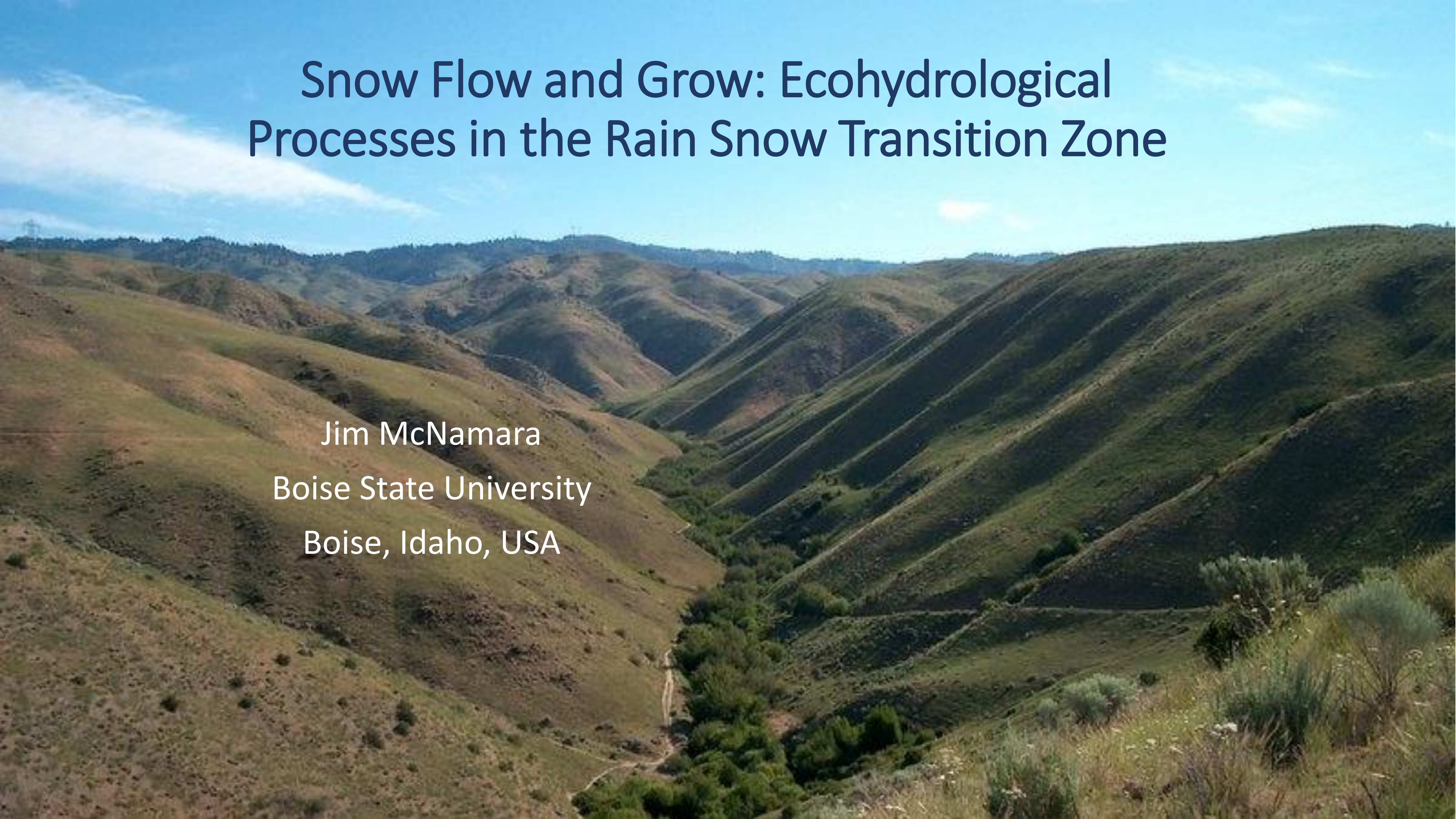
Snow Flow and Grow: Ecohydrological Processes in the Rain Snow Transition Zone



Jim McNamara

Boise State University

Boise, Idaho, USA

Catchment Hydrology: Thinking Inside the Box

Q = f(P, S, T)

Receive

Rain and Snow

Store

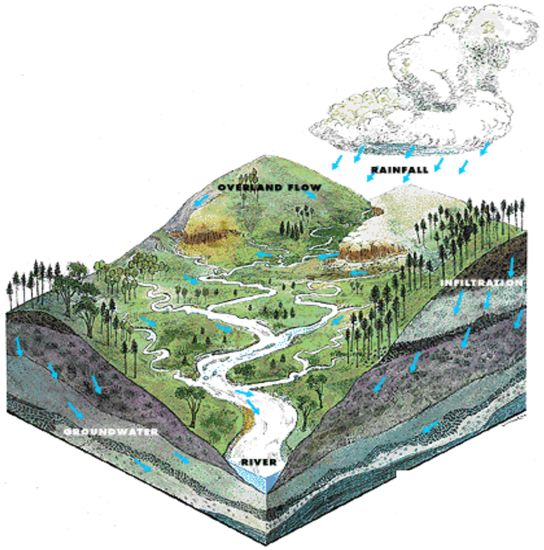
Transmit

Partition

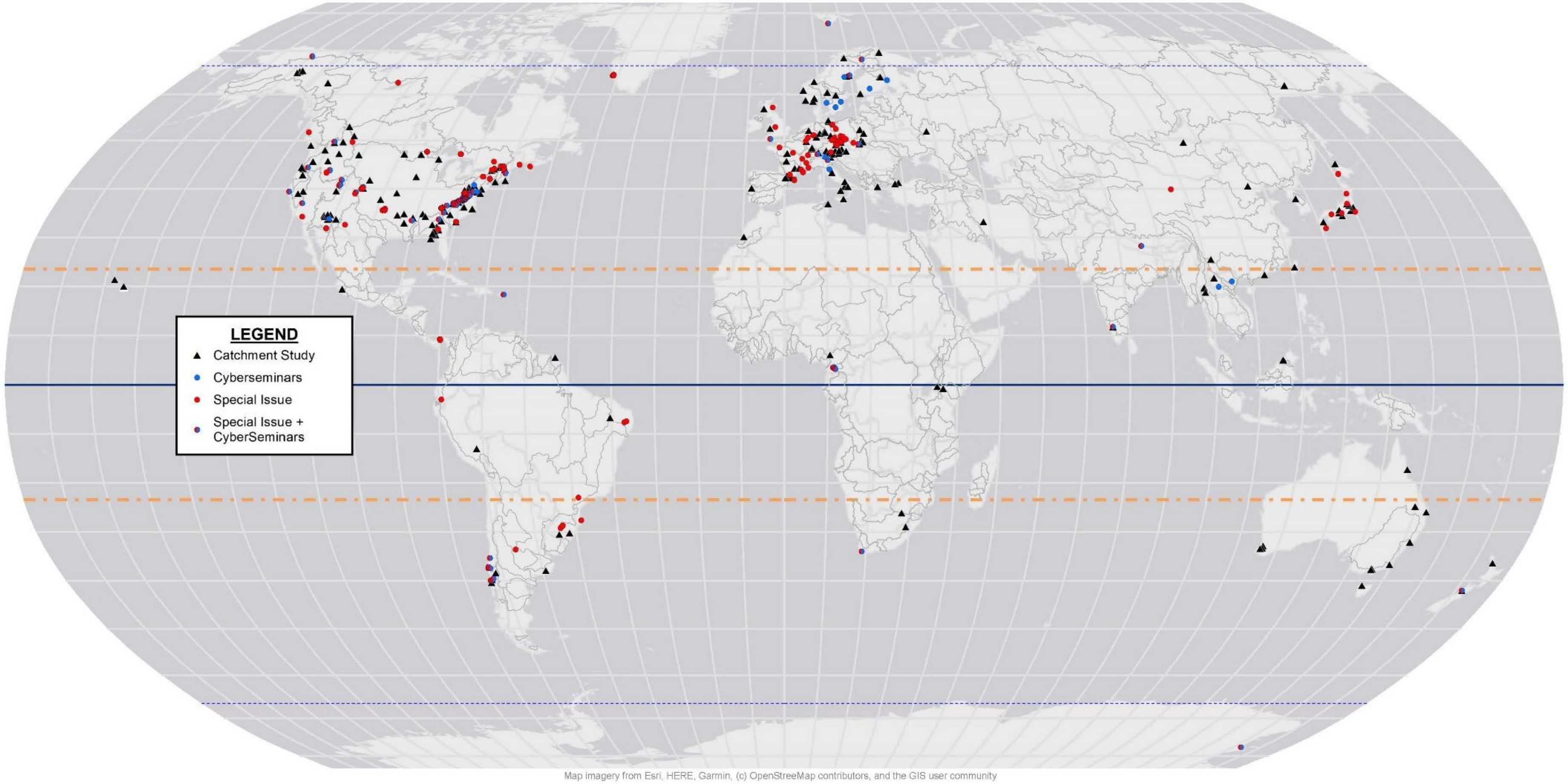
Release

Streamflow
Evapotranspiration
Deep Infiltration

We look inside the box to seek process understanding and provide model "targets"



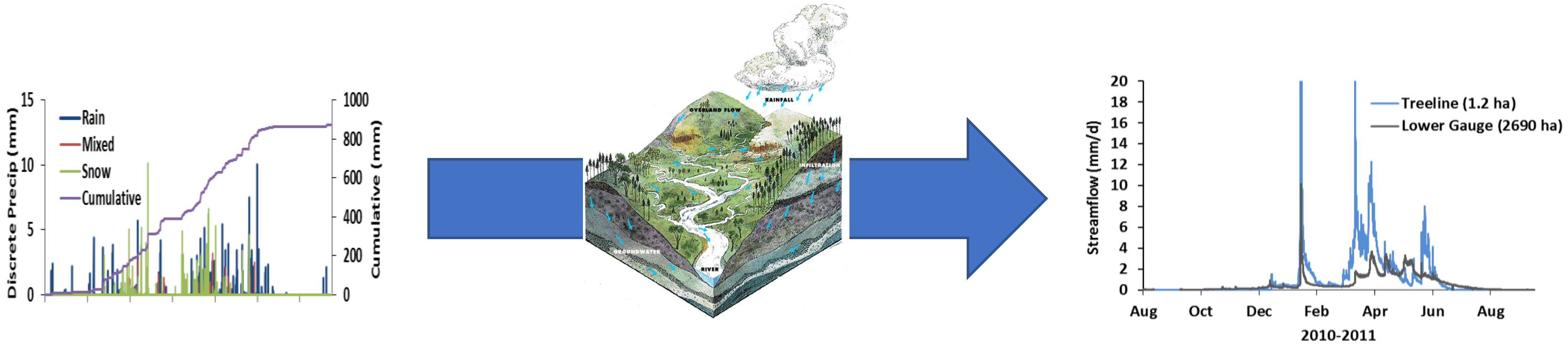
Long Term Research Catchments



Sebestyen et al., 2021

Long-term catchment research

- Provides a backbone of continuous water balance data to support focused campaign research
- Enhanced understanding that is undiscoverable in short-term funding cycles
- Will lead to Improved hydrologic prediction
- Helps answer questions we haven’t yet thought to ask



Never decommission a datalogger!!

VOL. 5, NO. 1 WATER RESOURCES RESEARCH FEBRUARY 1969

In Defense of Experimental Watersheds

JOHN D. HEWLETT

School of Forest Resources, University of Georgia, Athens 30601

HOWARD W. LULL AND KENNETH G. REINHART

Northeastern Forest Experiment Station, United States Forest Service
Upper Darby, Pennsylvania 19082

Abstract. Recent criticisms discount the contribution of experimental watersheds to the science of hydrology and to watershed management. The critics cite as disadvantages the cost of experimental watersheds, their unrepresentativeness, leakiness, difficulty in applying results to other areas, and the lack of progress in basic knowledge about hydrologic processes. Some critics propose mathematical synthesis, statistical analysis, plot studies, soil moisture studies, meteorological methods, and the study of individual hydrologic processes as alternatives to experimental watersheds. The criticisms lack weight, because published results of catchment experiments were not carefully reviewed. The alternatives are obviously aids rather than substitutes for experiments on watersheds. By reference to recent and older results, the authors argue that the experimental watershed method has produced much of our present knowledge about the land phase of the hydrologic cycle and man's influence on it, that the method is sound, and that its future in any comprehensive research program is secure.

AGU PUBLICATIONS

Water Resources Research

COMMENTARY

10.1002/2017WR020838

Special Section:
Earth and Space Science is Essential for Society

The essential value of long-term experimental data for hydrology and water management

Doerthe Tetzlaff[1], Sean K. Carey[2], James P. McNamara[3], Hjalmar Laudon[4], and Chris Soulsby[1]

[1]Northern Rivers Institute, School of Geosciences, University of Aberdeen, Aberdeen, UK, [2]School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario, Canada, [3]Department of Geosciences, Boise State University, Boise, Idaho, USA, [4]Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, Umeå, Sweden

Key Points:
- Hydrological data collected over many decades give us the greatest insights into how the water cycle "works" and is changing
- Such data have proven essential in understanding and managing water supplies, floods, and other ecosystem services
- We need to protect long-term studies, promote them, and make data available; their value to society increases over time

Correspondence to:
D. Tetzlaff,
d.tetzlaff@abdn.ac.uk

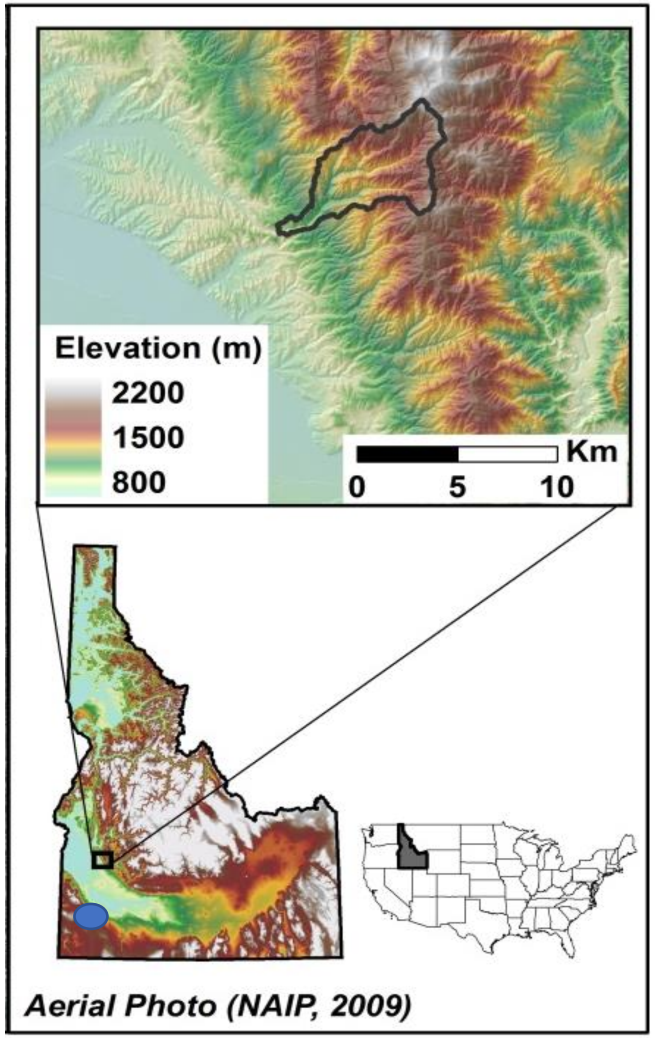
Citation:
Tetzlaff, D., S. K. Carey, J. P. McNamara, H. Laudon, and C. Soulsby (2017), The essential value of long-term experimental data for hydrology and

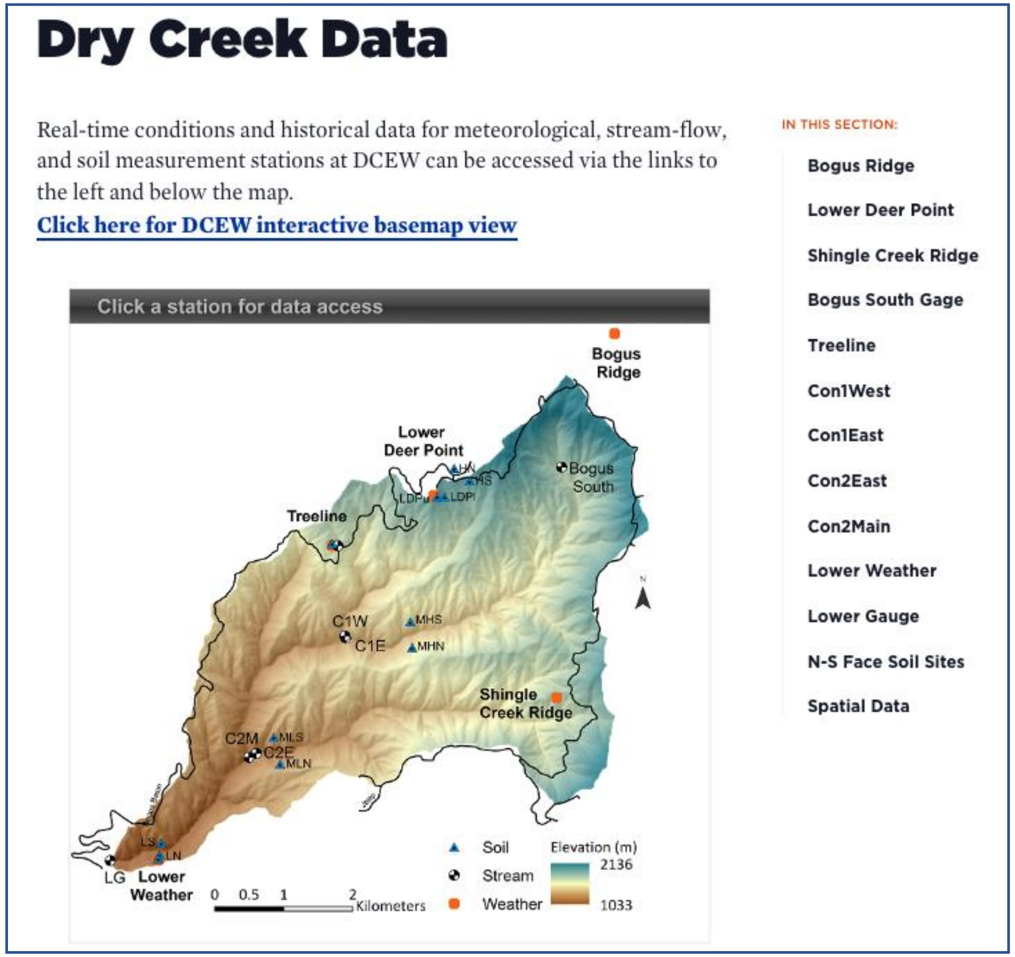
Abstract Observations and data from long-term experimental watersheds are the foundation of hydrology as a geoscience. They allow us to benchmark process understanding, observe trends and natural cycles, and are prerequisites for testing predictive models. Long-term experimental watersheds also are places where new measurement technologies are developed. These studies offer a crucial evidence base for understanding and managing the provision of clean water supplies, predicting and mitigating the effects of floods, and protecting ecosystem services provided by rivers and wetlands. They also show how to manage land and water in an integrated, sustainable way that reduces environmental and economic costs.

