# Observing the water balance in the Sierra Nevada: the Southern Sierra Critical Zone and the American River Hydrologic Observatories

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Collaborators: R Bales, UC Merced, S. Glaser,
UC Berkeley & many others

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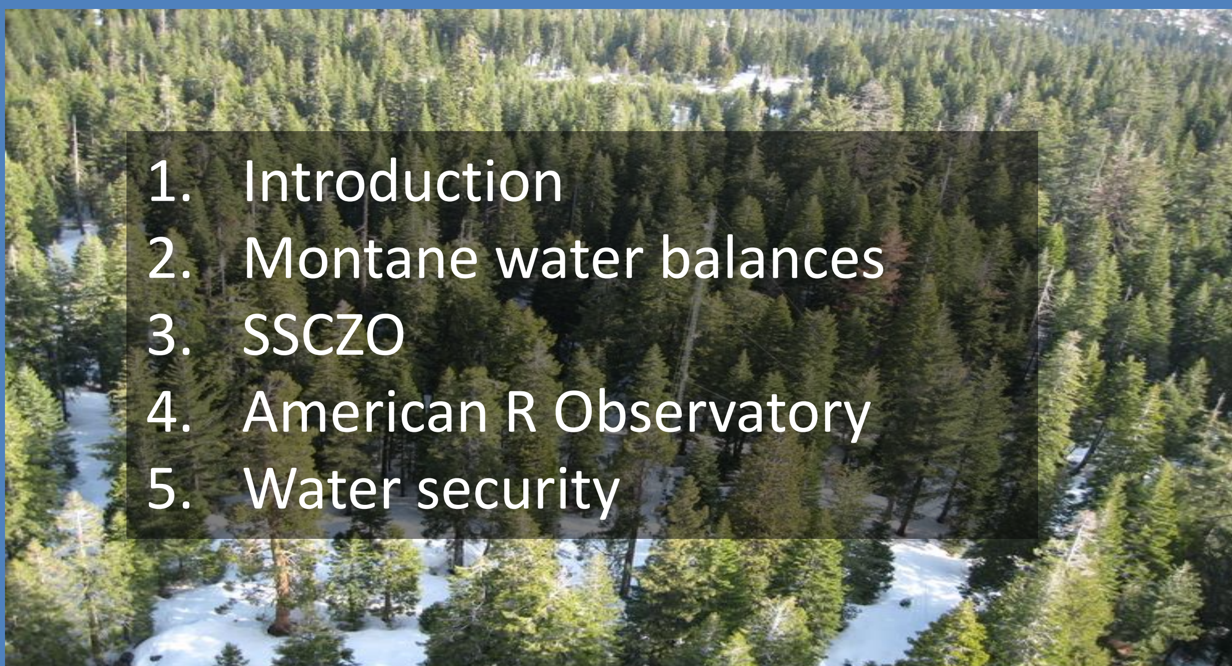


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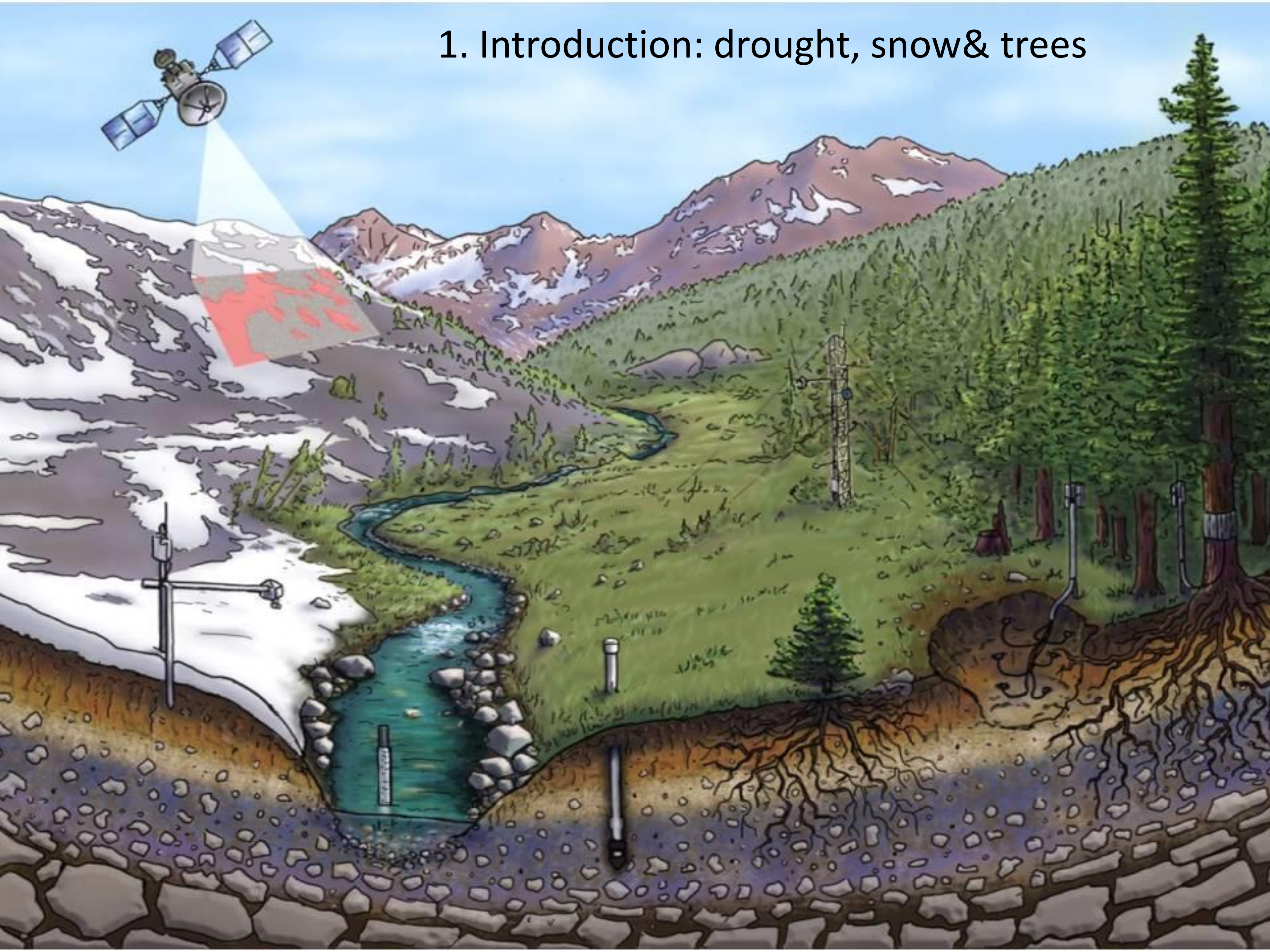
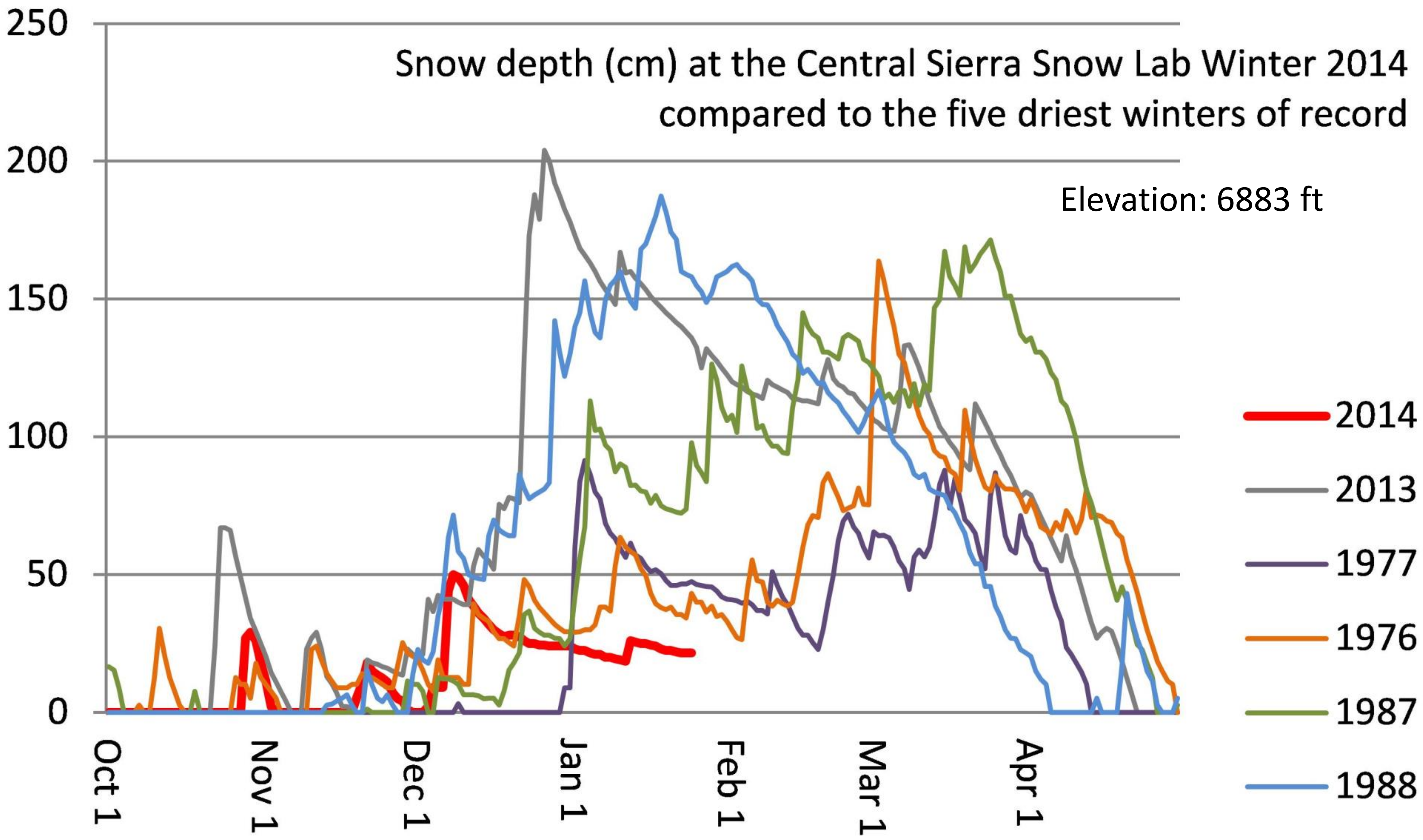
# 1. Introduction: drought, snow& trees

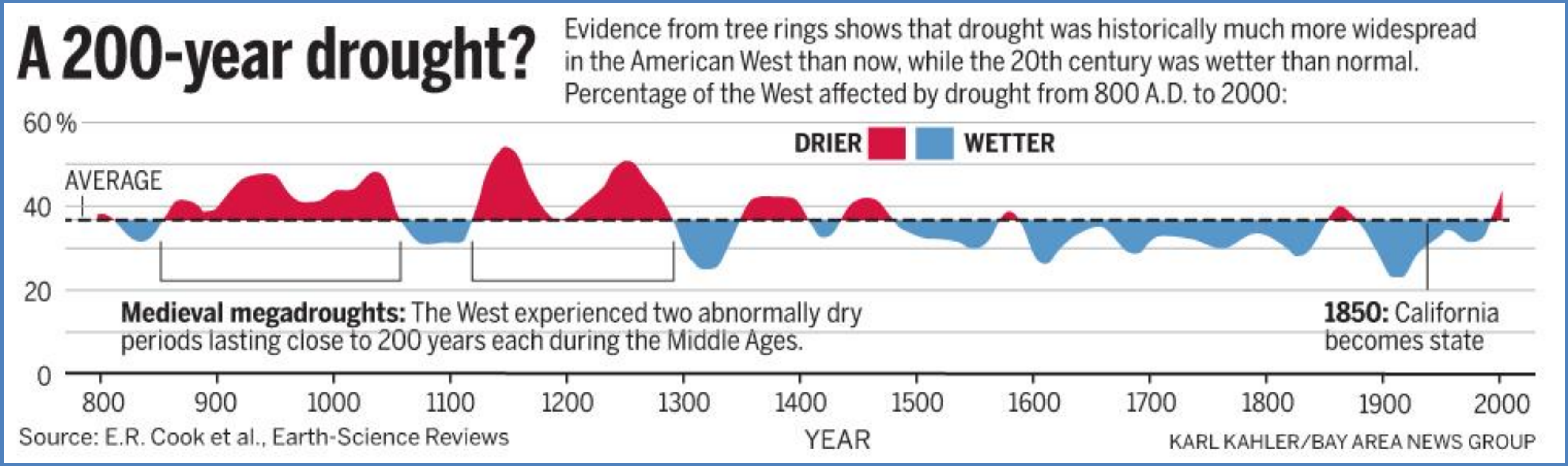


# CA snowpack…




Source: Randall Osterhuber; measurements since 1946

# The West has been drier…




Already, the 2013-14 rainfall season is shaping up to be the driest in 434 years, based on tree ring data, according to Lynn Ingram, a paleoclimatologist at UC Berkeley…

http://www.mercurynews.com/science/ci_24993601/california-drought-past-dry-periods-have-lasted-more



# Some background questions

1. How different were forests prior to fire suppression vs. today, pre-fire and post-fire?
2. Can we take forests back to pre-fire-suppression conditions?

