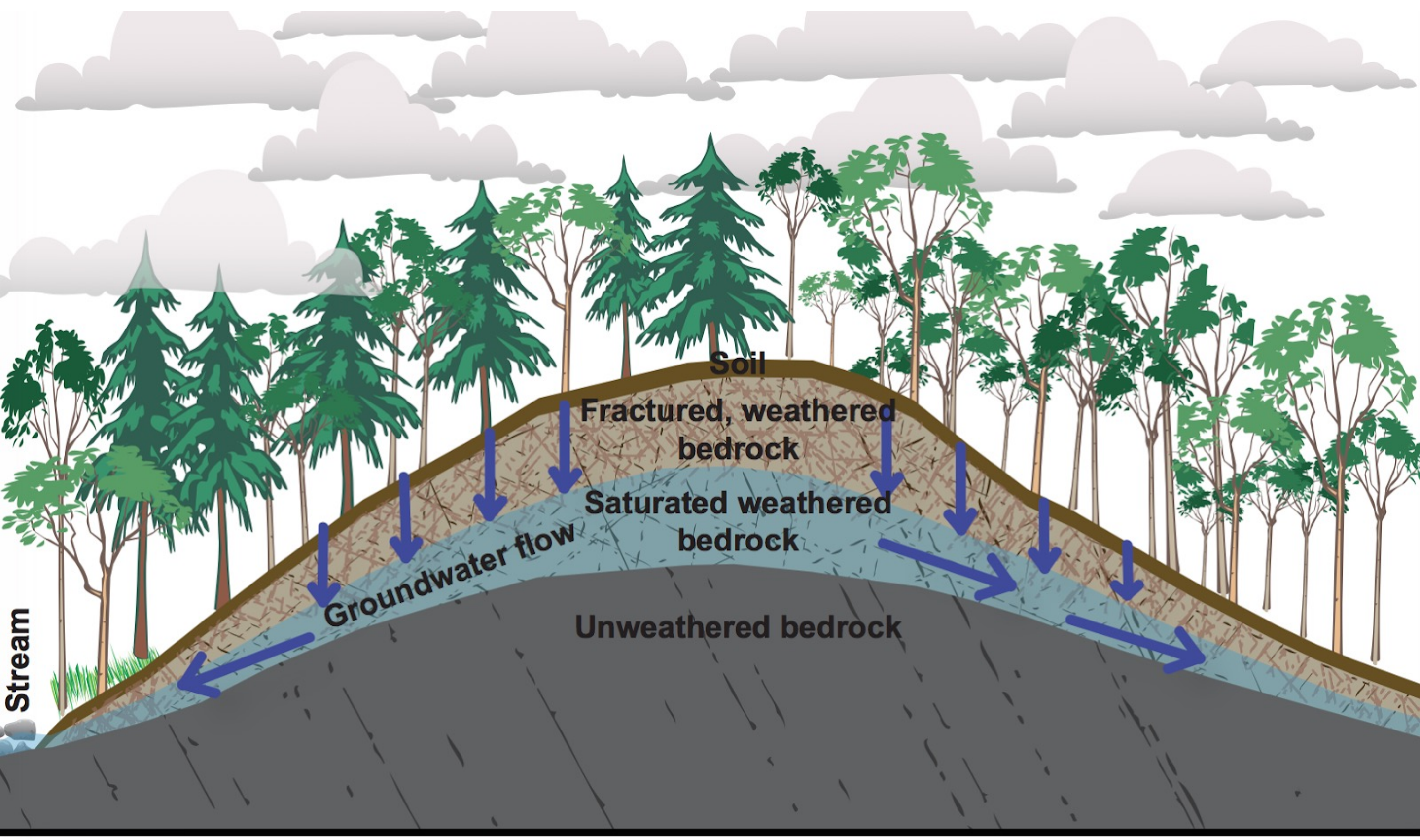
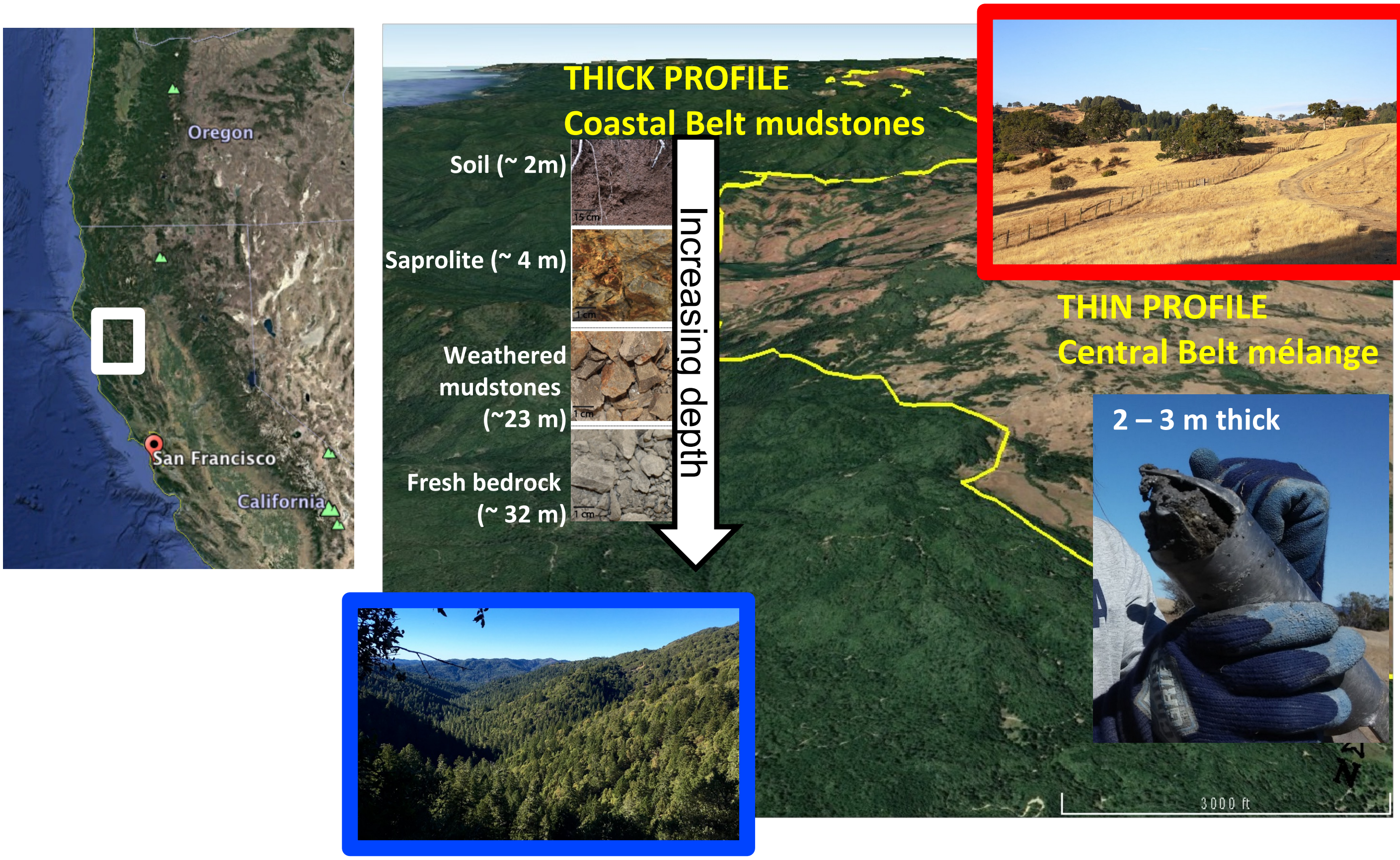
Only Scratching the Subsurface: An Ecohydrologically Themed Tour of the Eel River Critical Zone Observatory

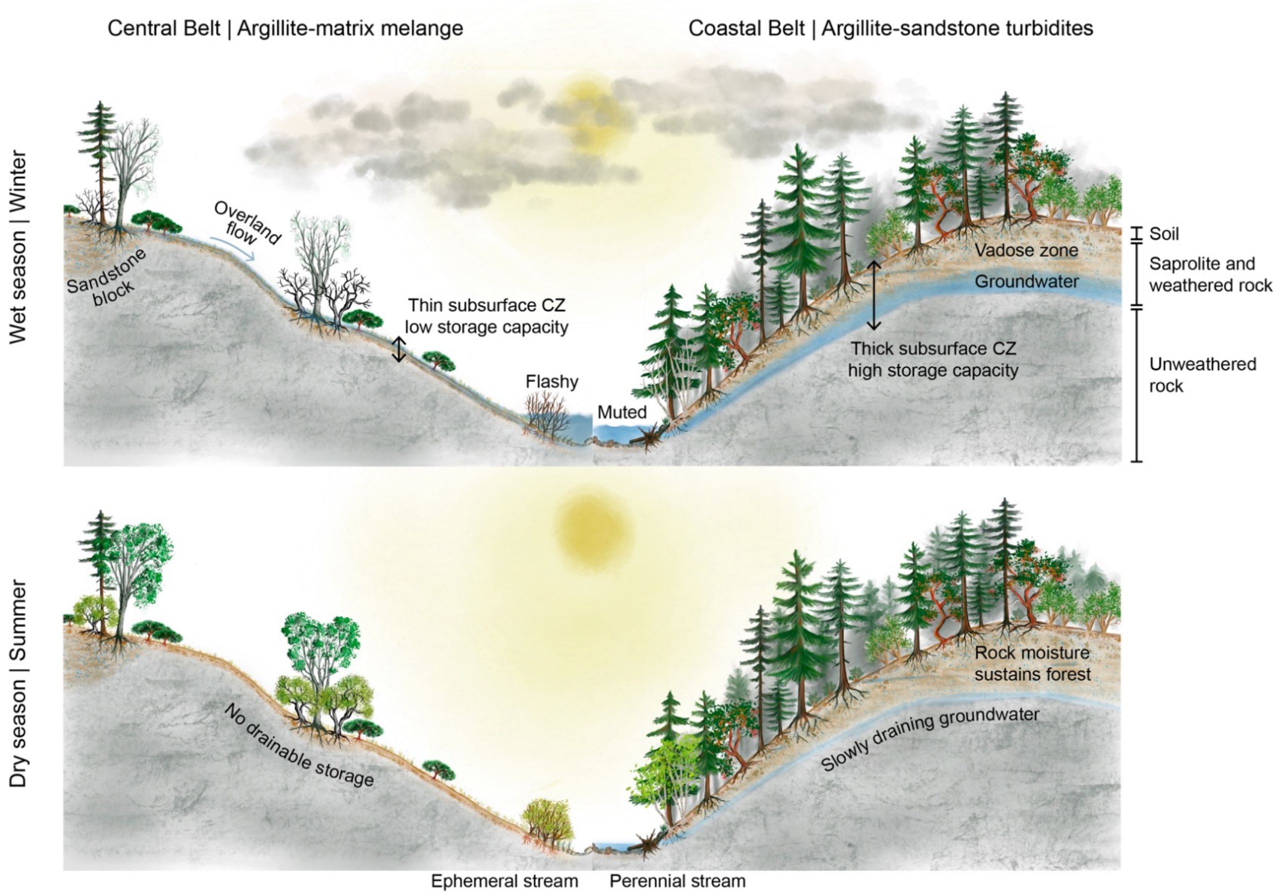
Today, we'll take a walking tour of the Eel River Critical Zone Observatory at the Angelo Coast Range Reserve. We'll begin by contemplating a North Coast ecological mystery that only geology can resolve. Next, we'll visit Angelo's experimental hillslope "workshop" – Rivendell – where extensive hydrological infrastructure produced a set of clues that reveal how a structured subsurface hillslope environment controls belowground water storage, and consequently water availability to streams and trees. Finally, we'll explore the confluence of the South Fork Eel and Elder Creek to discuss how subsurface water storage dynamics impact stream flow and temperature regimes that matter for salmonids.



