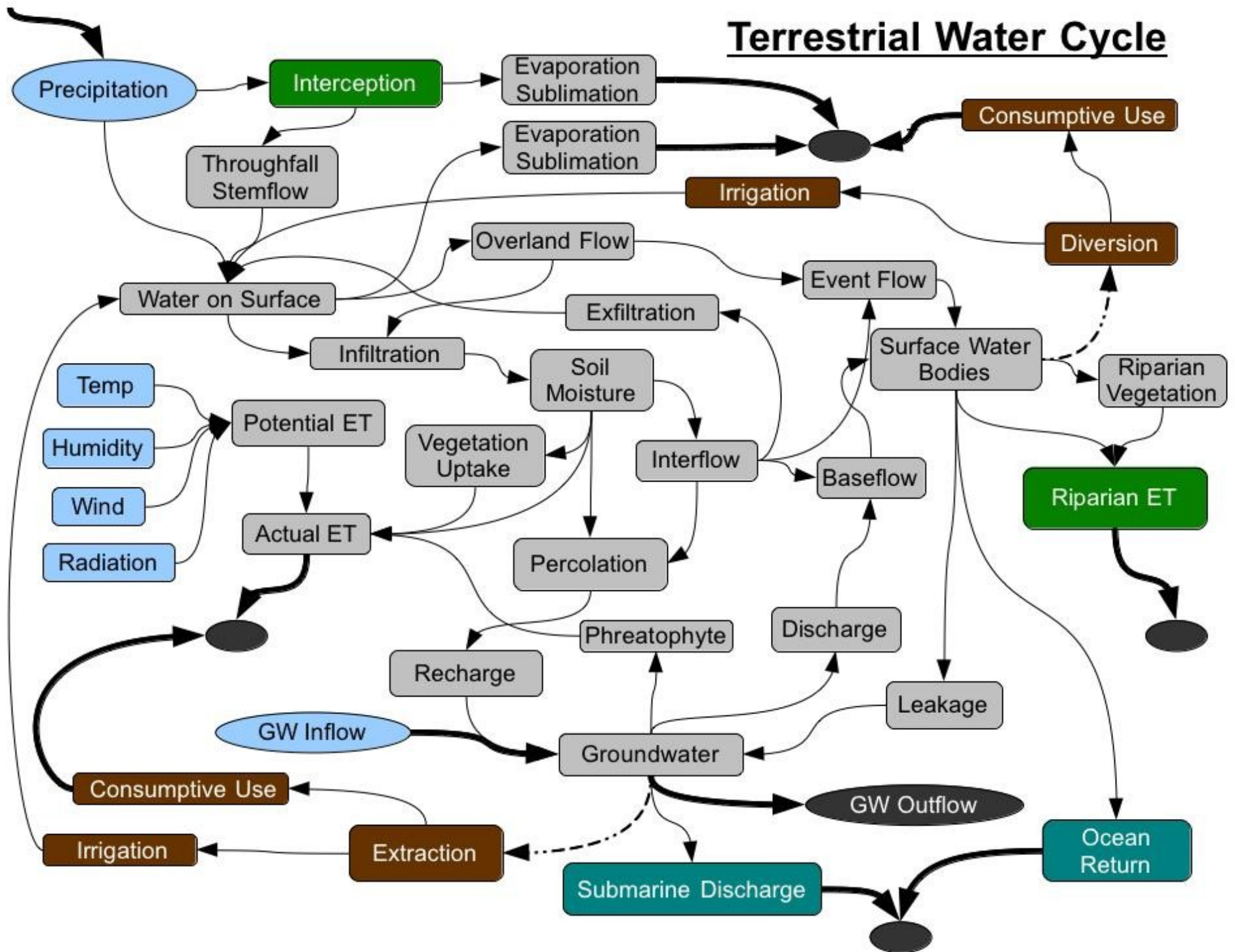
Jan. - Feb.

- (Snyder, Sloan, Bell JAWRA 2004)

Median Monthly Precipitation (mm/day)



# Terrestrial Water Cycle



# Design

- Testing with Hydrological Models
  - Quantification and Repeatability
- Change Single Precipitation Characteristic
  - Separation of Confounding Input Factors
- Stochastic Variation of Background Params
  - Yield Statements Confidence Level
- Explore Effects of Basin Choices

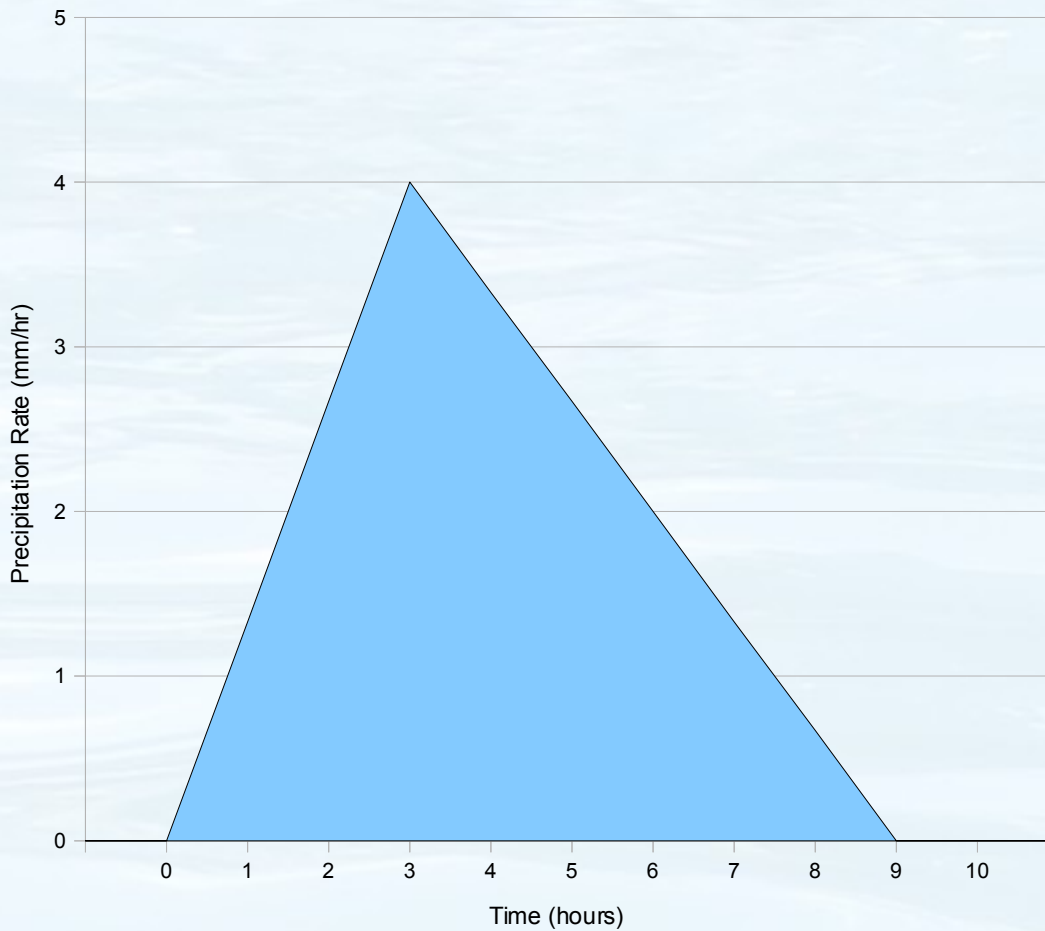
# Precipitation Tasks

- Precipitation Specification
- Precipitation Calculation Software
- Climate Model Precipitation Intercomparison
- Precipitation Adjustment Software

# Precipitation Characteristics

<u>Precipitation Characteristic</u>	<u>Units</u>
1. Total yearly, monthly, or seasonal precipitation	mm
2. Length of precipitation season (for regions with distinct seasonality)	days
3. Number of identifiable events in the season/year	count
4. Average event duration in the season/year	hrs or days
5. Delay time between events in the season/year	hrs or days
6. Average event rate in the season/year	mm/hr
7. Maximum event intensity in the season/year	mm/hr

