Effects of climate change and forest management on the ecohydrology of the Santa Fe Municipal Watershed

Santa Fe Watershed Forum
June 2011

Aubrey Dugger & Christina Tague

Bren School of Environmental Science and Management

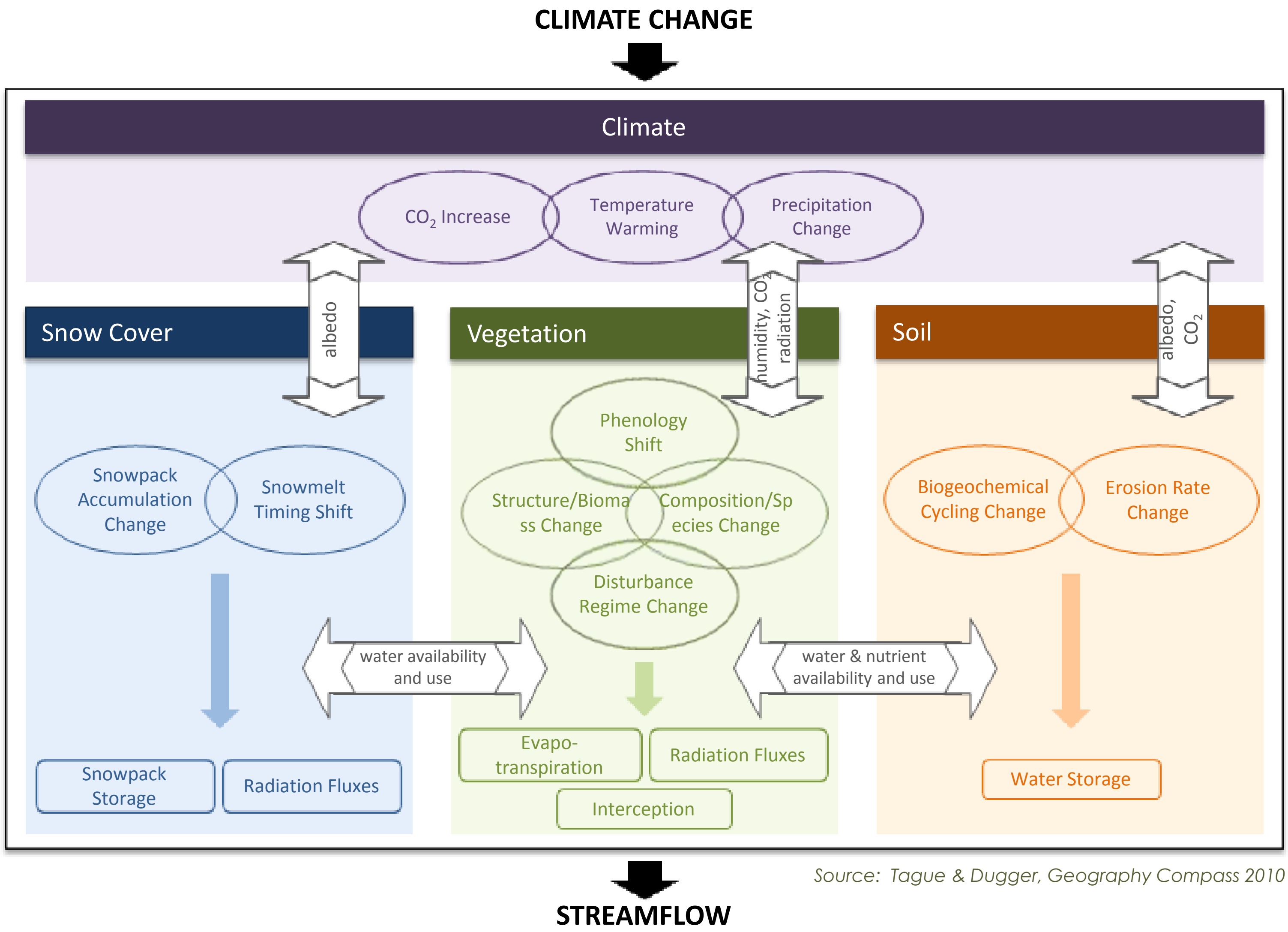
UC Santa Barbara

Introduction

BROAD GOAL: Model potential impacts of forest management strategies on the ecohydrology of the Santa Fe Municipal Watershed under historical and potential future climates

- Background
  - Why are ecologic-hydrologic interactions important?
  - RHESSys
- How well does the model capture these processes?
- Scenarios
  - Climate change
  - Forest thinning & disturbance
  - Combined effects

Background: Climate Change & Streamflow in the West



CLIMATE CHANGE

Climate

CO$_2$ Increase

Temperature Warming

Precipitation Change

albedo

humidity, CO$_2$ radiation

albedo, CO$_2$

Snow Cover

Snowpack Accumulation Change

Snowmelt Timing Shift

Snowpack Storage

Radiation Fluxes

water availability and use

Vegetation

Phenology Shift

Structure/Biomass Change

Composition/Species Change

Disturbance Regime Change

Evapo-transpiration

Radiation Fluxes

Interception

water & nutrient availability and use

Soil

Biogeochemical Cycling Change

Erosion Rate Change

Water Storage

Source: Tague & Dugger, Geography Compass 2010

STREAMFLOW

⬭ = climate change response

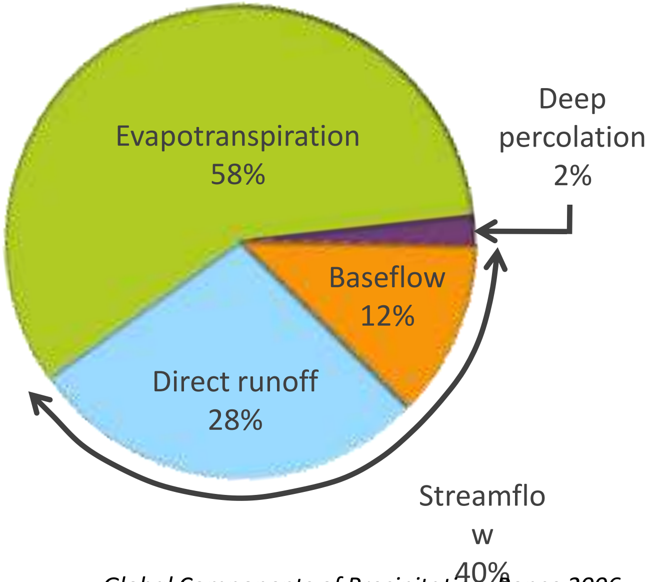
▭ = mechanism affecting streamflow

⟺ = potential feedback

Background: Climate Change & Streamflow in the West

Importance of Vegetation-Hydrology Interactions:

- Most studies on climate change impacts on hydrology do not consider vegetation dynamics (growth/dieback)
- ET can account for 75-85% of precipitation in semi-arid forest systems
- Vegetation dynamics may affect streamflow through:
  - Changes in ET
  - Shifts in phenology
  - Changes in vegetation structure and composition that lead to changes in water use
- Important mechanisms of vegetation change:
  - Fire and other disturbance
  - Management

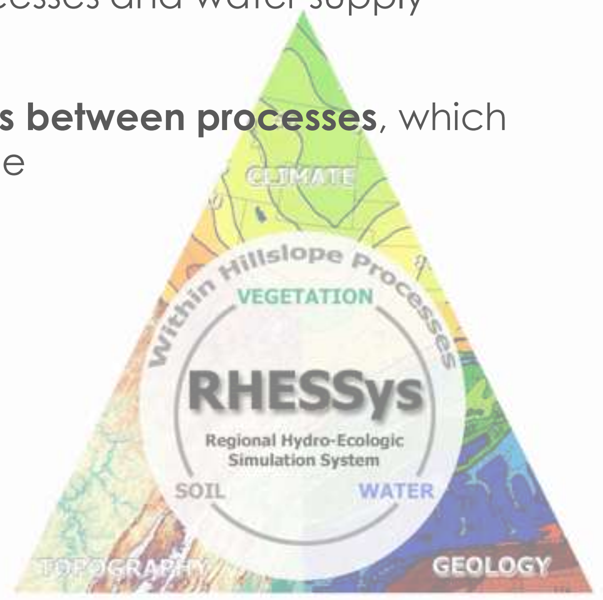


Global Components of Precipitation, Ponce 2006.

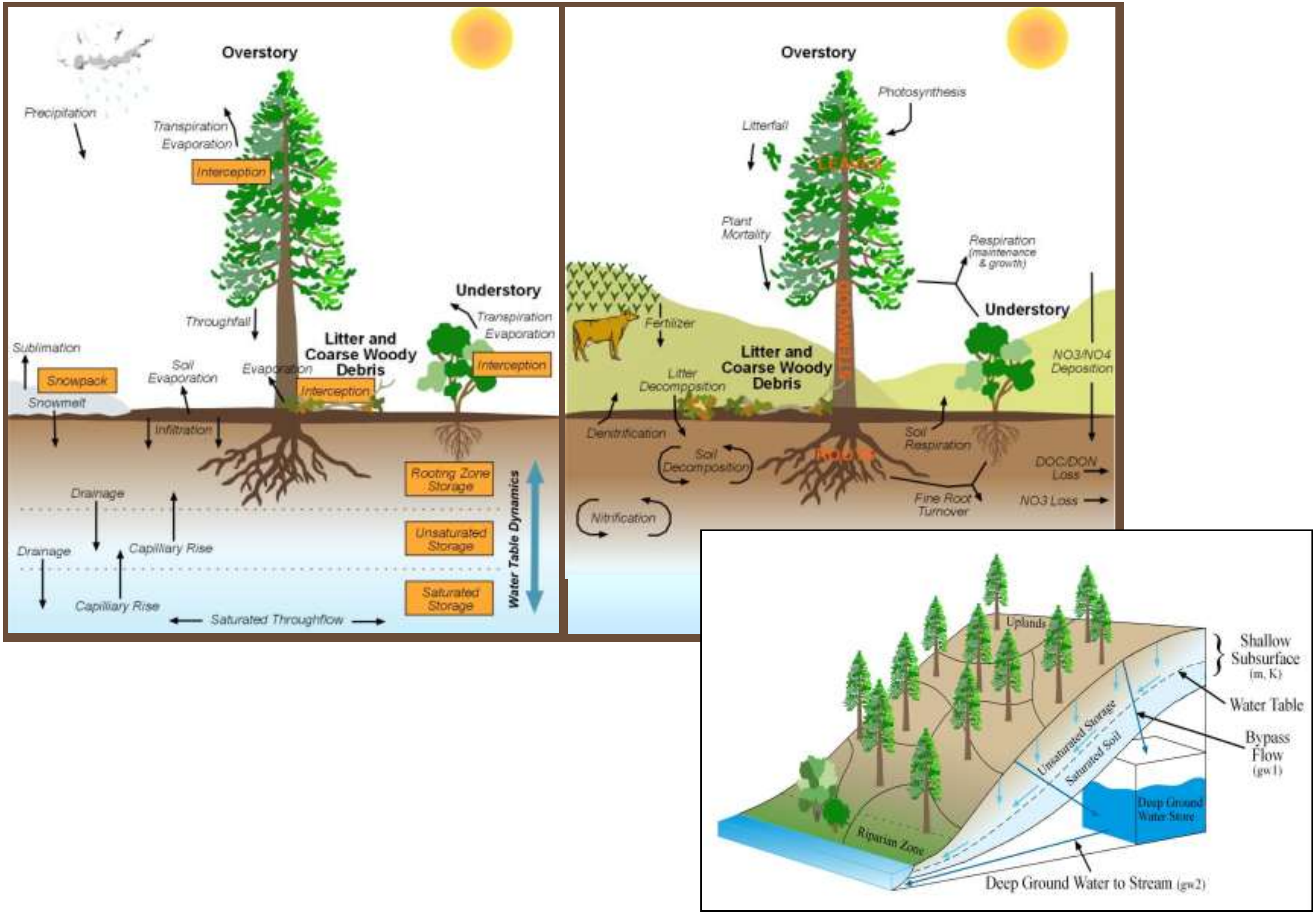
Background: Integrated Ecologic-Hydrologic Modeling