1. Establishing and Evolving Long-Term Watershed Research

The foundations of scientific hydrology and evidence base for sustainable water management are the observational data collected from long-term experimental watersheds distributed around the world [*Hewlett et al.*, 1969]. Many were established in response to the First International Hydrological Decade (1965–1974), which called for basic programs of data acquisition and research aimed at expanding quantitative process-

Dry Creek Experimental Watershed

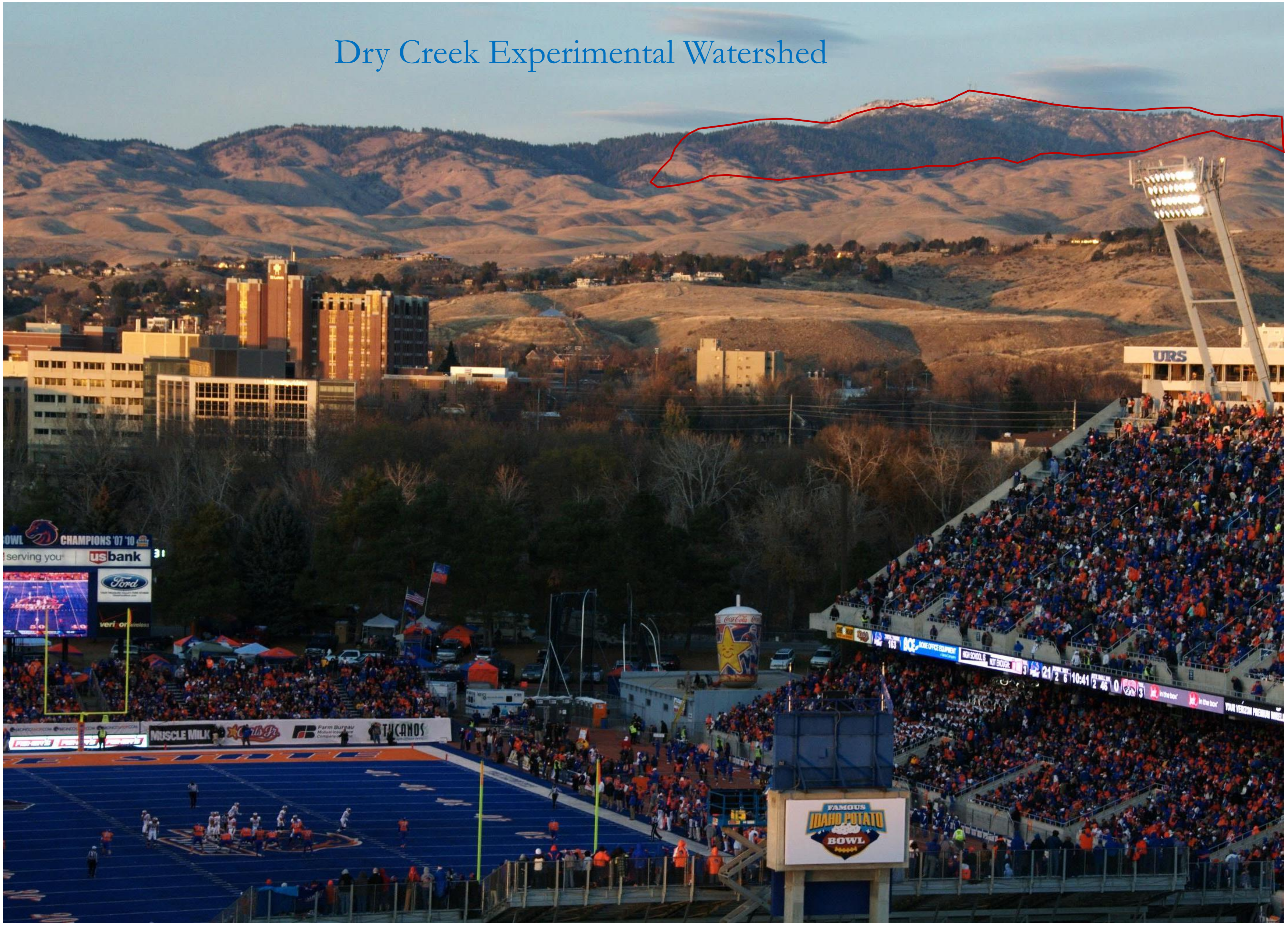




Drainage Area:	27 km^2
Years:	23
Soil moisture stations:	8+
Discharge stations:	7
Weather Stations:	5
Sapflow stations:	2
Flux towers:	1
Professional Technician	1
Deployed loggers:	30+
Theses:	~50
Publications	~50

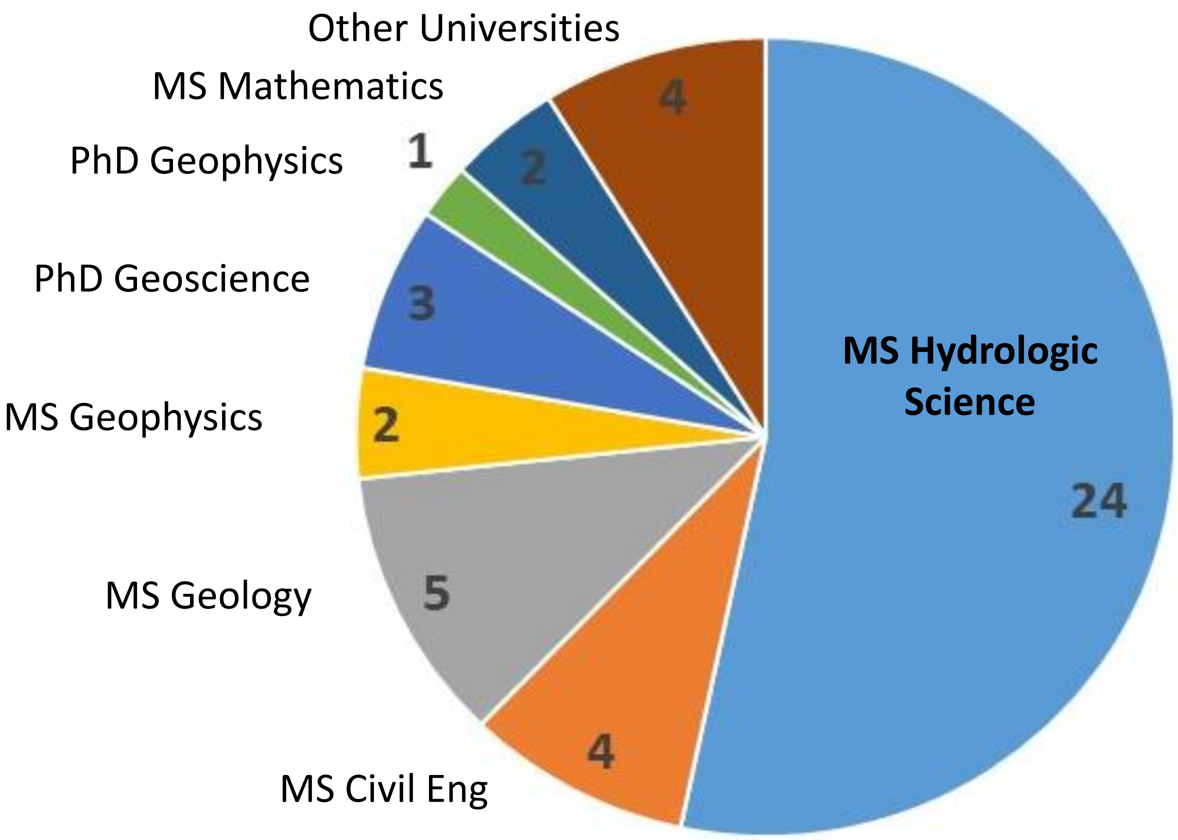
OBJECTIVE: To provide temporally continuous and spatially distributed hydrometeorological and geographical data from point to catchment scales for researchers and educators.

Dry Creek Experimental Watershed



Hydrologic Education

45 Dry Creek Theses



> 25 working hydrologists in Idaho

Value in Place

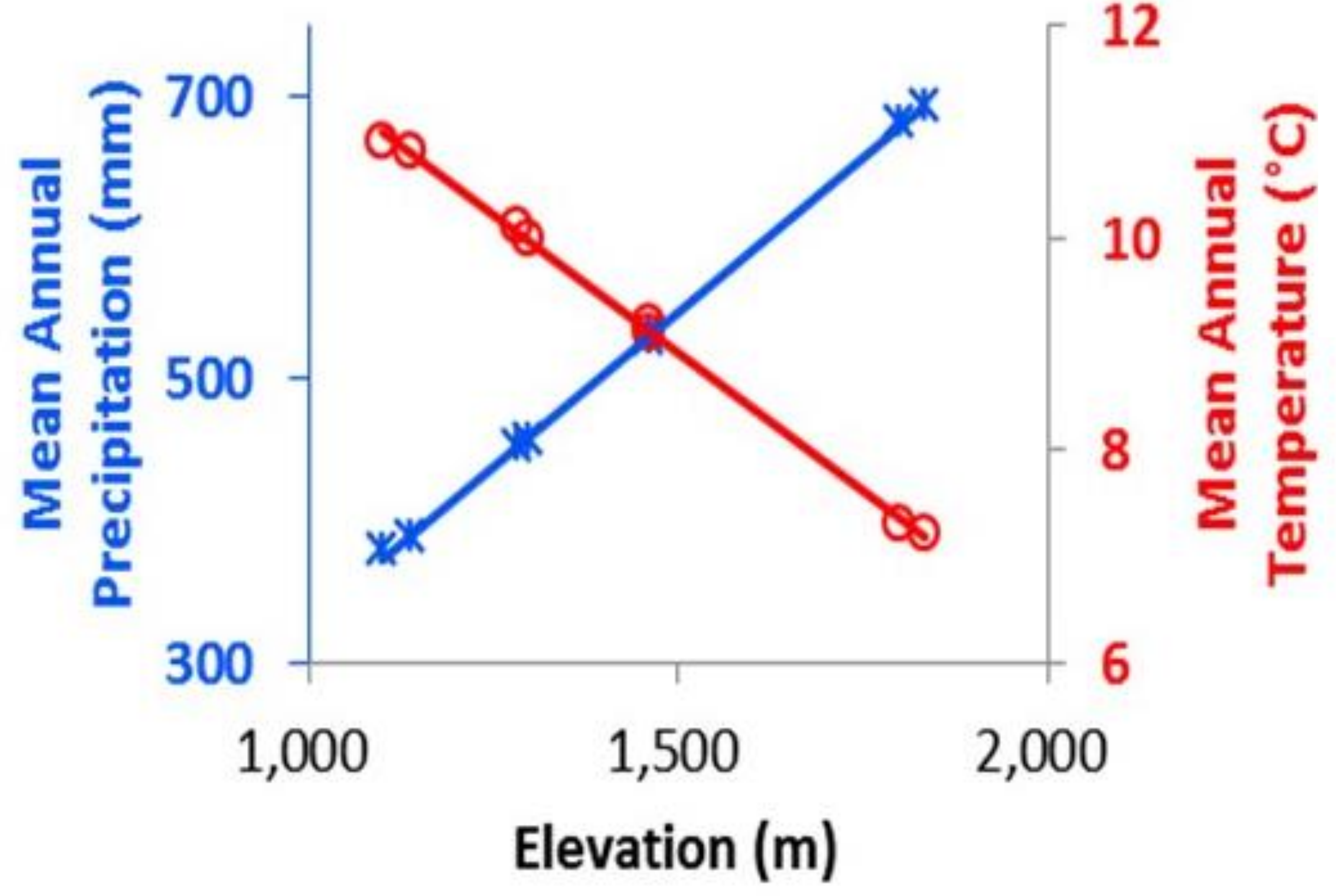
- …**PLACE** refers to a felt value regarding the relationships between people and spatial setting (Vidon, 2015)

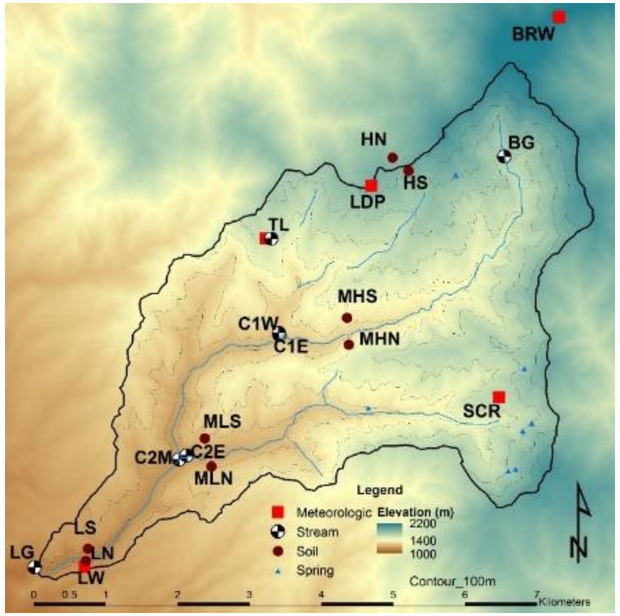
- …when we endow an undifferentiated space with value, space becomes place (Hidalgo and Hernadez 2001)

Outline

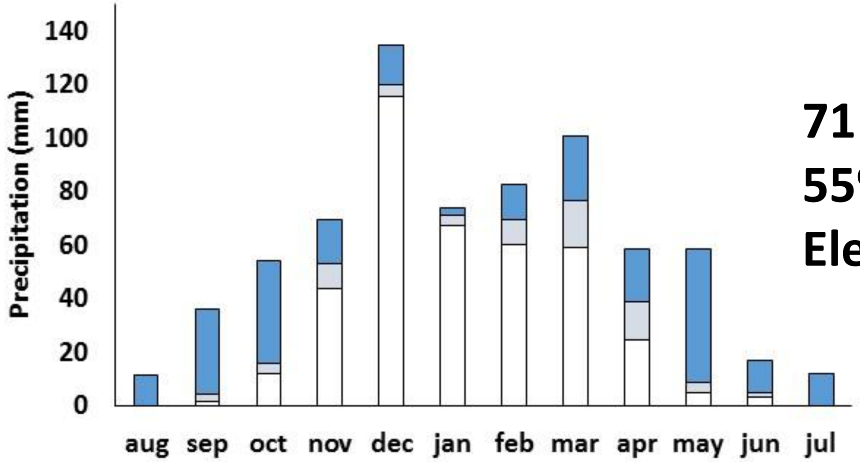
- Catchment Characterization
  - Inputs and Outputs
  - Catchment biophysical properties
- Processes inside the box
  - Soil Water-Vegetation relationships across the RSTZ
  - Evaptranspiration across the RSTZ
- Predictive modeling
  - How will changing precipitation phase impact hydrologic partitioning?

The Catchment:
Elevation Imposes Precipitation and Temperature Gradients

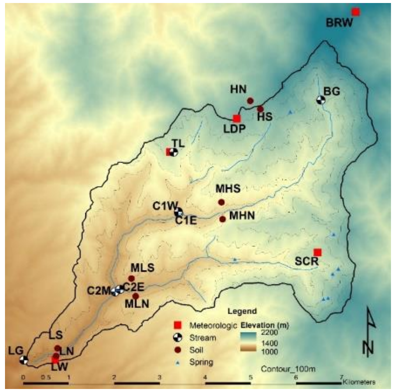


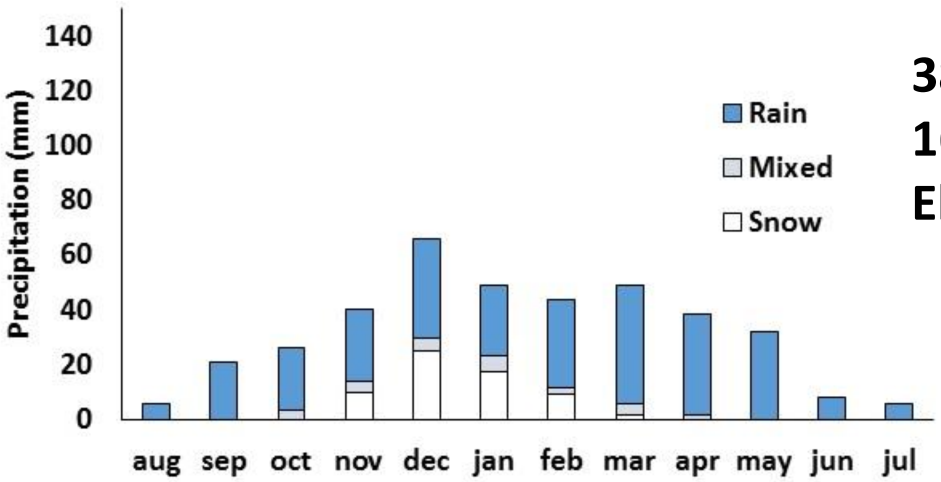


Straddles the Rain Snow Transition Zone (RSTZ)