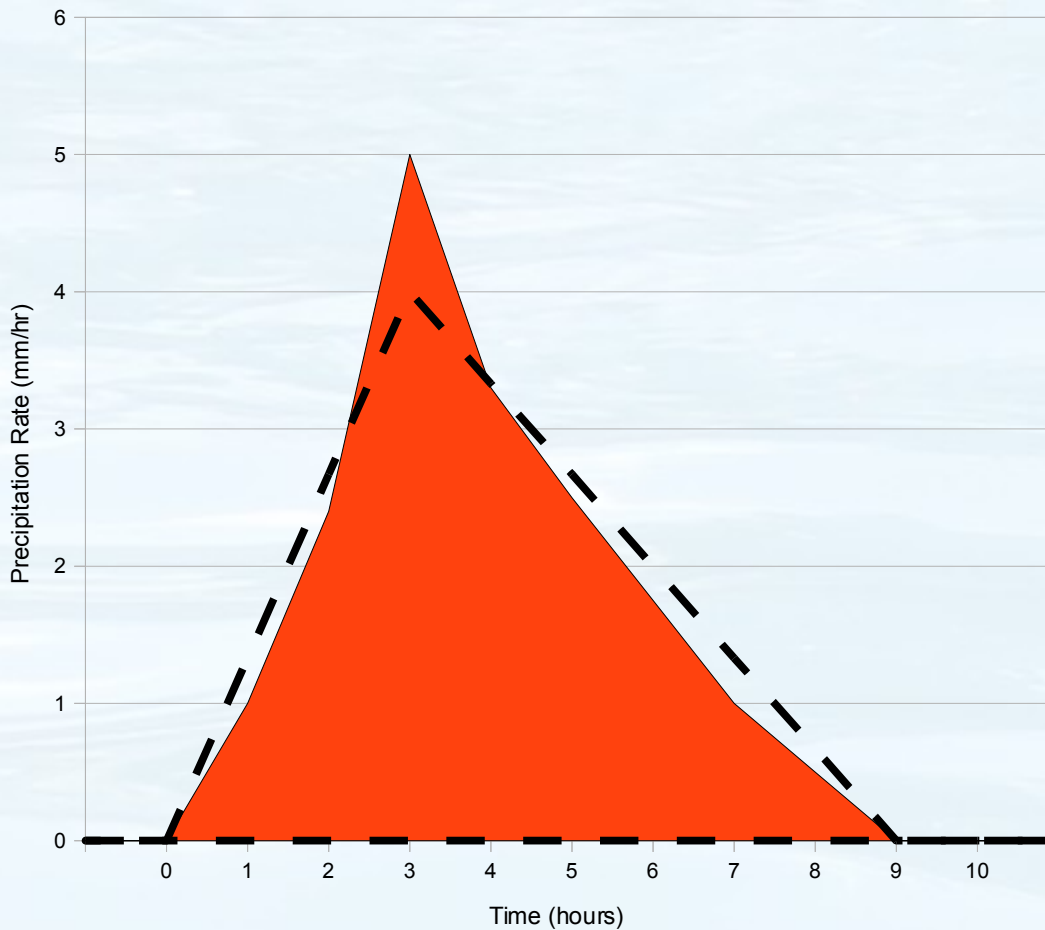
# Precipitation Event



## Initial Conditions

Maximum = 4  
Mean = 2  
Duration = 9

# Increase #7 Maximum Event Intensity



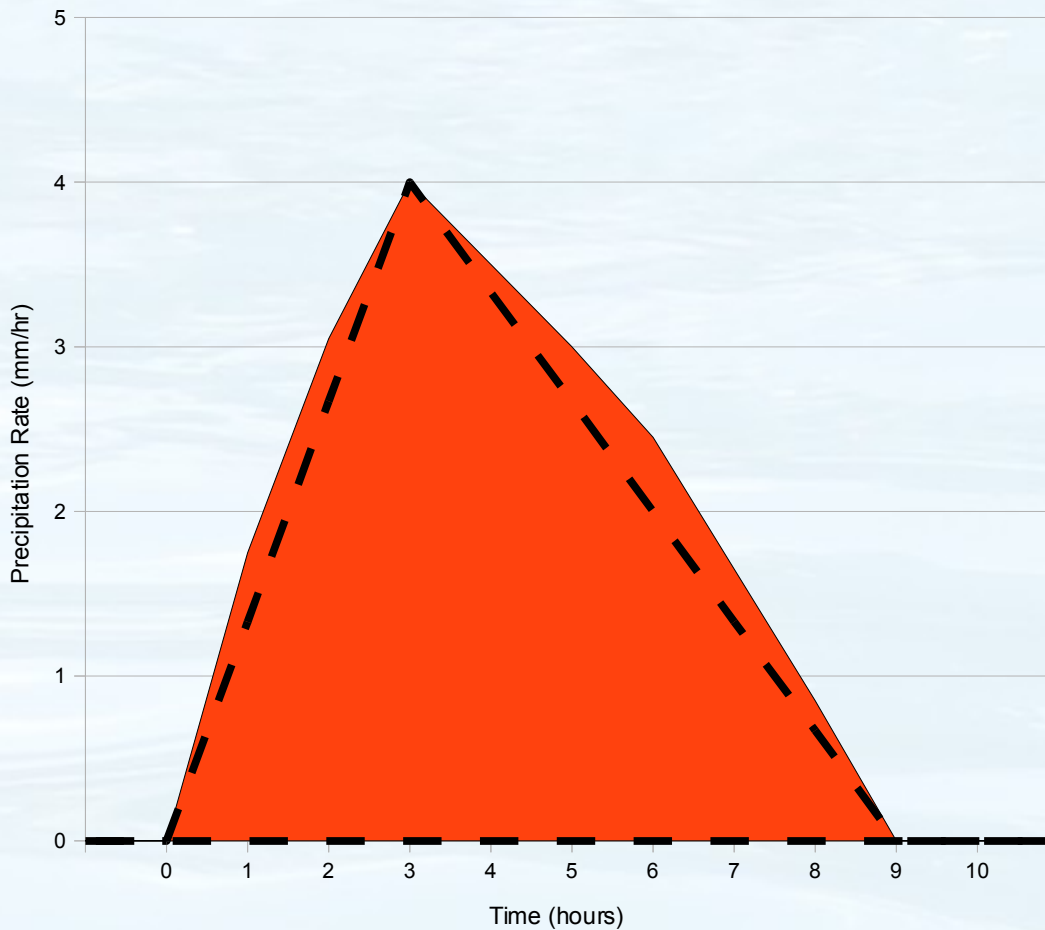
## Initial Conditions

Maximum = 4  
Mean = 2  
Duration = 9

## Changed Conditions

**Maximum = 5**  
Mean = 2  
Duration = 9

# Increase #6 Average Event Rate



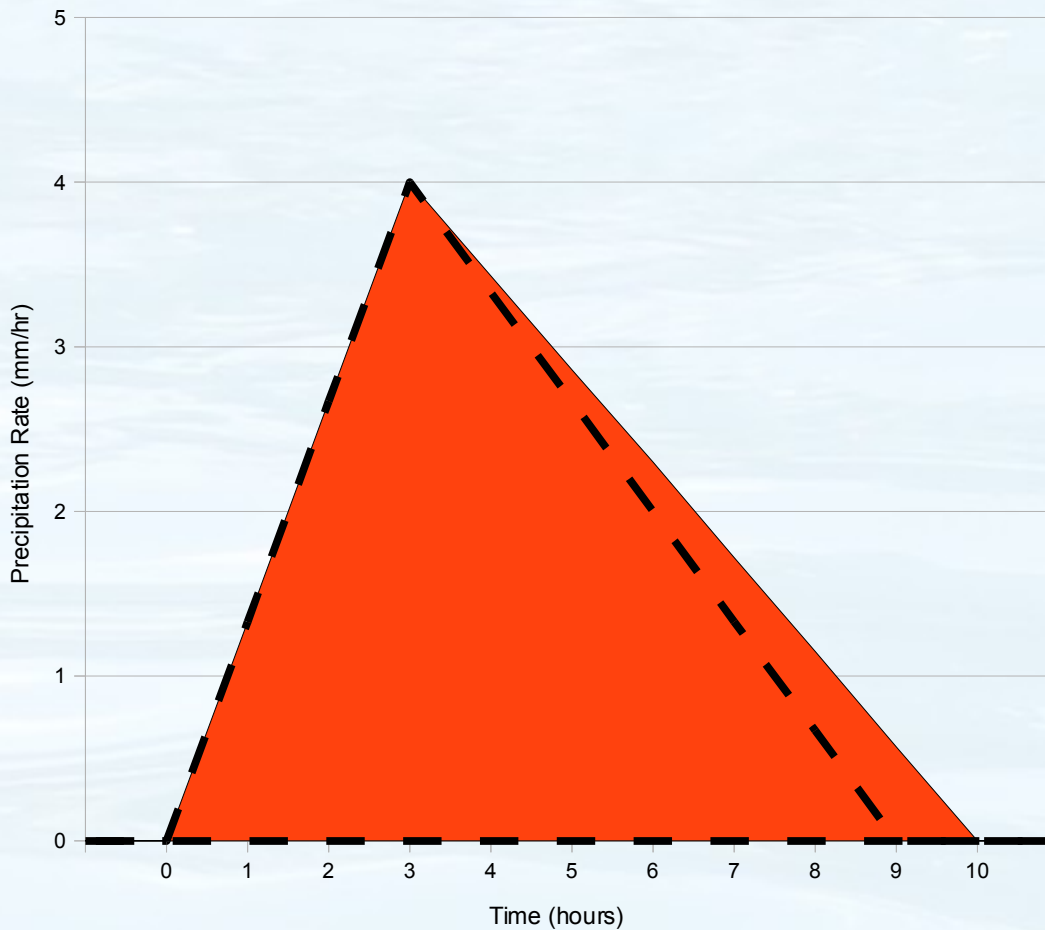
## Initial Conditions

Maximum = 4  
Mean = 2  
Duration = 9

## Changed Conditions

Maximum = 4  
**Mean = 2.5**  
Duration = 9

# Increase #4 Average Event Duration



## Initial Conditions

Maximum = 4  
Mean = 2  
Duration = 9

## Changed Conditions

Maximum = 4  
Mean = 2  
**Duration = 10**

# Precipitation Interdependence

Total Precipitation = Mean \* Duration

<u>Initial Conditions</u>	<u>Increase Mean</u>	<u>Increase Duration</u>
Maximum = 4	Maximum = 4	Maximum = 4
Mean = 2	<b>Mean = 2.5</b>	Mean = 2
Duration = 9	Duration = 9	<b>Duration = 10</b>
<b>Total = 18</b>	<b>Total = 22.5</b>	<b>Total = 20</b>

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## Increase #1 Total Precipitation +10%