E. Branch, N. Fork Feather R., 3400’

*Photos from G. Gruell*

Forests and Water in the Sierra Nevada: Sierra Nevada Watershed Ecosystem Enhancement Project

Roger C. Bales, John J. Battles, Yihsu Chen, Martha H. Conklin, Eric Holst, Kevin L. O'Hara, Philip Saksa, William Stewart

November 7, 2011

Sierra Nevada Research Institute, UC Merced
Center for Forestry, UC Berkeley
Environmental Defense Fund

# Scoping report

Three issues

1. Water use by vegetation

   Runoff = Precipitation – Evapotranspiration – Interception

2. Interception losses

3. Timing of snowmelt & runoff

# Trees & snow

Trees block low-angle winter sun, retarding snowmelt …

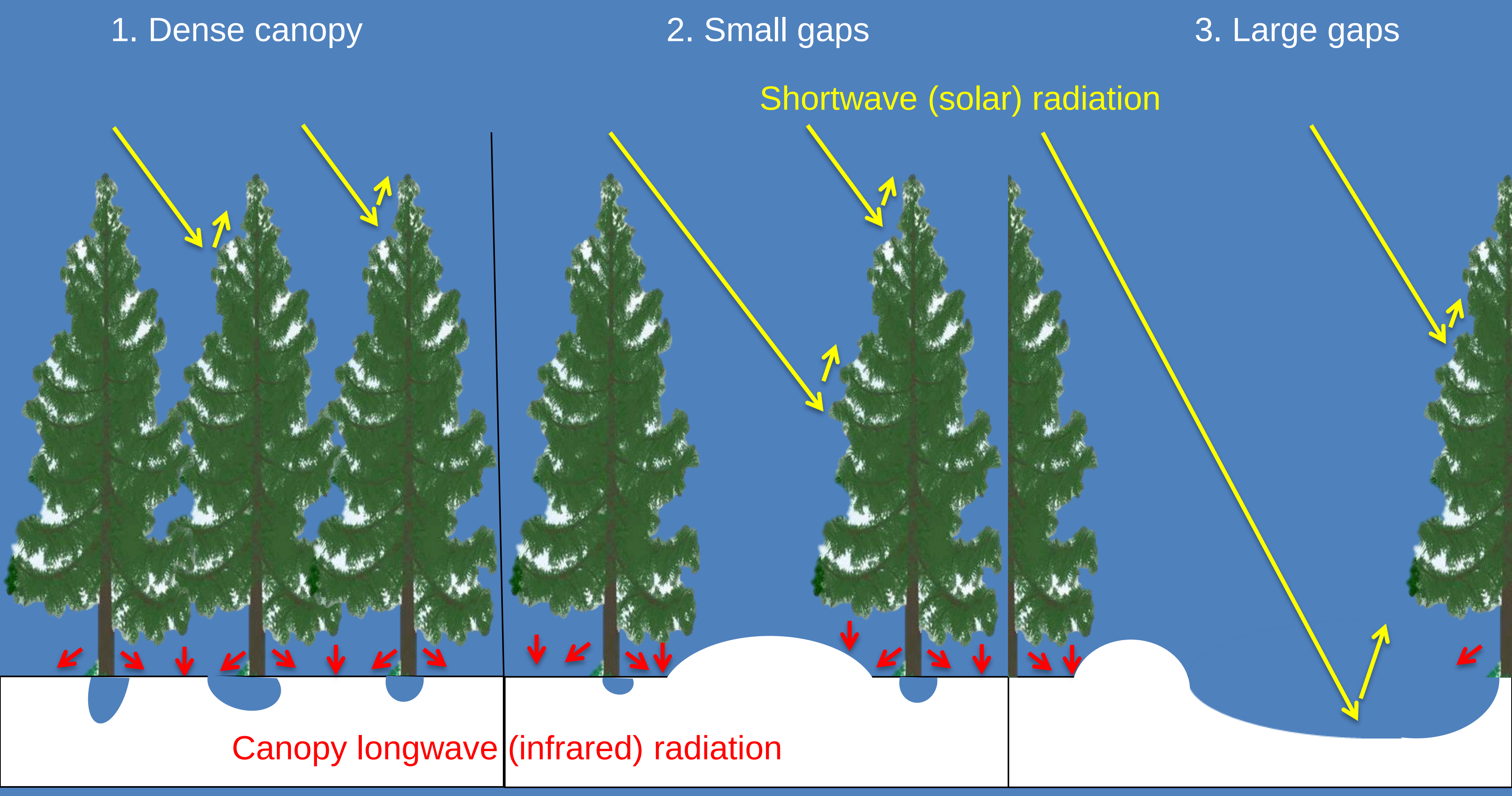
… but intercept snowfall, some of which sublimates (< 20%) …

… and emit longwave radiation that melts snow …

… resulting in tree wells

# How much snow gets to the ground & how fast does it melt?

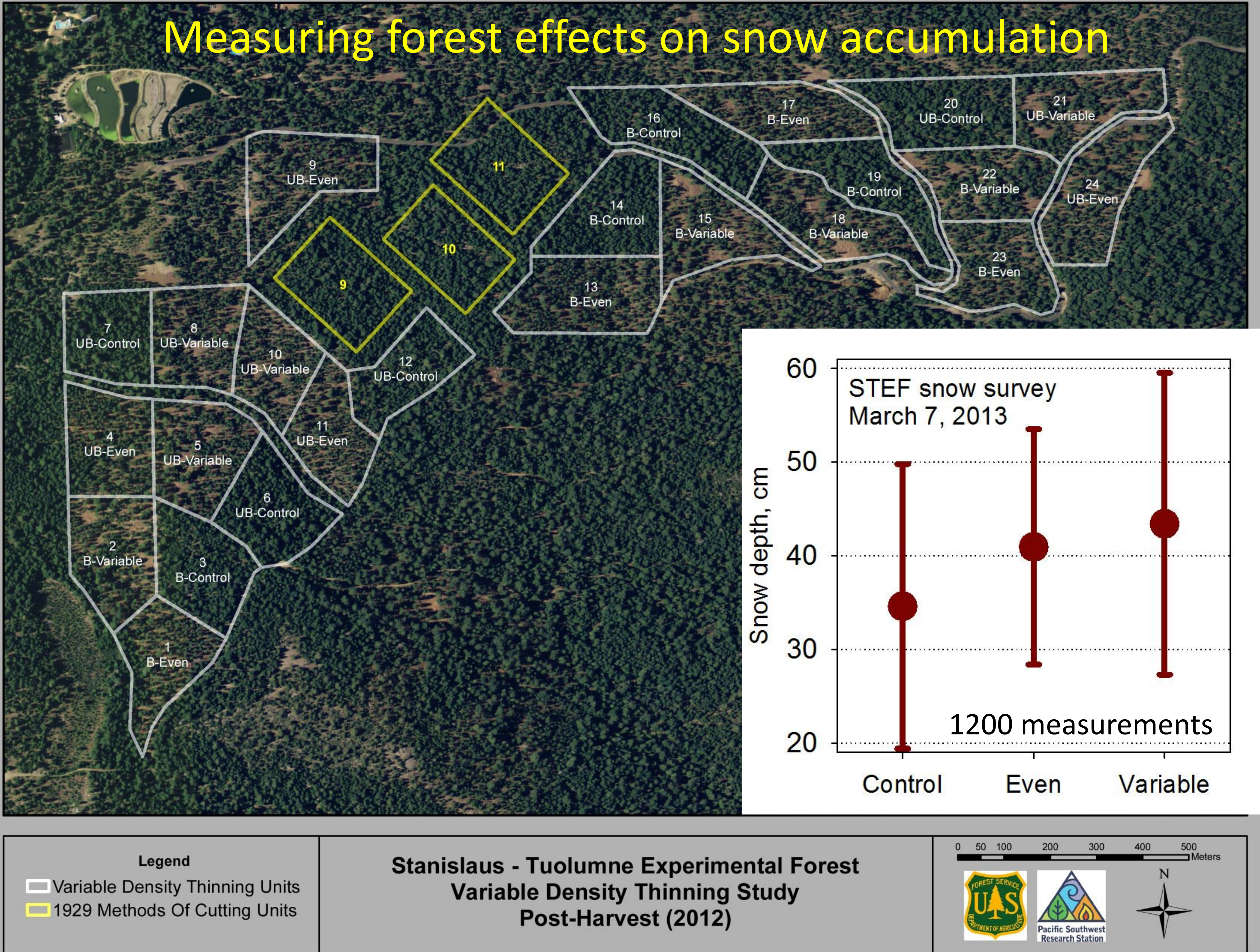
## 3 scenarios for solar & infrared radiation




| 1. Dense canopy | 2. Small gaps | 3. Large gaps |
|---|---|---|
| Lowest shortwave<br>High longwave | Low shortwave<br>Low longwave | High shortwave<br>Lower longwave |

# Thinned unit w/ control in background

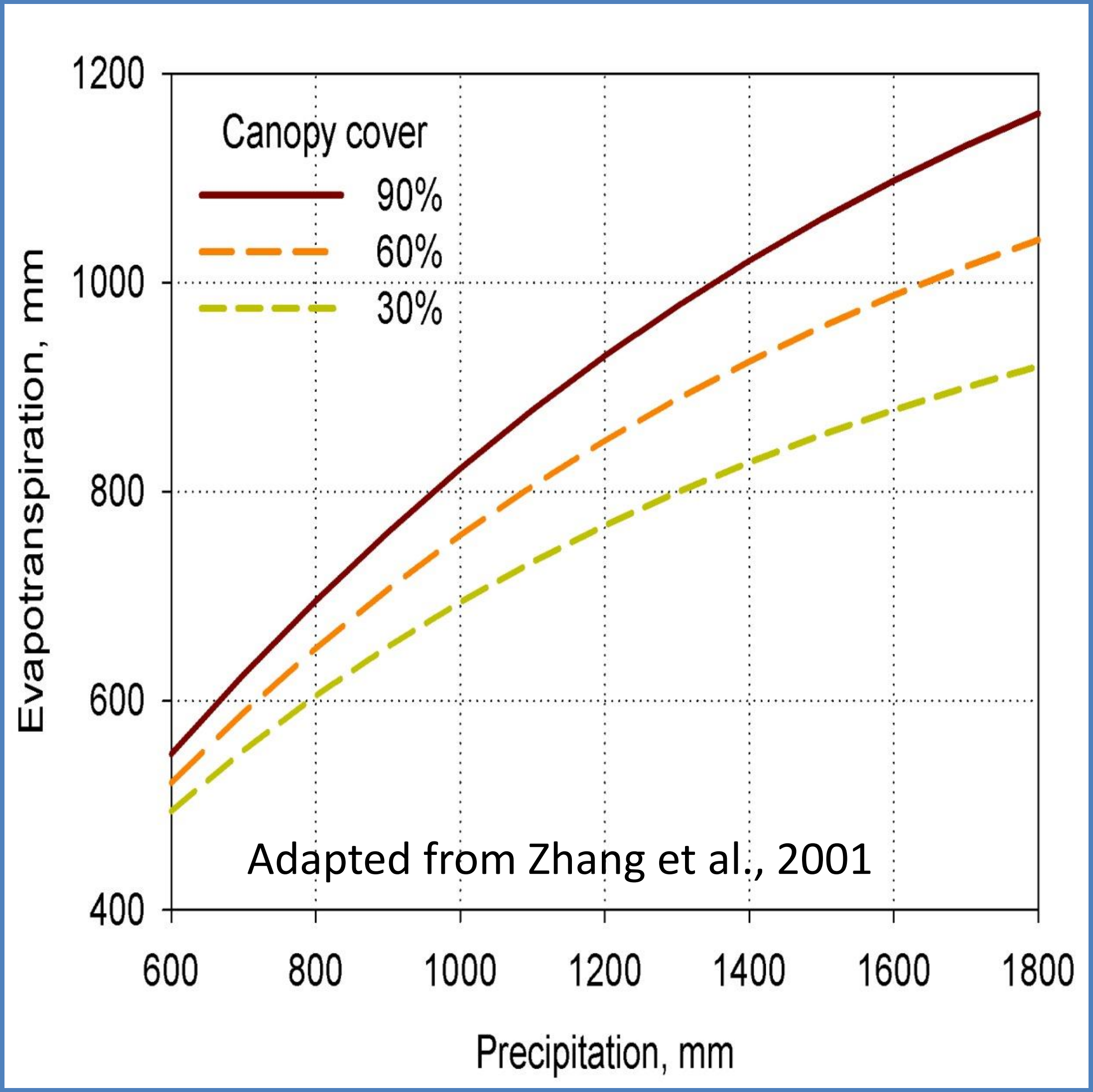
# Measuring forest effects on snow accumulation




**Stanislaus - Tuolumne Experimental Forest**
**Variable Density Thinning Study**
**Post-Harvest (2012)**

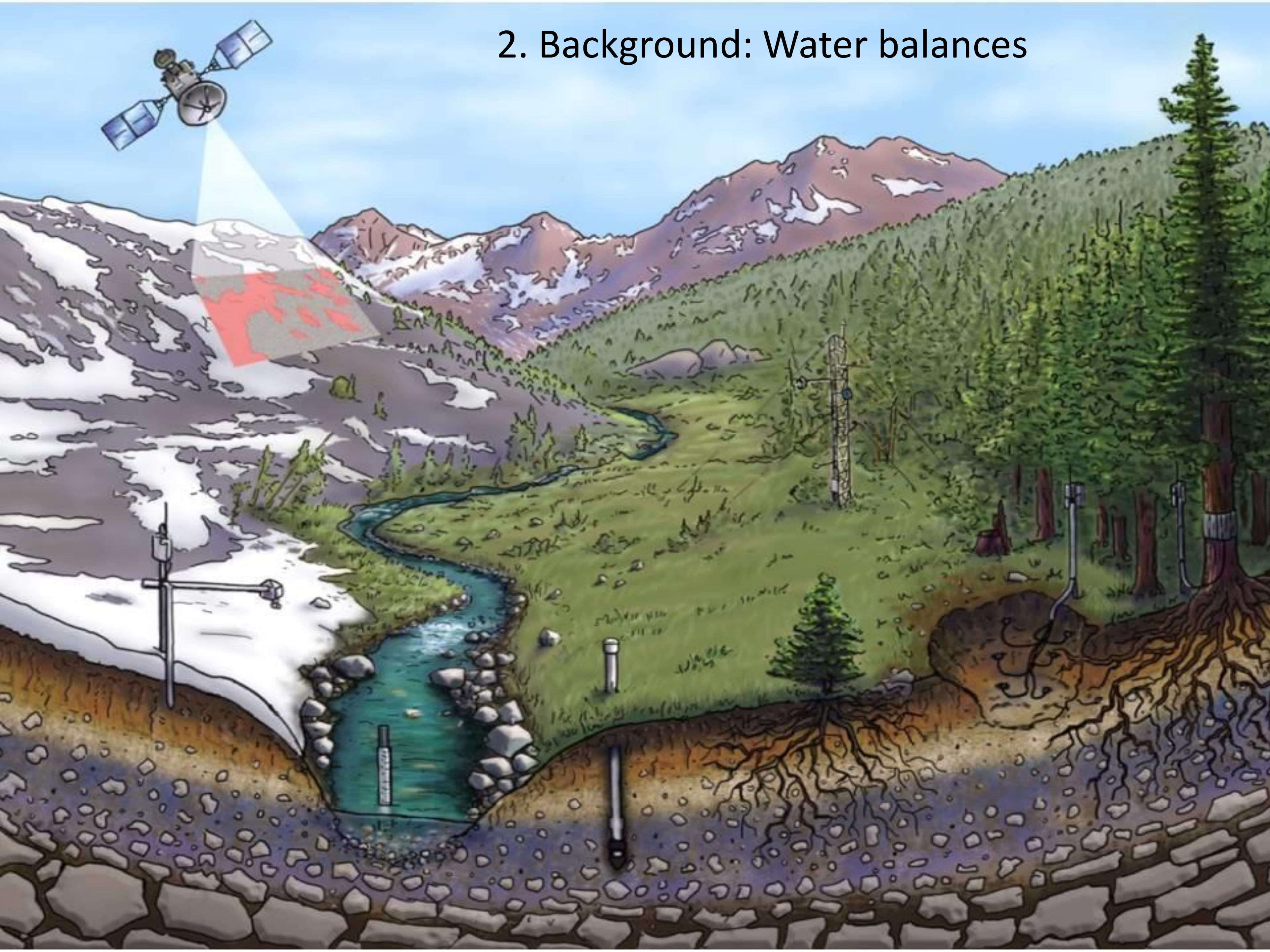
Pacific Southwest Research Station

# Vegetation water use: summary from literature



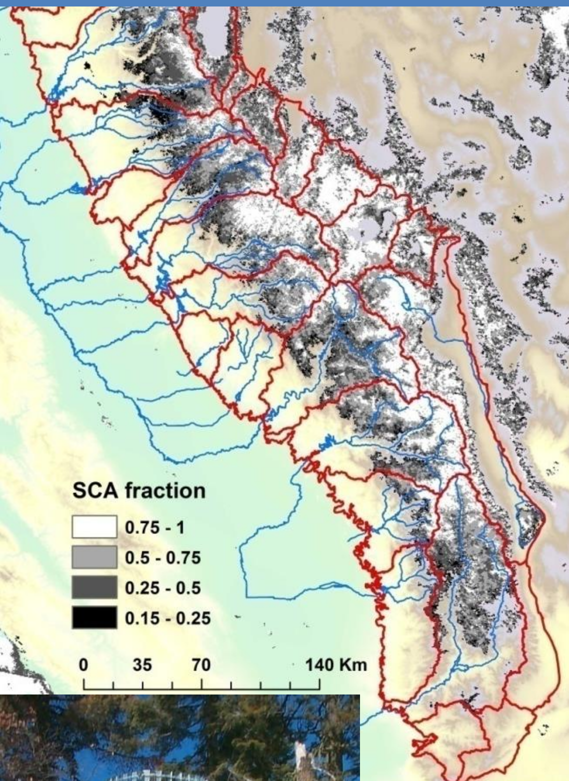

- Reducing forest cover by 40% of maximum levels across a watershed could increase water yields by about 9%
- Sustained, extensive treatments in dense Sierra Nevada forests could increase water yield by up to 16%
- These estimates are based on very limited data