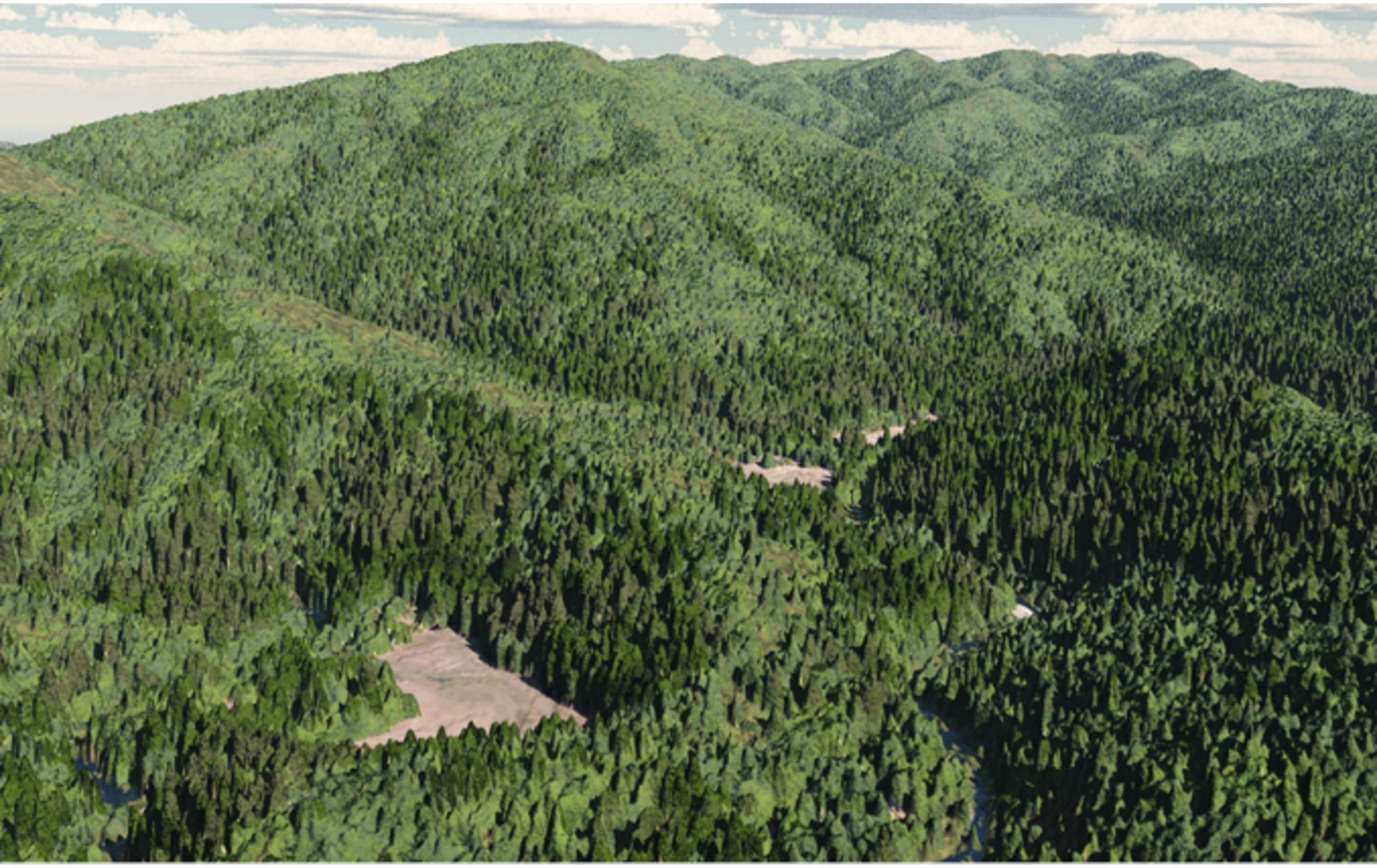
Conceptual diagram modified from original by Daniella Rempe

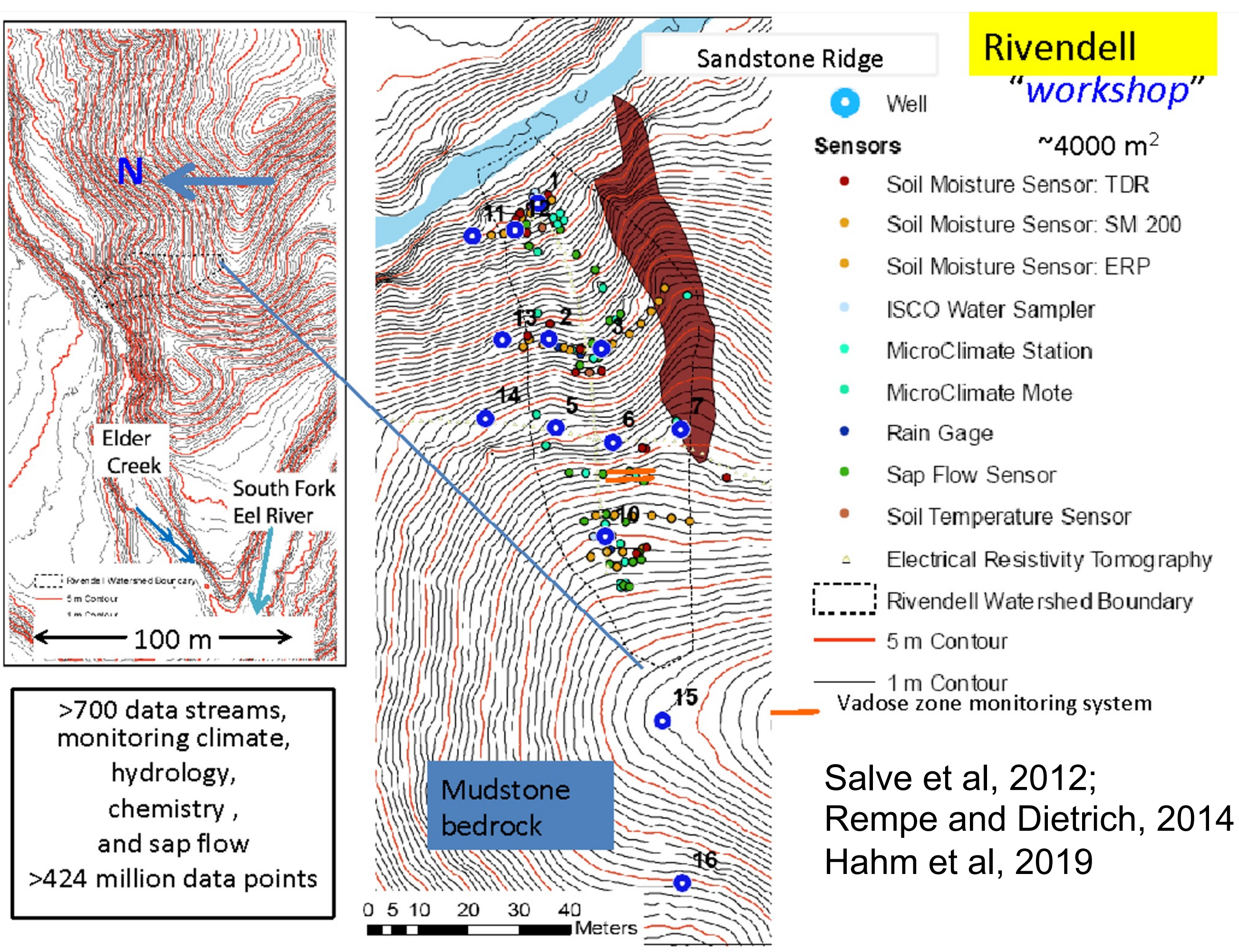


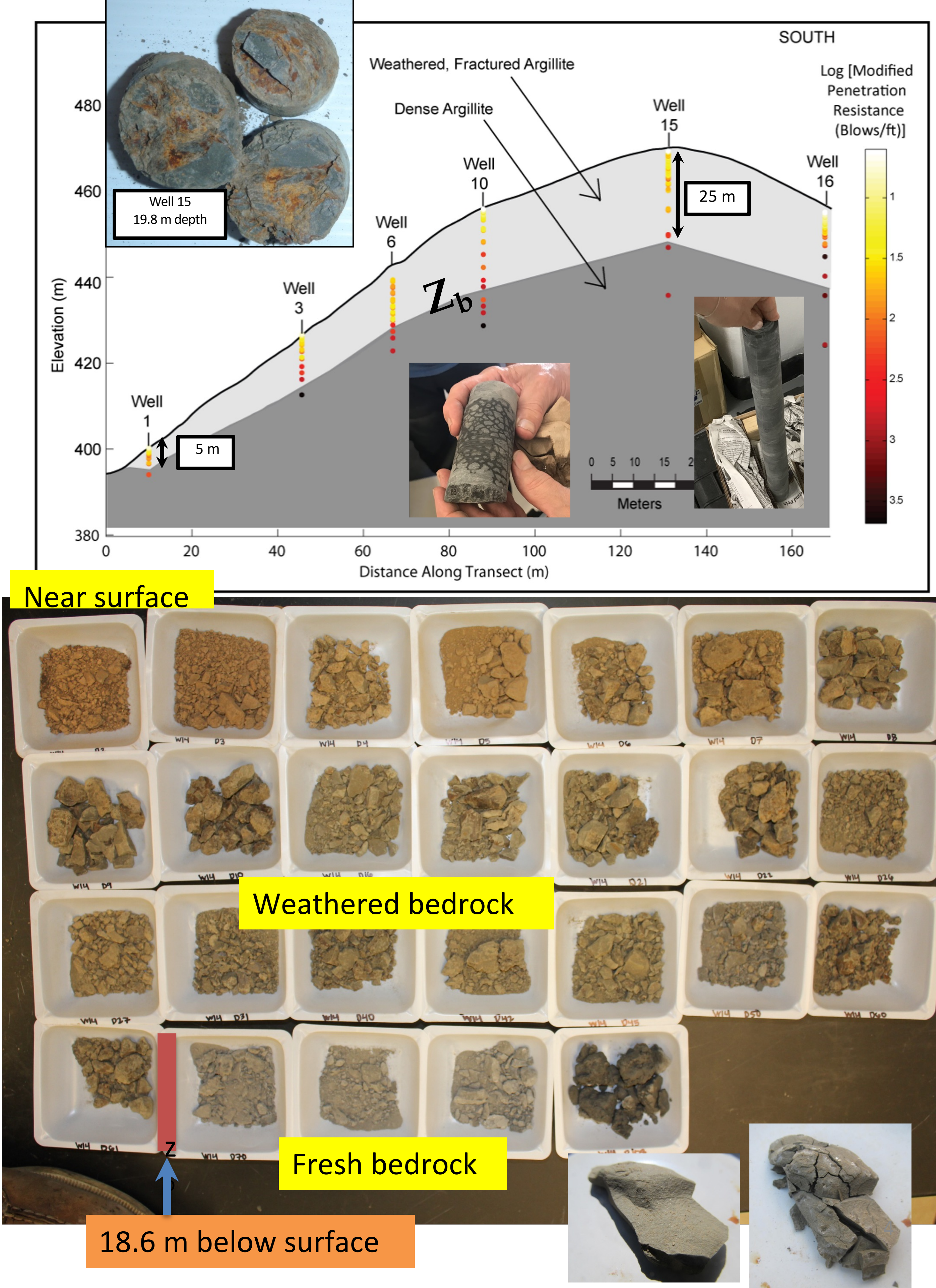
Hillslope structure, subsurface water storage, and seasonal hydrological dynamics



Hahm et al, 2019; Dralle et al, in review
Preprint: https://eartharxiv.org/repository/view/3526/




Rivendell
"workshop"
Sandstone Ridge
N
Elder
Creek
South Fork
Eel River
100 m
Well
Sensors
~4000 m2
Soil Moisture Sensor: TDR
Soil Moisture Sensor: SM 200
Soil Moisture Sensor: ERP
ISCO Water Sampler
MicroClimate Station
MicroClimate Mote
Rain Gage
Sap Flow Sensor
Soil Temperature Sensor
Electrical Resistivity Tomography
Rivendell Watershed Boundary
5 m Contour
1 m Contour
Vadose zone monitoring system
Mudstone
bedrock
0 5 10 20 30 40
Meters
>700 data streams,
monitoring climate,
hydrology,
chemistry ,
and sap flow
>424 million data points
Salve et al, 2012;
Rempe and Dietrich, 2014
Hahm et al, 2019