Increase both Max, Mean & Duration by  
 $\sqrt{1.10} = 1.0488 = +4.88\%$

## Changed Conditions

**Maximum = 4.2**  
**Mean = 2.1**  
**Duration = 9.4**  
**Total = 19.8**

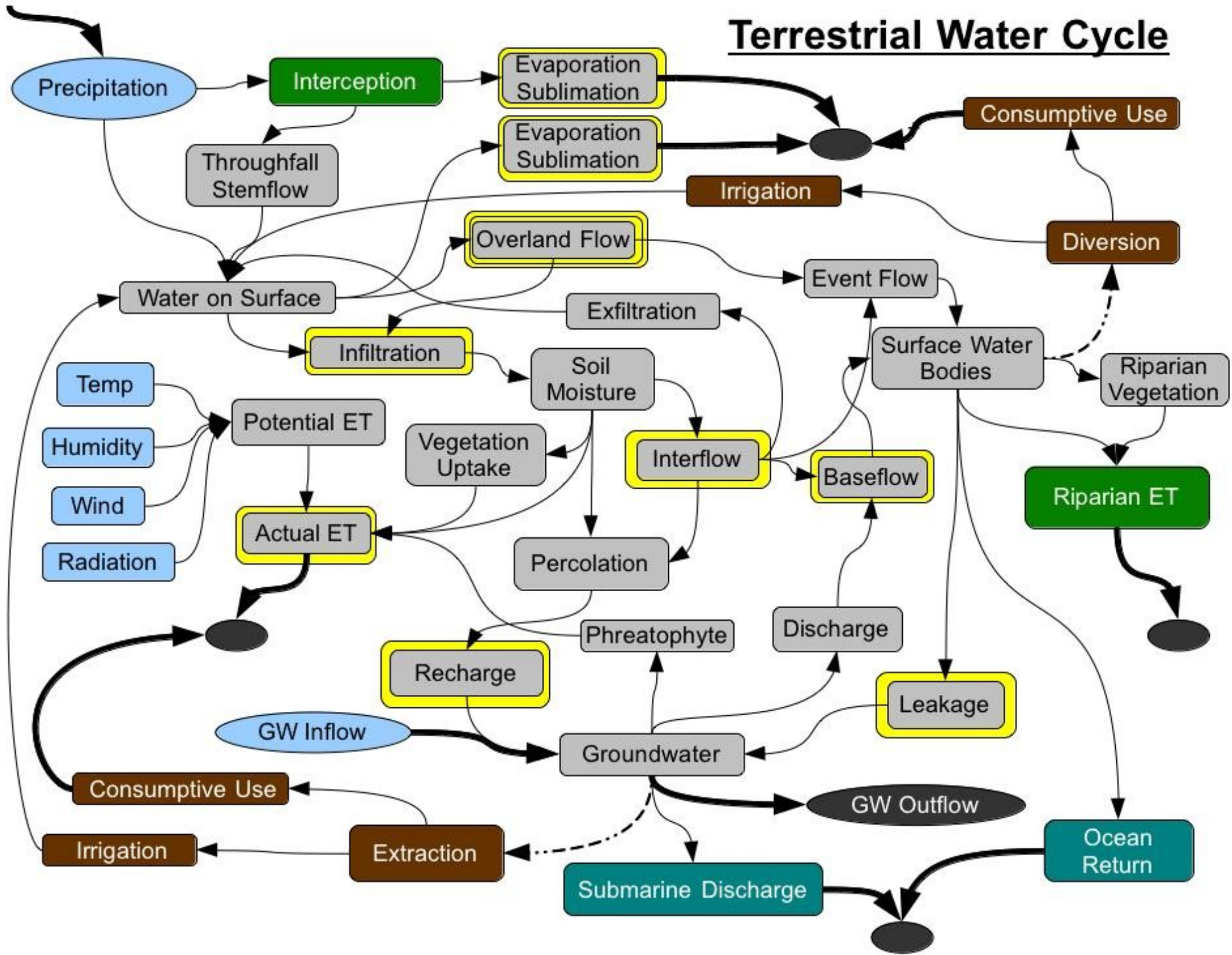
# Hydrology/Precipitation Tasks

- Hydrologic Component Specification ✓
- Hydrologic Software Choice ✓
- Test Automation (UCODE)
- Sensitivity and Differential Impact Testing
- Non-linear Response Processing
- Stochastic Confidence Testing
- Basin Choice Dependency Investigation

# Hydrologic Cycle Components

1. Interception evaporation/sublimation
2. Snowpack sublimation
3. Surface evaporation
4. Durnian saturation-excess overland flow
5. Horton infiltration-excess overland flow
6. Infiltration into soil
7. Soil evapotranspiration
8. Interflow to streams
9. Groundwater recharge
10. Baseflow to streams
11. Stream leakage

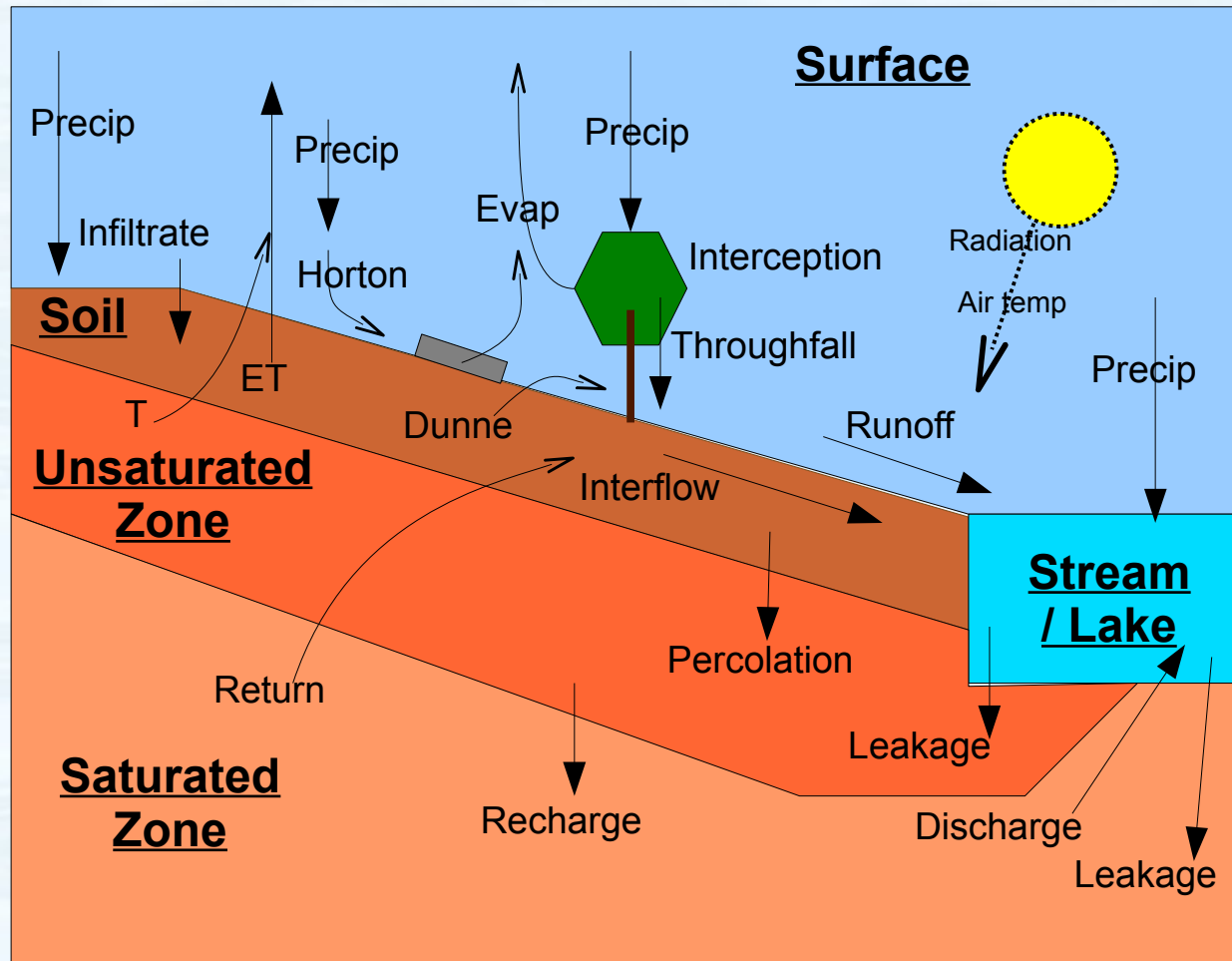
# Terrestrial Water Cycle



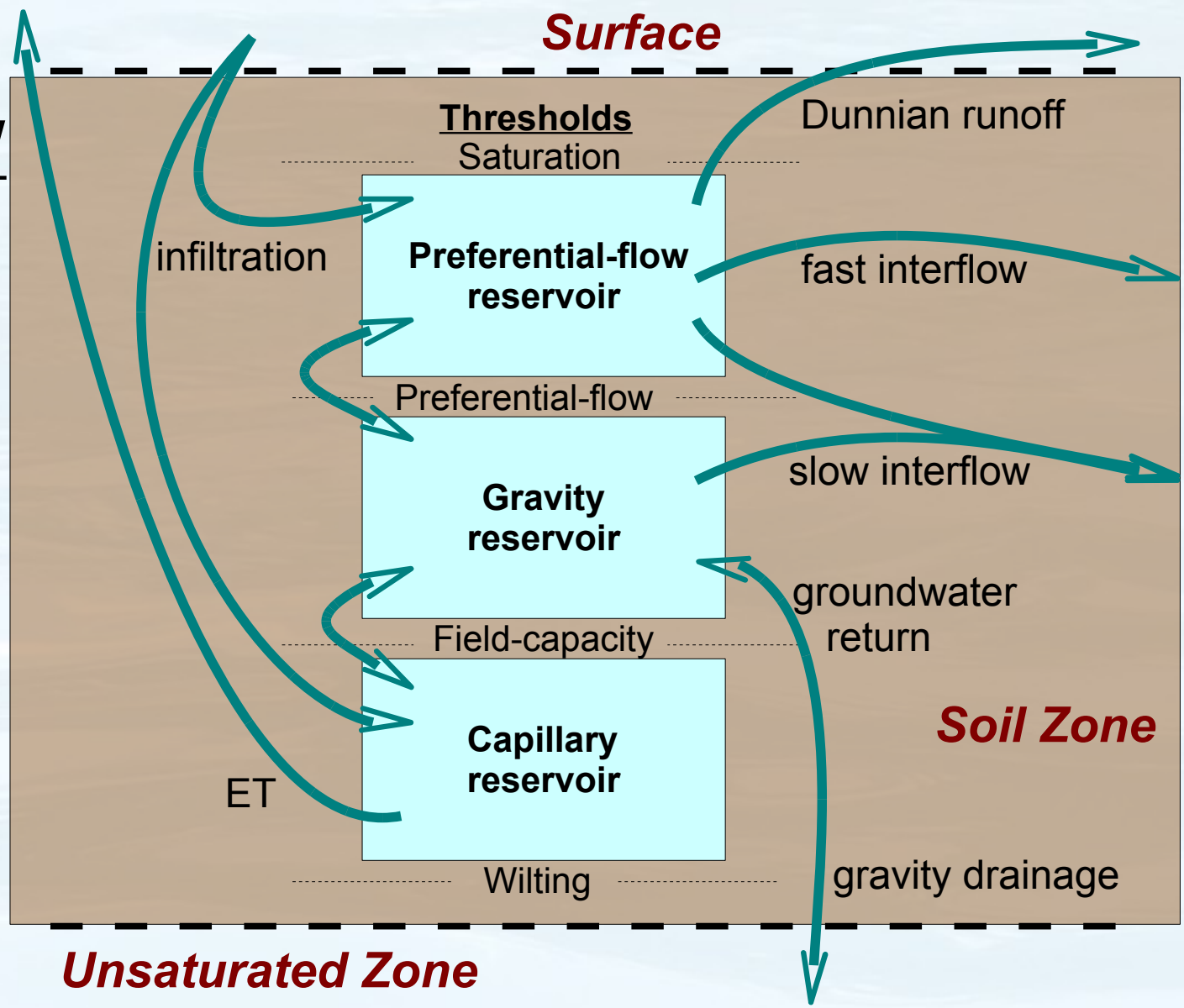
# GSFLOW Capabilities

- Surface Hydrological Response Units (HRUs)
- Canopy interception
- Snowpack accumulation, melting, sublimation
- Surface-water runoff (Horton & Dunne)
- Infiltration to soil zone
- Interflow (fast & slow)
- Actual ET within soil zone
- 1-D Unsaturated flow, storage, and ET
- 3-D Groundwater flow
- Streamflow
- Lakes