# 2. Background: Water balances



# Basic montane water balance

Precipitation = Evapotranspiration + Runoff

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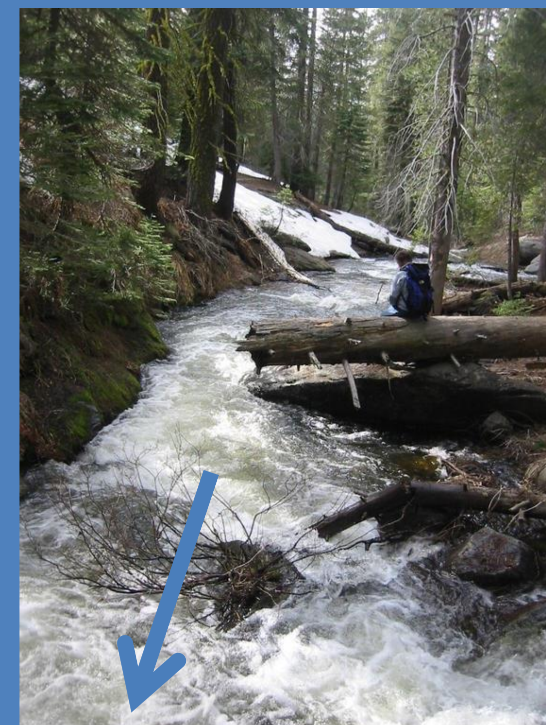
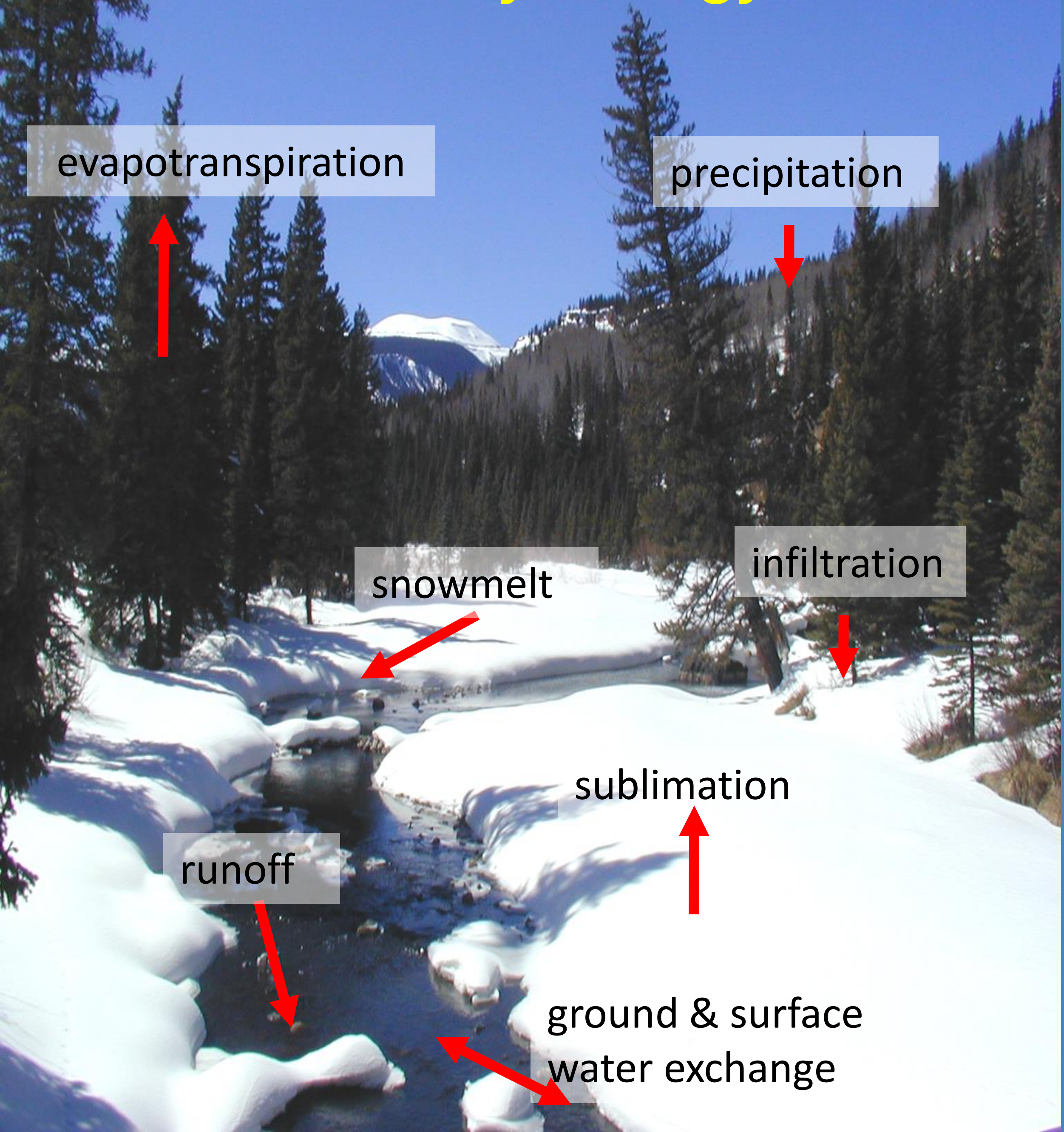


Groundwater recharge, mountain block vs. mountain front?

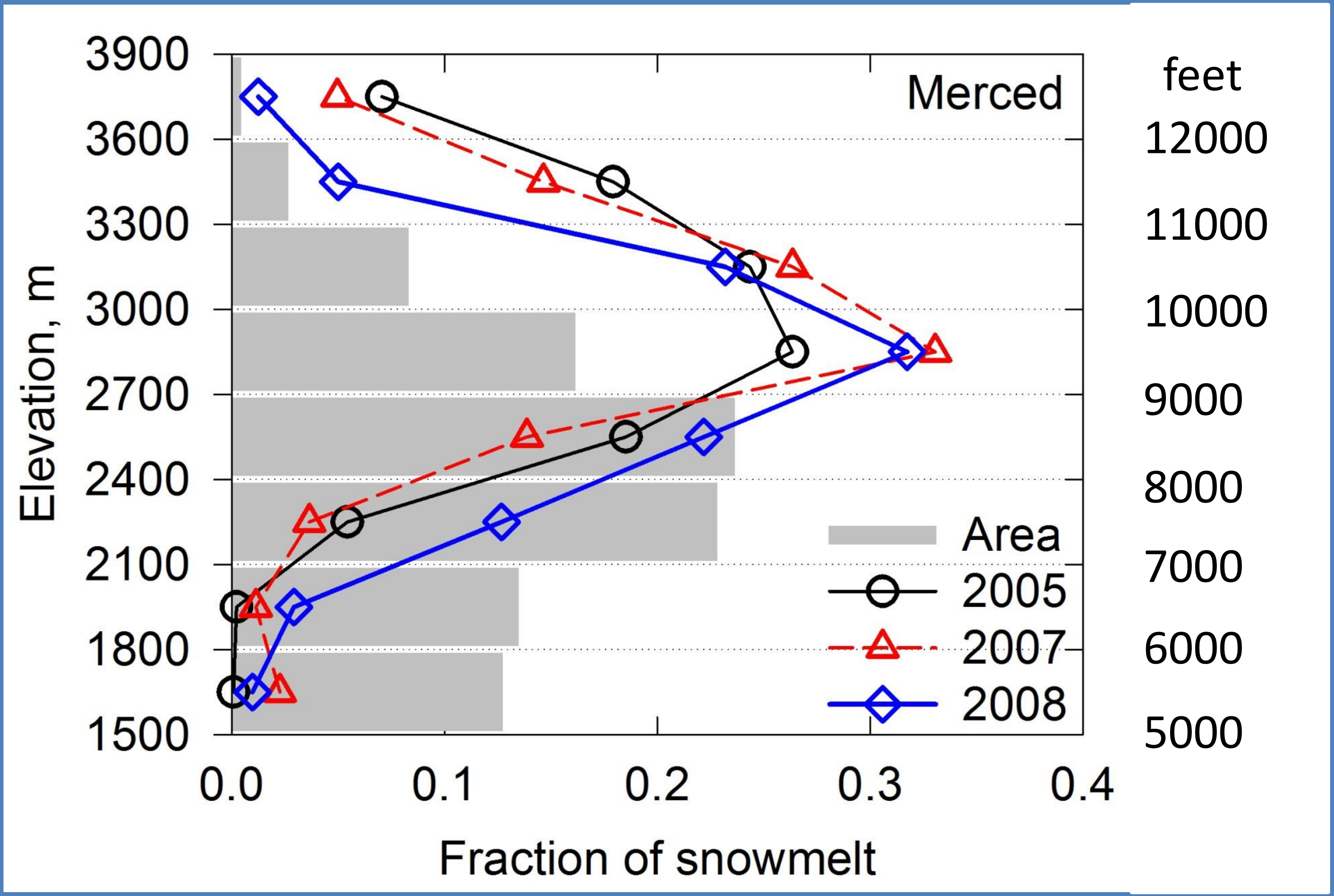
# Mountain hydrology – fluxes




How will this landscape & the hydrologic processes connecting it alter w/ climate warming & landcover change?

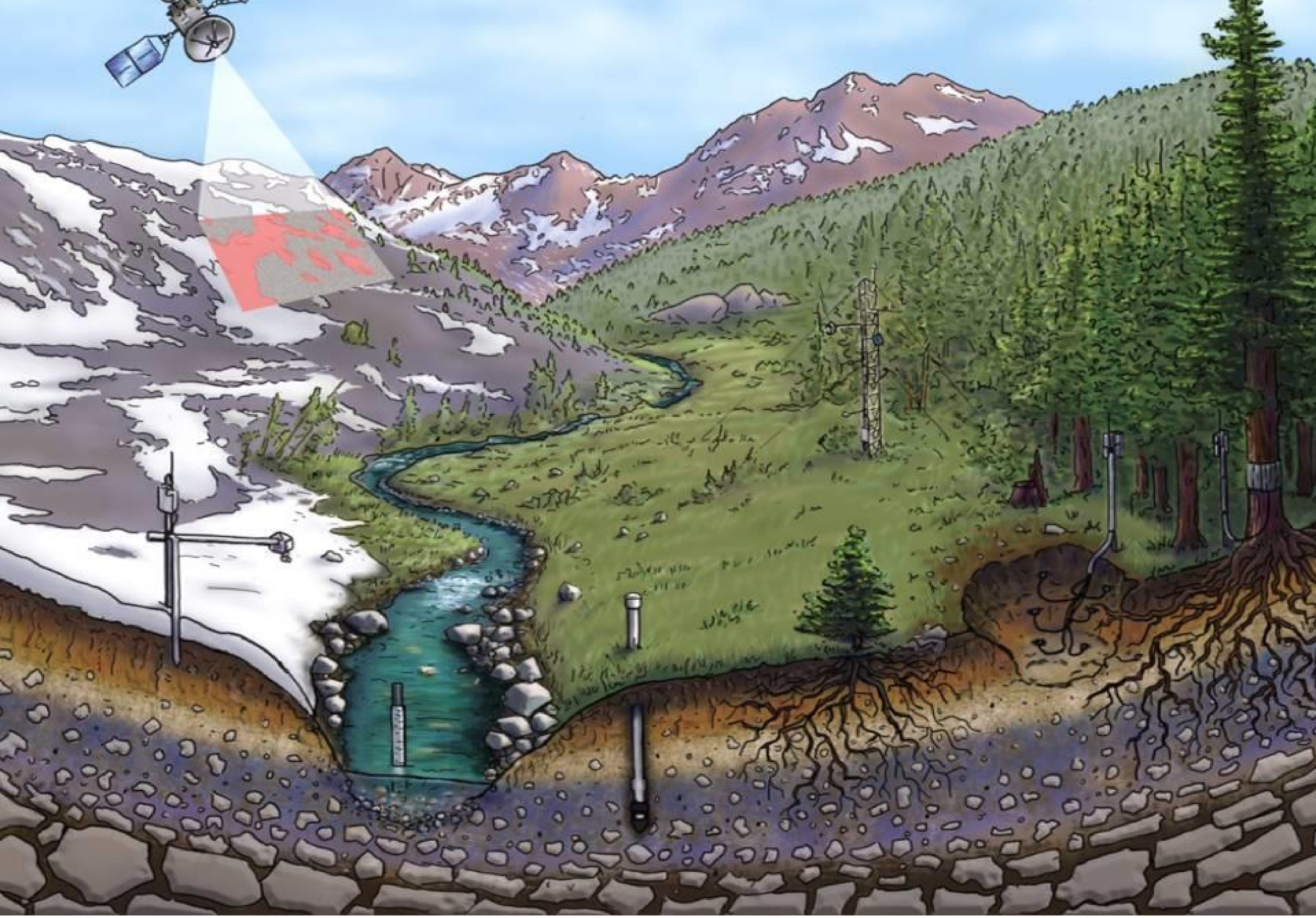
**Reservoirs:**
Snowpack storage
Soil-water storage

