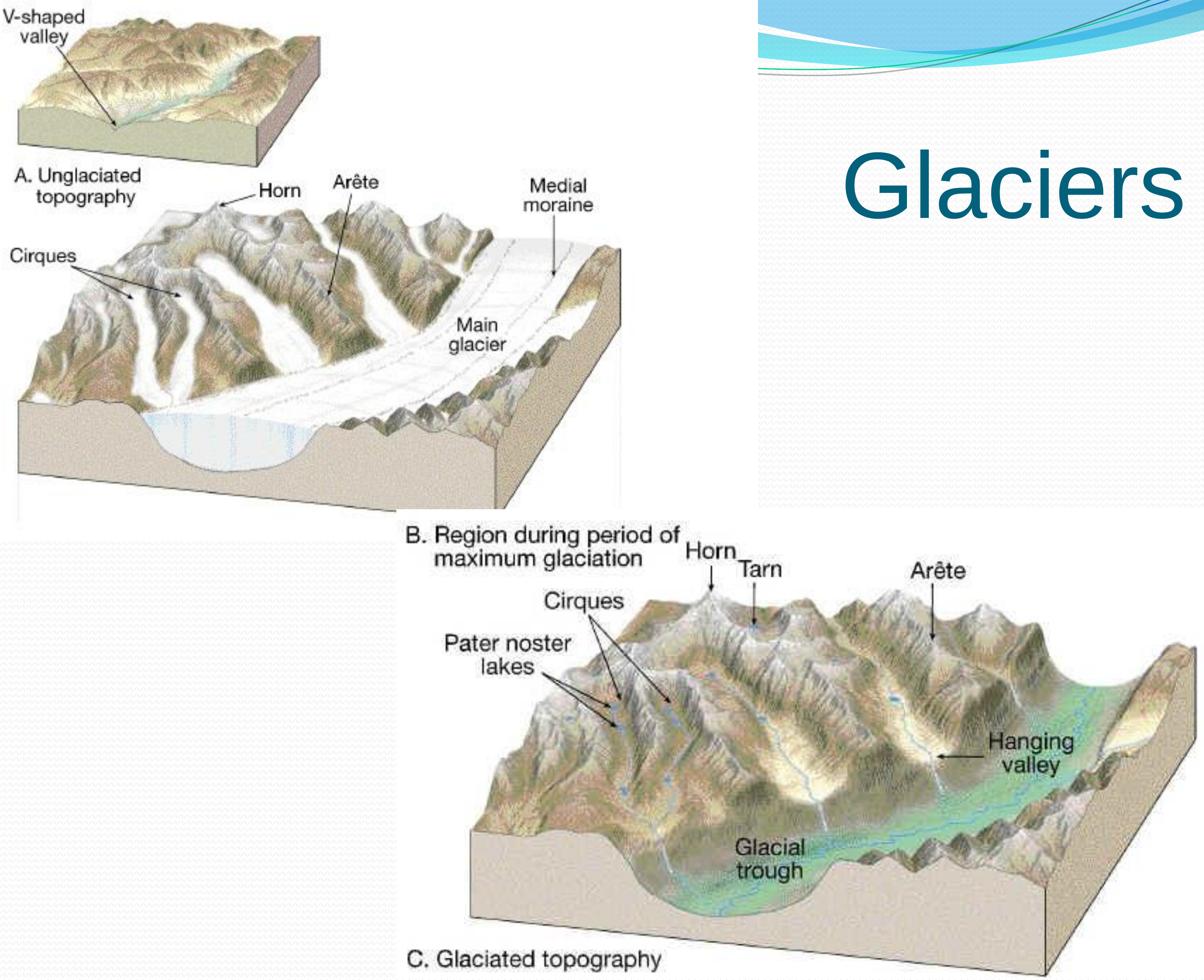
Water and hydrologic processes in California

Ryan G. Lucas
PhD Candidate
Environmental Systems

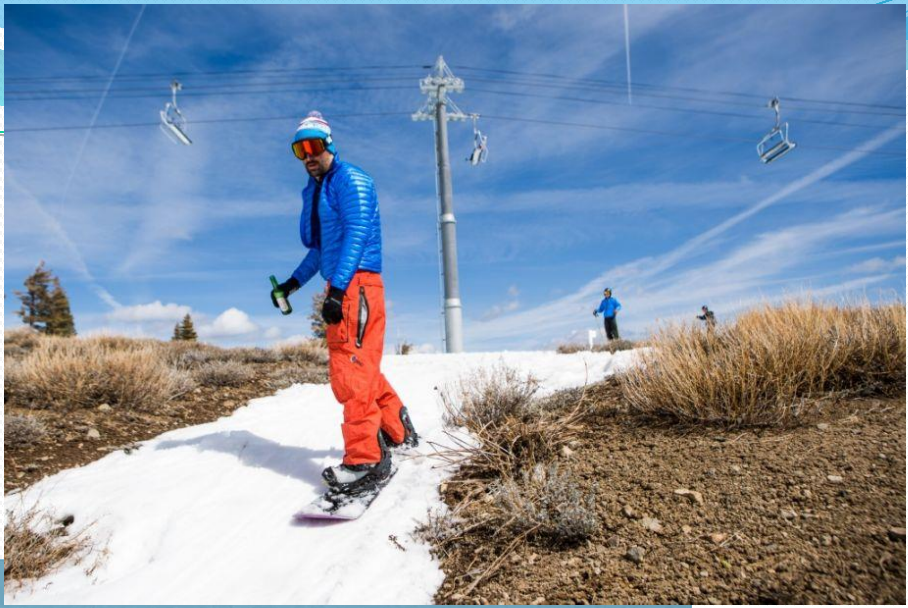
Outline

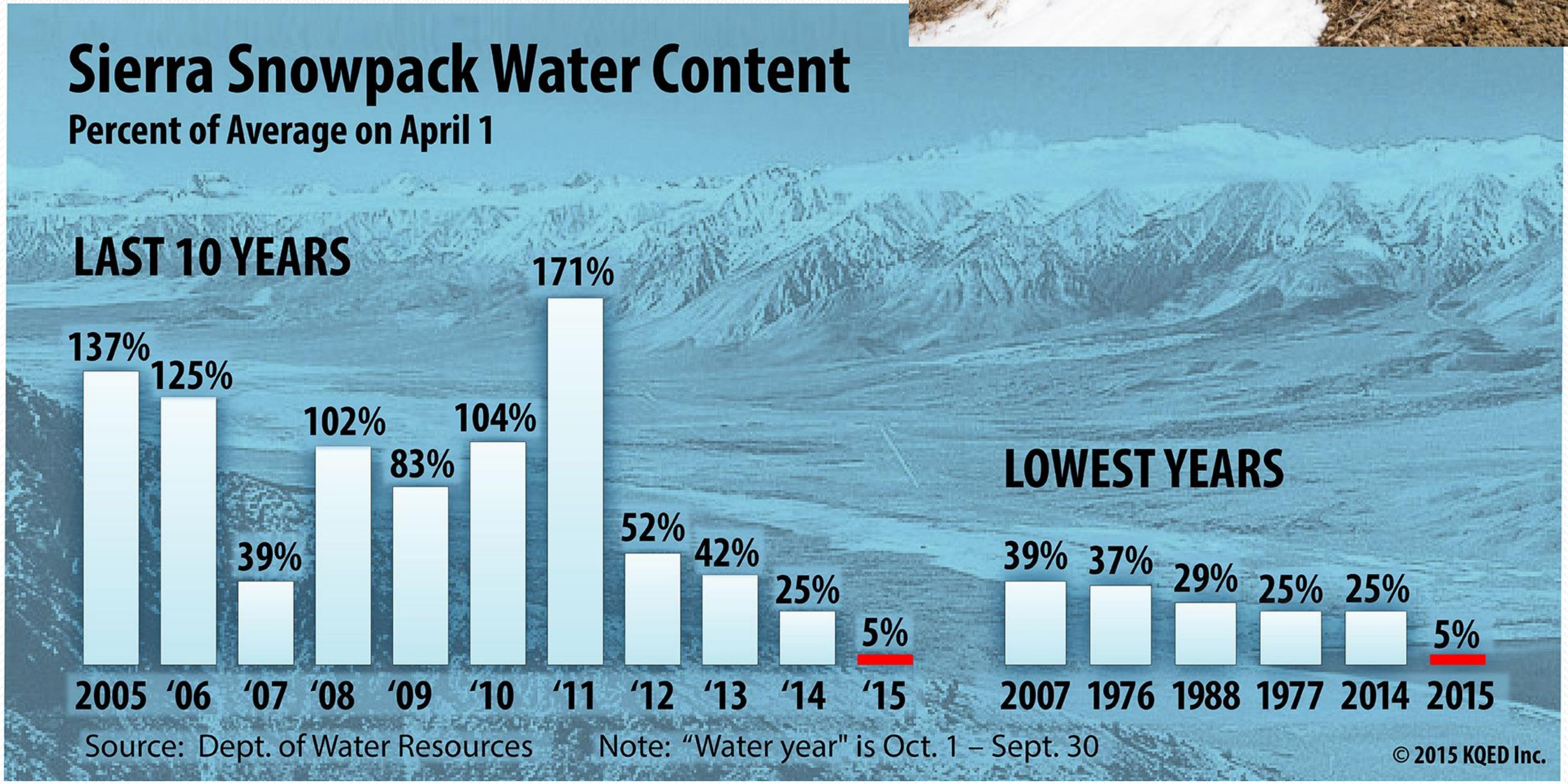
- Natural Processes
- Anthropogenic processes
- Background on my current research.

Glaciers

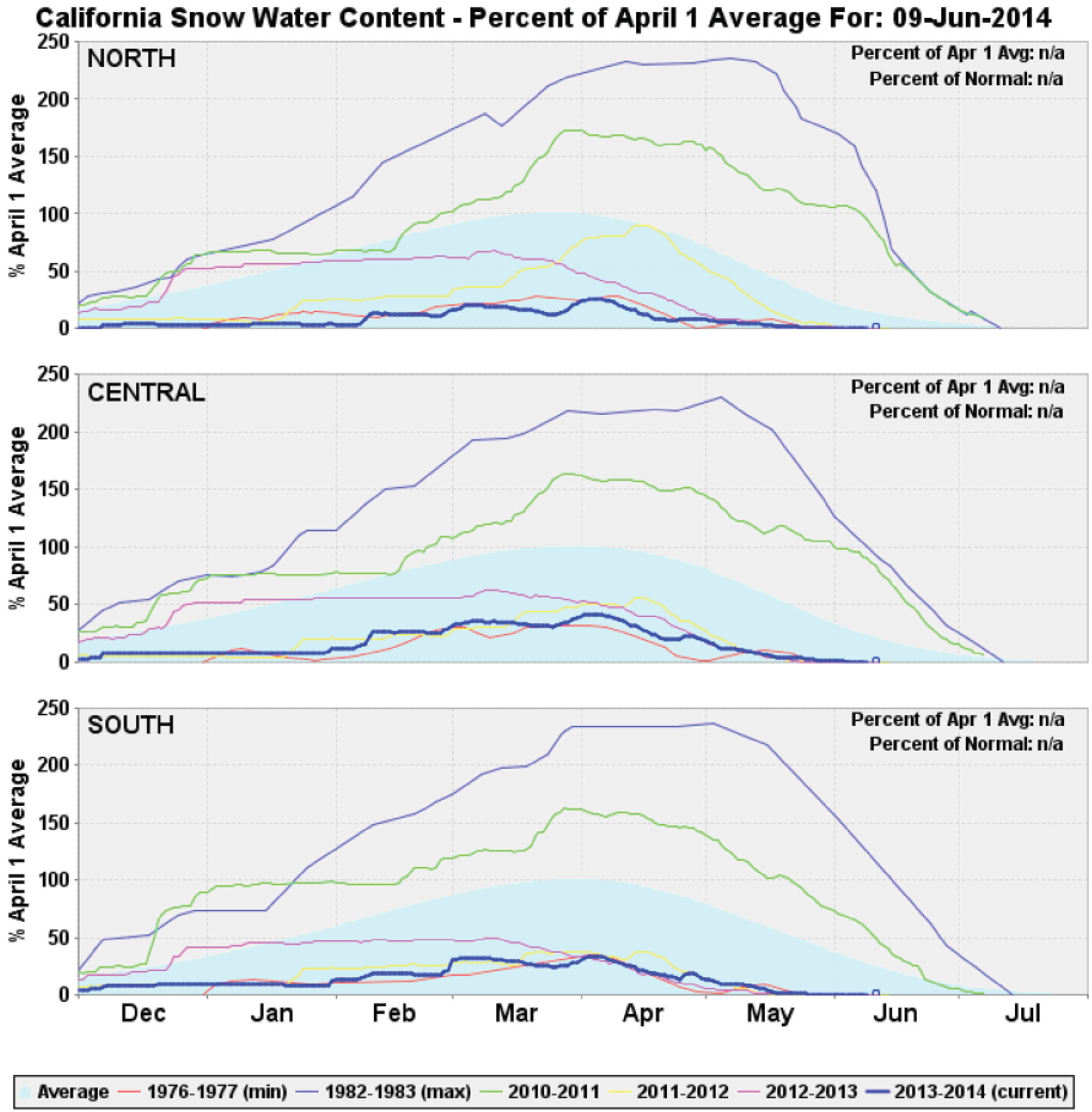

V-shaped valley
A. Unglaciated topography
Horn
Arête
Medial moraine
Cirques
Main glacier
B. Region during period of maximum glaciation
Horn
Tarn
Arête
Cirques
Pater noster lakes
Hanging valley
Glacial trough
C. Glaciated topography

Snow

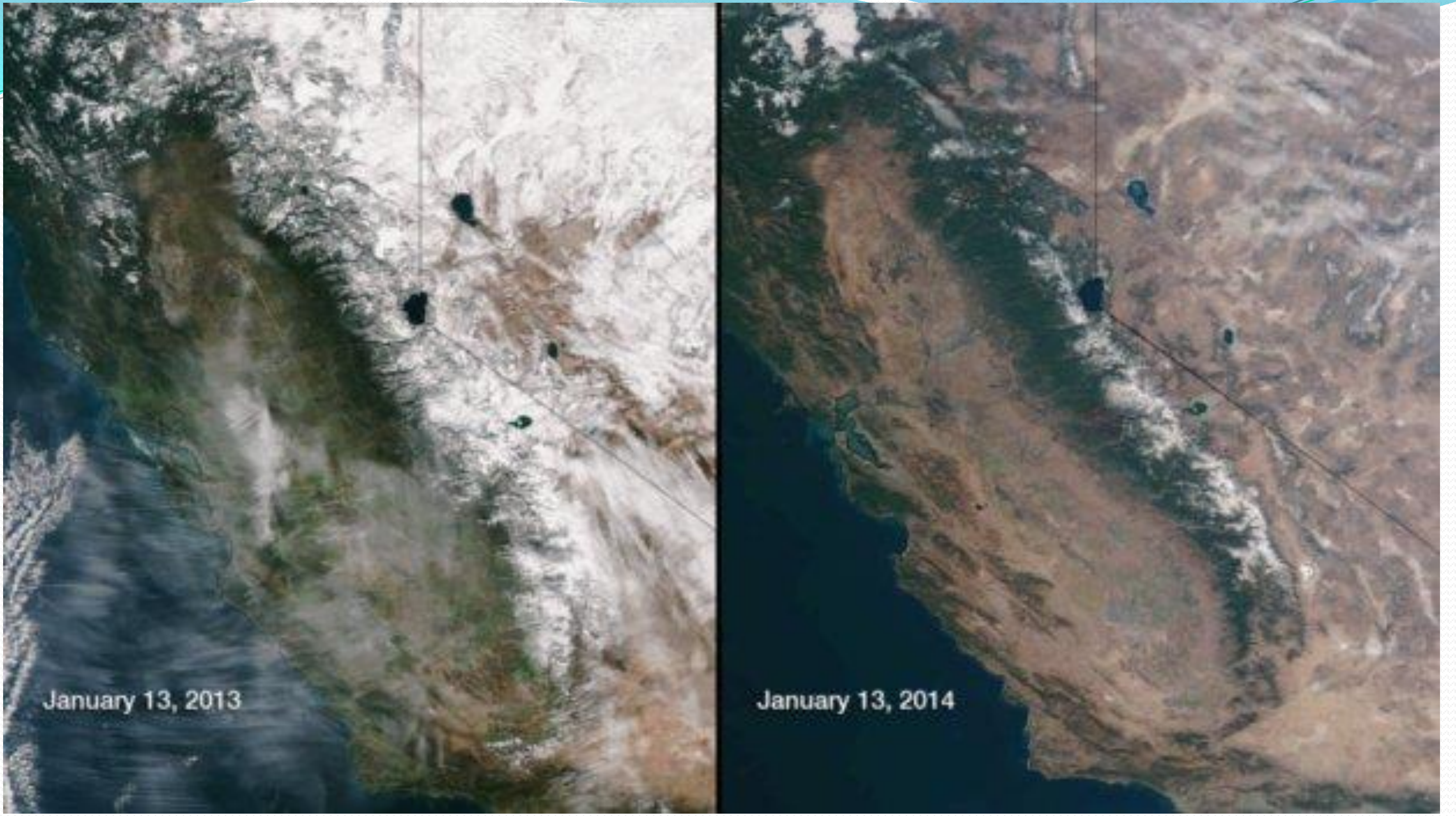




Sierra Snowpack Water Content
Percent of Average on April 1
LAST 10 YEARS
137%
125%
39%
102%
83%
104%
171%
52%
42%
25%
5%
2005 '06 '07 '08 '09 '10 '11 '12 '13 '14 '15
LOWEST YEARS
39%
37%
29%
25%
25%
5%
2007 1976 1988 1977 2014 2015
Source: Dept. of Water Resources
Note: "Water year" is Oct. 1 – Sept. 30
© 2015 KQED Inc.