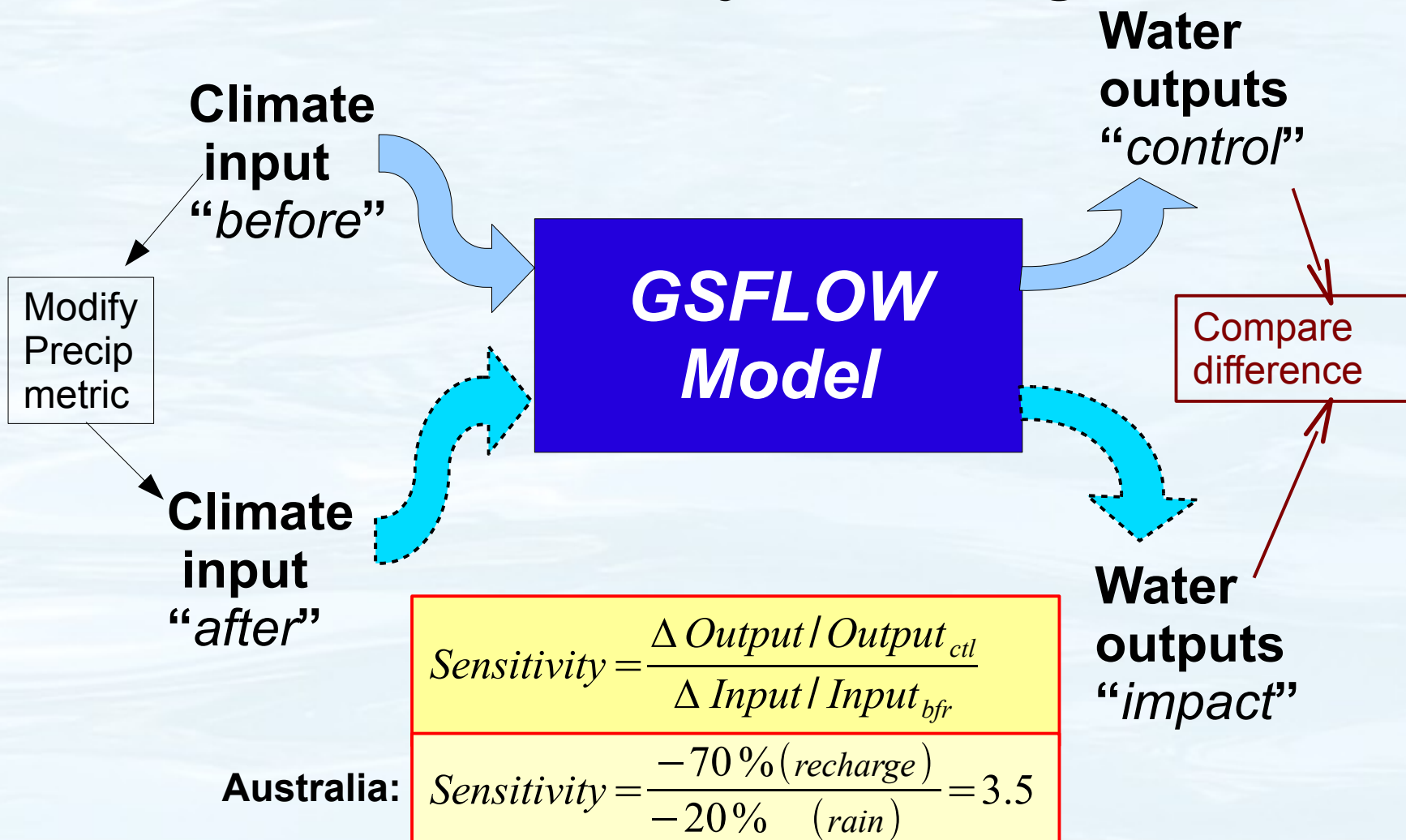
# GSFLOW Zones



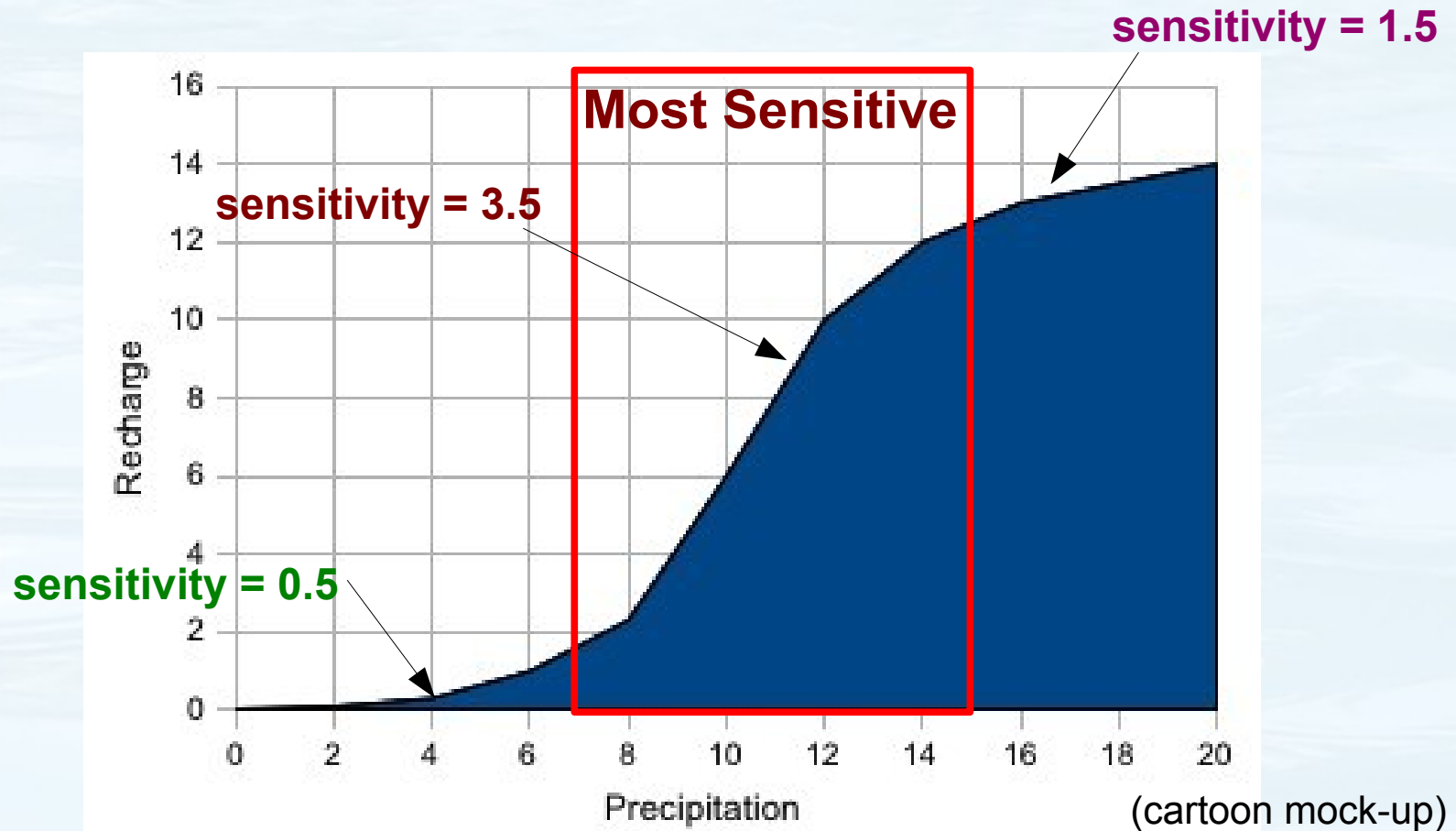
**GSFLOW**  
**Soil**  
**Element**



# Sensitivity Testing



# Non-Linear Relation Between Precipitation and Recharge

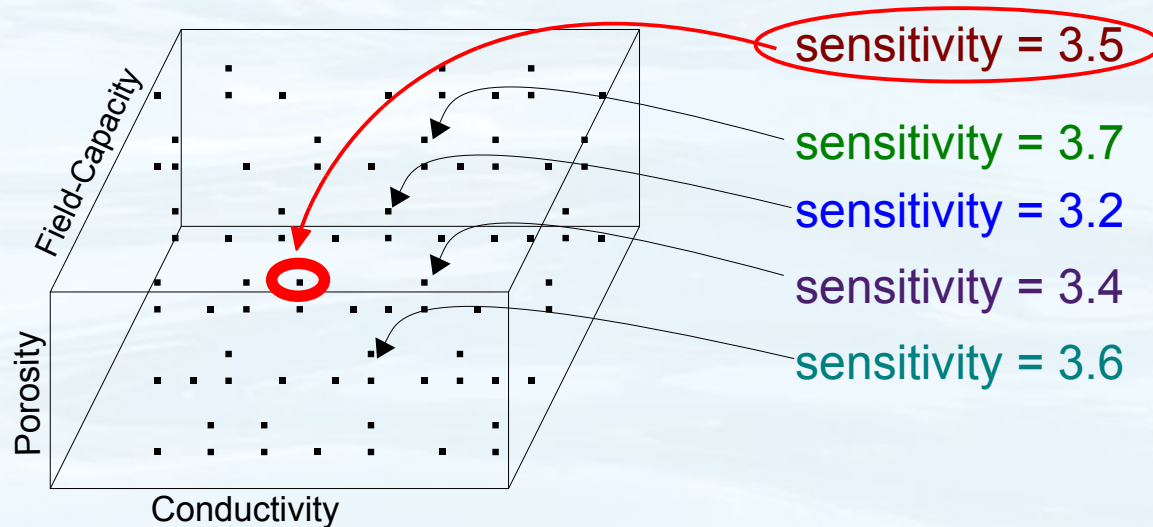


# Stochastic Confidence

1. Conductivity:  $10^{-1}$   $\leftarrow$   $\text{---}$   $\rightarrow$   $10^{-3}$

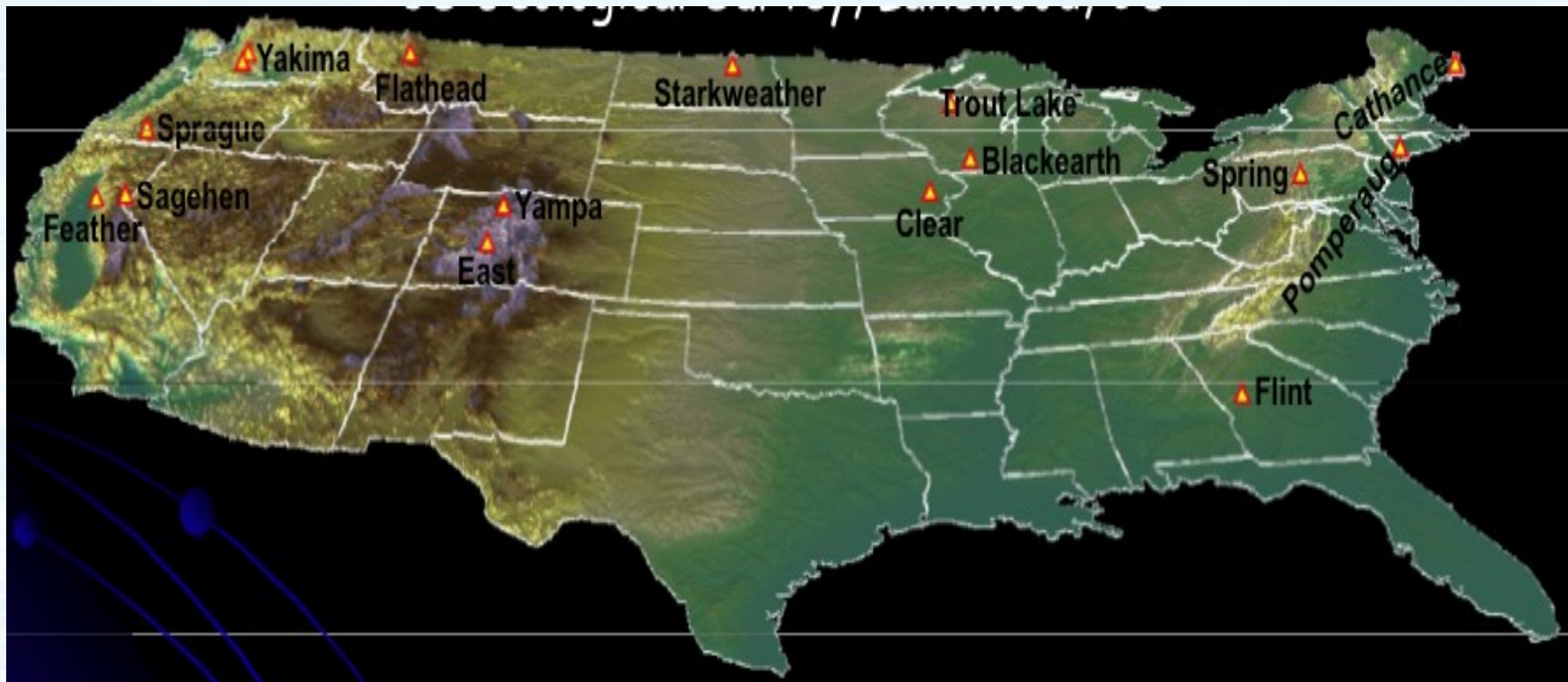
2. Porosity: 0.3  $\leftarrow$   $\text{---}$   $\rightarrow$  0.45