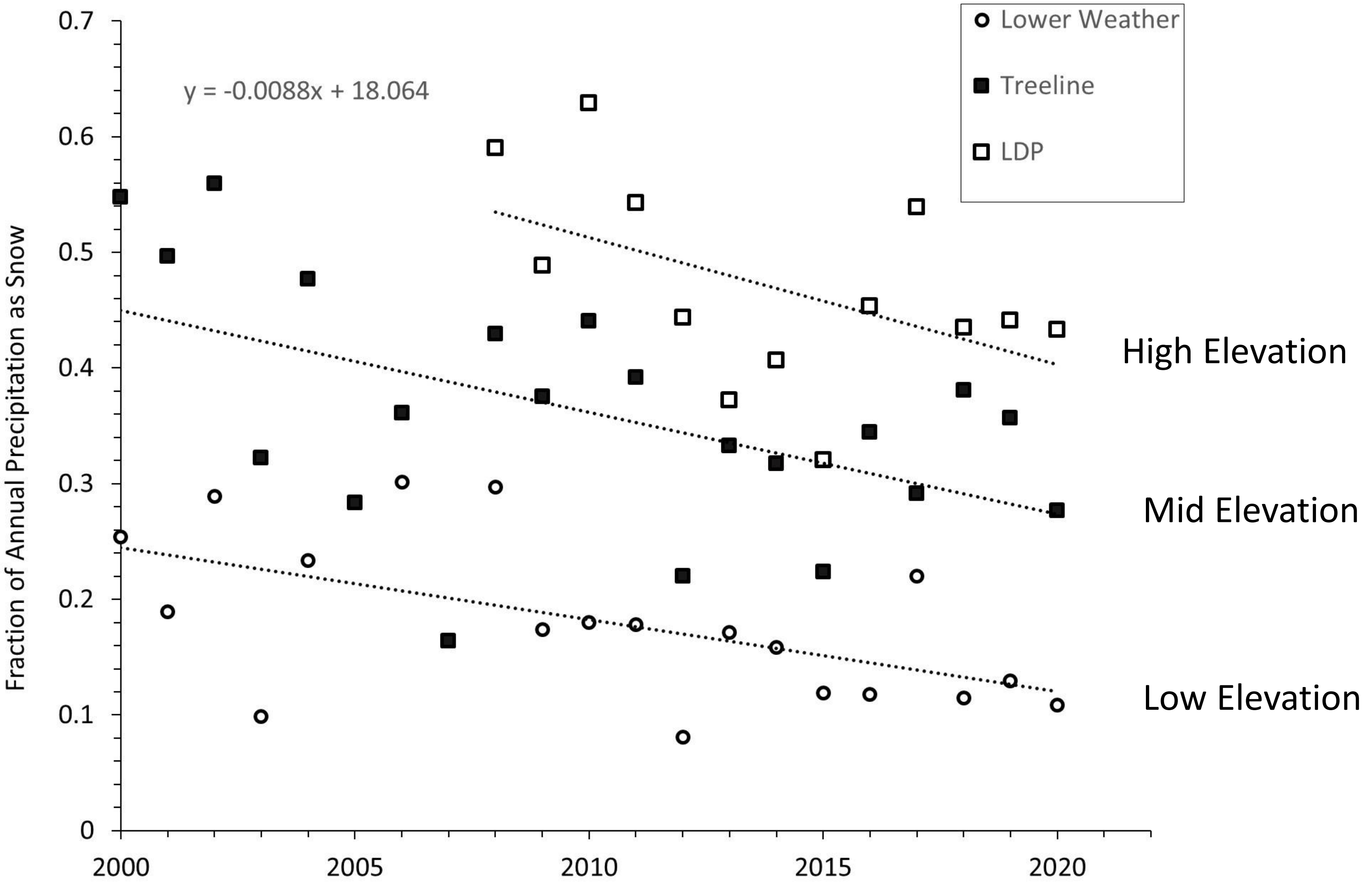
711 mm
55% snow
Ele. 2114 m



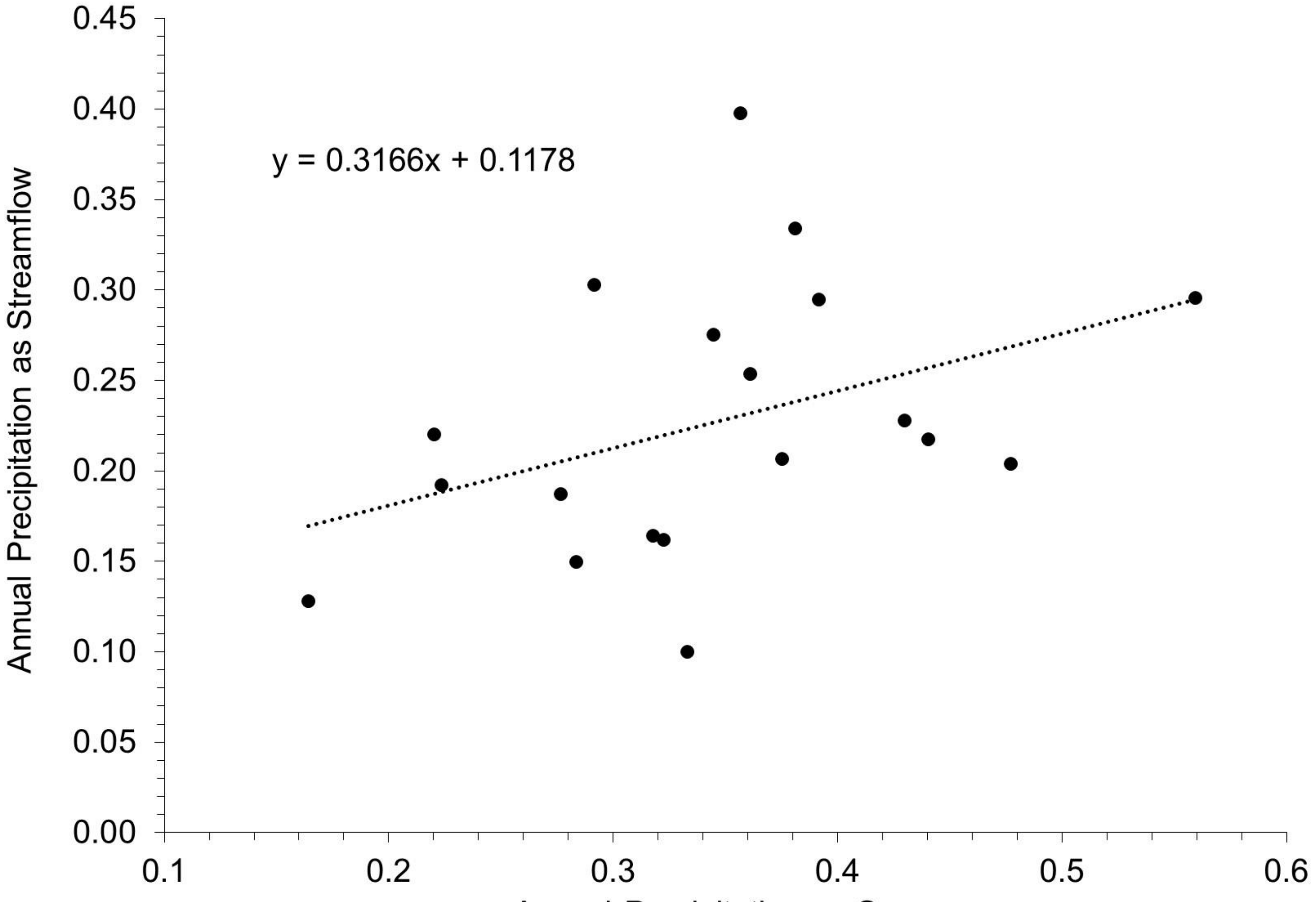


385 mm
16% snow
Ele. 1036 m

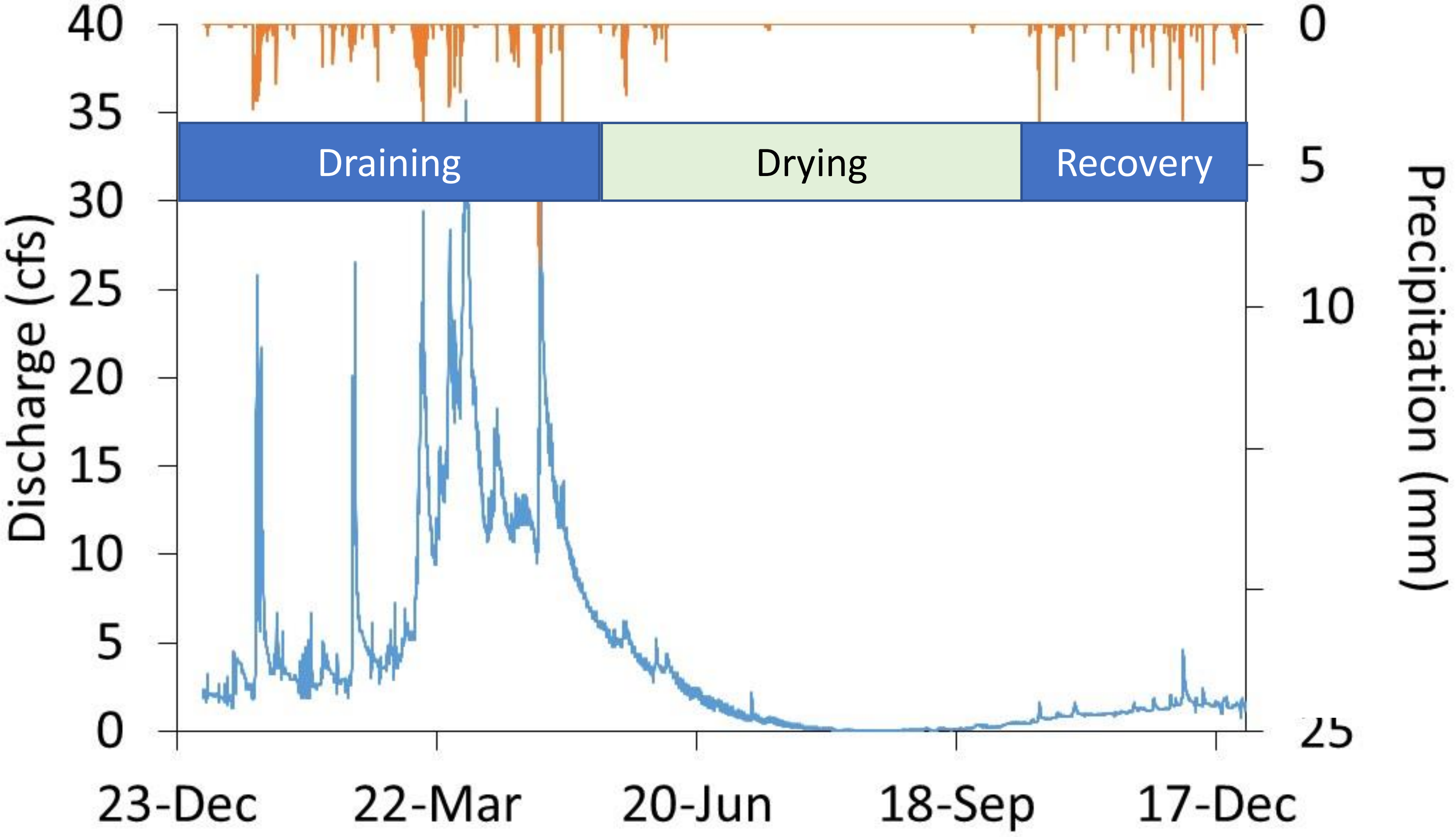
Snow Fraction is Declining by ~1% per year



Snowy Years Produce More Streamflow

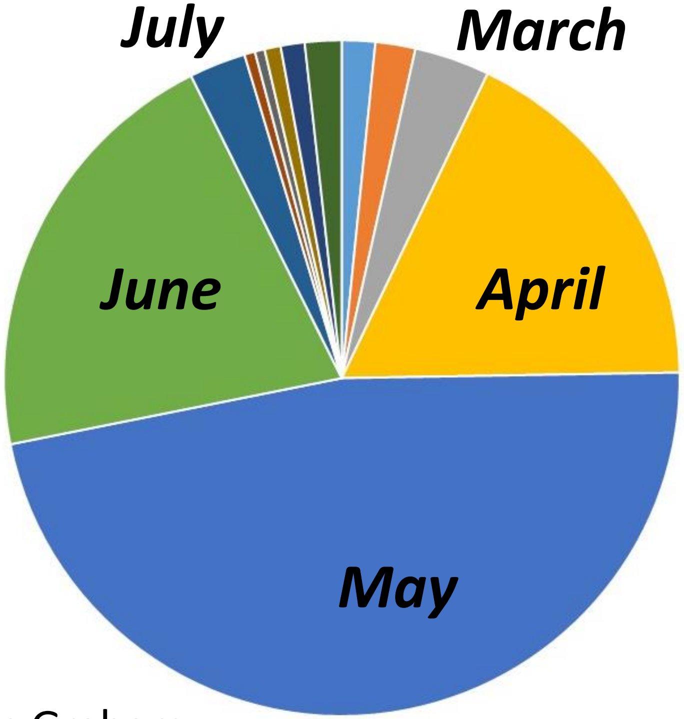


Precipitation Seasonality Imposes Distinct Draining and Drying Hydrology



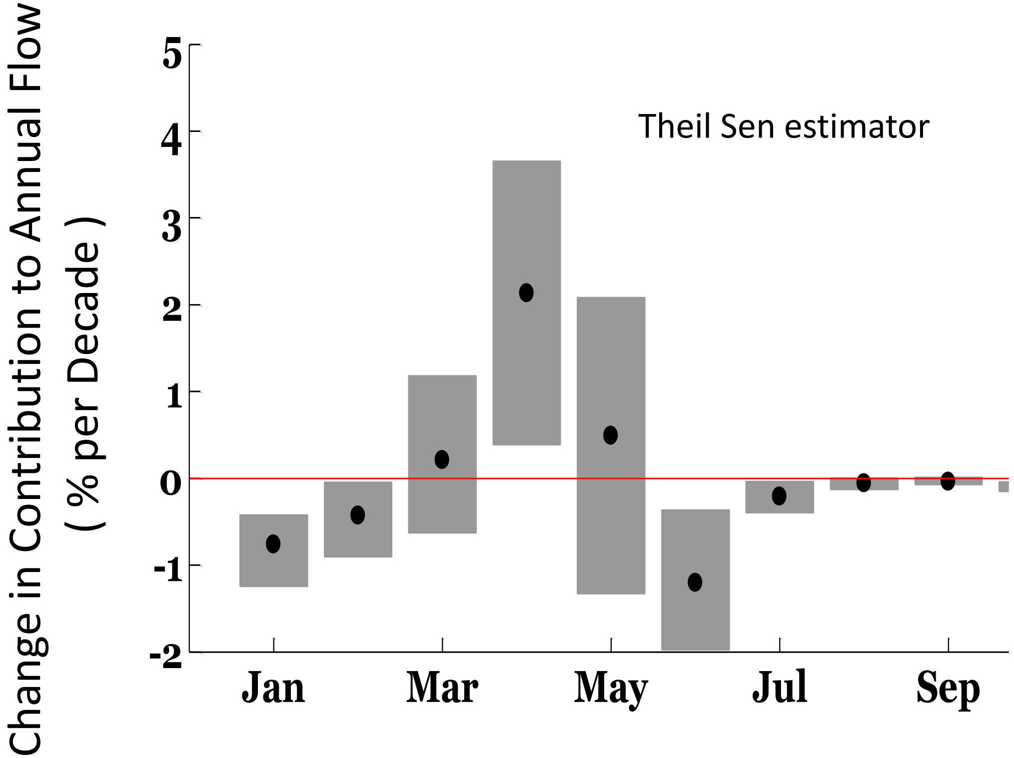
Spring is taking water from summer

Average
Proportion of Annual Flow

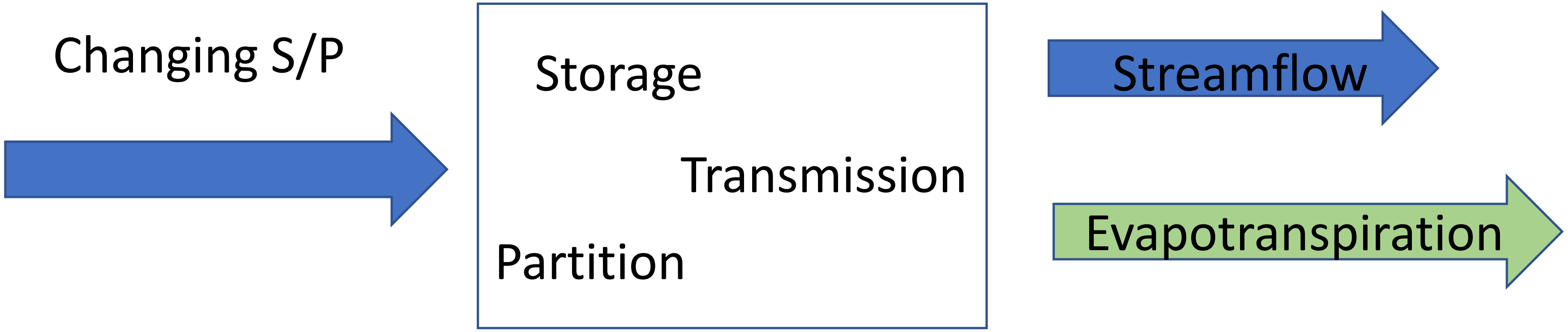


Chris Graham

Change in
Proportion of Annual Flow

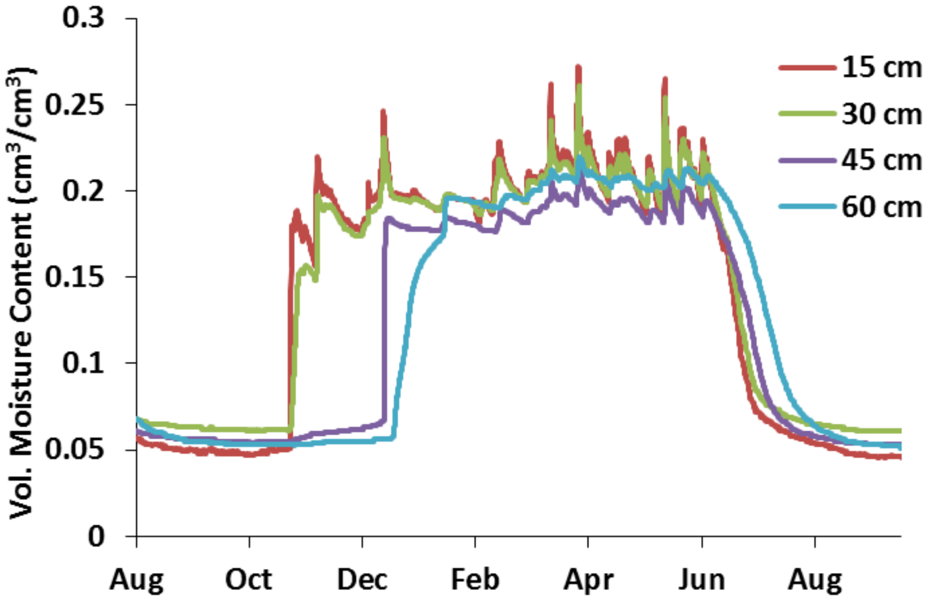


How will changes in annual snow fraction across the rain-snow transition zone impact catchment partitioning between evapotranspiration and streamflow?



What are the relevant internal processes that accomplish the transition for precipitation to streamflow?

Spatially variable vegetation-soil water relationships will regulate hydrologic response to precipitation phase transition



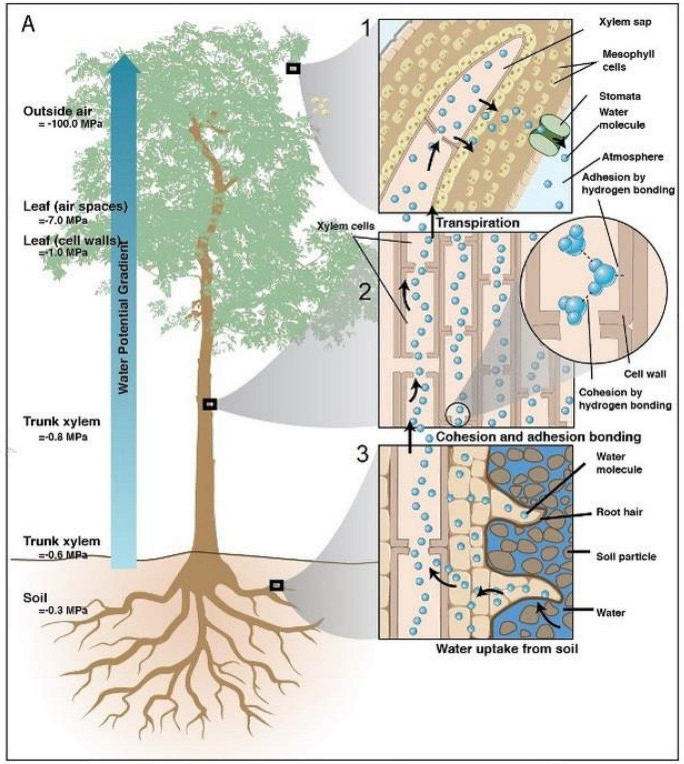
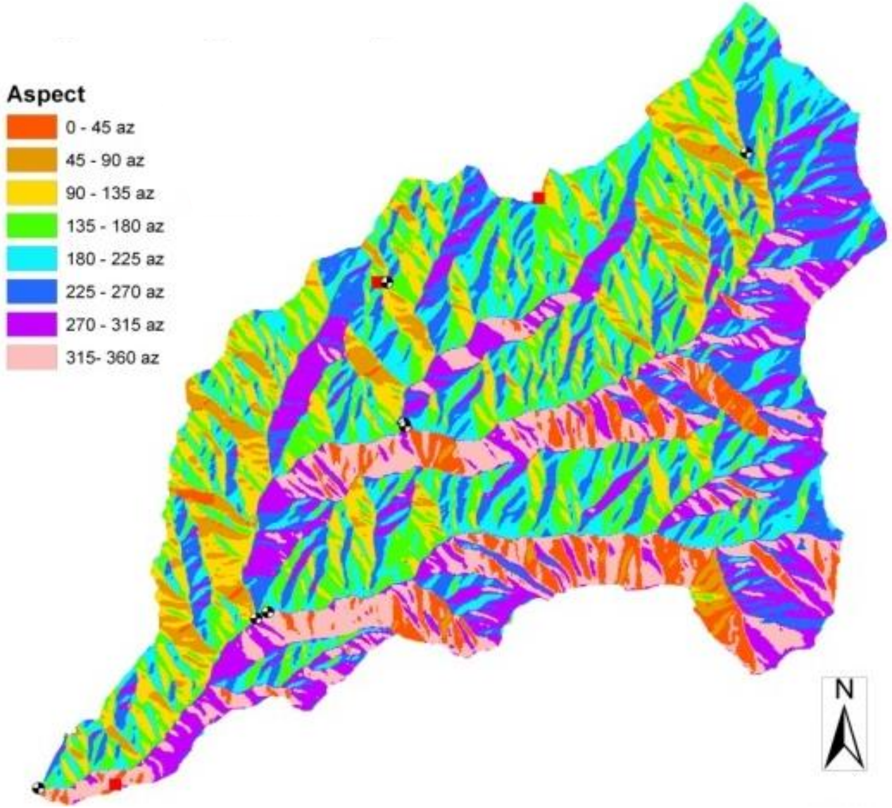
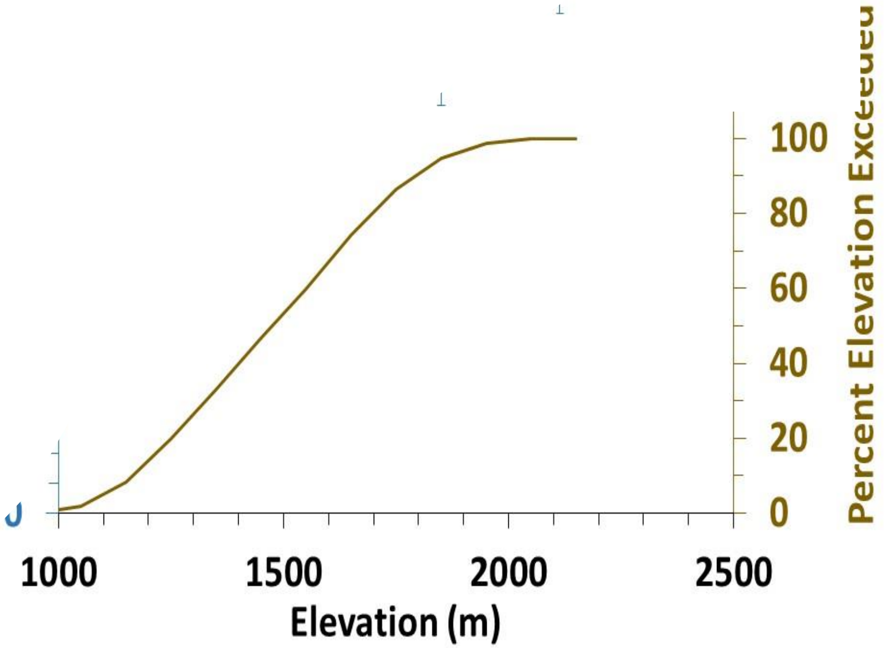


Image borrowed from McElrone et al., 2013

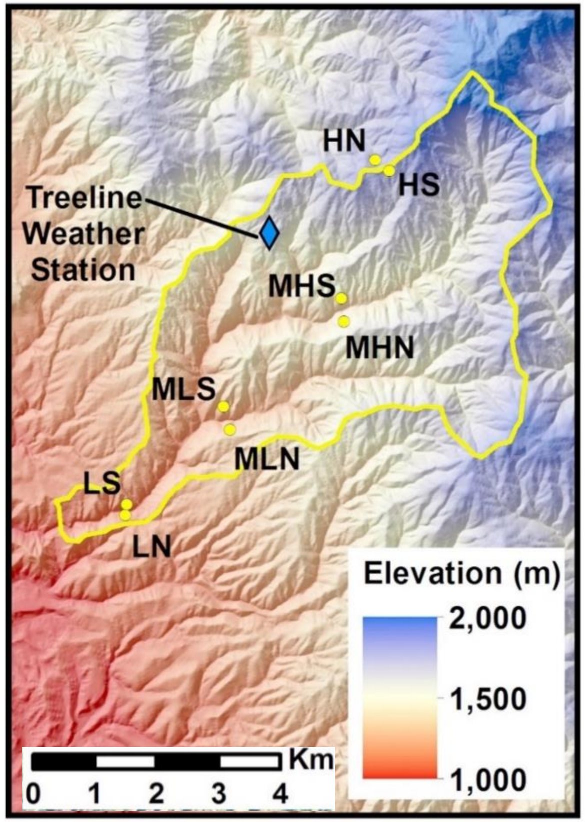
The orientation of terrain imposes spatial variability on catchment

