Development of a California-wide Soil Moisture Monitoring Strategy, and Application to the Hetch Hetchy Watershed

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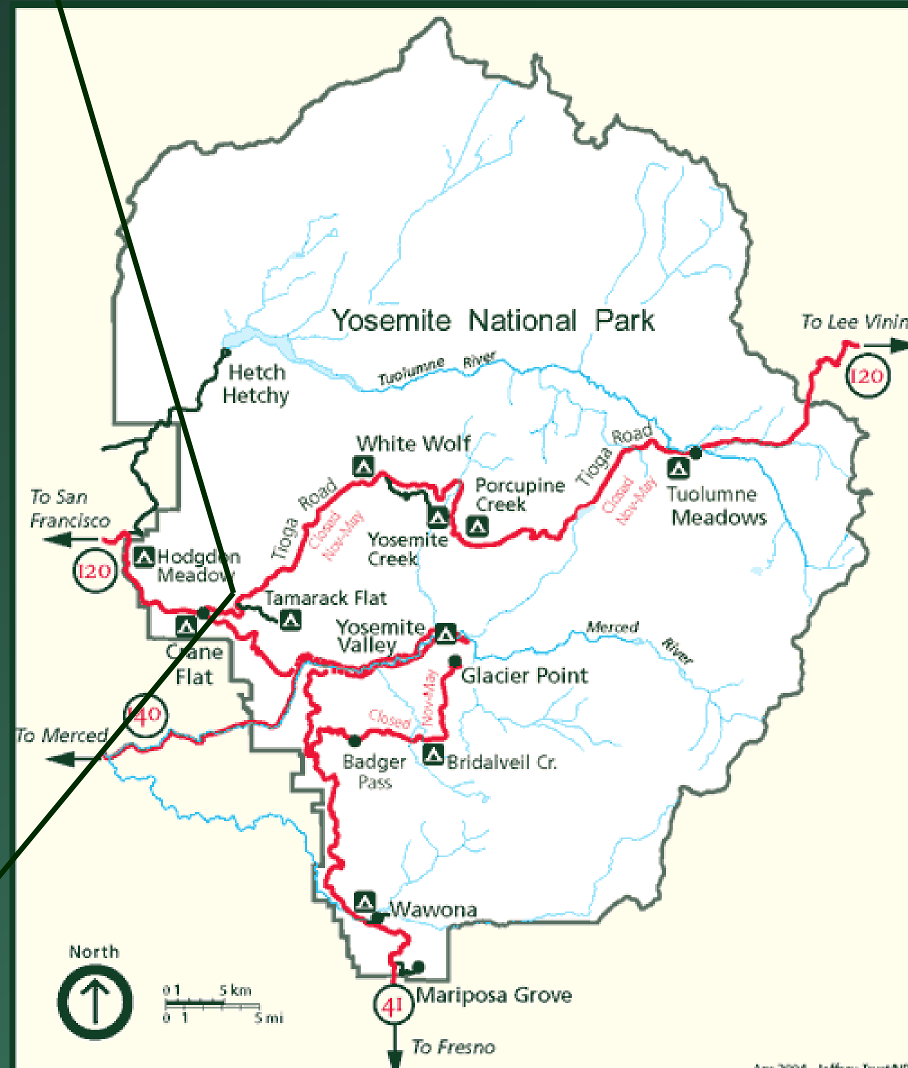
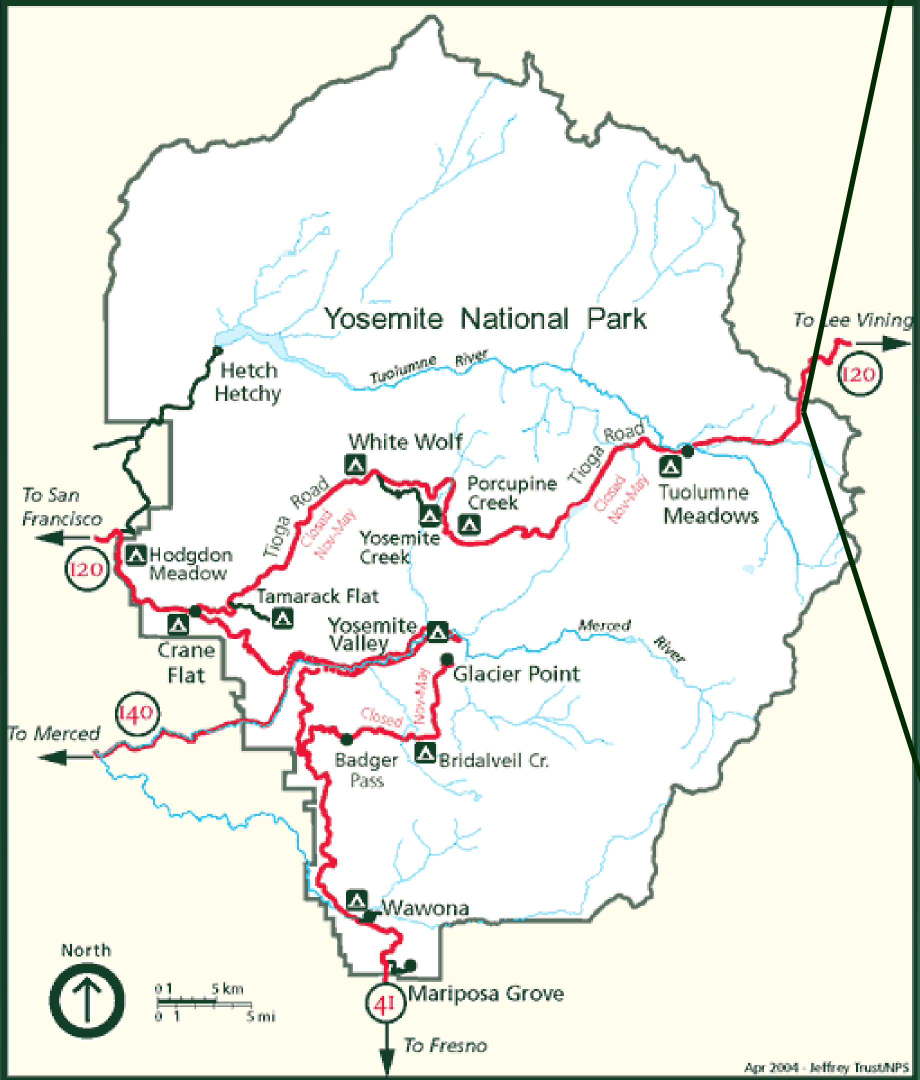
U.S. Geological Survey, Sacramento

Gin Flat
Elevation: 7050’ (2149m)



Dana Meadows Site
Elevation: 9728' (2965m)

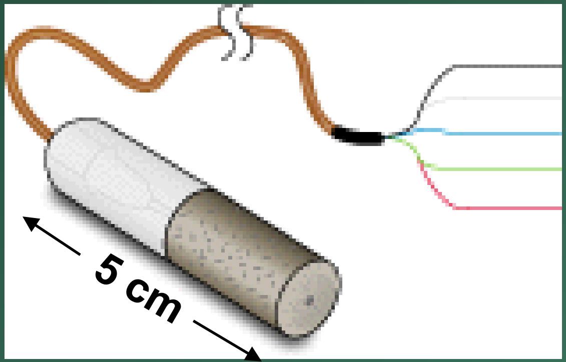


Picture Taken: 06/29/2011

Soil Moisture Monitoring Instrumentation

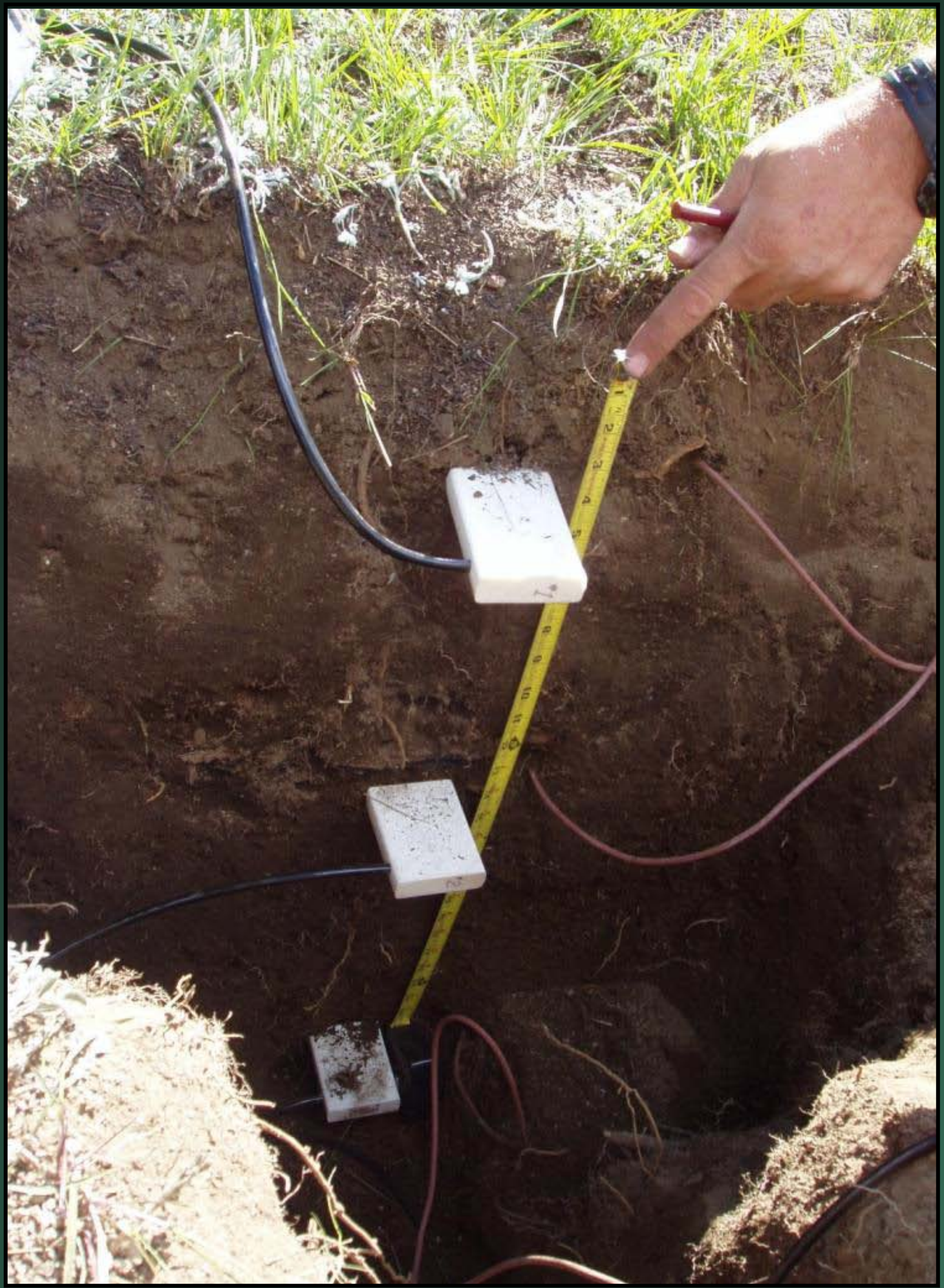
Water content:

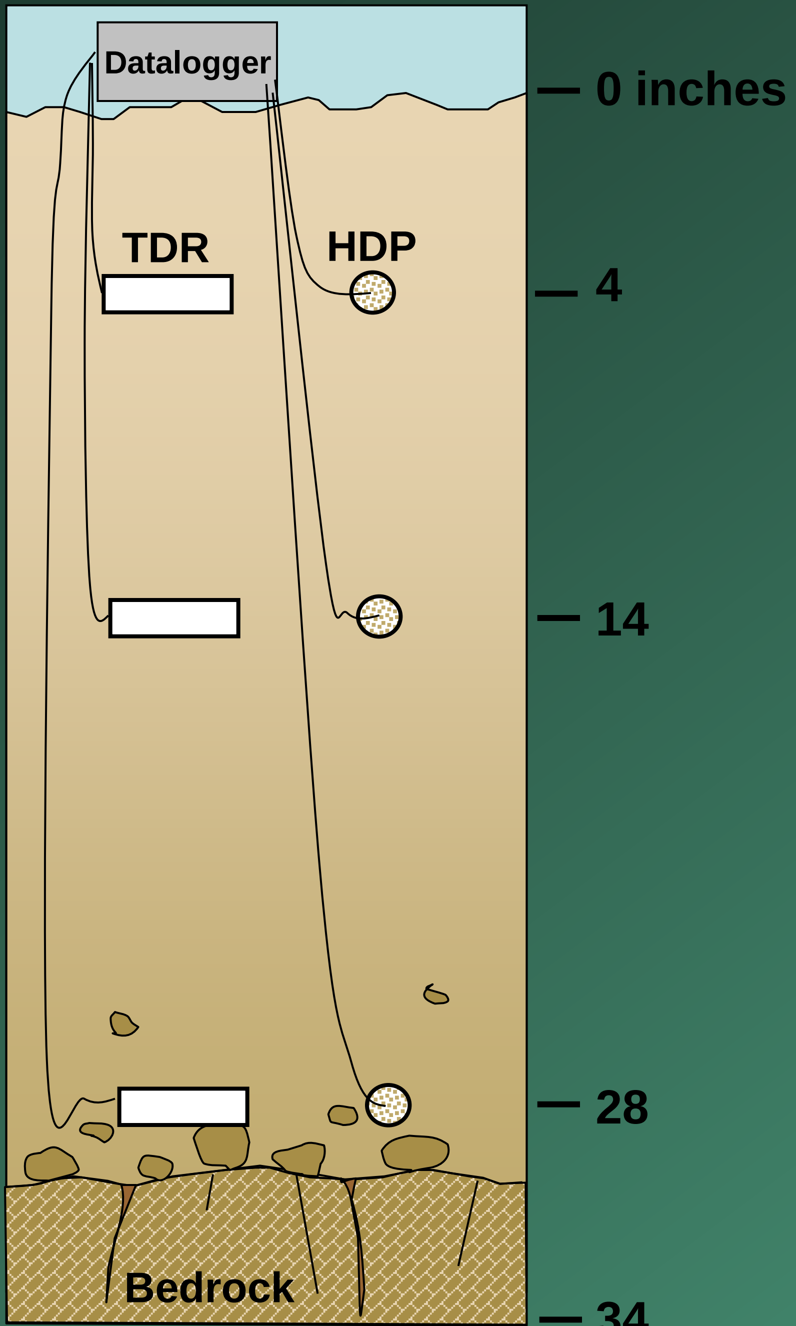
Time Domain Reflectometry (TDR)