3. Field-Capacity 0.1  $\leftarrow$   $\text{---}$   $\rightarrow$  0.25



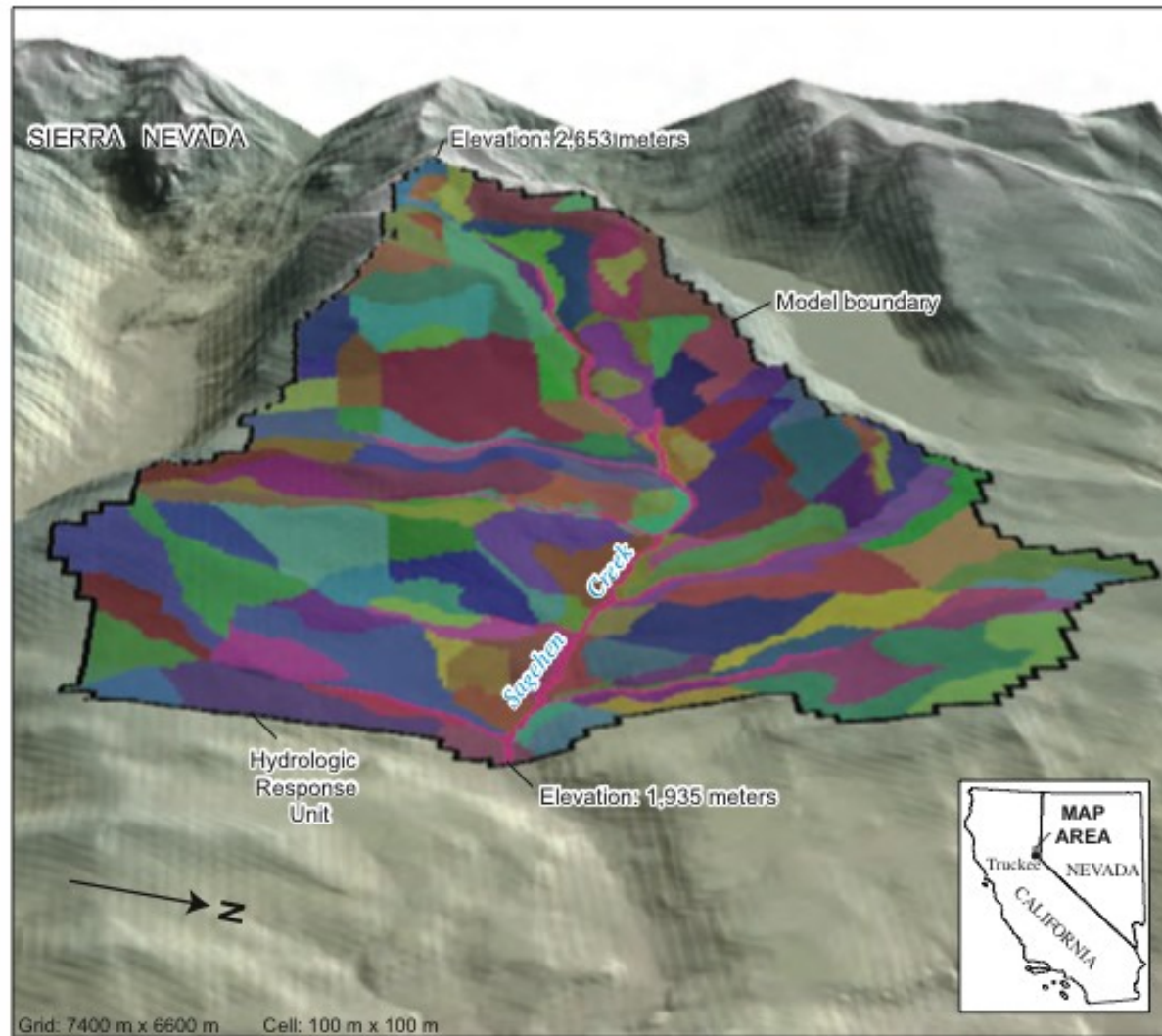
# Basin Choices

16 Basins in development, not including Santa Rosa CA



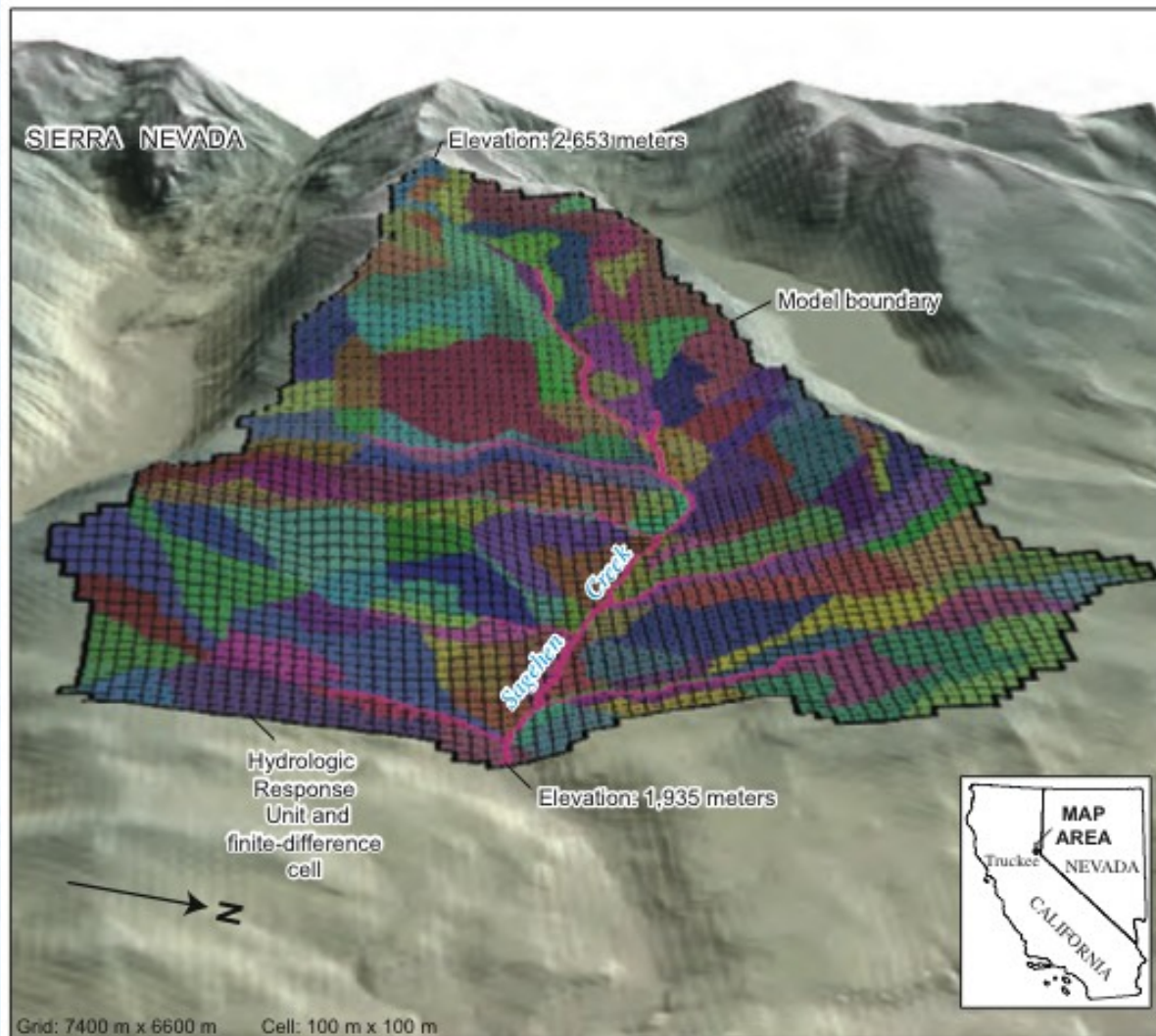
(USGS 2010)

# Sagehen HRUs



(Markstrom 2008)

# Sagehen Finite-Difference Cells



(Markstrom 2008)

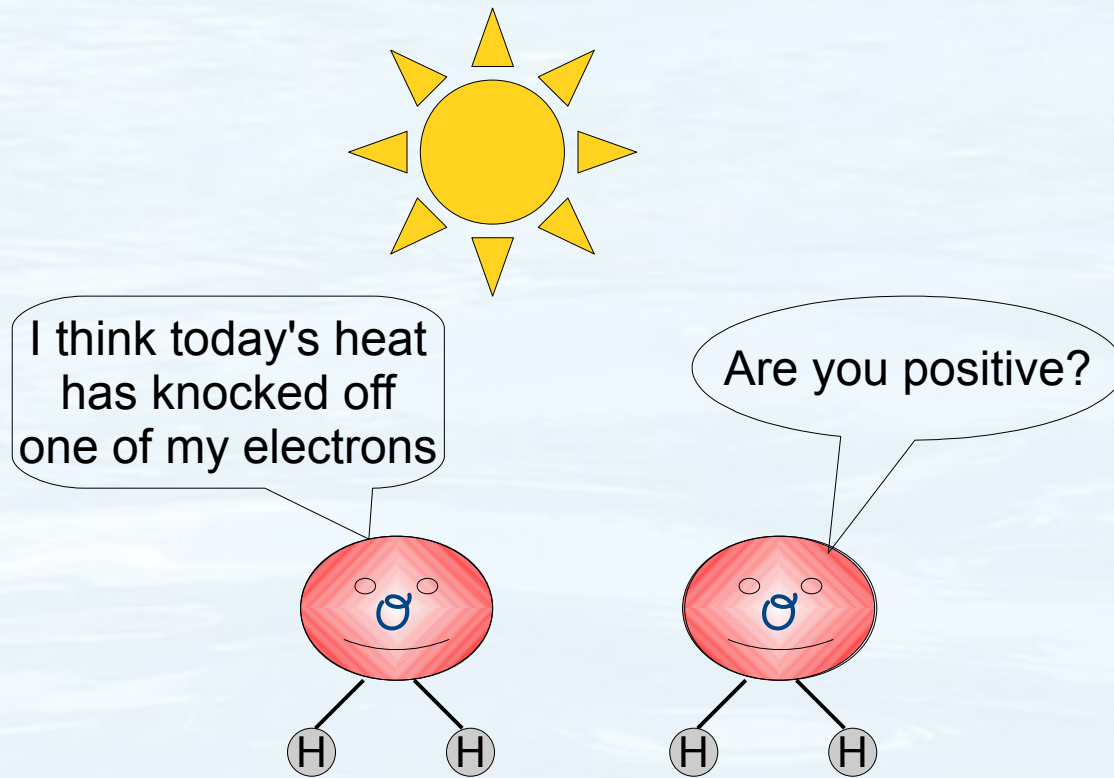
# Schedule

- Spring 2010
  - Test Automation
  - Precipitation Specification
- Summer 2010
  - Test Automation cont'd
  - Precipitation Calculation Software
  - Climate Model Precipitation Intercomparison
- Fall 2010
  - submit paper for Climate Model Precipitation Intercomparison