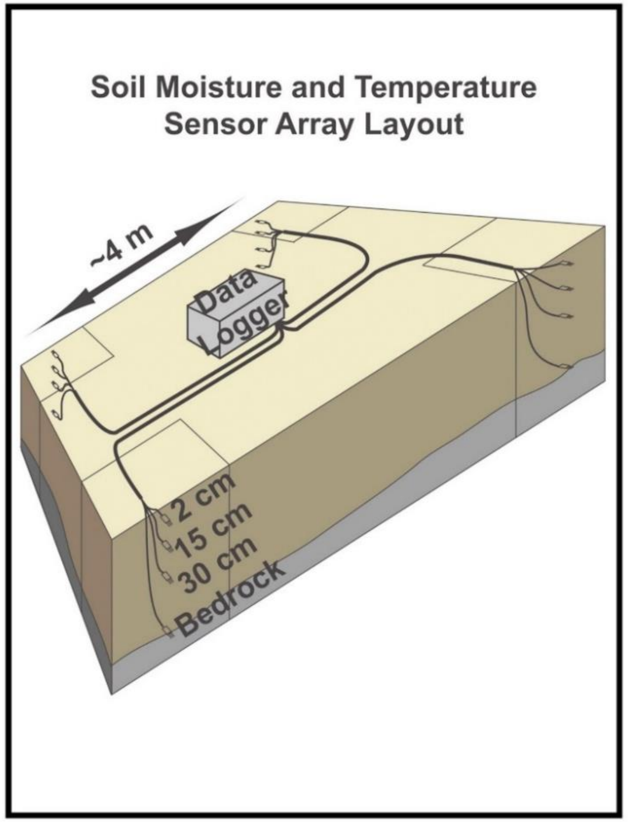




Topographically Moderated Soil Seasons Impact Vegetation Dynamics…

- 10 year Soil Moisture record
- Soil physical properties
- Landsat Normalized Difference Vegetation Index (NDVI)





Ten year record of…

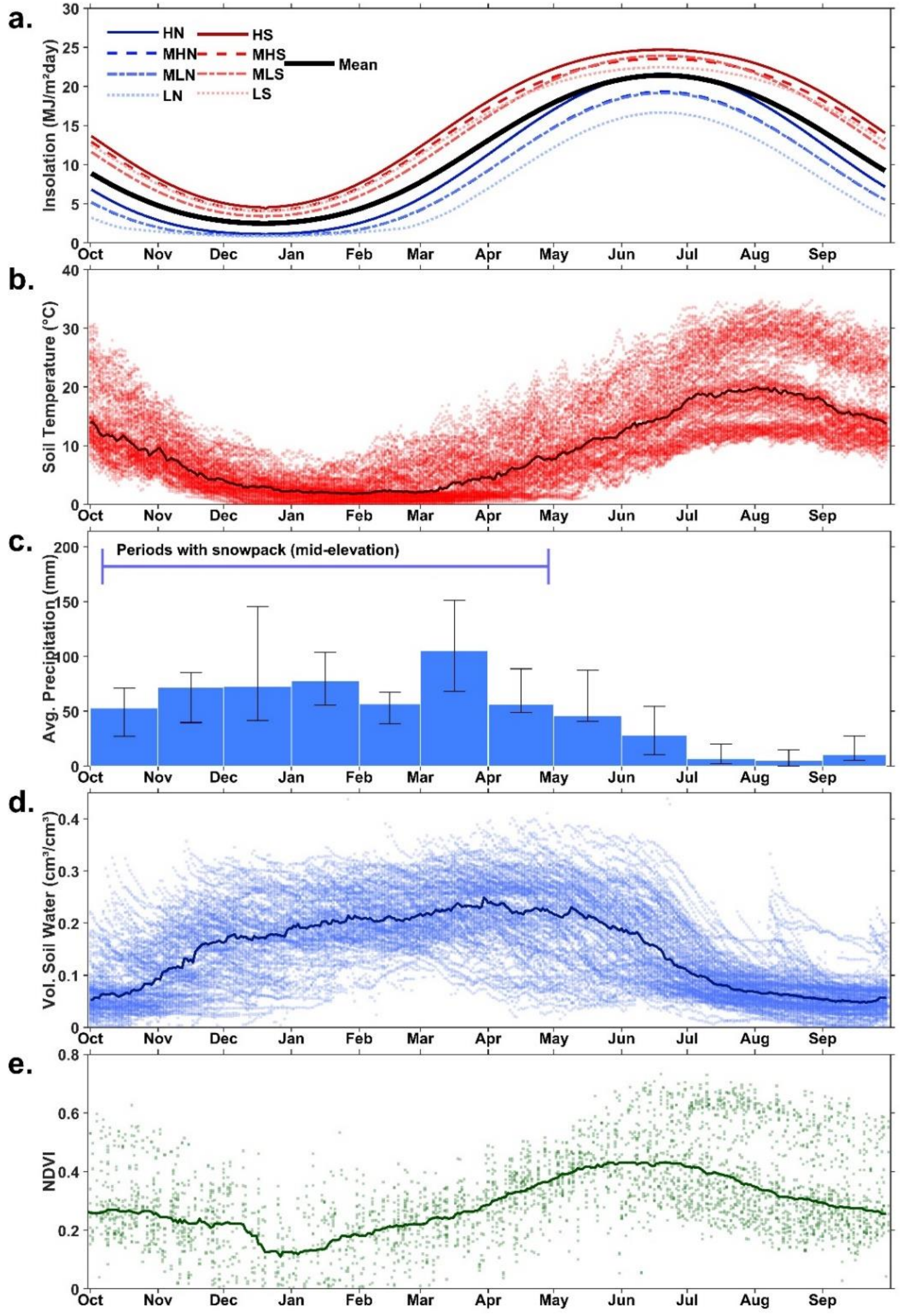
Insolation

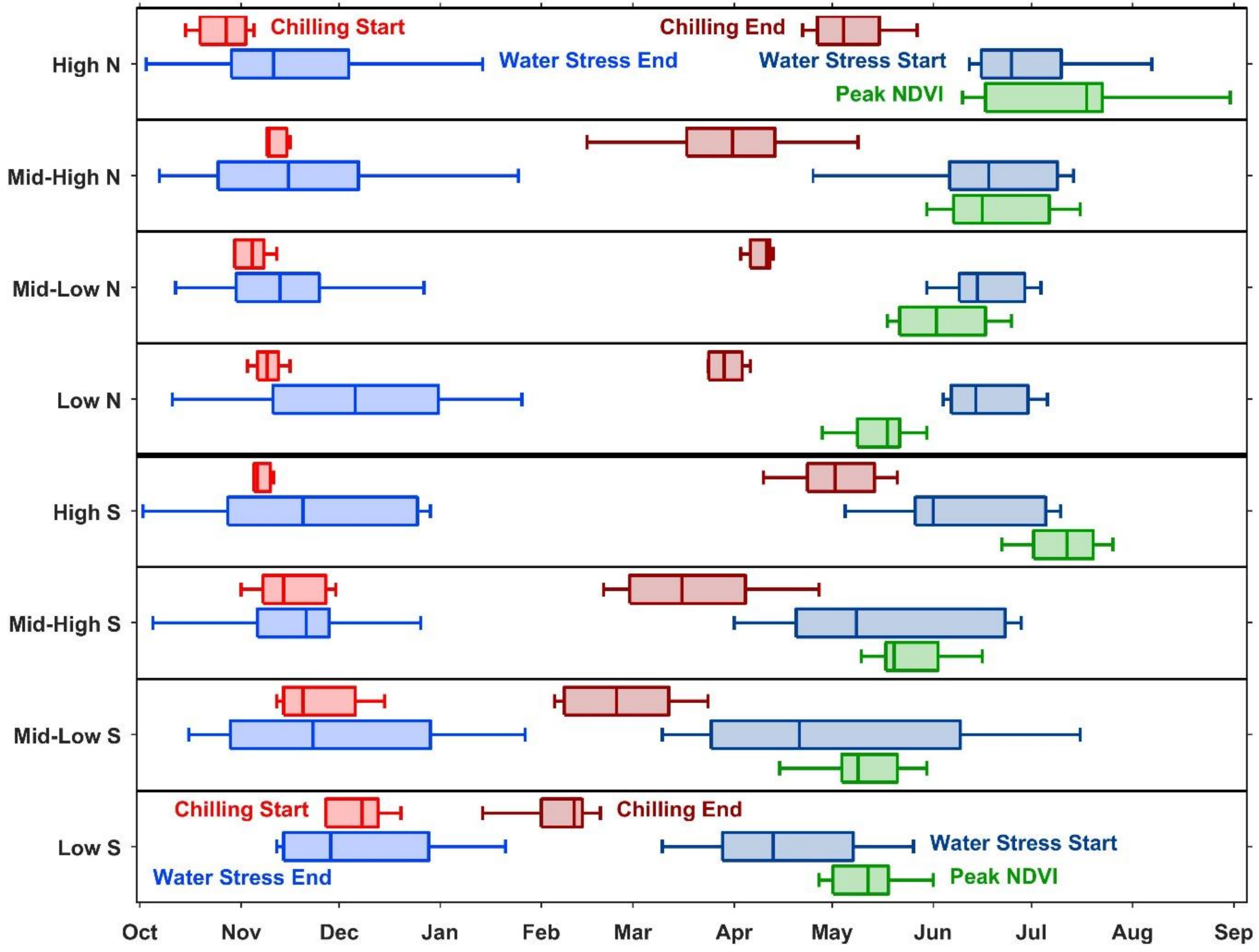
Soil Temperature

Precipitation

Soil Water

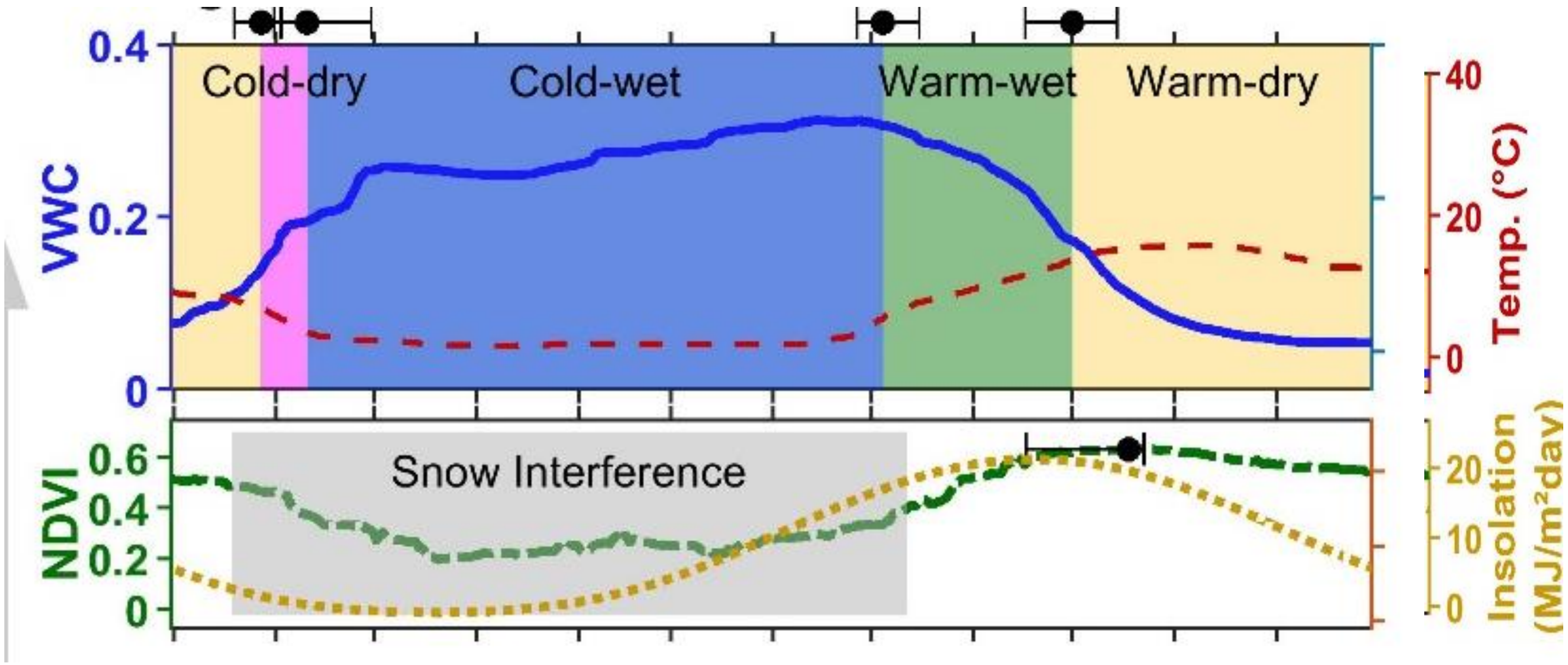
NDVI





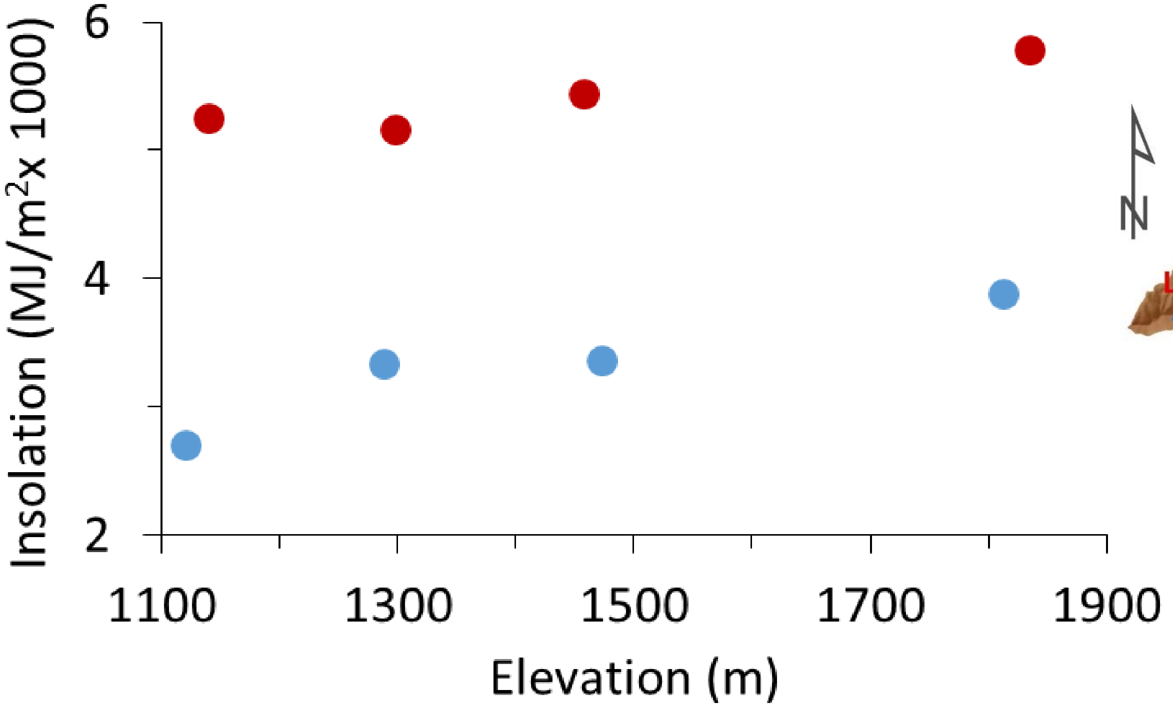
High N
Mid-High N
Mid-Low N
Low N
High S
Mid-High S
Mid-Low S
Low S
Chilling Start
Chilling End
Water Stress End
Water Stress Start
Peak NDVI
Chilling Start
Chilling End
Water Stress Start
Water Stress End
Peak NDVI
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

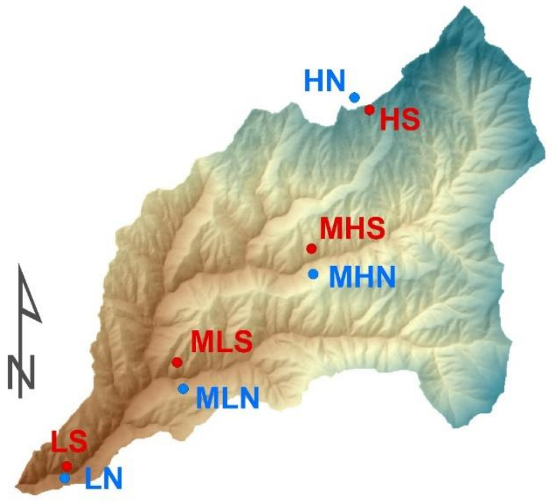
For each site



North Aspects…

…get less sunshine



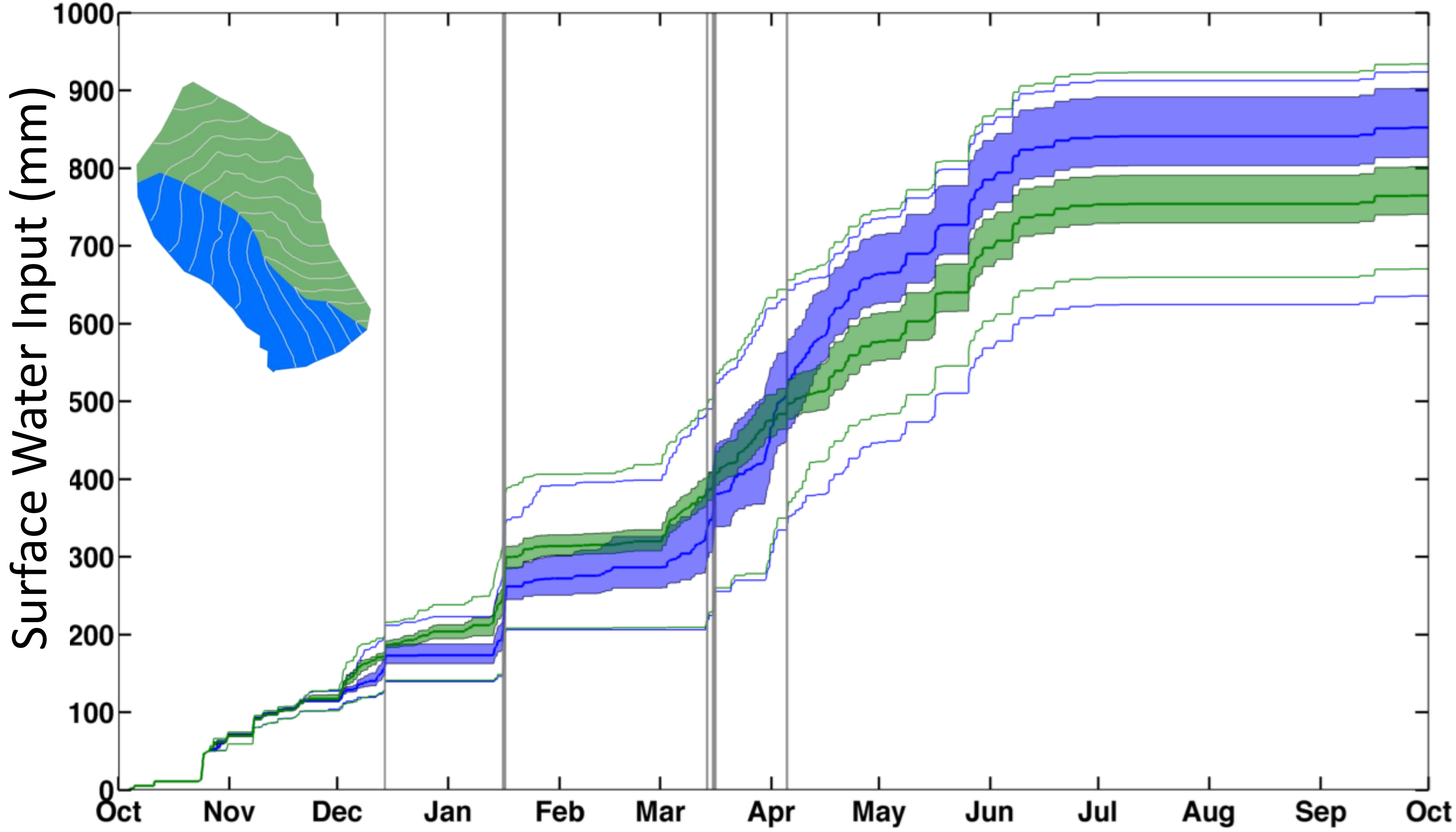


North aspects

South aspects

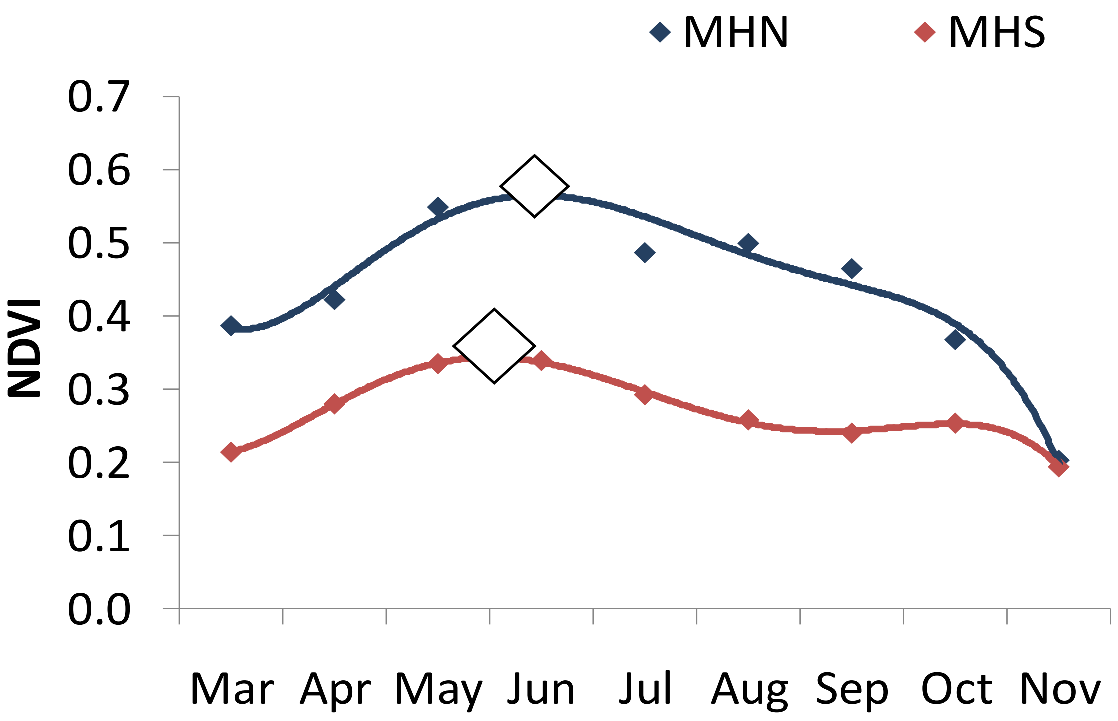
Aspect imposes highly heterogeneous snow accumulation and melt