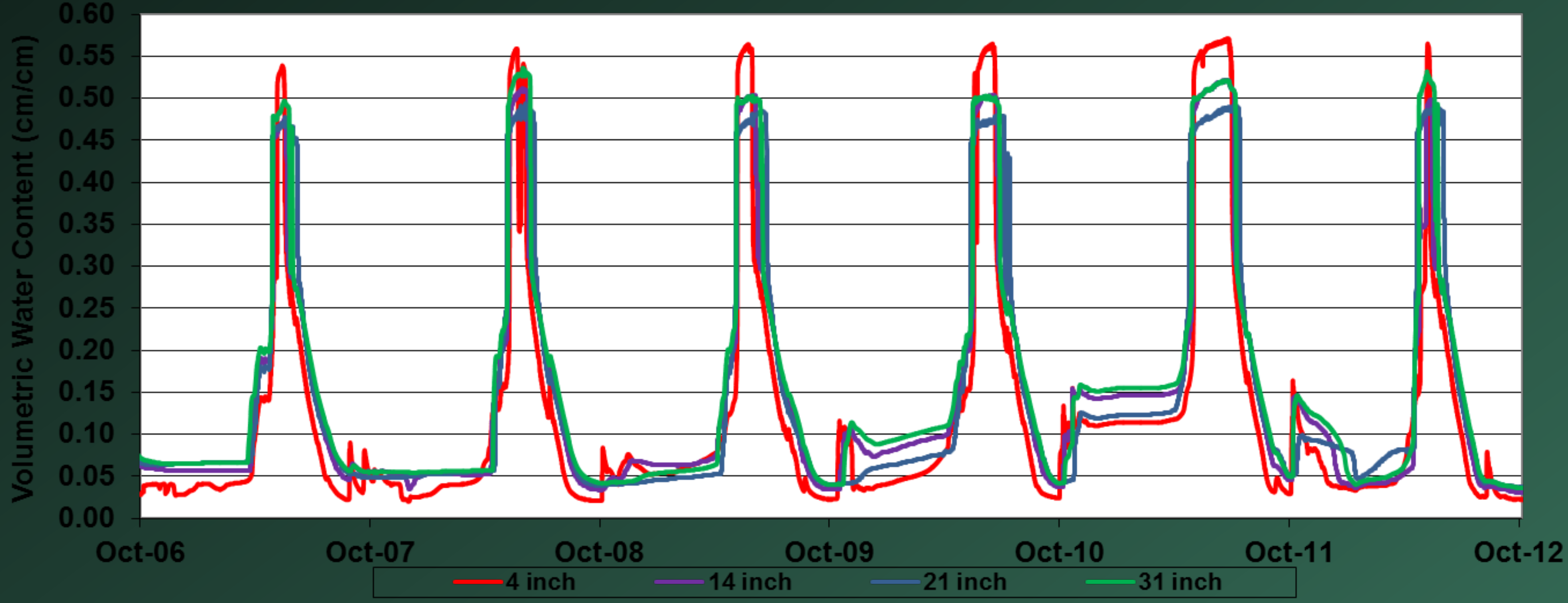
Water potential:

Heat Dissipation Probe (HDP)

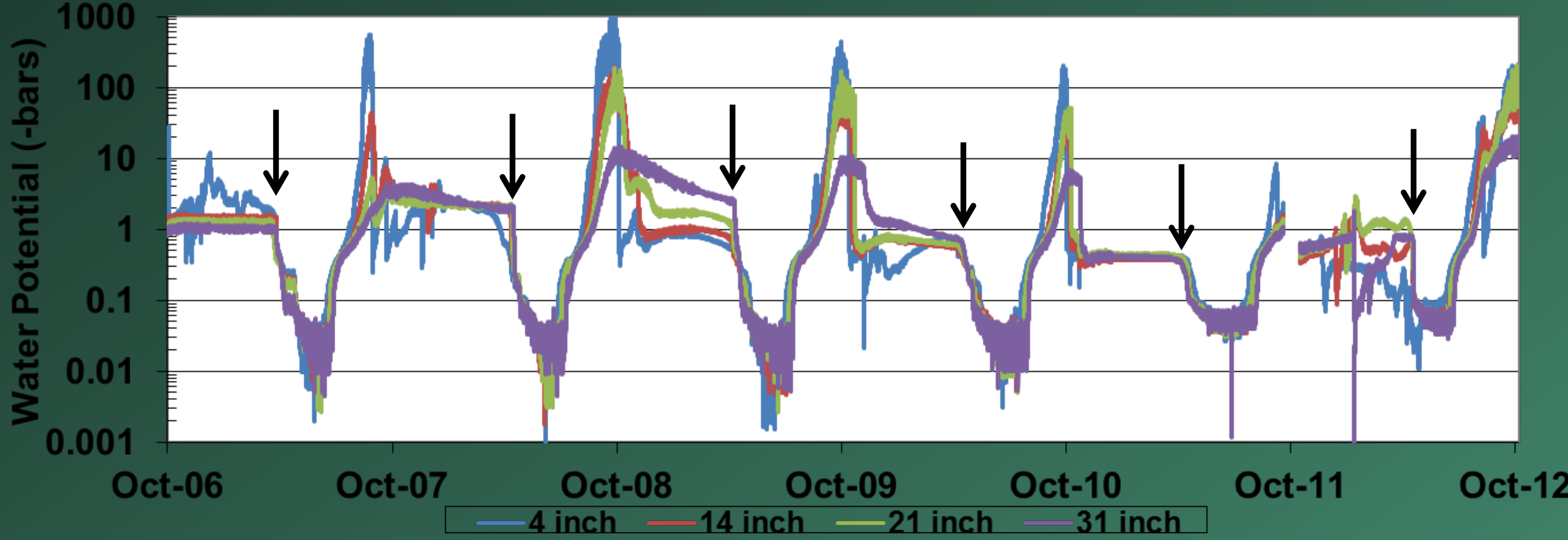



Datalogger
0 inches
TDR
HDP
4
14
28
Bedrock
34

Dana Meadows Water Content



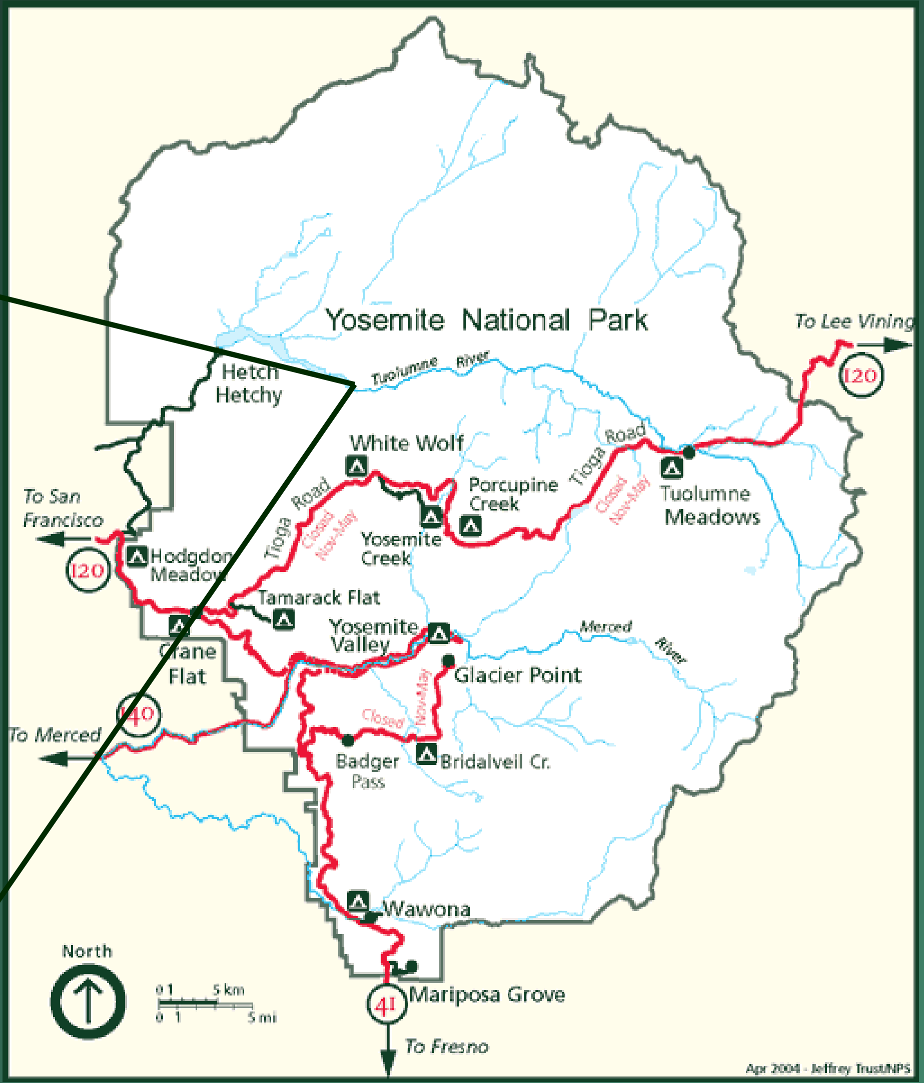
Dana Meadows Water Potential

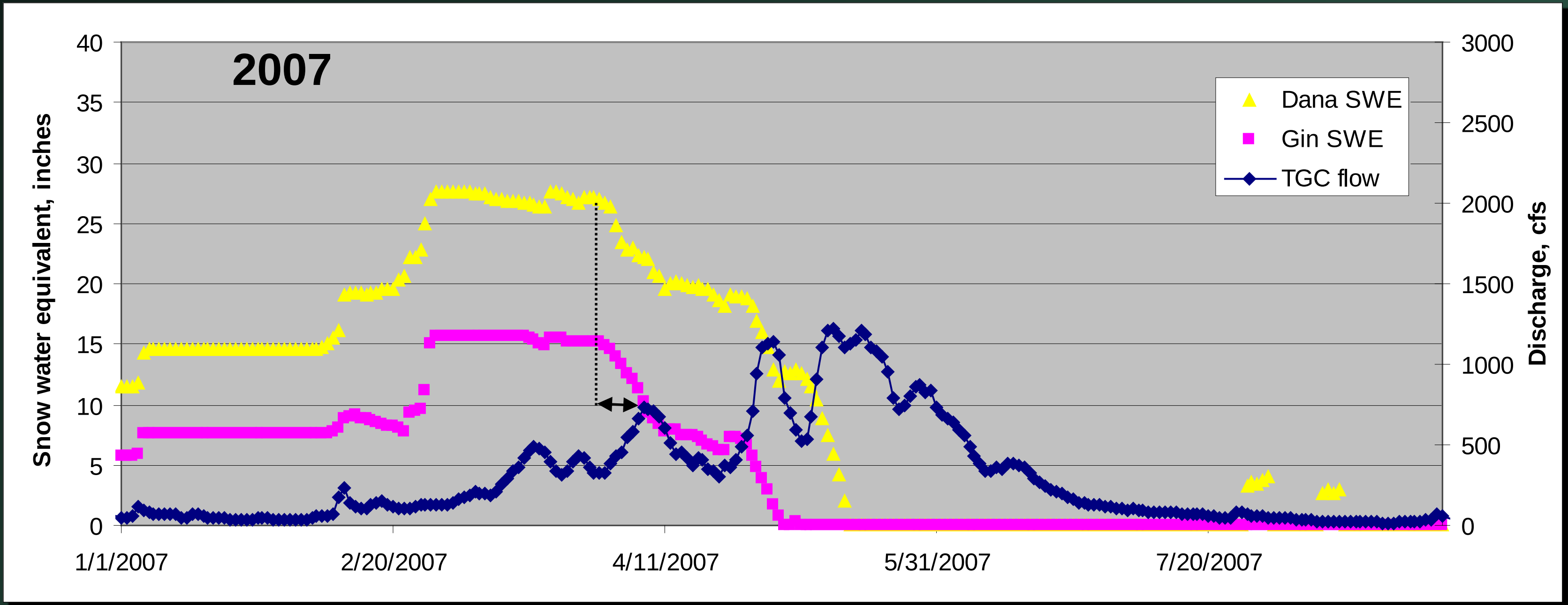


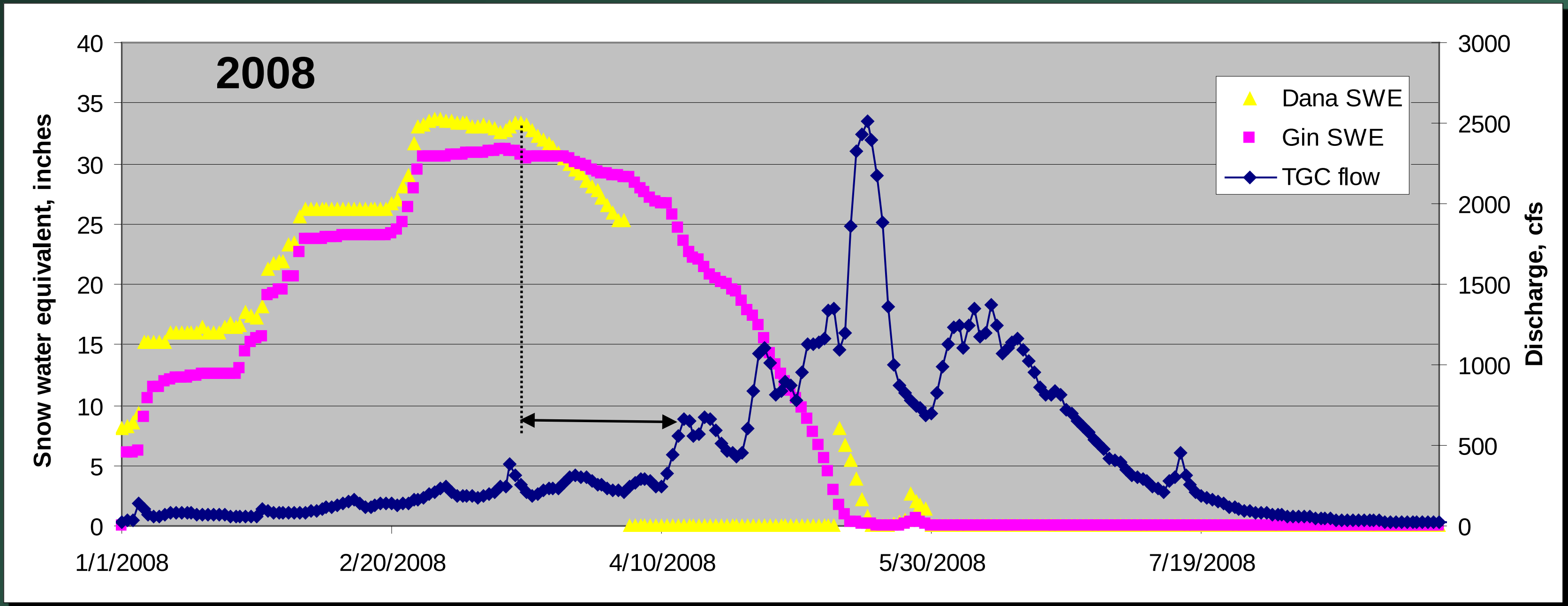
Applications

- Hydrologic model calibration/validation
- Calculations of volume of runoff lost to soil moisture replenishment under varying climatic conditions
- Real-time application for forecasting