  - Precipitation Adjustment Software
  - Sensitivity and Differential Impact runs for Basin #1
- Winter 2011
  - Non-linear Response testing for Basin #1
  - submit paper for Non-linear Response for Basin #1

# Schedule cont'd

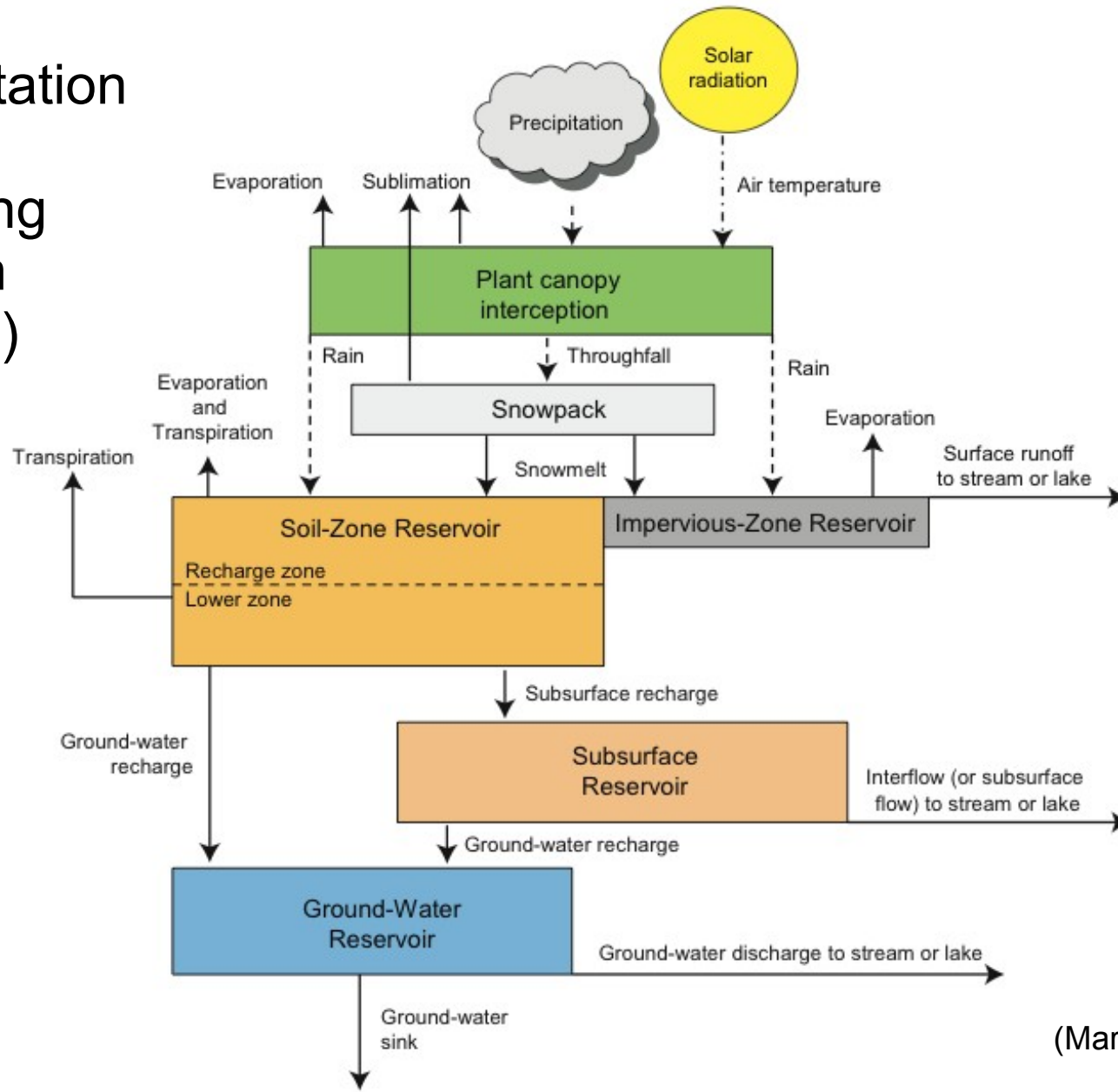
- Spring 2011  
Stochastic Confidence tests for Basin #1
- Summer 2011  
submit paper on Stochastic Confidence for Basin #1  
Sensitivity & Non-linear Response testing for Basin #2
- Fall 2011  
Sensitivity & Non-linear Response testing for Basin #3
- Winter 2012  
Sensitivity & Non-linear Response testing for Basin #4  
submit paper on Basin Choice Dependency
- Spring 2012  
Dissertation & defense