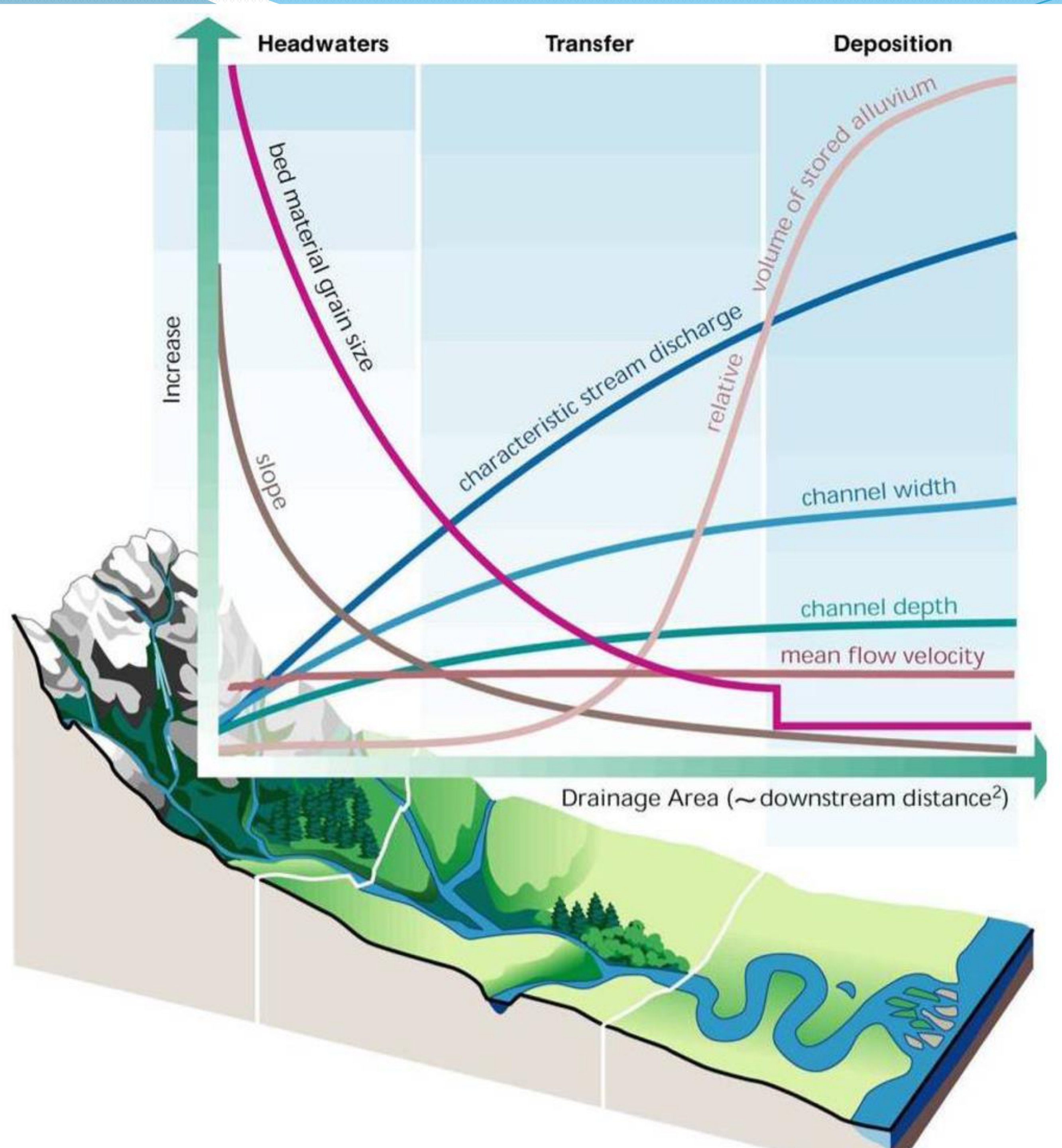


California Snow Water Content - Percent of April 1 Average For: 09-Jun-2014
NORTH
CENTRAL
SOUTH
Percent of Apr 1 Avg: n/a
Percent of Normal: n/a
% April 1 Average
250
200
150
100
50
0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Average
1976-1977 (min)
1982-1983 (max)
2010-2011
2011-2012
2012-2013
2013-2014 (current)

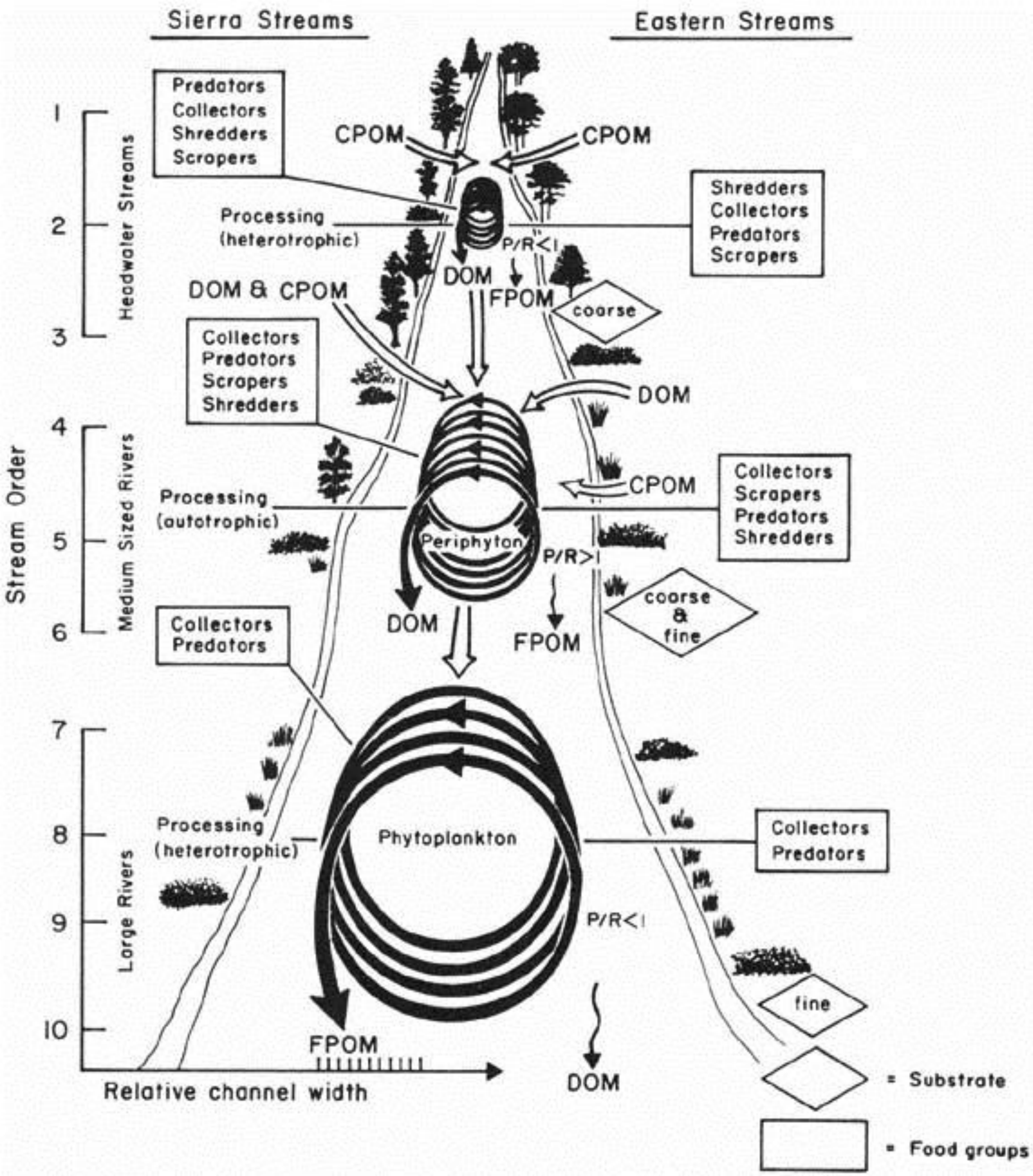


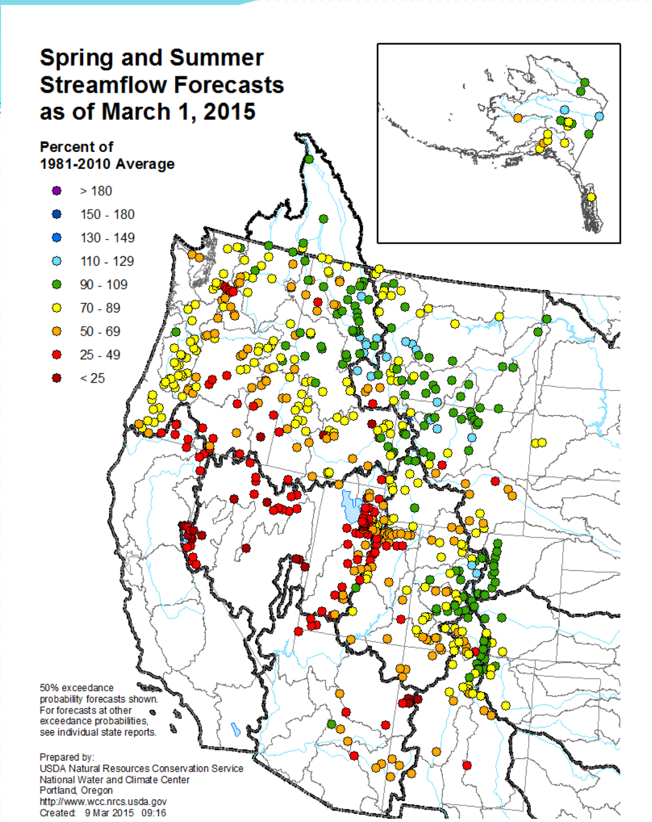
January 13, 2013
January 13, 2014

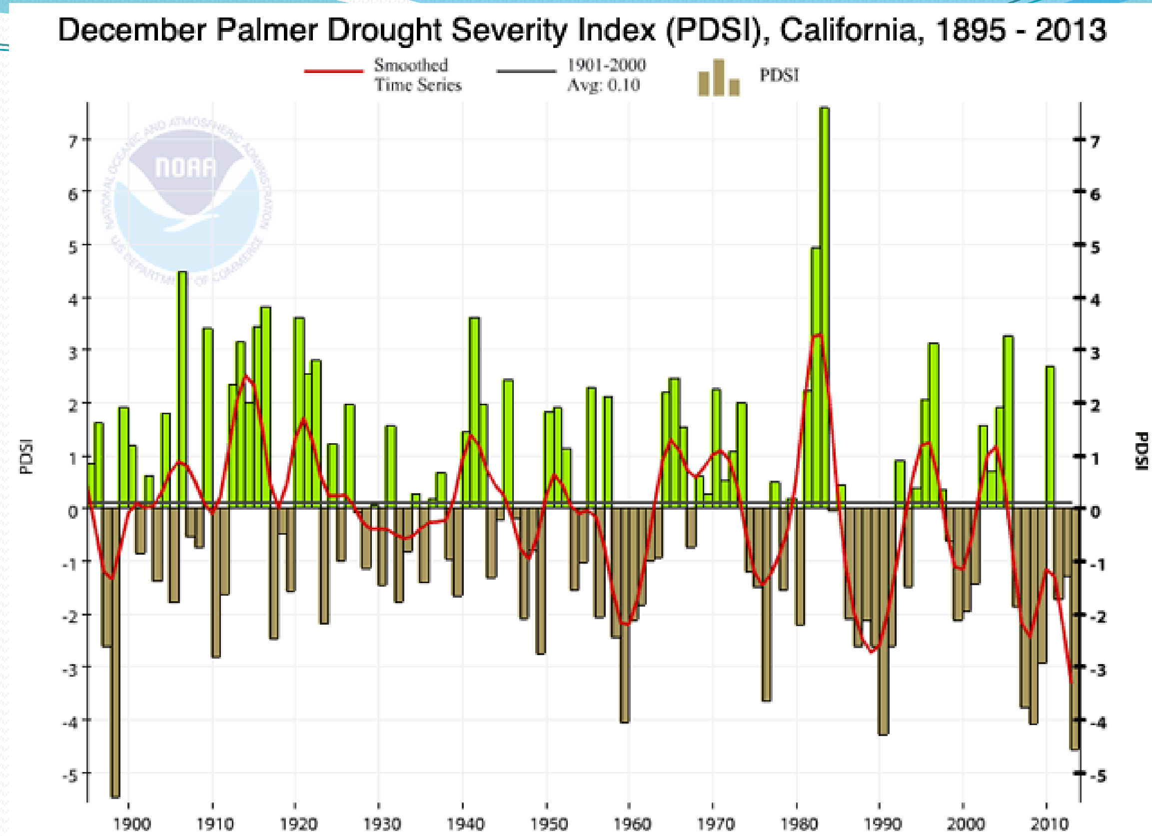

Streams

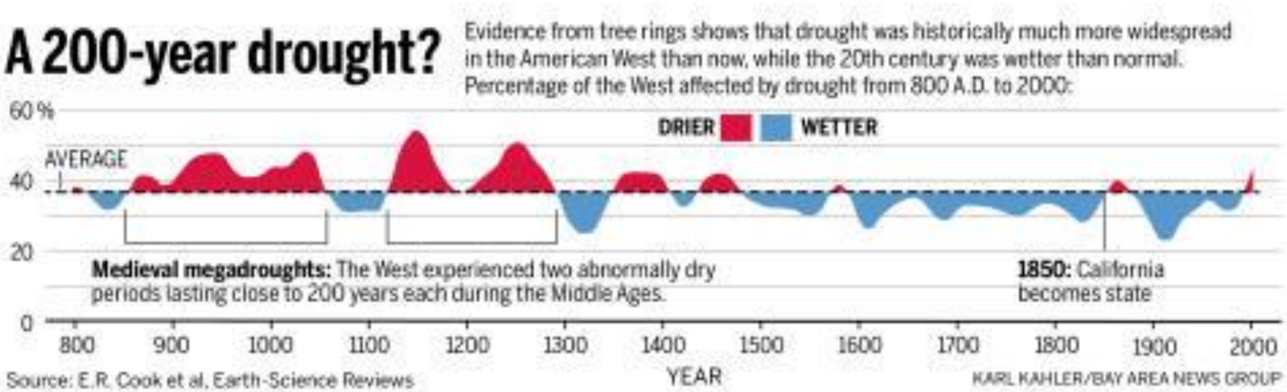


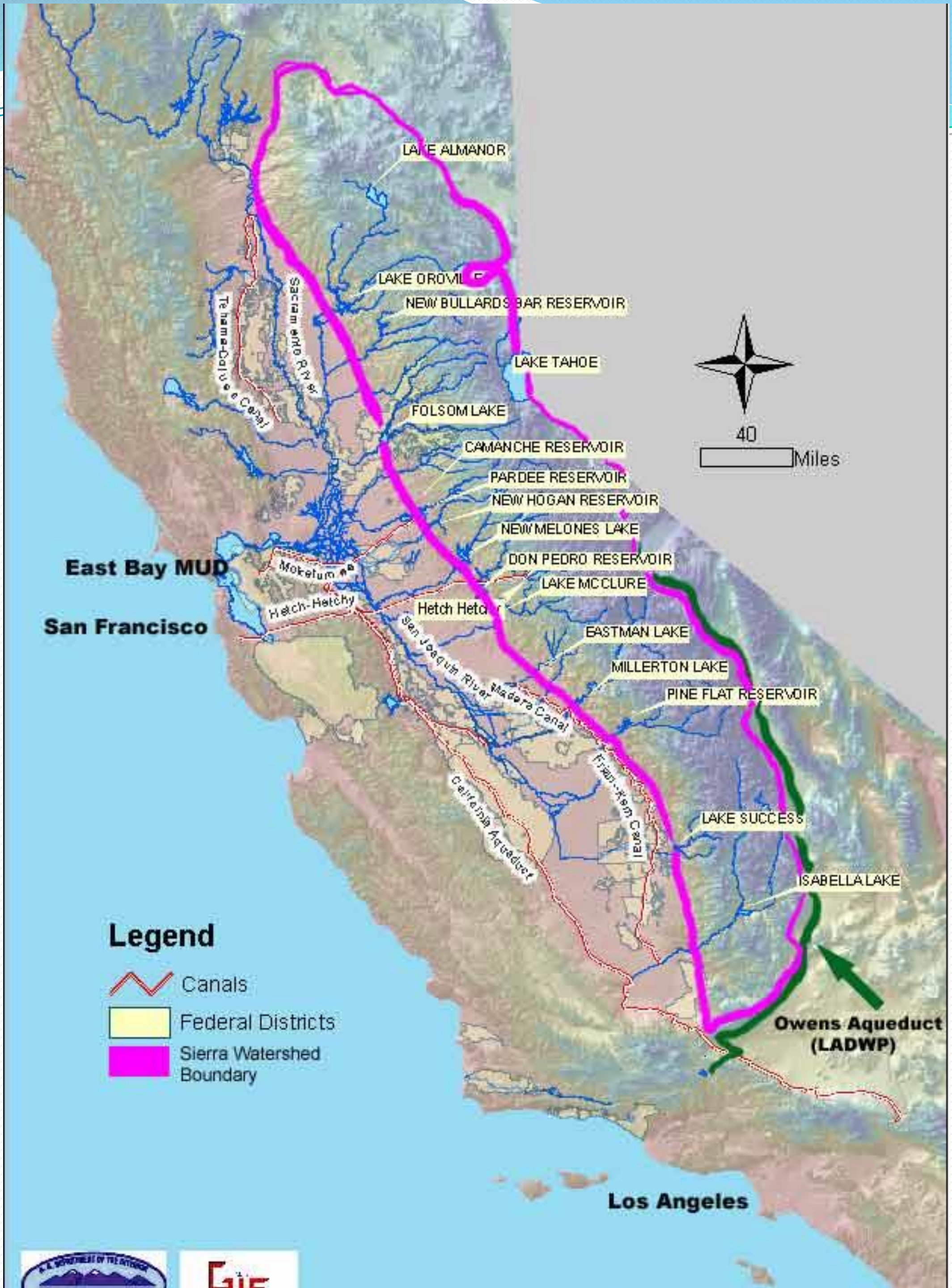
Headwaters
Transfer
Deposition
Increase
bed material grain size
slope
characteristic stream discharge
relative
volume of stored alluvium
channel width
channel depth
mean flow velocity
Drainage Area (~downstream distance^2)


Sierra Streams
Eastern Streams
Predators
Collectors
Shredders
Scrapers
CPOM
CPOM
Shredders
Collectors
Predators
Scrapers
Processing
(heterotrophic)
P/R<1
DOM
DOM & CPOM
FPOM
coarse
Collectors
Predators
Scrapers
Shredders
DOM
Headwater Streams
Stream Order
1
2
3
4
5
6
7
8
9
10
Medium Sized Rivers
Large Rivers
Processing
(autotrophic)
Periphyton
CPOM
Collectors
Scrapers
Predators
Shredders
P/R>1
coarse
&
fine
DOM
FPOM
Collectors
Predators
Processing
(heterotrophic)
Phytoplankton
Collectors
Predators
P/R<1
fine
FPOM
DOM
Relative channel width
= Substrate
= Food groups


Spring and Summer Streamflow Forecasts as of March 1, 2015
Percent of 1981-2010 Average
> 180
150 - 180
130 - 149
110 - 129
90 - 109
70 - 89
50 - 69
25 - 49
< 25
50% exceedance probability forecasts shown. For forecasts at other exceedance probabilities, see individual state reports.
Prepared by:
USDA Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov
Created: 9 Mar 2015 09:16


December Palmer Drought Severity Index (PDSI), California, 1895 - 2013
Smoothed Time Series
1901-2000 Avg: 0.10
PDSI
NOAA
PDSI
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010


A 200-year drought?
Evidence from tree rings shows that drought was historically much more widespread in the American West than now, while the 20th century was wetter than normal.
Percentage of the West affected by drought from 800 A.D. to 2000:
60 %
40
20
0
AVERAGE
DRIER
WETTER
Medieval megadroughts: The West experienced two abnormally dry periods lasting close to 200 years each during the Middle Ages.
1850: California becomes state
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
YEAR
Source: E.R. Cook et al, Earth-Science Reviews
KARL KAHLER/BAY AREA NEWS GROUP