# What elevations provide the most snowmelt?

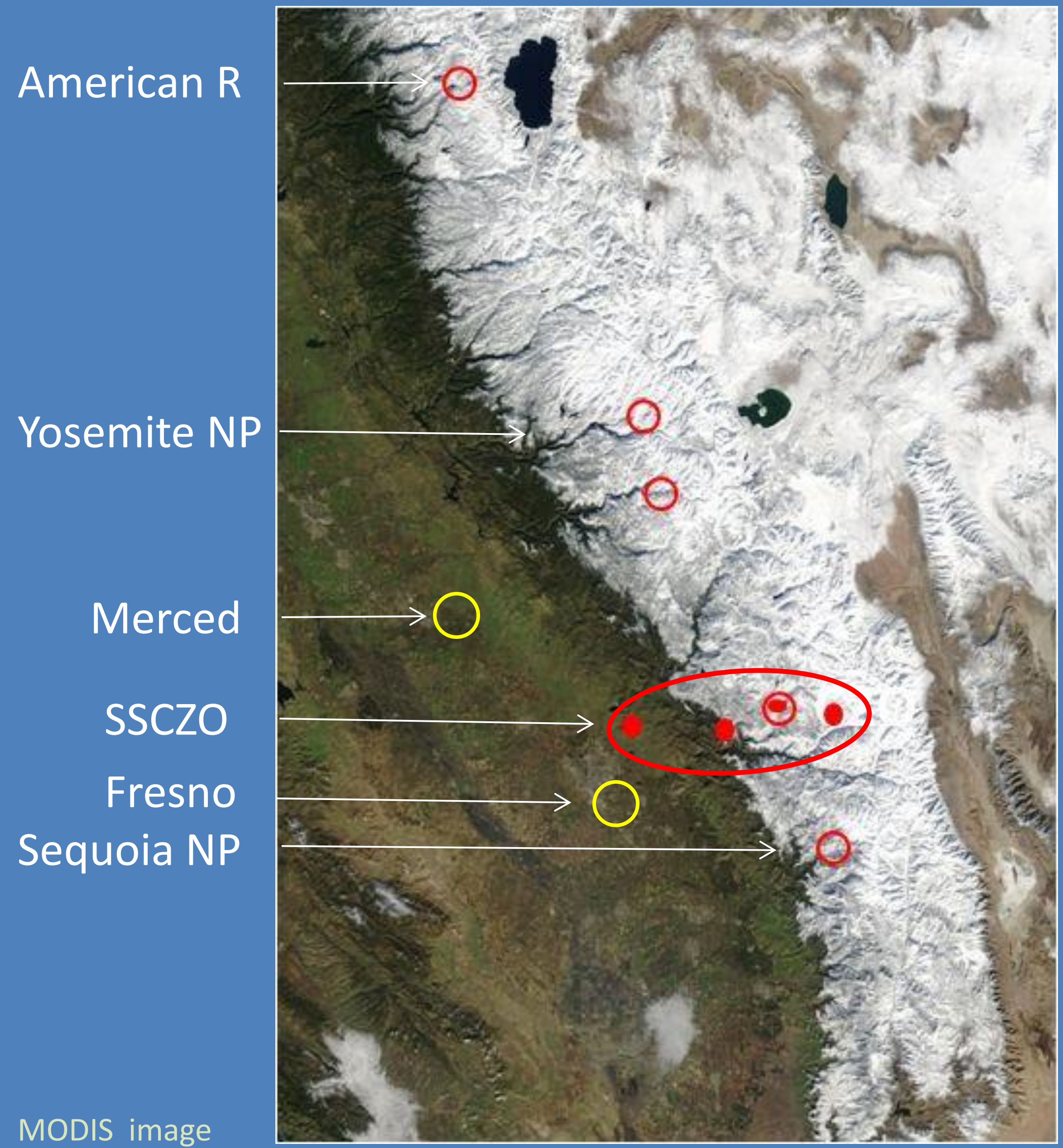



Based on SNRI research

# 2. Southern Sierra Critical Zone Observatory



# SSCZO site location, gradients & infrastructure




4 instrumented sites along steep climate gradient: 12°C, 60 km

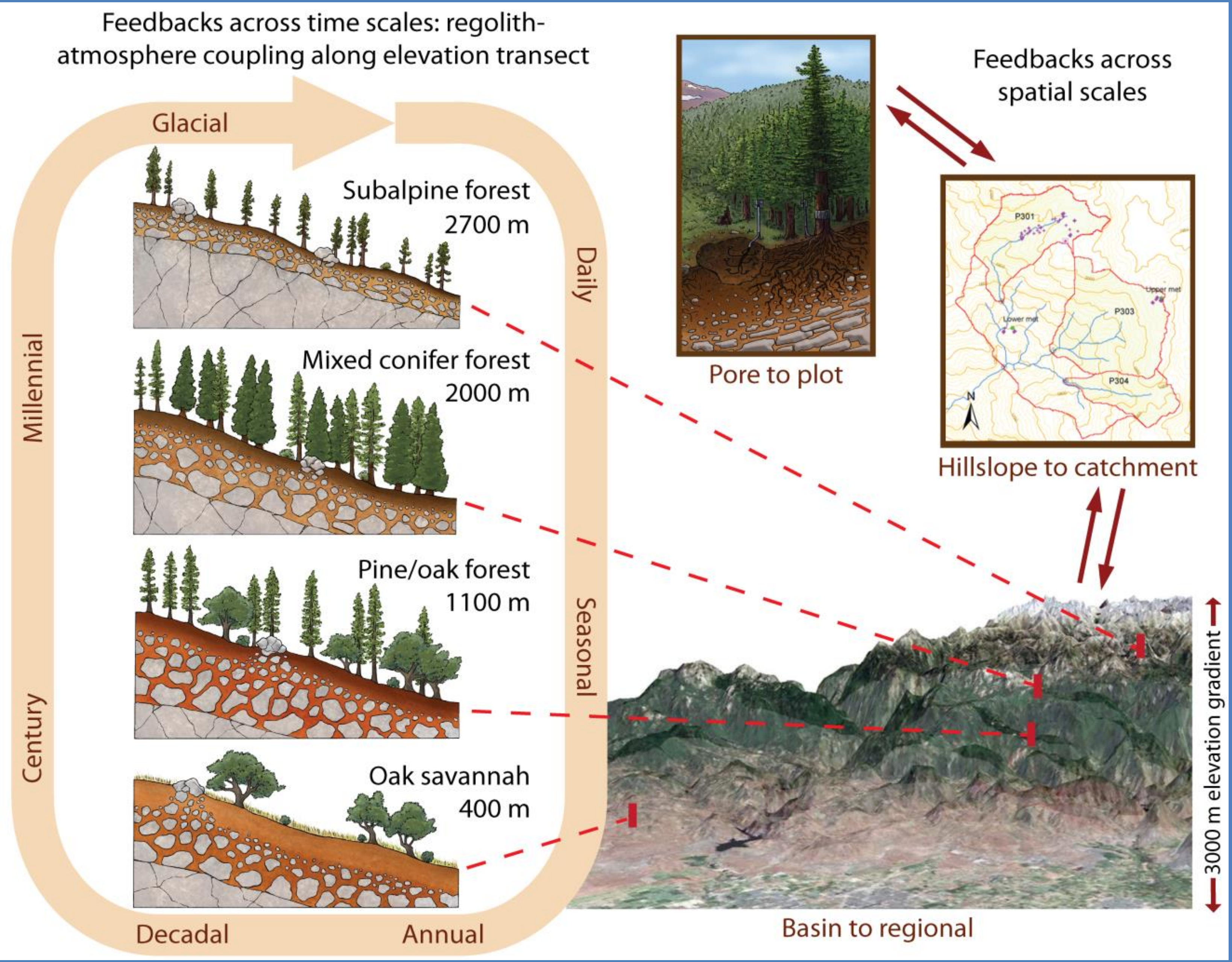
Co-located w/ USFS watershed research site: 8 headwater catchments ~ 100 ha each