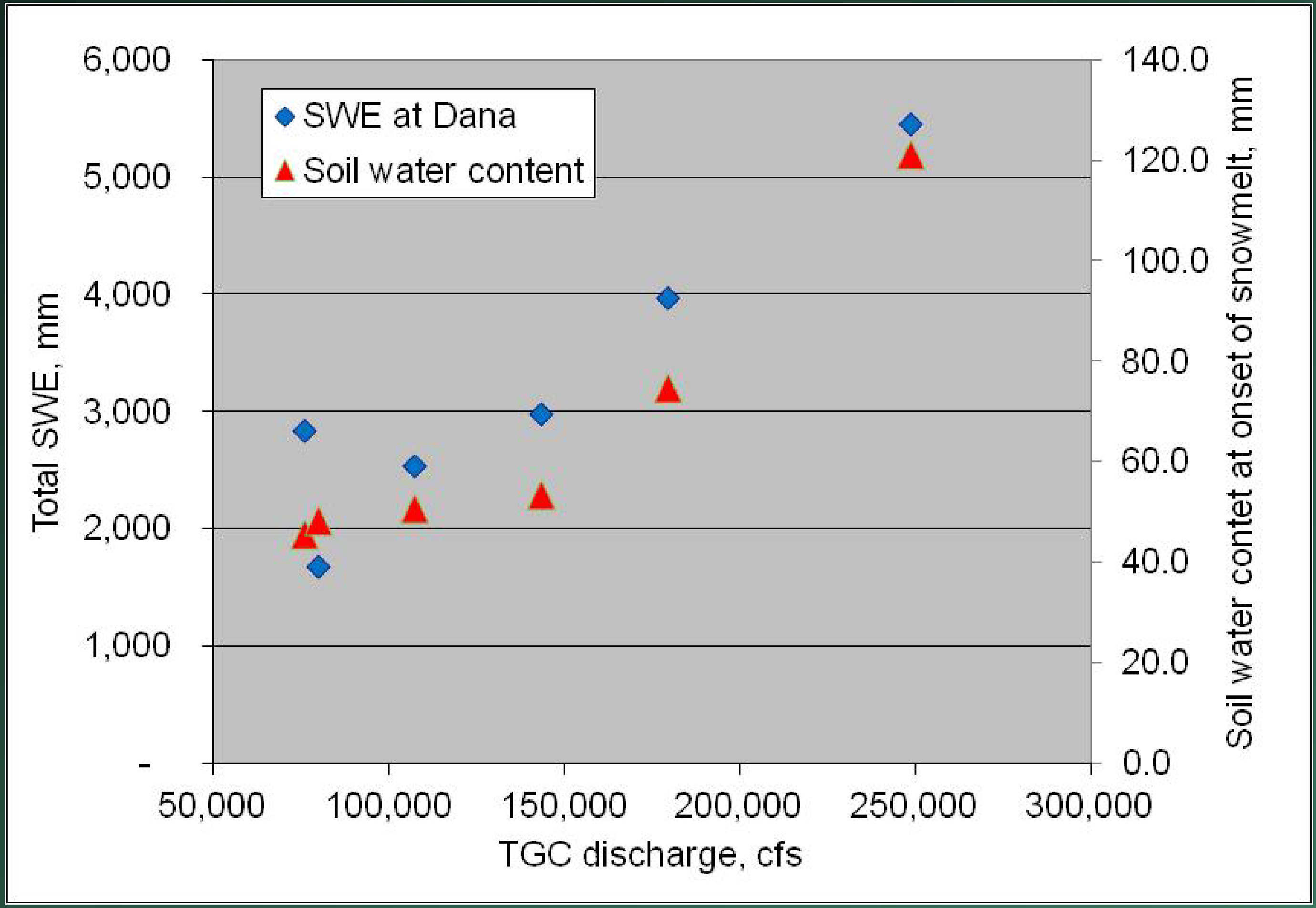
Tuolumne R. @ Grand CYN of Tuolumne
Elevation: 3830' (1167m)

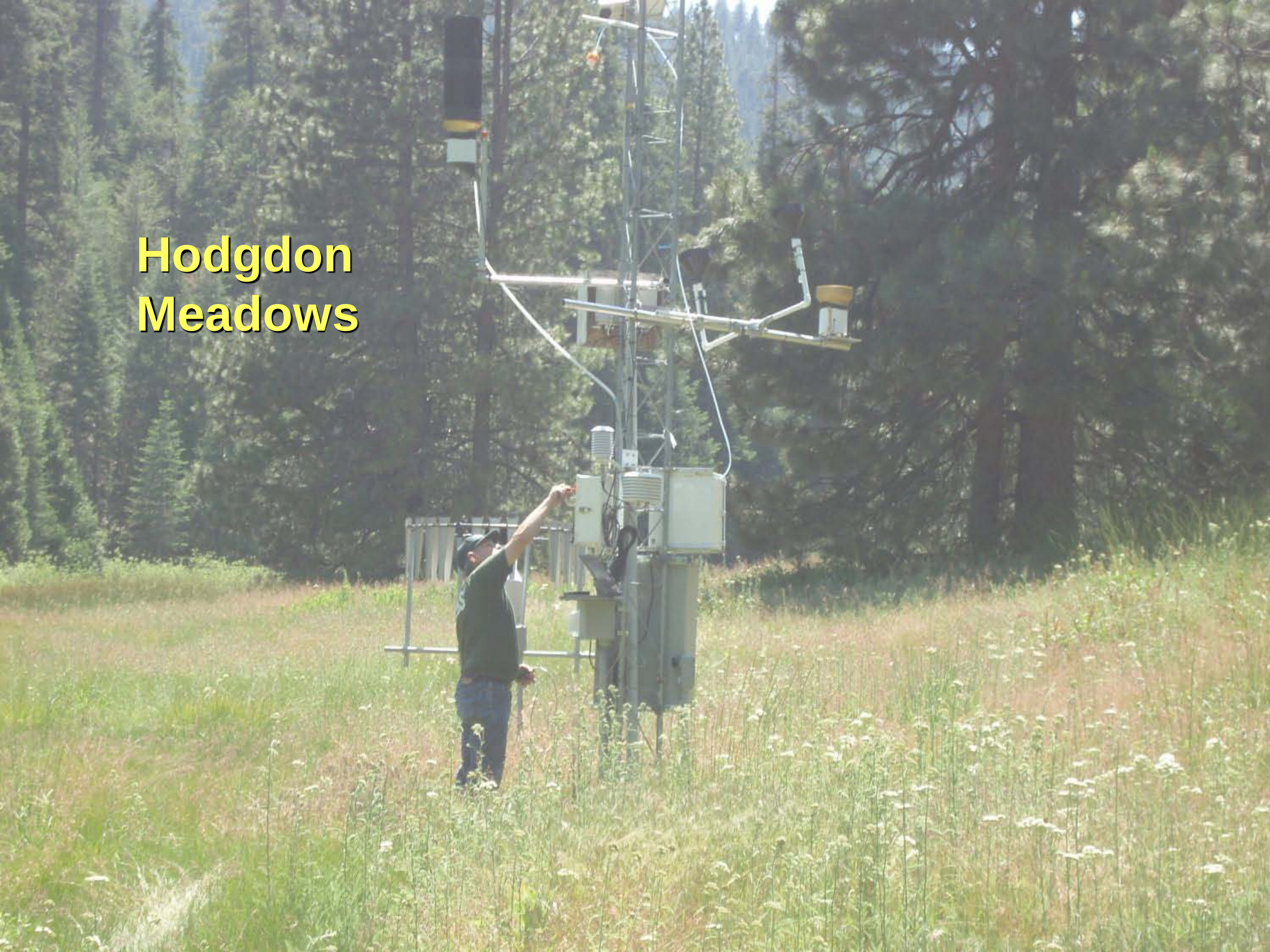



2007
Dana SWE
Gin SWE
TGC flow
Snow water equivalent, inches
Discharge, cfs
40
35
30
25
20
15
10
5
0
3000
2500
2000
1500
1000
500
0
1/1/2007
2/20/2007
4/11/2007
5/31/2007
7/20/2007


2008
Dana SWE
Gin SWE
TGC flow
Snow water equivalent, inches
Discharge, cfs
40
35
30
25
20
15
10
5
0
3000
2500
2000
1500
1000
500
0
1/1/2008
2/20/2008
4/10/2008
5/30/2008
7/19/2008

	2007	2008	2009
Onset of snowmelt	3/31	3/15	4/1
Lag time to rise in flow (days)	0	24	18
Driest potential at bottom of soil (bars)	-1	-4	-12
Soil water potential at onset (bars)	-0.8 - -1.2	-1.5 - -1.8	-0.1 - -2.7
Soil water content at onset (v/v)	0.1-0.15	0.04-0.06	0.05-0.07
# weeks to wet soil profile	0	5	6
# weeks to full saturation	7	11	8


SWE at Dana
Soil water content
6,000
5,000
4,000
3,000
2,000
1,000
-
Total SWE, mm
50,000
100,000
150,000
200,000
250,000
300,000
TGC discharge, cfs
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Soil water contet at onset of snowmelt, mm


Hodgdon
Meadows

Pepperwood Preserve Sonoma County

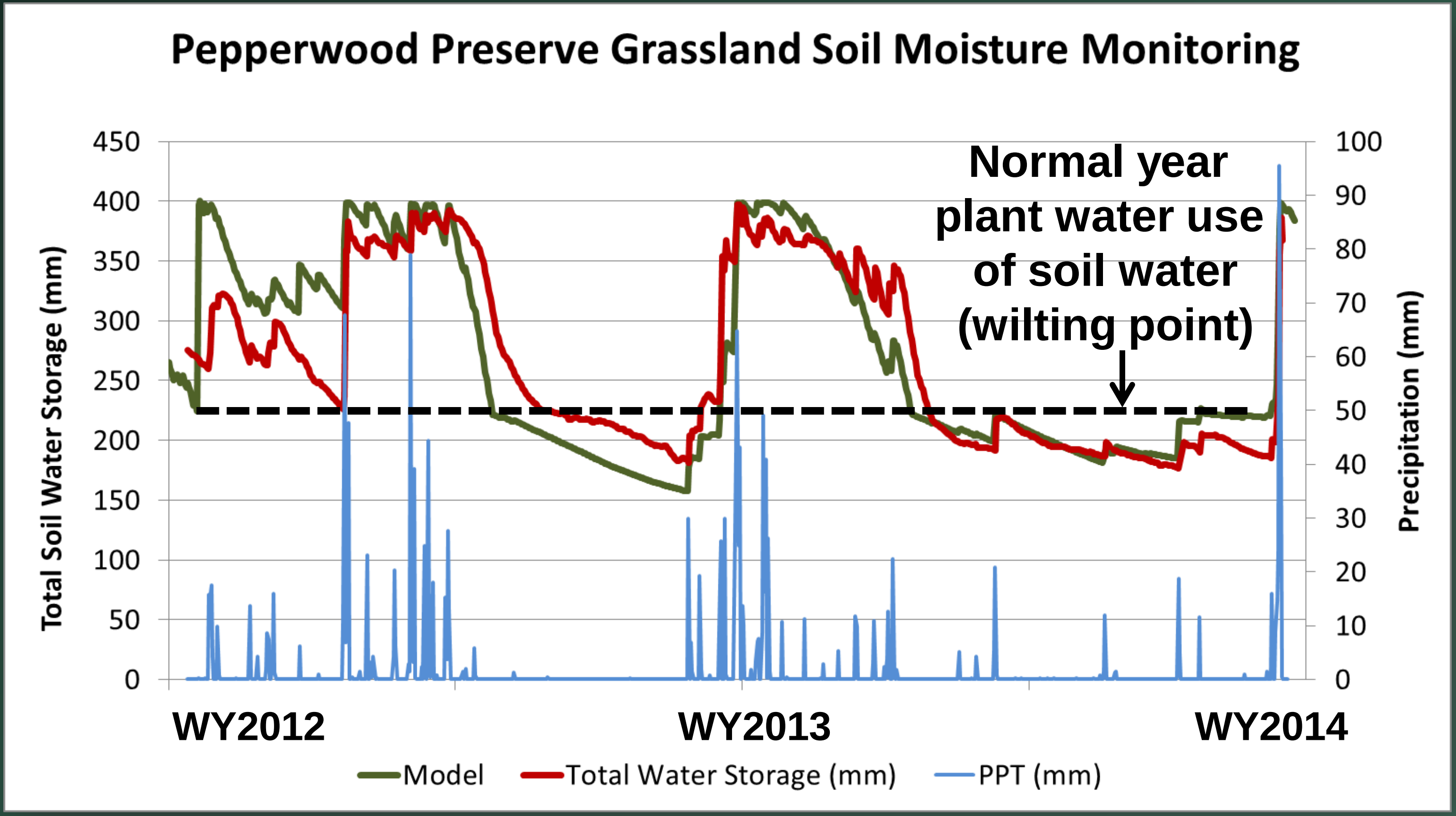
Why Water Potential?

