Quantitative Impact of Climate Change On Water Resources

Bruce Daniels

NGWA Theis Conference
“Ground Water and Climate Change”
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Bruce Daniels - Background

- Director, Soquel Creek Water District
  - Santa Cruz County, California
  - Urban/Suburban Water Supply 55K People
  - All Groundwater (5K af/yr)
- Regional Water Quality Control Board Member (past)
  - California Central Coast
  - U.S. Clean Water Act [surface water]
  - Calif Water Quality Control Act [groundwater]
- Ph.D. Student Researcher in Hydroclimatology
  - University of California - Santa Cruz
  - Earth and Planetary Sciences Dept.
  - Climate Change and Impacts Laboratory
    (Prof. Lisa Sloan)

Topics Summary

- What is Climate Change?
- What Previous Work has been Done?
- What Precipitation Aspects are Important?
- What Water Elements do we care about?
- How does Precipitation Relate to Water?
- What is my Research Program?

Introduction

- Water Managers need to know the Impact of Climate Change on Water Resources!
  esp. <u>Numerical</u> Impacts
  - Future is not going to be Anything like the Past!

- Scientists need Deeper Understanding of Climate Connections to Hydrological Cycle!
  esp. Better Models

Status Today: Poorly Understood

"Changes in surface and groundwater have been observed in many systems, and some have been linked with statistical significance to trends in temperature and precipitation, but because of different trends in regional climate change, climate variability, and the complexity of non-climatic influences on surface and groundwater, uniform global trends have not been identified."

[Moser 2009 CEC]

Climate Change

- Climate Change ≠ Global Warming

- Climate Change =

  Δ Temperature (warm or cool)

  --» **<u>Δ Precipitation</u>**

  Δ Humidity

  Δ Wind Speed

  Δ Radiation

  Δ Clouds

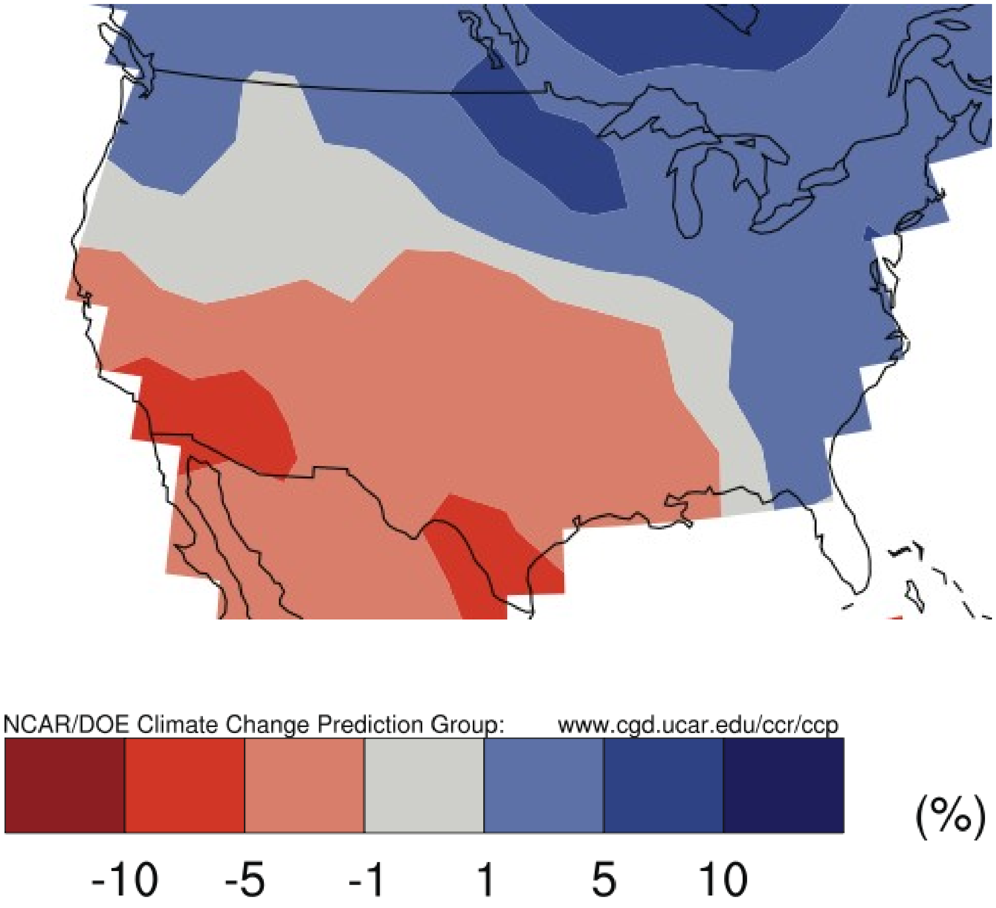
  Δ Ice Cover

  Δ Oceans (temp, currents, acidity)

  Δ Biota

Precipitation Amount Change

U.S. Annual Precipitation Change 1990 to 2030, *(IPCC emissions scenario A1B)*



[U.S. CCSP, Backlund et al, 2008]

