Measuring Soil Moisture: Lessons for the Sierra Nevada

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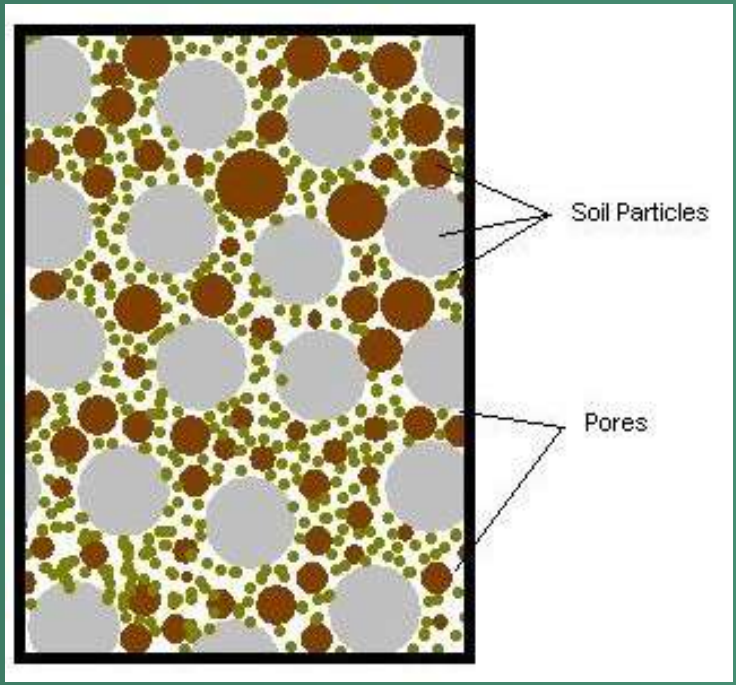
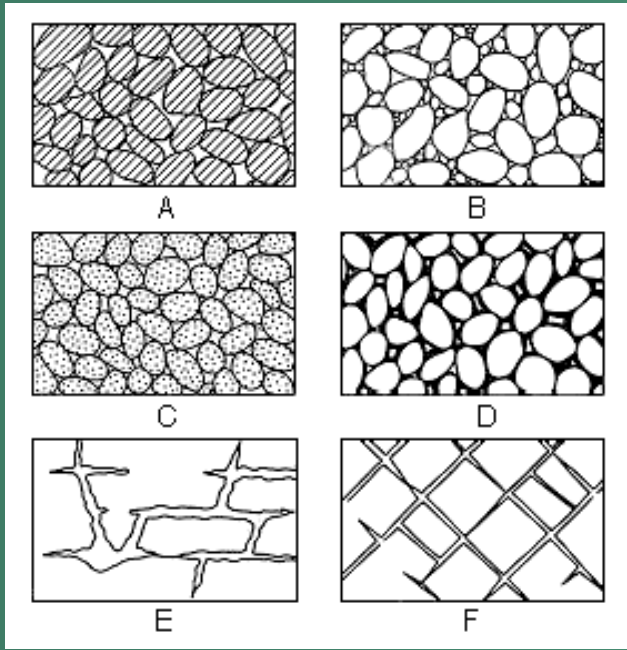
Outline

- Soil moisture 101
- Measuring soil moisture
- Why do we care, what does it tell us?
- Data observations at Dana Meadows
- Extending the conceptual model to the Tuolumne Basin
- Thoughts about field monitoring





Soil Properties

- Texture (sand, silt, clay)
- Porosity
- Bulk density
- Particle density
- Water holding capacity
- Hydraulic conductivity
- Water retention

Calculations

Porosity =
1 – (bulk density/particle density)

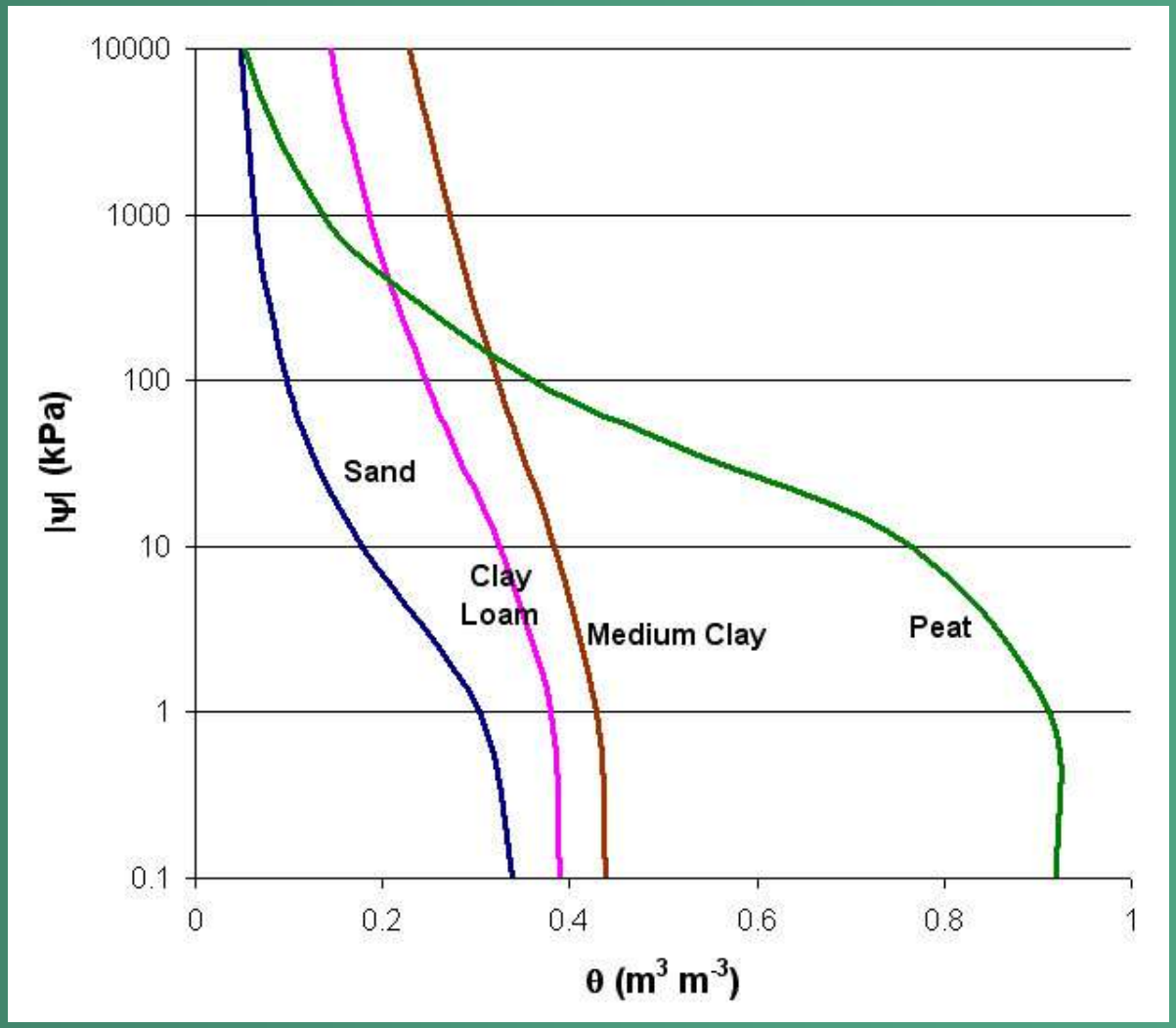
Bulk density = $\frac{\text{mass of dry soil}}{\text{volume of soil}}$

Particle density = mass of mineral material/volume of mineral material

Gravimetric water content (GWC) = mass of water/ mass of soil

Volumetric water content = volume of water/ volume of sample
= GWC * bulk density

Soil Water Retention



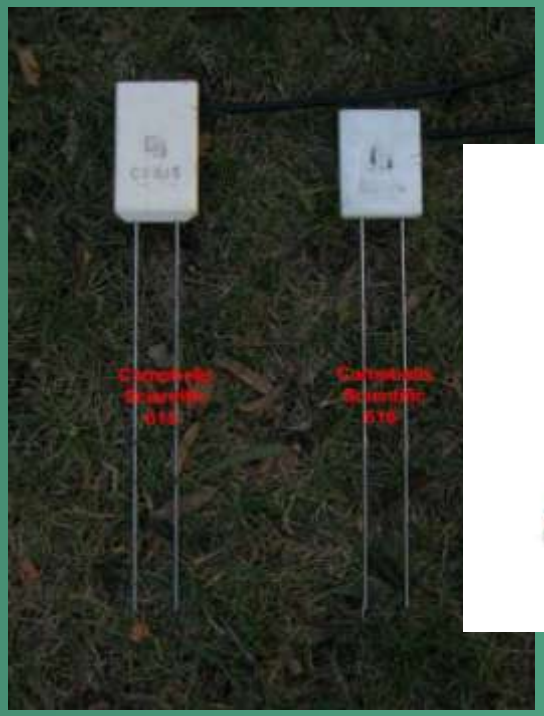
Water Content

Soil Moisture Measurements

- **Measurements**
  - **Soil moisture**
  - **Soil water potential**
  - **CALIBRATION**
- **Soil water potential**
  - **Water moves according to soil water potential gradients**
  - **Measurements have high resolution over large range**
  - **Plants respond directly to water potential**
  - **Reflects large scale processes, regardless of soil type**
- **Soil water content**
  - **Useful for calculation of volume changes**
  - **Lower resolution over smaller range**
  - **More locally relevant, reflects differences among soil types**

Soil Moisture Sensors

- Gravimetric (lab)
- Neutron
- Dielectric constant measurement
- Time domain reflectometry