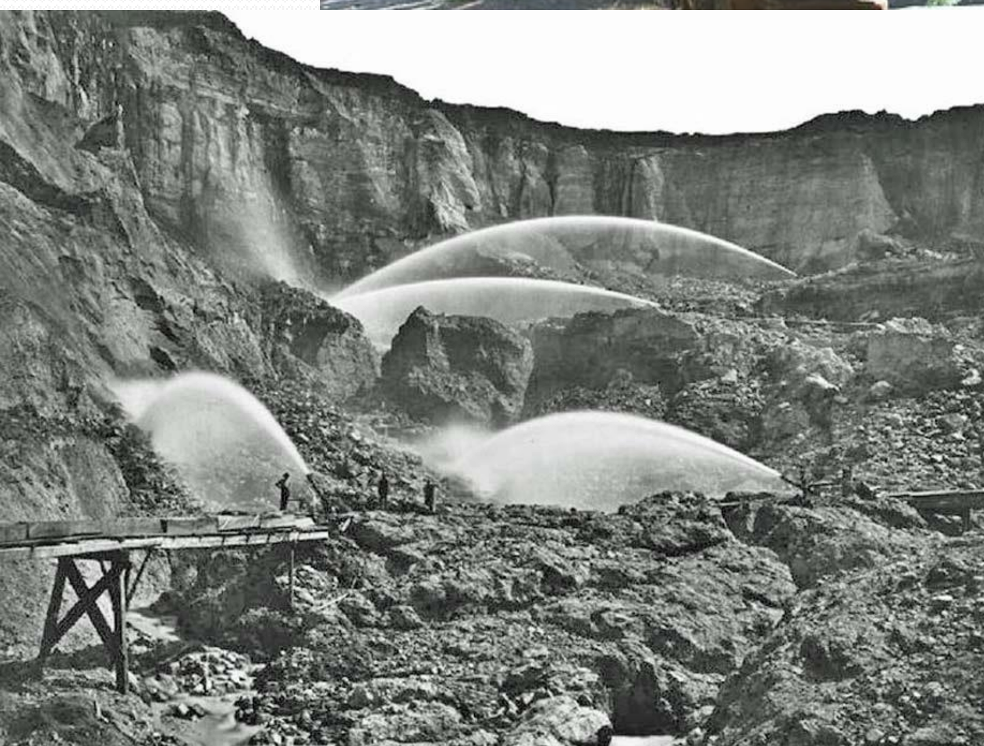

LAKE ALMANOR
LAKE OROVILLE
NEW BULLARDS BAR RESERVOIR
LAKE TAHOE
FOLSOM LAKE
CAMANCHE RESERVOIR
PARDEE RESERVOIR
NEW HOGAN RESERVOIR
NEW MELONES LAKE
DON PEDRO RESERVOIR
LAKE MCCLURE
Hetch Hetchy
EASTMAN LAKE
MILLERTON LAKE
PINE FLAT RESERVOIR
LAKE SUCCESS
ISABELLA LAKE
Tehama-Colusa Canal
Sacramento River
Mokelumne
Hetch-Hetchy
San Joaquin River
Madera Canal
Friant-Kern Canal
California Aqueduct
East Bay MUD
San Francisco
Los Angeles
40
Miles
Owens Aqueduct
(LADWP)
Legend
Canals
Federal Districts
Sierra Watershed
Boundary

Delta

https://www.youtube.com/watch?v=cPSZ3iMmdT8

Anthropogenic Influences

- Mining
- Water diversions, dams, and irrigation
- Logging
- Climate Change



Malakoff Diggins SP

Old hydraulic mine and dump, canyon of Stanislaus River near Parrott bridge. The tailings are said to have been arrested by a brush dam, which afterwards gave way. Big Trees quadrangle, Tuolumne County, California. 1905.

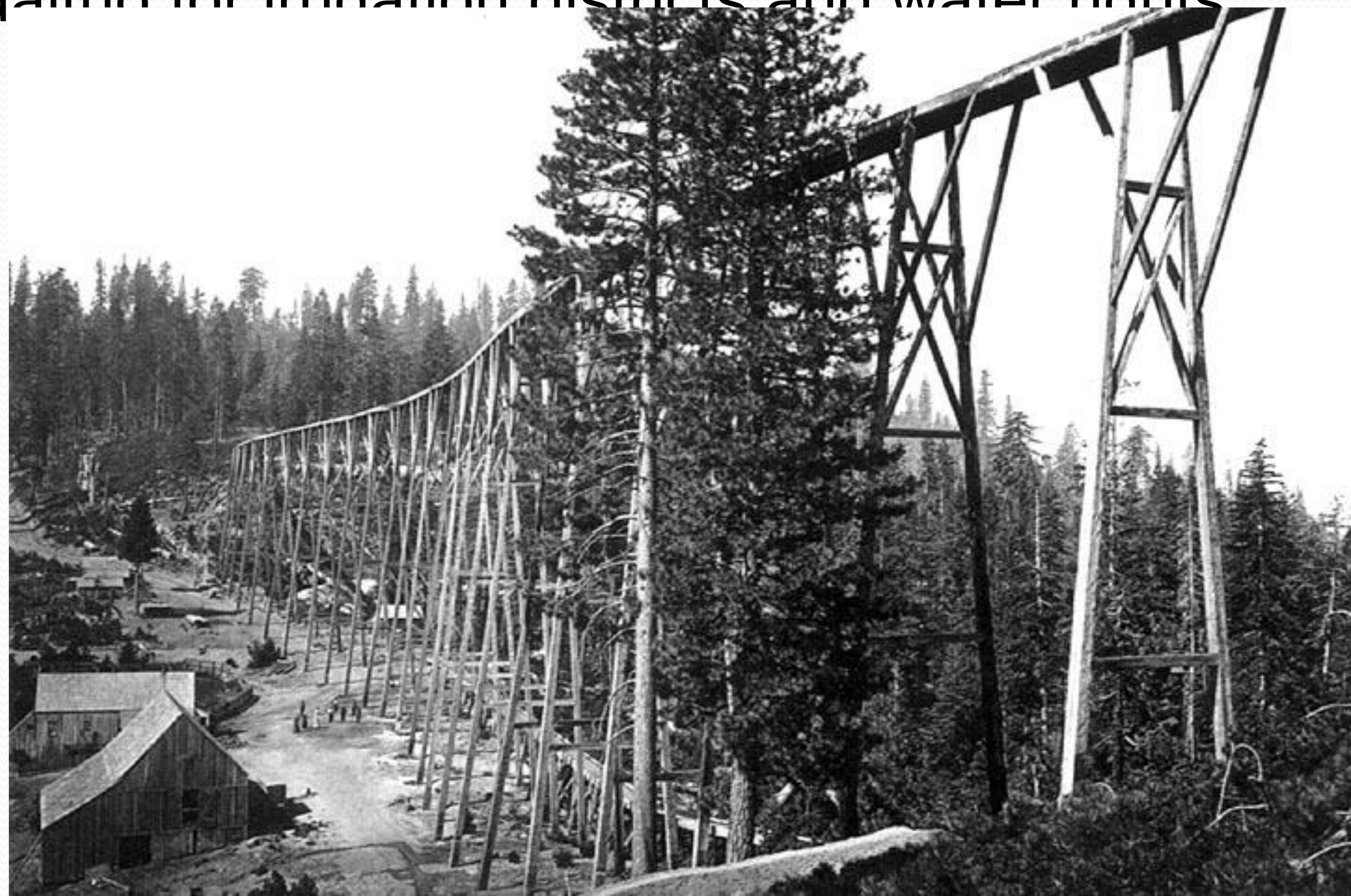

ogle earth


gle earth


Gold Dredge – between
Snelling and Hornitos, Calif.
Zan 1386

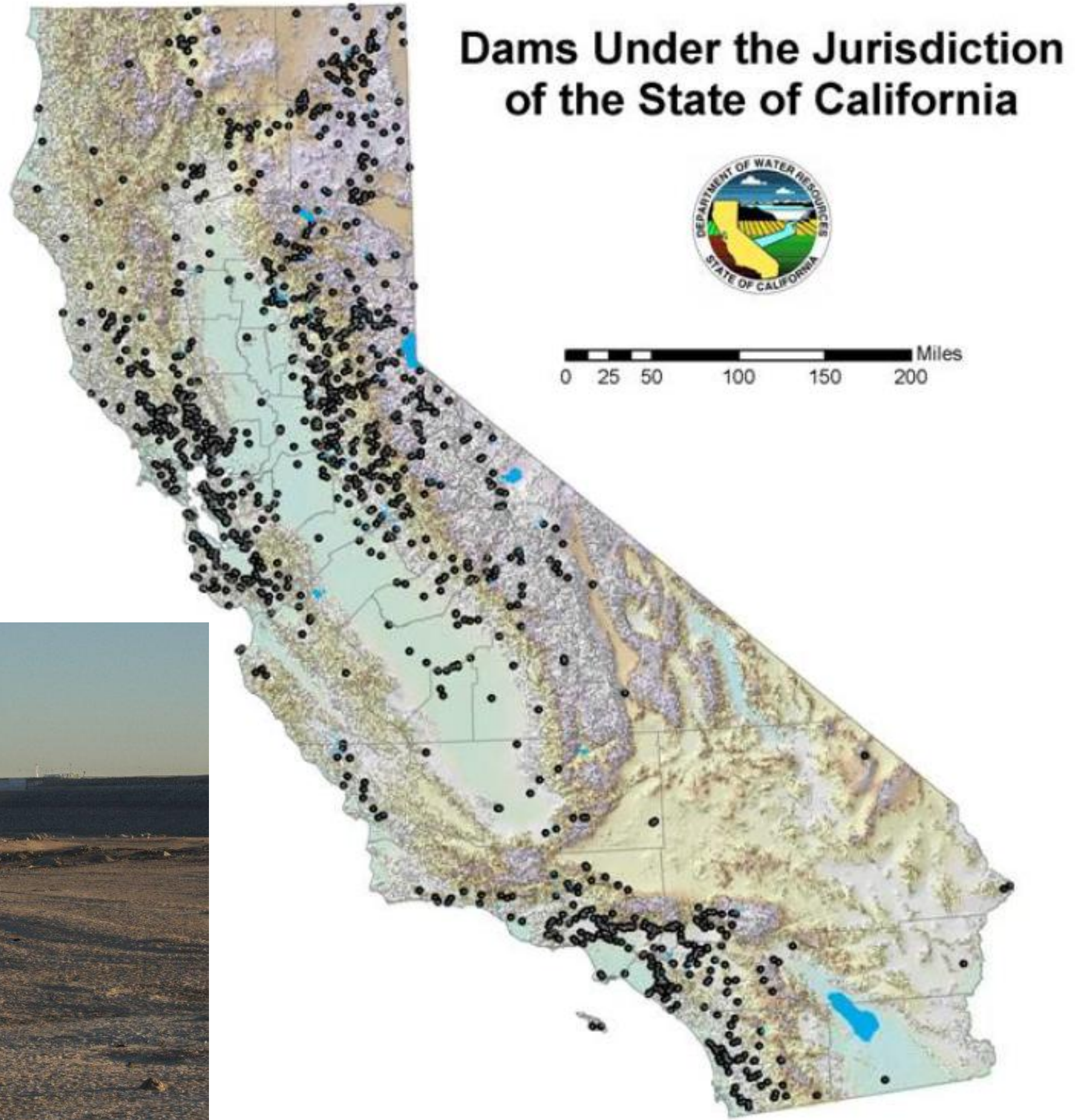
Diversions

- Mining resulted in large ammounts of water diversions
- Laid foundaitno for irrigation districts and water rights laws.




KLAMATH RIVER
Ah Pah Reservoir
TRINITY TUNNEL
EEL RIVER
SACRAMENTO RIVER
Glenn Reservoir
Dos Rios Reservoir
Sites Reservoir
Antelope Lake
Lake Davis
Frenchmans Lake
Lake Oroville
Oroville-Thermalito Complex
FEATHER RIVER
Sacramento
NORTH BAY AQUEDUCT
PERIPHERAL CANAL
SACRAMENTO-SAN JOAQUIN RIVER DELTA
Lake Del Valle
Clifton Court Forebay
San Francisco
SOUTH BAY AQUEDUCT
O'Neill Forebay
San Luis Reservoir
Los Banos Grande Reservoir
CALIFORNIA AQUEDUCT
COASTAL BRANCH
Bakersfield
Lake Cachuma
CCWA EXTENSION
WEST BRANCH
EAST BRANCH
Pyramid Lake
Castaic Lake
Los Angeles
Silverwood Lake
EAST BRANCH EXTENSION
Lake Perris
Lake Skinner
SECOND SAN DIEGO AQUEDUCT
San Diego

Dams


Dams Under the Jurisdiction of the State of California
DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
0 25 50 100 150 200
Miles

Groundwater use

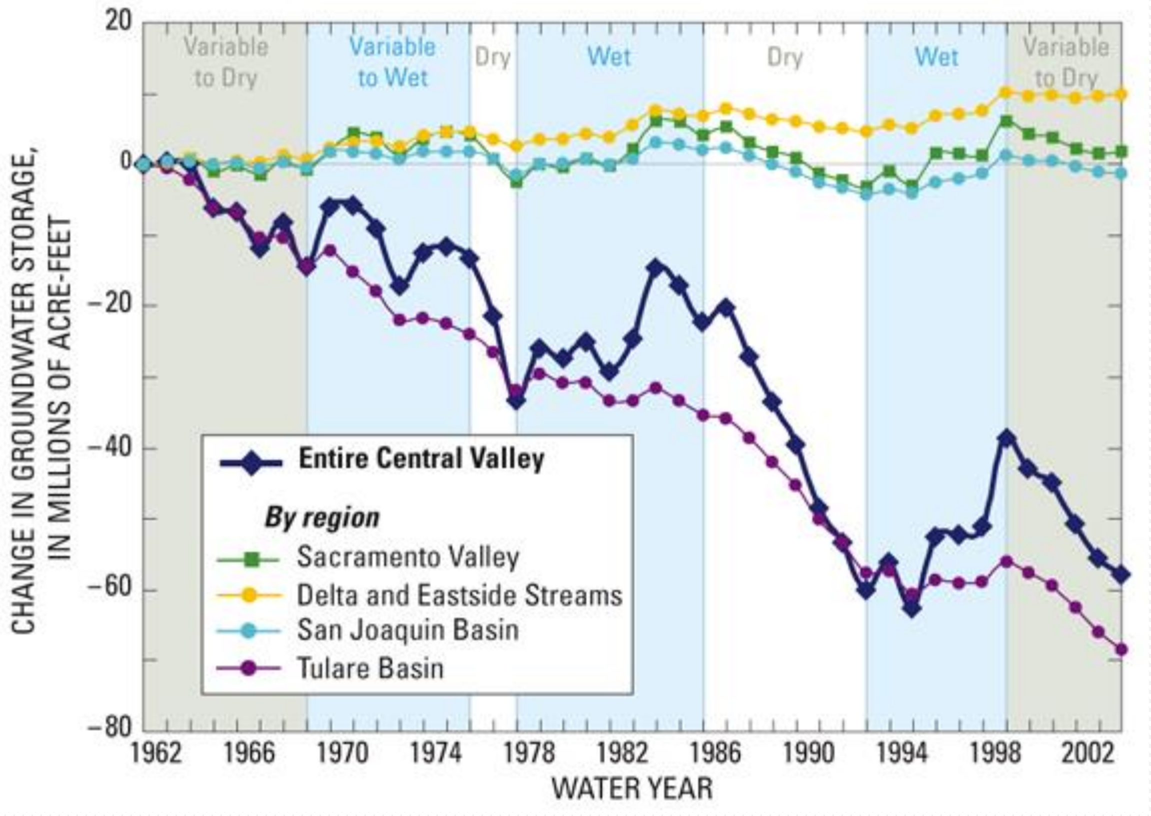
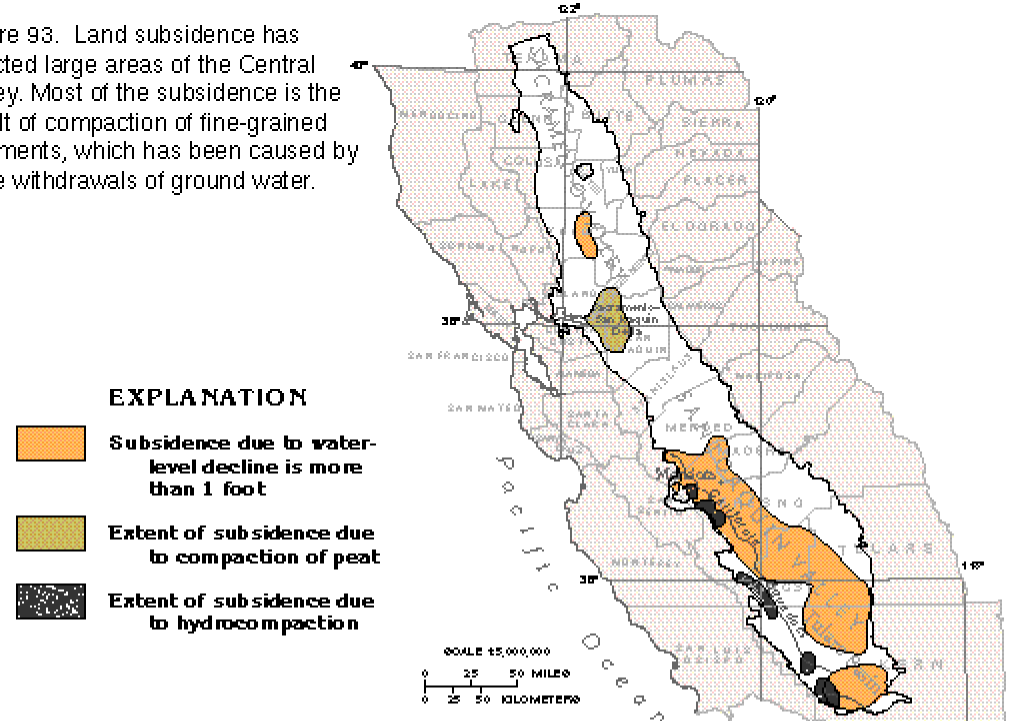
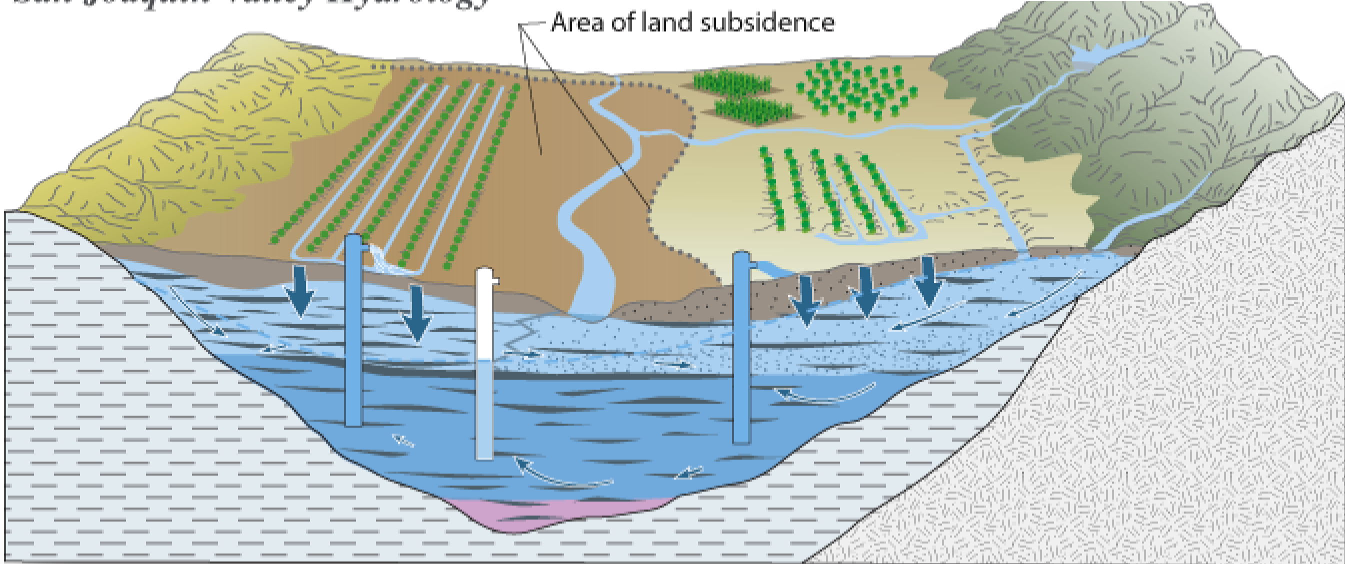


Figure 93. Land subsidence has affected large areas of the Central Valley. Most of the subsidence is the result of compaction of fine-grained sediments, which has been caused by large withdrawals of ground water.