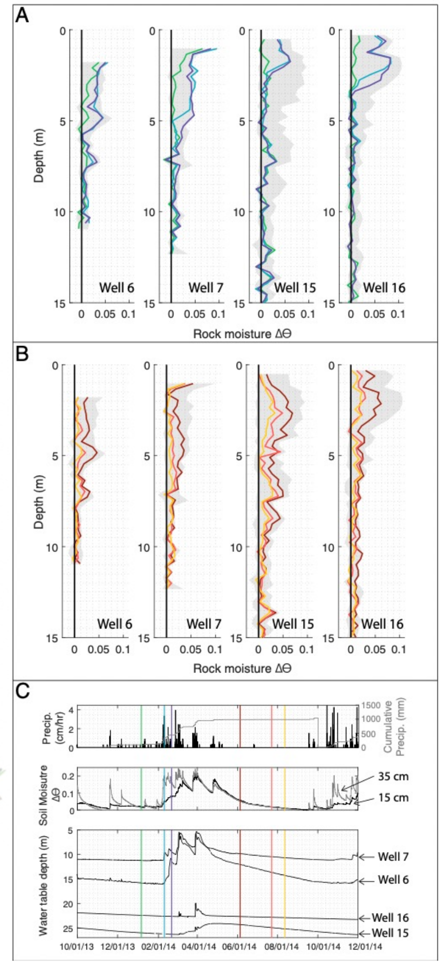


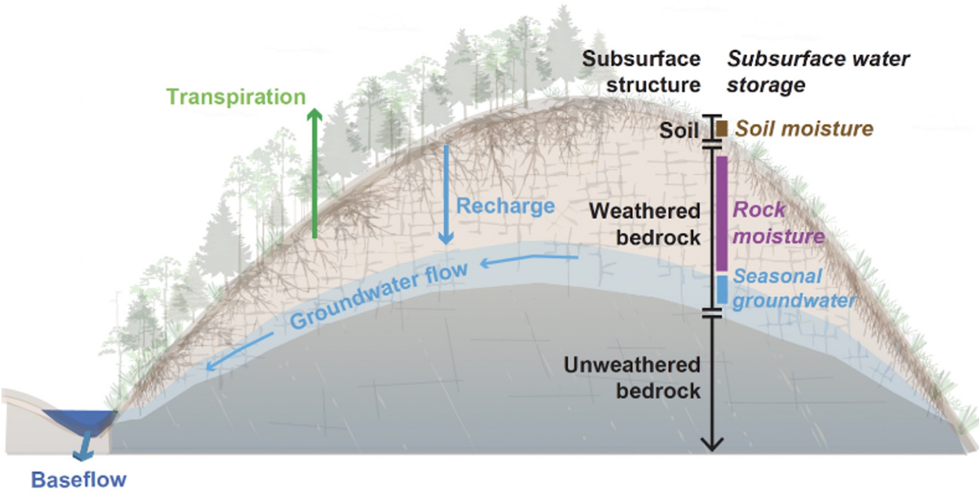
SOUTH
Weathered, Fractured Argillite
Dense Argillite
Log [Modified Penetration Resistance (Blows/ft)]
1
1.5
2
2.5
3
3.5
Well 1
Well 3
Well 6
Well 10
Well 15
Well 16
Well 15
19.8 m depth
25 m
5 m
Zb
0 5 10 15 2
Meters
Elevation (m)
480
460
440
420
400
380
0
20
40
60
80
100
120
140
160
Distance Along Transect (m)
Near surface
Weathered bedrock
Fresh bedrock
Z
18.6 m below surface

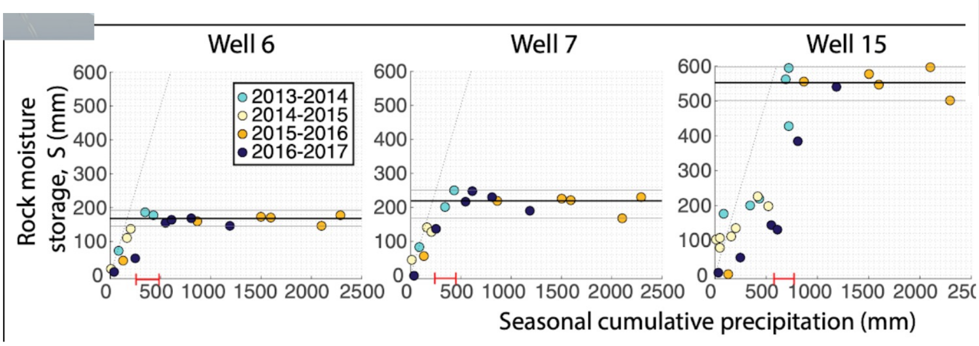
Groundwater: water in *saturated* soil or bedrock; i.e. the water table

Soil moisture: water in soil in the *unsaturated* zone

Rock moisture: matrix and fracture water in weathered bedrock in the *unsaturated* zone

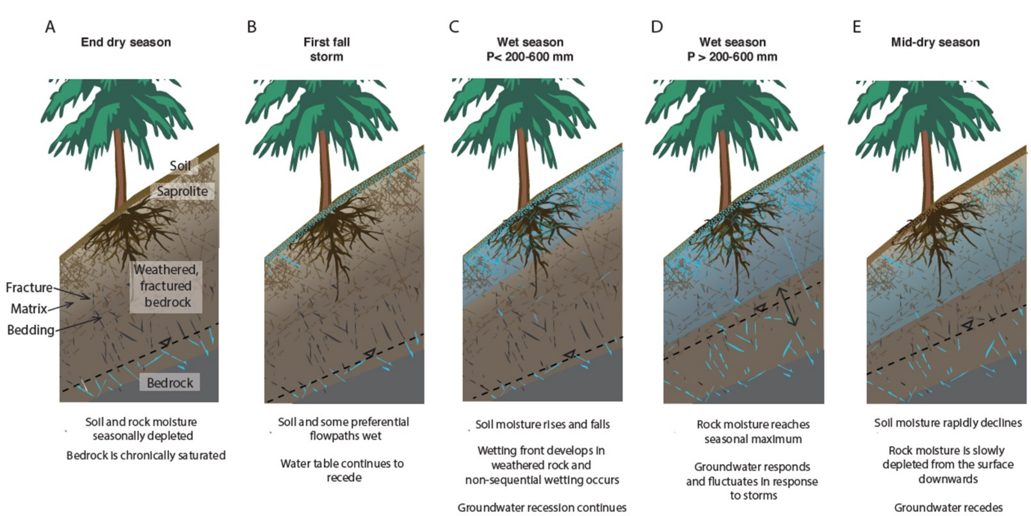






Rempe and Dietrich, 2018

Annually consistent cycle of storage dynamics

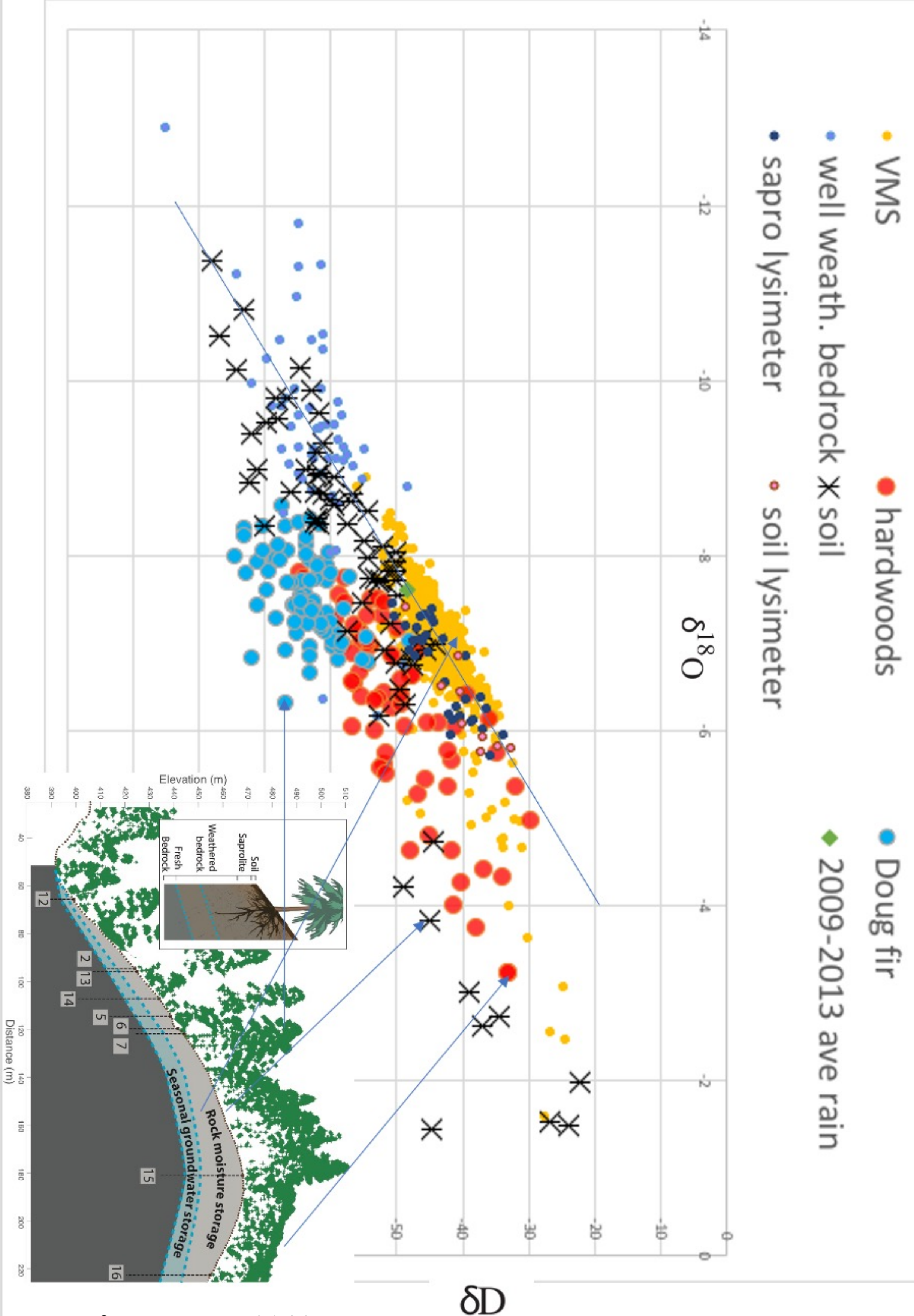


Each year in the upper 5 to 12 m at individual wells about the same amount of rock moisture is gained and lost.

At individual wells this amount is equal to about 30 to 60% of the annual precipitation.

In the 2014 drought, of the 1000 mm of total rainfall, 300 mm of it was stored as rock moisture and used by trees.