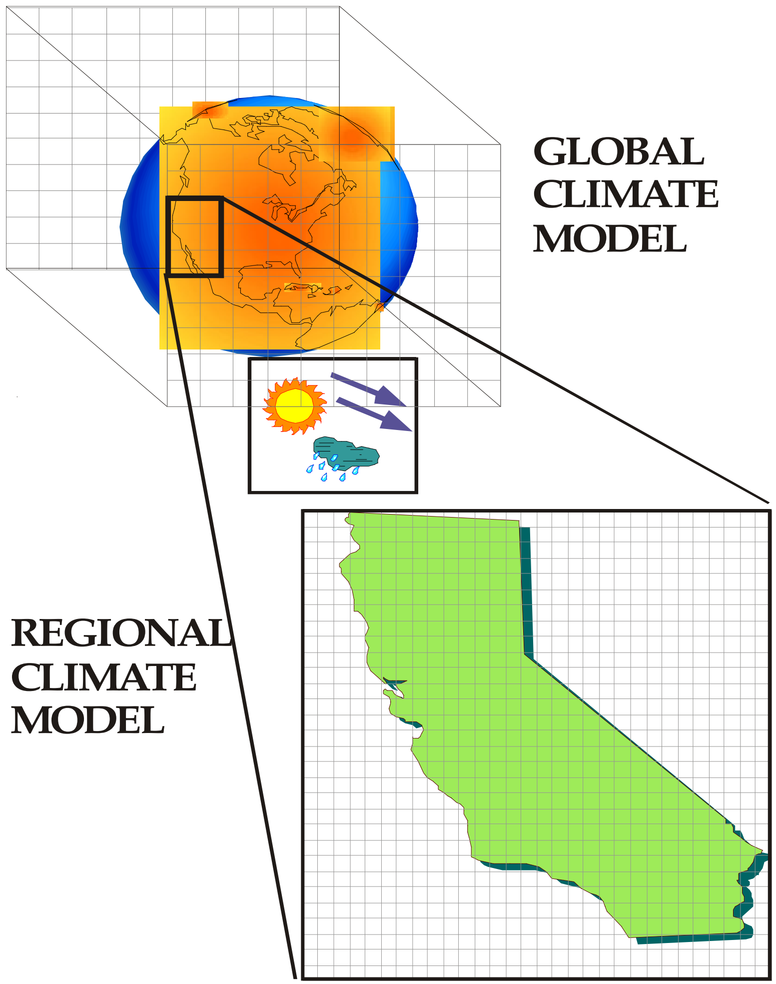
Previous Work

- Special Studies
  - Winter Snowpack Impacts
- Direct Estimates
  - Extract Water Impacts from Climate Model Projections

Winter Snowpack Impacts

- Well Studied, esp. California & West
  - Involves mainly analysis temperature effects
    "More winter precipitation falling as rain rather than as snow, the snow line retreating upward, earlier snow melt and associated increases in spring and decreases in summer river flow."
    [Moser 2009 CEC]
- Big Impacts Found
  "Sierra Nevada snowpack could decline 70 to 90 percent"
  [CEC & CalEPA, 2006]
- Quite Important
  - 30% Water Supply in California
- Limited Utility
  - Irrelevant for other 70% usage?!
  - Esp. Groundwater supply

Climate Model Projections



Global Climate Model (GCM) is a coarse-grained computer representation of the entire Earth climate, e.g. temperature, radiation, moisture, and motion

Regional model is more fine-grained and is driven by global model output at the common boundaries

Water Impact Realities

- Which of 22 IPCC GCMs to use?
- Which of 40 Emission Scenarios to use?
- How to Compute Impacts on Water?
- Precipitation Not Yet Well Represented
  - esp. precipitation aspects

"In general, downscaling methods represent regional air temperature well, but they have variable results in representing regional precipitation"
[Fowler et al. 2007]

"Future changes in total precipitation due to human-induced warming are more difficult to project than changes in temperature."
[Karl 2009]

Precipitation Change Aspects

- Δ Precipitation ≠ Δ Annual Precipitation

- Δ Precipitation =

  Δ annual precipitation
  Δ length of precipitation season
  Δ number of storms in the season
  Δ duration of storms
  Δ avg precipitation in storms
  Δ max storm precipitation intensity
  Δ time delay between storms