Unique take…

- RHESSys – Process-based, spatially-distributed, integrated ecologic-hydrologic model that simulates carbon, nutrient, and water cycling across a landscape
  - Linked **physically-based process models**, so can track all components in the carbon and water cycle
  - **Spatially distributed** model, so can track components across the landscape
  - **Daily time-step**, so appropriate for ecosystem processes and water supply management
  - Ideally suited for investigating **complex interactions between processes**, which are difficult to capture through measurement alone



Background: Integrated Ecologic-Hydrologic Modeling



Model Process Capture: Hydrology

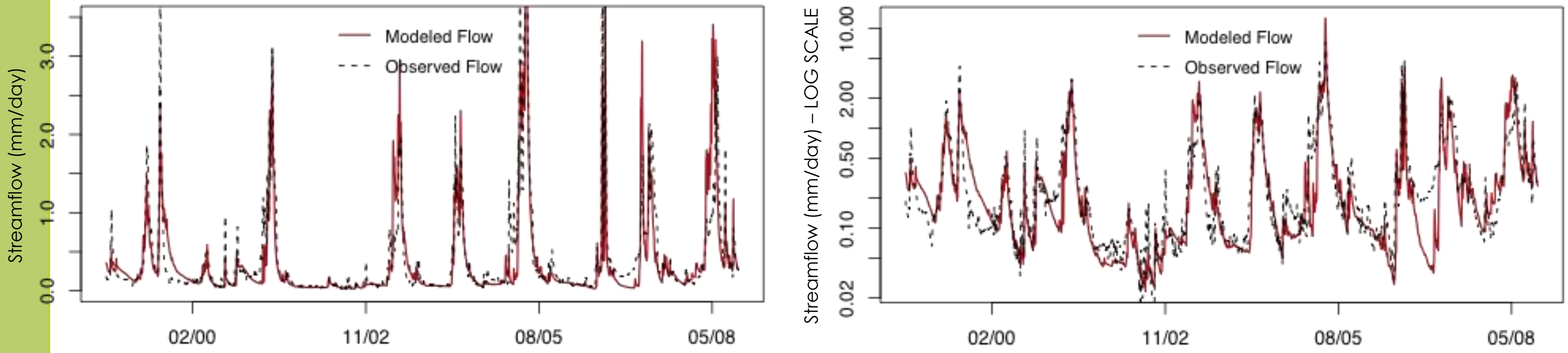
RHESSys model development and hydrologic calibration

- Build landscape (topography, soil, hydrology) and vegetation models
- Calibrate subsurface drainage parameters (saturated hydraulic conductivity, decay of conductivity with depth, pore size index, air entry pressure) by comparing modeled and observed daily streamflow

Model performance measures for DAILY streamflow predictions:

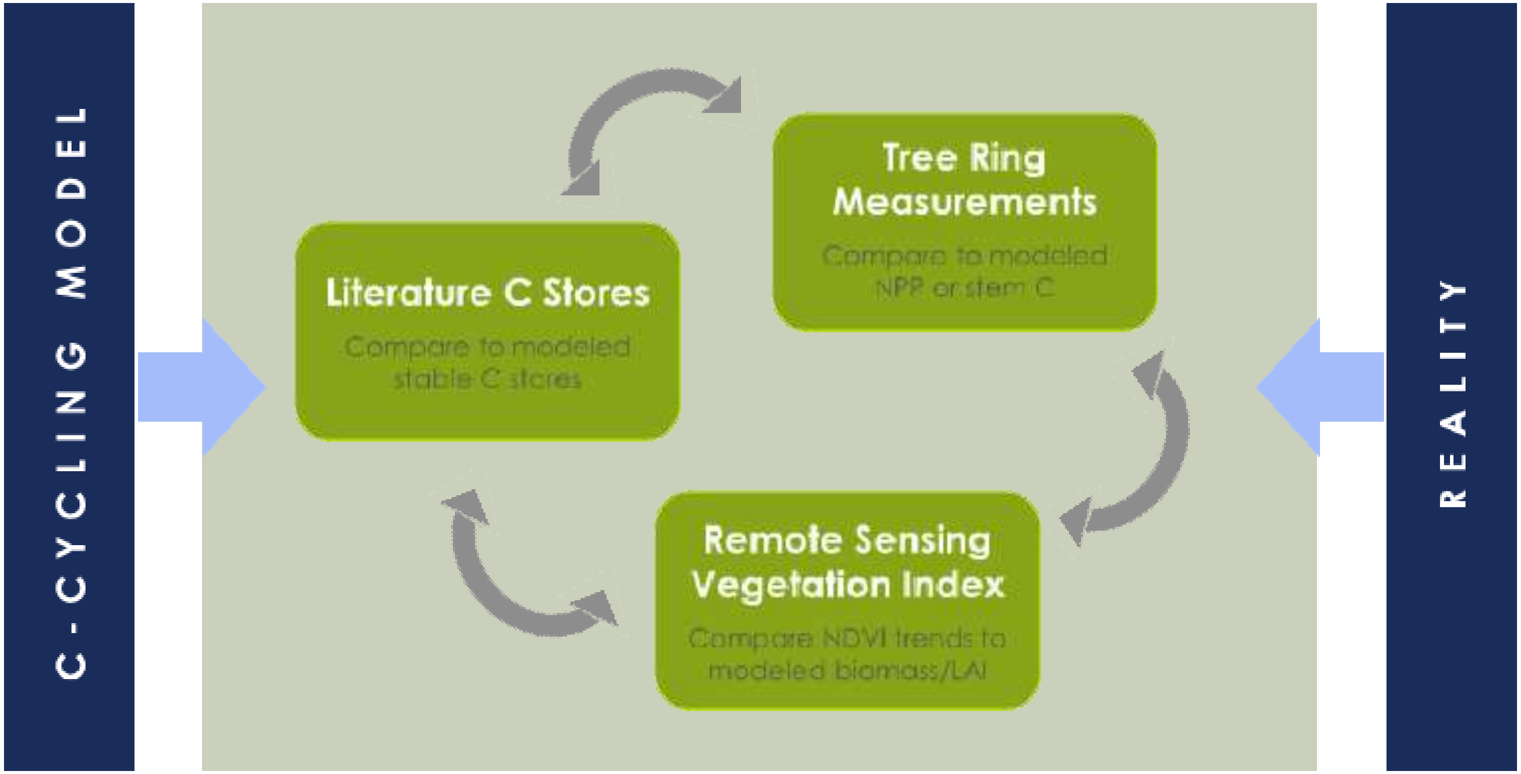
$R^2 = 0.75$ Nash-Sutcliffe Efficiency = 0.68 Log Nash-Sutcliffe Efficiency = 0.71