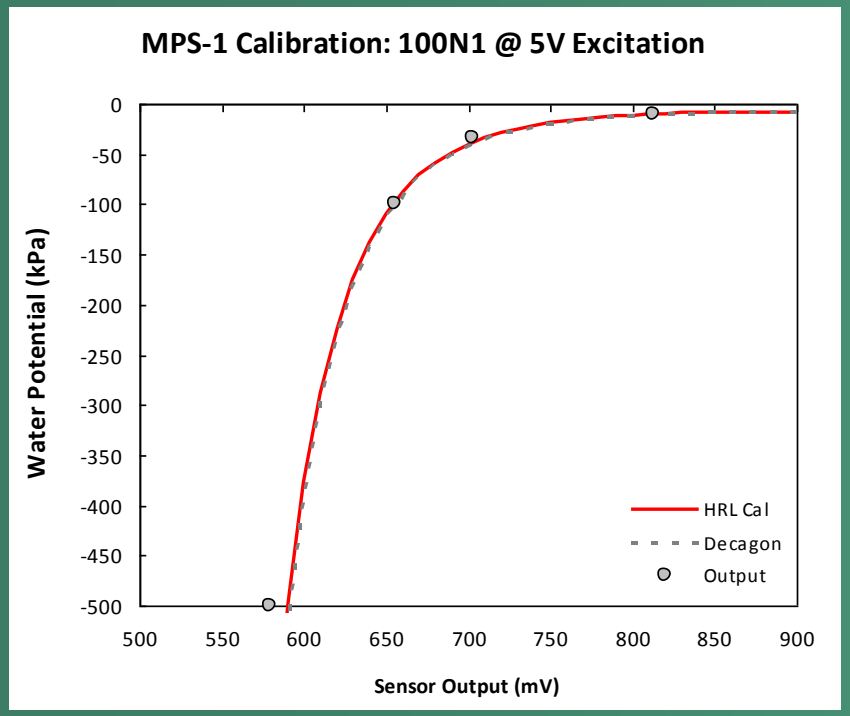
Soil Water Potential Sensors

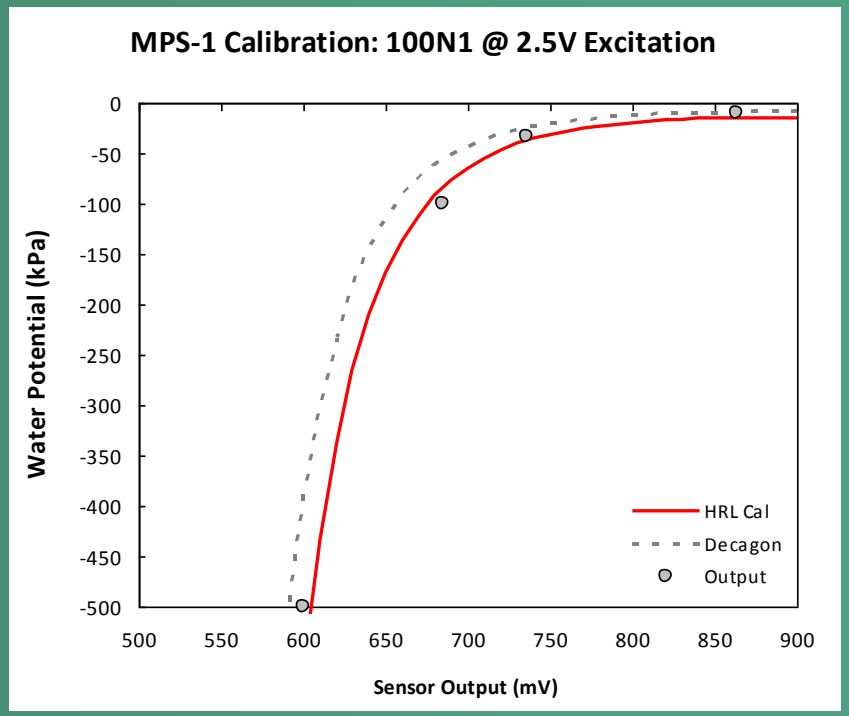
- Dielectric constant measurement
- Heat dissipation
- Resistance
- Hanging water column, tensiometry

Soil Moisture Measurements

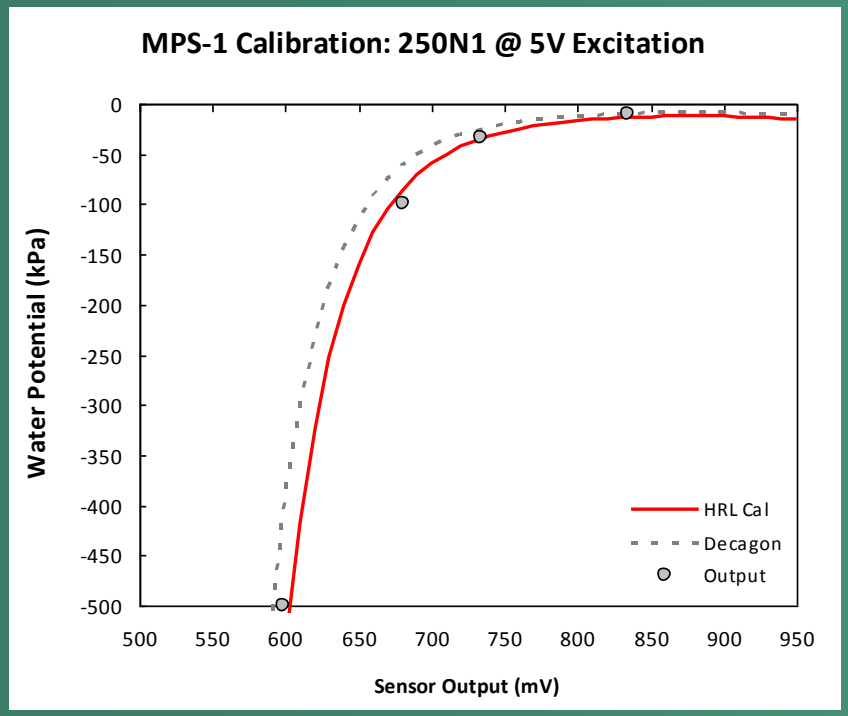
- **Sensor accuracy is dependent on a good calibration**
- **Rigorous testing is advised**
- **Requires laboratory calibration and field checking**

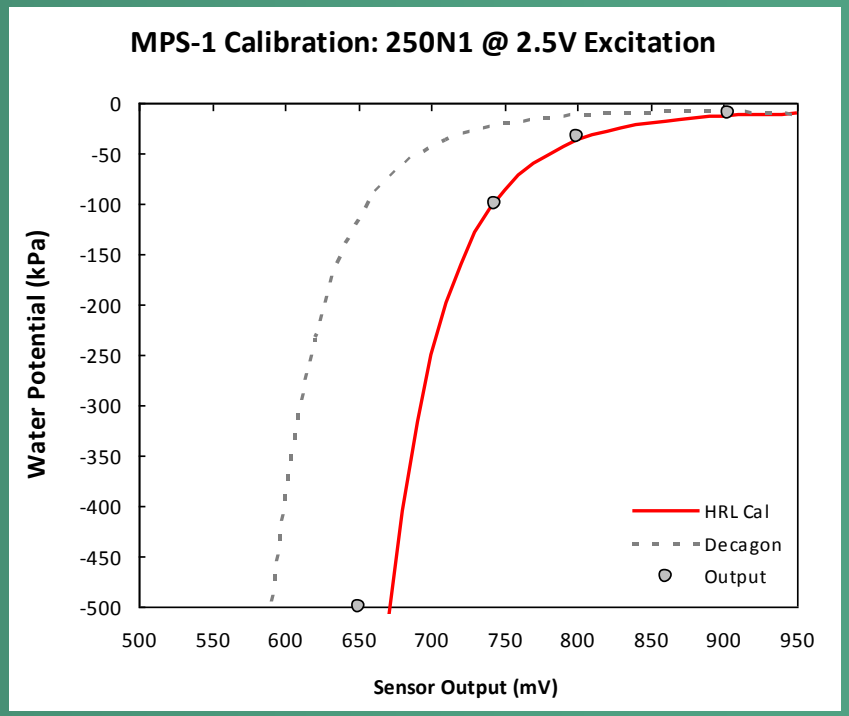
Same sensor, different excitation voltage