Precipitation Intensity

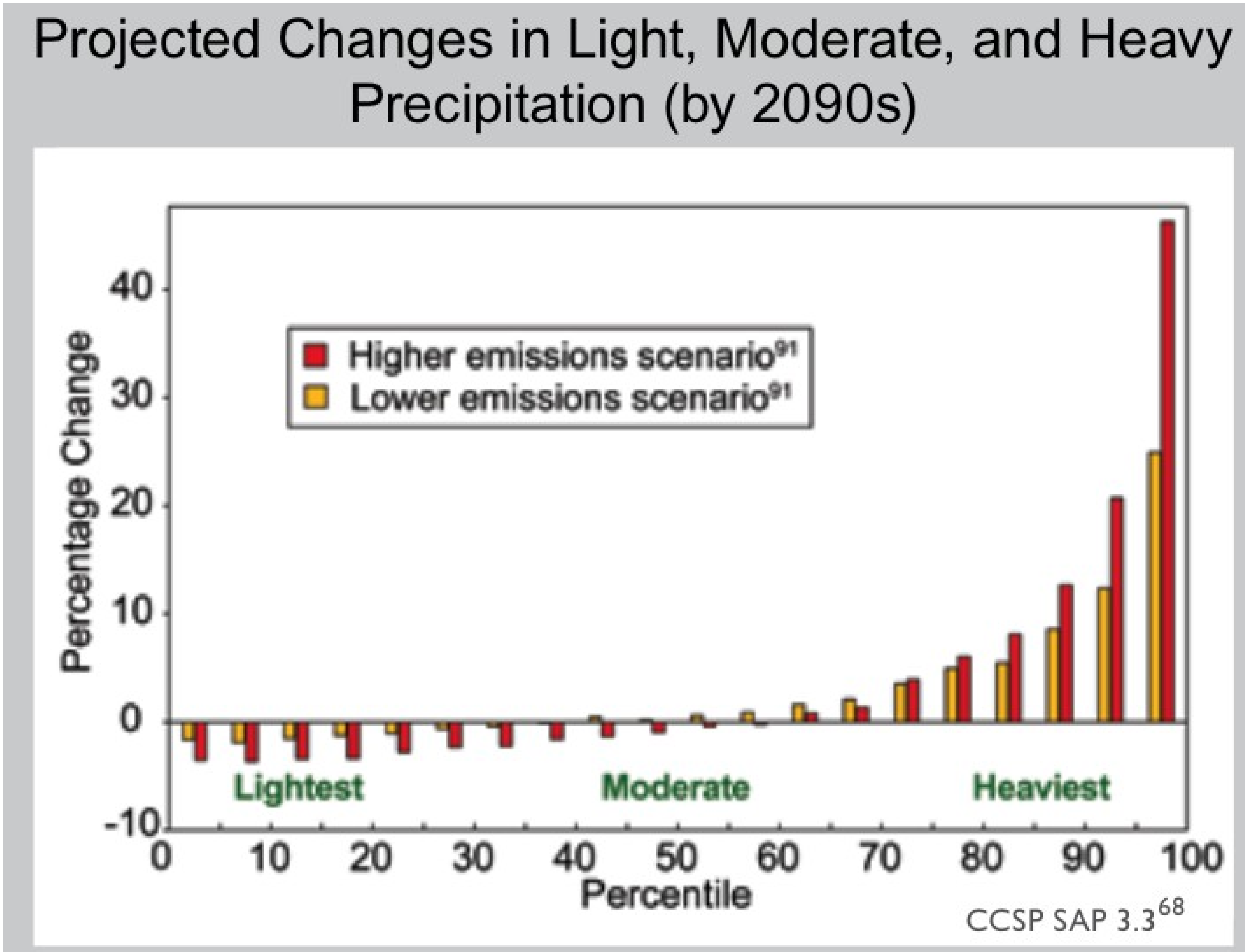
"Widespread increases in heavy precipitation events have occurred, even in places where total rain amounts have decreased."

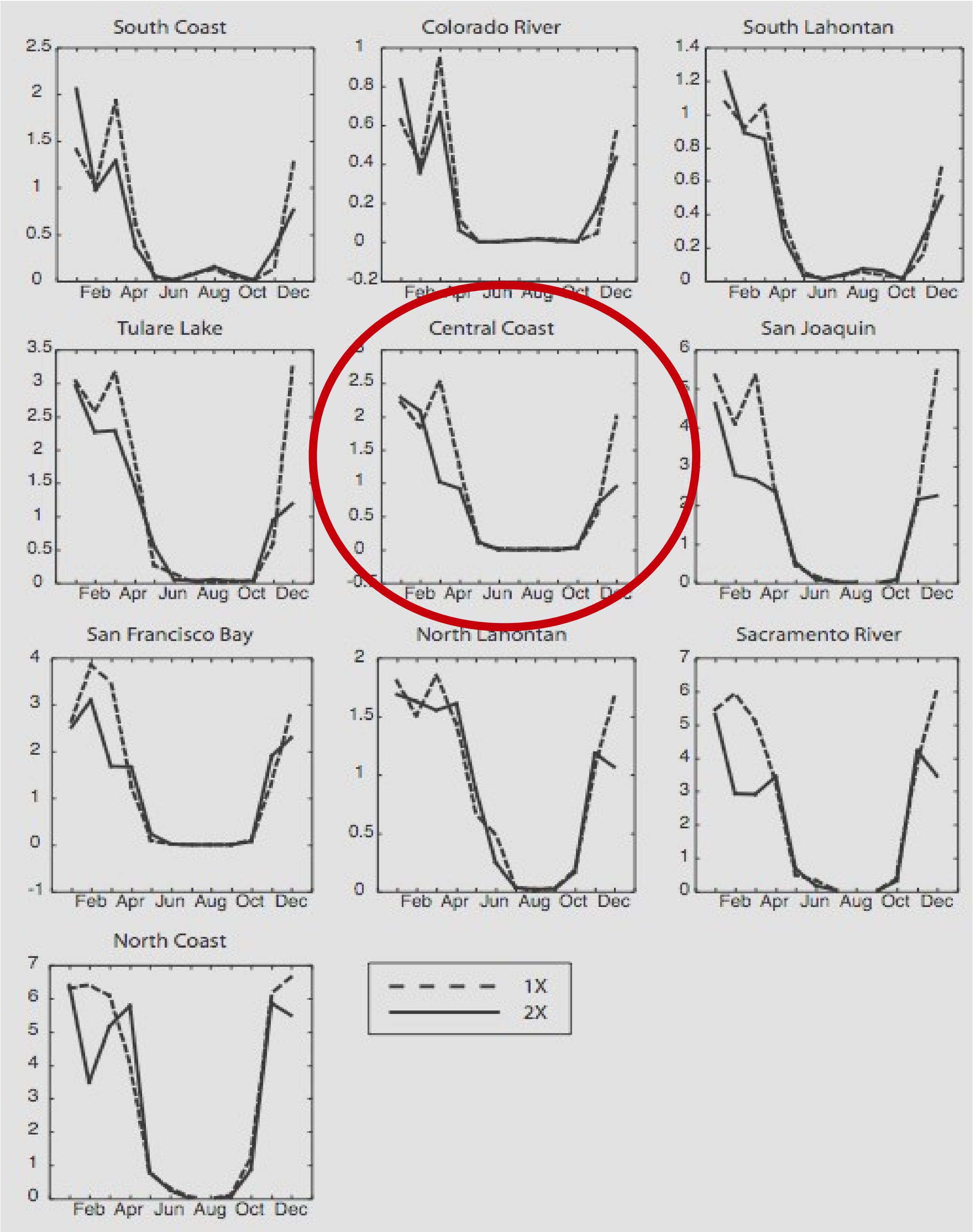
"One of the clearest precipitation trends in the United States is the increasing frequency and intensity of heavy downpours."