Observed and Modeled Daily Streamflow



Model Process Capture: Vegetation Dynamics

Three-Pronged Dynamic Vegetation Model Validation



Tree Ring Measurements

Compare to modeled NPP or stem C

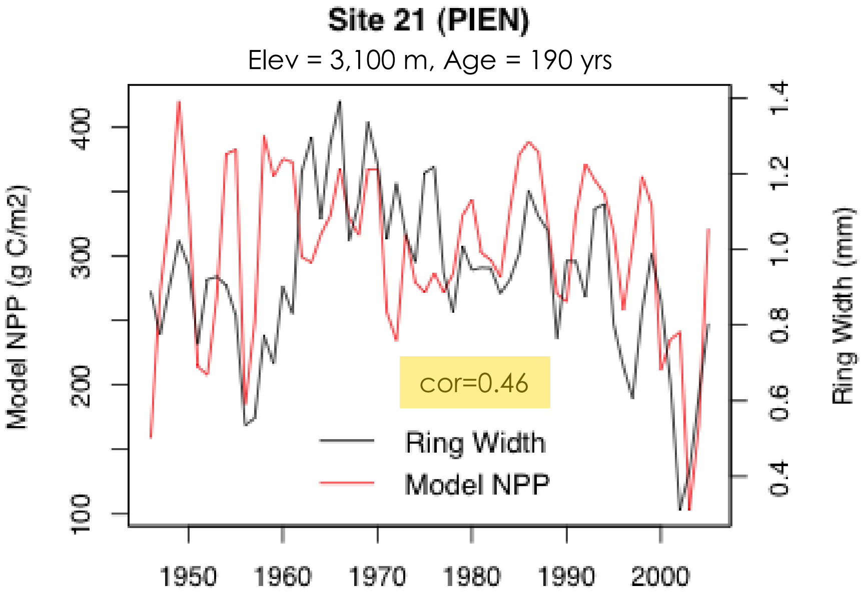
Literature C Stores