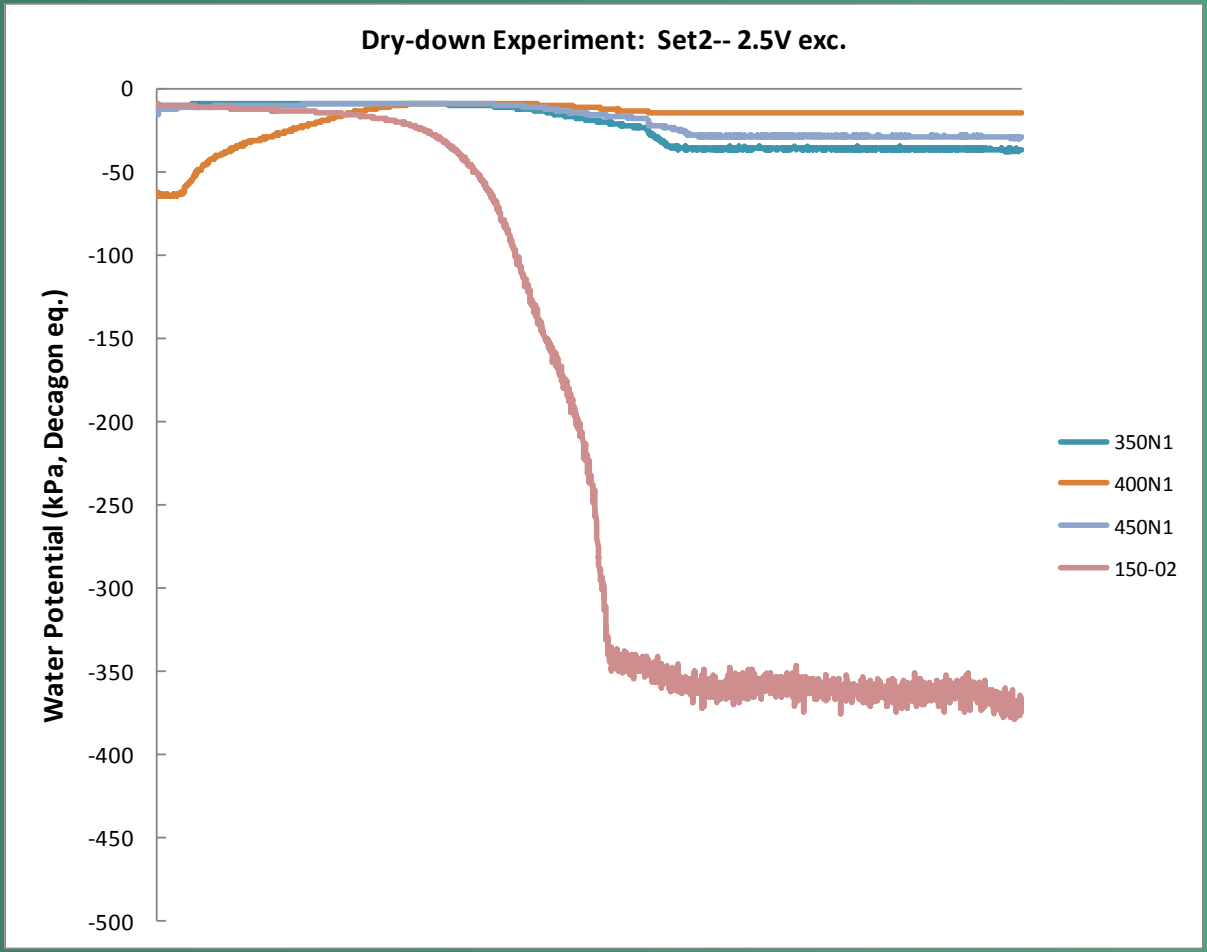


Same sensor, different excitation voltage





Dry down experiment



MPS-1 Sensor Calibrations - status update 09/28/09

	2.5V and 5V excitation					
MPS-1 ID	**wet end (-10 kPa)**	**dry end (-500 kPa)**	**-34 kPa**	**-100 kPa**	**Dry-down experiment results**	**Comments**
100N1	x	x	x	x	n/a	Decagon cal. ok for 5V exc. only
150N1	x	x	x	x	5V-- pass;	new cal. eq. preferred (out of spec.)
200N1	x	x	x	x	5V-- fail; new test underway	**requires new cal. eq.**
250N1	x	x	x	x	n/a	new cal. eq. preferred (out of spec.)
300N1	x	x	x	x	n/a	**requires new cal. eq.**
350N1	x	x	underway		5V-- fail; 2.5V fail	**requires new cal. eq.**
400N1	x	x	underway		5V-- fail; 2.5V fail	**requires new cal. eq.**
450N1	x	x	underway		5V-- fail; 2.5V fail	**requires new cal. eq.**
100-01	x	x	underway		5V-- pass; 2.5V-- pass	TBD-- Decagon cal. may be ok
100-02	x	x	underway		5V-- pass; 2.5V-- pass	TBD-- Decagon cal. may be ok
100-03	x	x	underway		5V-- pass; 2.5V-- pass	TBD-- Decagon cal. may be ok
150-01	x	x	n/a	n/a	5V-- fail; 2.5V fail	bad sensor
150-02	x	x	underway		5V-- pass; 2.5V-- fail	TBD-- Decagon cal. may be ok
150-03		underway				TBD

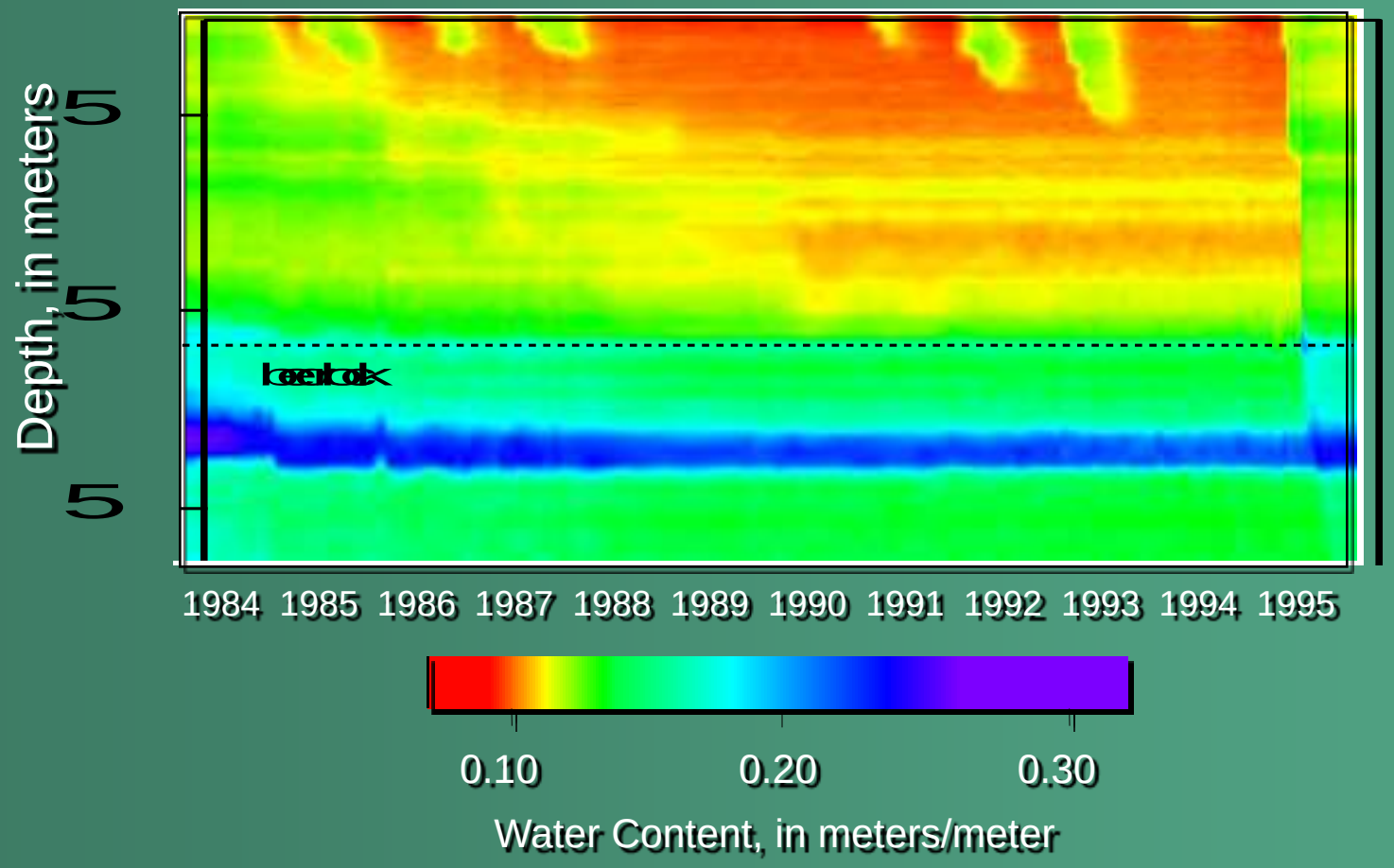
OFF

Soil moisture measurements

- **Provide information to develop a conceptual model for understanding the hydrologic system**
- **Can be used for soil and bedrock**