- Helps you understand processes
- Helps identify hydraulic properties
- When plants shut down (wilting point) and drainage is occurring

USGS science for a changing world

Soil Moisture Monitoring

(headwaters of Mark West Creek)

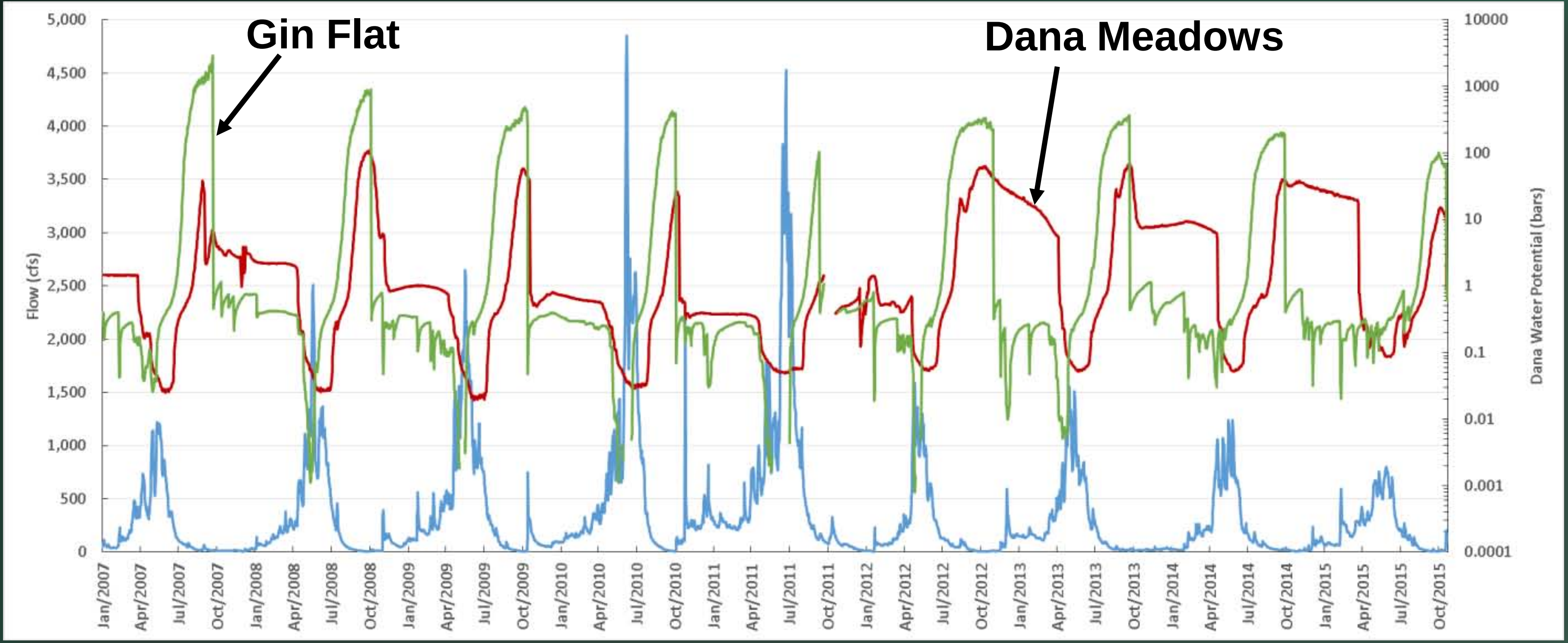


Data US Geological Survey

Why Multiple Depths?

- Helps you understand physical and physiological processes
- Rain gage, rooting zone, ponding zone

Can we use soils data for forecasting?



Gin Flat
Dana Meadows
Flow (cfs)
Dana Water Potential (bars)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
Jan/2007
Apr/2007
Jul/2007
Oct/2007
Jan/2008
Apr/2008
Jul/2008
Oct/2008
Jan/2009
Apr/2009
Jul/2009
Oct/2009
Jan/2010
Apr/2010
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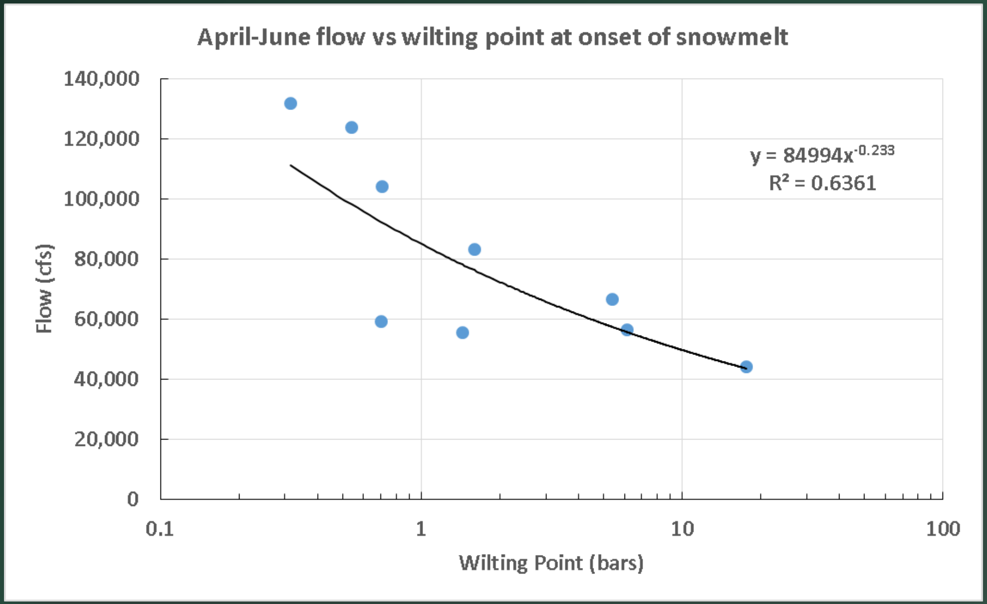
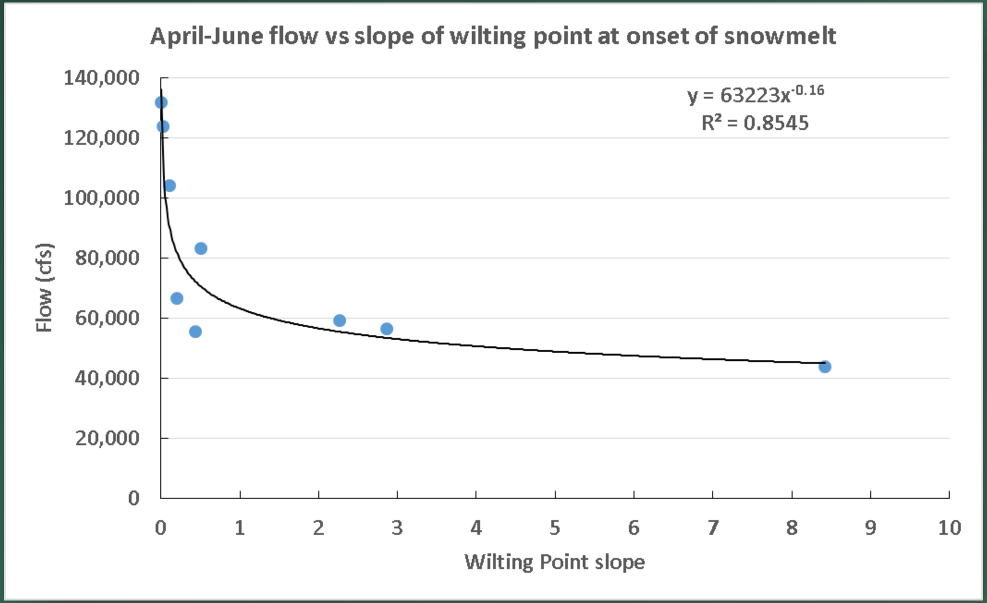
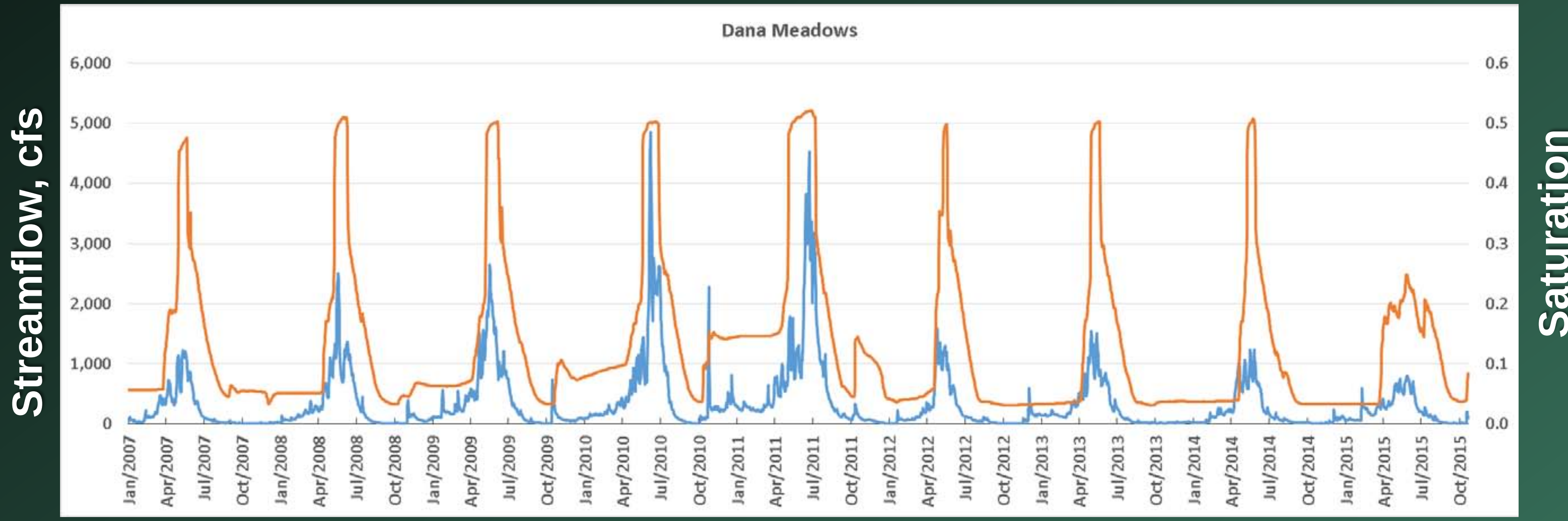
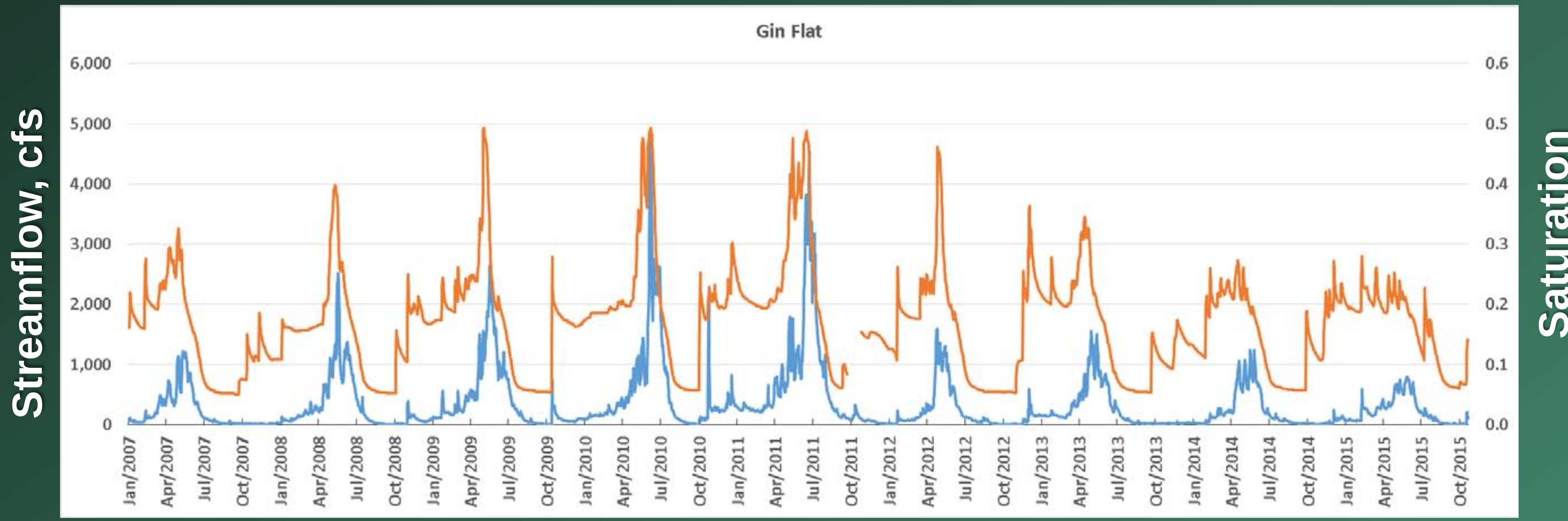
Apr/2015
Jul/2015
Oct/2015

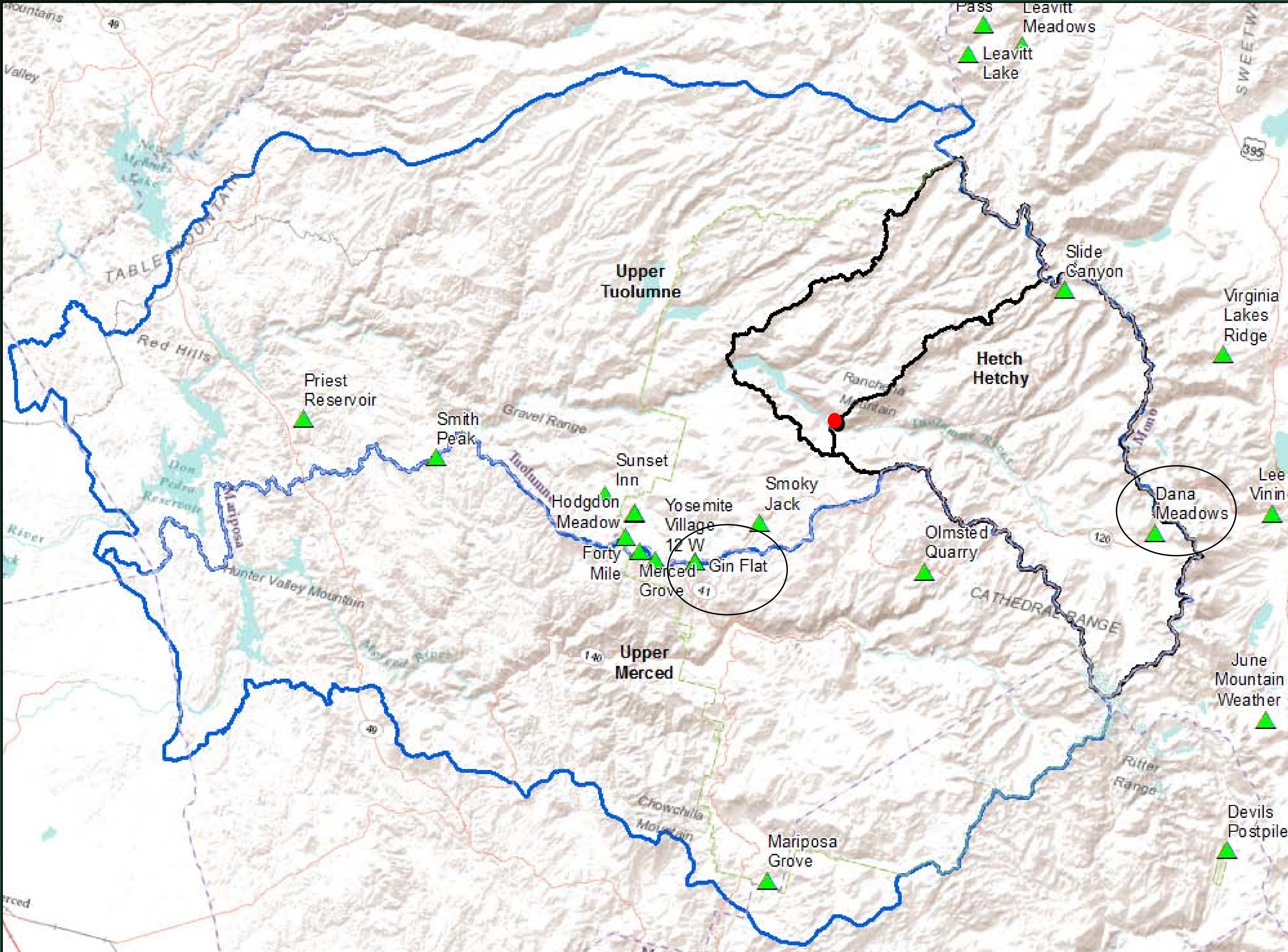

April-June flow vs wilting point at onset of snowmelt
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
0.1
1
10
100
Wilting Point (bars)
y = 84994x-0.233
R² = 0.6361


April-June flow vs slope of wilting point at onset of snowmelt
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
0
1
2
3
4
5
6
7
8
9
10
Wilting Point slope
y = 63223x-0.16
R² = 0.8545

Can we forecast streamflow with soil moisture?