"The widespread trend toward more heavy downpours is expected to continue, with precipitation becoming less frequent but more intense."

[Global Climate Change Impacts in the United States, Karl 2009]

Precipitation Intensity



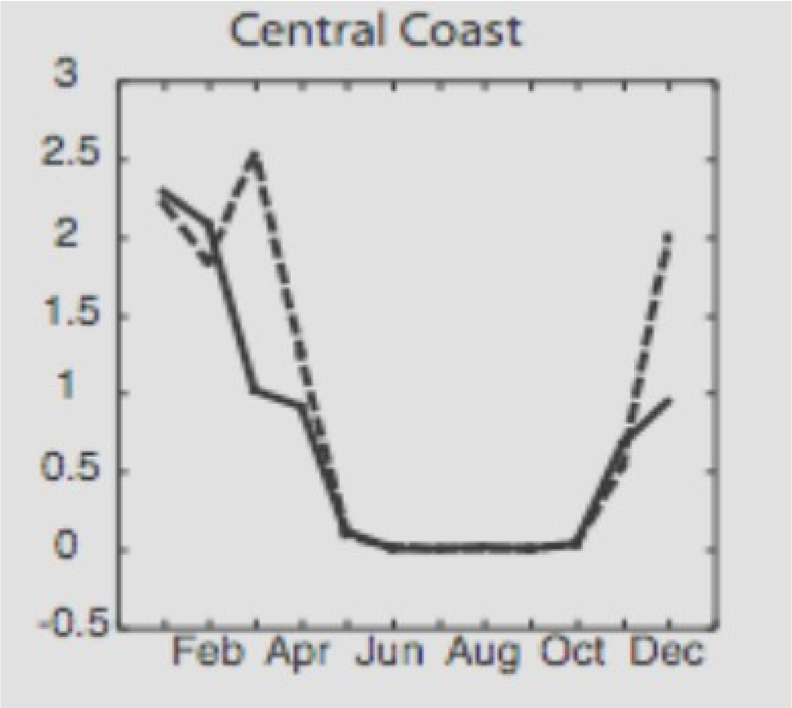


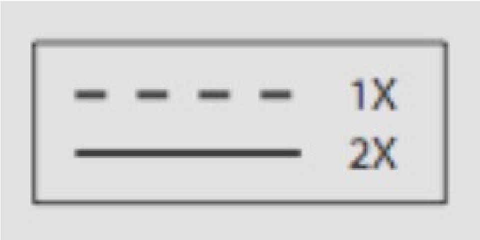
Precipitation Season Changes

Monthly Precipitation Response to Double CO_2 For Hydrologic Basins In California

[Snyder et al., 2002]

Precipitation Season Changes





Current Rainfall Season
Dec. - Jan. - Feb. - Mar.

Future Rainfall Season
Jan. - Feb.