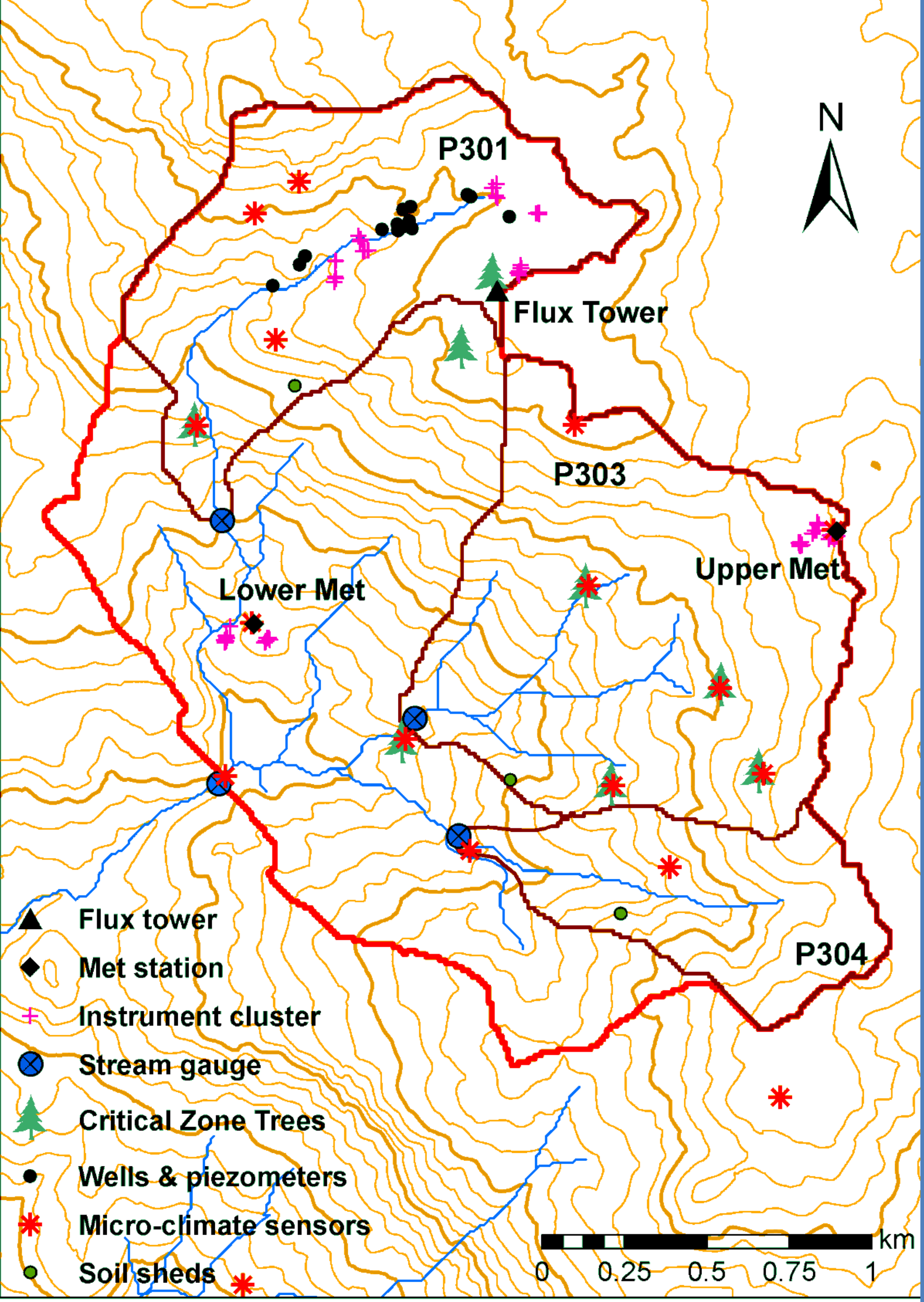
Lower SSCZO site proposed for NEON core

Winter access to upper sites over snow

Field work & bunk space

# SSCZO conceptual model



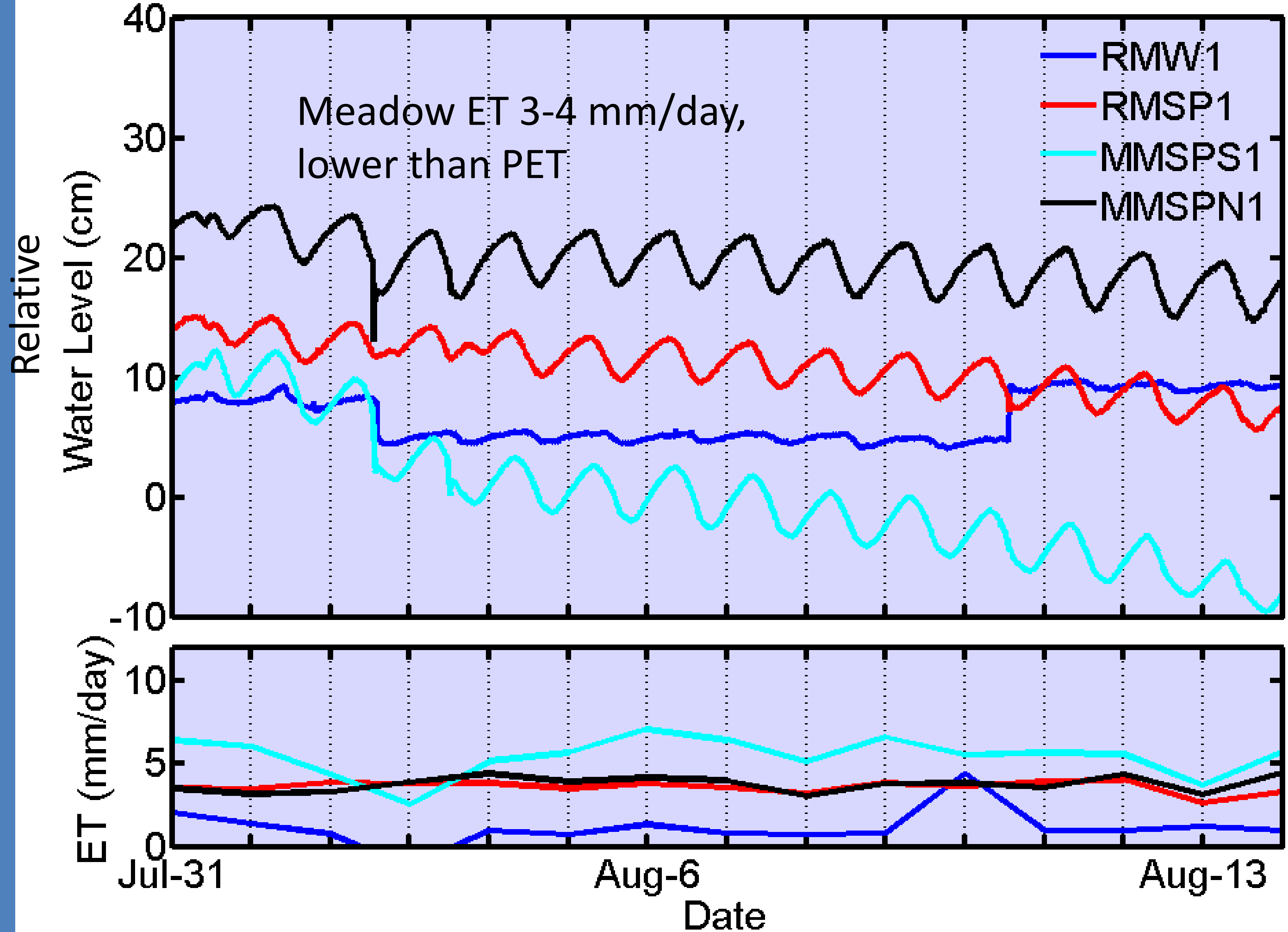



# Providence Ck (2000 m) – instrumentation

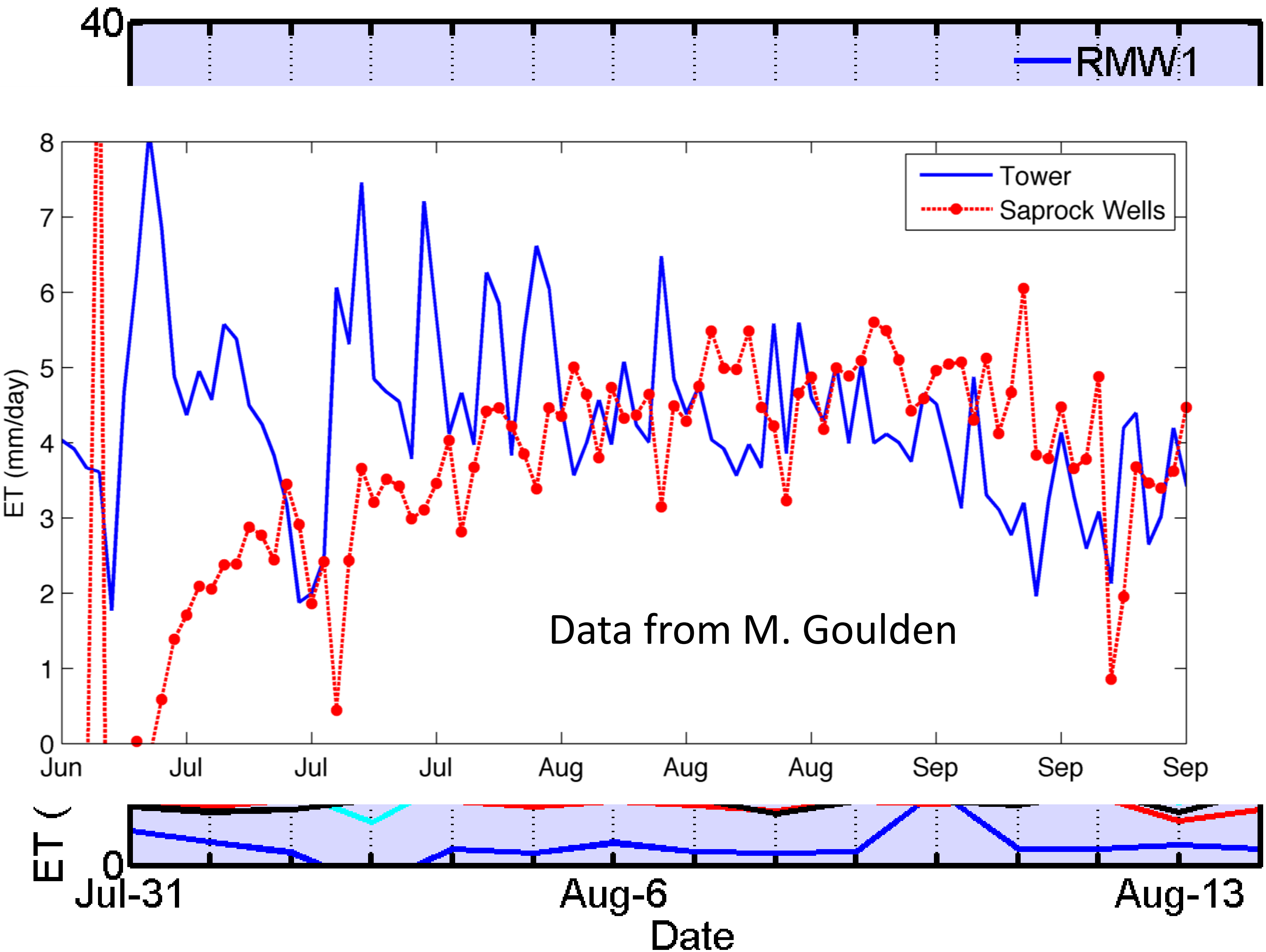
- 3 headwater catchments w/ stream gauges & water-quality measurements
- 2 met stations
- 60-m tall flux tower
- 60-node wireless embedded sensor network
- 214 EC-TM sensors for volumetric water content
- 113 MPS sensors for matric potential
- 57 snow-depth sensors
- Meadow piezometers & wells
- Sap-flow sensors

# Meadow piezometers & wells

- Chemical composition
- Levels & pressure

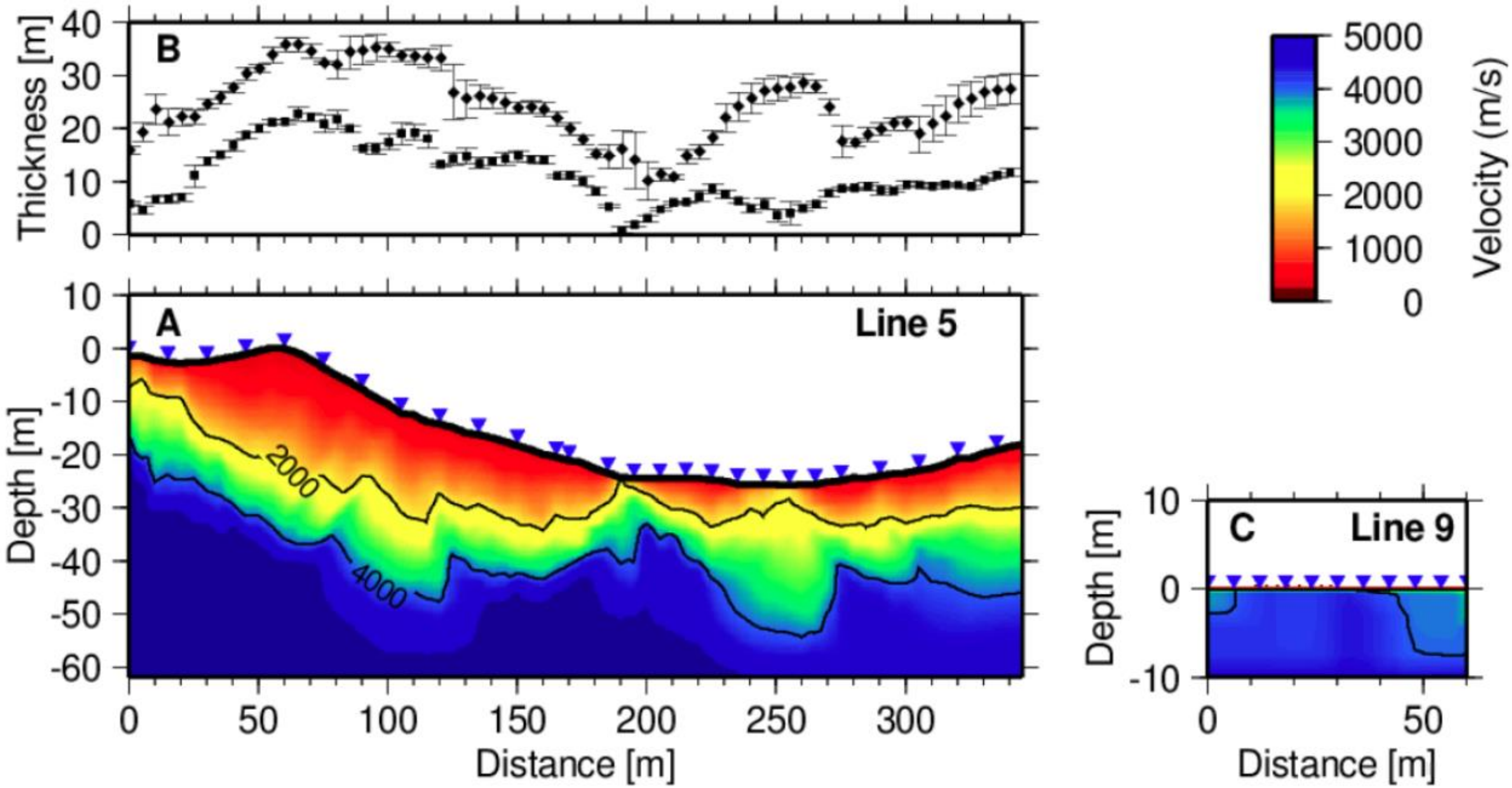


Meadow ET 3-4 mm/day,
lower than PET
RMW1
RMSP1
MMSPS1
MMSPN1
Relative
Water Level (cm)
40
30
20
10
0
-10
ET (mm/day)
10
5
0
Jul-31
Aug-6
Aug-13
Date


40
RMW1
Tower
Saprock Wells
ET (mm/day)
8
7
6
5
4
3
2
1
0
Jun
Jul
Jul
Jul
Aug
Aug
Aug
Sep
Sep
Sep
Data from M. Goulden
ET (
0
Jul-31
Aug-6
Aug-13
Date

# Drilling, deeper wells, additional geophysics in progress

# Seismic survey results at Providence




**Regolith thickness from a seismic survey at the Southern Sierra CZO. Upper panel shows thickness to the 2000 and 5000 m/s velocity profile (Holbrook et al. 2013).**

# Water balance on regolith

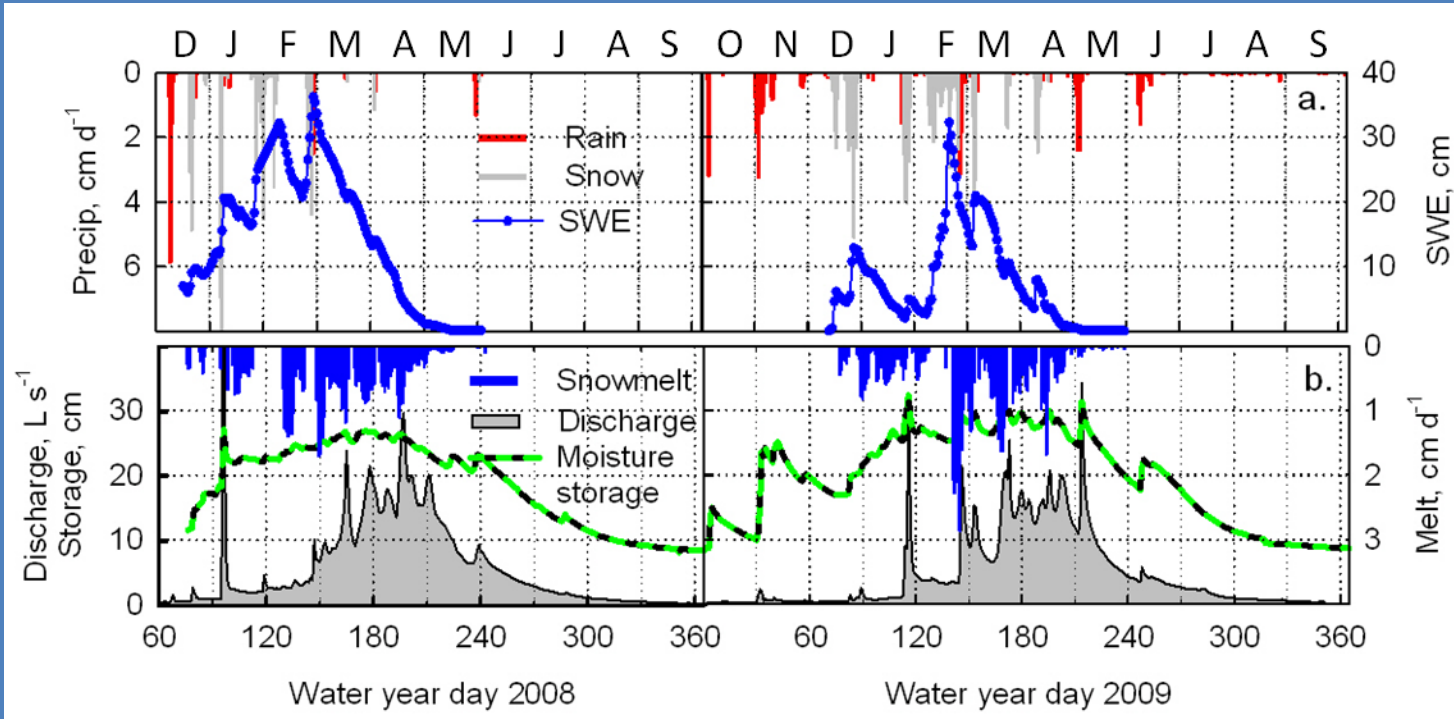
Change in storage

shallow

Deep

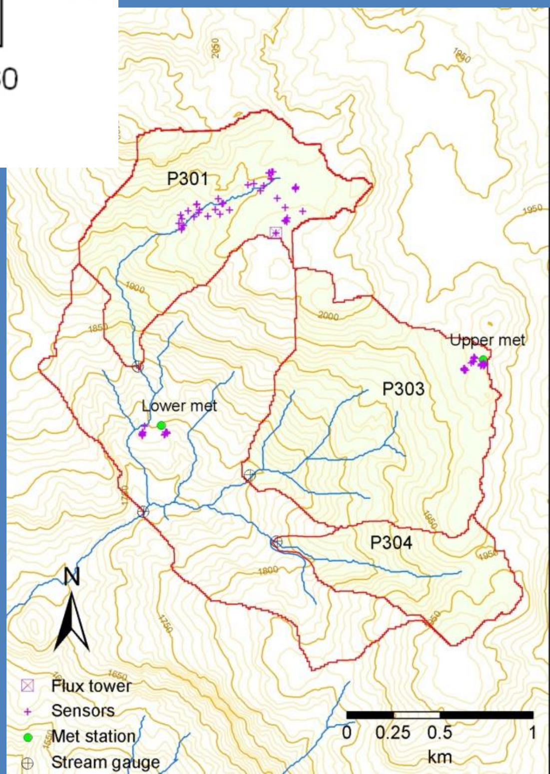
Focus: the regolith's contribution to the annual water budget