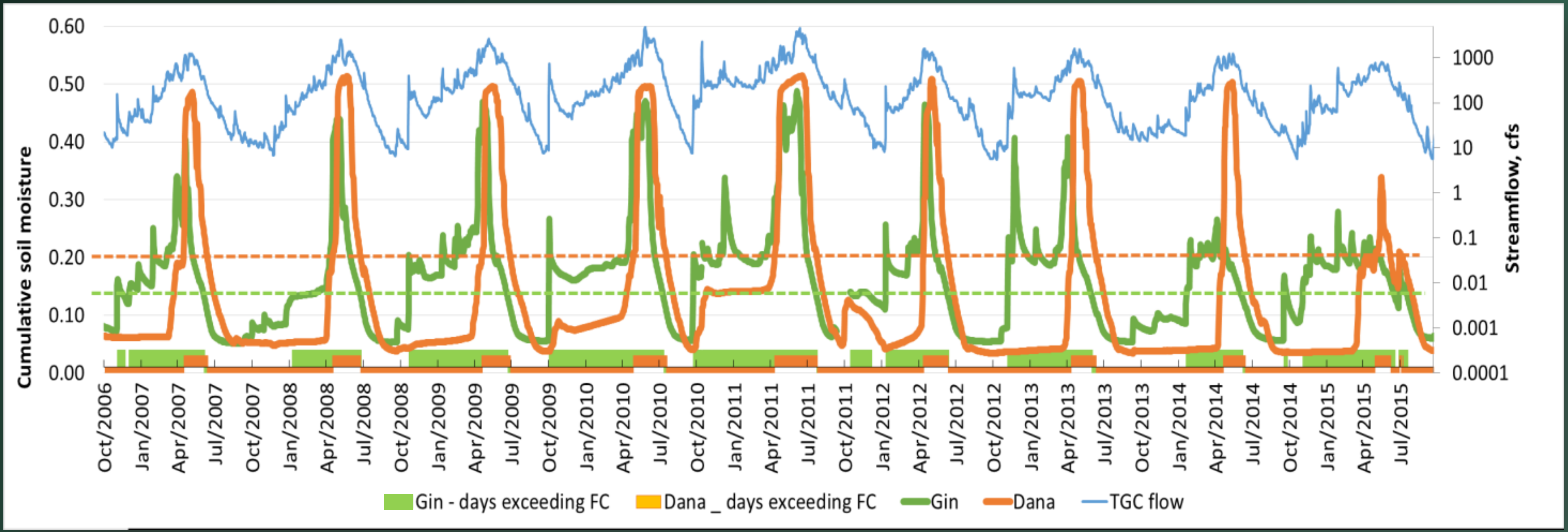




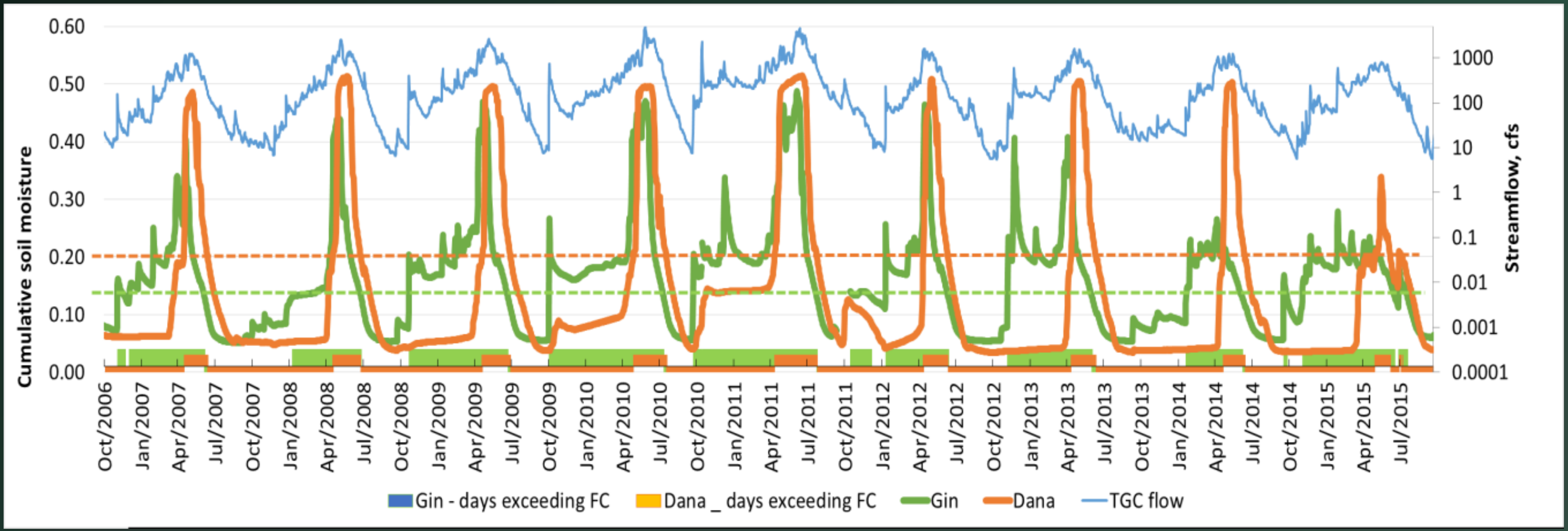


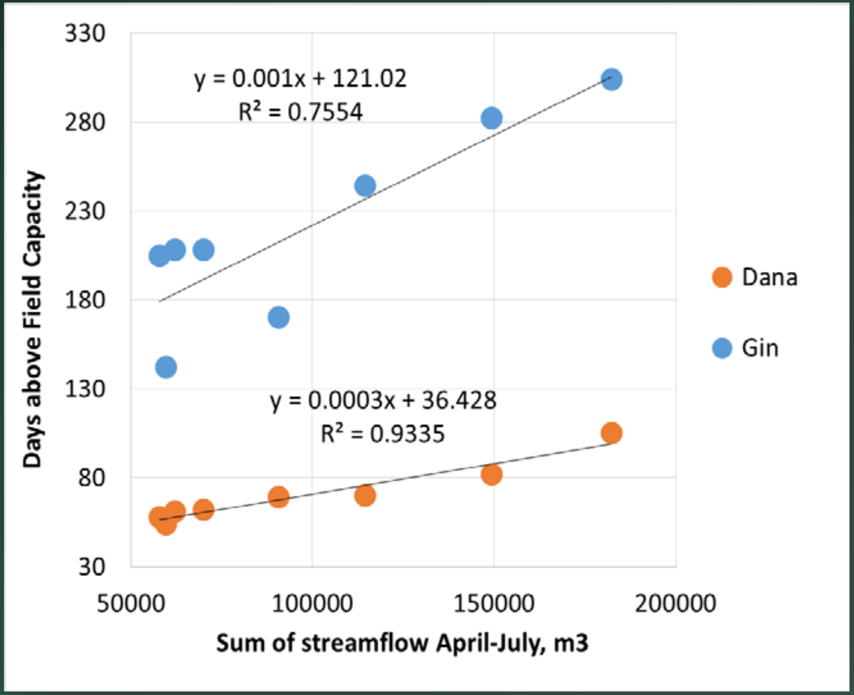
Pass
Leavitt Meadows
Leavitt Lake
Upper Tuolumne
Slide Canyon
Virginia Lakes Ridge
Hetch Hetchy
Priest Reservoir
Smith Peak
Gravel Range
Rancheria Mountain
Sunset Inn
Hodgdon Meadow
Smoky Jack
Yosemite Village 12 W
Forty Mile
Merced Grove
Gin Flat
Olmsted Quarry
Dana Meadows
Lee Vining
CATHEDRAL RANGE
Upper Merced
June Mountain Weather
Ritter Range
Devils Postpile
Mariposa Grove
Chowchilla Mountain
Hunter Valley Mountain
Merced River
Tuolumne
Mariposa
Don Pedro Reservoir
New Melones Lake
TABLE MOUNTAIN
Red Hills
Mono
120
41
140
49
395

Tuolumne River Basin/Hetch Hetchy Subbasin



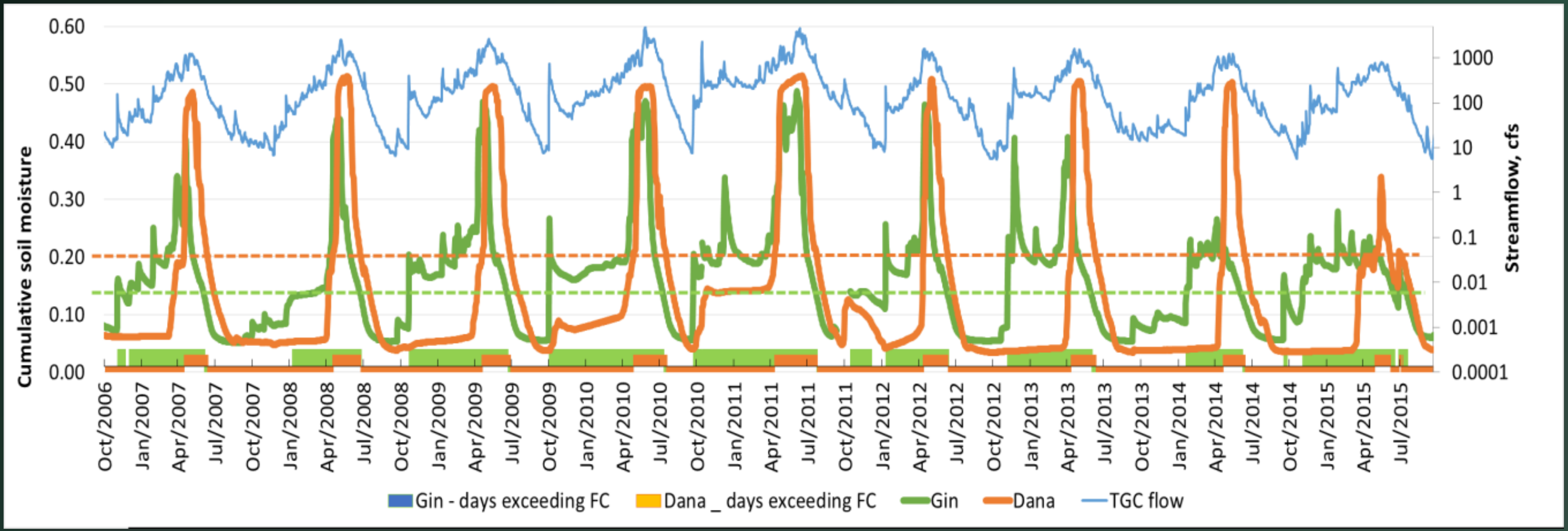
Threshold Field Capacity
Dana Meadows = 20% saturation
Gin Flat = 16% saturation