Average rock moisture seasonal storage for entire hillslope: **400 mm**

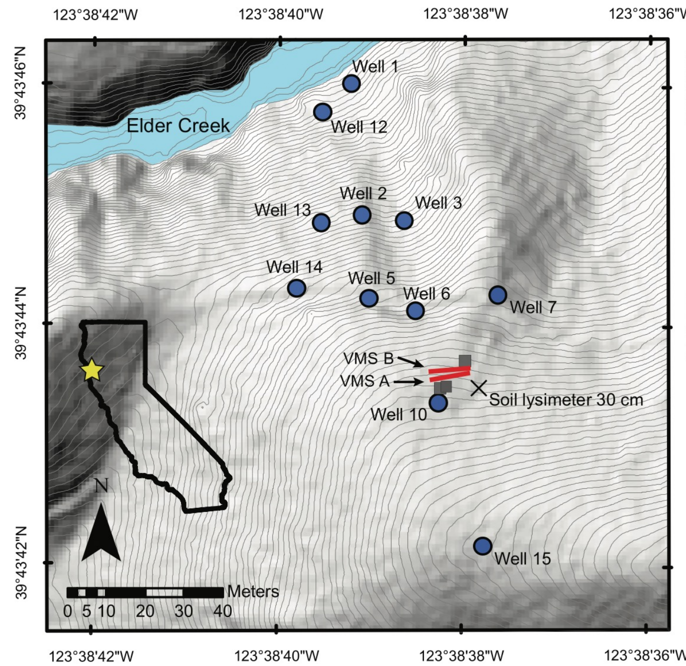


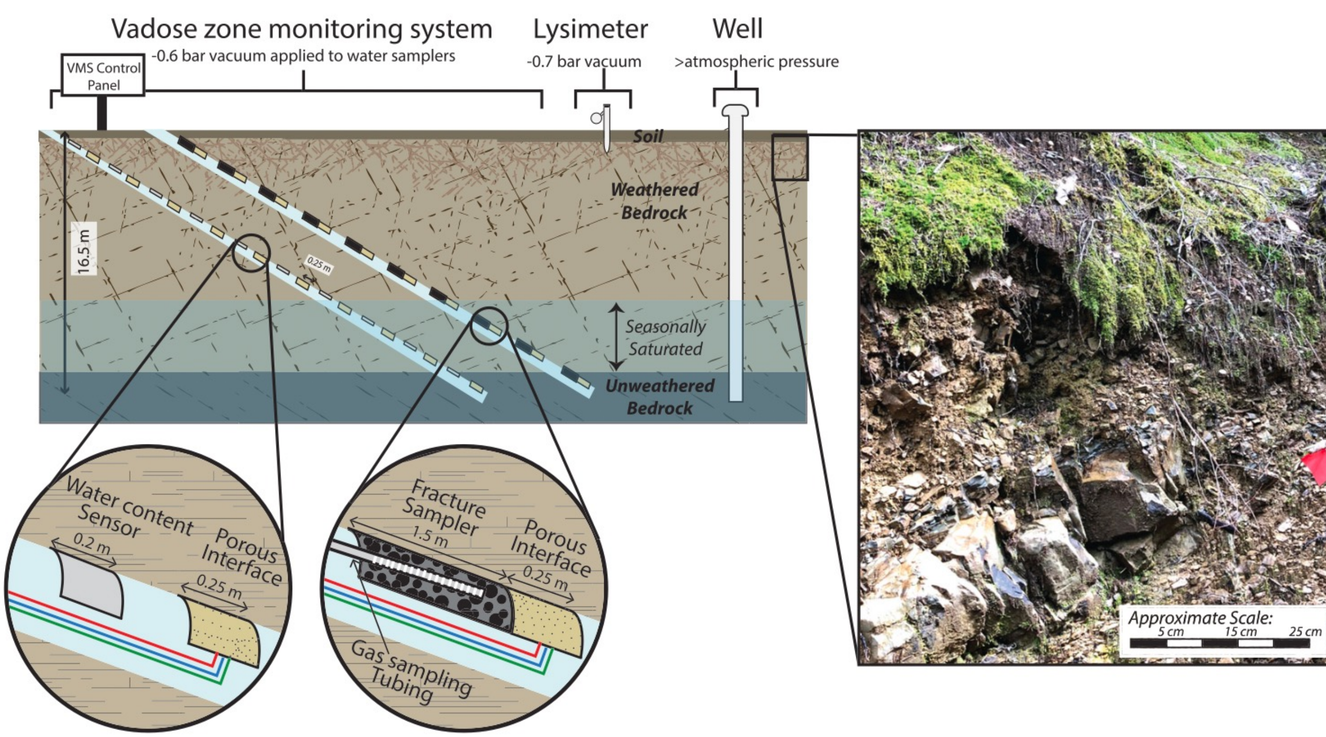
Oshun et al, 2016
Hahm et al, 2020 (oaks at Dry Creek)
Lapides et al 2022 (isotopes in streamflow)

The Eel River CZO Vadose Zone Monitoring System (VMS)

A direct investigation of the processes controlling critical zone structure and hydrologic dynamics

Vadose Zone Monitoring System: two 19 m long sleeves in 55 degree (from horizontal) inclined holes. One hole-TDT moisture and lysimeters every 2 m; other hole- 2 m long lysimeters to capture fracture flow and tubes to collect gas at each interval depth. **Installed October 25, 2015**