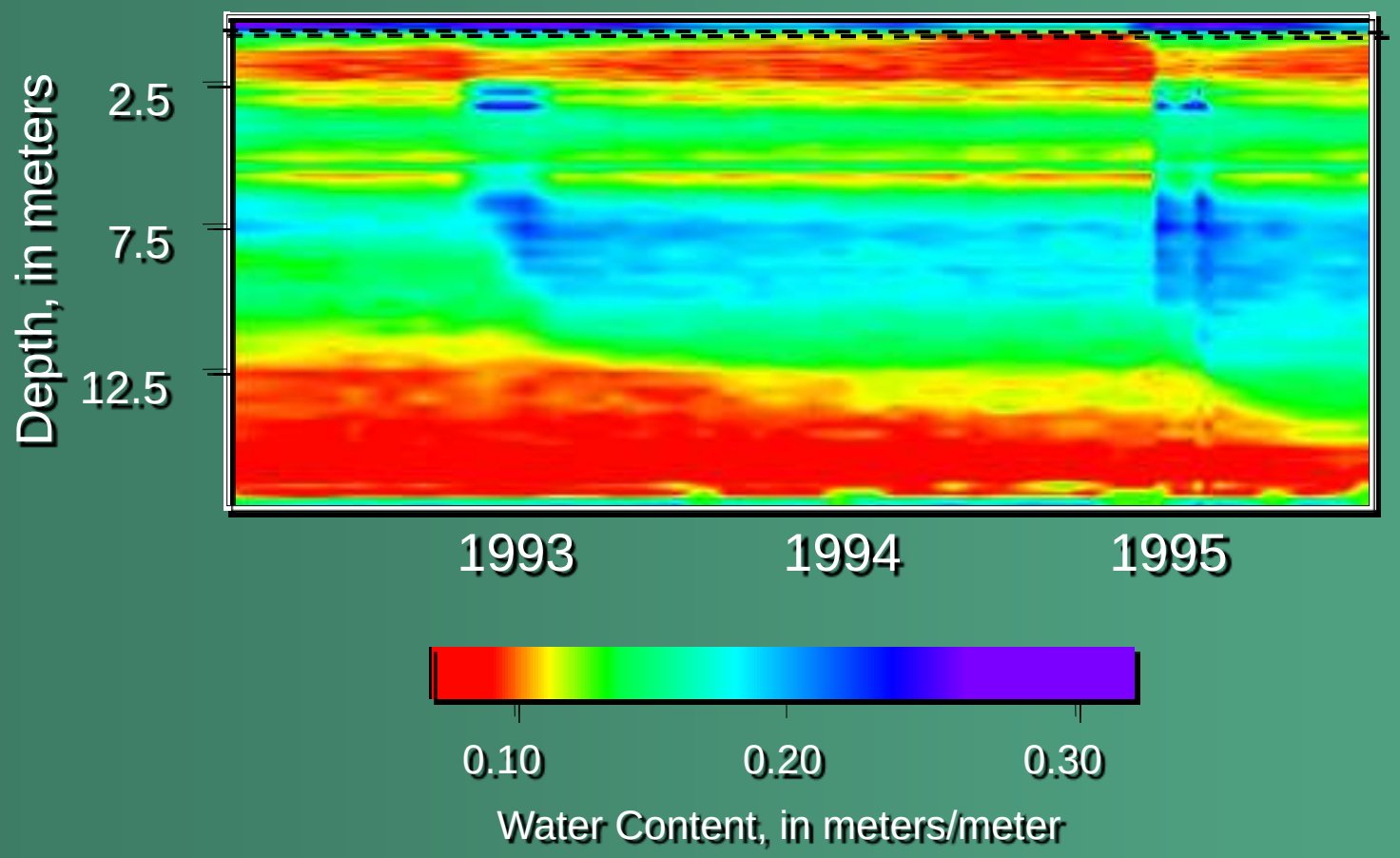
Infiltration at Borehole UZN #1

Active channel, 8-meter deep soil

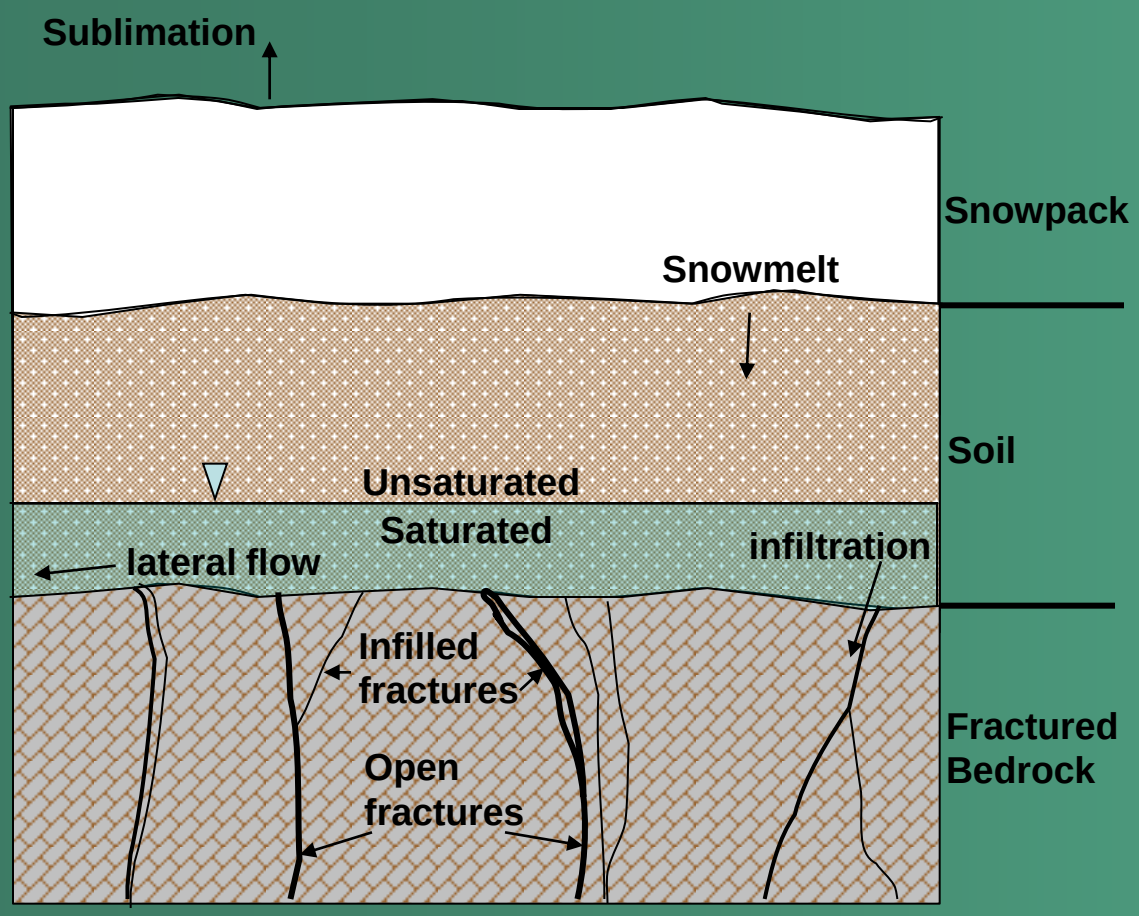


Infiltration at Borehole UZN-15

(75 cm soil over 2 m lower porosity fractured bedrock, underlain by 10 m high porosity fractured bedrock)



Measurement Field Setting

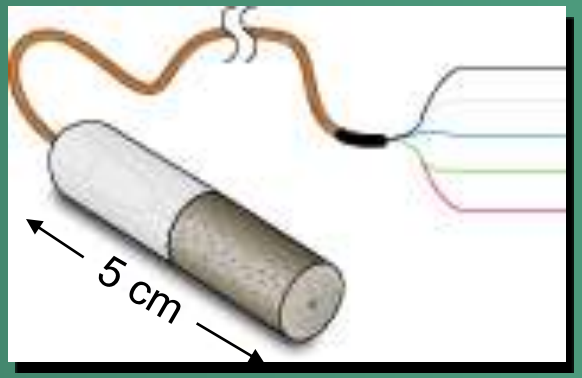


- **What do we want to know?**
  - **Snowmelt**
  - **Evapotranspiration**
  - **Sublimation**
  - **Drainage or recharge**
  - **Soil storage**
  - **Timing of runoff**
  - **Volume of runoff**

Recommended Soil Moisture Monitoring Instrumentation

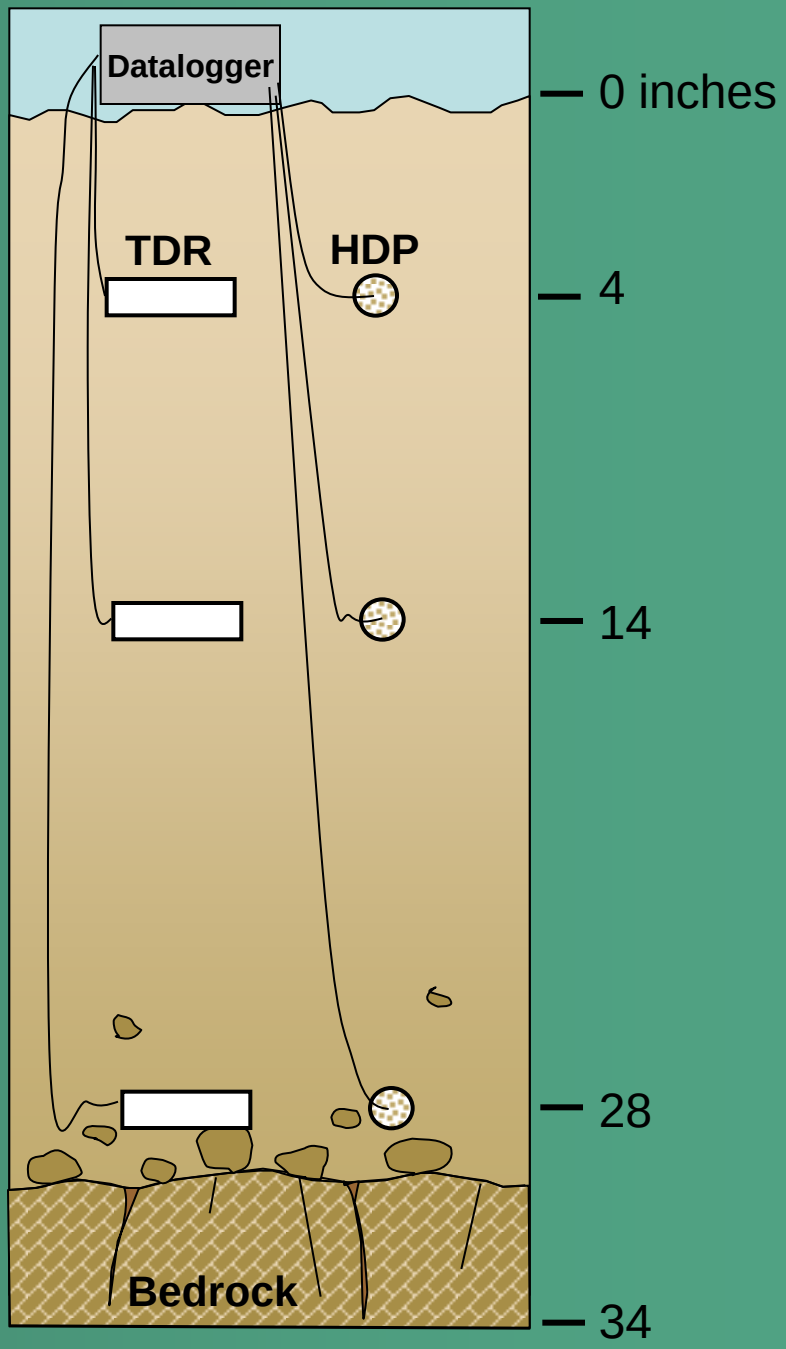
Water content:

Time Domain Reflectometry (TDR)



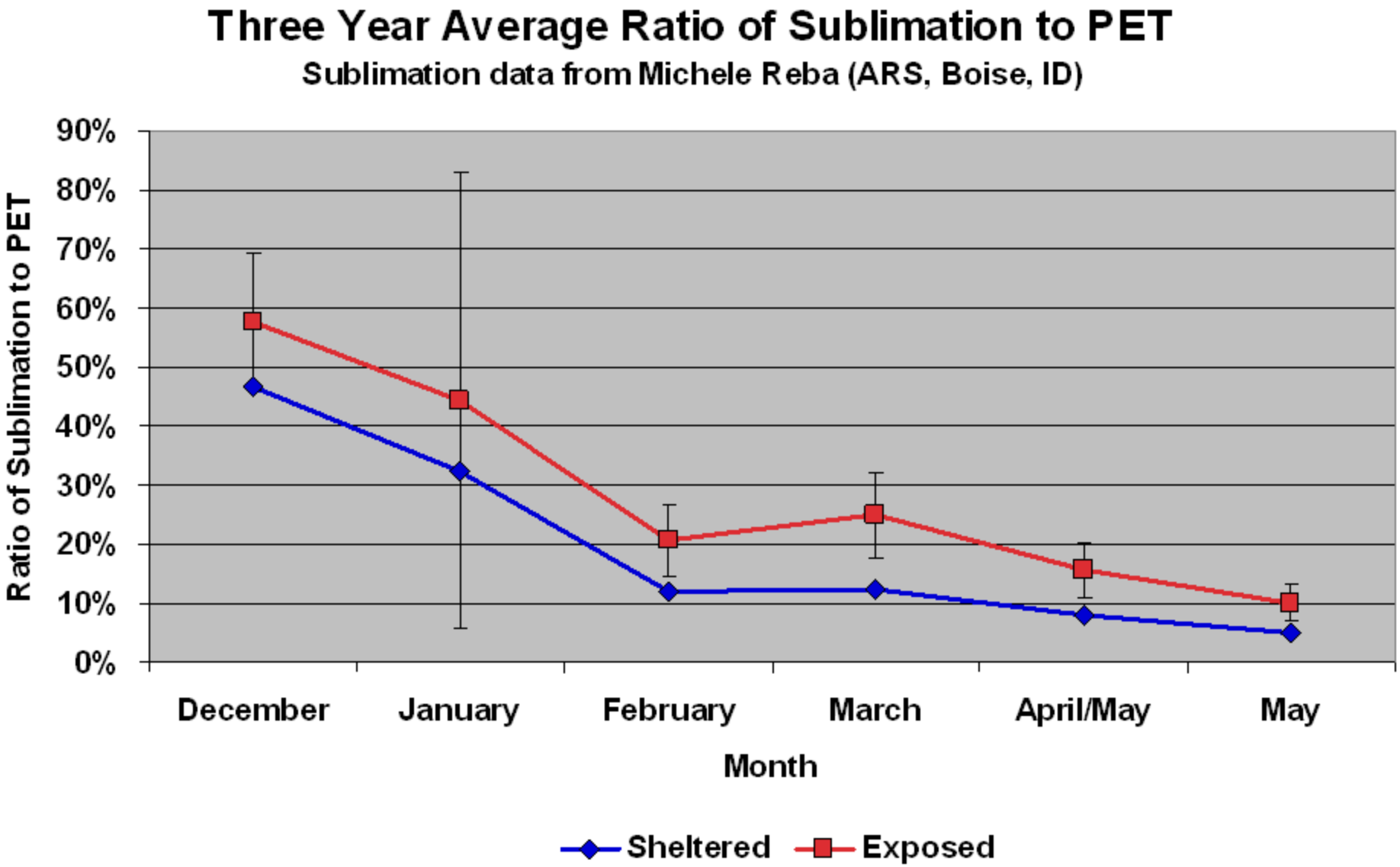
Water potential:

Heat Dissipation Probe (HDP)


Datalogger
TDR
HDP
Bedrock
0 inches
4
14
28
34

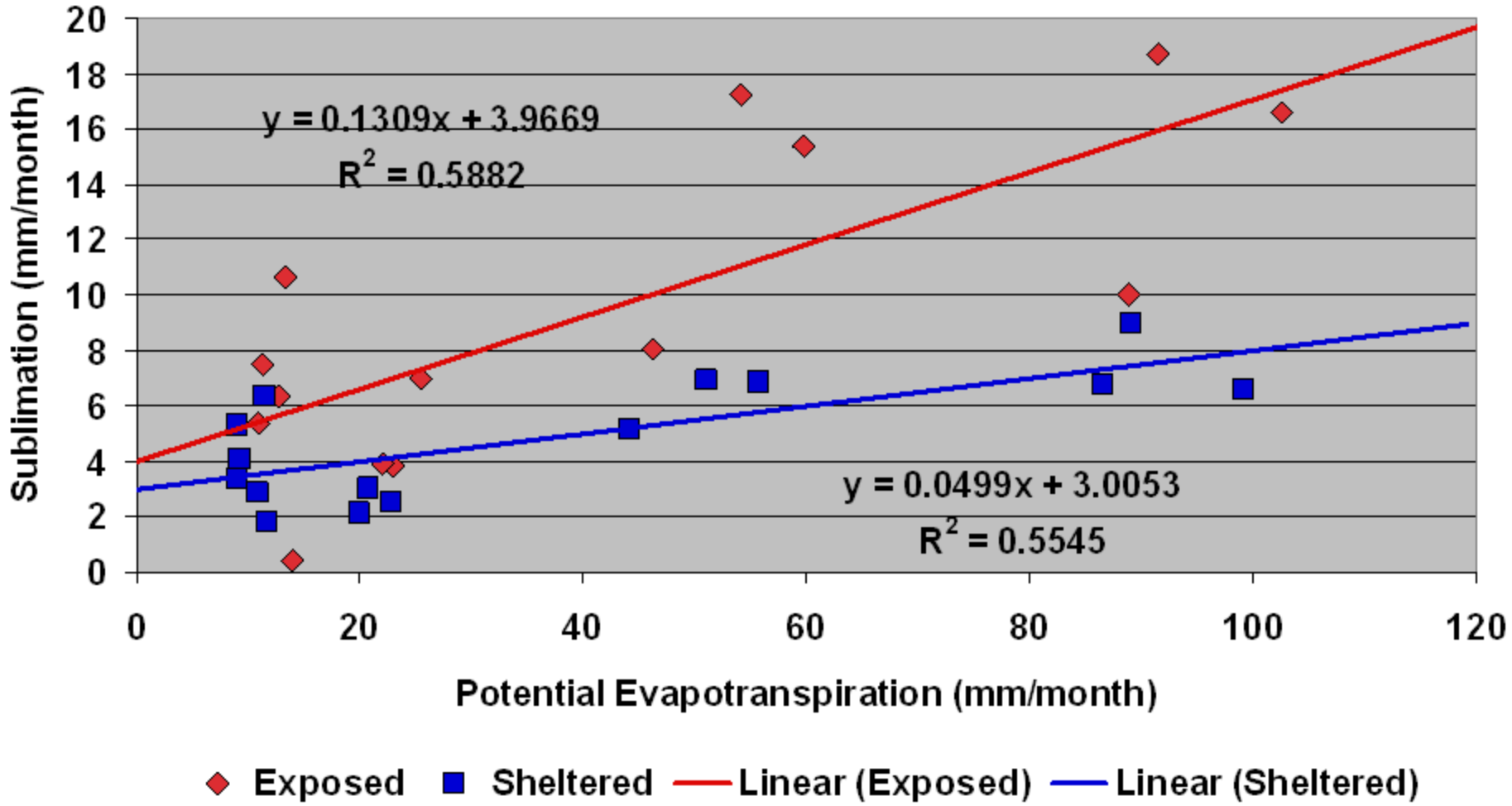
Water Availability and Springtime Snowmelt

- **Forecasting**
  - **Typically based on SWE measurements**
- **Climate change -> changing timing of snowmelt**
- **Losses can be due to**
  - **Increases in ET and sublimation**
  - **Replenishment of soil moisture profile**



USGS science for a changing world Results subject to USGS approval and modification

Three Years of Monthly Sublimation Data Versus PET

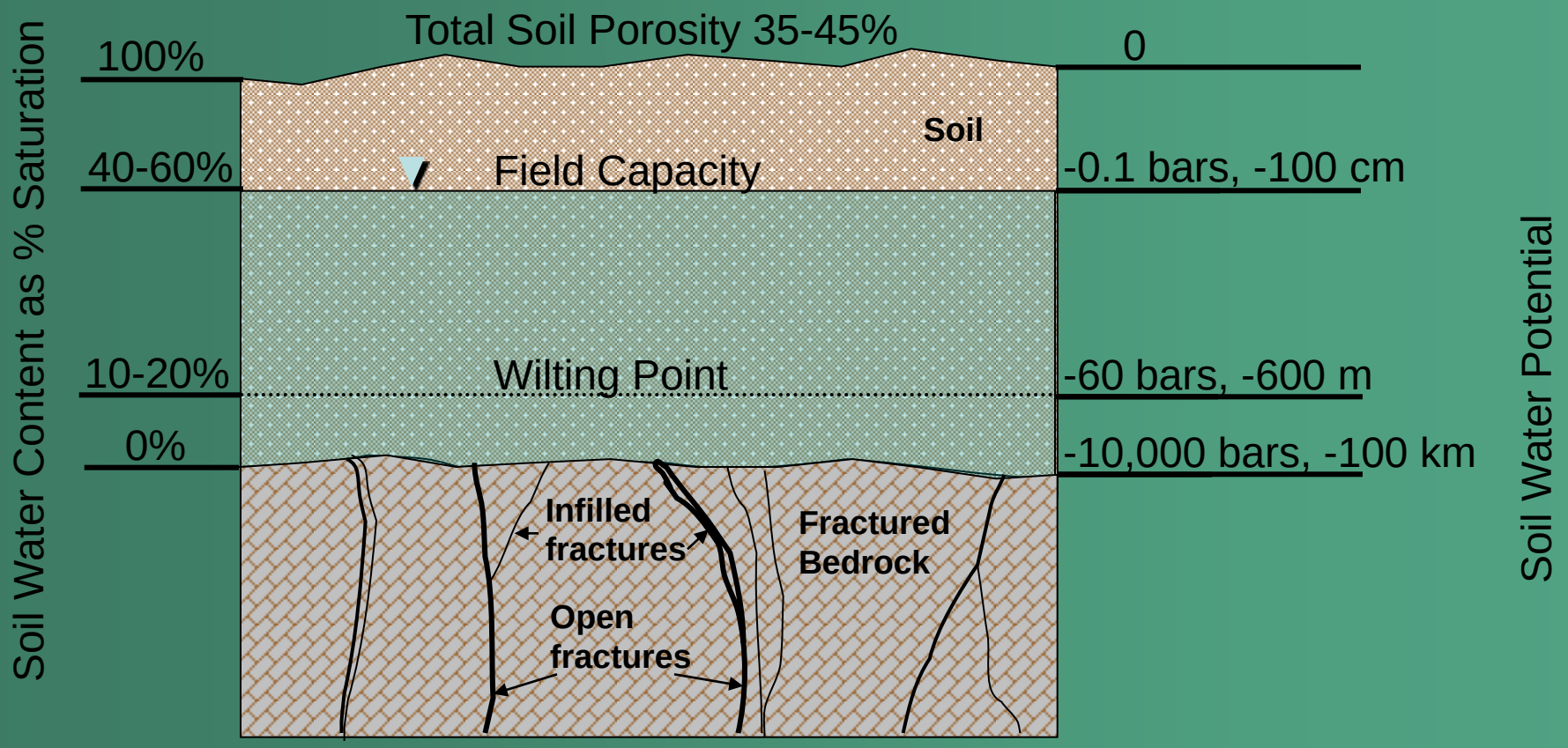


USGS science for a changing world Results subject to USGS approval and modification