# Catchment-scale water balance




Snowmelt estimated from Δ SWE

0-100 cm soil




*Bales et al., 2011*

# Results: trees & water

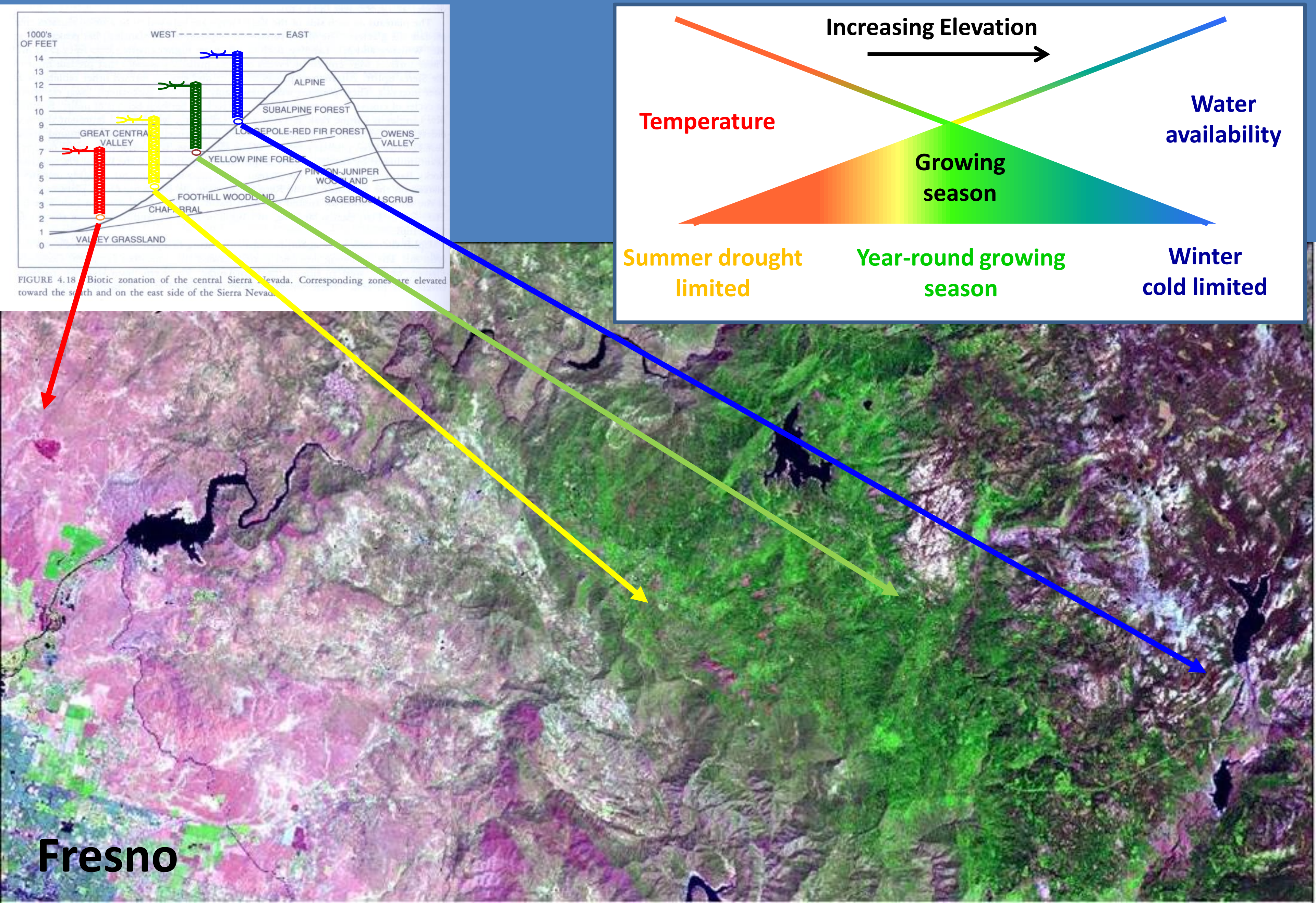
Oak savannah
$T_{ave}$ 14.4°C
P 500 mm
0 d snow
$H_{tree}$ 11 m
25% tree cover

Pine/oak forest
$T_{ave}$ 10.9°C
P 850 mm
11 d snow
$H_{tree}$ 29 m
63% tree cover

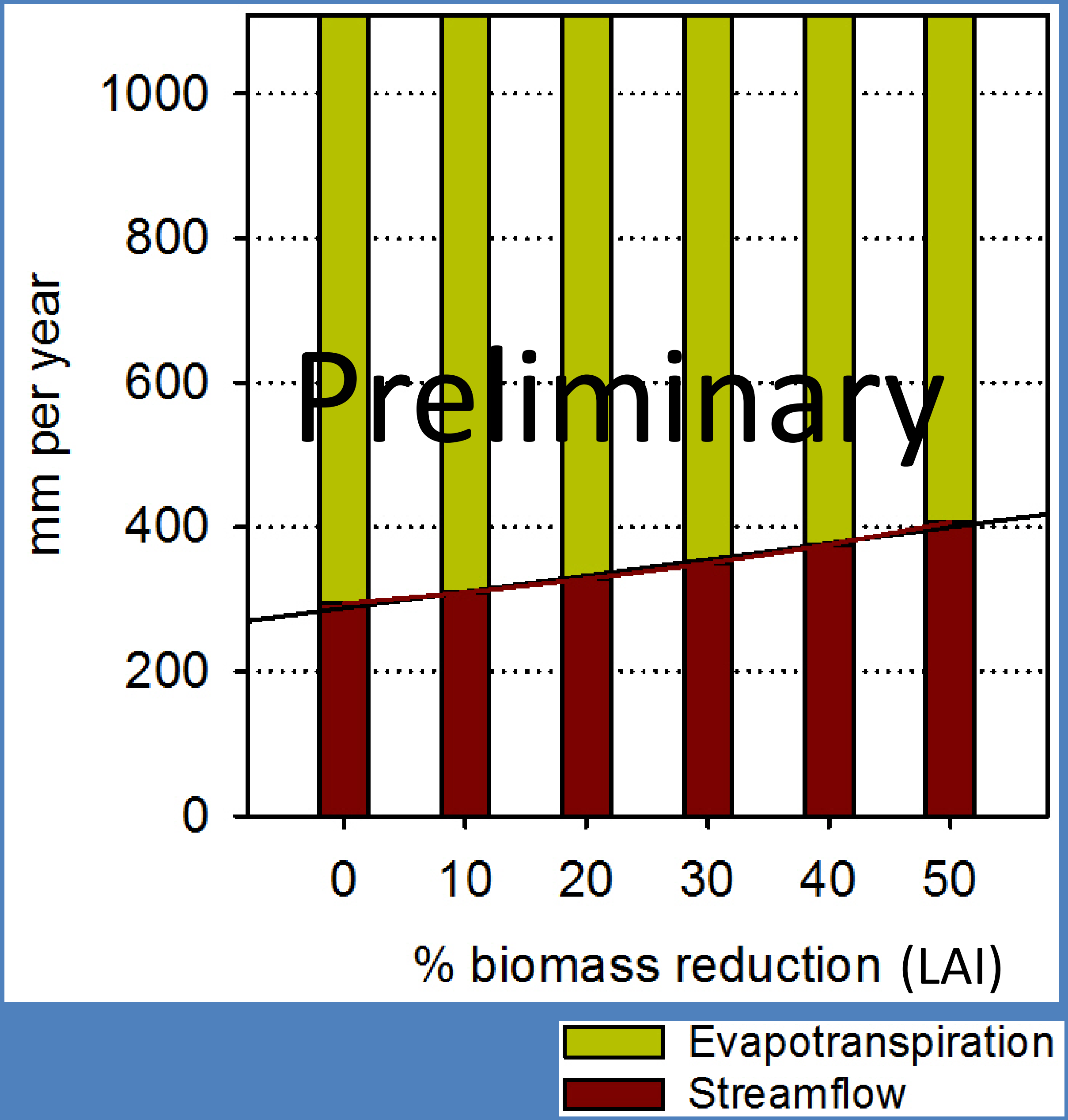
Mixed conifer forest
$T_{ave}$ 8.9°C
P 1000 mm
$H_{tree}$ >30 m
53% tree cover

Subalpine forest
$T_{ave}$ 4.1°C
P 1100 mm
$H_{tree}$ 22 m
31% tree cover

# Flux Tower Transect



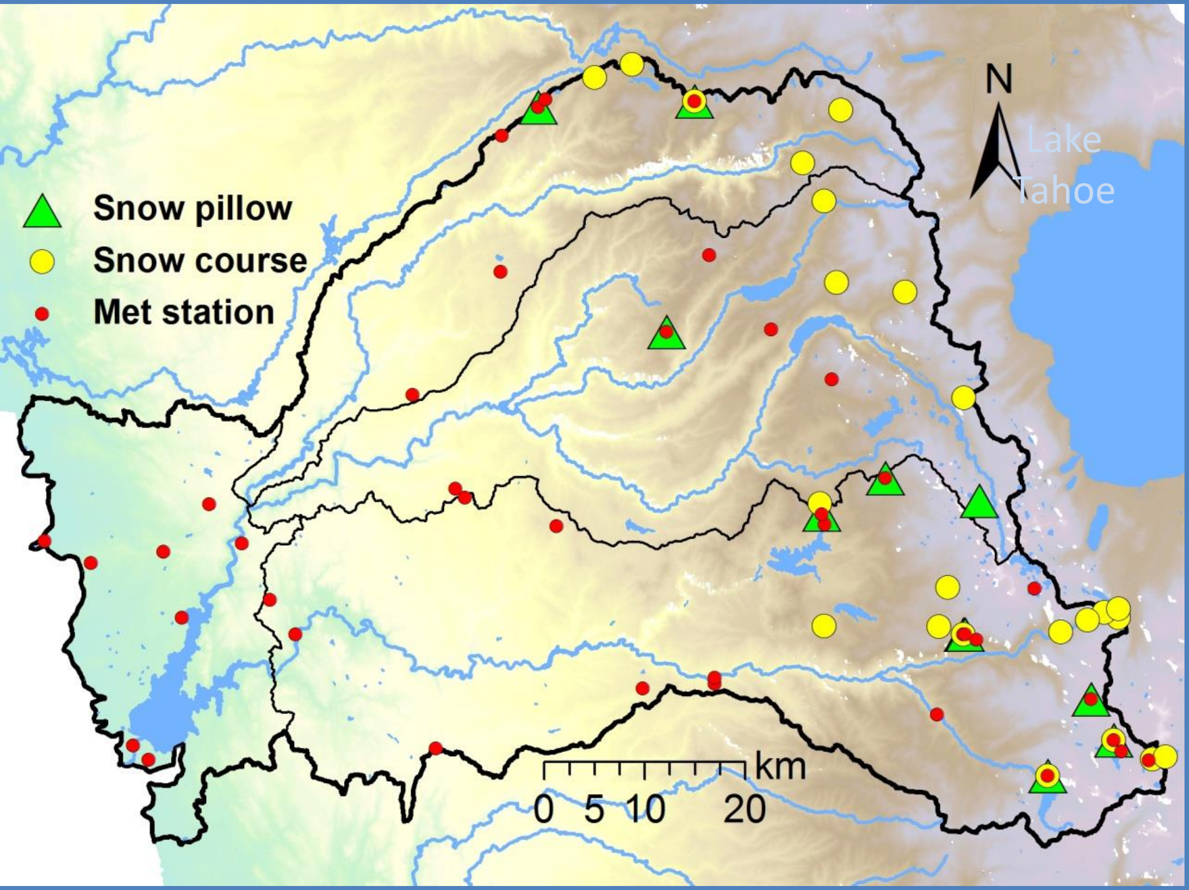
# Impact of thinning on evapotranspiration & streamflow




- P303 headwater catchment, Southern Sierra CZO/KREW, Sierra NF
- Rain-snow transition, 2000 m elev
- Results based on very-detailed pre-treatment data & hydrologic modeling
- 5-yr average, 2004-2008
- Indicates steeper gain from thinning than do Zhang curves

# 4.ARHO: Advances in water information – verifying effects of management & improving forecasts

# American River basin – current hydrologic measurements




- 2 snow pillows in N. Fork, 1 in Middle Fork, 8 in S. Fork
- Non-representative network
- Stations are on flat ground, in clearings, at mid elevations

# Basin-wide deployment of hydrologic instrument clusters – American R. basin

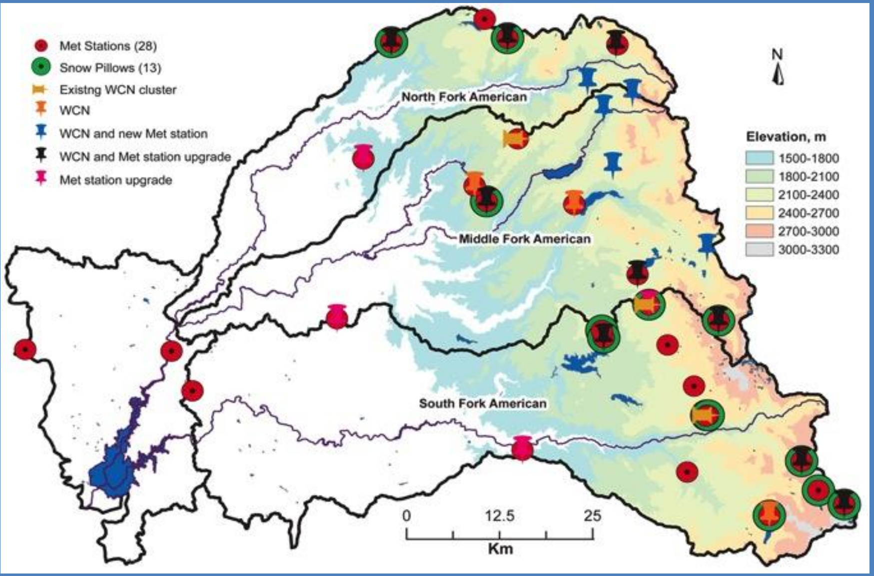
- Strategically place low-cost sensors to get spatial estimates.
- Integrate with satellite imaging to map out entire basin
- Key statistics:

– 4,500 km$^2$

– 47 reservoir inflow points; 50 water supply points; 81 Flood forecast points

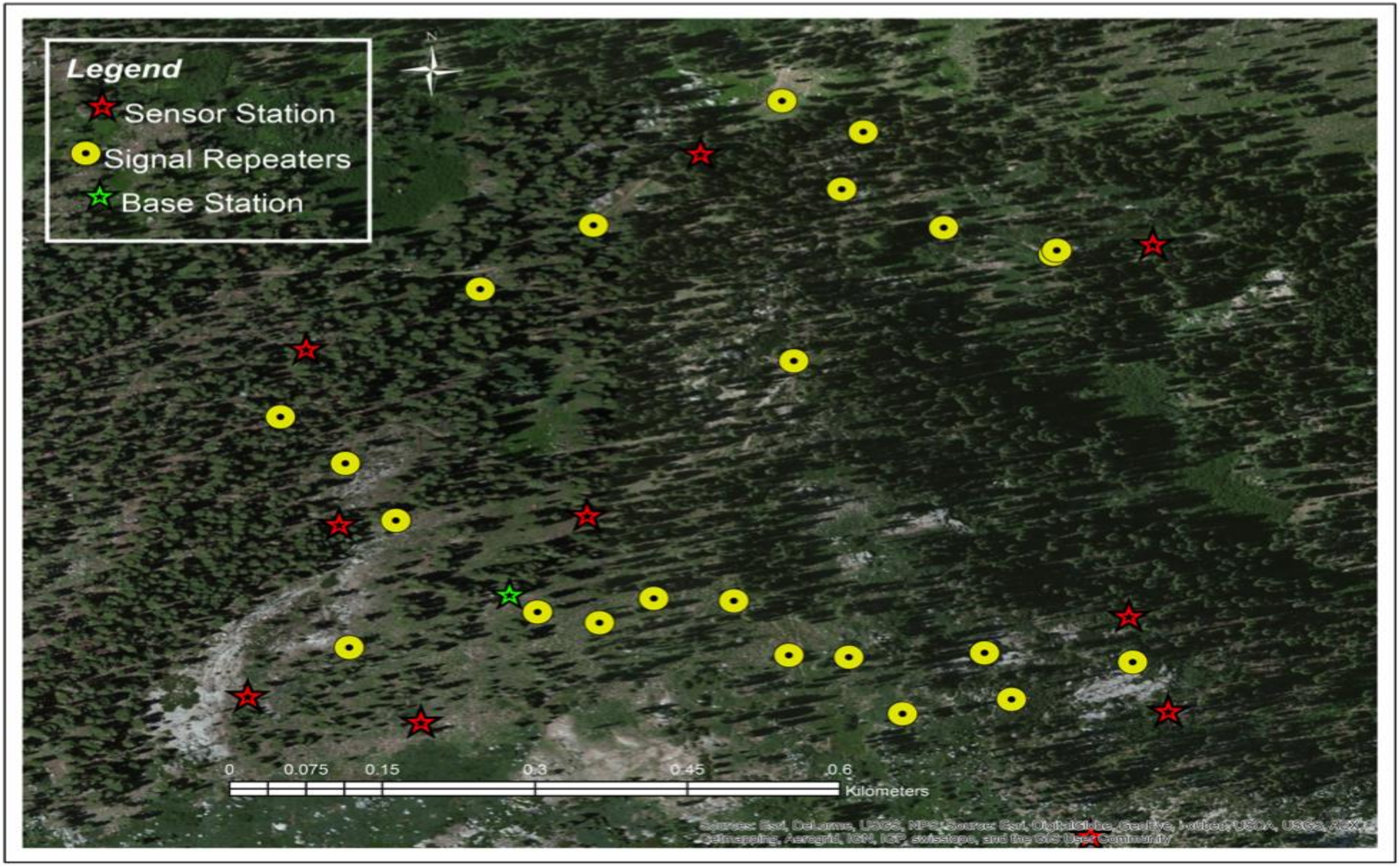
– 18 networks; 10 sensor nodes/netwk

– Sensor nodes - snow depth, temperature, humidity, solar radiation, soil moisture (1000's)



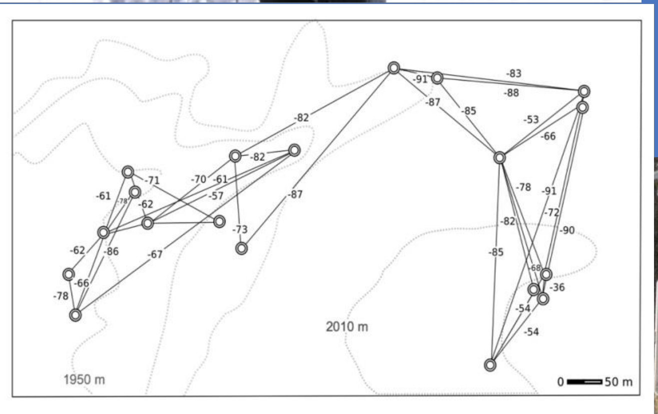

*Real time data acquired by wireless sensor networks provides better predictive capabilities for reservoir mass-balance and system dynamics*

# Each network designed to sample key landscape elements

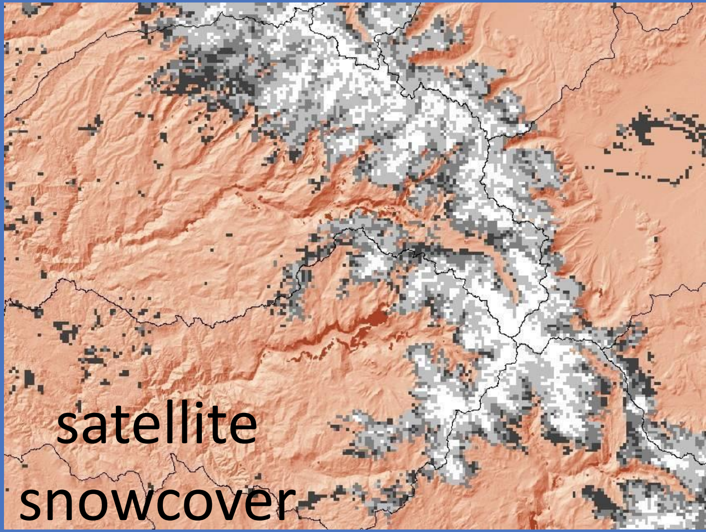


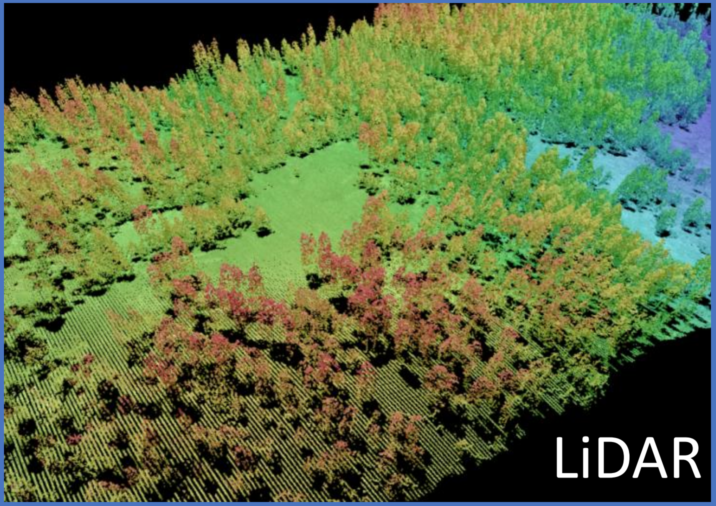
# Measurement technology – verification & forecasts

Available now: blending data from satellites, aircraft, wireless sensor networks, advanced modeling tools