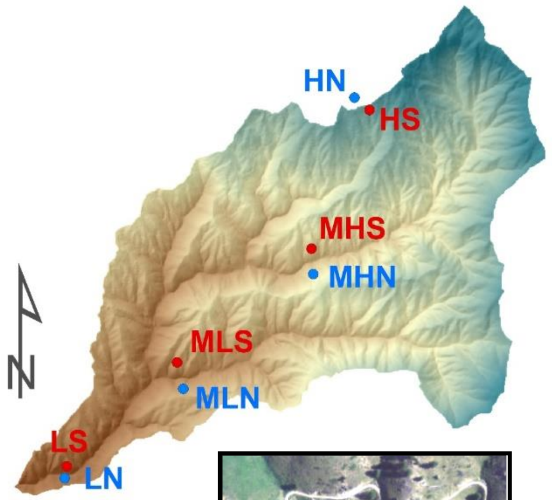
Aspect imposes Spatially and Temporally variable infiltration

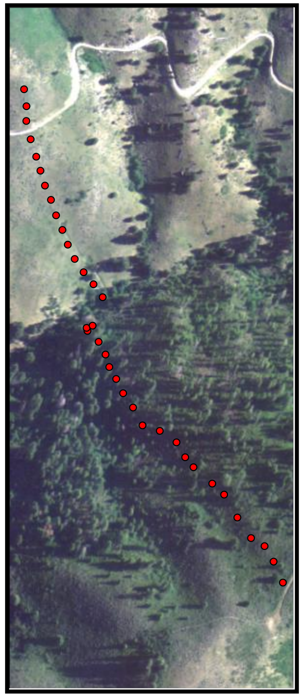


Kormos et al., 2014

North aspects are more productive





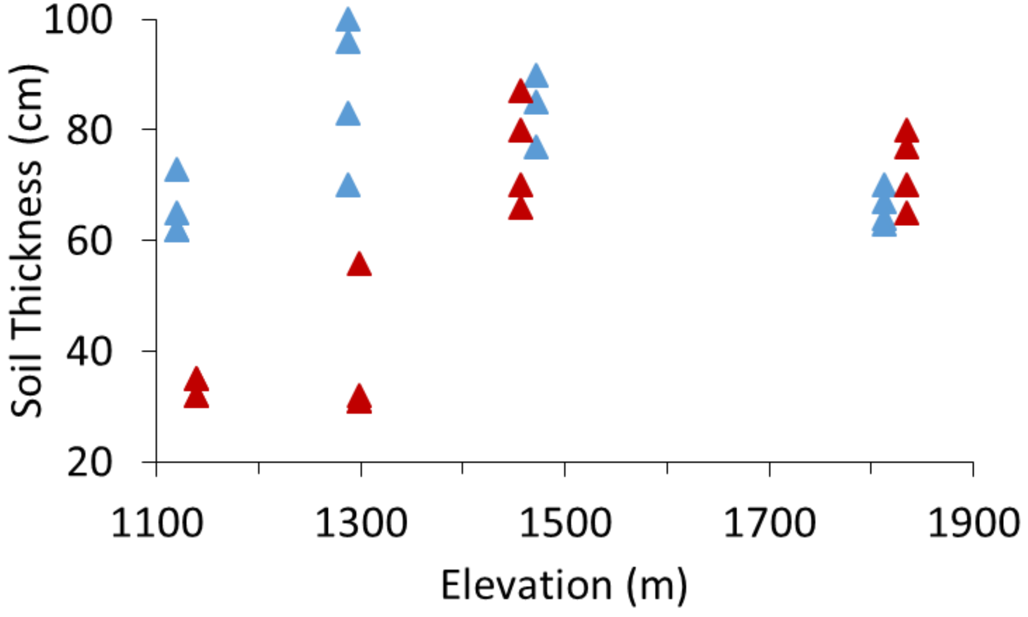


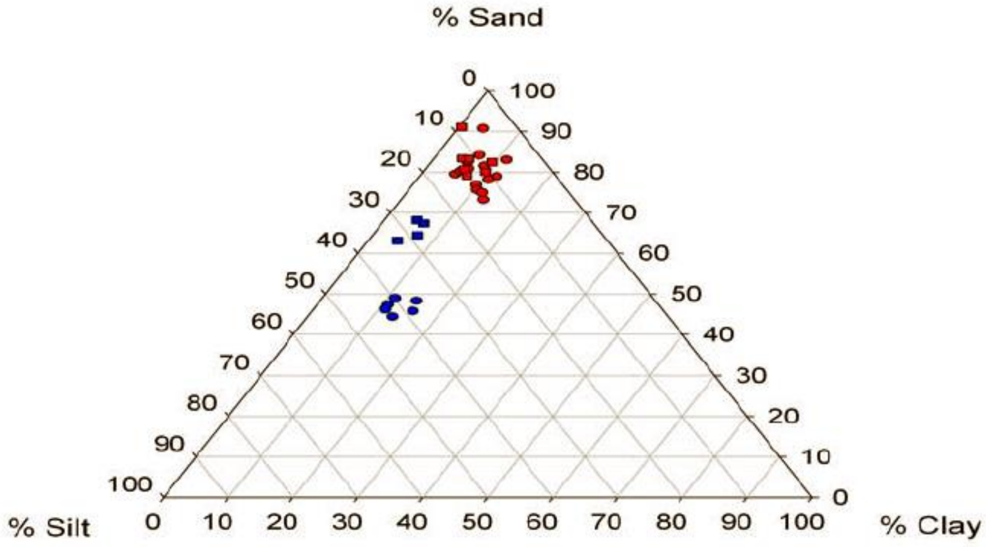
North aspects

South aspects

Smith et al., 2011

North Aspects have thicker and fine soils





North aspects

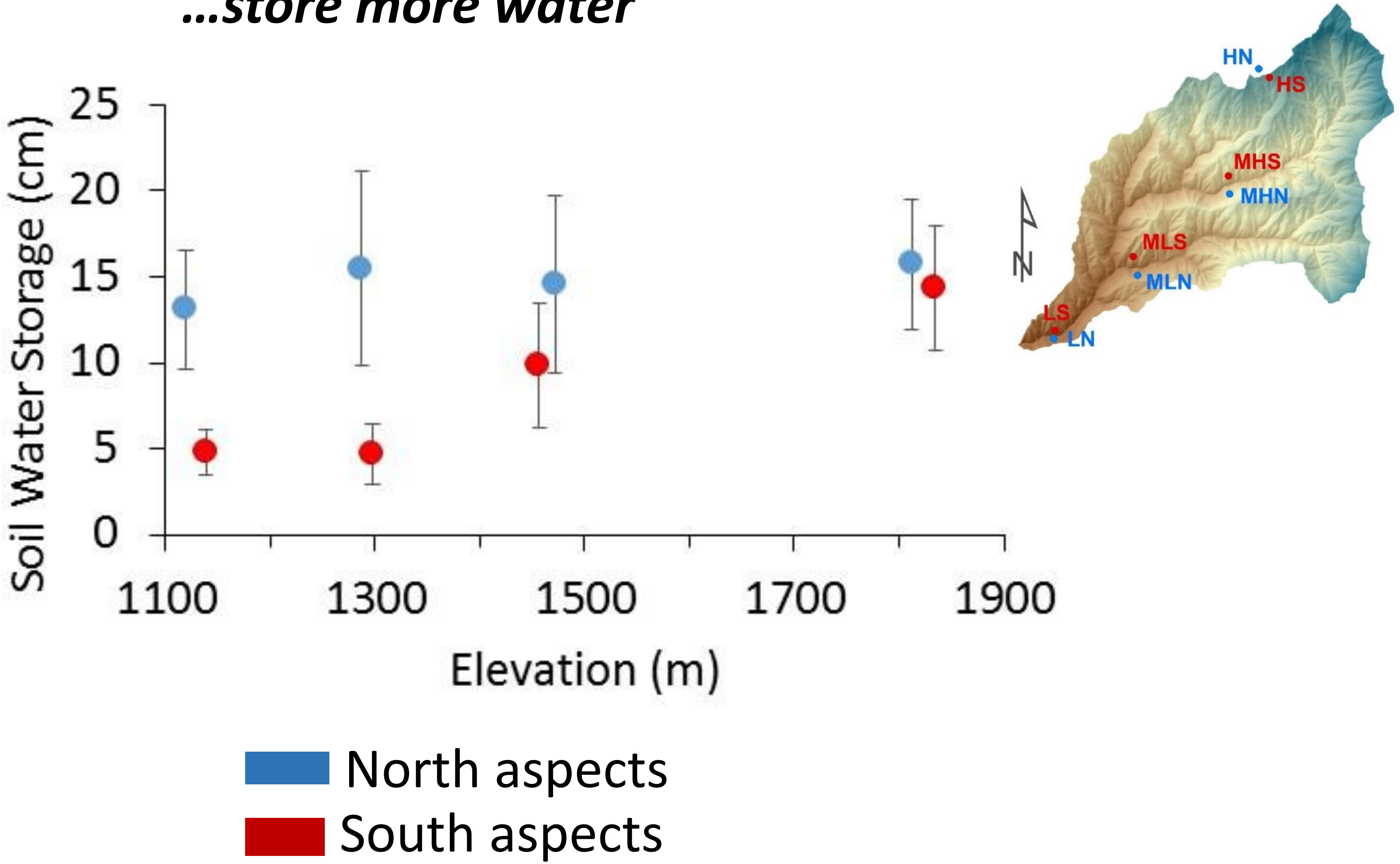
South aspects

Tesfa et al., 2009, Water Resources Research

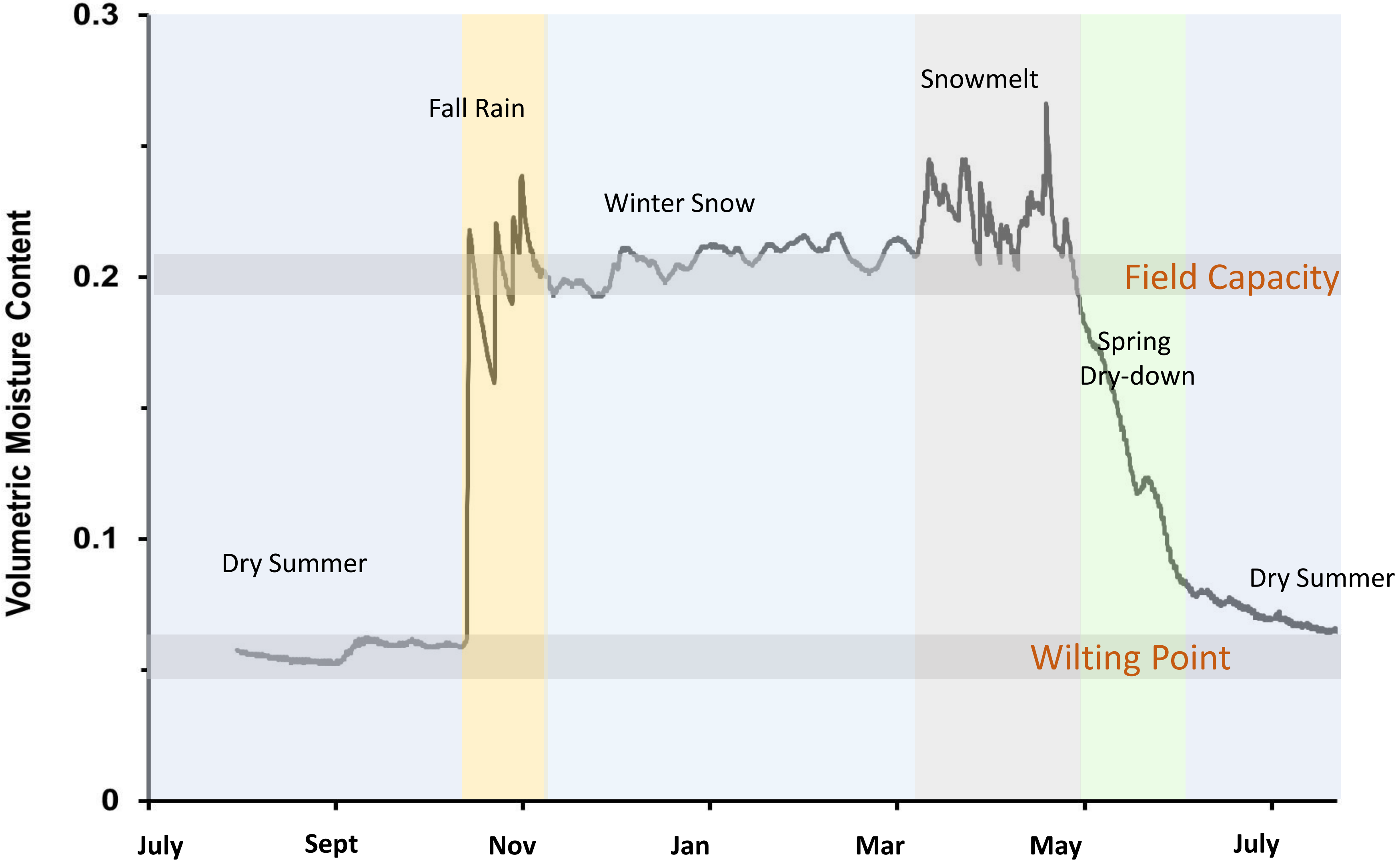
Smith et al., 2011, Hydrological Processes

North Aspects…

…store more water

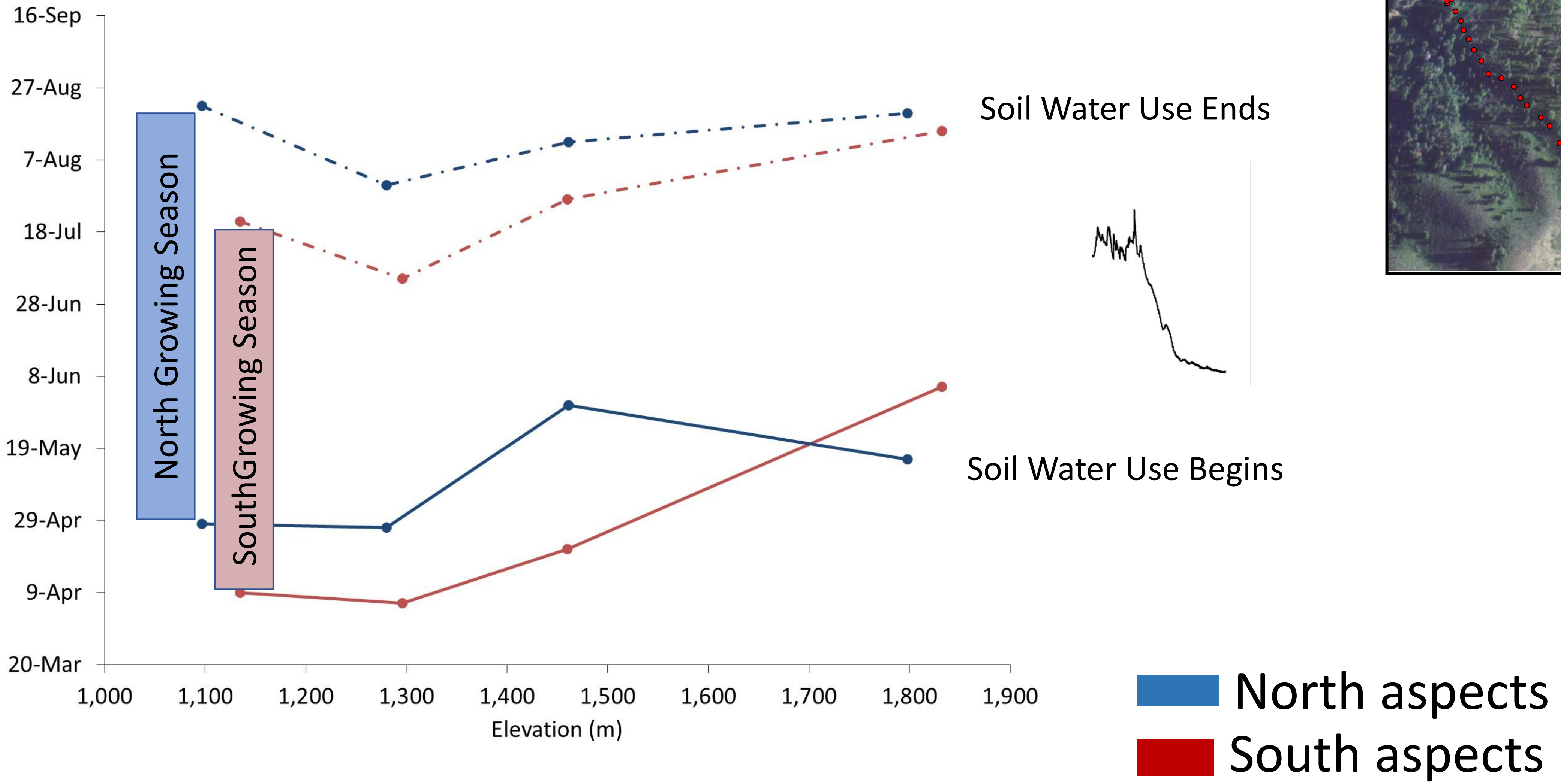


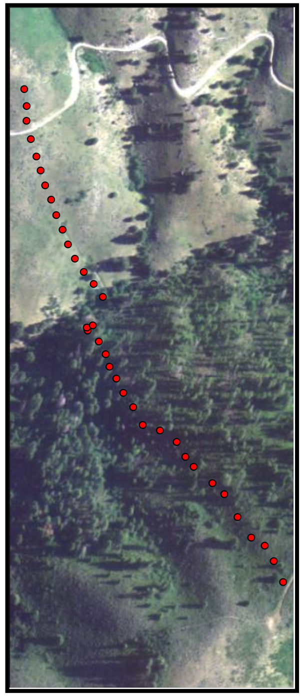
Characteristic Soil Water Year



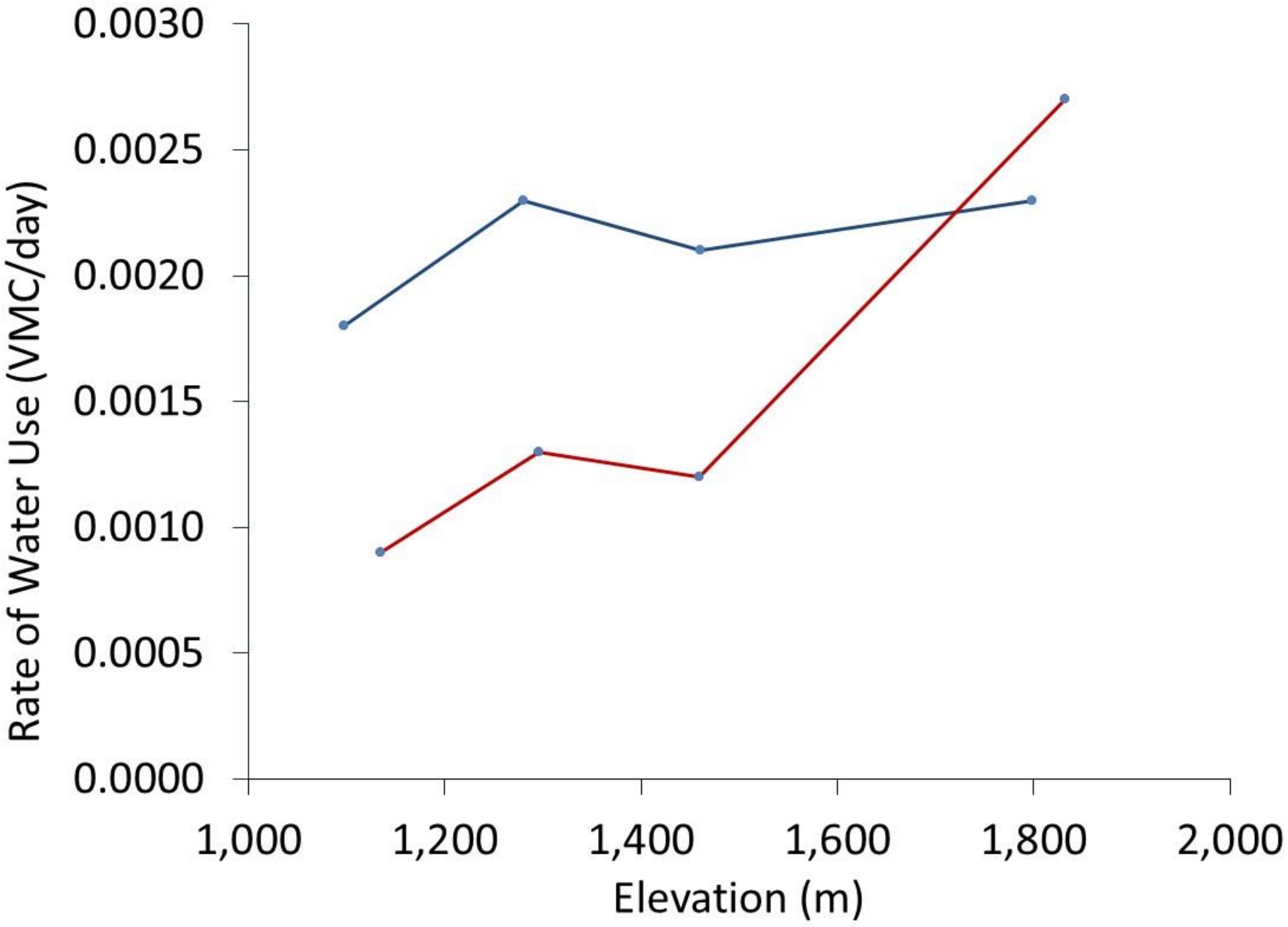
High Energy High Water High Energy

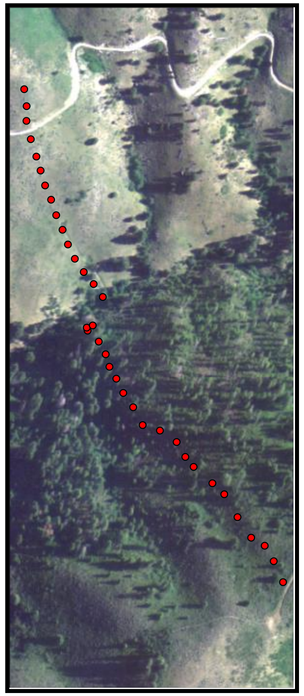
North Facing Slopes Growing seasons are later, but similar duration