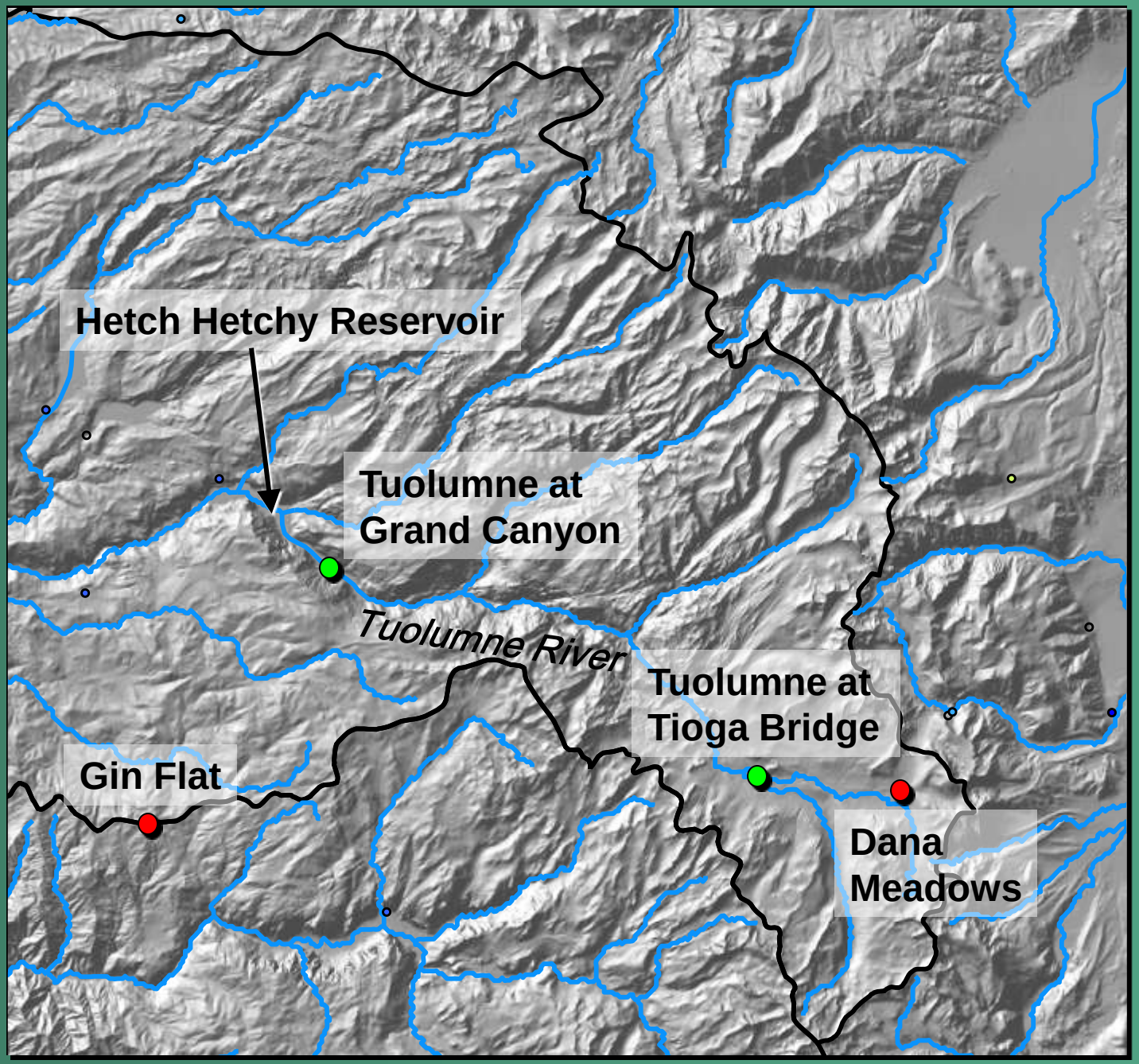
Snowmelt in the Sierras

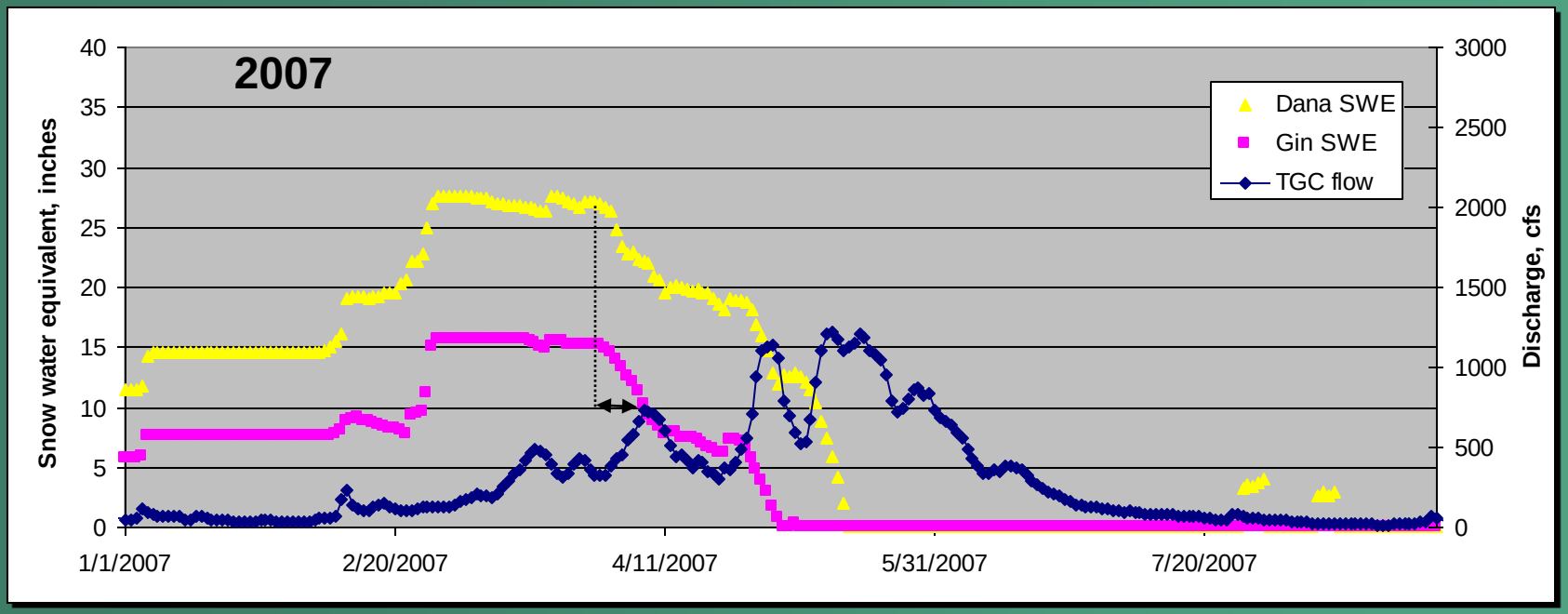
- Runoff from springtime snowmelt isn’t just a function of energy melting the snowpack
- In fall of 2007 snow fell on dry soils
- Available soil storage can provide a delay, and even a loss to streamflows