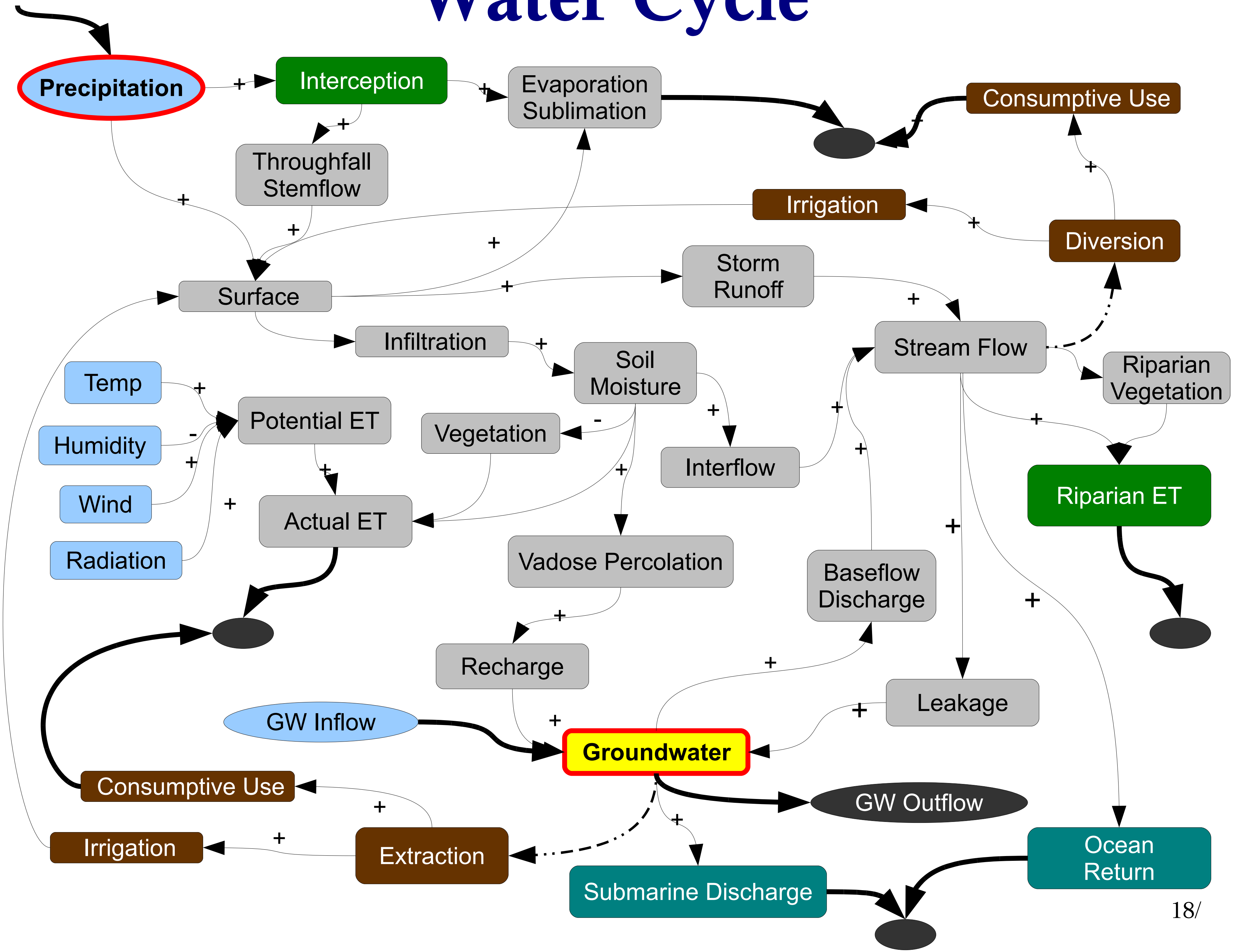
"The climatological spring season, March through May, has been the driest in 114 years of record in the state of California."
- California Dept Water Resources 2008

Terrestrial Hydrologic Cycle

- Water Cycle is NOT Simple System
- Multiple Elements & Pathways:
  1. Precipitation
  2. Vegetation Interception
  3. Surface Ponding
  4. Overland Runoff
  5. Infiltration
  6. Soil Moisture
  7. Plant Uptake & Evapotranspiration
  8. Interflow
  9. Percolation
  10. Groundwater Recharge
- Looks Like a Straight Progression & Flow

  but looks can deceive

Water Cycle



Precipitation
Interception
Evaporation Sublimation
Consumptive Use
Throughfall Stemflow
Irrigation
Diversion
Storm Runoff
Surface
Infiltration
Stream Flow
Soil Moisture
Riparian Vegetation
Temp
Potential ET
Vegetation
Humidity
Interflow
Riparian ET
Wind
Actual ET
Radiation
Vadose Percolation
Baseflow Discharge
Recharge
Leakage
GW Inflow
Groundwater
Consumptive Use
GW Outflow
Irrigation
Extraction
Ocean Return
Submarine Discharge

Climate Impacts Water

Precipitation aspects

1. annual precip
2. length of season
3. storms in season
4. duration storms
5. avg storm precip
6. max storm precip
7. time between storms

?

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Water elements

a) interception
b) surface ponding
c) runoff
d) infiltration
e) soil moisture
f) evapotranspiration
g) interflow
h) percolation
i) recharge

Climate Impacts Water

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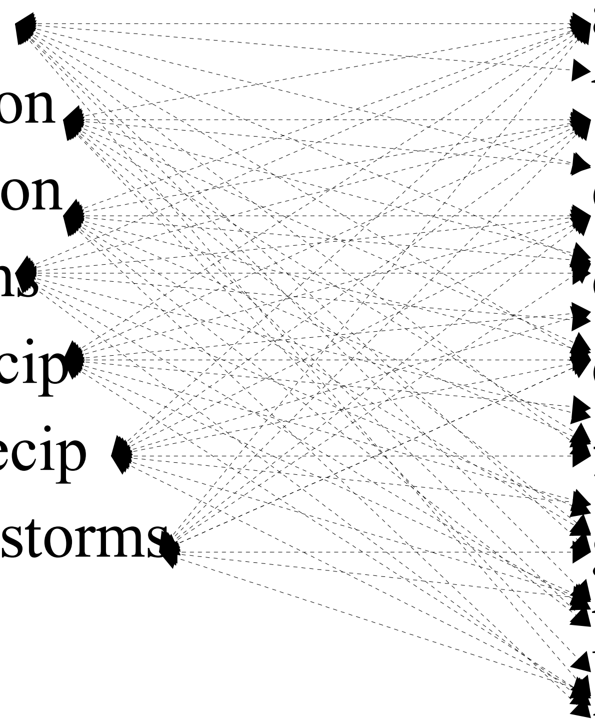