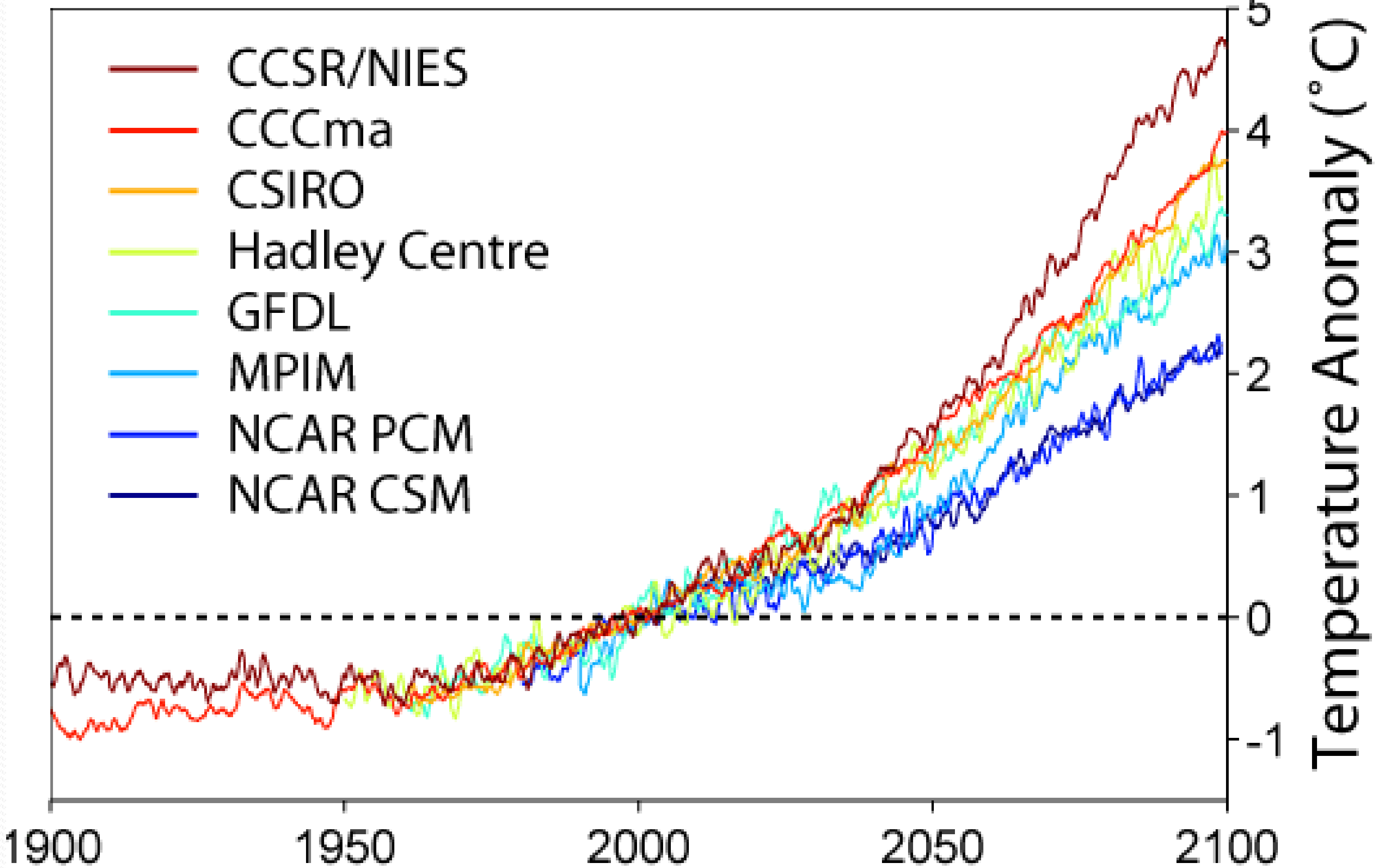


Williamson, A.K., Prudic, D.E., and Swain, L.A., 1989, Ground-water flow in the Central Valley, California: U.S. Geological Survey Professional Paper 1401–D, 127 p.

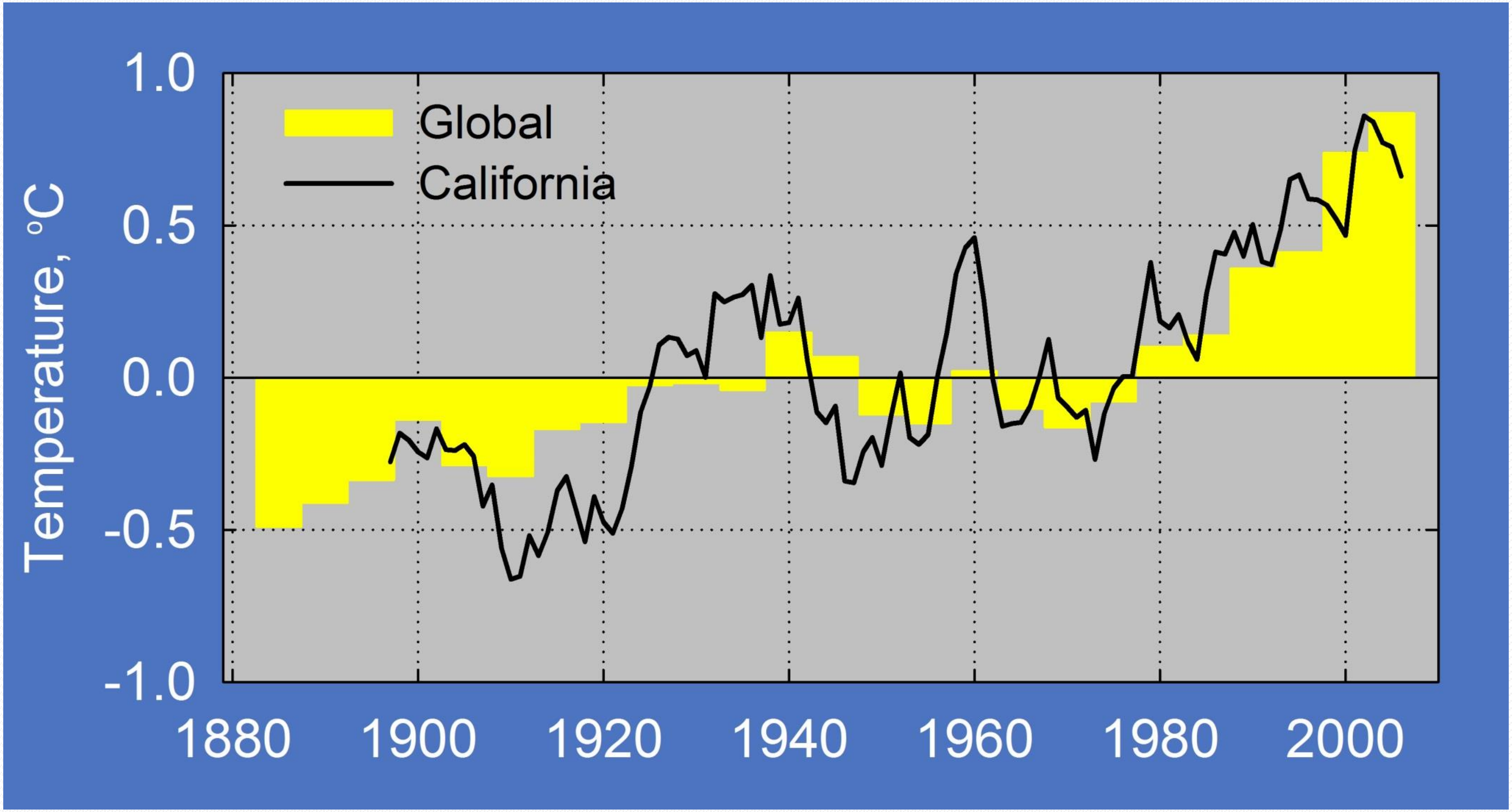
San Joaquin Valley Hydrology



Global Warming Projections

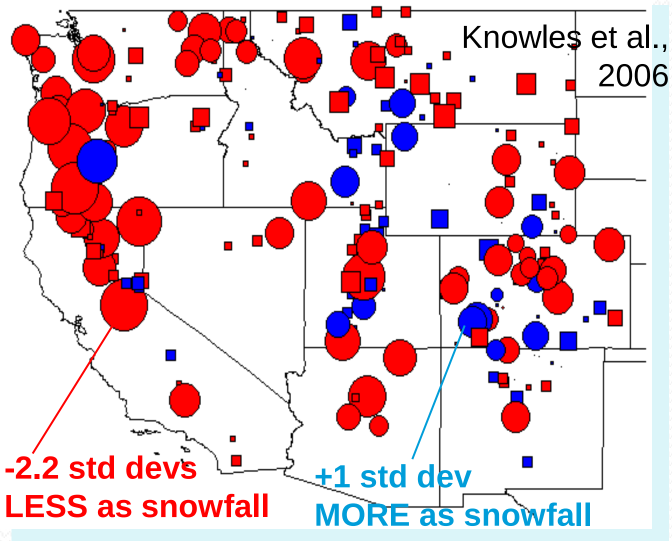


California has been warming in recent decades, following the global trend



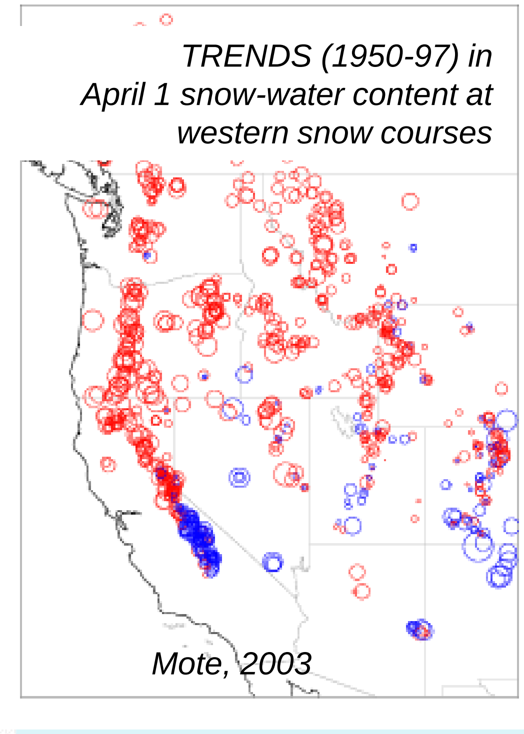
Land surface temperatures
5-yr average departure from 1901-2000 mean

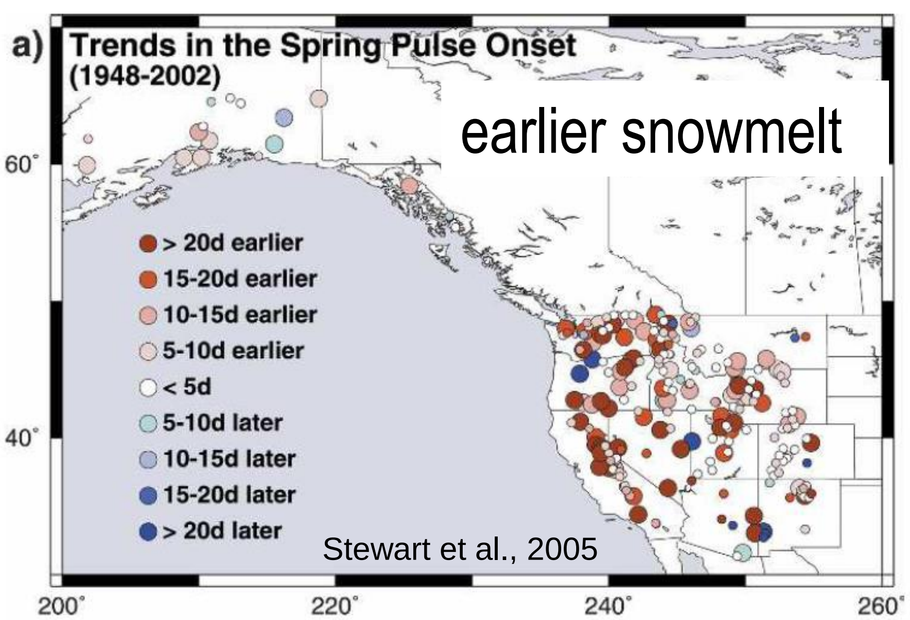
Observed changes in water cycle go beyond historical levels



less snow
more rain

less spring
snowpack

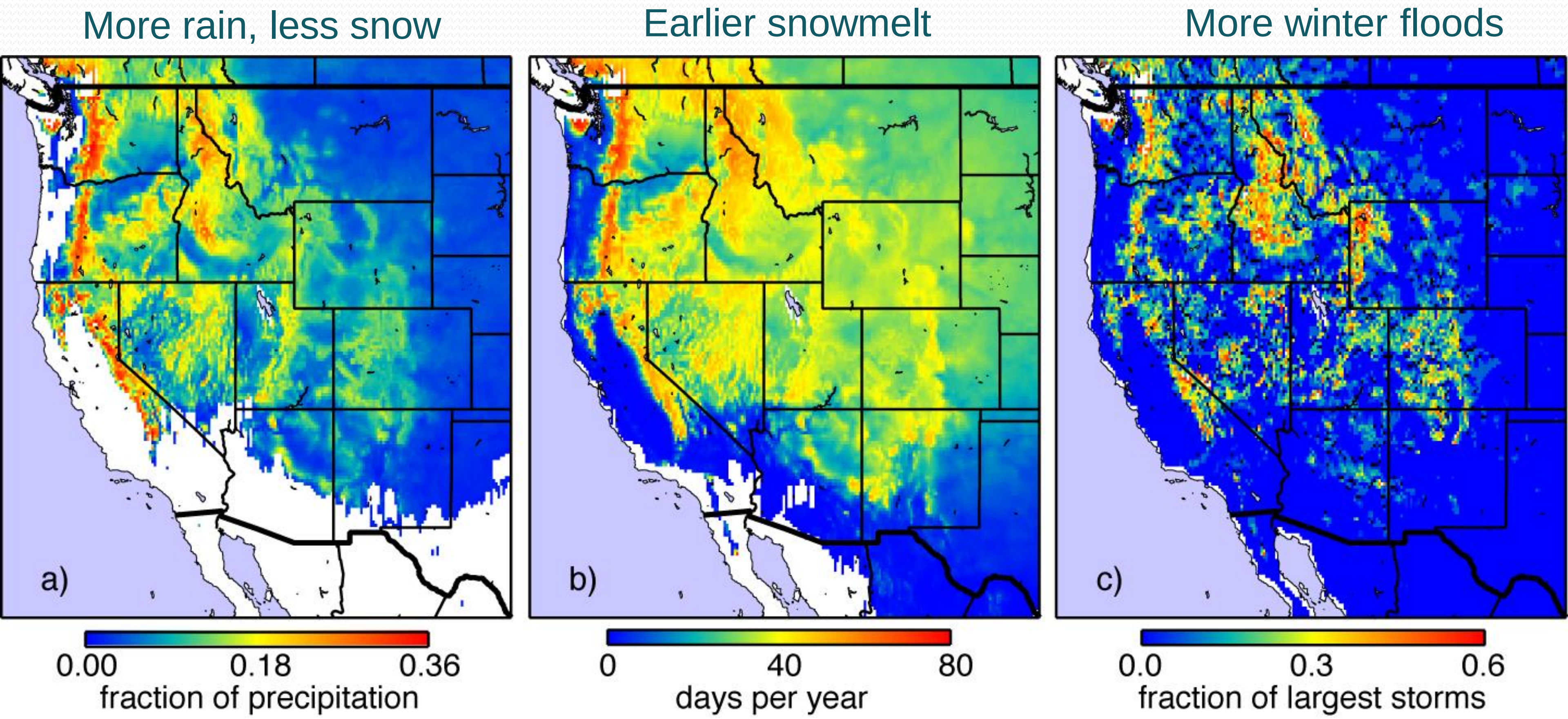




Related effects:

- Earlier greenup, Cayan 2001
- Greater fire severity in warm/dry years, Westerling 2006
- Increasing forest mortality, van Mangten 2009
- Reduced summer streamflows, Stewart 2006

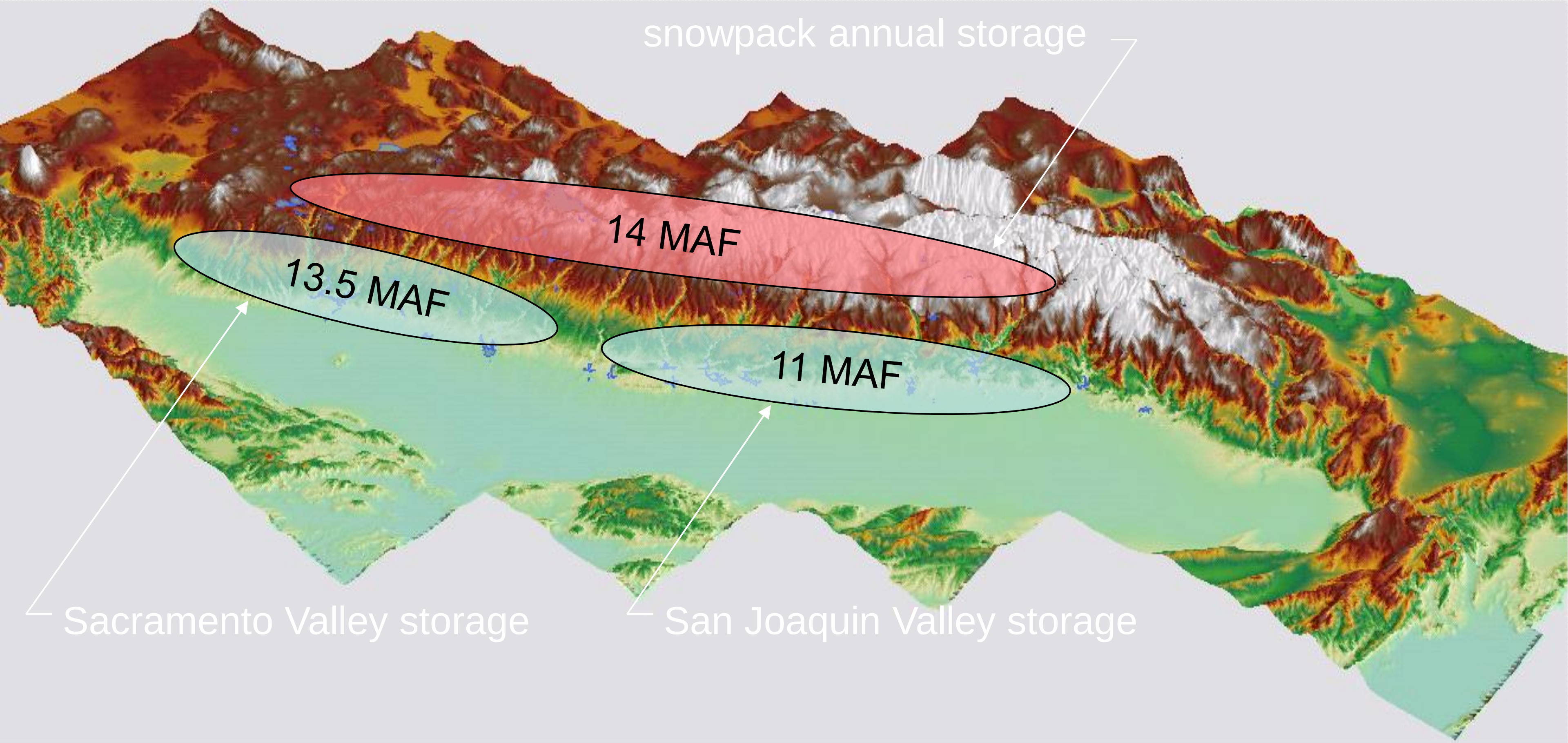
Influence of +3ºC on SNOW vs RAIN



Historical, 0 to -3ºC

The water cycle in California's mountains is undergoing long-term shifts.