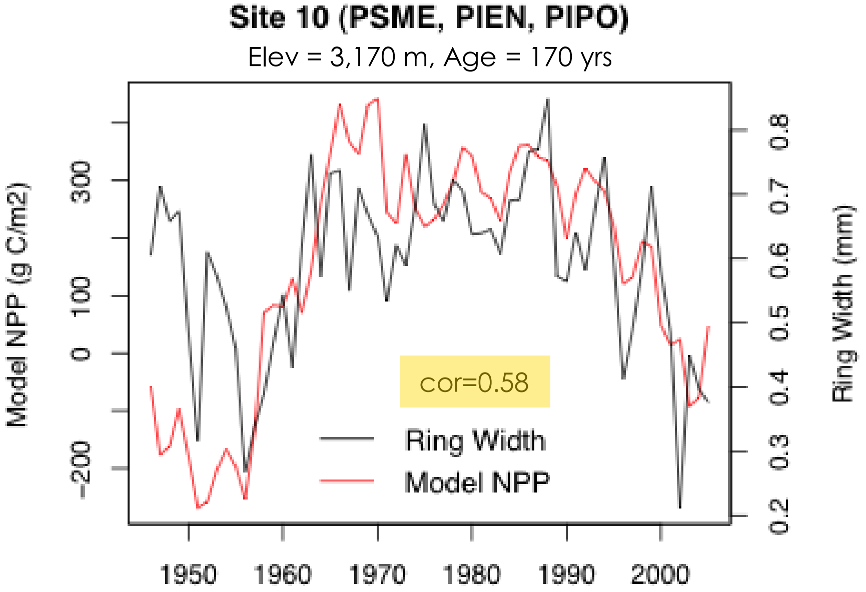
Compare to modeled stable C stores

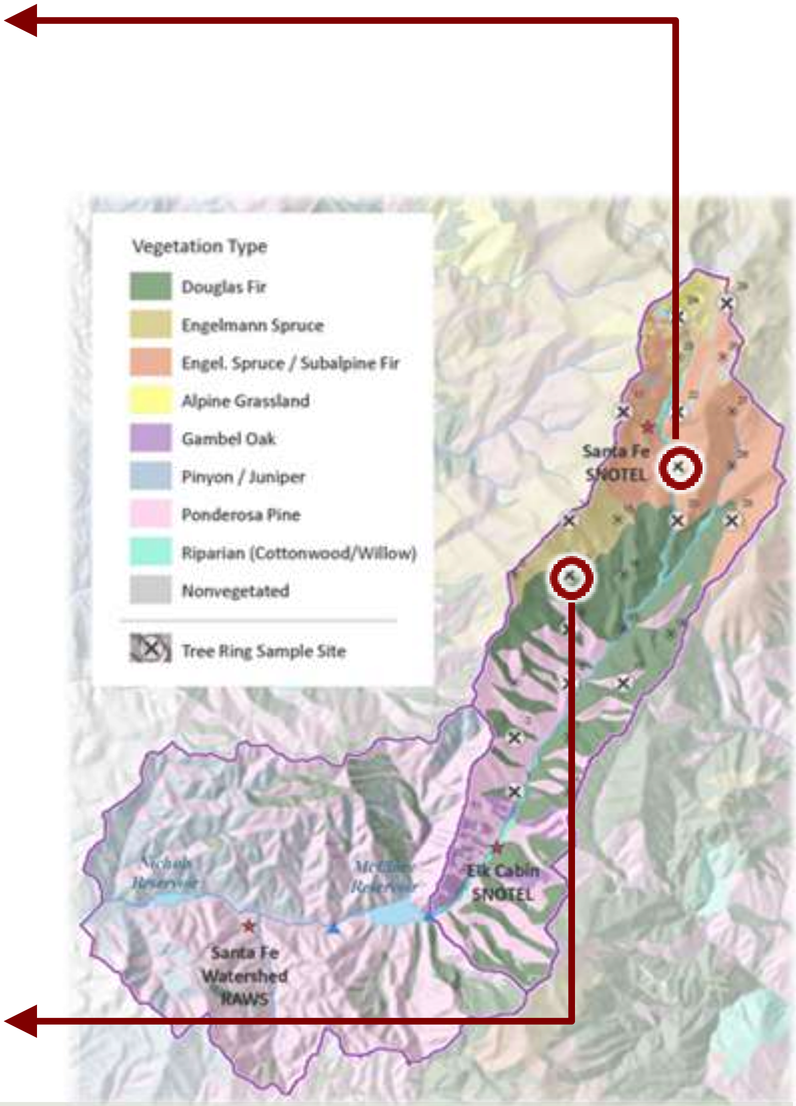
Remote Sensing Vegetation Index

Compare NDVI trends to modeled biomass/LAI

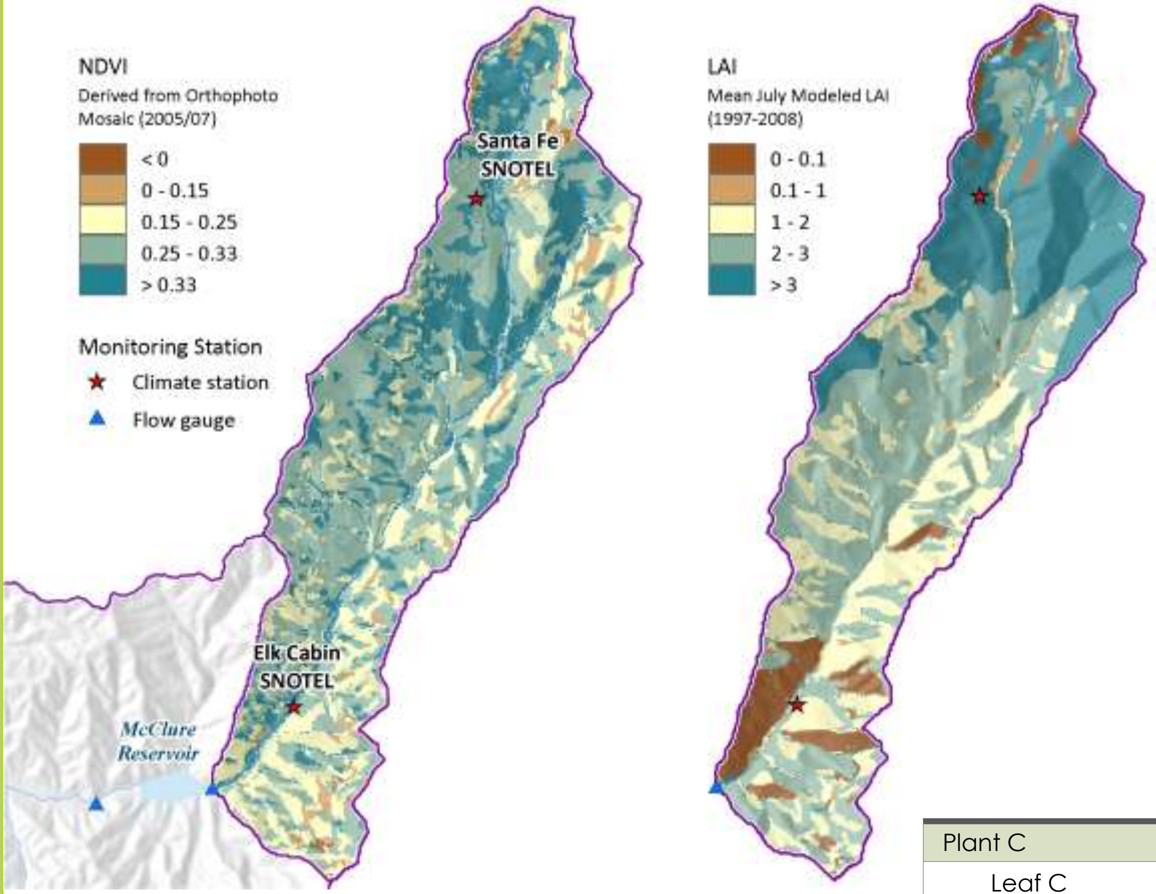
Model Process Capture: Vegetation Dynamics