Water elements

a) interception
b) surface ponding
c) runoff
d) infiltration
e) soil moisture
f) evapotranspiration
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h) percolation
i) recharge

Climate Impacts Water

- Each Precipitation Aspect (7) Can Impact Each Water Element (9)
- Impacts are Different,
  - Amounts Differ, Even Signs Differ
  - Intense Rain Storm
    - Channel more water into Storm Runoff (more erosion & flooding)
    - Diverts from percolation & recharge (less water supply)
  - Light Rain or Drizzle
    - Most absorbed by Vegetation or Soil Surface (evaporation)
    - Reduces percolation & recharge (less water supply)

#1 Annual Precip Impacts Water

Precipitation

1. annual precip
2. length of season
3. storms in season
4. duration storms
5. avg storm precip
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7. time between storms

Water

a) interception
b) surface ponding
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#5 Storm Intensity Impacts Water

Precipitation

1. annual precip
2. length of season
3. storms in season
4. duration storms
5. avg storm precip
6. max storm precip
7. time between storms

Water

a) interception
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Impact Changes Not Equal

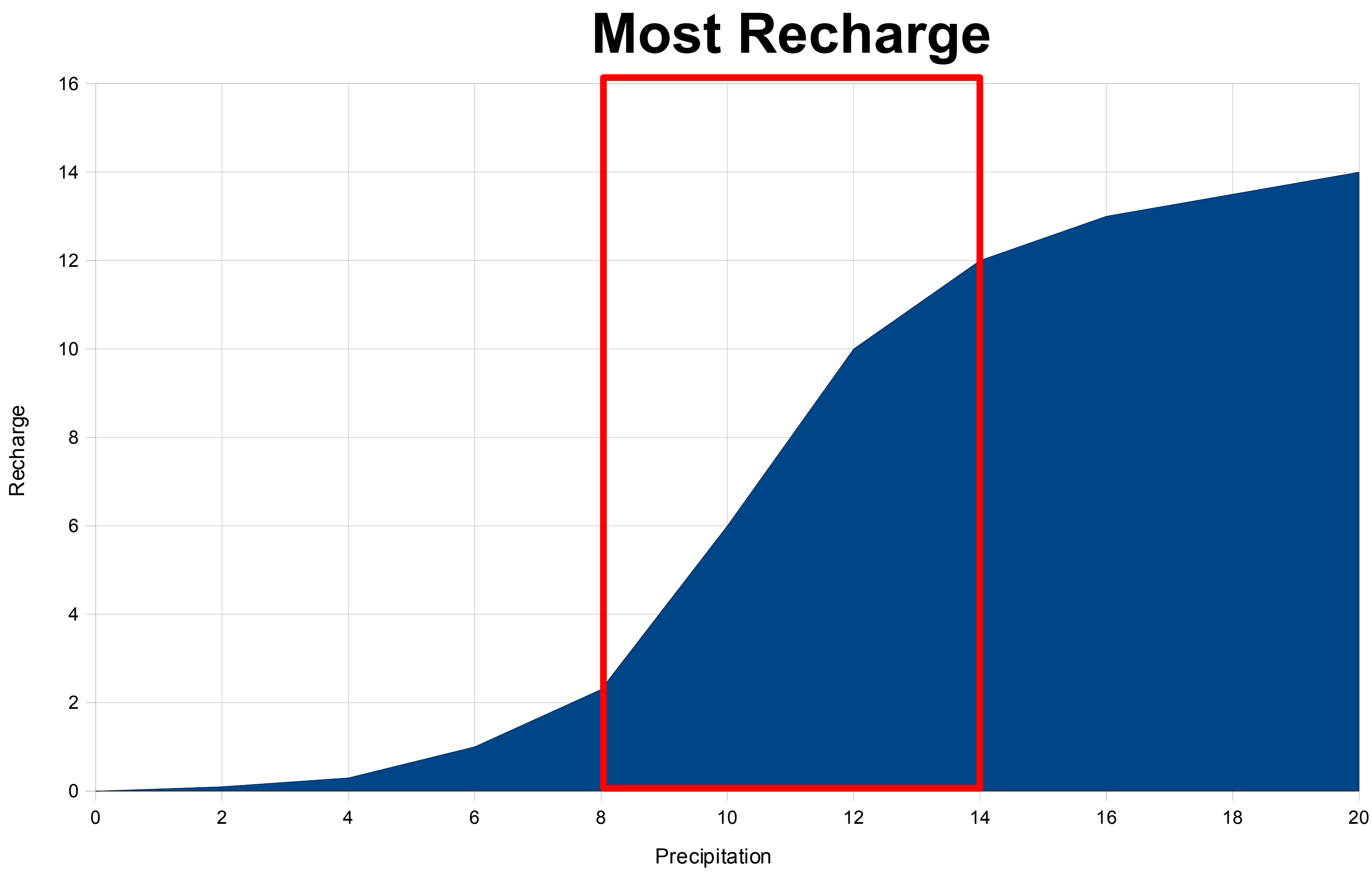
- Does 20% Less Precipitation Produce 20% Less Recharge?
- Probably NOT!
- Australia 1990's decade-long drought
  - Average rain reduced by about 20%
  - Groundwater recharge lowered by 70%