Snowpack loss & water storage: 30-yr horizon

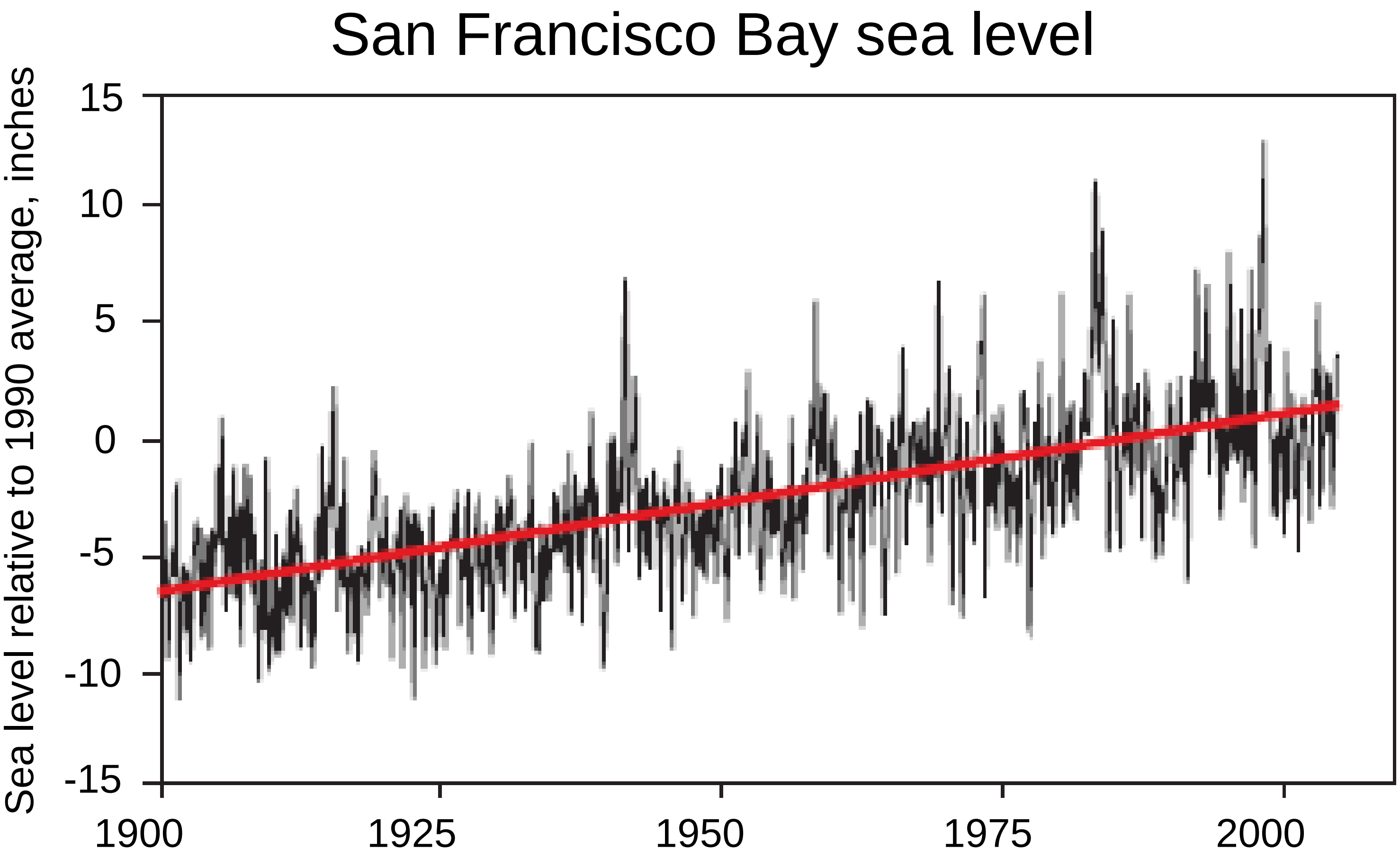


Likely loss of ~3.5 MAF of snowpack storage in next 1-3 decades

MAF: million acre feet

Data from DWR

Rising sea level threatens Delta & water supplies

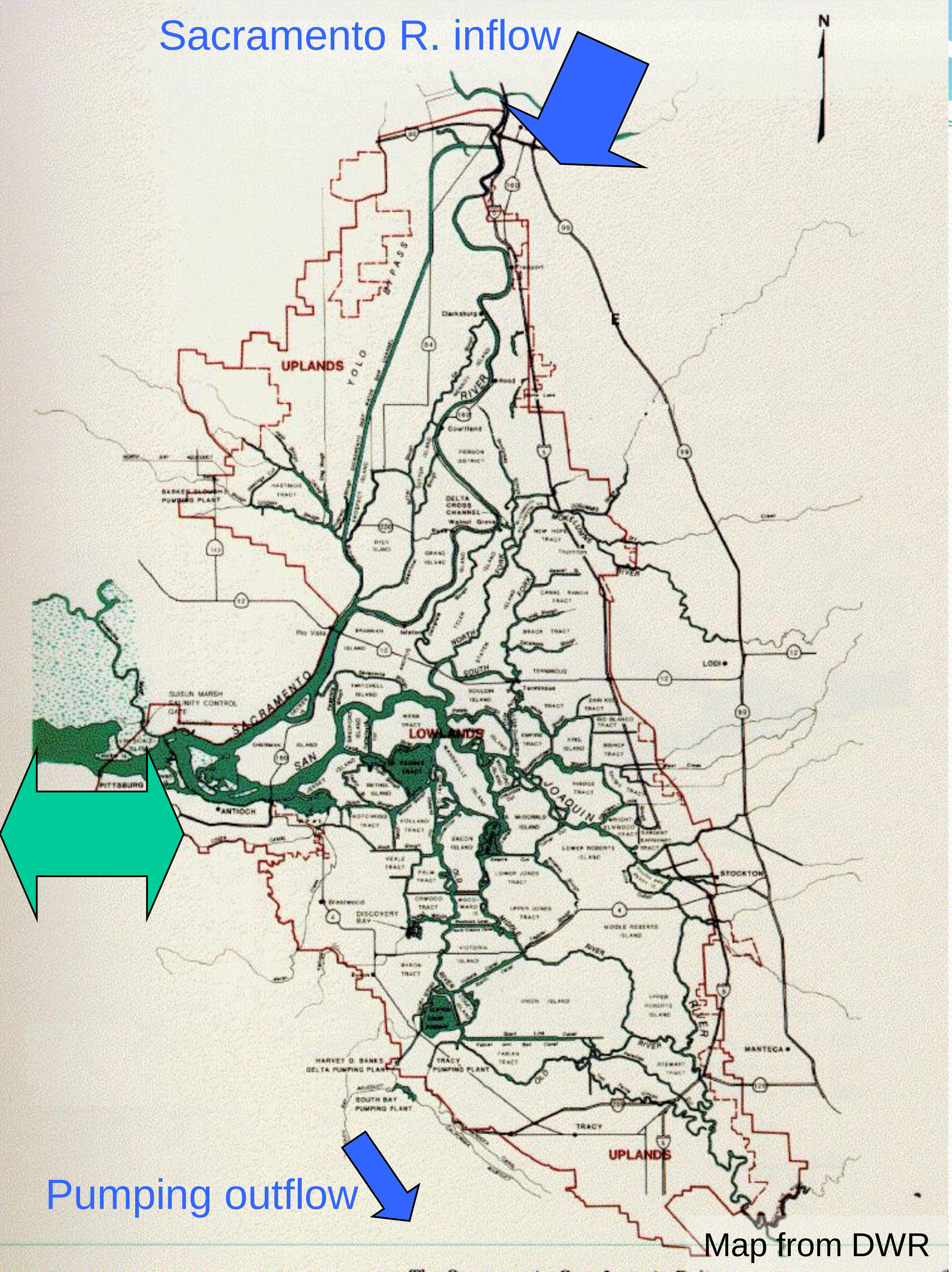


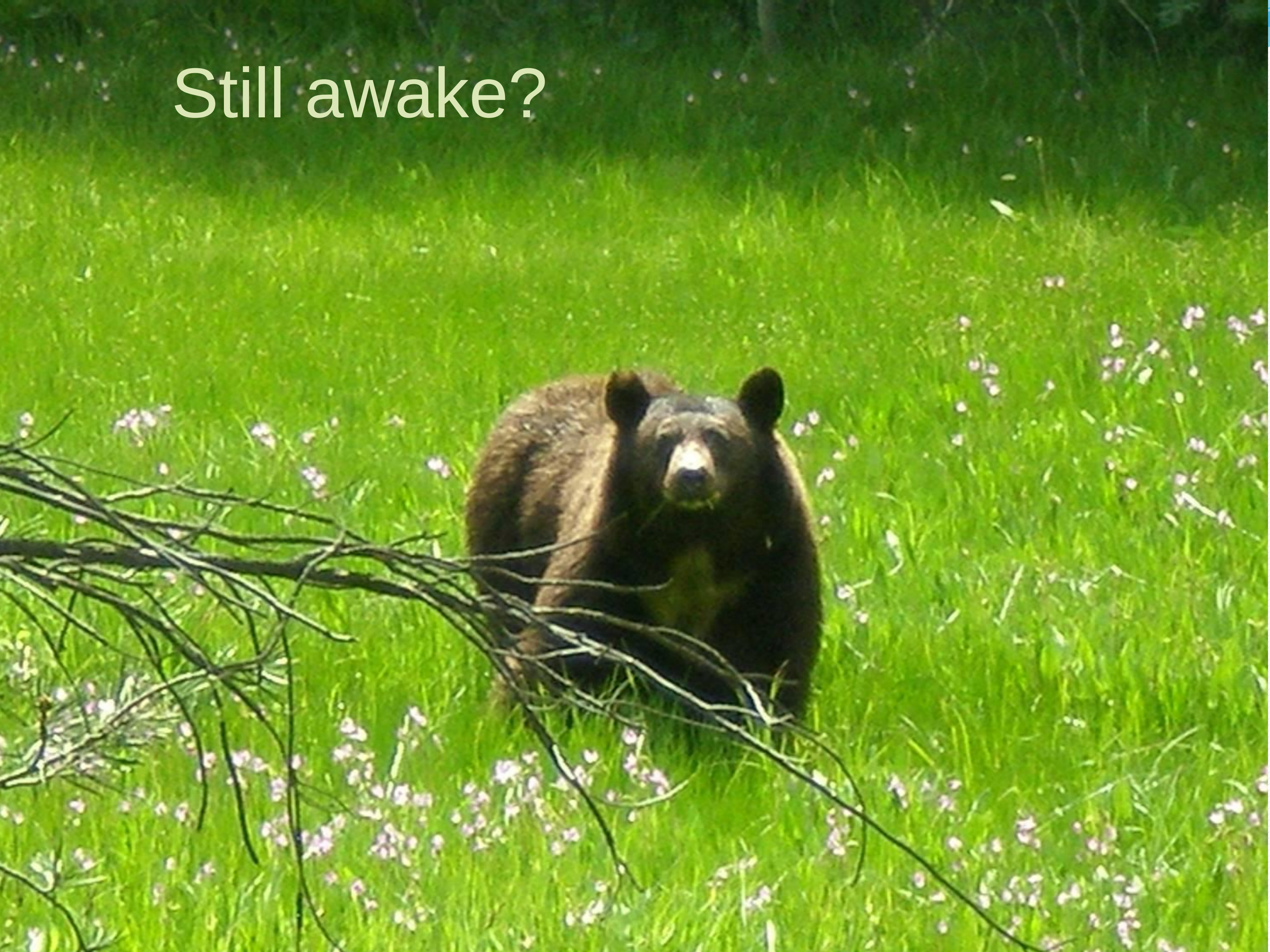
Sea level scenarios:

+ 6-10 inches by mid century

+ 20-30 inches by end of century

Rising sea level threatens Delta & water supplies




Still awake?

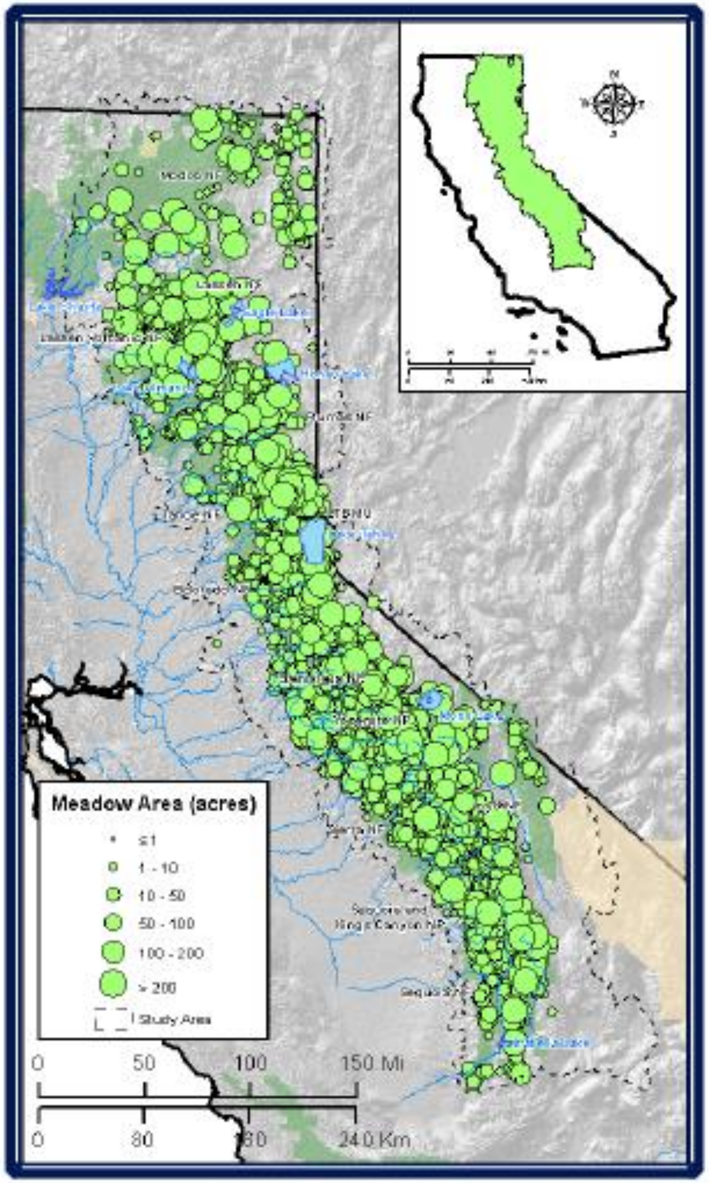
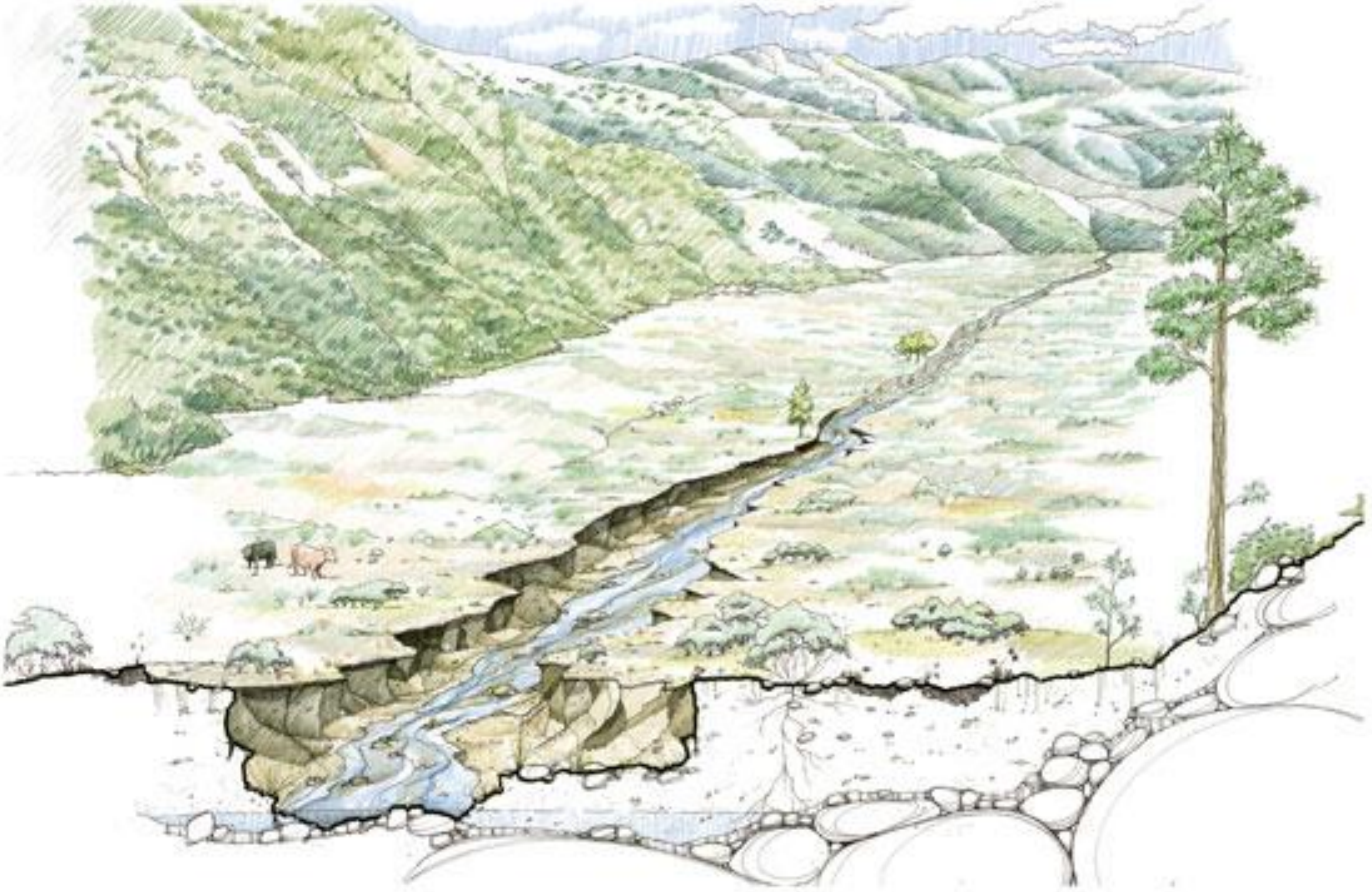


Figure 4. Sierra Nevada meadows are non-uniformly distributed across the range. See Appendix C for a detailed description of data developed for this report.