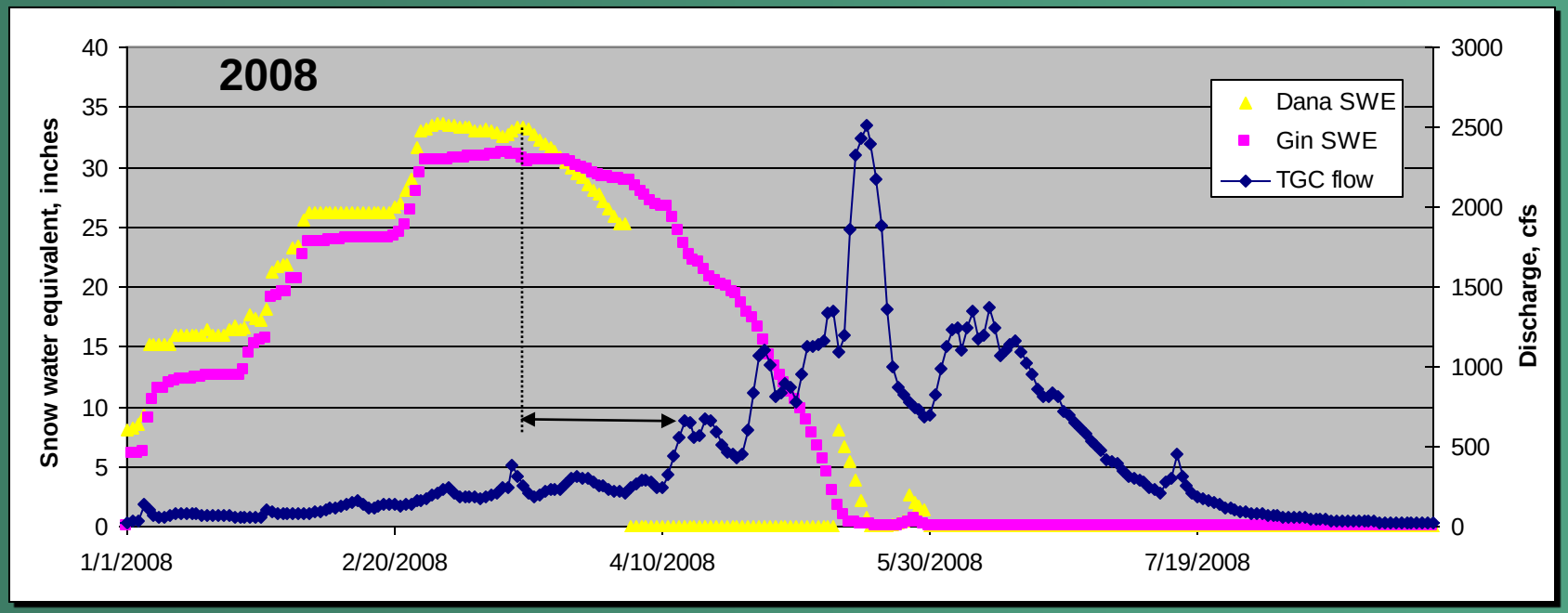
Soil Moisture Processes in Forest Soils

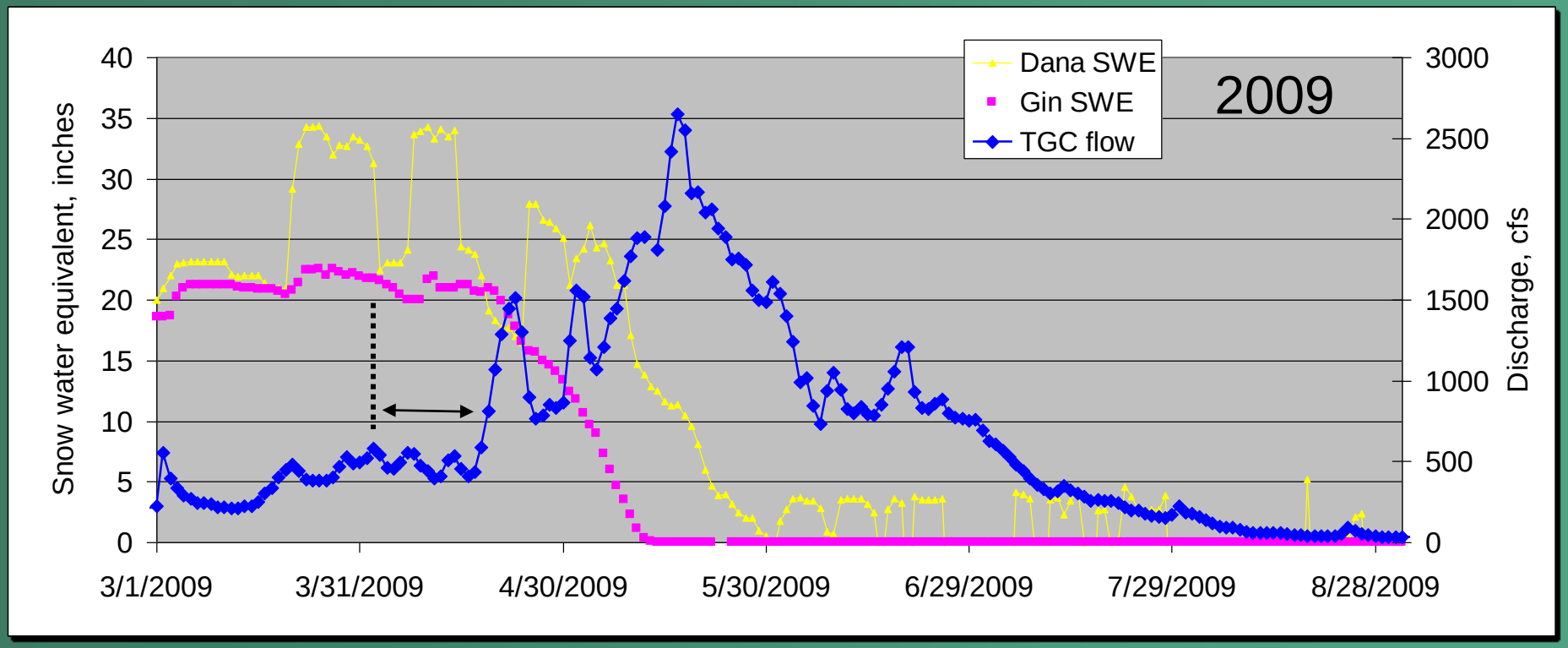


- Snowpack and soil moisture monitoring
- Streamflow gages

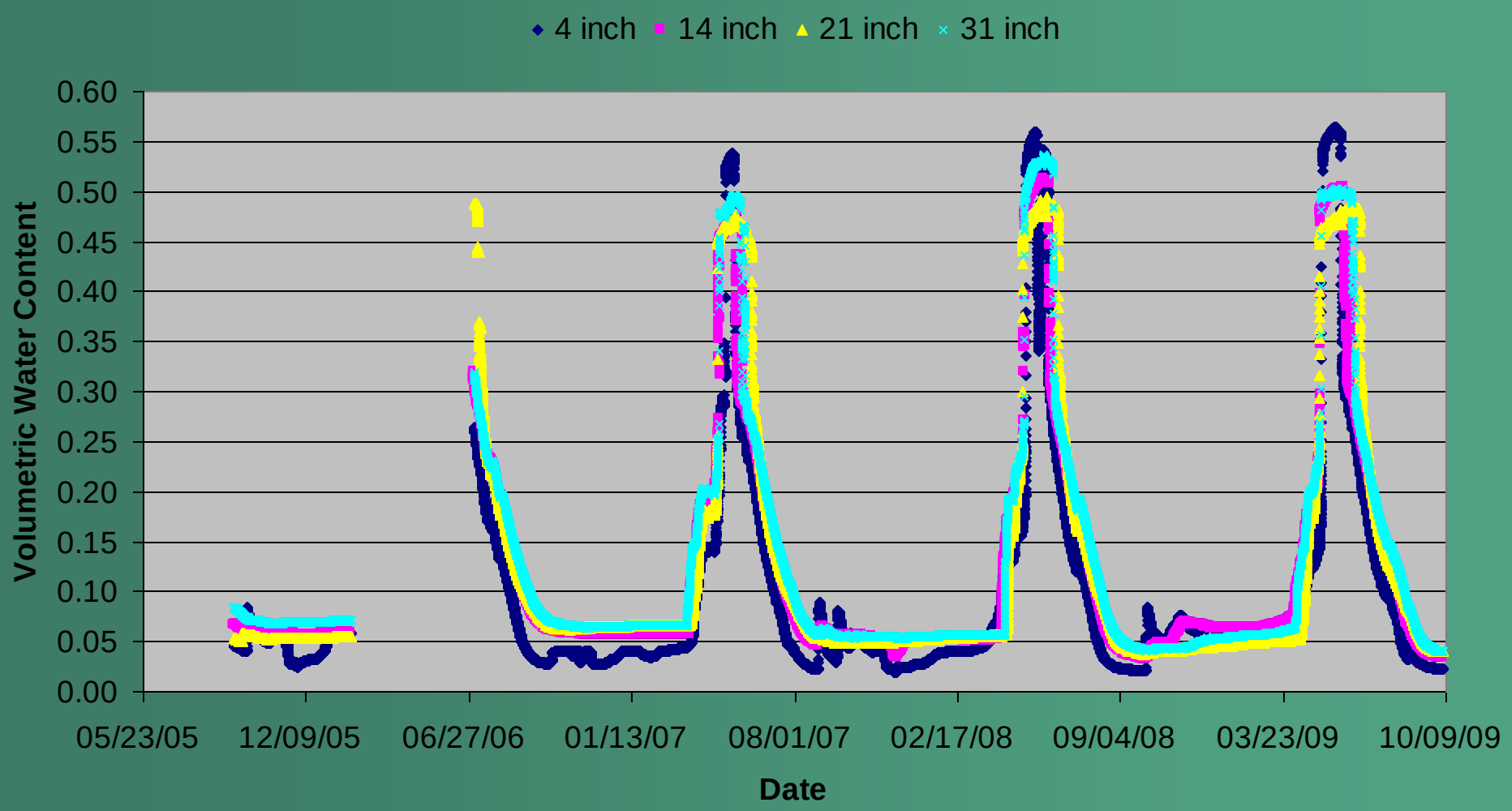



2007
Dana SWE
Gin SWE
TGC flow
Snow water equivalent, inches
Discharge, cfs
40
35
30
25
20
15
10
5
0
3000
2500
2000
1500
1000
500
0
1/1/2007
2/20/2007
4/11/2007
5/31/2007
7/20/2007

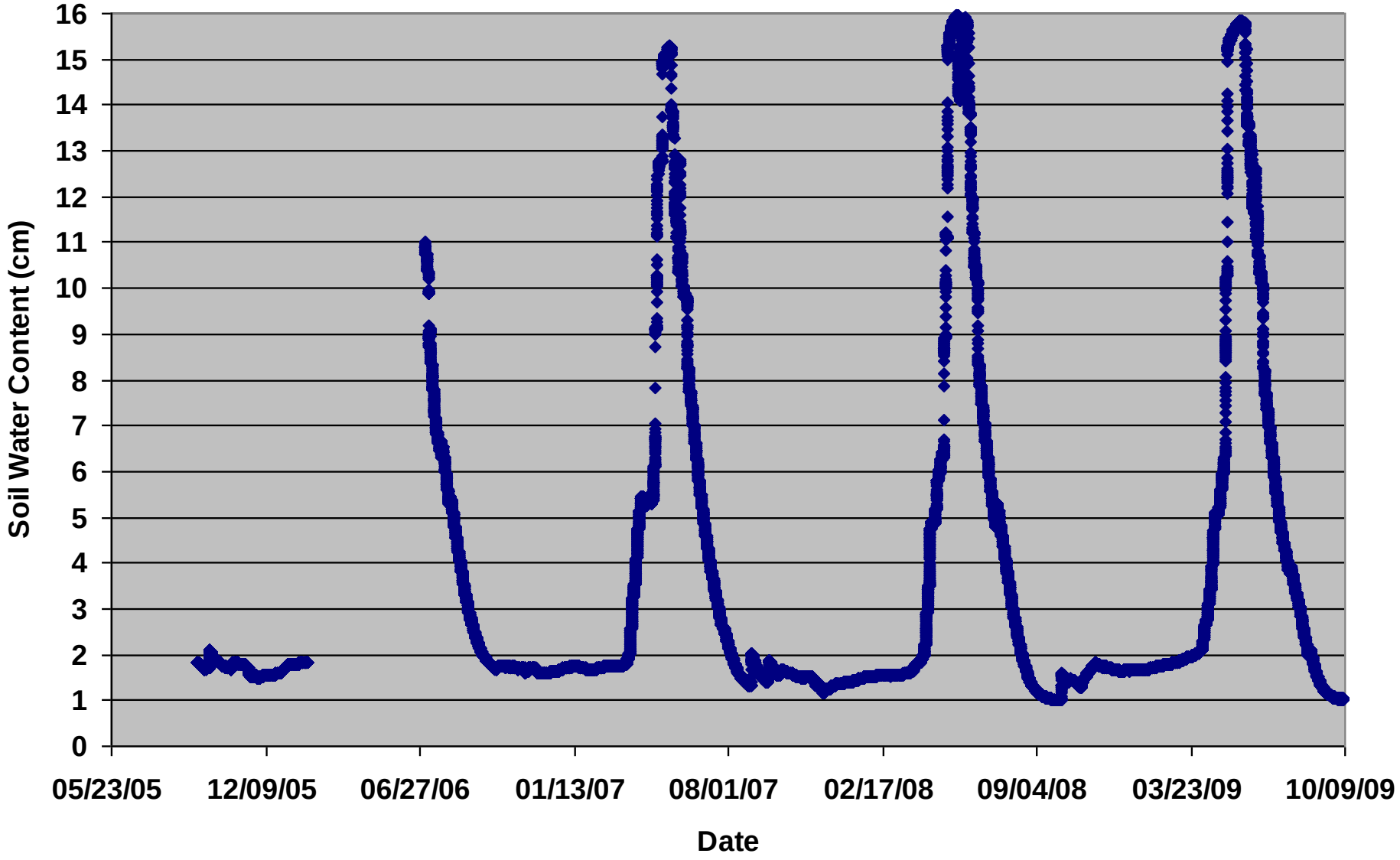

2008
Dana SWE
Gin SWE
TGC flow
Snow water equivalent, inches
Discharge, cfs
40
35
30
25
20
15
10
5
0
3000
2500
2000
1500
1000
500
0
1/1/2008
2/20/2008
4/10/2008
5/30/2008
7/19/2008


Dana SWE
Gin SWE
TGC flow
2009
Snow water equivalent, inches
Discharge, cfs
40
35
30
25
20
15
10
5
0
3000
2500
2000
1500
1000
500
0
3/1/2009
3/31/2009
4/30/2009
5/30/2009
6/29/2009
7/29/2009
8/28/2009