[GRAC conference 2008]

Impact Changes Not Even Linear

- First rain wets plants & surface
  - Evaporation but no recharge
- More rain infiltrates soil & root zone
  - Evapotranspiration (ET) but no recharge
- Even more rain allows percolation
  - **RECHARGE Happens!**
- More intense rain saturates surface
  - Lost to runoff but no more recharge

Impact Changes Not Even Linear



Research Program Goals

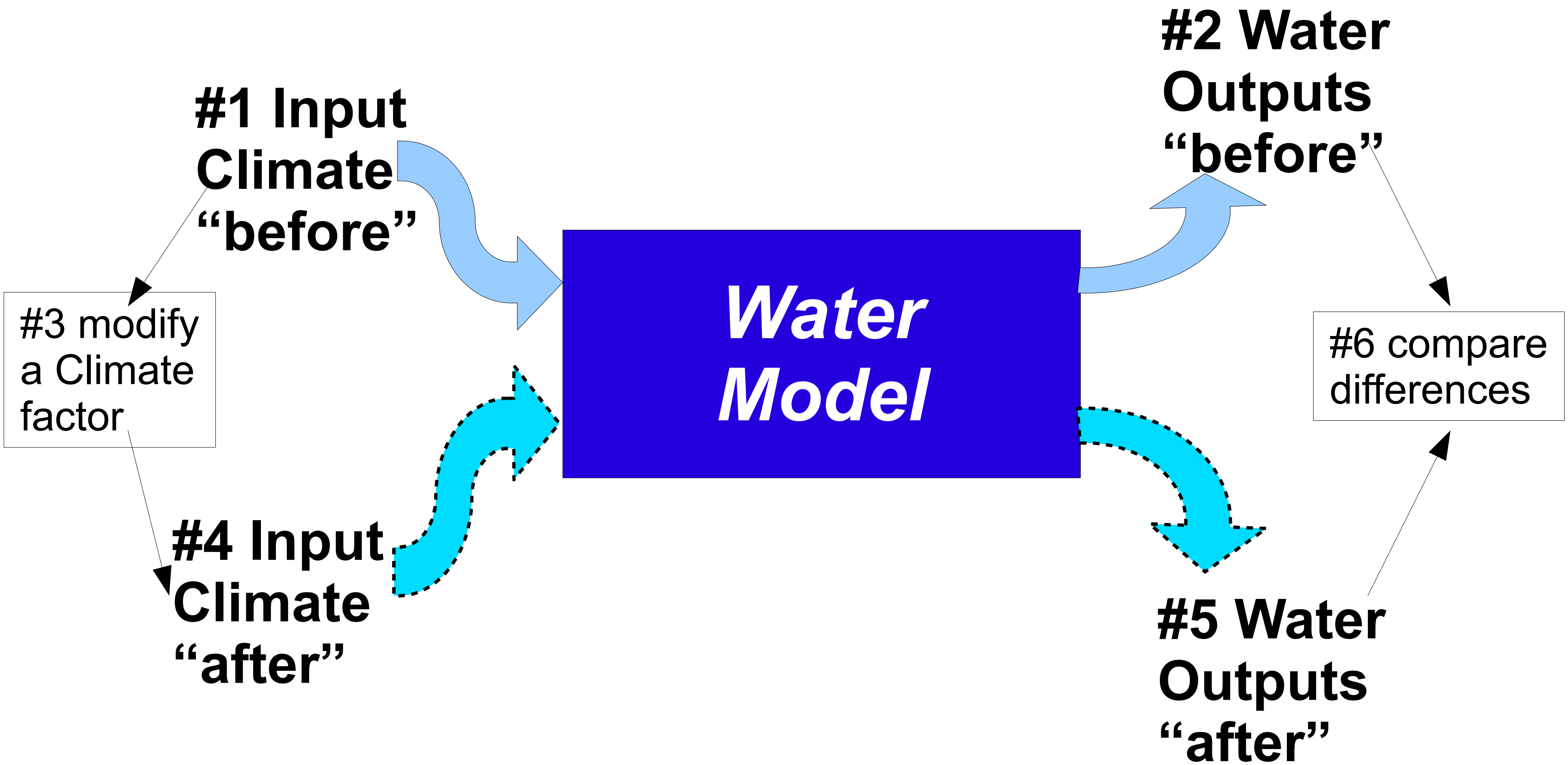
- Quantify Results
  - Nature is difficult to measure, e.g. recharge
- Ensure Repeatability
  - Observational climate "testing" happens every year
  - Reality is very messy
- Separate Confounding Factors
  - Everything changing all at once
  - Hides cause & effect
- Provide Numerical Confidence
  - How other factors affect results
- Evaluate Site Independence
  - Validity at other locations, features, geology, etc.