Viers et al., 2013

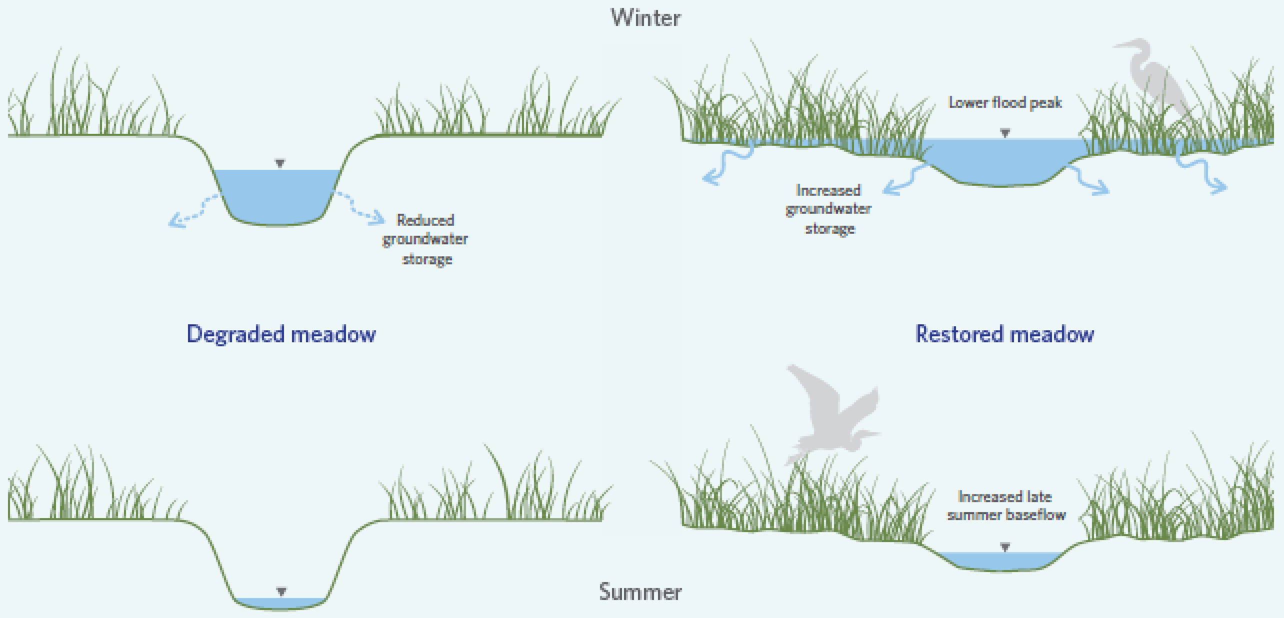
- Less than 1% of land area
- Drastically different landform than forest
  - Shallow water table
  - Marshlike vegetation
  - Wet, fine textured soils
- Disproportianate ecosystem services



Source: http://www.nps.gov/yose/learn/nature/meadow-health.htm

Source: http://www.nps.gov/yose/learn/nature/meadow-health.htm

FIGURE 2. Meadow restoration approaches in the Sierra Nevada reconnect incised stream channels with the floodplain by realigning and re-creating new channel dimensions or by "plug and pond" techniques that slow down the water and increase groundwater recharge.



Source: Podolak, K., D. Edelson, S. Kruse, B. Aylward, M. Zimring, and N. Wobbrock. 2015. Estimating the Water Supply Benefits from Forest Restoration in the Northern Sierra Nevada. An unpublished report of The Nature Conservancy prepared with Ecosystem Economics. San Francisco, CA.

California Water Action Plan

Restore Key Mountain Meadow Habitat

The Department of Fish and Wildlife in coordination with other state resource agencies will restore 10,000 acres of mountain meadow habitat in strategic locations in the Sierra Nevada and Cascade mountain ranges, which can ***increase groundwater storage*** and provide habitat for more than 100 native species, many of which are at risk as threatened or

The Red Clover – McReynolds Project, the first spring after construction (2008) (Photo: Jim Wilcox)

Source: **THE POND-AND-PLUG TREATMENT FOR STREAM AND MEADOW RESTORATION: RESOURCE EFFECTS AND DESIGN CONSIDERATIONS A Briefing Paper for Plumas National Forest Resource Specialists and Managers**

Is restoration worth the cost?

- Early reports suggest potential for 50,000-500,000 acre-feet increase in groundwater storage
- Recent studies suggest 25,000-50,000 acre-feet more reasonable effort
  - Lake McClure currently has ~92,000 acre-feet.

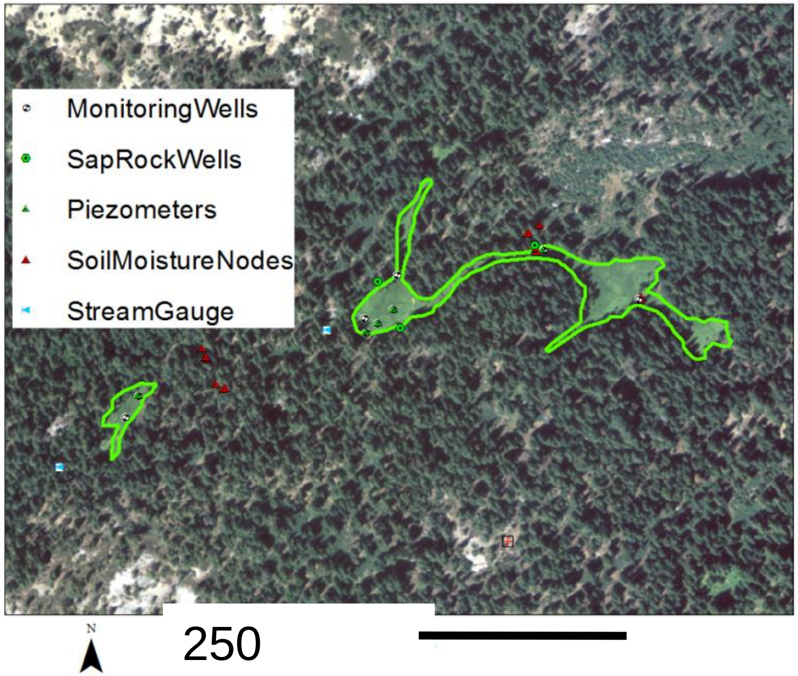
Wawona Meadow's restoration is meant to repair human impacts like the CCC's 1936 ditch digging.

Source: http://www.nps.gov/yose/learn/nature/meadow-health.htm

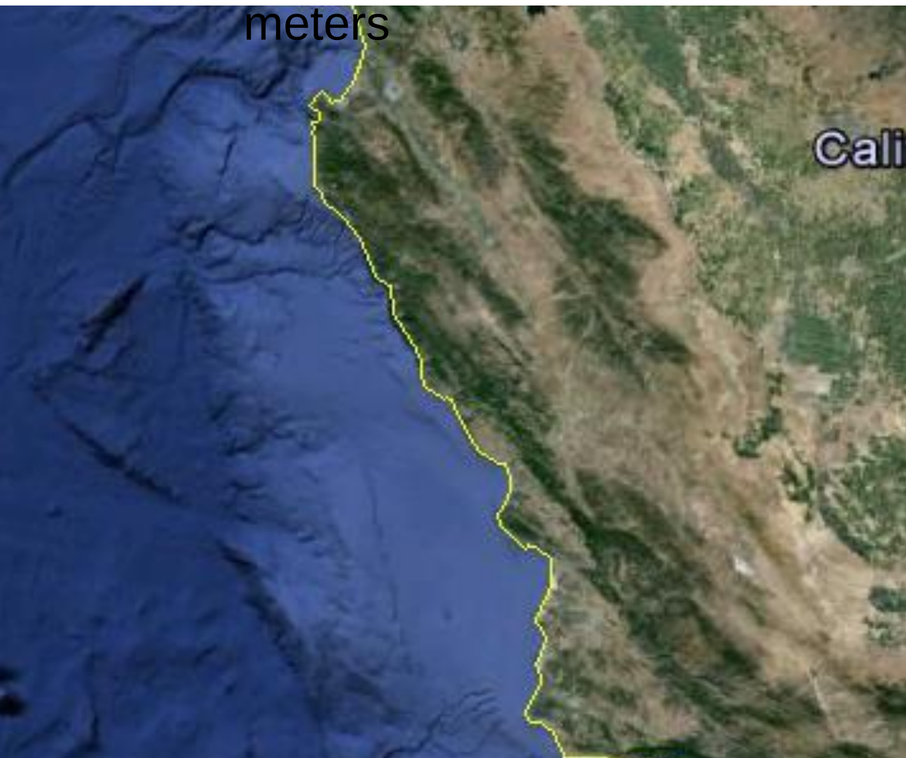
My questions:

What are the dominant terms of the meadow water balance?

How do meadow hydrologic processes relate to the greater watershed?



250 meters



P301 Meadow

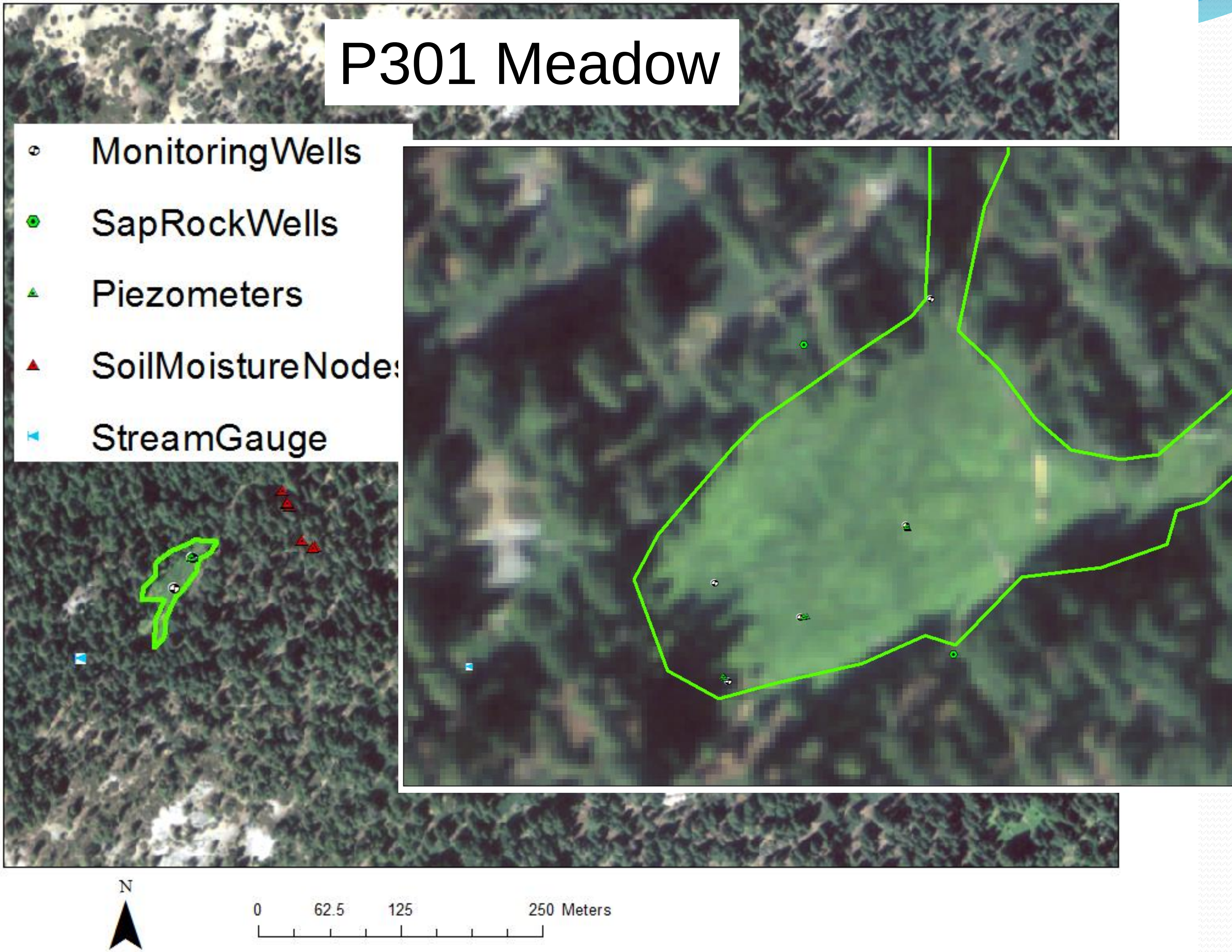
Elevation – 1900m

Area ~ 2 hectares

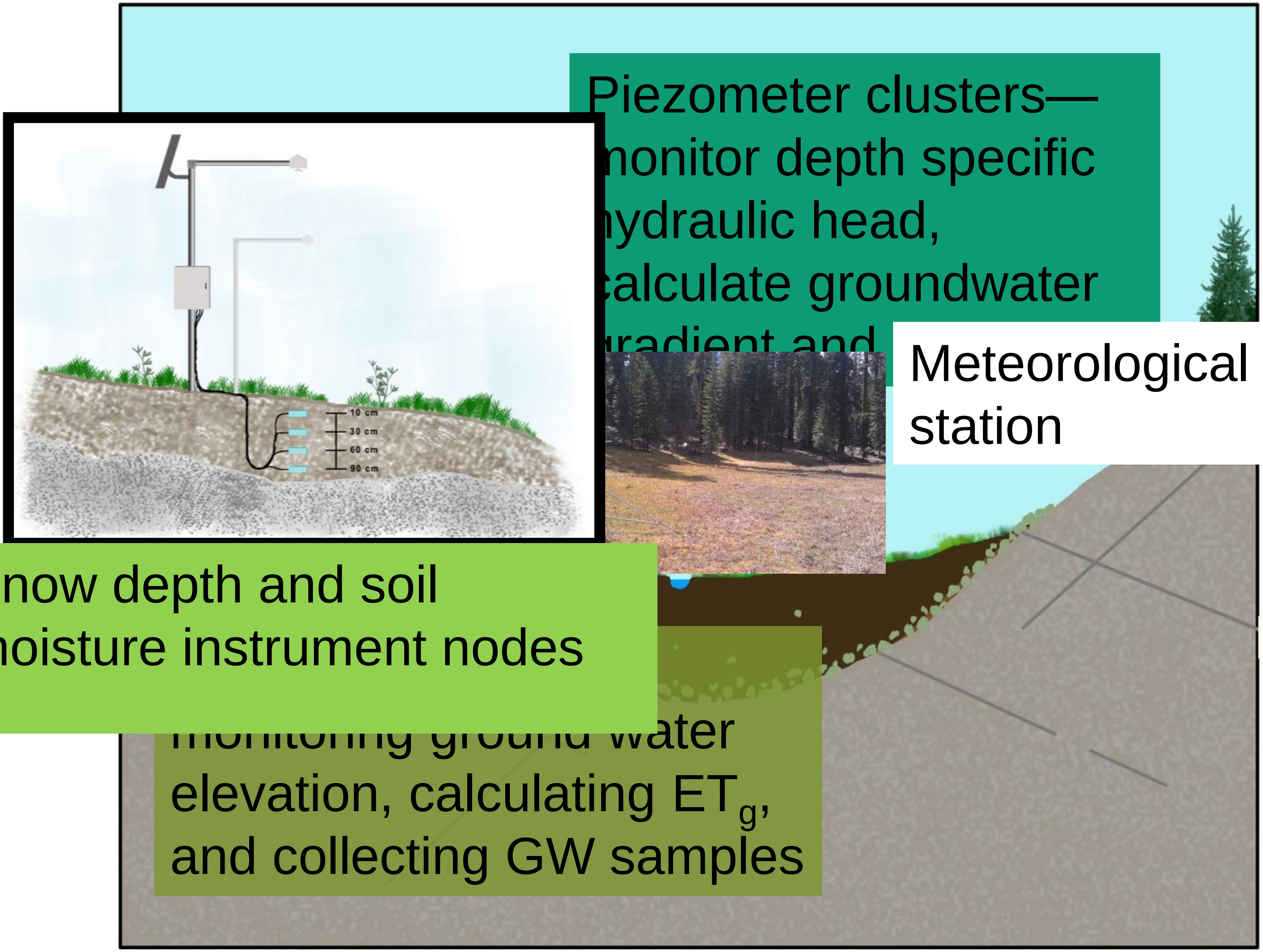
~ 1-2 m alluvium, 10’s m weathered bedrock (saprock or saprolite).

No defined stream channel in the meadow. Defined surface water output from middle and lower meadows

SSCZO and KREW provide supporting data from the Providence Creek catchment including SM/T/met data/snow depth/Q/flux data: H_2O and CO_2.