Site 21 (PIEN)
Elev = 3,100 m, Age = 190 yrs


Site 10 (PSME, PIEN, PIPO)
Elev = 3,170 m, Age = 170 yrs



Model Process Capture: Vegetation Dynamics



Comparison of spatial distribution of vegetation density

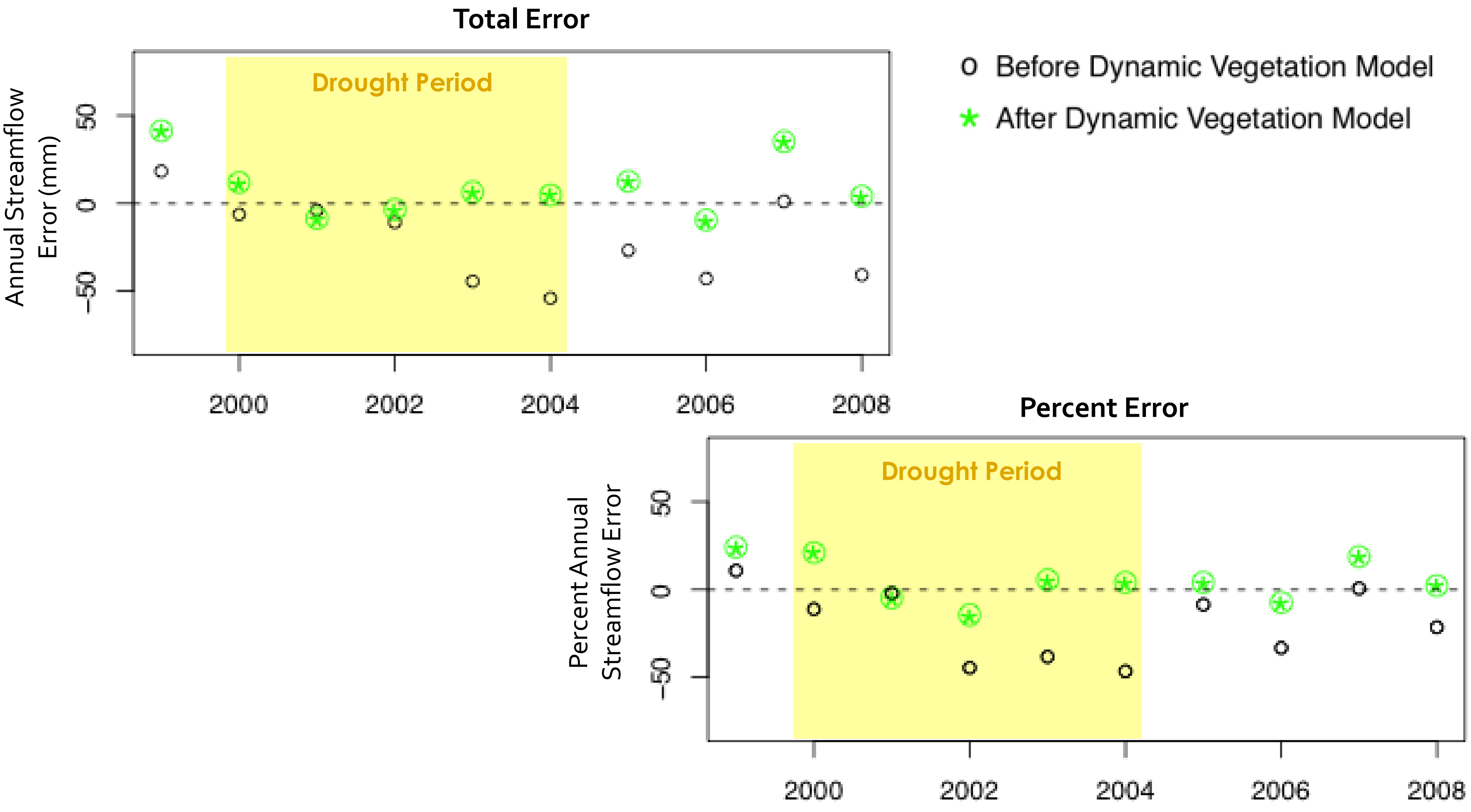
Comparison of total biomass stores

	Model Steady State LAI=3.0 kg C / m²	Ponderosa Pine in Oregon LAI=2.0 kg C / m²	Spruce-Fir in Colorado kg C / m²
Plant C	13.45	12.67	15.1
Leaf C	0.57	0.27	12.4
Stem C	9.49	10.5	
Root C	3.38	1.9	2.7
Coarse Woody Debris	5.24	1.3	7
Litter C	0.55	1.2	6.8
Soil C	6.60	5.3	12.6
Total C	25.84	20.47	41.5

Model Process Capture: Vegetation Dynamics

Improvement in Annual Streamflow Prediction

The dynamic vegetation model improved streamflow predictions during drought years, shifting the mean annual streamflow percent error from 20% to 10%.



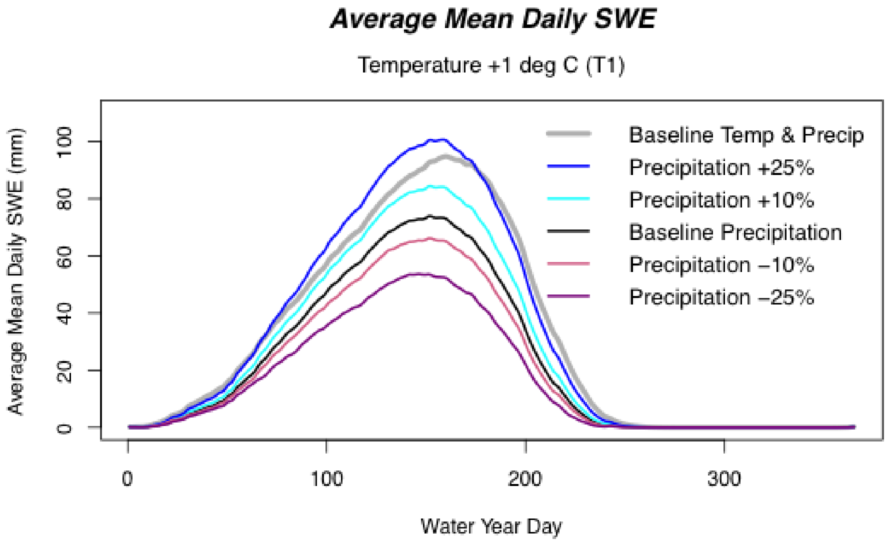
Scenarios: Climate Change & Forest Management

Climate and Management/Disturbance Scenarios

Climate	Landscape
Temperature	Management
Baseline (historical)	Baseline
+ 1° C	Thinning in lower watershed only*
+ 2° C	Thinning of south aspects only in upper watershed*
+ 4 C	Thinning over entire watershed
Precipitation	Disturbance
Baseline (historical)	No fire
± 10 %	Burn over entire watershed
± 25 %	Partial burn in lower watershed*
Downscaled GCMs*	Partial burn in upper watershed*