Research Program Design

- Employ water models
  - Deliver Numerically Precise Results
  - Provide Repeatability

- Follow Experimental Design
  - Conduct Single Factor Tests
    - change just 1 input at a time
    - give that 1 input multiple values (+1%, +2%, +5% …, -1%, ...)
    - quantify output differences & sensitivities
  - Repeat Tests Changing Other Factors
    - e.g. vary across a range of hydrologic conductivity
    - compute confidence levels
  - Redo Testing for Other Site Settings
    - characterize locale effects

Research Experiments



Research Water Model

Surface Water Model → **GroundWater Model**

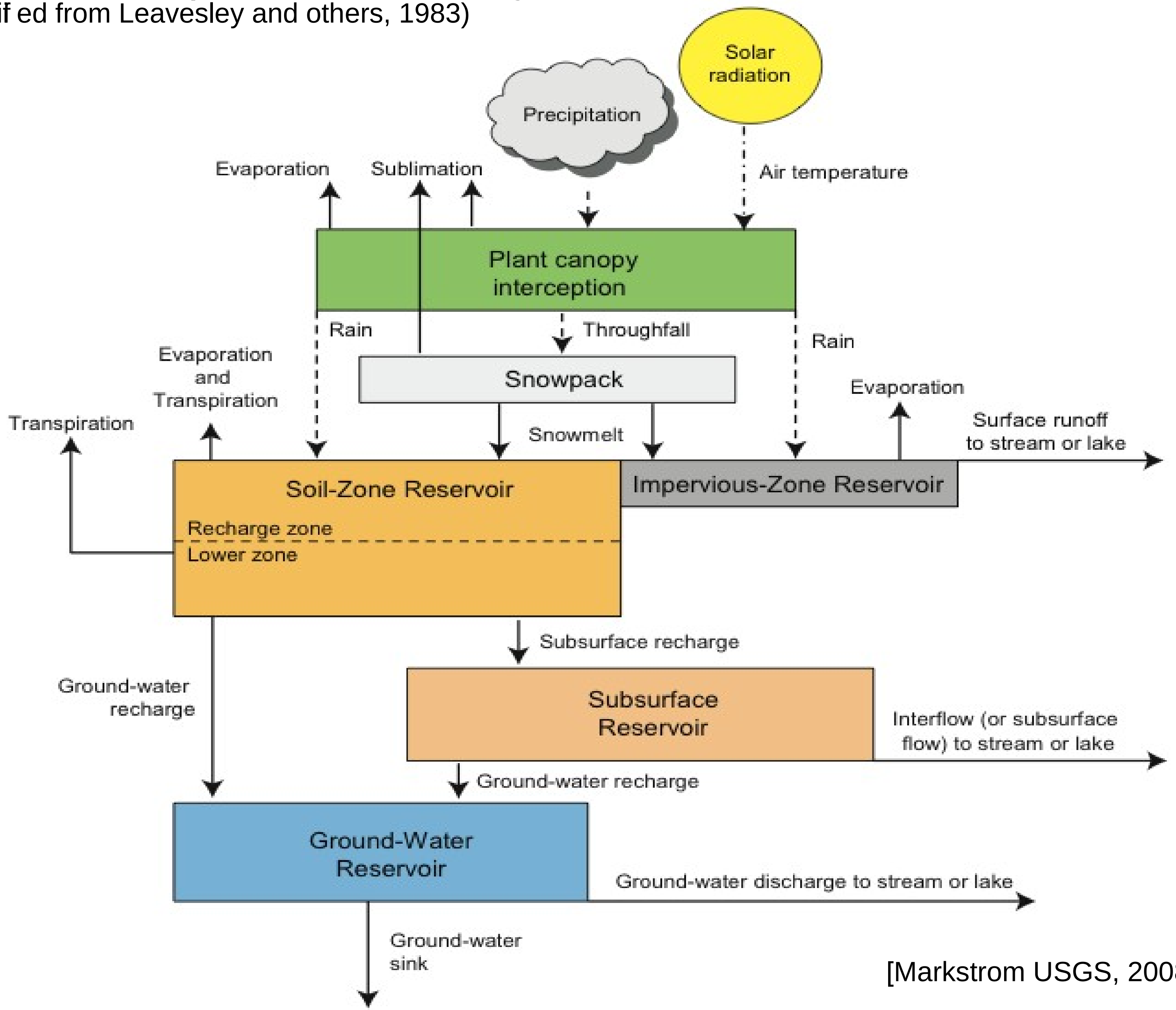
PRMS (USGS)
Precipitation-Runoff
Modeling System

MODFLOW (USGS)

GSFLOW (USGS)

Schematic Diagram of a Watershed and Its Climate Inputs Simulated by PRMS

(modified from Leavesley and others, 1983)



[Markstrom USGS, 2008]

Research Conclusion

- Identify Most Sensitive and Important Precipitation Aspects for Water Impacts

- Water Managers:
  - Extract Precipitation Aspects from Climate Projections
  - Deliver Rigorous Estimates Water Quantities and Confidence Levels

- Scientists:
  - Focus Development Efforts for Better Climate Models
  - Improve Evaluation and Comparison of Climate Models

Acknowledgements

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