P301 Meadow
MonitoringWells
SapRockWells
Piezometers
SoilMoistureNodes
StreamGauge
N
0
62.5
125
250 Meters

Methods: Meadow Instruments



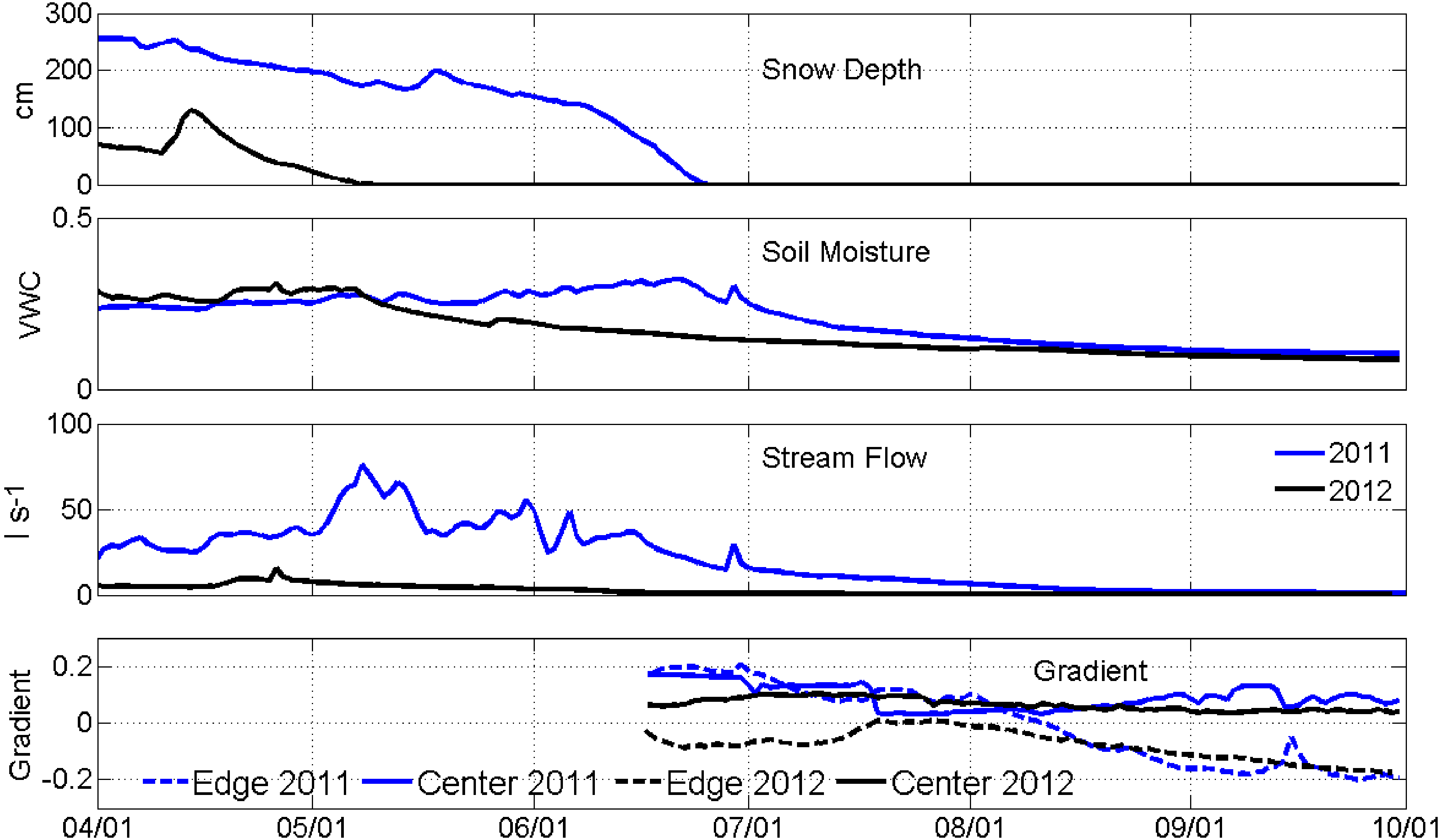
Piezometer clusters—
monitor depth specific
hydraulic head,
calculate groundwater
gradient and

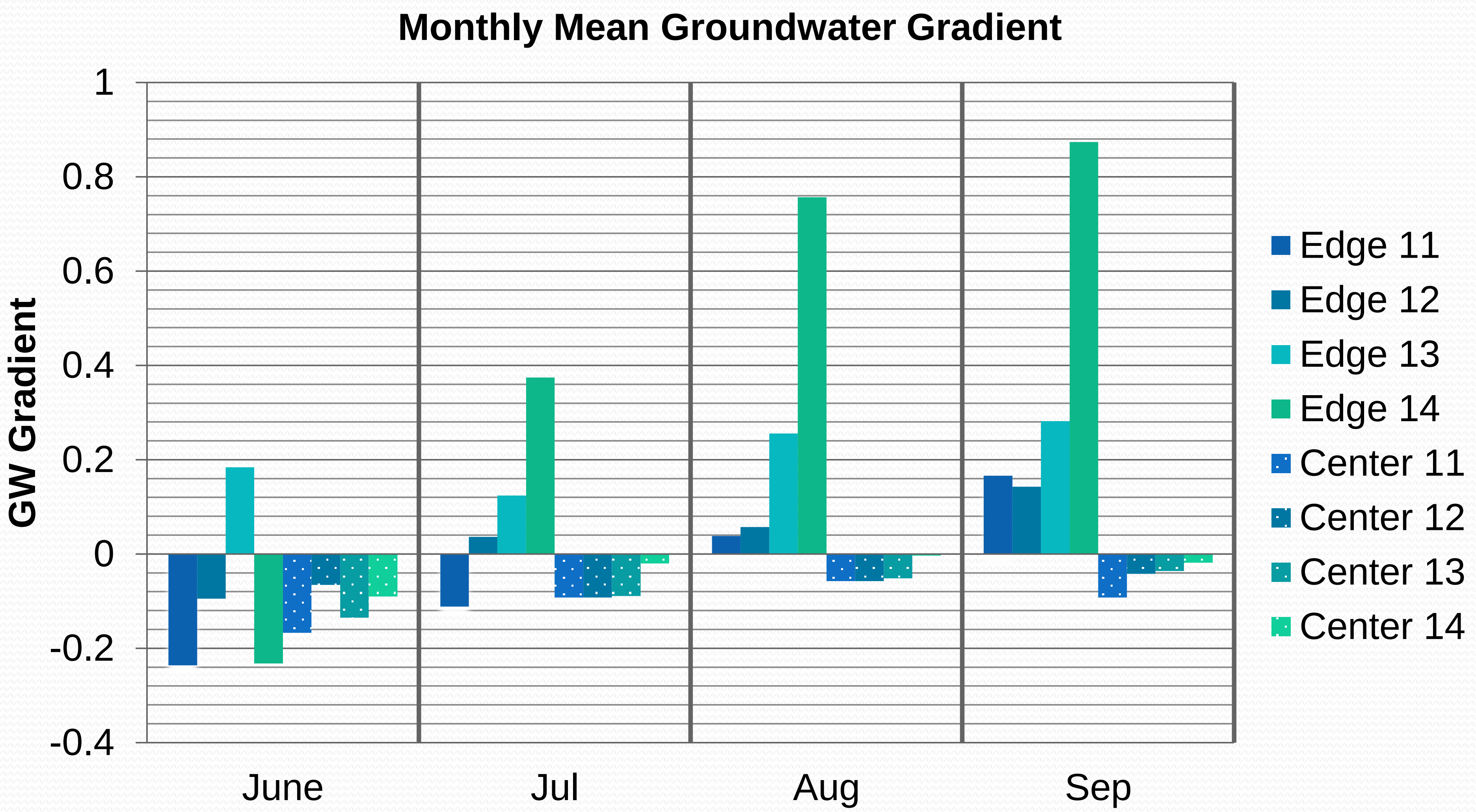
Meteorological
station

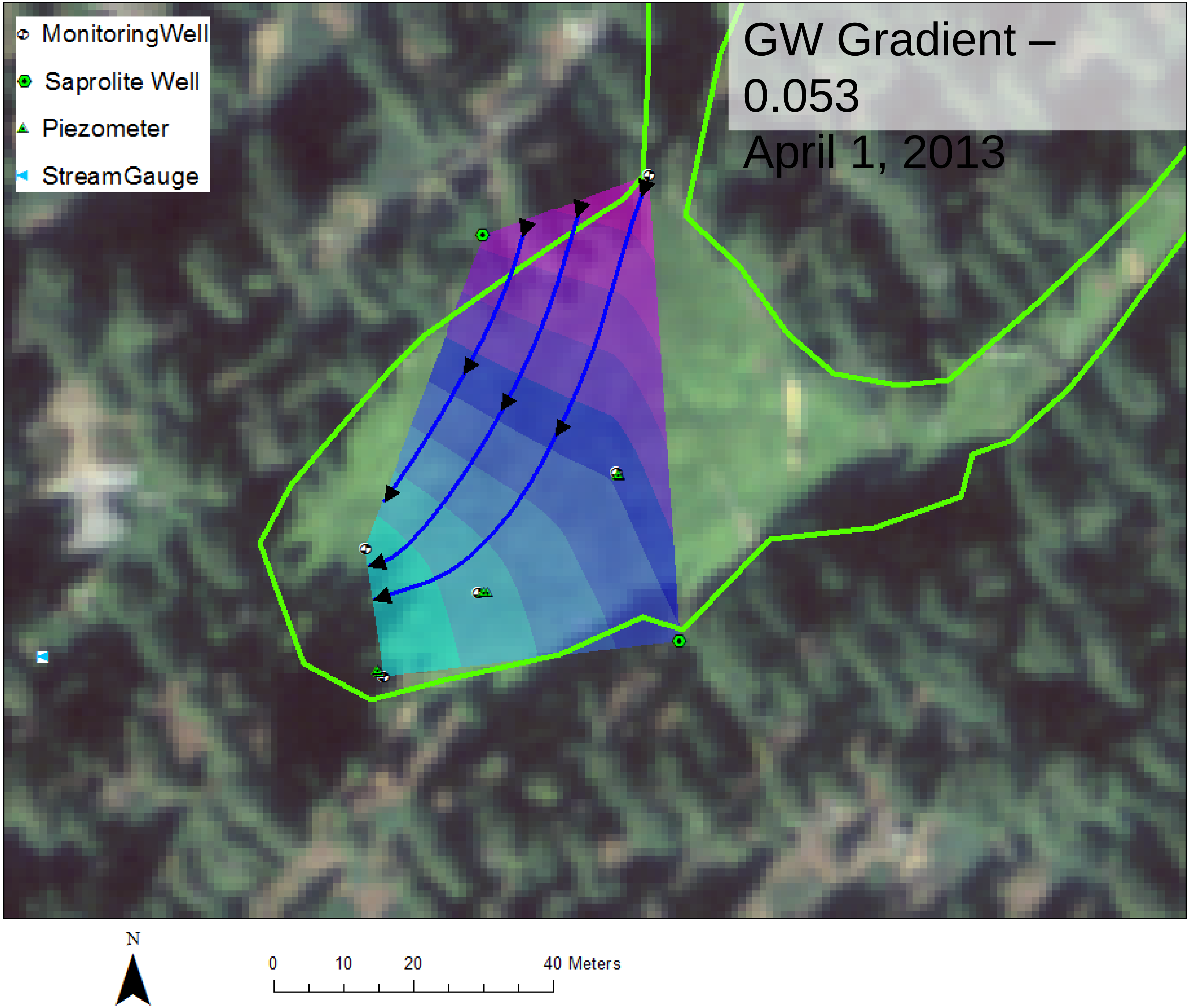
Snow depth and soil
moisture instrument nodes