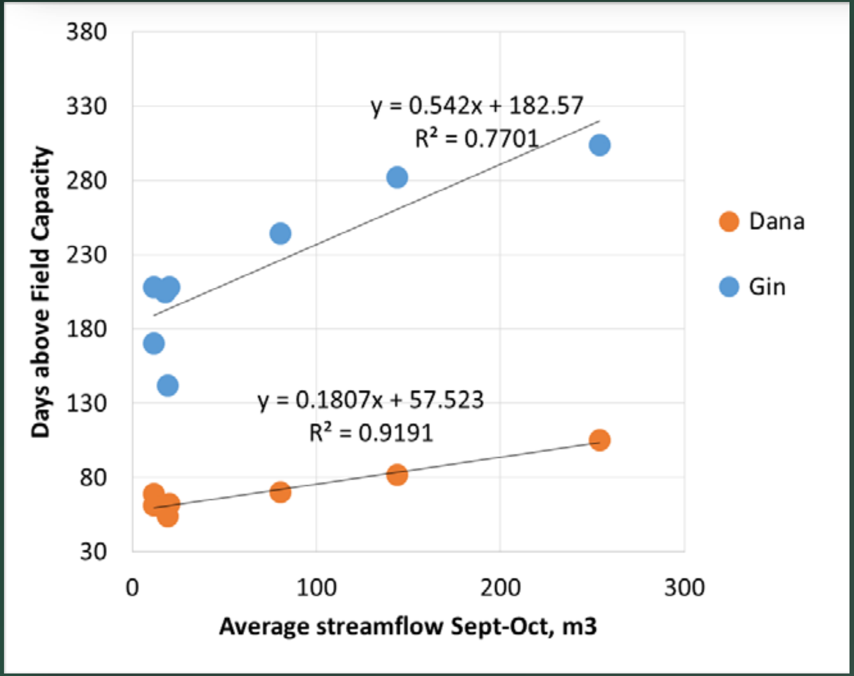




Forecasting Springtime Runoff

Threshold Field Capacity
Dana Meadows = 20% saturation
Gin Flat = 16% saturation

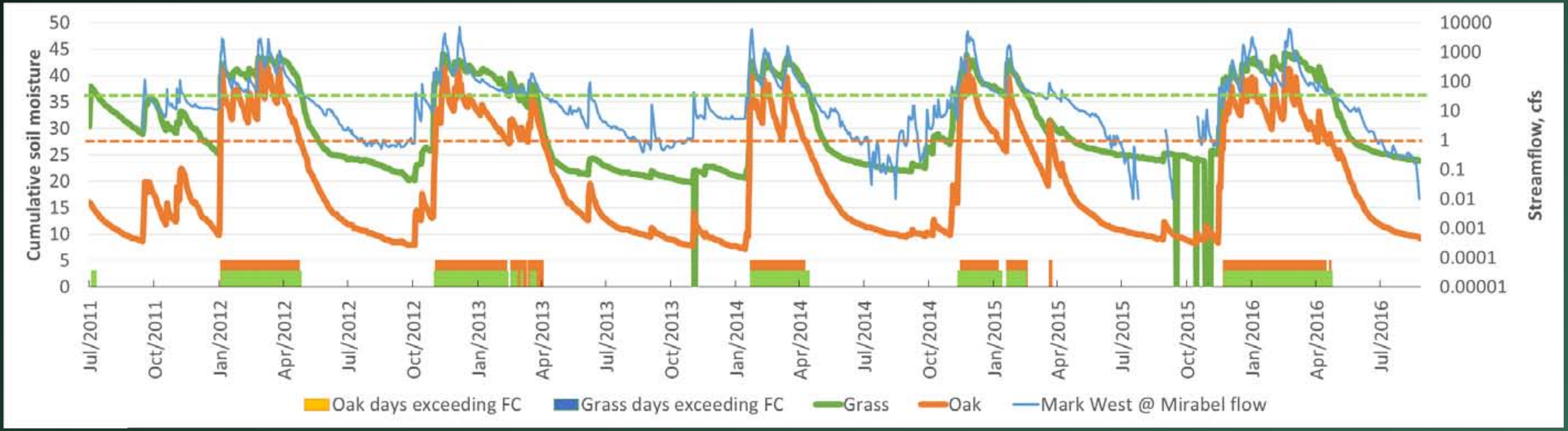


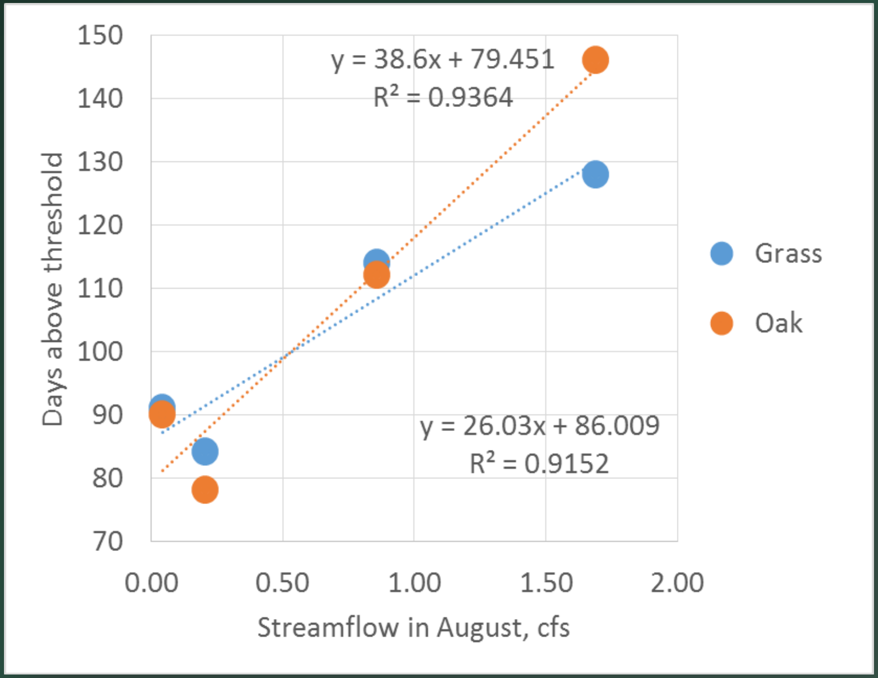


Forecasting Summer Low Flows

Threshold Field Capacity
Dana Meadows = 20% saturation
Gin Flat = 16% saturation

Sonoma County Pepperwood Preserve





Forecasting Summer Low Flows

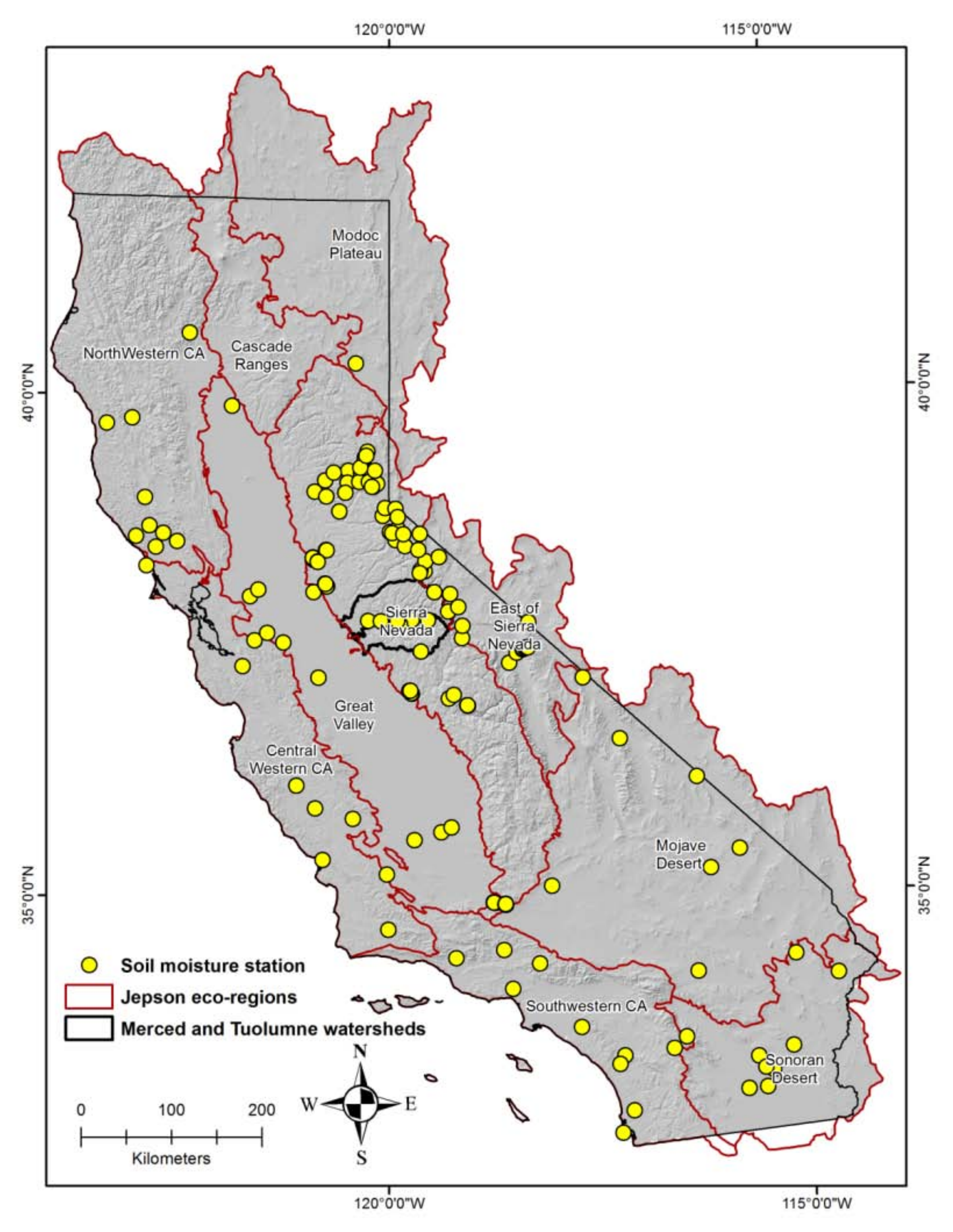
Threshold Field Capacity
Grass = 36.6% saturation
Oak = 27.7% saturation

Soil moisture monitoring for forecasting

- Snowpack is critical but not always the whole story
- Point measurements help us understand the state of the system at that location and may inform reservoir operations
- Soil moisture measurements can help to validate or constrain models, which can distribute and quantify processes for all watersheds

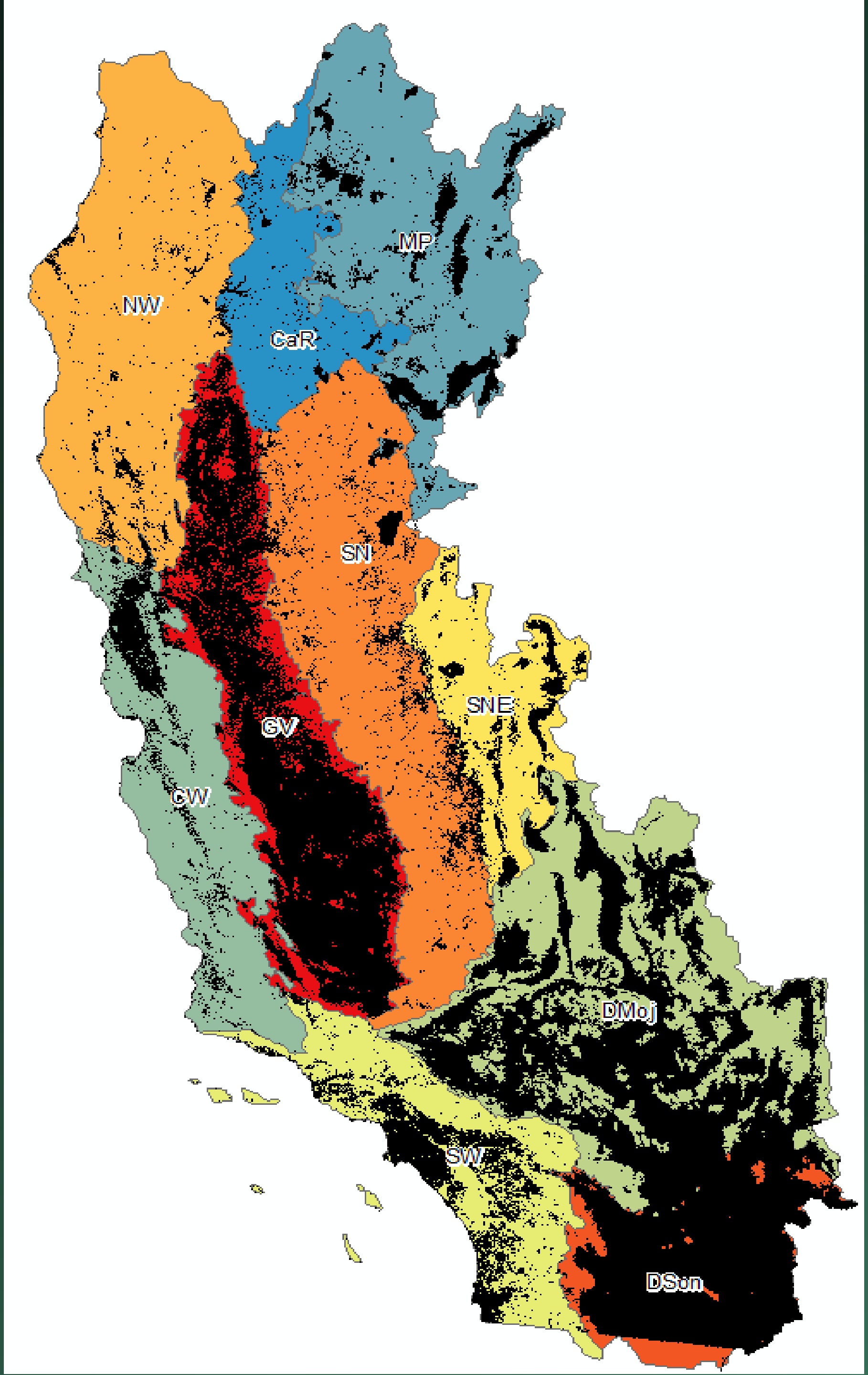
Monitoring Strategy

- Statewide monitoring locations should
  - Mask out unlikely or non useful locations
  - Capture range of soil types
  - Capture range of climatic conditions
  - Capture range of soil responses to climate
  - Provide scaleable strategy for multiple applications from statewide to individual watersheds



Jepson 10 boundaries

- Northwestern CA
- Cascade Ranges
- Modoc Plateau
- Central Western CA
- Great Valley
- Sierra Nevada
- East of Sierra Nevada
- Southwestern CA
- Mojave Desert
- Sonoran Desert

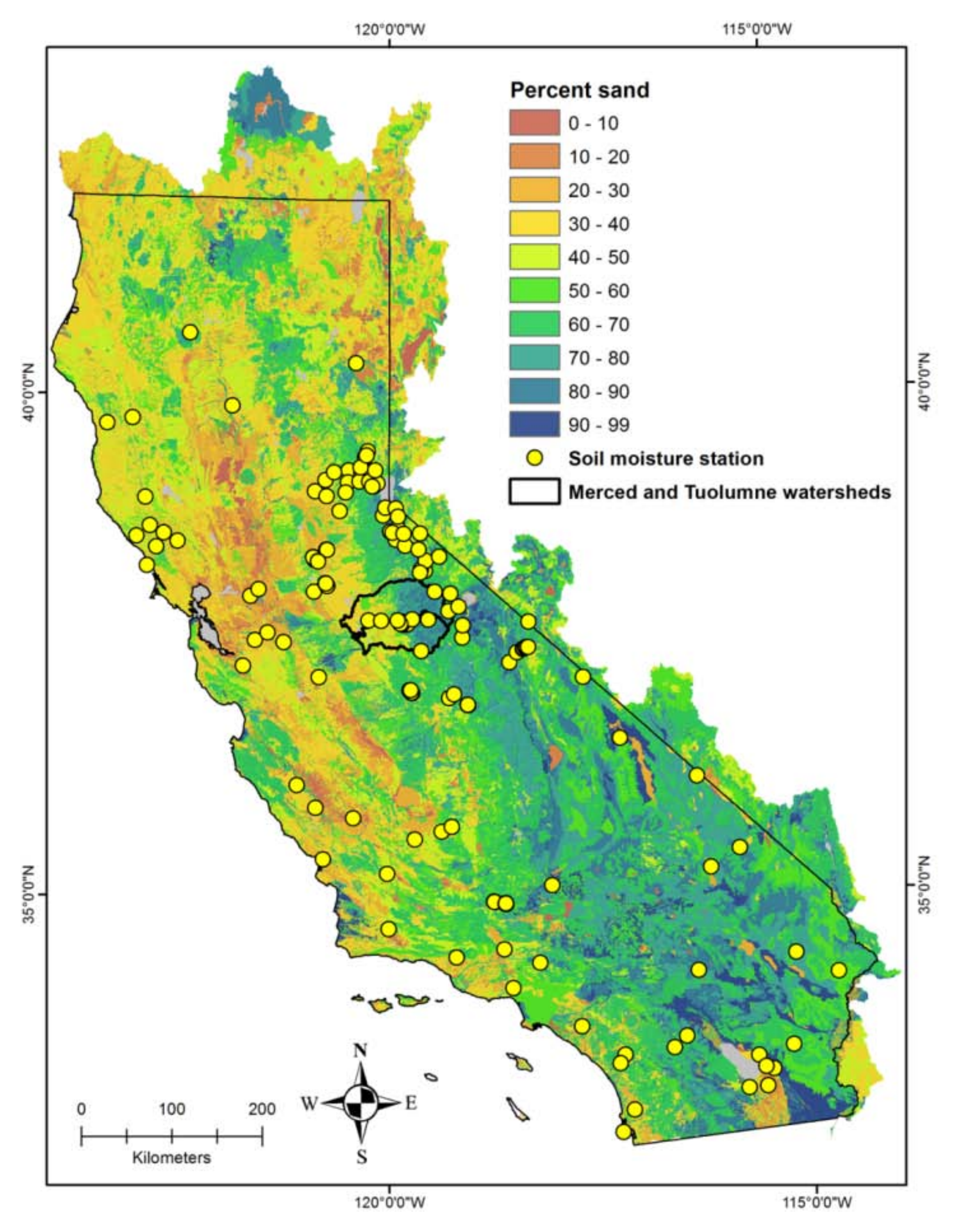


Mask Layer Includes:

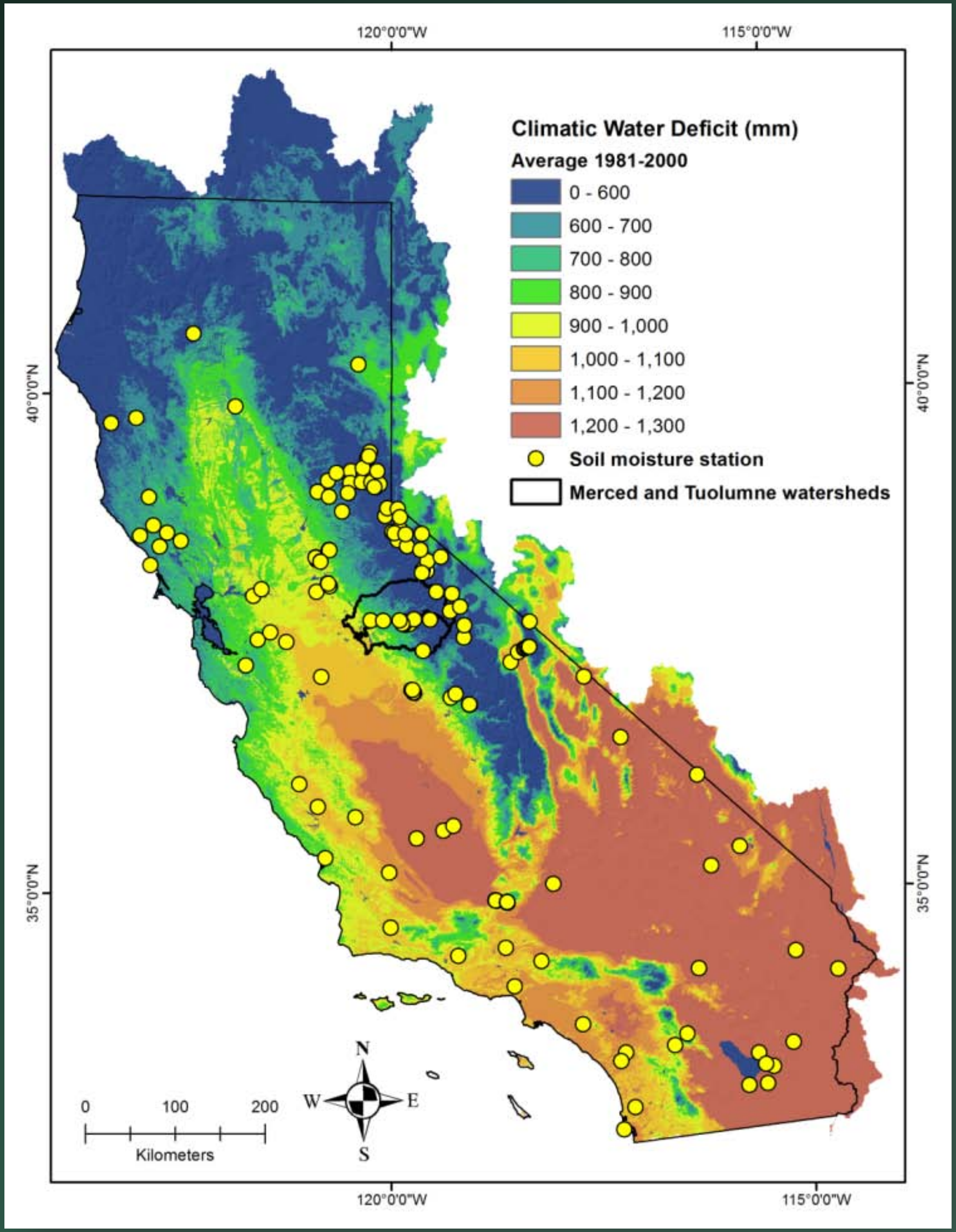
- WY98_rch+run <10mm
- water
- vineyard
- urban
- riverine
- rice
- orchVineyard
- marsh
- lacustrine
- irrigRowFieldCrops
- irrigHay
- irrigGCrops
- evergreenOrchard
- estuarine
- deciduousorchard
- cropland
- Barren

Soil moisture monitoring strategy

- Mask out unnecessary locations
- Select a range of variables that may describe soil moisture response units
- Scale variables 0-1
- Use principal components analysis to remove variables that are highly correlated
- Perform unsupervised cluster analysis
  - CA, ecoregions, watershed
- Topographic analysis for fine scale site selection



120°0'0"W
115°0'0"W
40°0'0"N
35°0'0"N
Percent sand
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 99
Soil moisture station
Merced and Tuolumne watersheds
0
100
200
Kilometers
N
S
E
W



120°0'0"W
115°0'0"W
40°0'0"N
35°0'0"N
Climatic Water Deficit (mm)
Average 1981-2000
0 - 600
600 - 700
700 - 800
800 - 900
900 - 1,000
1,000 - 1,100
1,100 - 1,200
1,200 - 1,300
Soil moisture station
Merced and Tuolumne watersheds
0
100
200
Kilometers
N
S
E
W

PCA California: Correlation (<= 50%):

CWD and PET 93%
Precip and Recharge 74%
Precip and Runoff 81%
Precip and CWD 65%
Precip and PET 55%
CWD and runoff 51%
Porosity and AWC 49%

Run #1 - CA

Name	layer	variance	Eigen value	Percent of Eigen values	Percent Total
cwd	8	0.0097	0.0198	52.16	52.16
psand	5	0.0092	0.0086	22.61	74.77
precip	3	0.0050	0.0043	11.36	86.14
pet	6	0.0049	0.0021	5.56	91.69
rch	10	0.0032	0.0014	3.59	95.29
run	9	0.0024	0.0009	2.26	97.54
porosity	2	0.0013	0.0006	1.65	99.20
awc	4	0.0012	0.0003	0.75	99.95
snow	7	0.0011	0.00002	0.05	99.999
rch/run	1	0.000001	0.000001	0.0014	100

PCA California

CWD
Percent sand
Precipitation
Porosity
Snow (st. dev)

Run #2 - CA

Name	layer	variance	Eigen value	Percent of Eigen values	Percent Total
cwd	5	0.0097	0.0139	52.83	52.83
psand	3	0.0092	0.0083	31.47	84.30
precip	2	0.0050	0.0024	9.17	93.47
porosity	1	0.0013	0.0009	3.43	96.89
snow	4	0.0011	0.0008	3.11	100.00

PCA Sierra Nevada:

Correlation:
- CWD and PET 89%
- Precip and Runoff 71%
- CWD and Precip 64%
- Precip and CWD 65%
- Precip and Recharge 57%
- CWD and runoff 52%
- Precip and PET 49%

Run #1 – Sierra Nevada

Name	layer	variance	Eigen value	Percent of Eigen values	Percent Total
psand	5	0.0076	0.0112	42.82	42.82
cwd	8	0.0056	0.0076	29.17	71.99
pet	6	0.0027	0.0026	9.98	81.97
precip	3	0.0026	0.0018	7.05	89.02
rch	10	0.0024	0.0010	3.90	92.91
run	9	0.0019	0.0009	3.30	96.22
porosity	2	0.0013	0.0007	2.74	98.95
snow	7	0.0012	0.0003	0.98	99.93
awc	4	0.0009	0.00002	0.06	99.997
rch/run	1	0.000001	0.000001	0.0031	100

PCA Sierra Nevada:

CWD
Percent sand
Precipitation
Porosity
AWC
Snow (st.dev)

Run #2 – Sierra Nevada

Name	layer	variance	Eigen value	Percent of Eigen values	Percent Total
psand	4	0.0076	0.0086	44.84	44.84
cwd	6	0.0056	0.0069	35.81	80.65
precip	2	0.0026	0.0012	6.46	87.12
porosity	1	0.0013	0.0010	5.16	92.28
snow	5	0.0012	0.0009	4.45	96.73
awc	3	0.0009	0.0006	3.27	100.00

Understanding multivariate classification

- In an **unsupervised** classification, you do not know what features are actually at any specified location, but you want to aggregate each of the locations into one of a specified number of groups or clusters.
- Assignments to each class or cluster is dependent on the **multivariate statistics** that are calculated on the input rasters.
- Each location is characterized by a set or vector of values and can be visualized as a point in a multidimensional attribute space.
- A class or cluster is a grouping of points in this multidimensional attribute space. Two locations belong to the **same class or cluster if their attributes (raster values) are similar**.

CA 30 class – cluster analysis

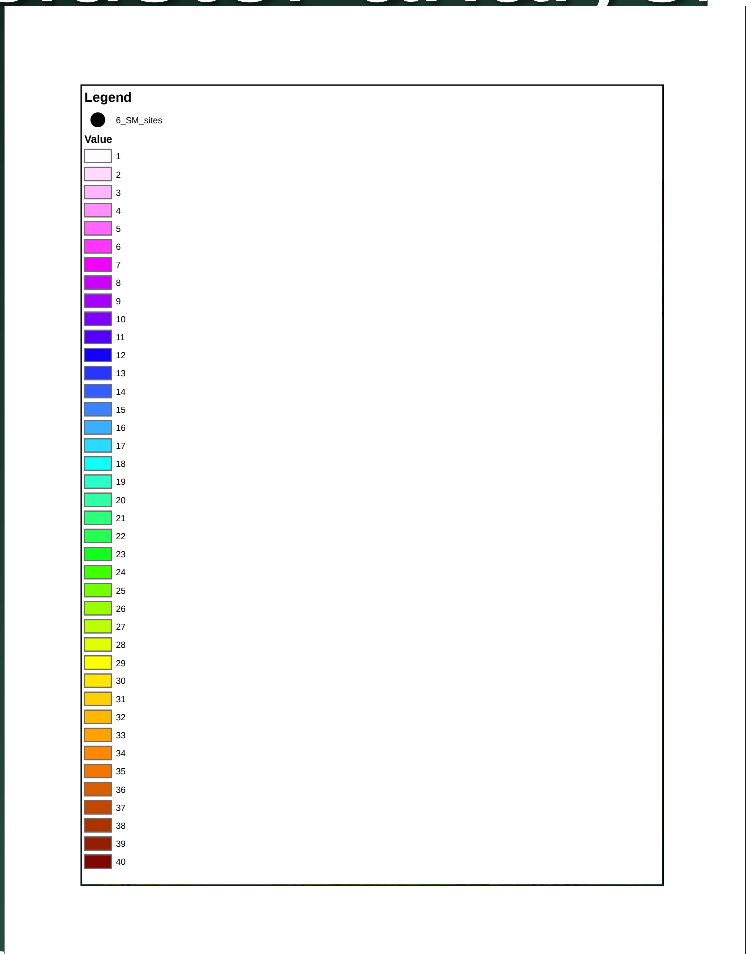
30

GinFlat, Forty Mile, Dana, Smoky Jack, Olmstead = Class 17

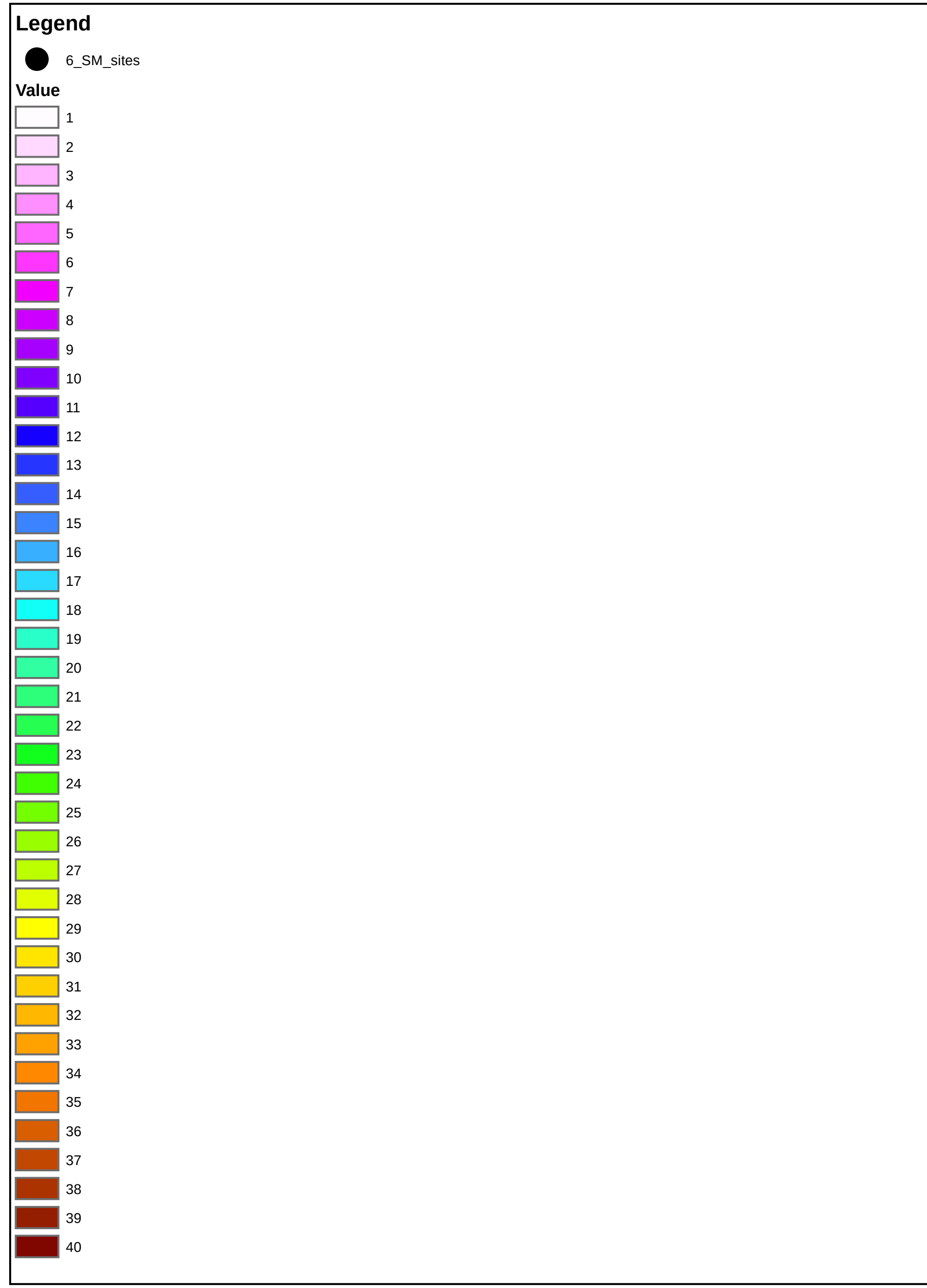
Merced Grove = Class 14

30

CA 40 class - cluster analysi



GinFlat, Forty Mile = class 25
Dana, Smoky Jack, Olmstead = Class
Merced Grove = Class 23