** scenarios in process*

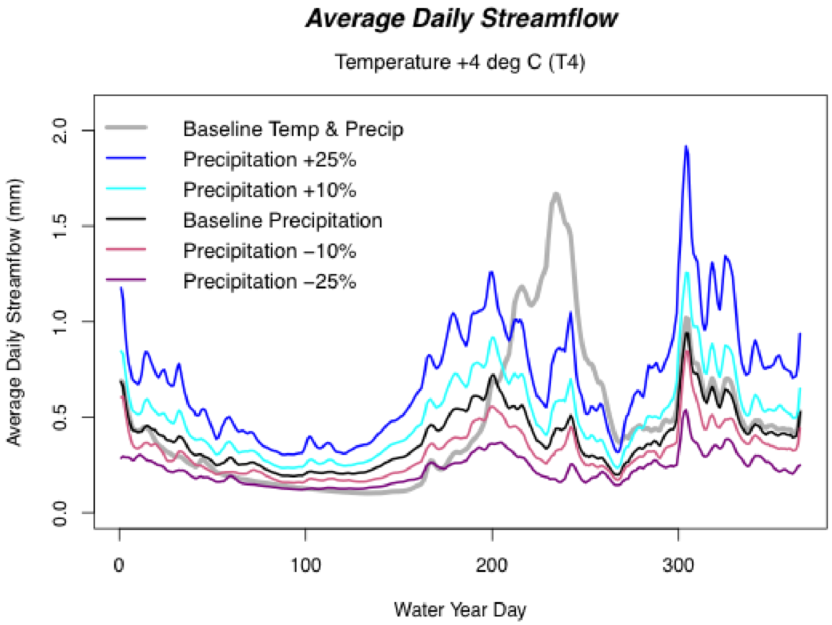
Scenarios: Climate Change



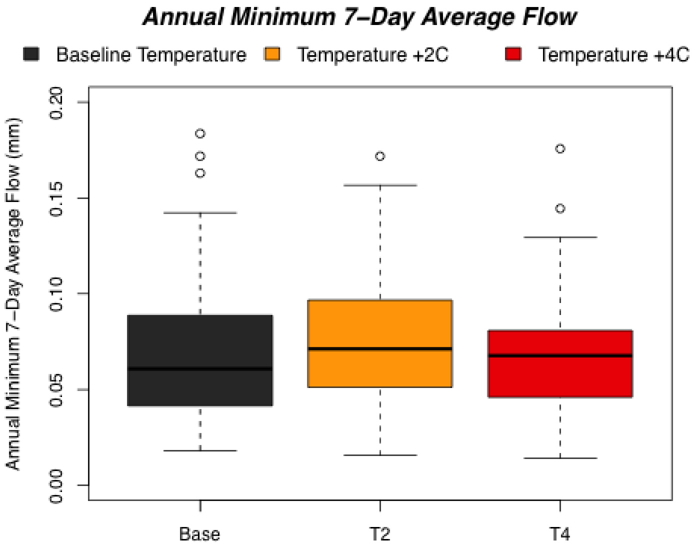
A 1°C temperature increase requires an almost 25% precipitation increase to maintain snowpack

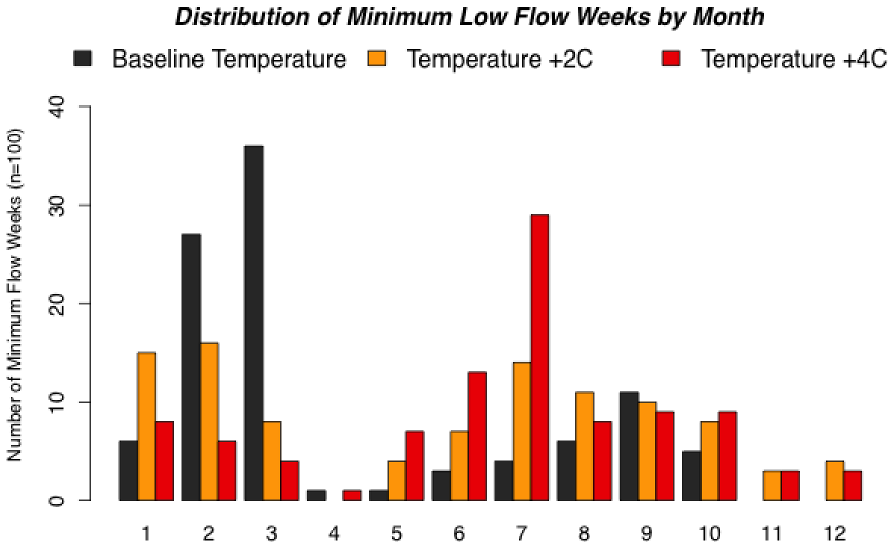
At 4° C warming, the streamflow regime shifts from snowmelt-dominant to summer monsoon-dominant peaks.

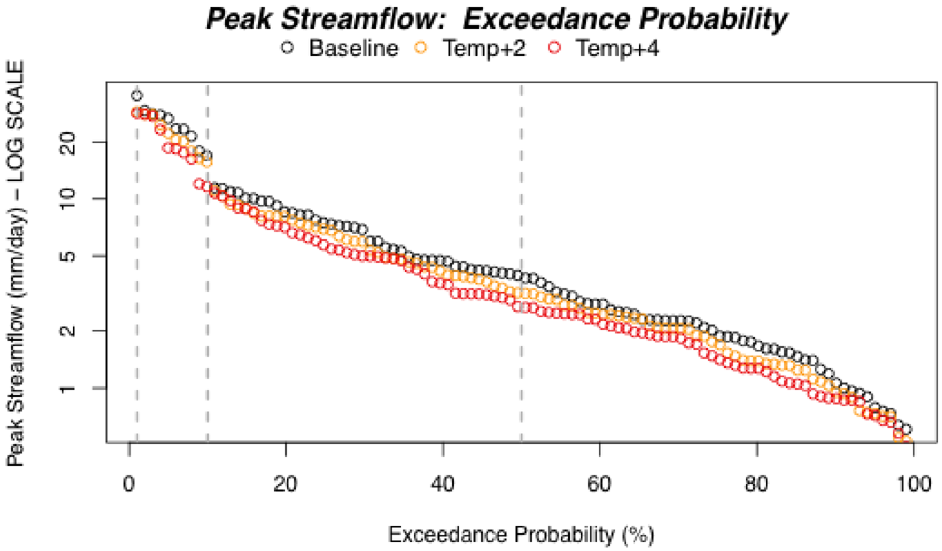
Temperature warming	Change in center of mass timing
1° C	7 days
2° C	14 days
4° C	25 days