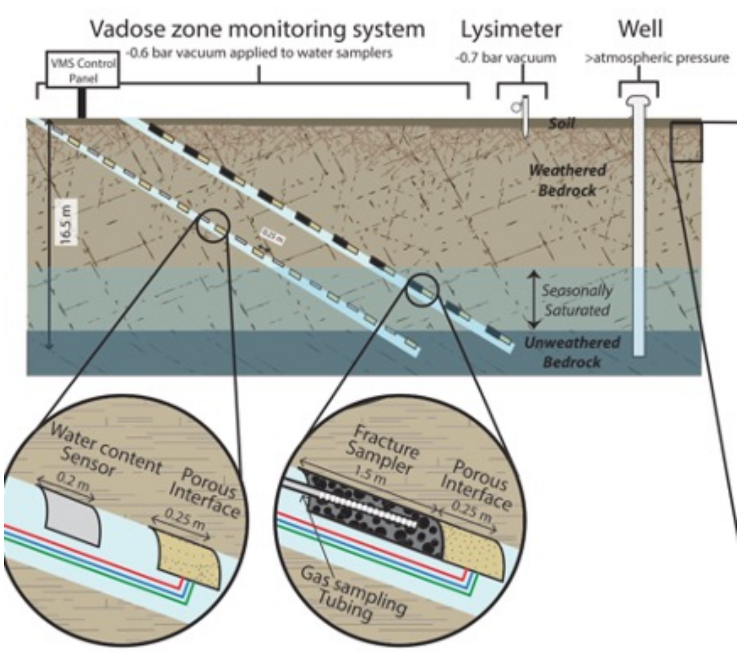


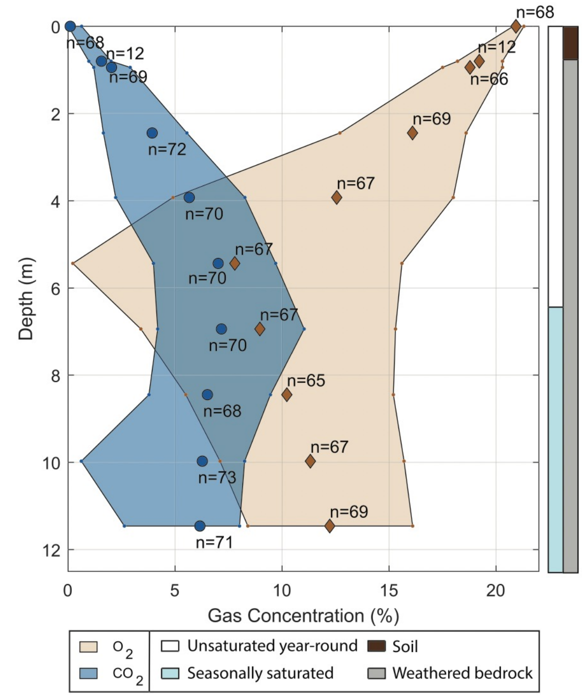


Tune et al, 2020

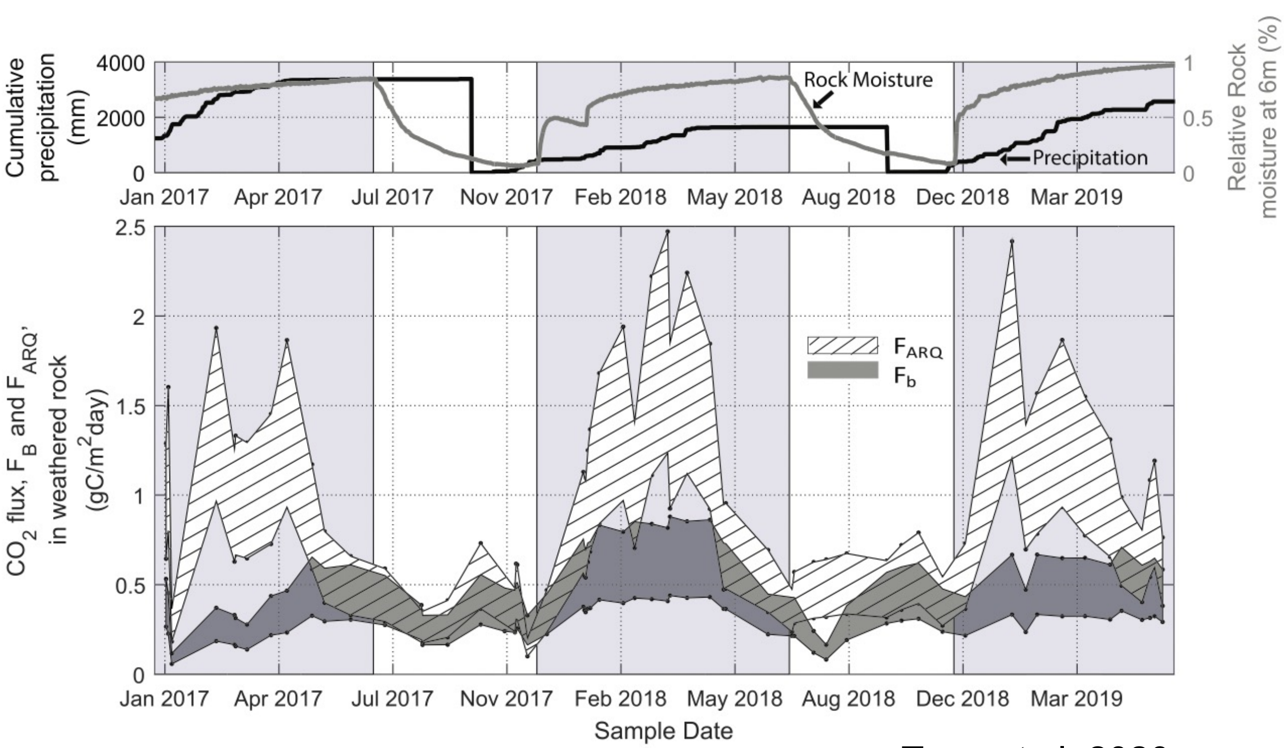
Druhan et al, 2017; Golla et al, 2021

Forest carbon balance



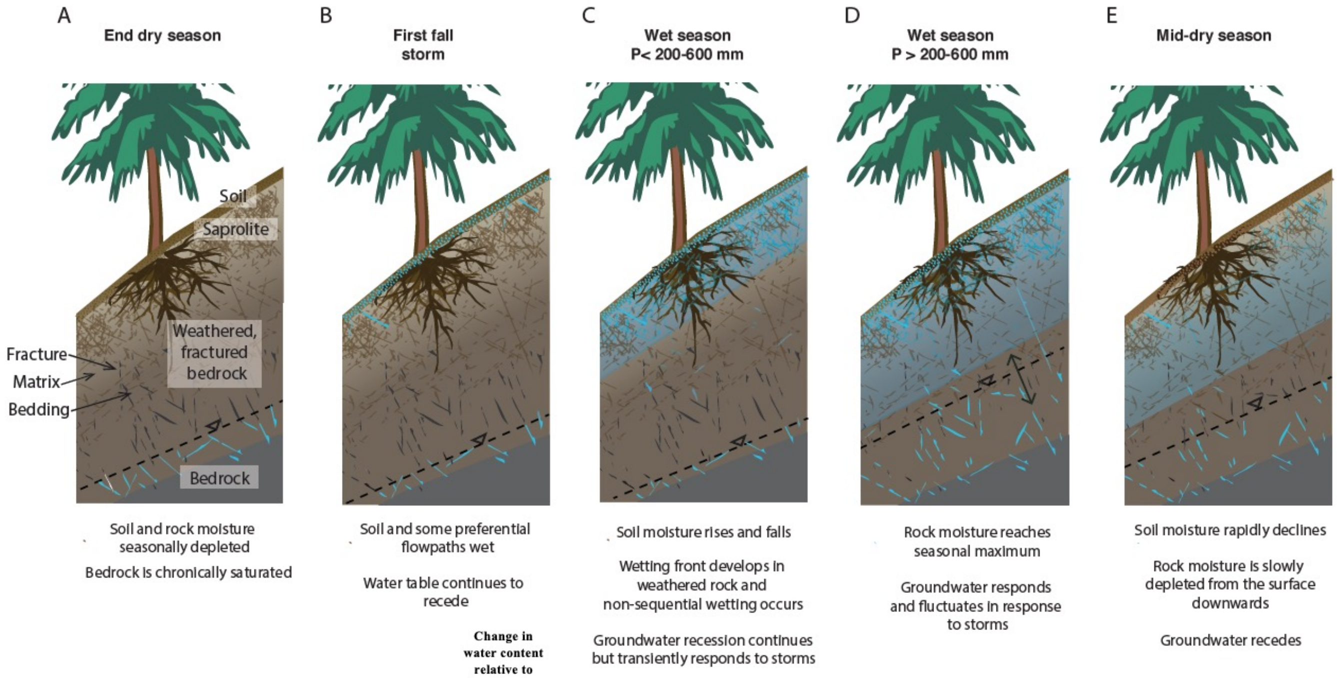


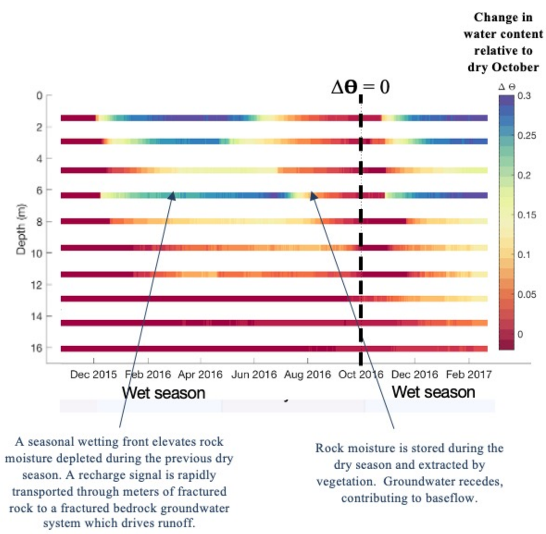
Aerobic respiration in weathered rock



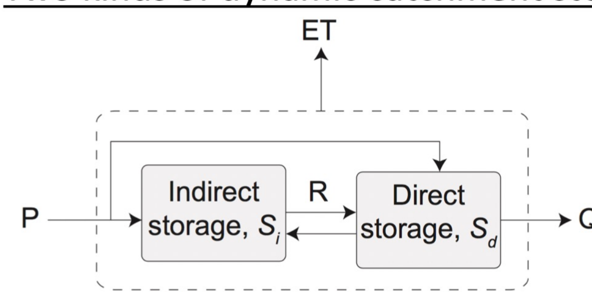
Tune et al, 2020

Hydrological modeling





Two kinds of dynamic catchment storage

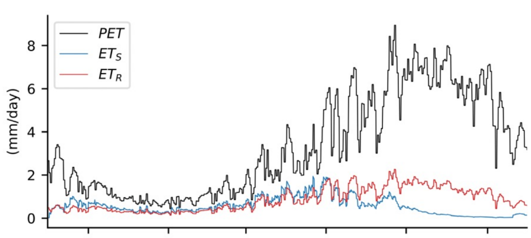


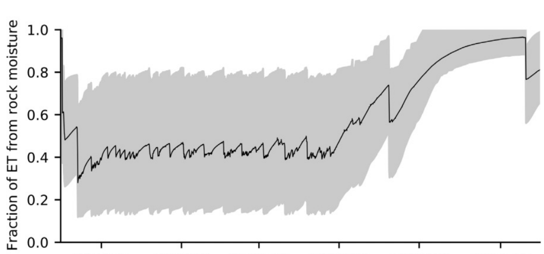
Total dynamic storage

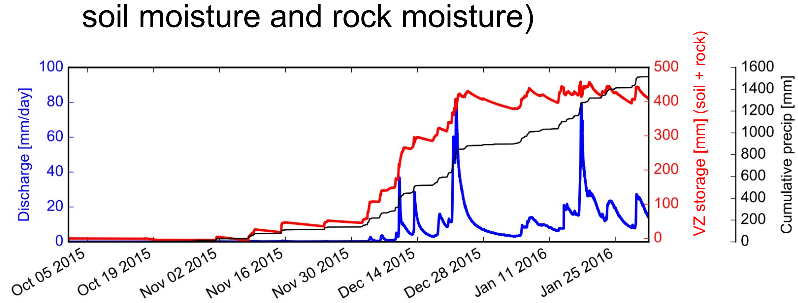
$$S_T = S_d + S_i = \sum P - ET - Q$$

S_d : Storage that directly influences discharge in the stream (i.e. groundwater table)

S_i : Storage that may vary through time, but does not *directly* influence runoff (i.e. vadose zone = soil moisture and rock moisture)



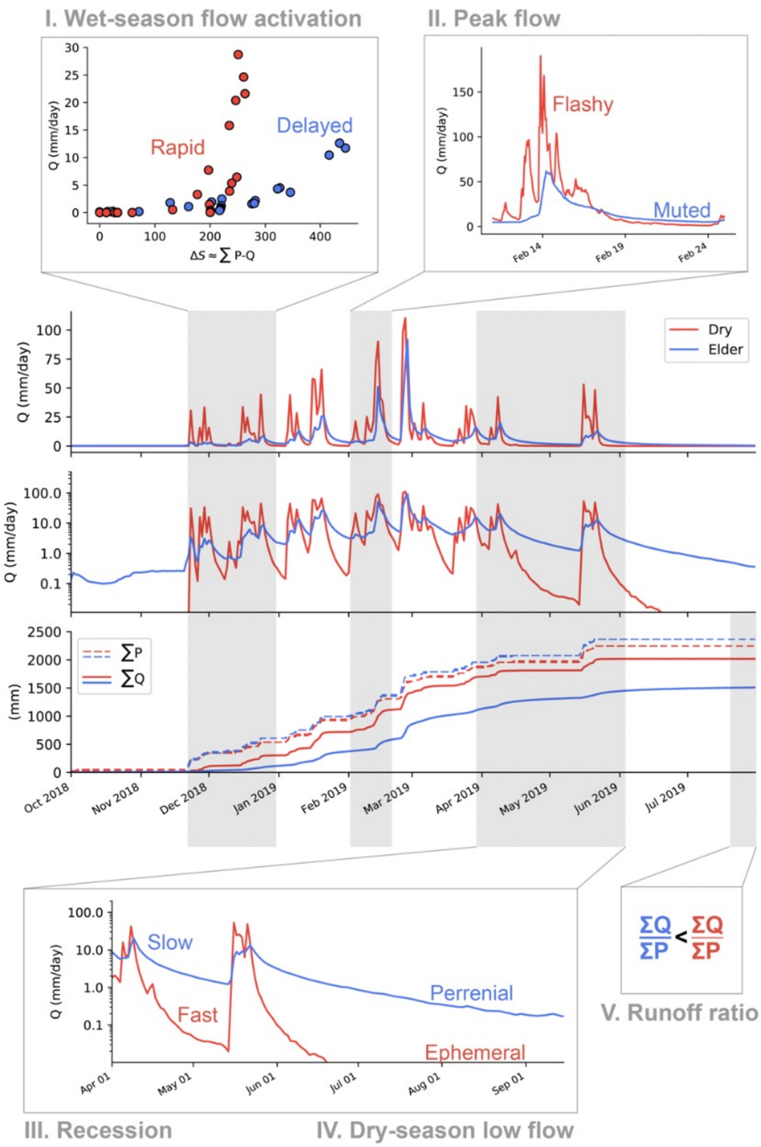


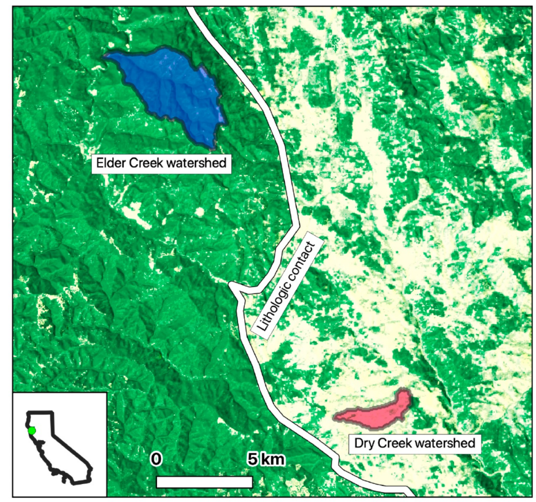


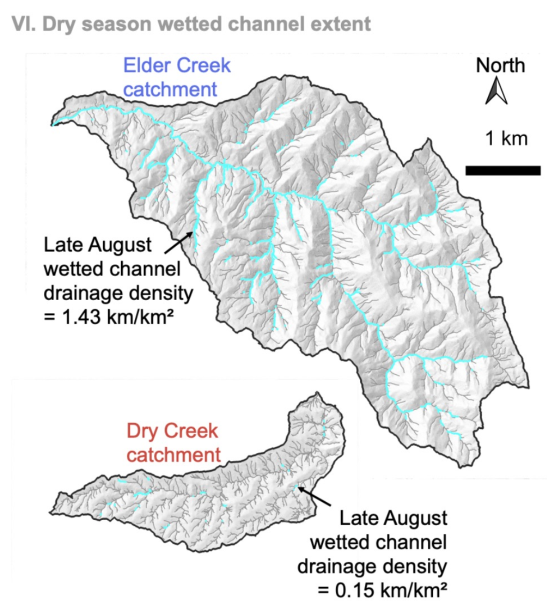
La Follette et al, 2022

Dralle et al, 2018

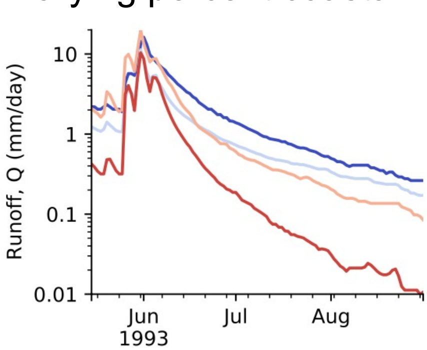
Storage capacity and flow regime

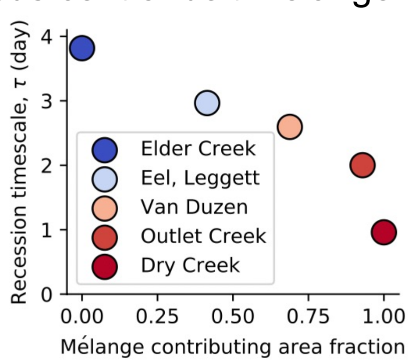


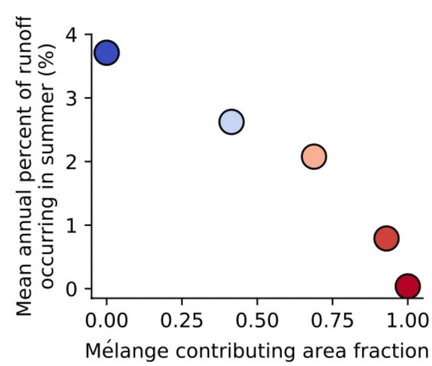




Hydrological scaling – Eel subcatchments are geological “hybrids” made up of varying percent coastal versus central belt melange