SN 10 class – cluster analysis

Dana = Class 6
Merced Grove = Class 7
GinFlat, Forty Mile, Smoky Jack, Olmstead = Class 8

Merced -Tuolumne 10 class – cluster analysis

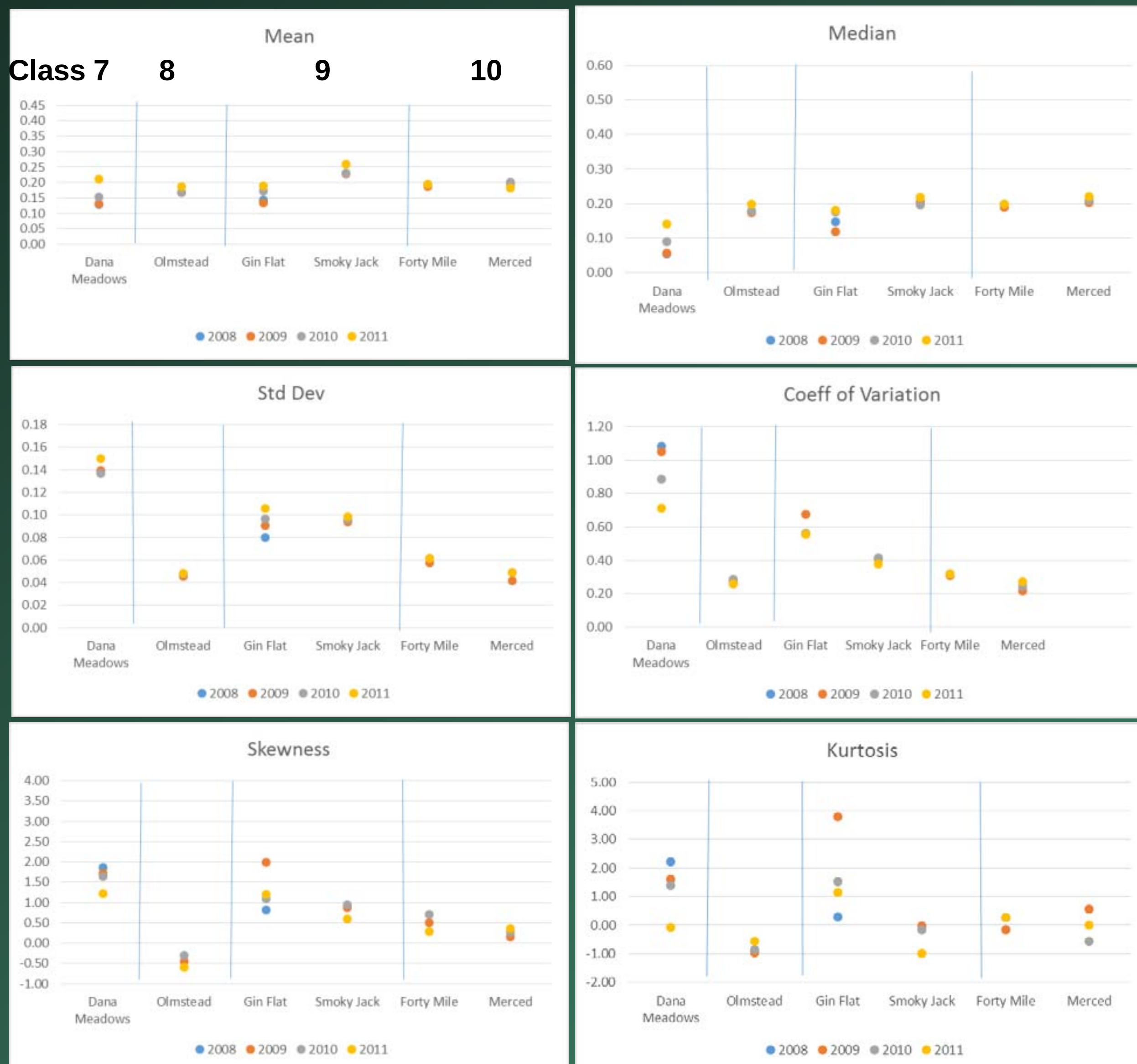
Dana (2965m) = Class 7
Olmstead (2601m) = Class 8
GinFlat (2149m),
Smoky Jack (2180m) = Class 9
Merced Grove (1810m),
Forty Mile (1720m) = Class 10

Merced -Tuolumne 6 class – cluster analysis

Merced Grove (1810m) = Class 3
Dana (2965m) = Class 4
Olmstead (2601m), Smoky Jack (2180m),
GinFlat (2149m),
Forty Mile (1720m) = Class 5

Verification annual WY data

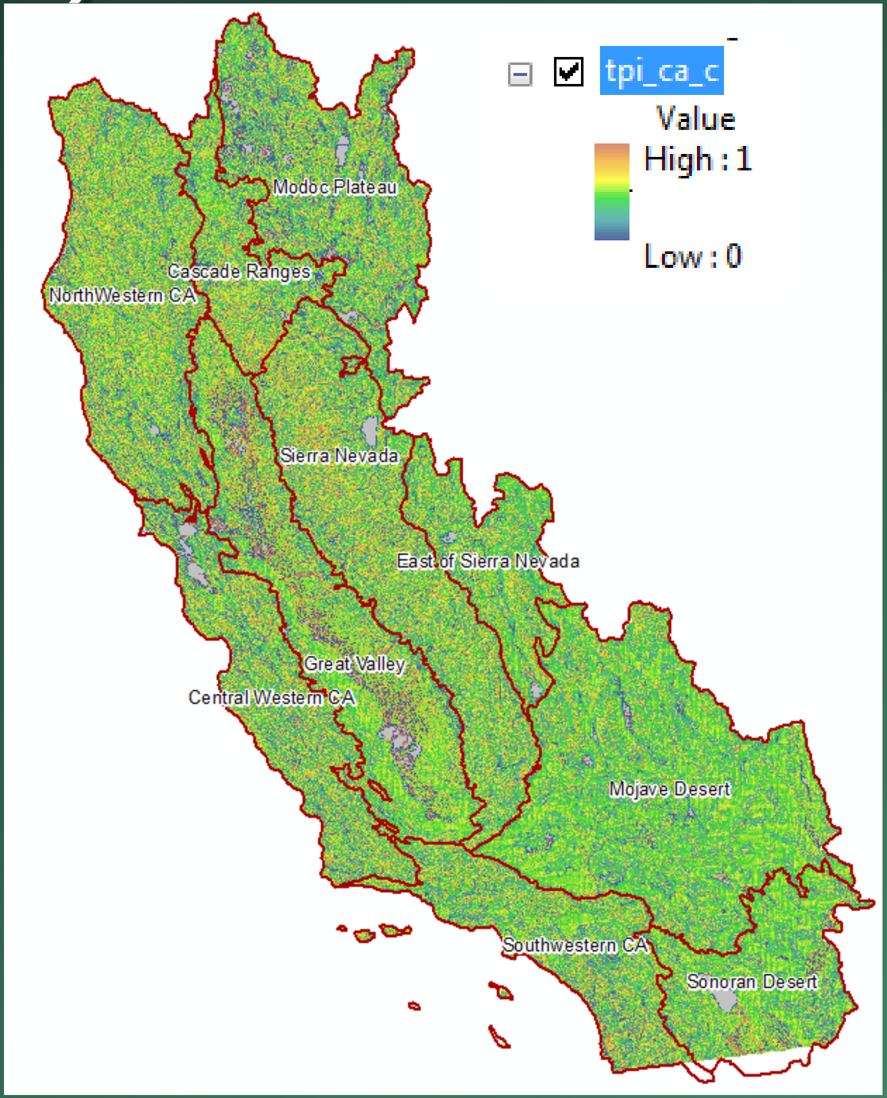
- ANNUAL WY DATA
- Looked at statistics using MT 10 classes
- Class 7 – lowest median values and highest CV values
- Class 8 – very little among year variability in any of the stats
- Class 9 – higher variability in SKEW and KURT, relatively high SD and CV but lower than class 7
- Class 10 – very little among year variability in Mean, Median, SD, and CV

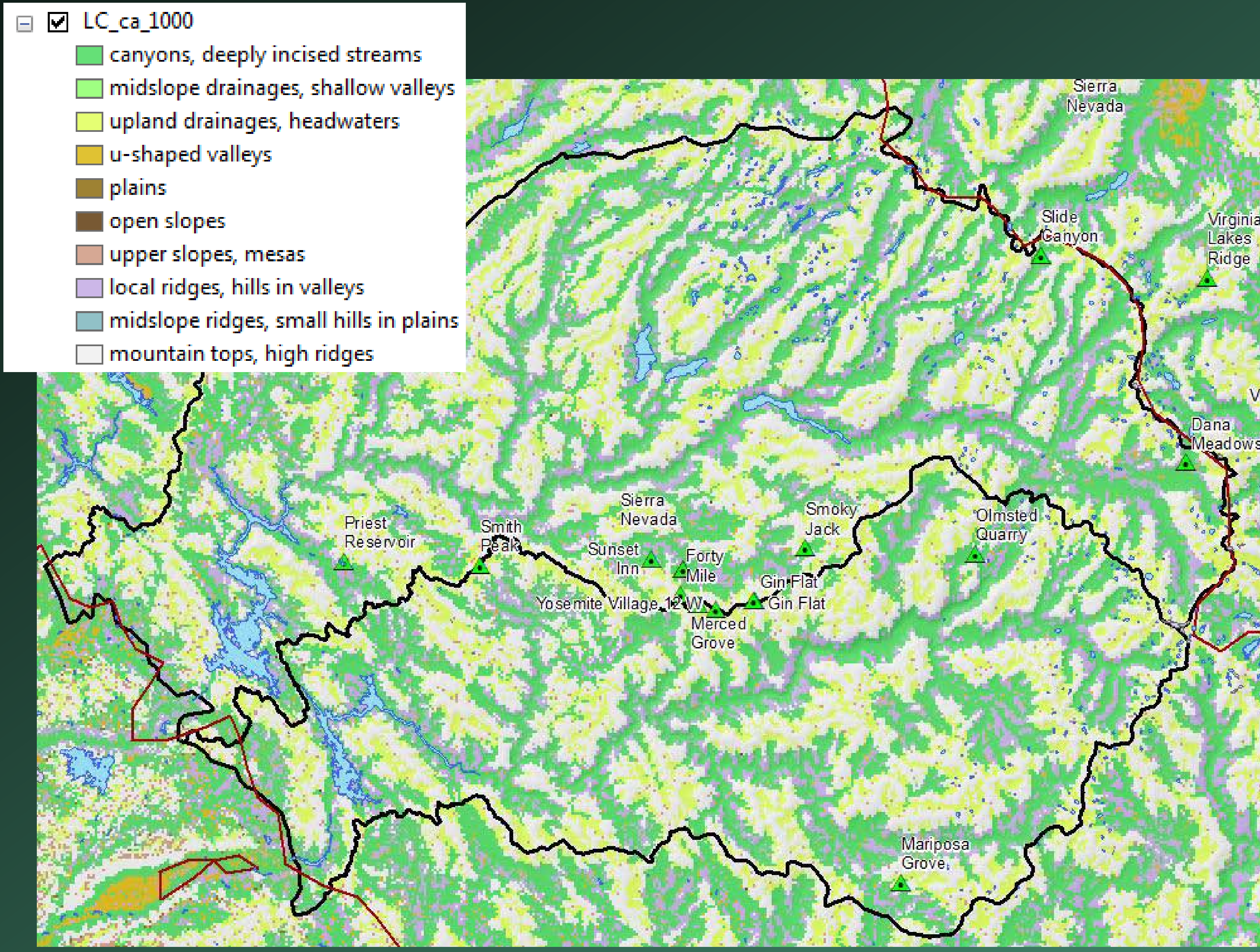


Topographic Position Index (TPI)

- Topographic position index (*TPI*) is an algorithm increasingly used to measure topographic slope positions and to automate landform classifications.

TPI = (DEM – focal min) / (focal max – focal min)




LC_ca_1000
canyons, deeply incised streams
midslope drainages, shallow valleys
upland drainages, headwaters
u-shaped valleys
plains
open slopes
upper slopes, mesas
local ridges, hills in valleys
midslope ridges, small hills in plains
mountain tops, high ridges
Sierra Nevada
Slide Canyon
Virginia Lakes Ridge
Dana Meadows
Sierra Nevada
Smoky Jack
Olmsted Quarry
Priest Reservoir
Smith Peak
Sunset Inn
Forty Mile
Gin Flat
Gin Flat
Yosemite Village 12 W
Merced Grove
Mariposa Grove

Merced -Tuolumne
10 class –
cluster analysis

Merced -Tuolumne
6 class –
cluster analysis

Soil Moisture Datasets: Yosemite National Park, Sierra Nevada and Pepperwood Preserve, Coastal Ranges, California

Prepared in cooperation with the Department of Water Resources

By Michelle Stern, Frank Anderson, Lorraine E. Flint and Alan L. Flint

Soil conditions before the onset of winter precipitation in California affect surface runoff, sub-surface water storage, and overall water supply management. (Photos taken by Frank Anderson)

USGS OFR describing soil moisture and water potential from 3 sites in YNP (2007-2016) and 2 sites in Sonoma County (2011-2016)