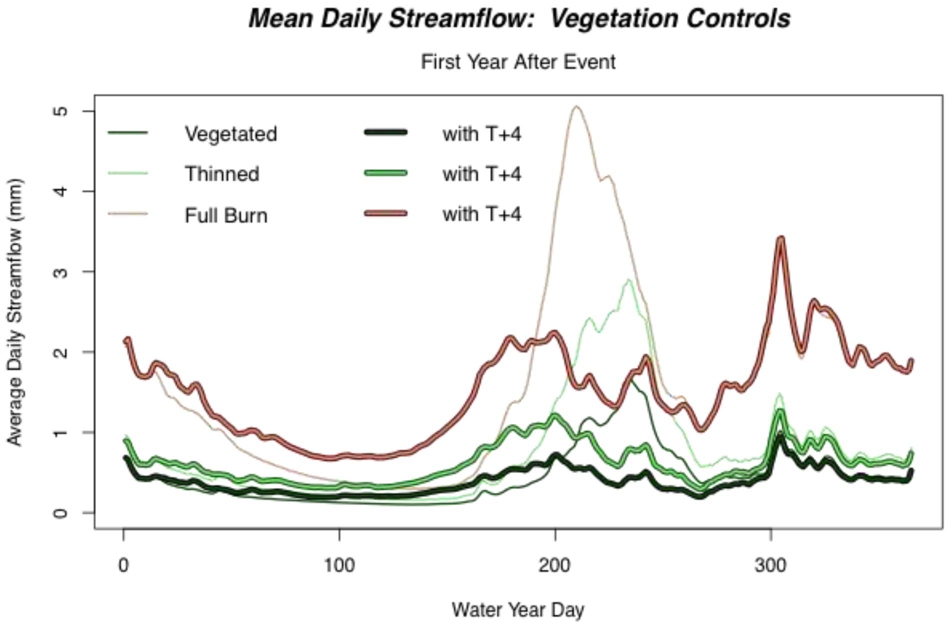
Scenarios: Climate Change


Annual Minimum 7–Day Average Flow


Distribution of Minimum Low Flow Weeks by Month

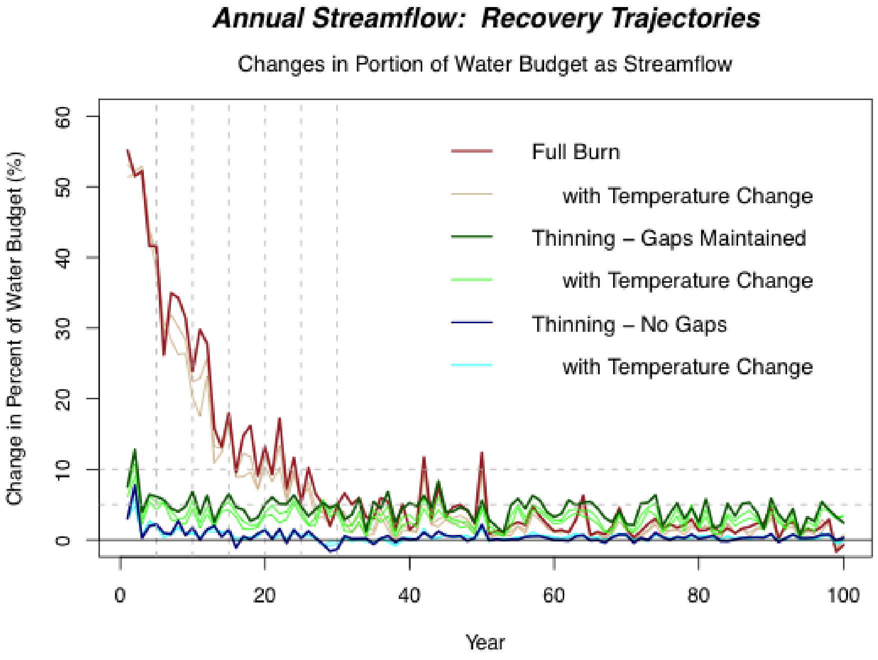

Peak Streamflow: Exceedance Probability

Scenarios: Vegetation Management



Large response immediately after thinning and disturbance events, but streamflow recovers quickly without additional treatment.

Vegetation Cover	Change in Streamflow – Year 1	Change in Streamflow – Years 5-10
Thinning (Full Watershed)	74%	7%
Thinning (Full Watershed) – Gaps Maintained	74%	22%
Full Burn	300%	142%



Conclusions

- RHESSys captures daily, seasonal, and annual streamflow patterns as well as interactions between hydrology and vegetation growth
- The modeled watershed exhibits high sensitivity of snowmelt to warming
  - ❾ 1° C warming requires a 25% increase in winter precipitation to maintain snowpack
- Low flows shift from late winter to pre-monsoon summer under 4° C warming; peak flows show only minor temperature impacts.
- In the year immediately after a watershed-wide thinning, annual streamflow increases are on the order of 74%; by 5-10-yrs post-thinning increases reduce to 7%

Next steps

- Expand to full watershed.
- Incorporate downscaled GCM projections for climate change trajectories.
- Generate additional thinning and disturbance scenarios and run over full range of climate projections (i.e., variable start dates).
- Develop vegetation change scenarios.

Contact Info:
adugger@bren.ucsb.edu
ctague@bren.ucsb.edu

http://fiesta.bren.ucsb.edu/~rhessys/