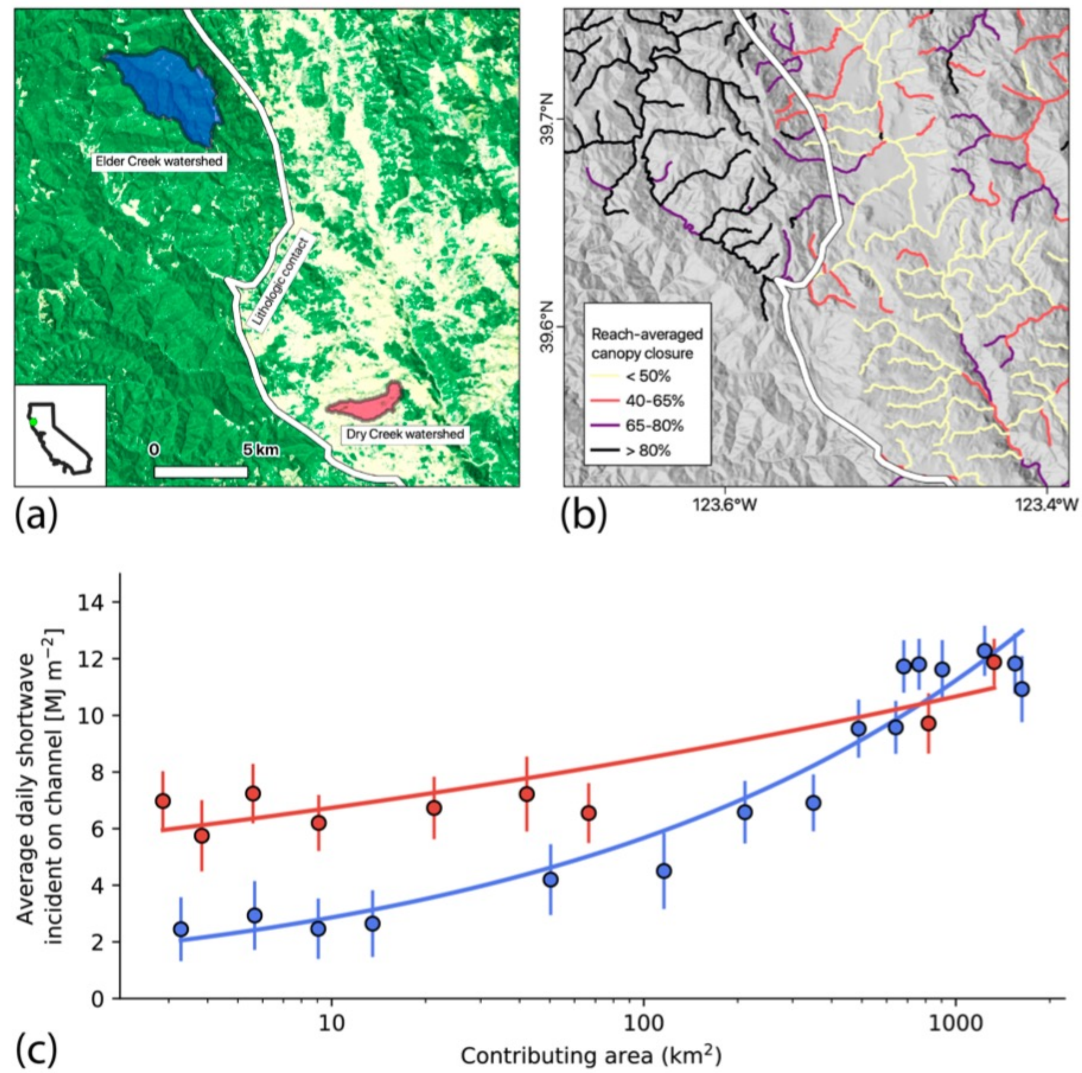




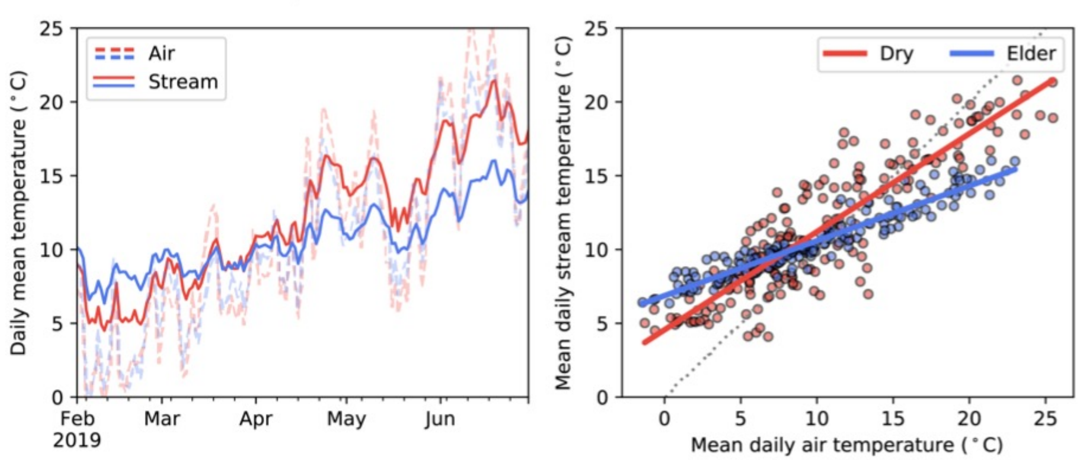
Dralle et al, in review
Preprint: https://eartharxiv.org/repository/view/3526/

Storage capacity and stream temperature

VII. Channel shading

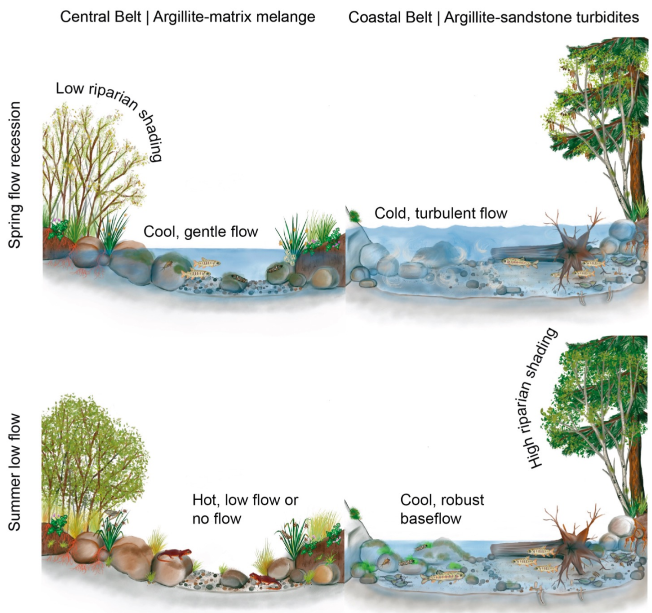


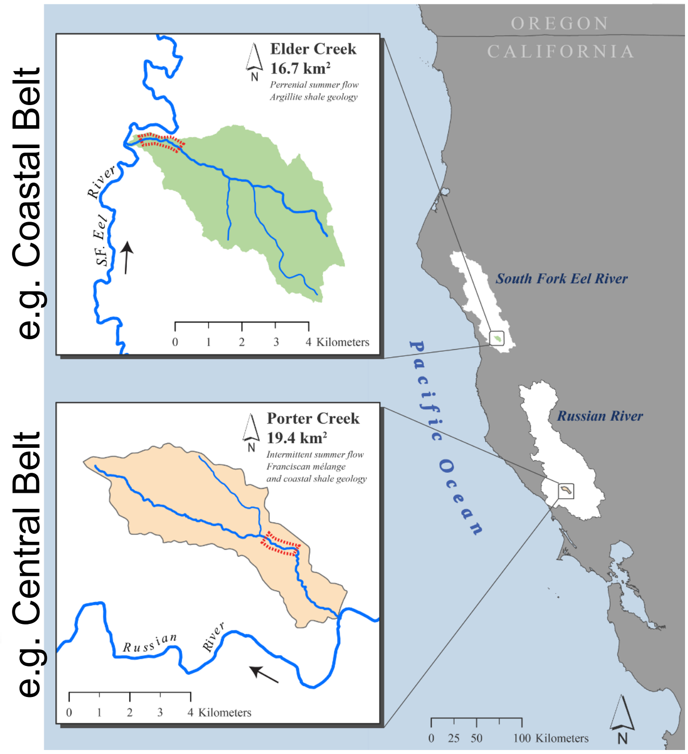
VIII. Stream temperature



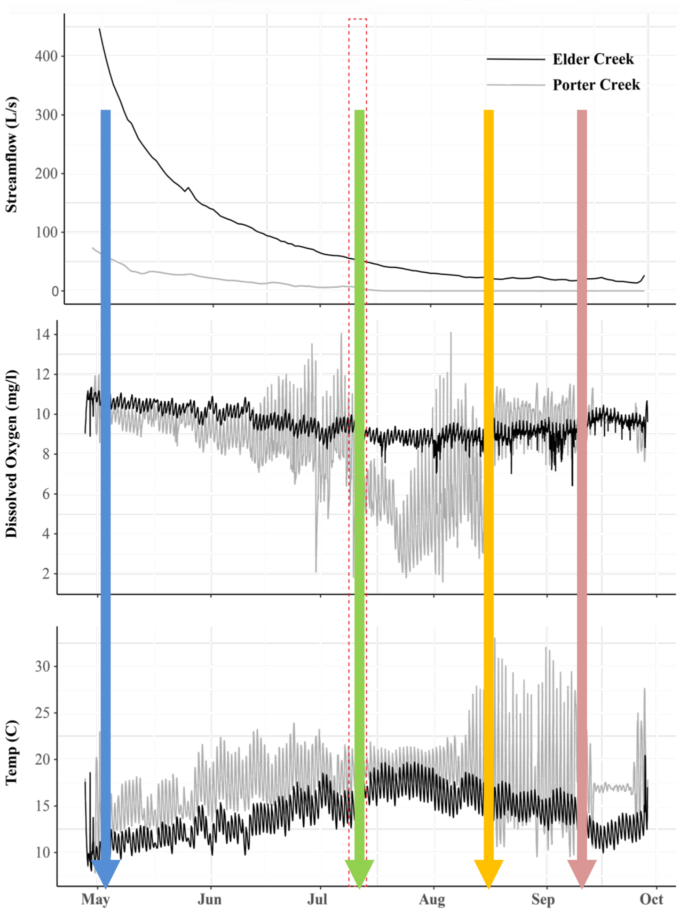
Dralle et al, in review
Preprint: https://eartharxiv.org/repository/view/3526/

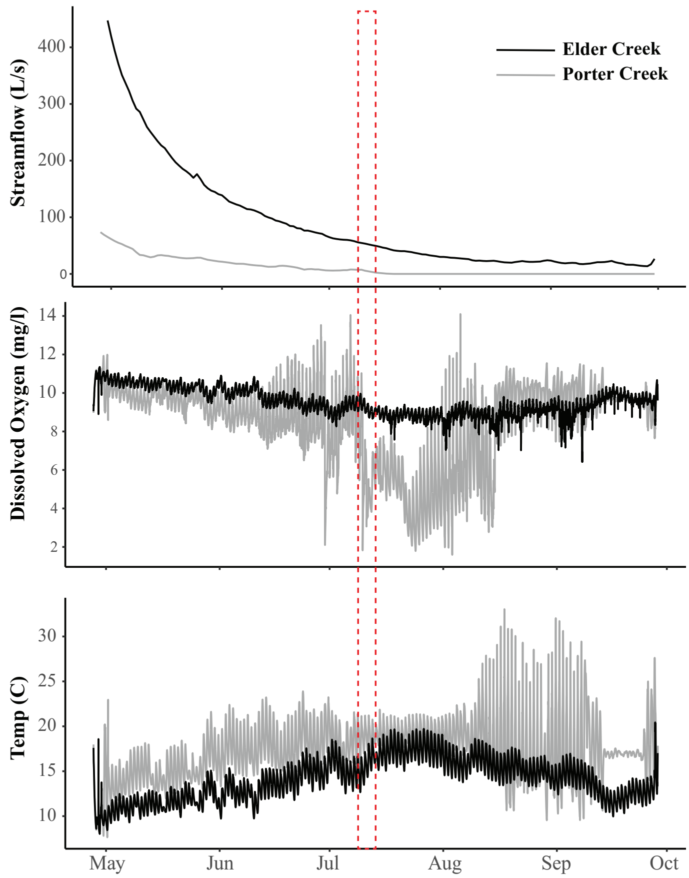
Habitat quantity, quality, and distribution