North Facing Slopes Use Water Faster





North aspects
South aspects

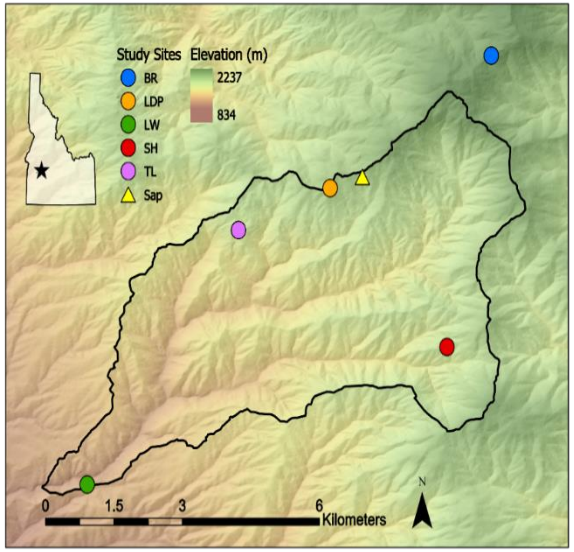
Evapotranspiration across the Rain-Snow Transition – Penman Monteith

$$ET = \frac{\Delta(K+L) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\lambda_v(\Delta + \gamma(1+\frac{r_a}{r_s}))}$$

Meteorological conditions

$$r_s = LAI * k * g_c^{mod}$$

Plant conductance

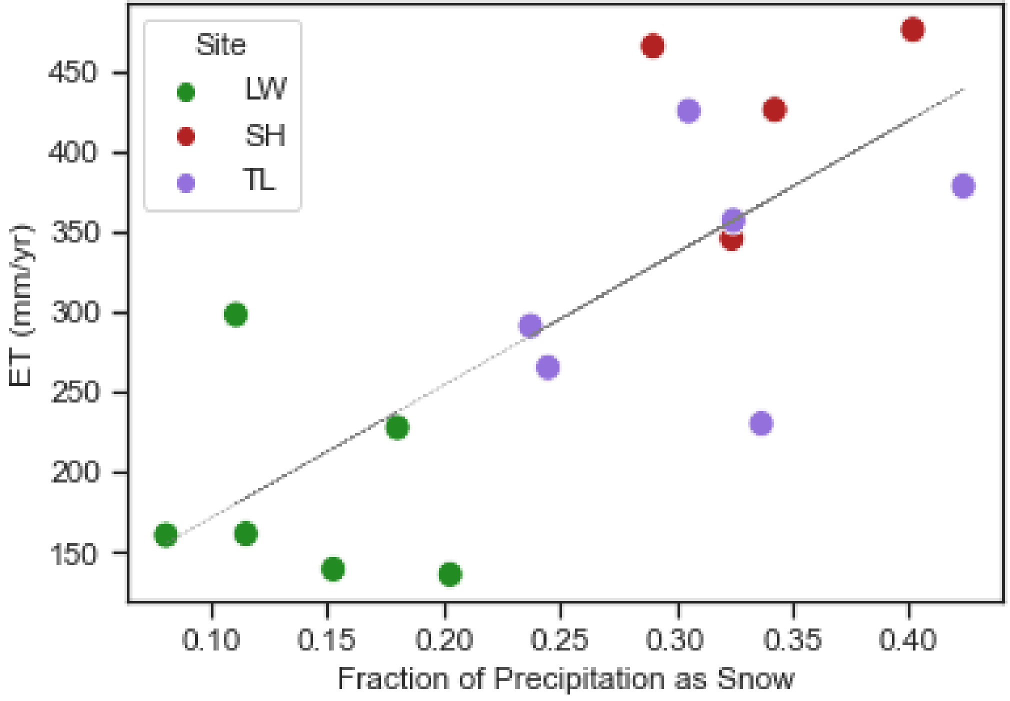


$$g_c^{mod} = g_c^{max} f(R) f(T) f(D) f(W)$$

Modified by soil water availability

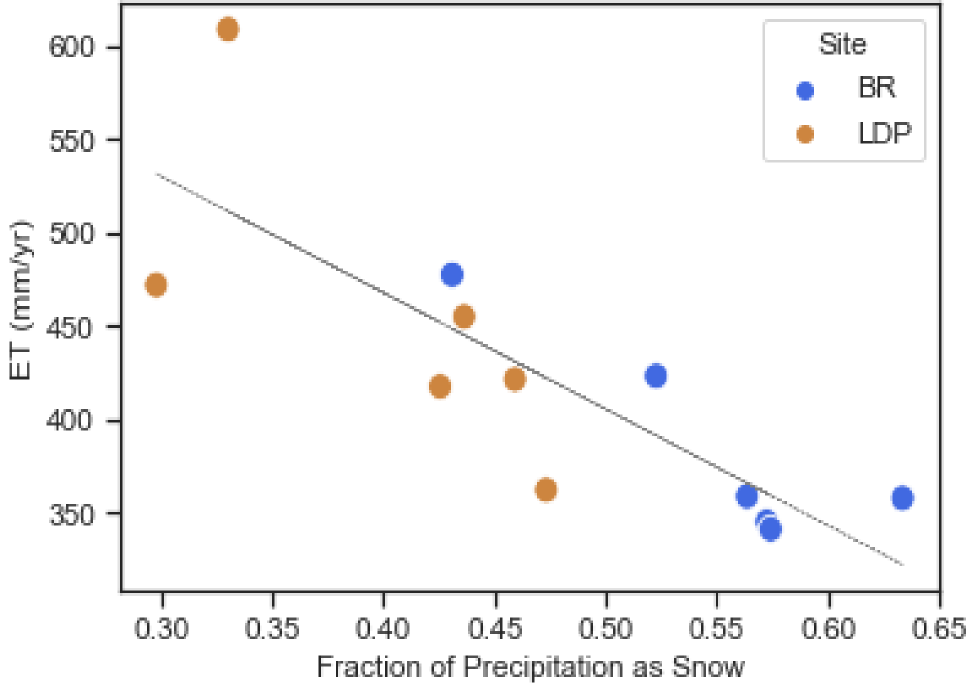
ET, Snow Fraction, and Elevation

Below Rain-Snow Transition Zone



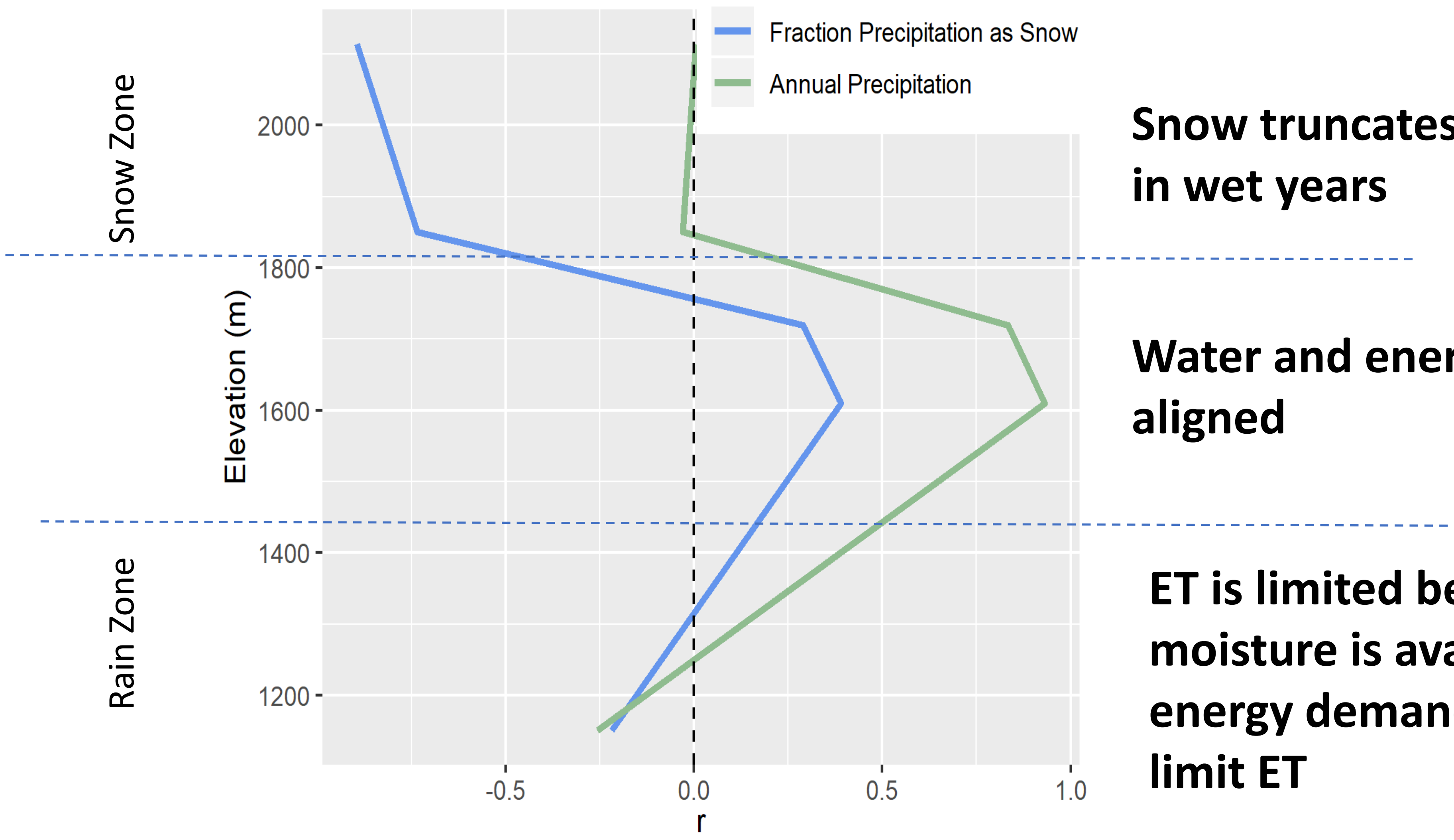
Snow fraction and ET increase with elevation, but low correlations within a site

Above Rain-Snow Transition Zone



Snow fraction and ET increase with elevation, negative correlation within a site

Mid Elevation ET Optimum

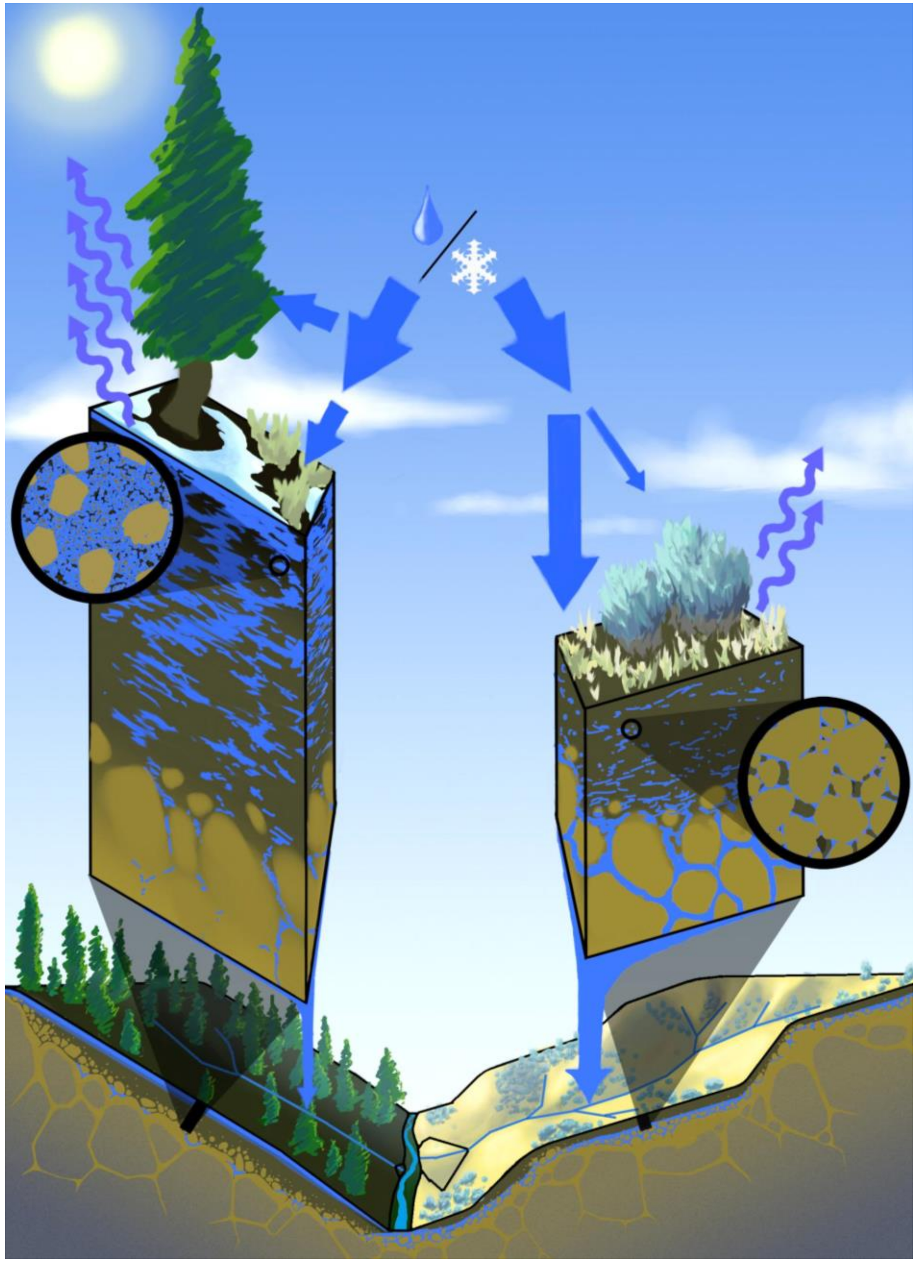


Spearman Rank Correlation Coefficient

Snow truncates growing season in wet years

Water and energy availability aligned

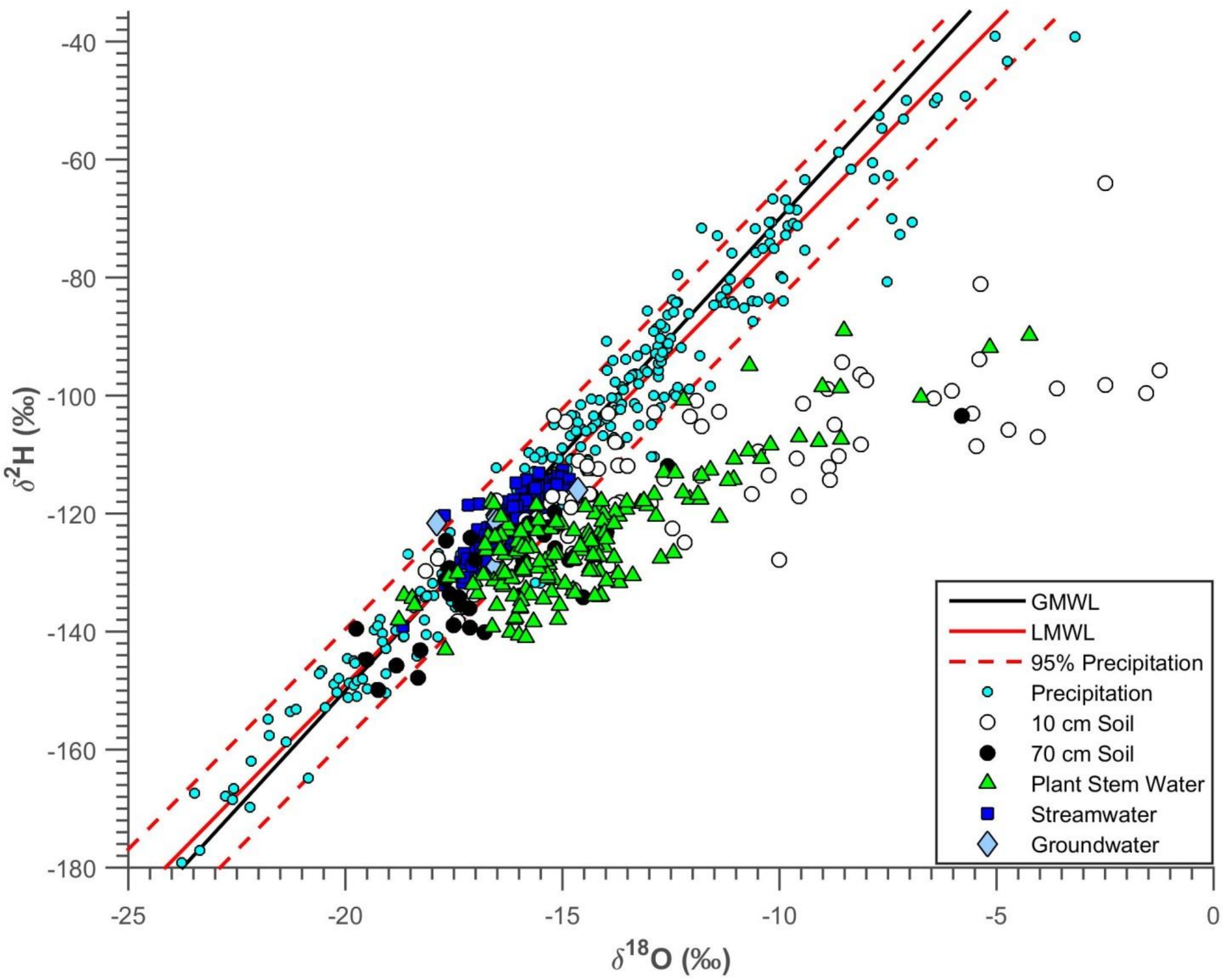
ET is limited because soil moisture is available when energy demand is low – Clouds limit ET



Soil Water – Plant Interactions

- **Thicker, finer soils on high, north aspects enable higher productivity by storing water until periods when energy is available, which supports faster soil water use and growth rates**

- **Evapotranspiration is maximum in the RSTZ where energy and water are optimally aligned**



- **Isotopes reveal plant-soil water relationships**

EcH2O-ISO Model

"…a dynamic, spatially explicit model that couples a vertical energy balance scheme (surface and canopy layer) to a hydrologic model and a forest growth component to capture the dynamic interactions between energy, vegetation, and hydrology at hourly to daily time scales."