monitoring ground water
elevation, calculating ET_g,
and collecting GW samples

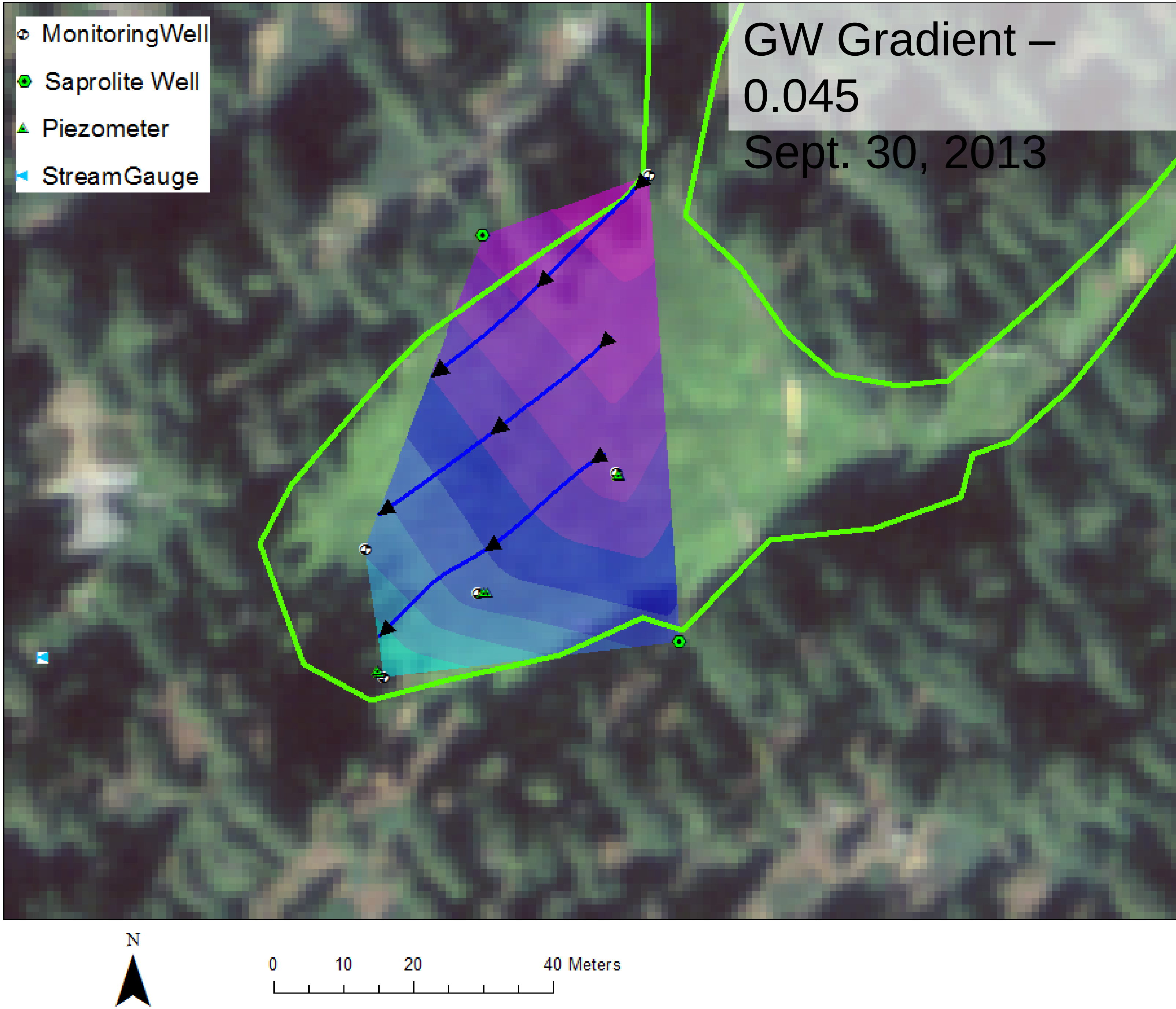
Data: Hydrologic data

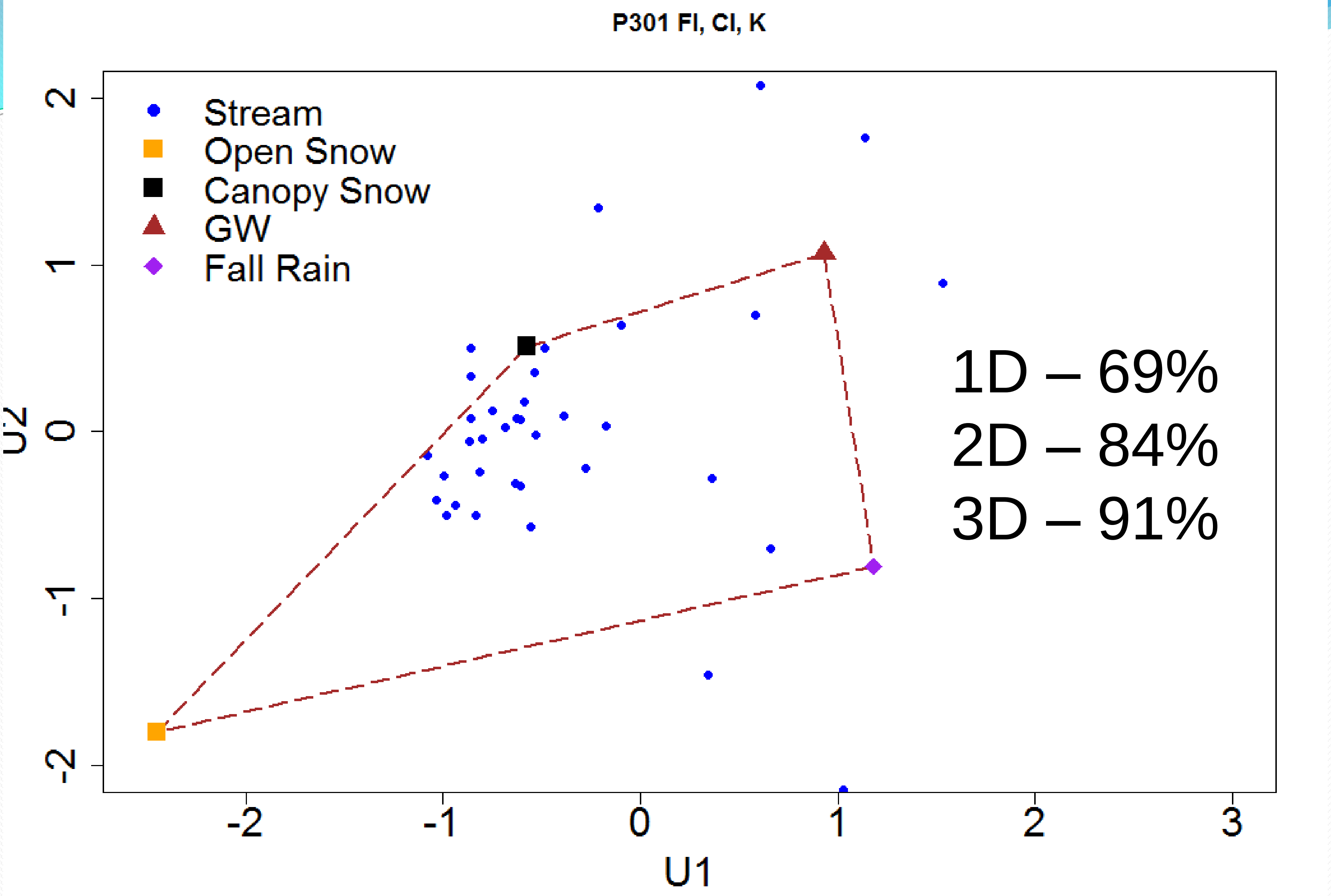


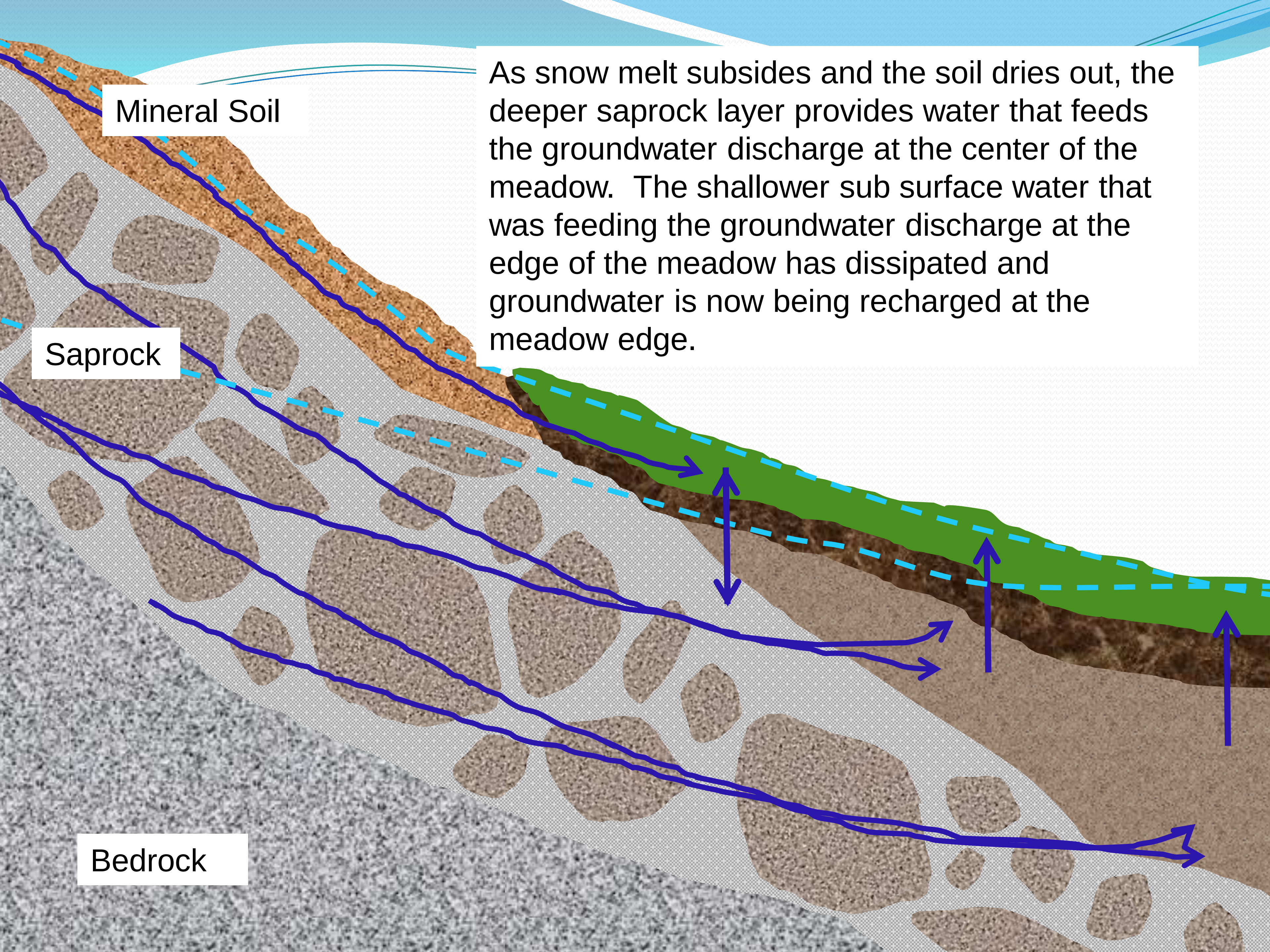

Monthly Mean Groundwater Gradient
GW Gradient
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
June
Jul
Aug
Sep
Edge 11
Edge 12
Edge 13
Edge 14
Center 11
Center 12
Center 13
Center 14



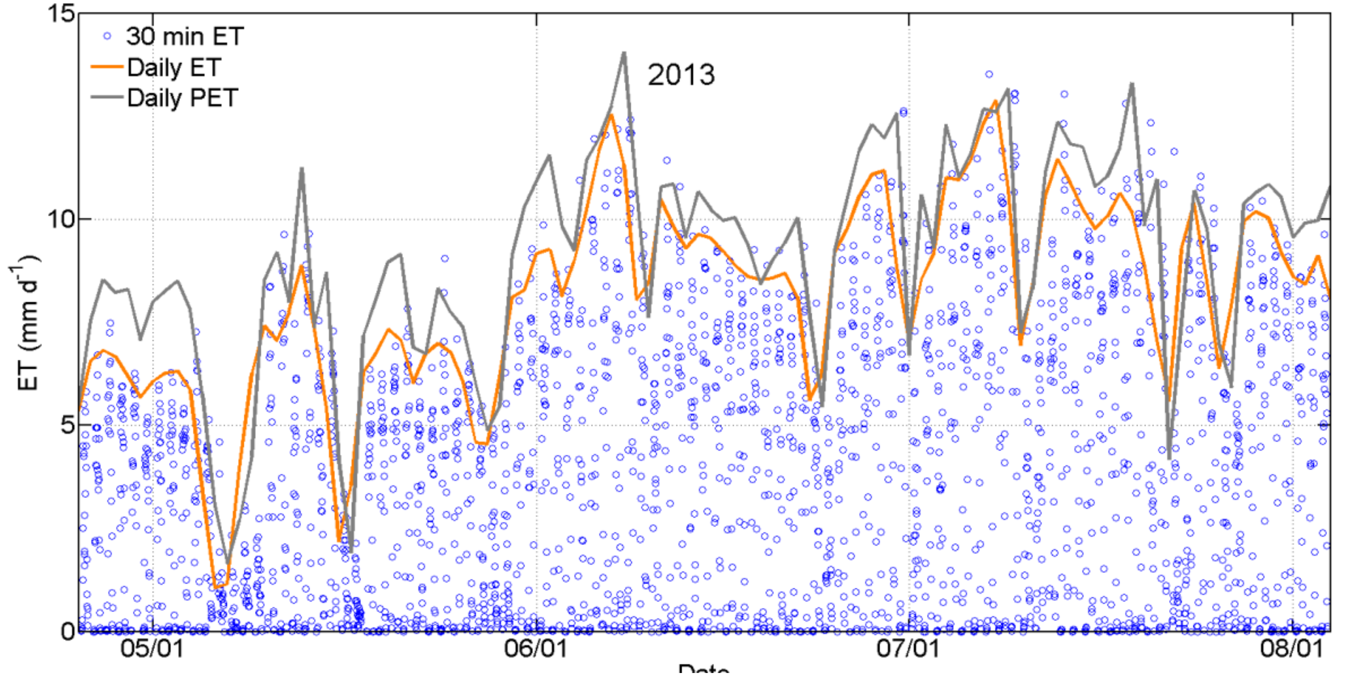
GW Gradient –
0.053
April 1, 2013
MonitoringWell
Saprolite Well
Piezometer
StreamGauge
N
0
10
20
40 Meters

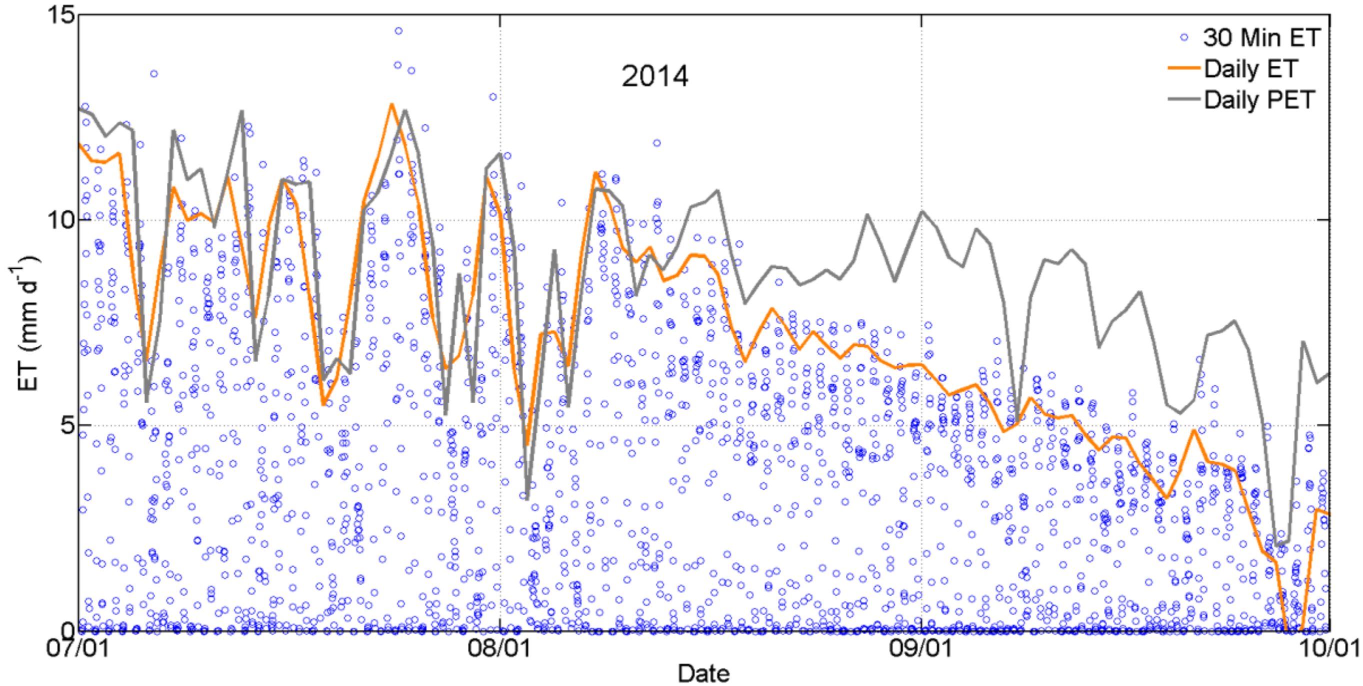

MonitoringWell
Saprolite Well
Piezometer
StreamGauge
GW Gradient –
0.045
Sept. 30, 2013
N
0
10
20
40 Meters


P301 FI, CI, K
Stream
Open Snow
Canopy Snow
GW
Fall Rain
1D – 69%
2D – 84%
3D – 91%
U2
U1
2
1
0
-1
-2
-2
-1
0
1
2
3

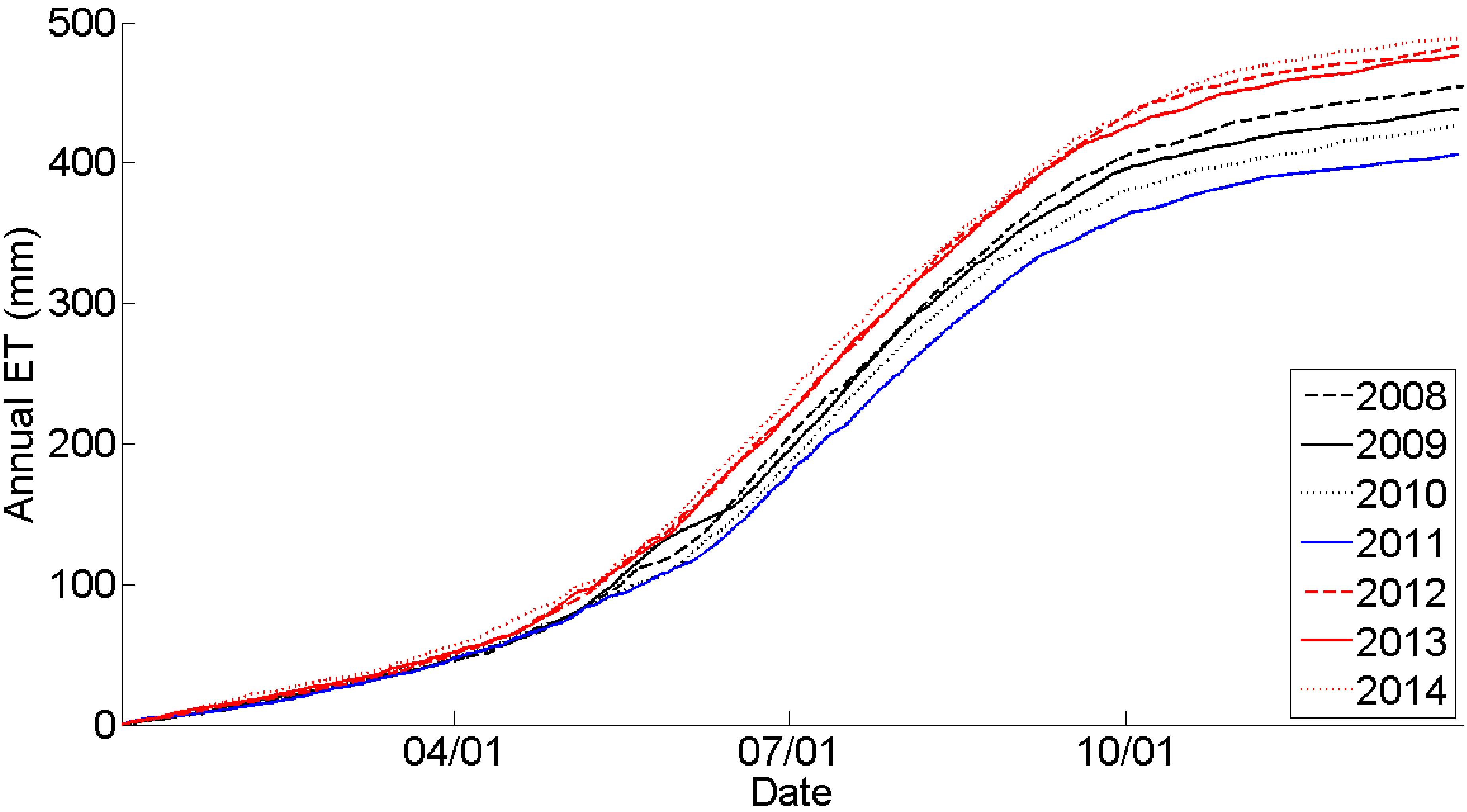


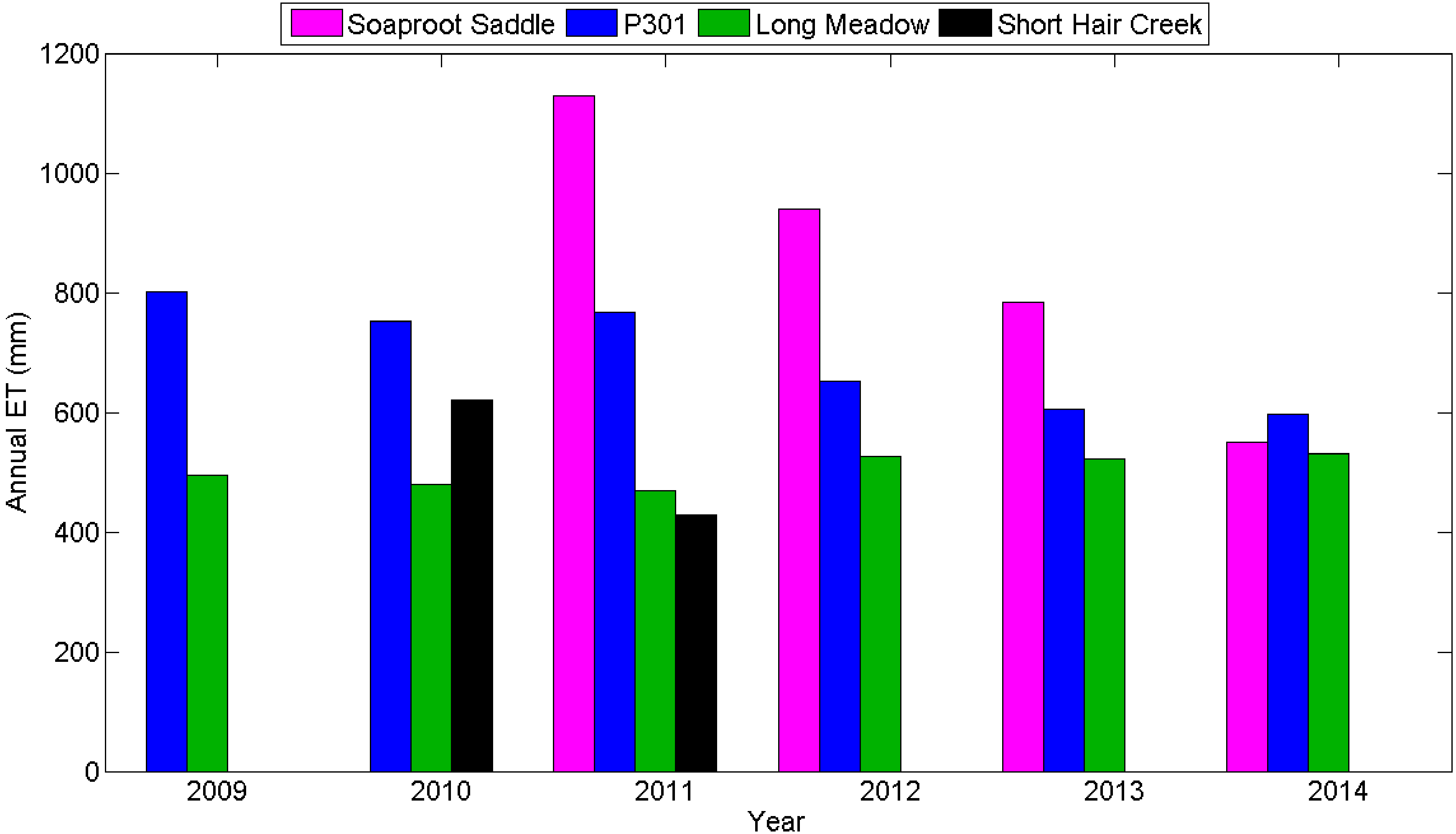
As snow melt subsides and the soil dries out, the deeper saprock layer provides water that feeds the groundwater discharge at the center of the meadow. The shallower sub surface water that was feeding the groundwater discharge at the edge of the meadow has dissipated and groundwater is now being recharged at the meadow edge.


30 min ET
Daily ET
Daily PET
2013
ET (mm d-1)
15
10
5
0
05/01
06/01
07/01
08/01


30 Min ET
Daily ET
Daily PET
2014
ET (mm d-1)
15
10
5
0
07/01
08/01
09/01
10/01
Date

Long Meadow, Sequoia National Park





Soaproot Saddle
P301
Long Meadow
Short Hair Creek
1200
1000
800
600
400
200
0
Annual ET (mm)
2009
2010
2011
2012
2013
2014
Year

Conclusions

- Meadow has multiple groundwater sources.
  - Timing and magnitude reflect watershed processes.
- Meadow groundwater storage may be insignificant compared to overall Sierra water storage.
  - Meadow soil properties may play a key role in retarding GW discharge
- Meadow ET highest in dry years, less variable than forest ET, and small fraction of watershed ET.

Questions?