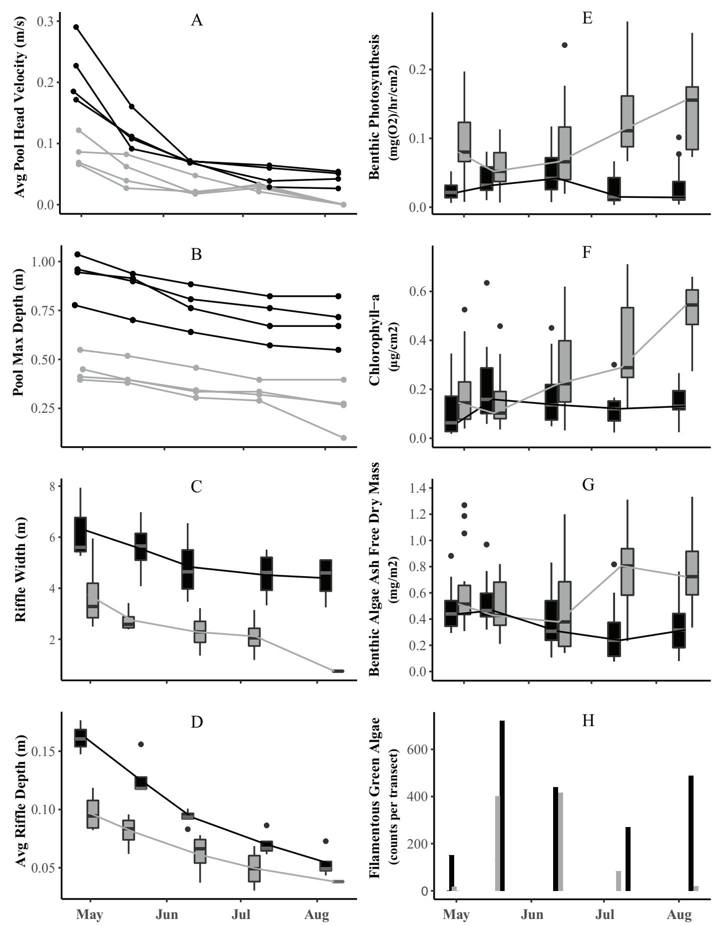


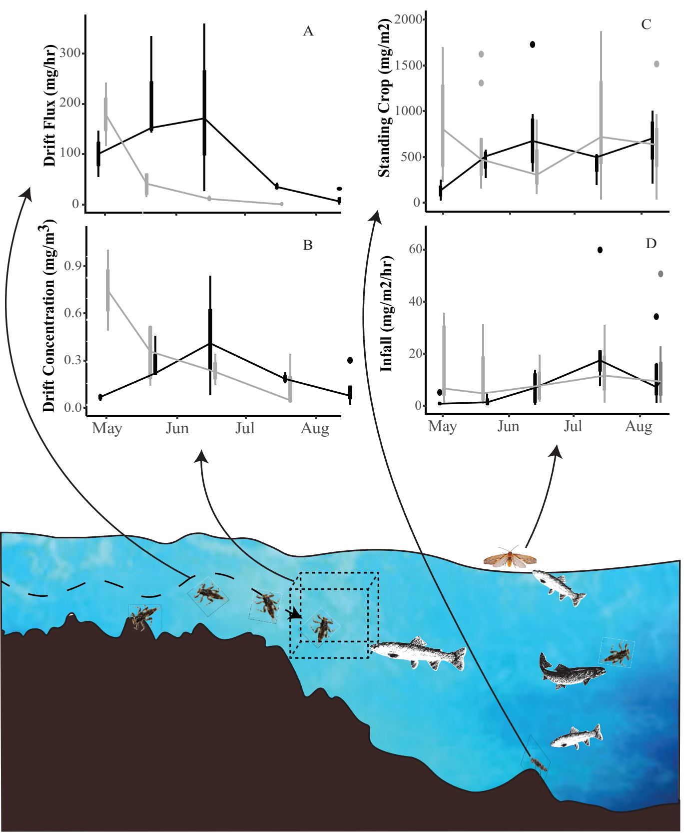


Adapted from Rossi et al. 2022

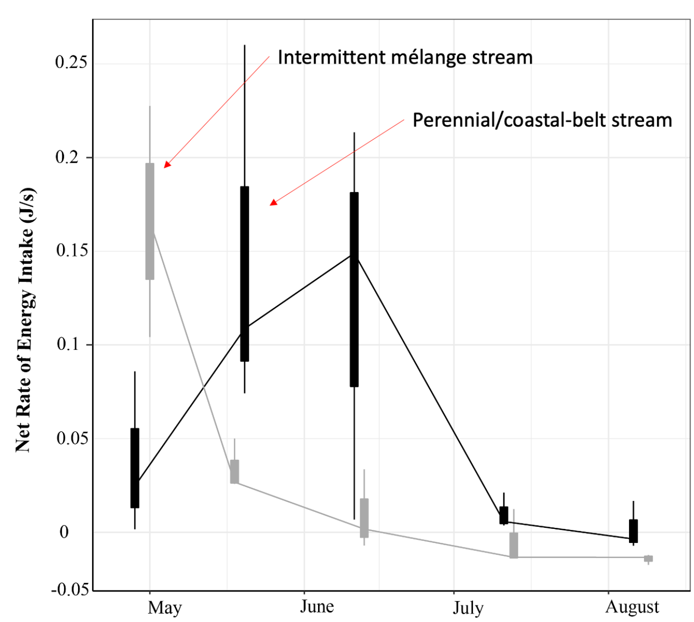


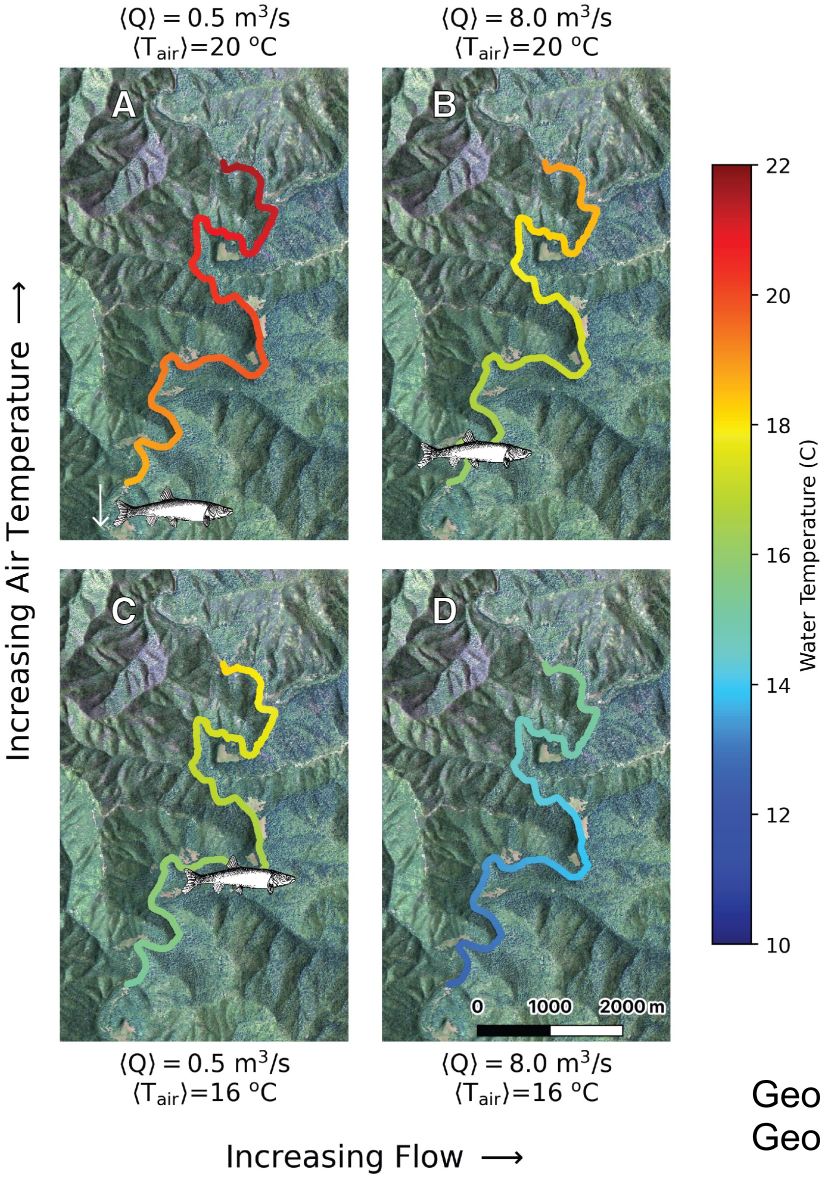






Adapted from Rossi et al. 2022

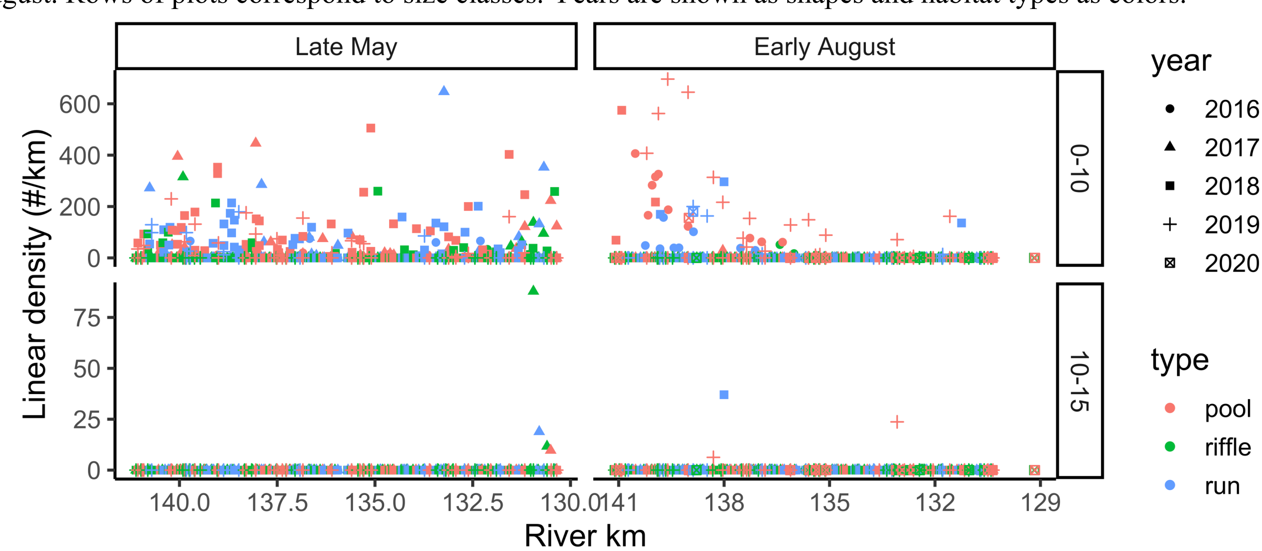


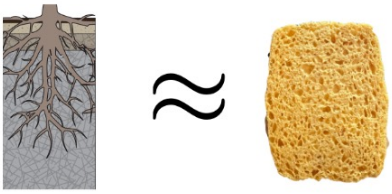


Predicted mean temperature from May 15- July 1 in 4 scenarios. Scenarios are combinations of two mean flow conditions (0.5 and 8.0 m^3/s, x-axis) and two air mean temperatures (16 and 20 °C, y-axis). Mean river temperatures are calculated from the parameter estimates of a linear mixed-effect model. The pikeminnow icon shows where channel mean temperature is 16.3°C, which was the mean temperature from May 15- date of pikeminnow arrival at Wilderness pool from 2015-2019 and is an estimate of pikeminnows upstream distribution July 1 in each scenario. In scenario A the whole reach is above 16.3 °C, and scenario D the 16.3 temp threshold, and presumably the upstream limit of pikeminnow migration for such years, is below our study reach.

Georgakakos 2020 (dissertation)
Georgakakos et al, in prep

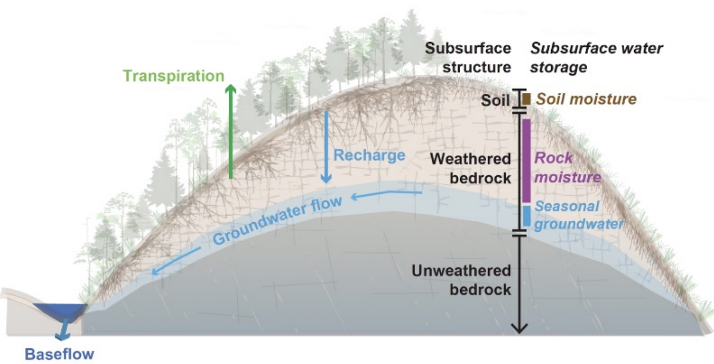
Linear densities of Coho Salmon, (*Oncorhynchus kisutch* calculated by summing the total counts within each unit and dividing by its length. Each point represents one survey. Densities are plotted against River km (where 0 = mouth of SFER, increasing upstream). Left column of plots show surveys in late May and the right Surveys in early August. Rows of plots correspond to size classes. Years are shown as shapes and habitat types as colors.



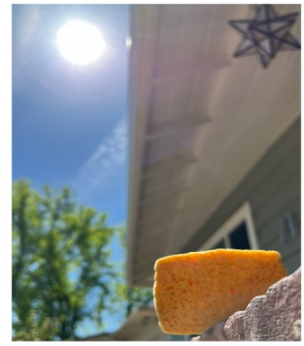


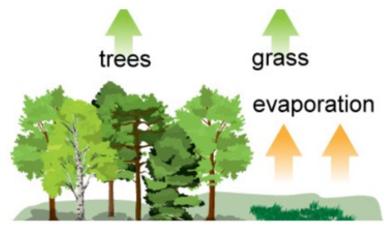
Wisdom of the sponge

Wet sponge drips excess water, and stays wet

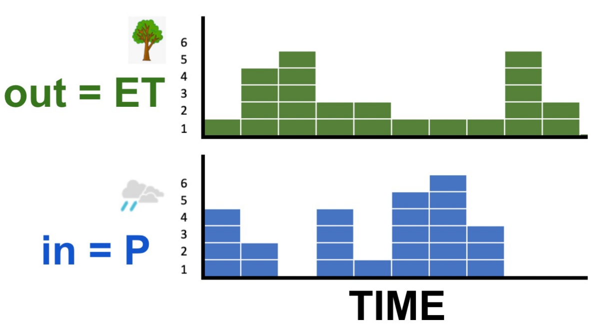


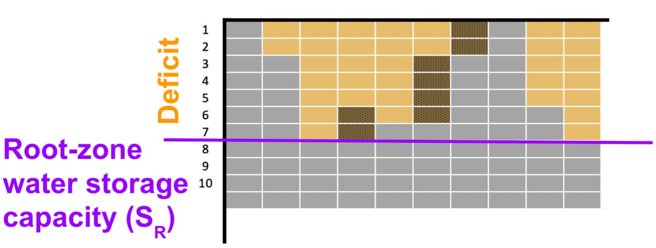
Evaporation fully dries the wet sponge



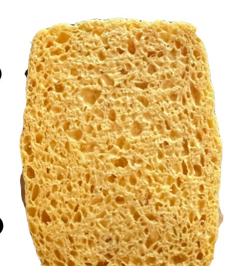


Upscaling by tracking storage deficits





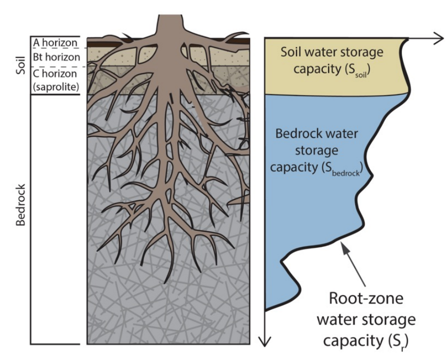
How big?
&
How dry?