# Questions?



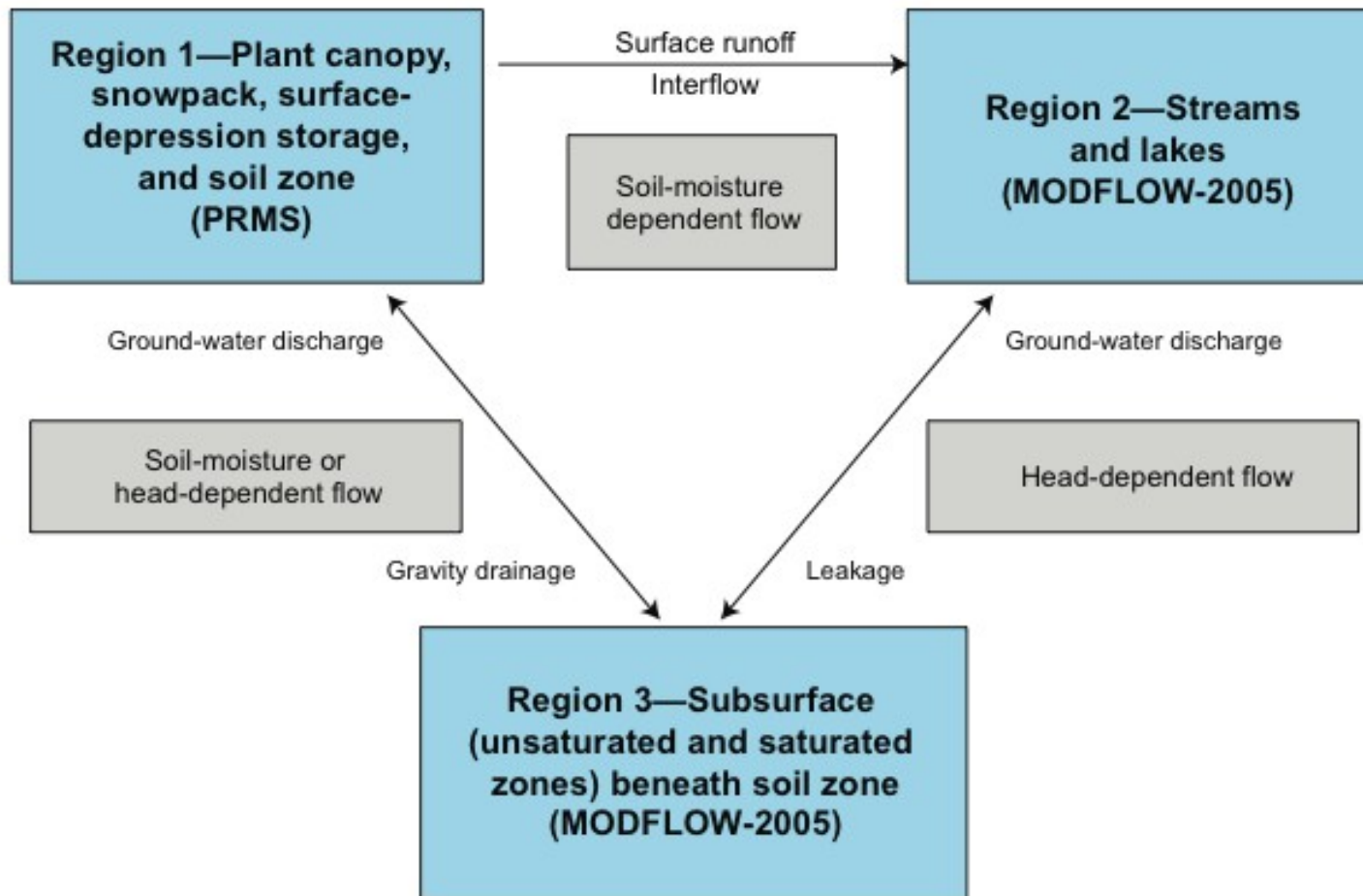
**Climate Change Impacts on Water**

# Precipitation Runoff Modeling System (PRMS)



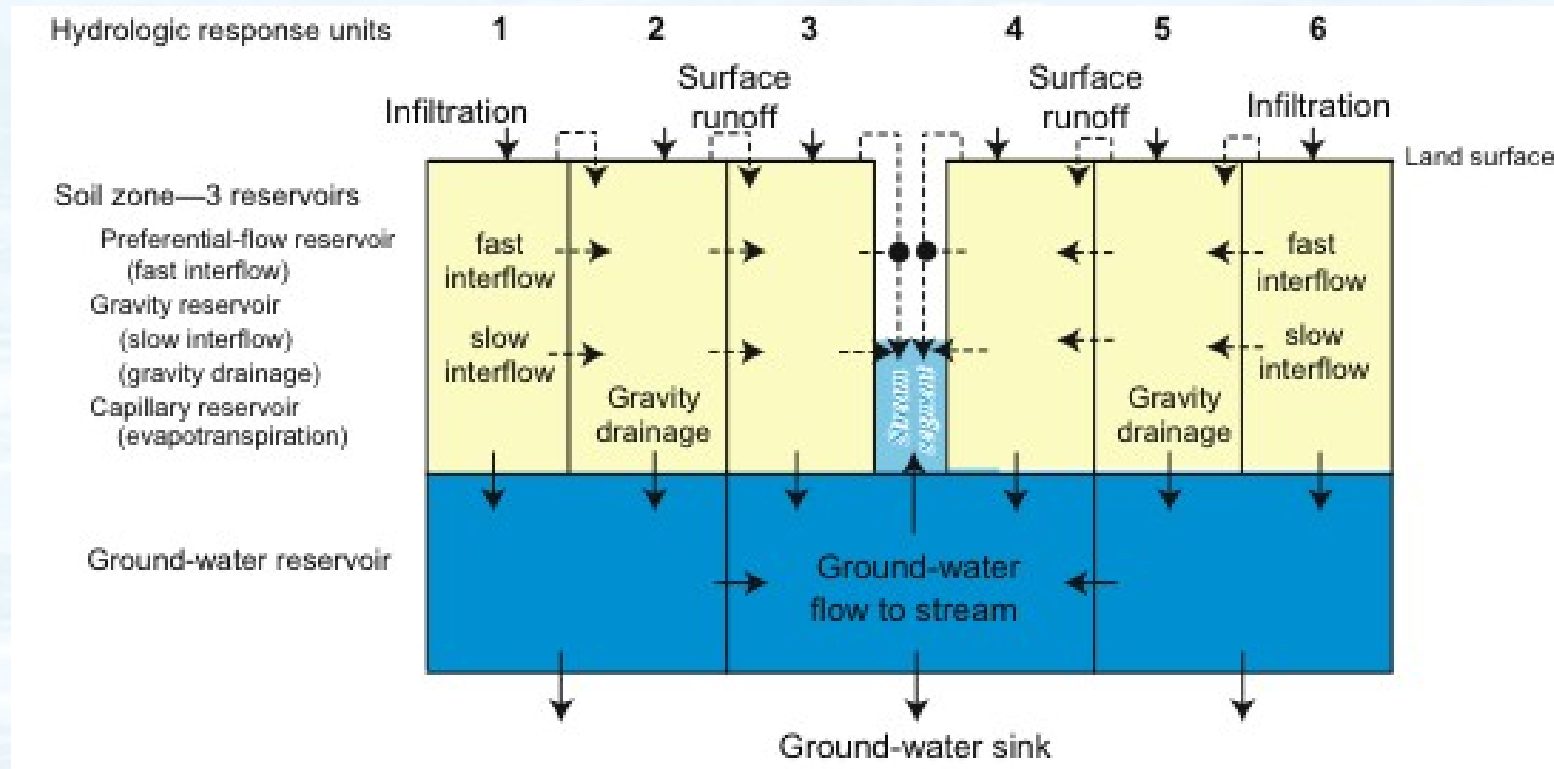
(Markstrom 2008)

# GSFLOW Regions



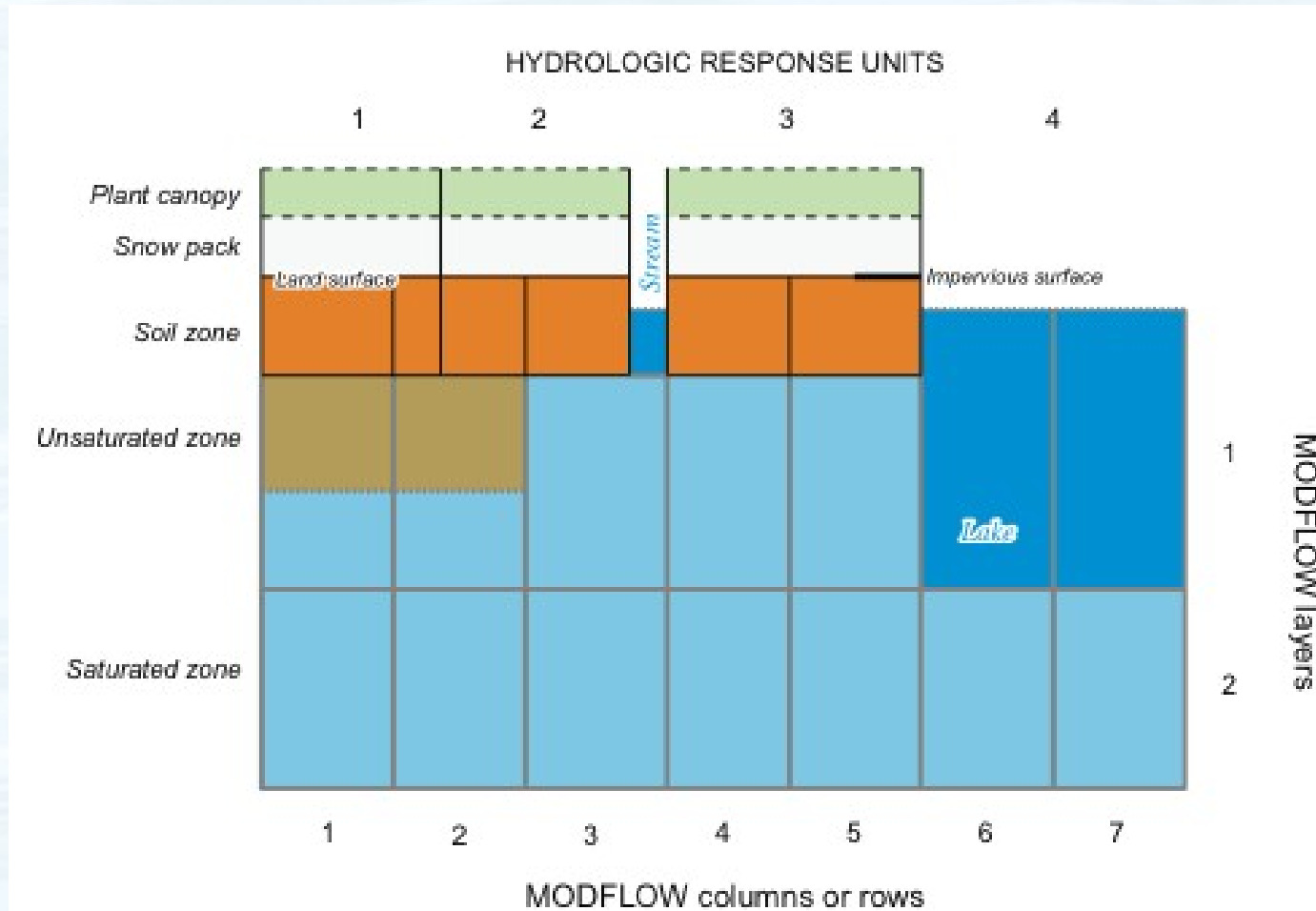
(Markstrom 2008)