-Maneta and Silverman, 2013

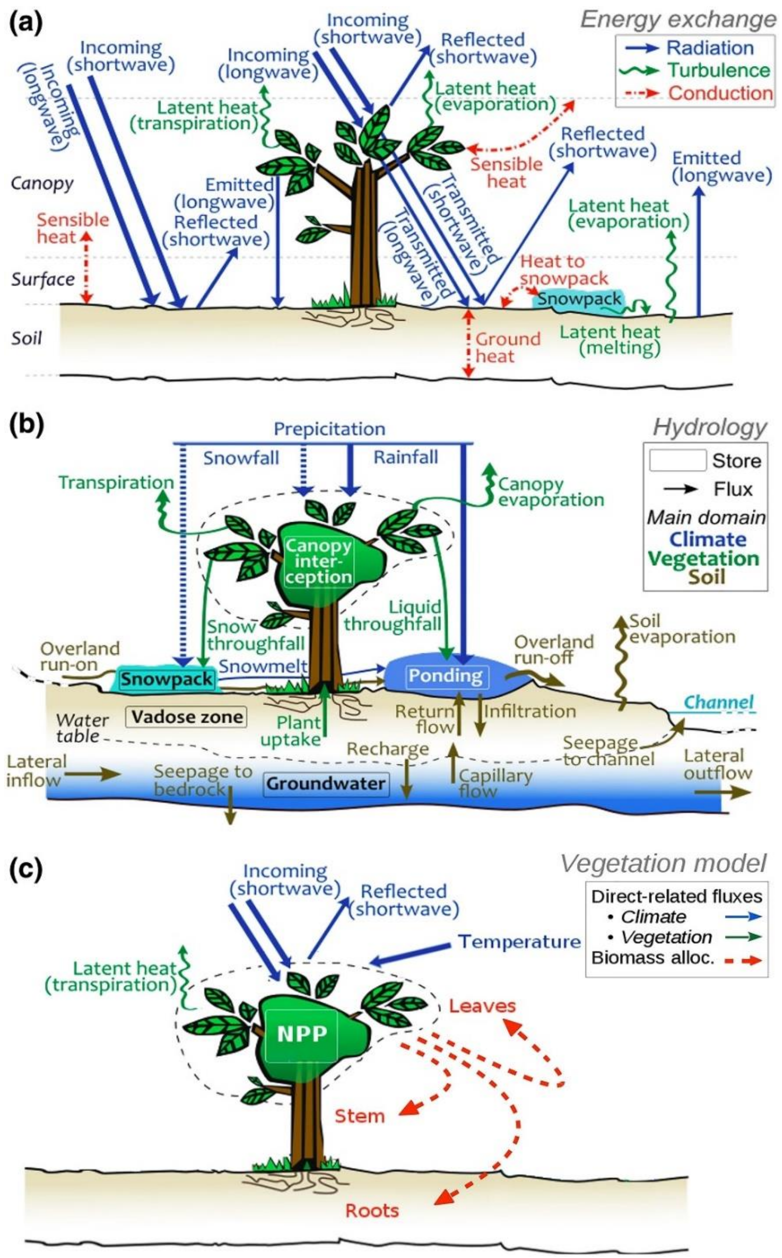
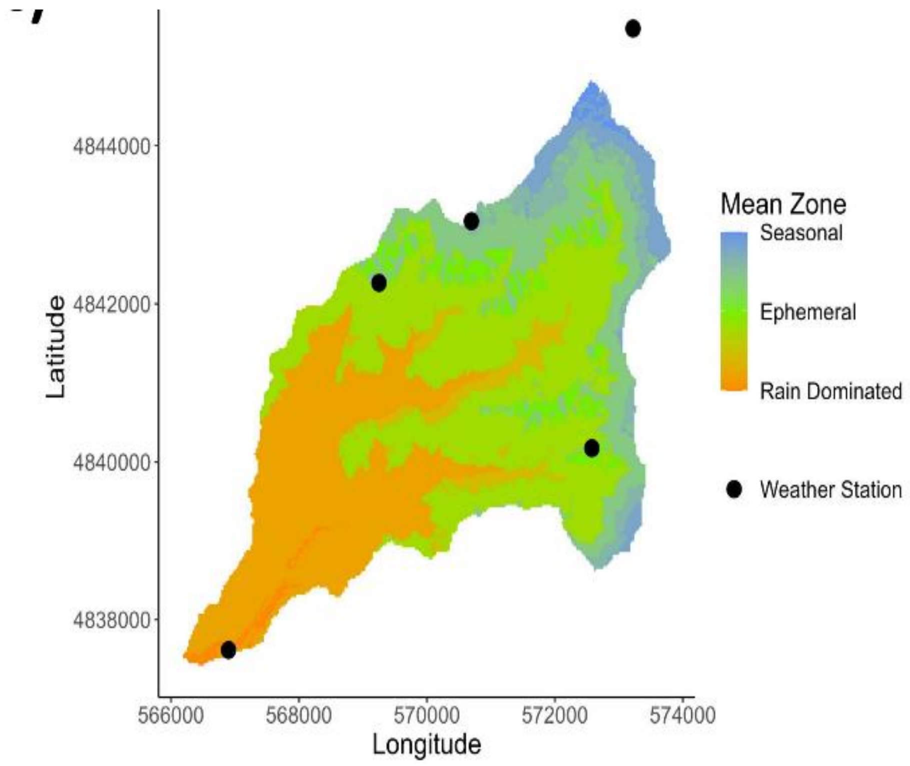
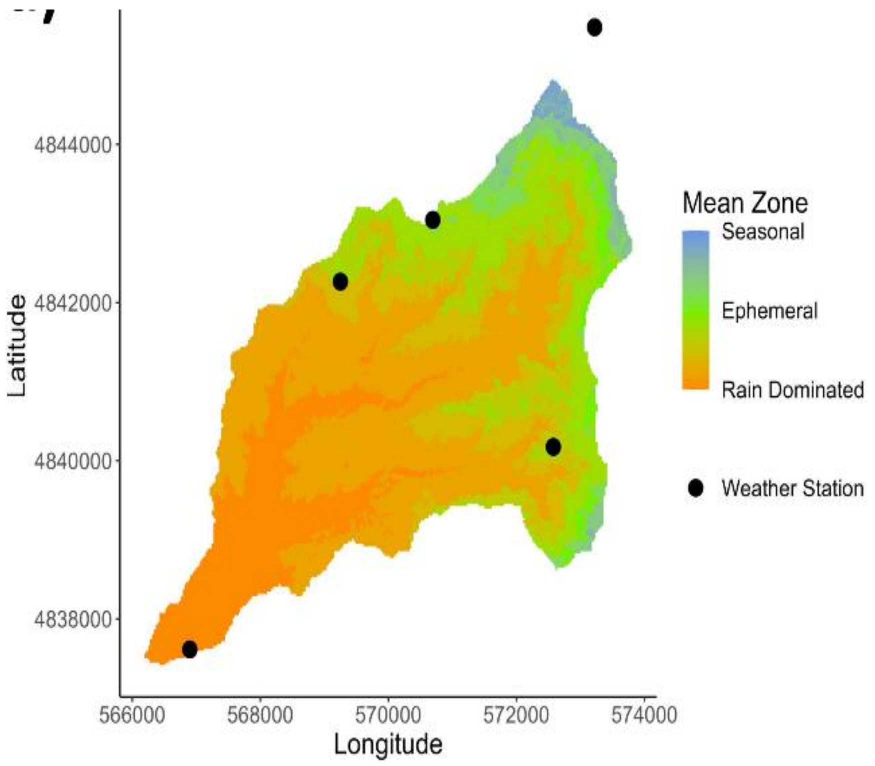


Image from Douinot et al., 2019

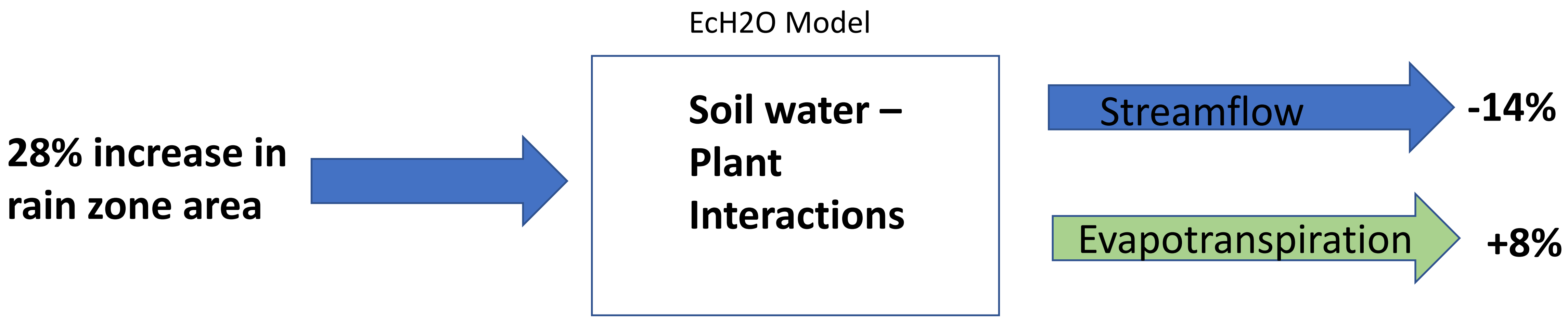
Modeling Scenarios

- SSP2-4.5 scenario in the IPCC report
- +2 C for 8 months (Oct-June)
- Rain zone increases by 28%, Snow zone decreases by 10%





How will changes in annual snow fraction across the rain-snow transition zone impact catchment partitioning between evapotranspiration and streamflow?



Parting Comments

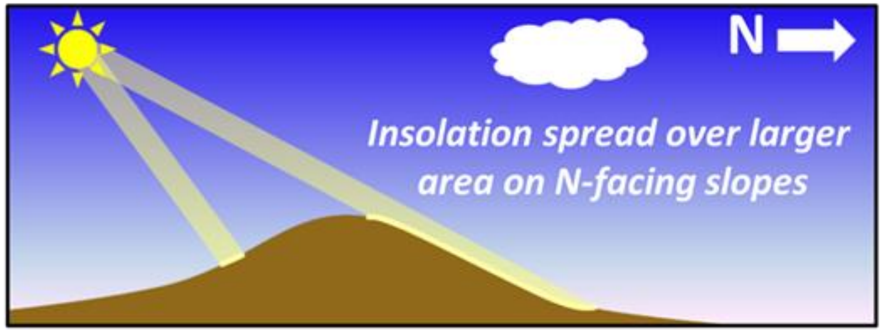
- Plant-moisture interactions vary across the rain-snow transition

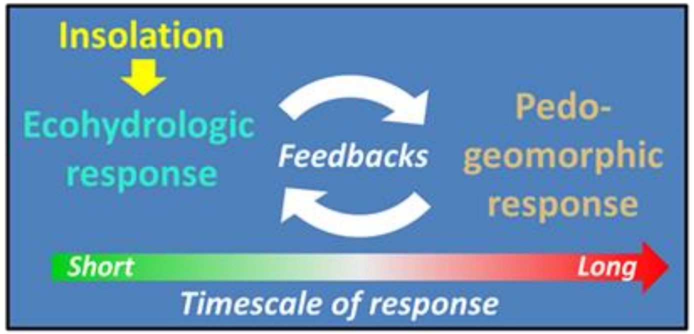
- Plant-moisture interactions regulate how precipitation is partitioned to ET and Streamflow

- Precipitation phase is changing from snow to rain

- Changes in hydrologic partitioning in response to precipitation phase change is complex

Coevolution of function and form





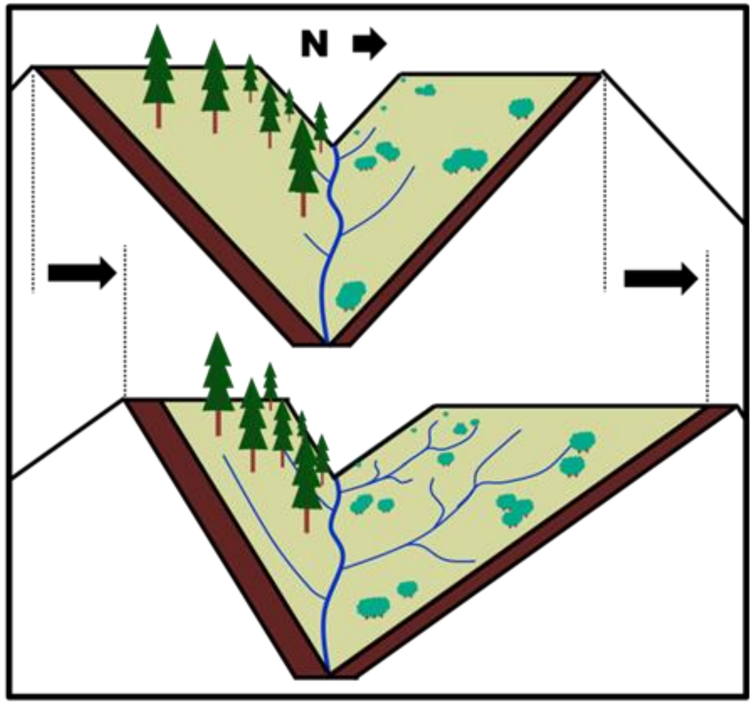
Conceptual model of landscape response to aspect-induced climate on north-facing slopes:

① **Initial response:**
↓insolation → ↑moisture
→ ↑vegetation → ↓erosion
→ ↑soil development

② **Positive Feedbacks:**
↑soil development → ↑ water storage
→ ↓ runoff → ↓drainage competition
→ ↑ridgeline migration
→ ↓length & ↑gradient → ↓insolation

③ **Negative Feedbacks:**
↑gradient + ↑soil thickness + ↓ length
→ ↑ erosion + ↑drainage competition
→ ↓ ridgeline migration

③ **Positive & negative feedbacks**
→ dynamic equilibrium



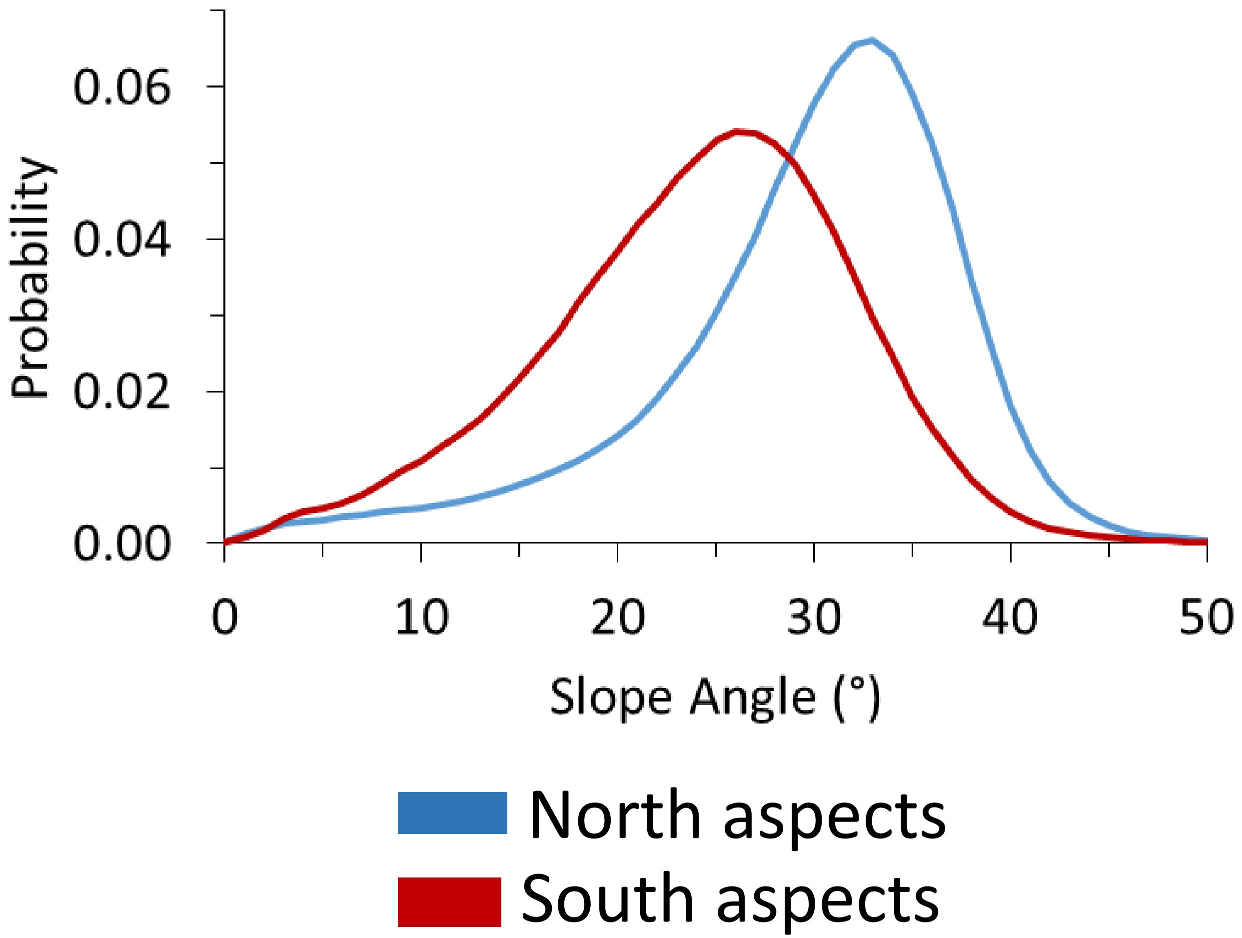
Conceptual summary:

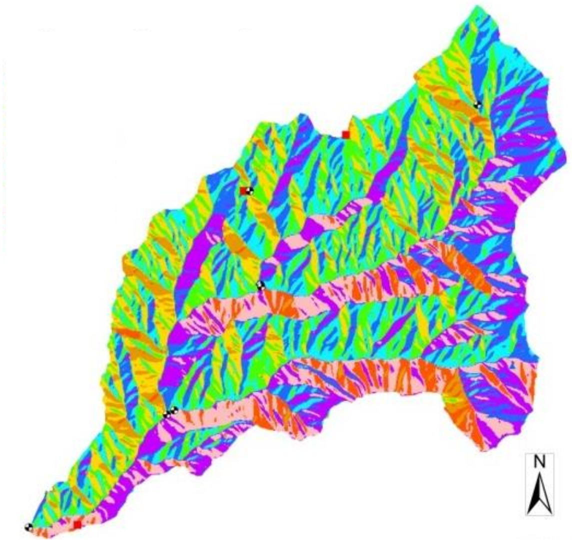
1. Initial moisture and vegetation asymmetry induces differences in drainage incision and expansion, ridgeline migration and landscape transience.

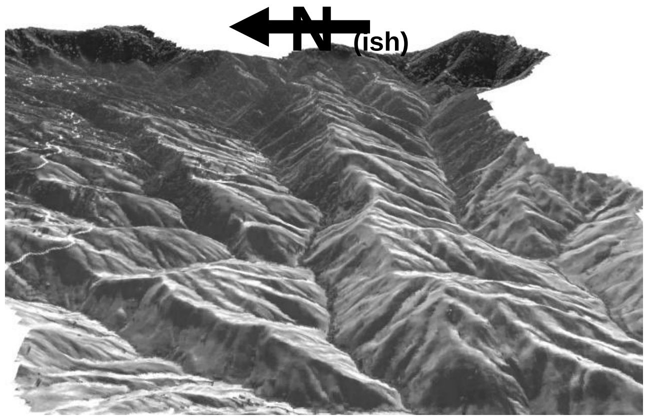
2. Erosion differences are counteracted by gradient changes, promoting ridgeline and drainage stability and equal denudation rates (i.e. a local steady state)

North Aspects…

…are steeper and shorter







Dry Creek Experimental Watershed

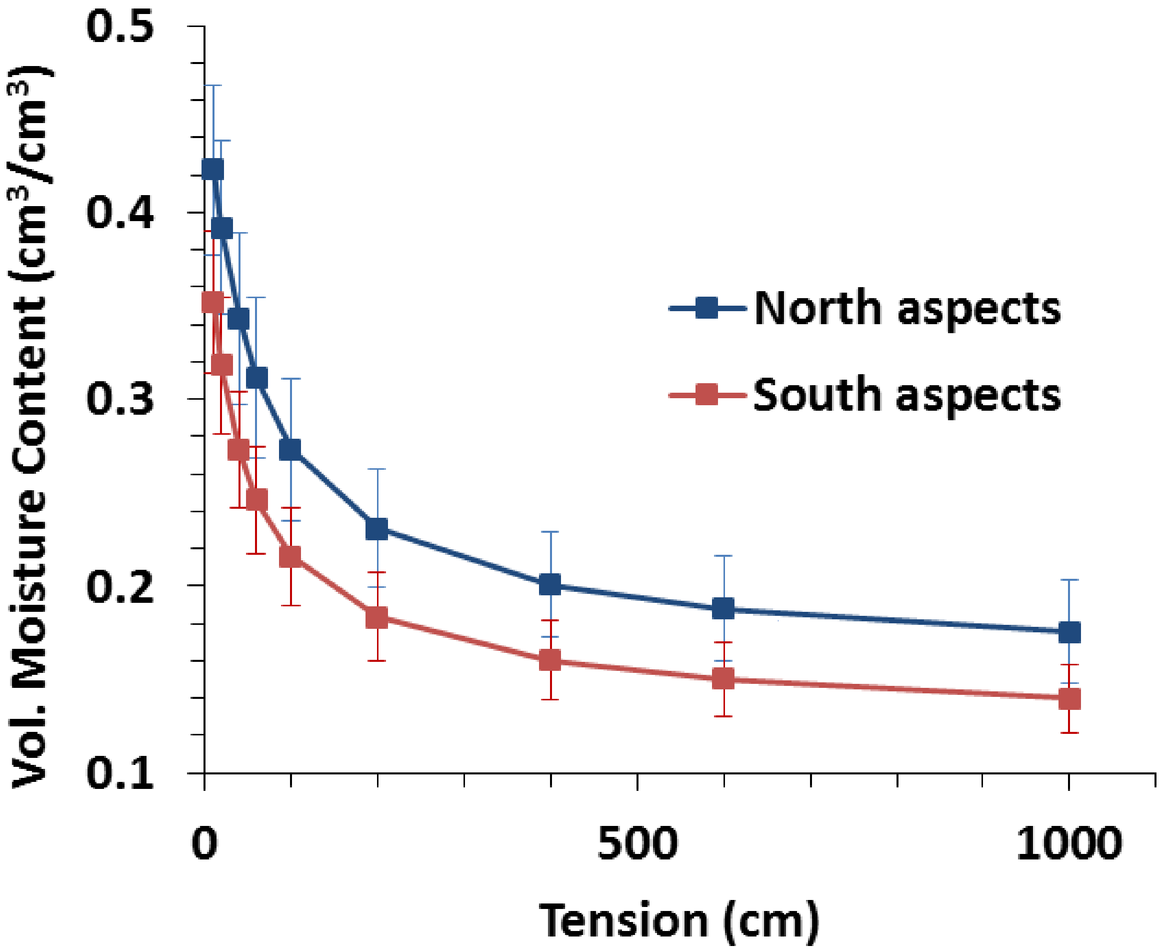
MISSION: Improve UNDERSTANDING and PREDICTION of interactions between Water, Rock, Plants, and Animals in the Past, Present and Future**.**

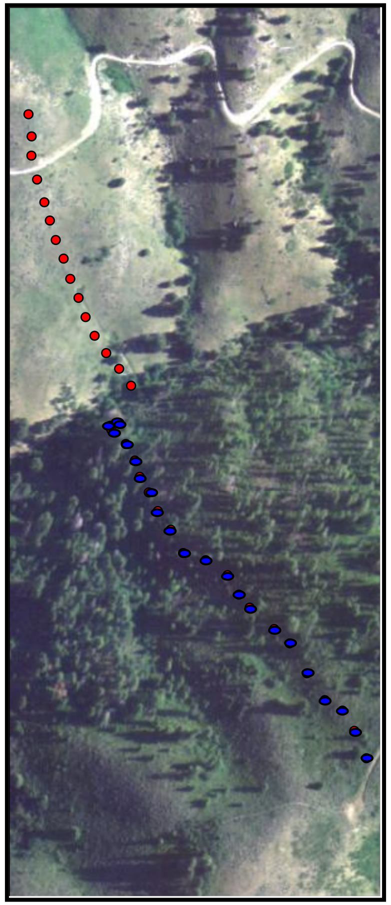
OBJECTIVE: To provide temporally continuous and spatially distributed hydrometeorological and geographical data from point to catchment scales for researchers and educators.