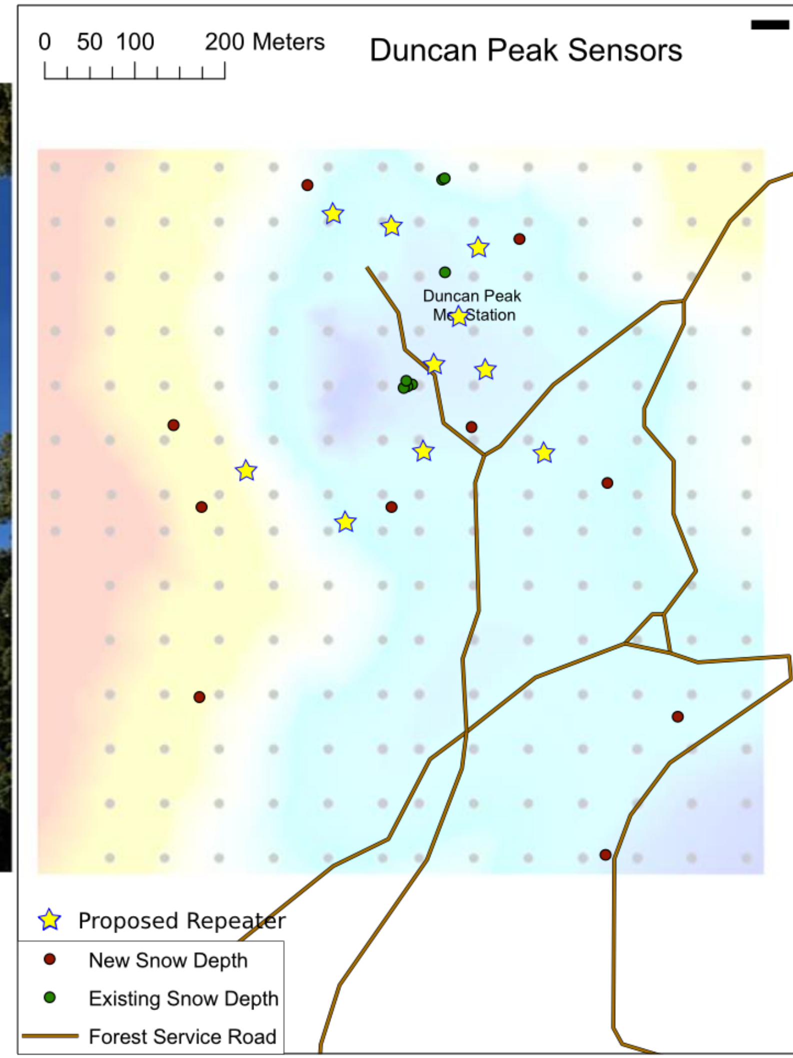


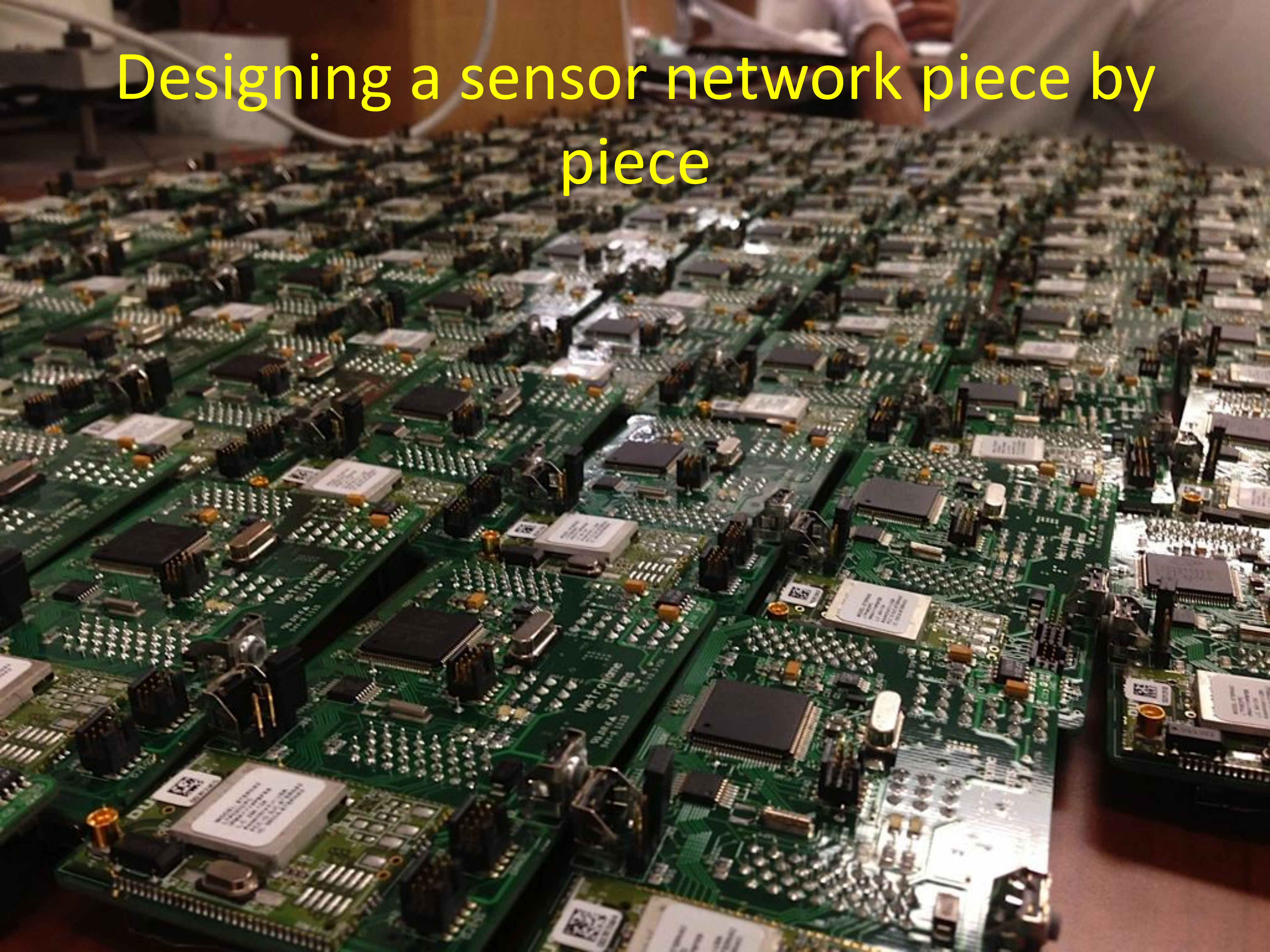

Together these add up to Big Data challenges

# Current setup: *wireless* nodes

Improved representation of the landscape: topography & vegetation



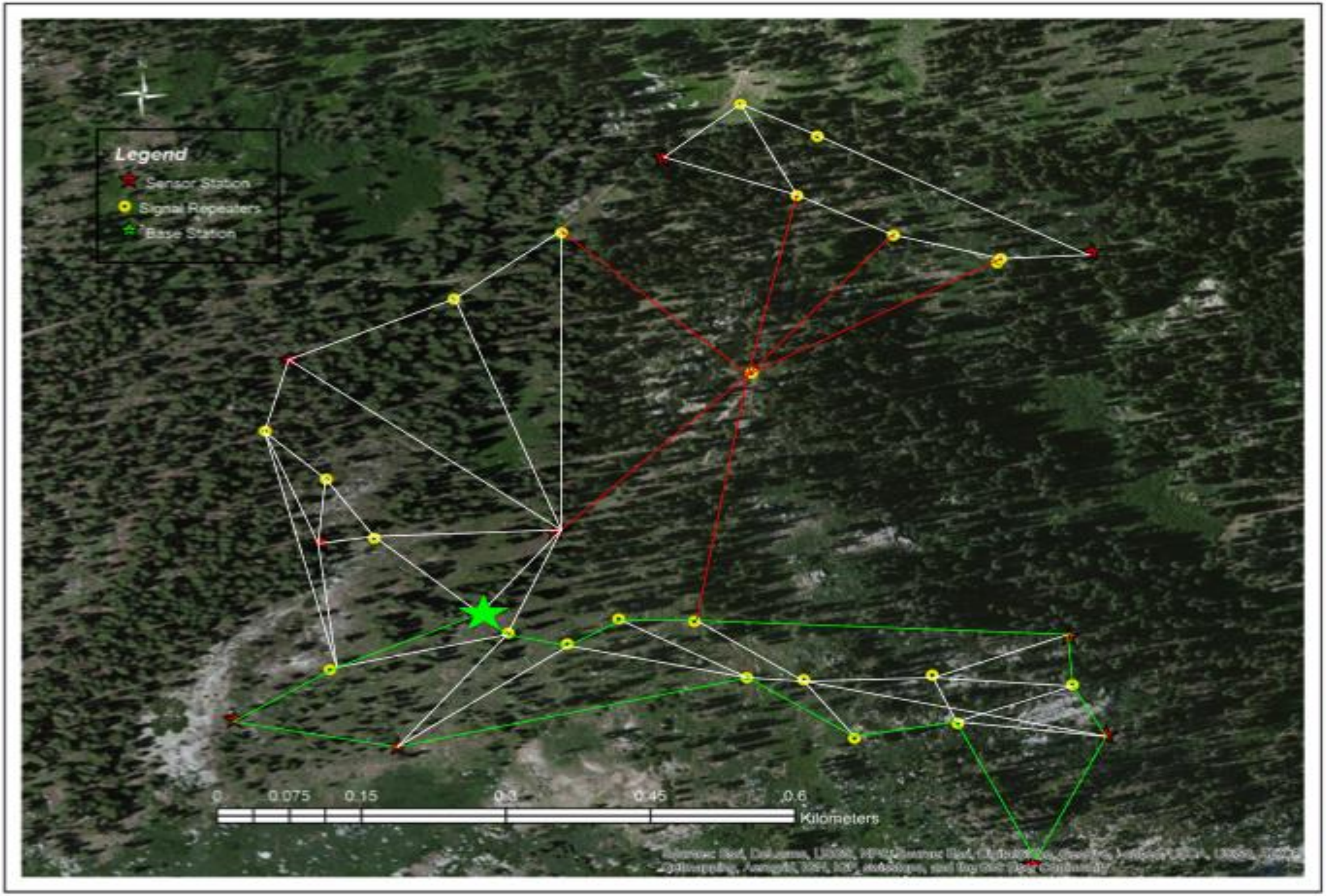
# Designing a sensor network piece by piece



# Node construction at Alpha site


AMR Site
Spring

# Built-in redundancy



# Of course nature trumps all!

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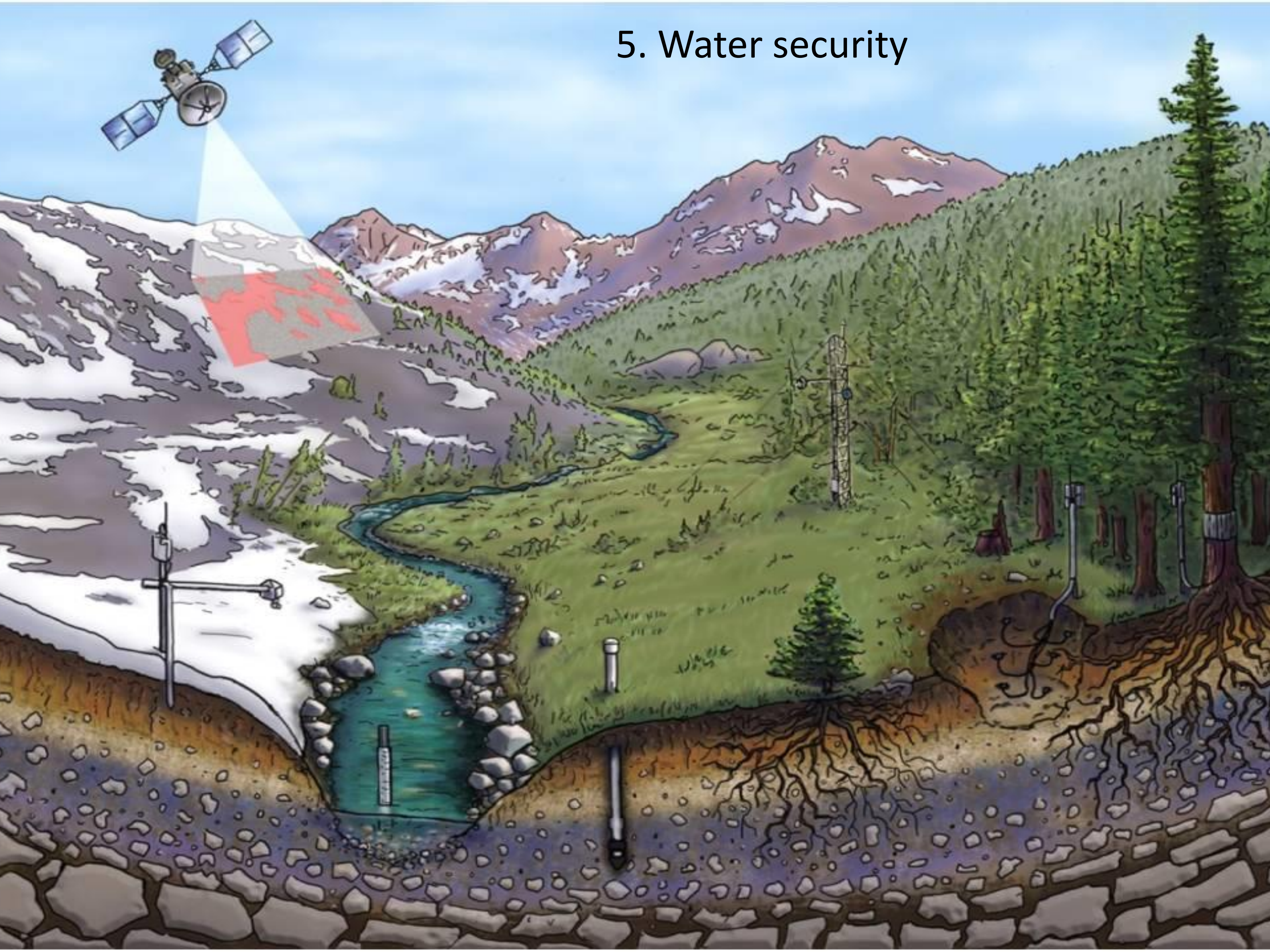
# 5. Water security



# Making a water-secure world – the three I's

**INFRASTRUCTURE**
to store, transport
& treat water

Stronger & more-
adaptable
**INSTITUTIONS**

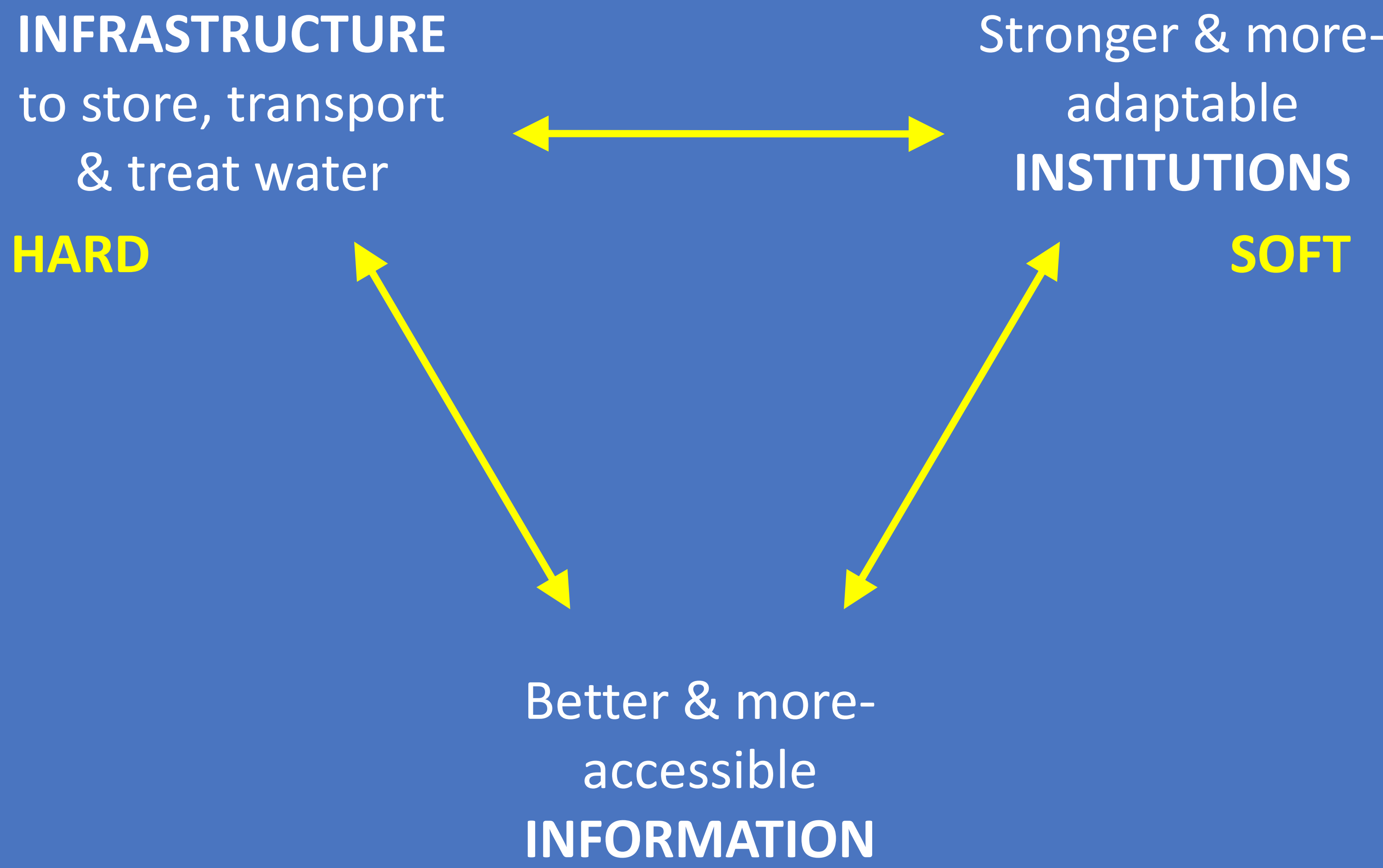
**SOFT**


Madden: The Beast that
ate the earth

Better & more-
accessible
**INFORMATION**

Water security: the reliable availability of an acceptable quantity & quality of water for health, livelihoods & production, coupled w/ an acceptable level of water-related risks

# Making a water-secure world – the three I's

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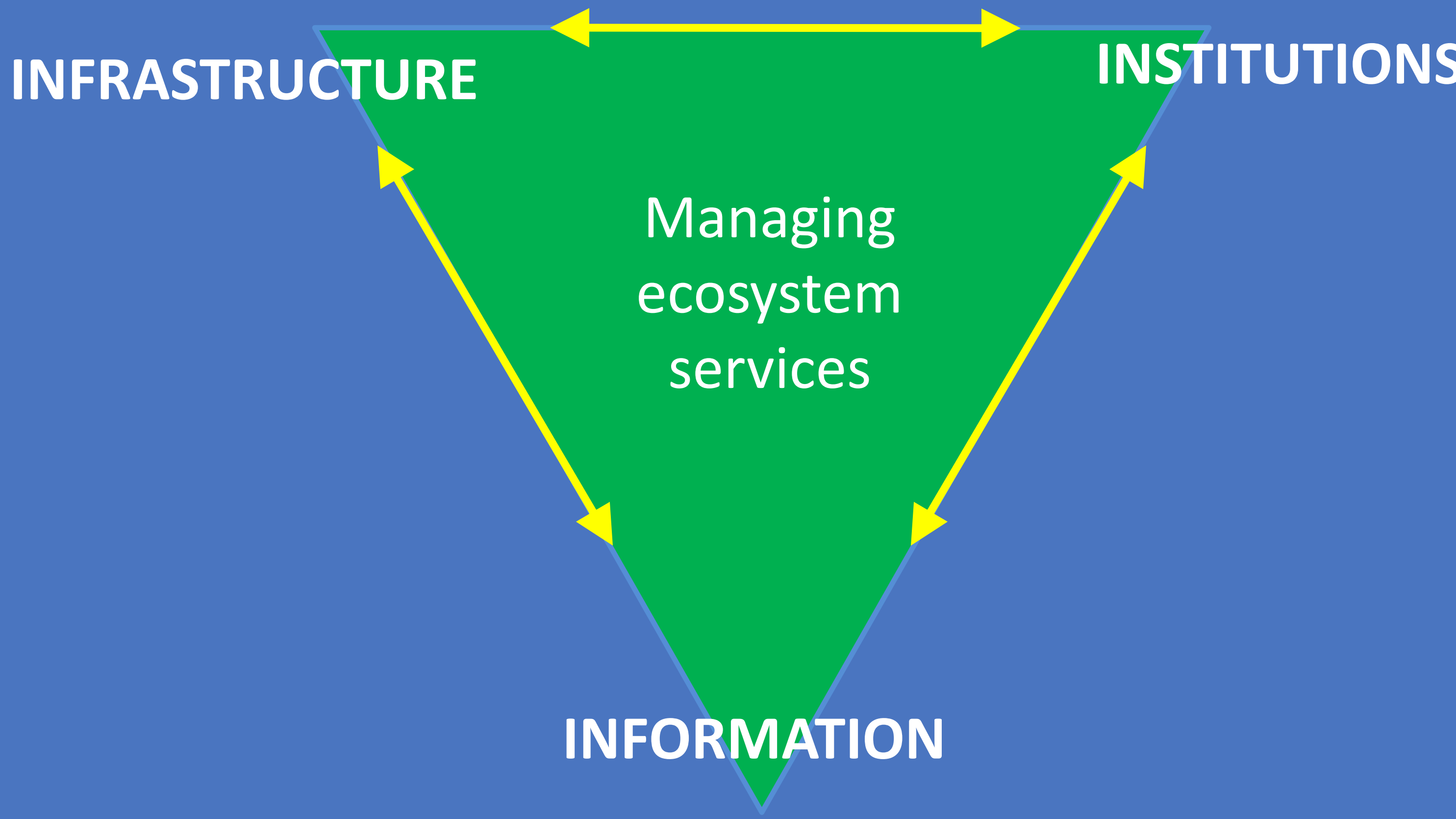


Managing water is central to climate preparedness; and water management translates into managing ecosystem services (e.g. forest vegetation management).

# Concluding points

1. Sustained forest management that provides measurable benefits for water supply will require investment , verification & maintenance
2. American R basin is both research platform & core element of new water-information system
3. Better information is a critical foundation for water security, especially in a warming & more-variable climate
4. Research is still needed on several basic engineering, hydrologic-science, social-science questions, e.g.:
   - Effect of sustained forest restoration & management
   - Systems design for accurate spatial measurements
   - Blending of data w/ modeling tools to improve forecasts
   - Economic value & use of better information

# SSCZO team