# GSFLOW HRUs



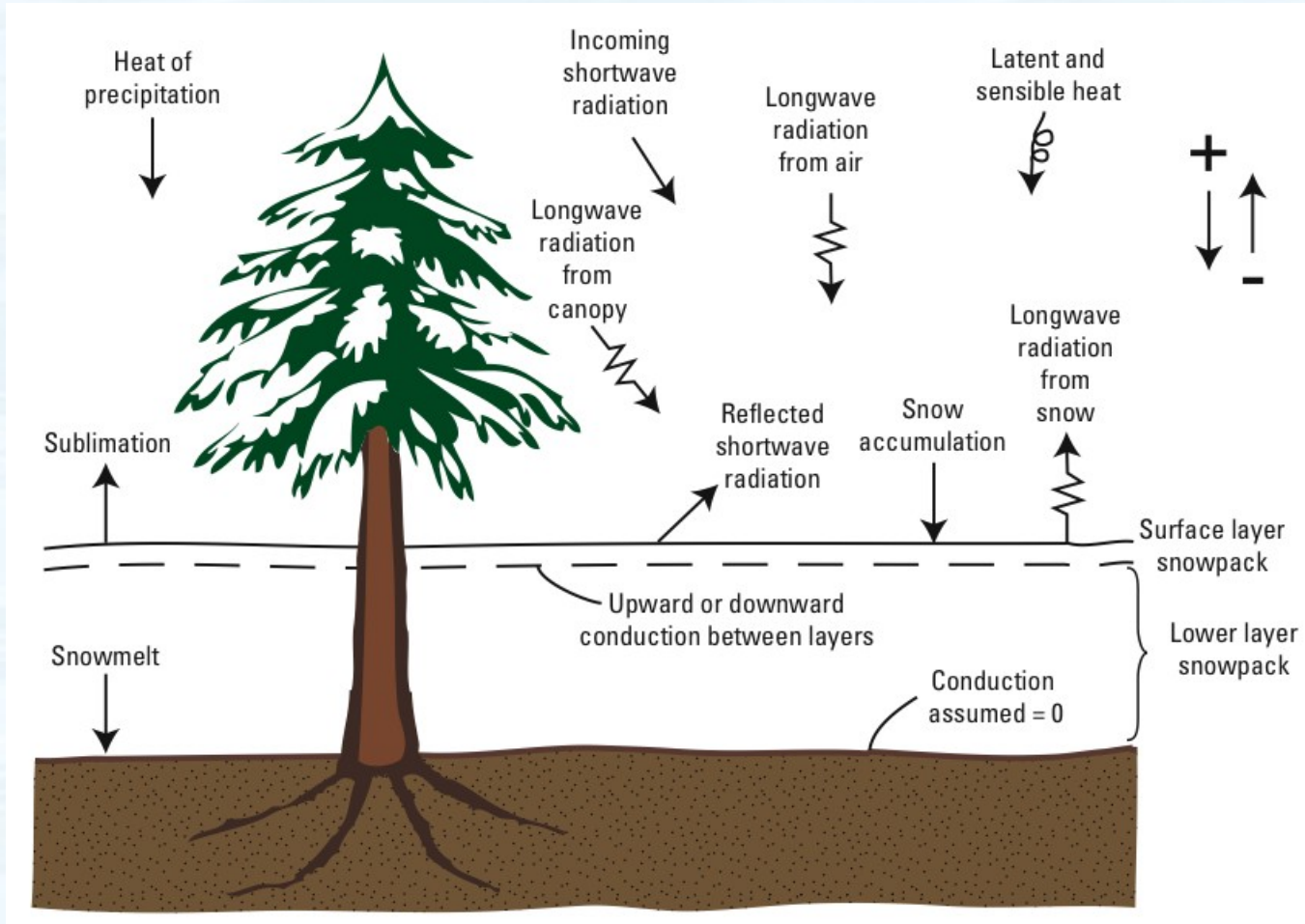
(Markstrom 2008)

# GSFLOW Reservoirs

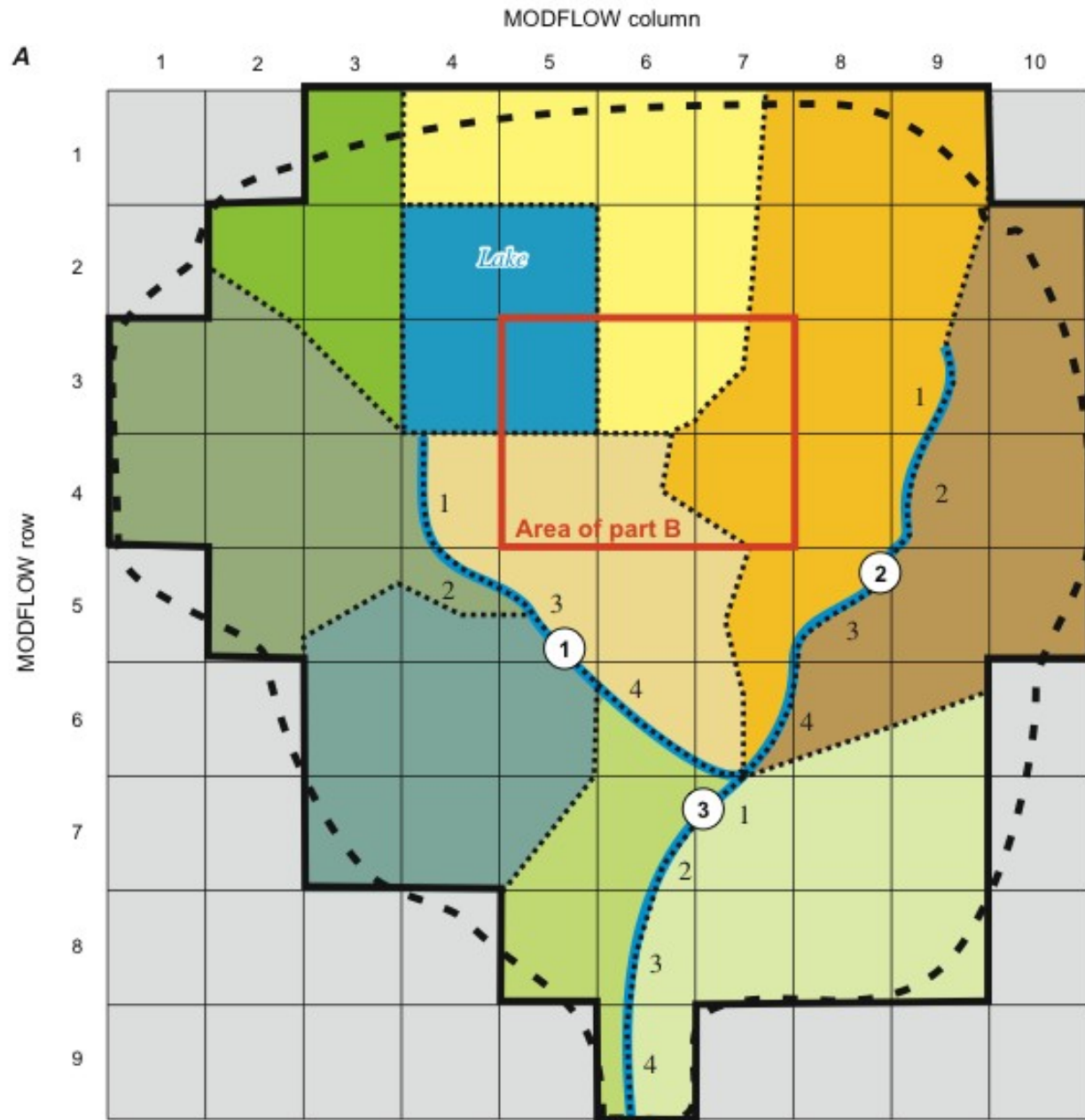


(Markstrom 2008)

# GSFLOW Snowpack



(Markstrom 2008)

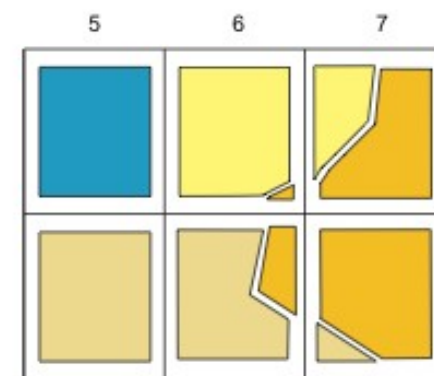


## Soil Elements

connections between hydrologic response units (HRUs), shown as colored areas, from PRMS and finite-difference cells in MODFLOW

## Part B

4 HRUs,  
6 difference cells,  
& 9 soil elements



(Markstrom 2008)

# GS Assumptions and Limitations

- Discrete Time & Space (1 day mean, gridding)
- Canopy Zone (bad land-use and cover data)
- Land-Surface Precip (bad precip & temp data)
- Soil Zone (HRU uniform, no freeze, const roots)
- Streams (1D flow down, no waves, no headloss)
- Lakes (mixed, gridded, no headloss)
- Ground Water (laminar, anisotropy gridded)
- Unsaturated (vertical flow, no capillary, V homogen)