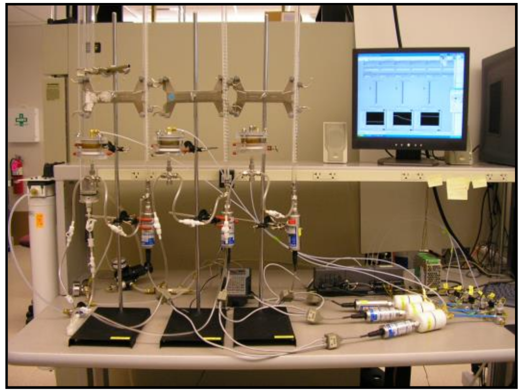
So that scientists can Think Inside the Box

North Aspects…

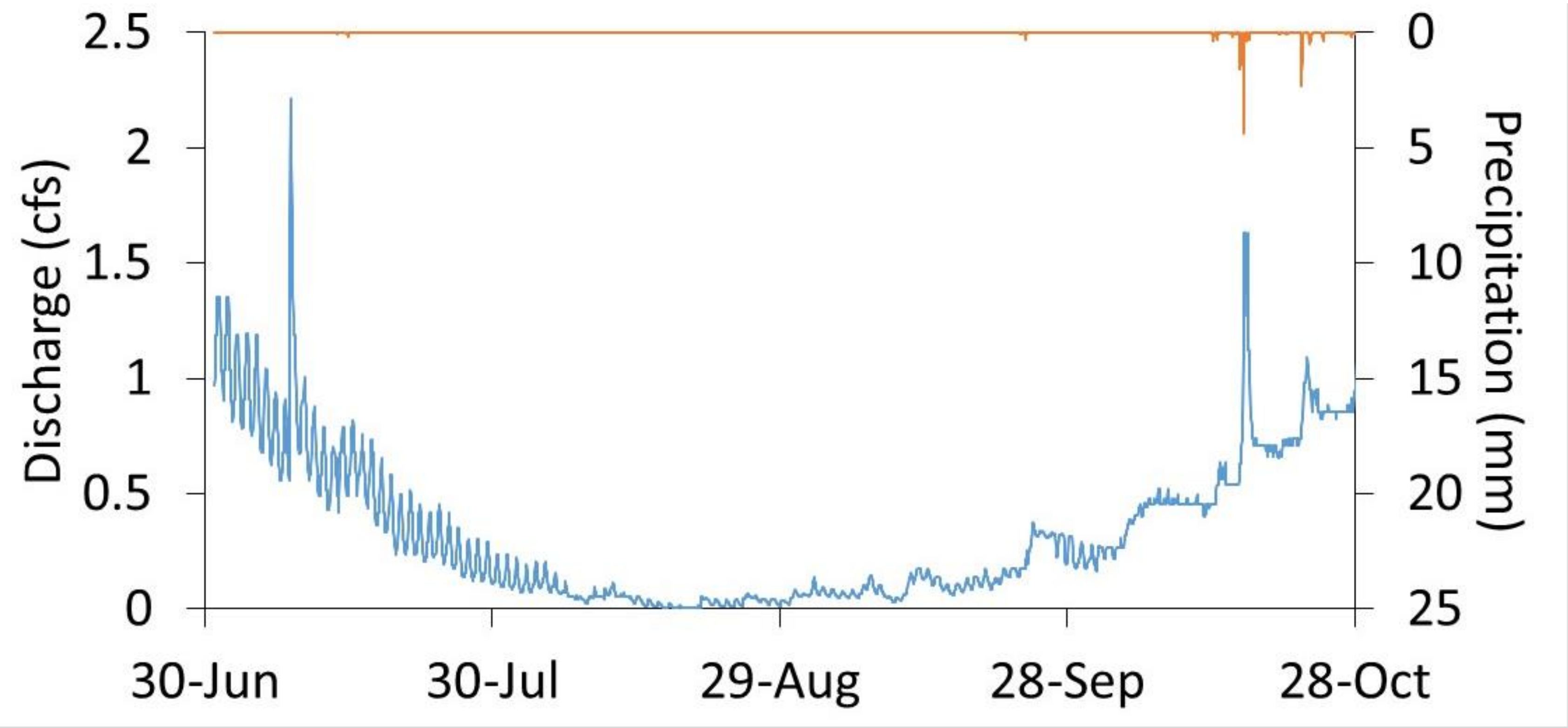
…have higher water holding capacity



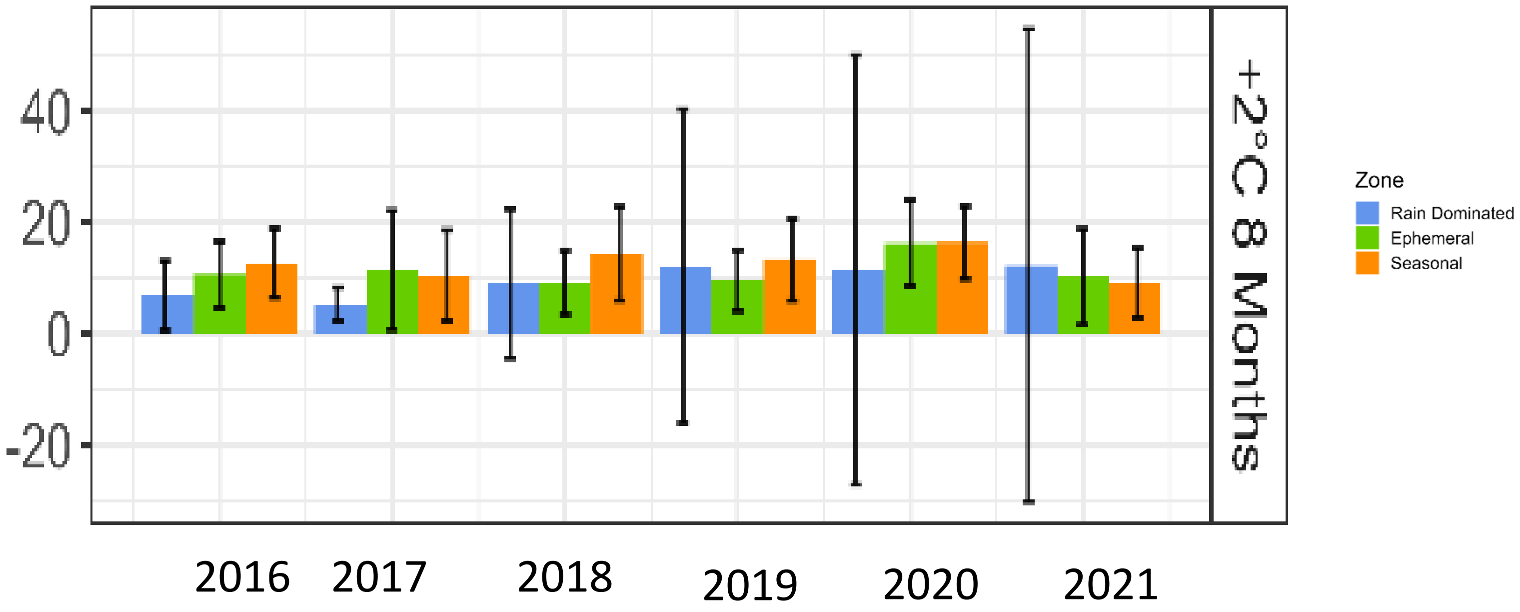




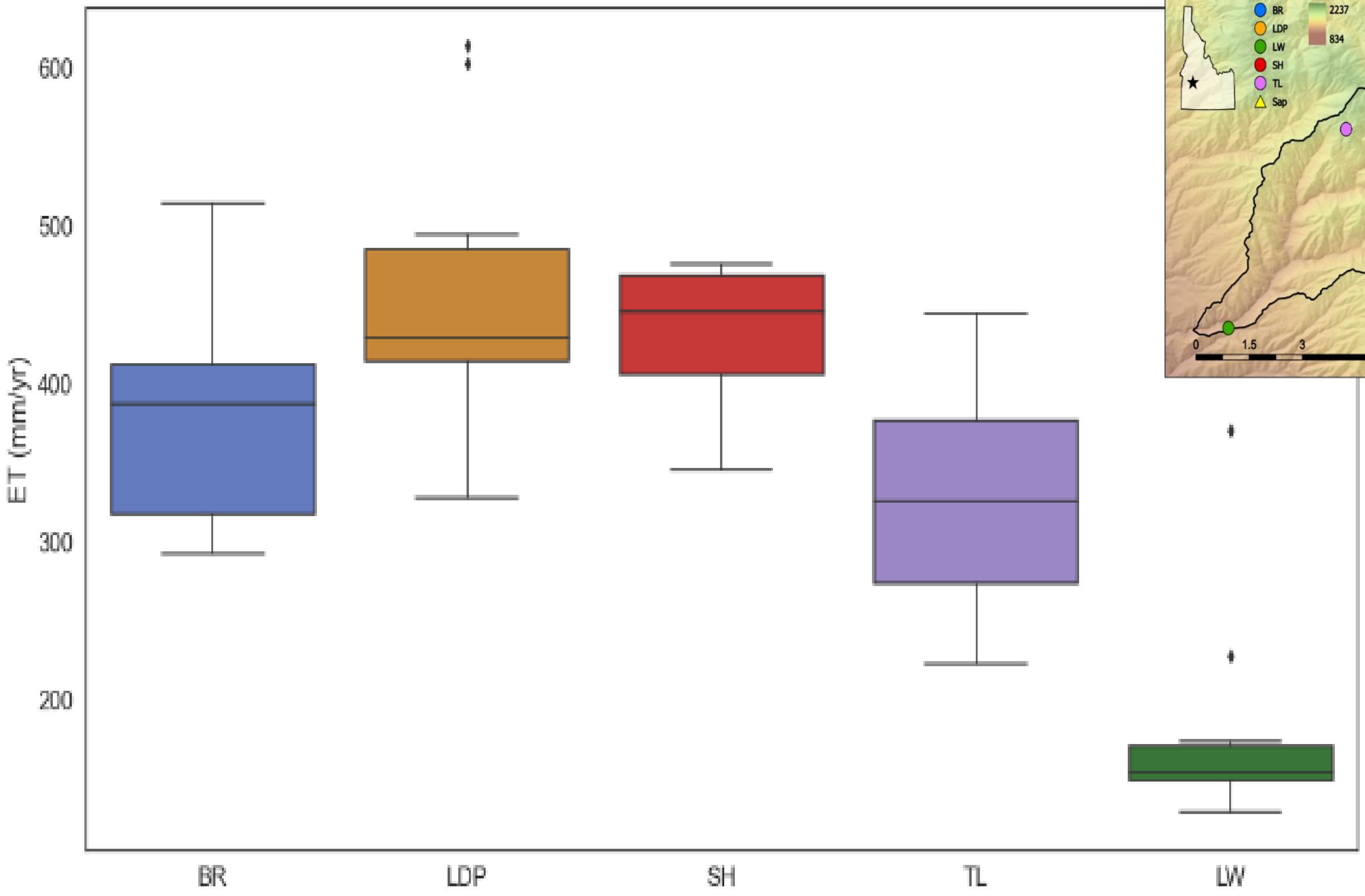
Vegetation impacts streamflow

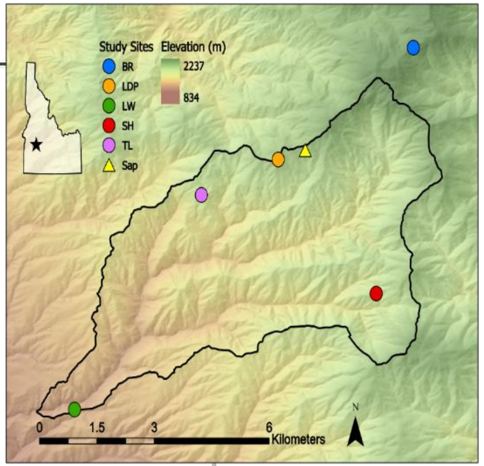


Simulated changes in each zone



Annual ET Declines with Elevation





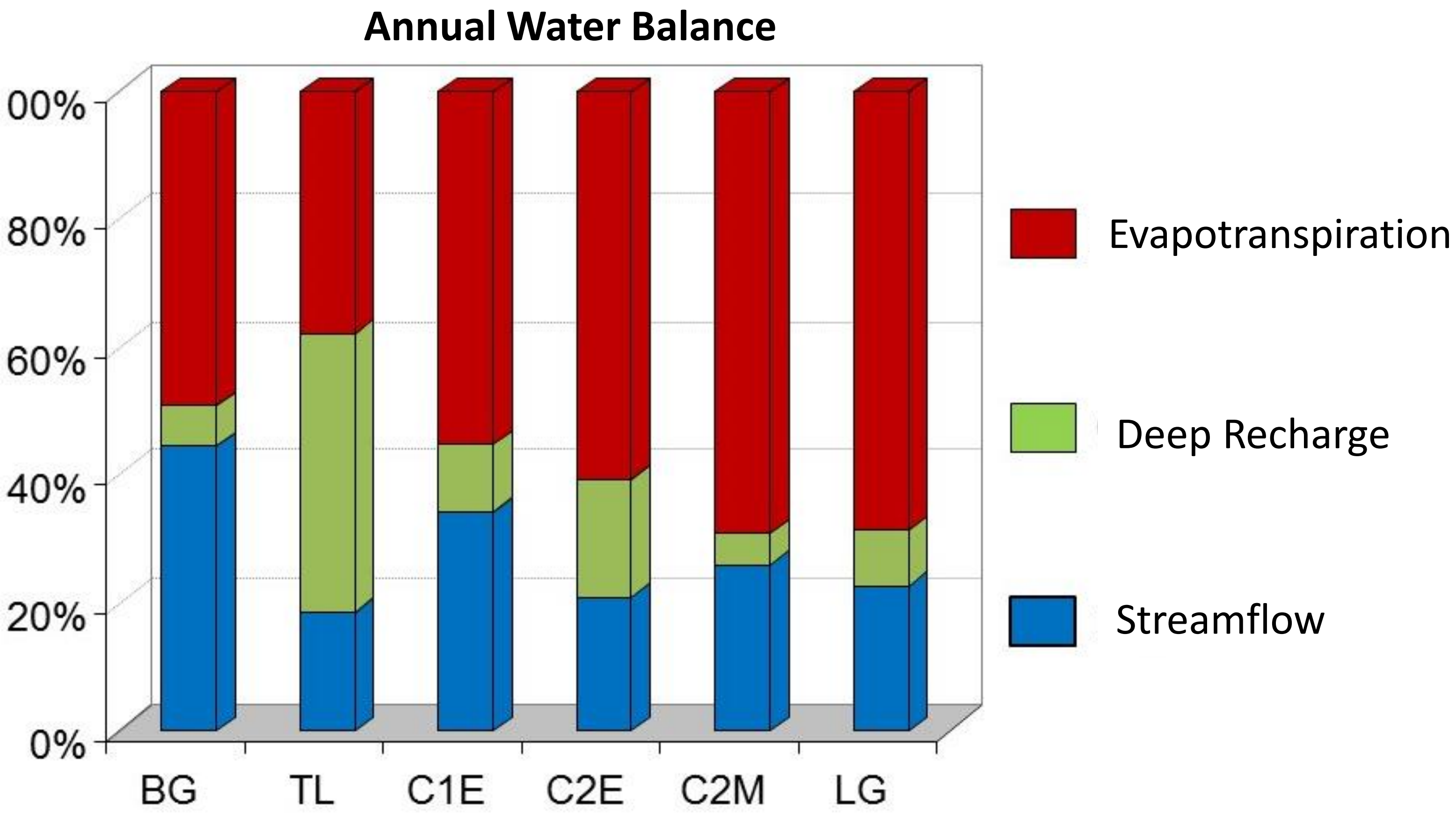
High Elevation

Low Elevation

Evapotranspiration Summer

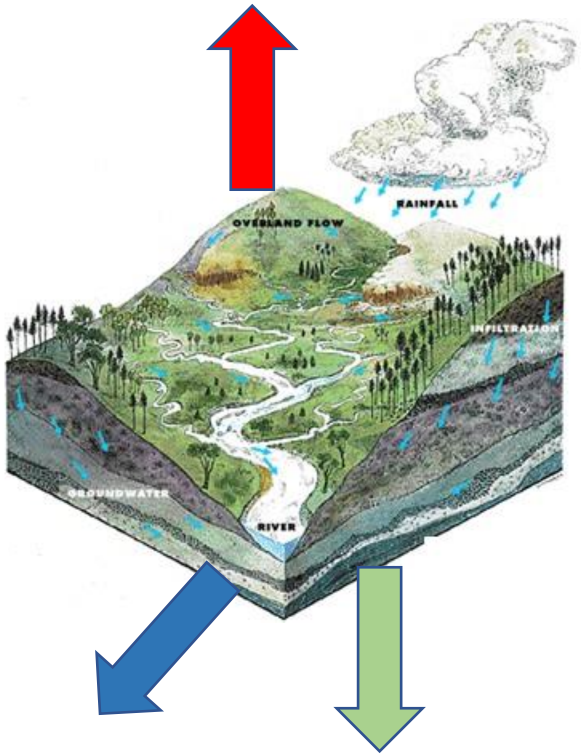
- ET is controlled by the alignment of water availability and energy demand
- ET is water limited in low elevations, **BUT wet years produce less ET due to cloudy conditions**
- ET is energy limited at higher elevations, **BUT more snow shortens growing season due to longer snow persistence in spring**
- The rain-snow transition zone is in the energy-water optimum where more precipitation AND more energy lead to increased ET

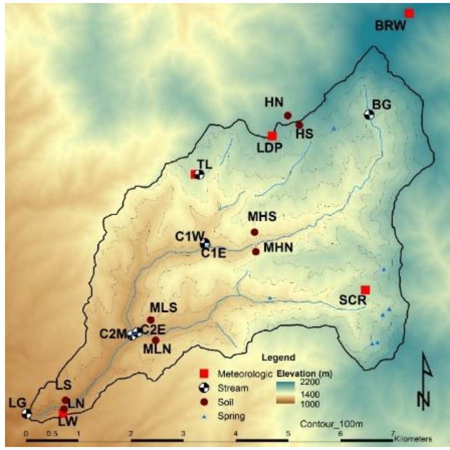
ET Dominates Exports



High elevation

Low elevation





Characteristic Soil Water Spring-Summer