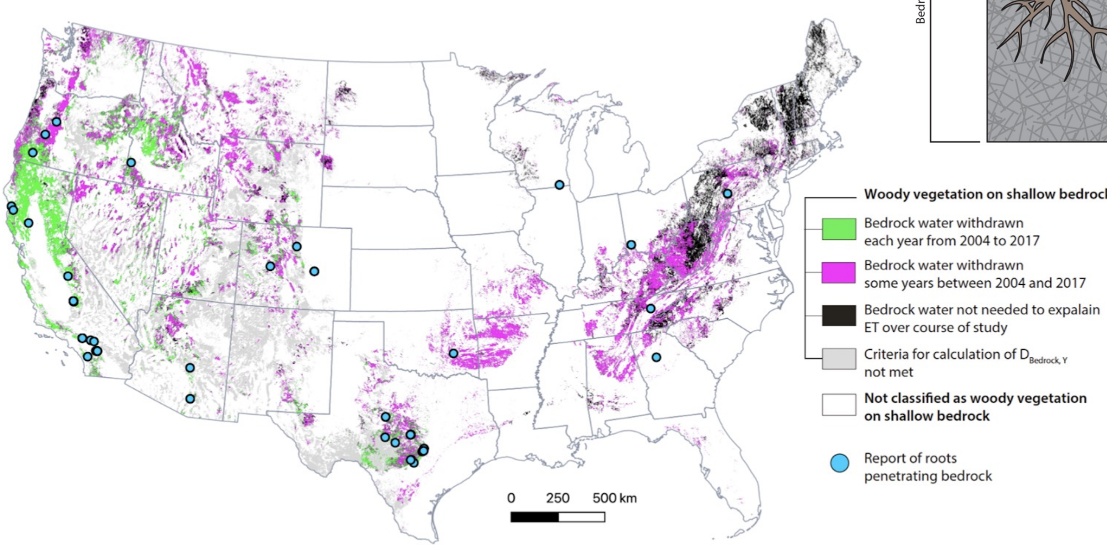


Dralle et al, 2021;
Wang-Erlandsson et al, 2016

Forests in the American West are commonly rooted into weathered bedrock mantled by thin soils

$$S_r = S_{bedrock} + S_{soil}$$





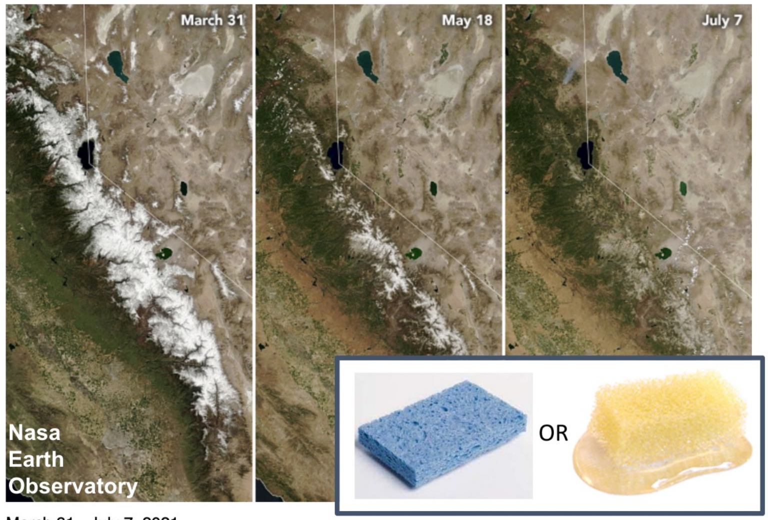
In CA, $S_{bedrock}$ >> S_{soil} and *the volume of bedrock water supplied to forests exceeds that stored in man-made reservoirs.*

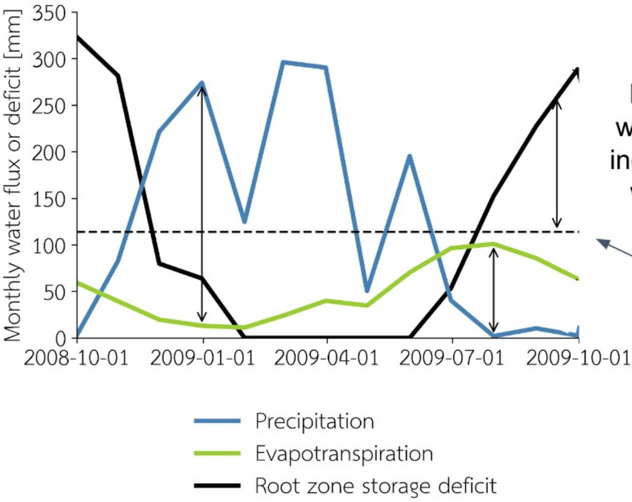
McCormick et al, 2021

The Case of California’s Missing Streamflow

“We have 100 years of data saying if you have this much snow, you would expect this much runoff,” de Guzman said. “But that fell apart this year.”

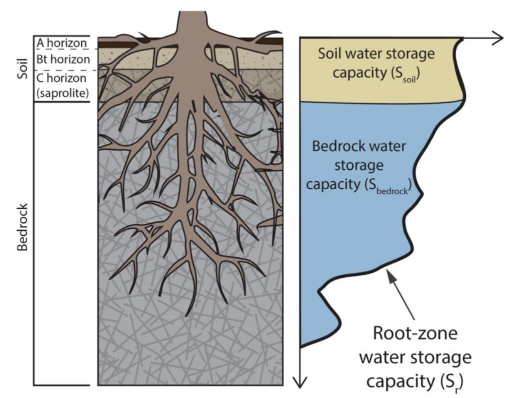
Sean de Guzman, chief of snow surveys and water supply forecasting, CA DWR



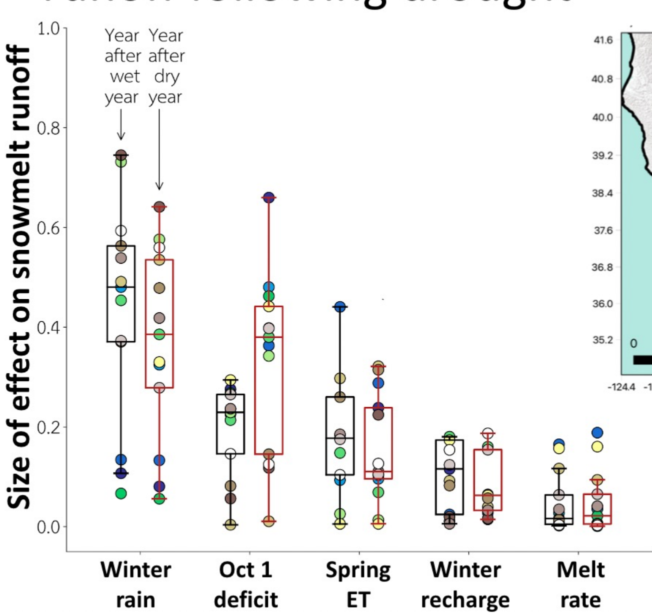


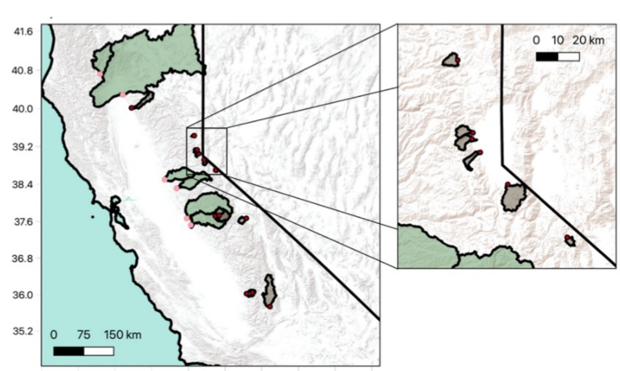
Deficit exceeds soil water capacity—must include water stored in weathered bedrock

Soil water capacity



Deep (below soil) storage deficits explain “missing” runoff following drought



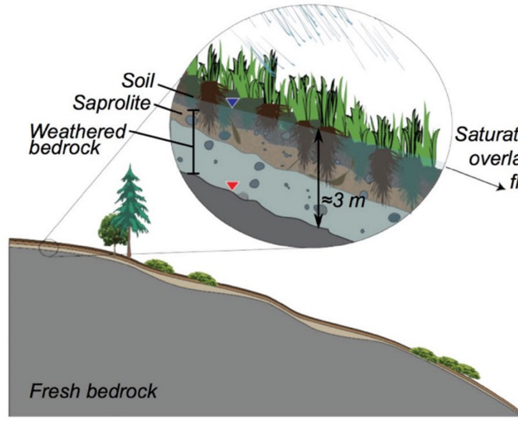


Lapides et al, pending minor revisions (GRL)

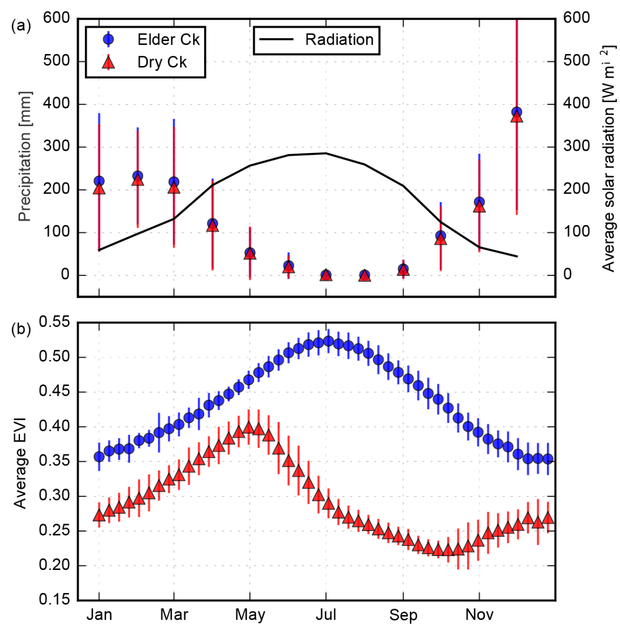
Preprint: https://eartharxiv.org/repository/view/3142/

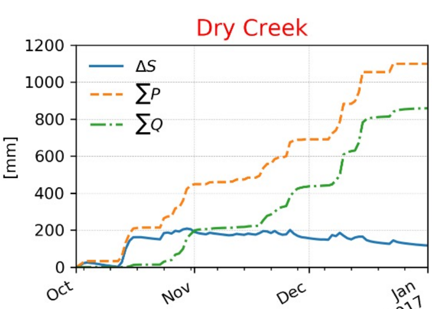
A Central Belt WaterSHED (39.7732, -123.5460)

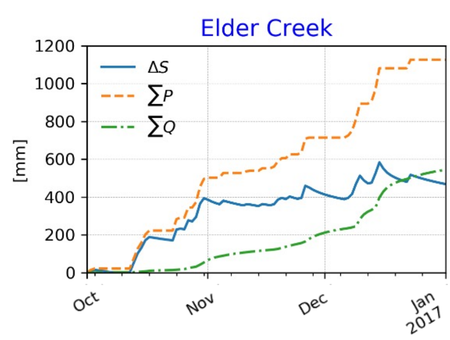
b)



Hahm et al, 2019







Dralle et al, 2018

$$= \boxed{\Delta S} = \sum(\boxed{P} - \boxed{Q} - ET)$$