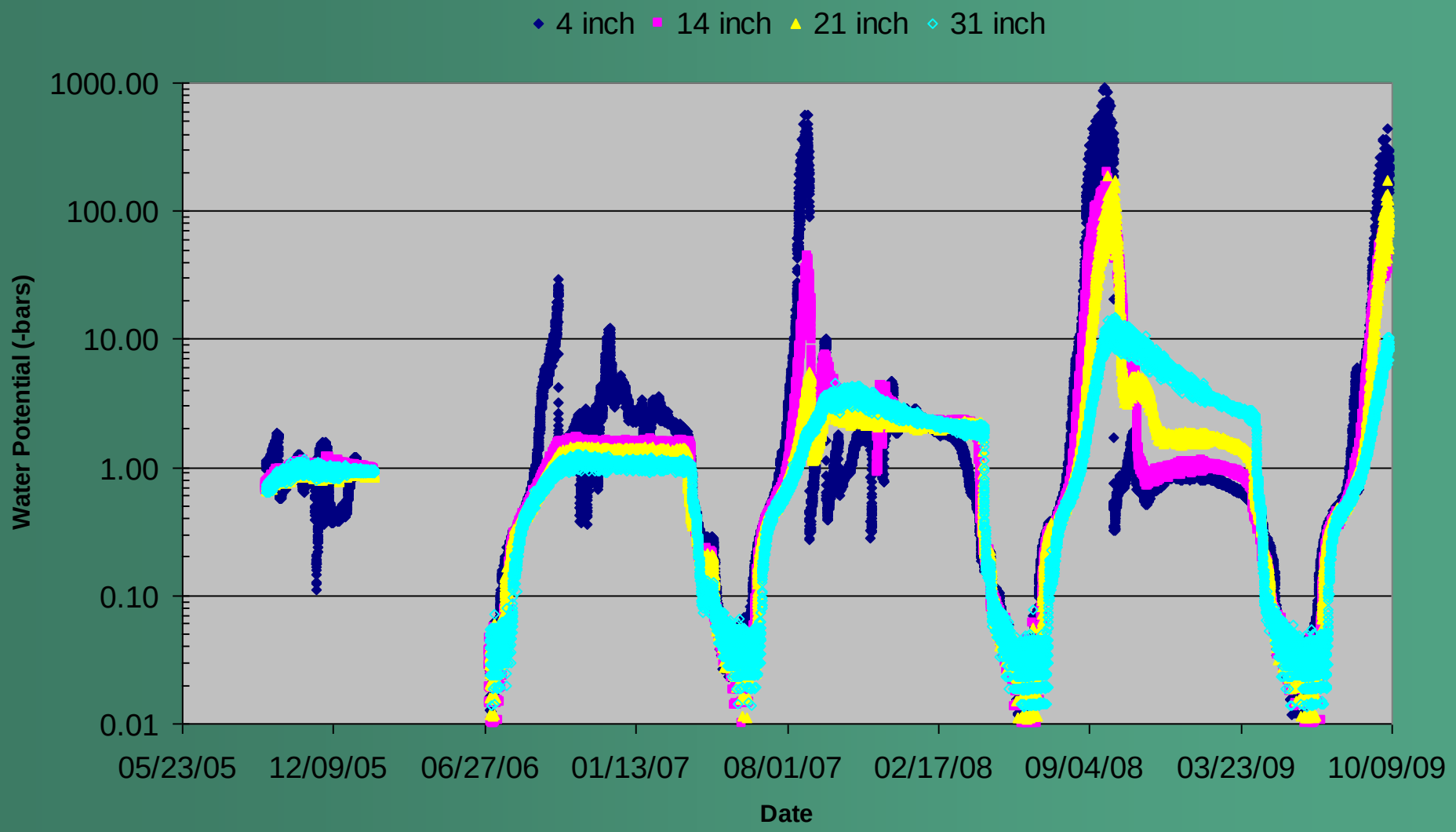
Dana Meadows



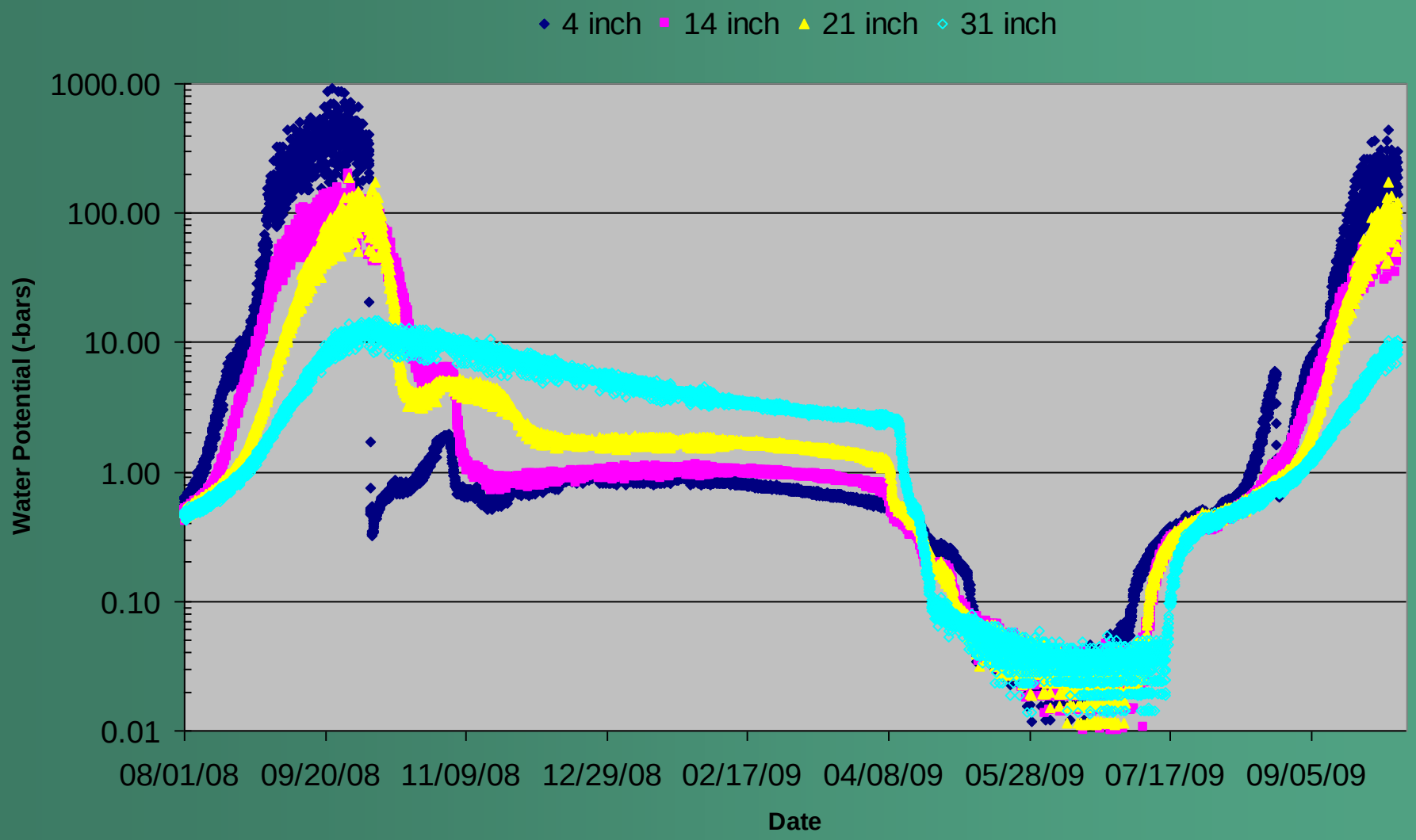
Dana Meadows



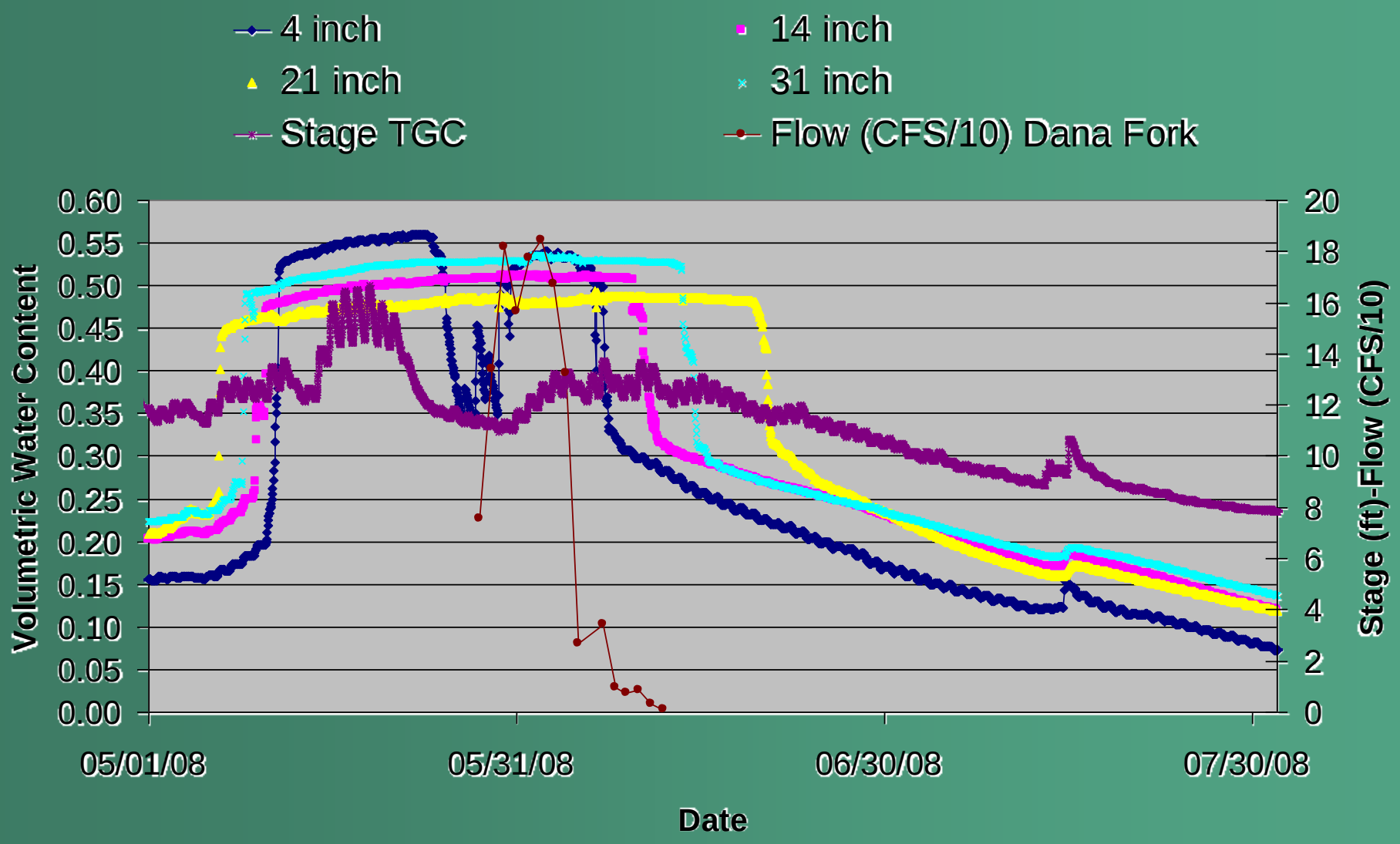
Dana Meadows



Dana Meadows



Dana Soil Water Content and Stage at Tuolumne at GC

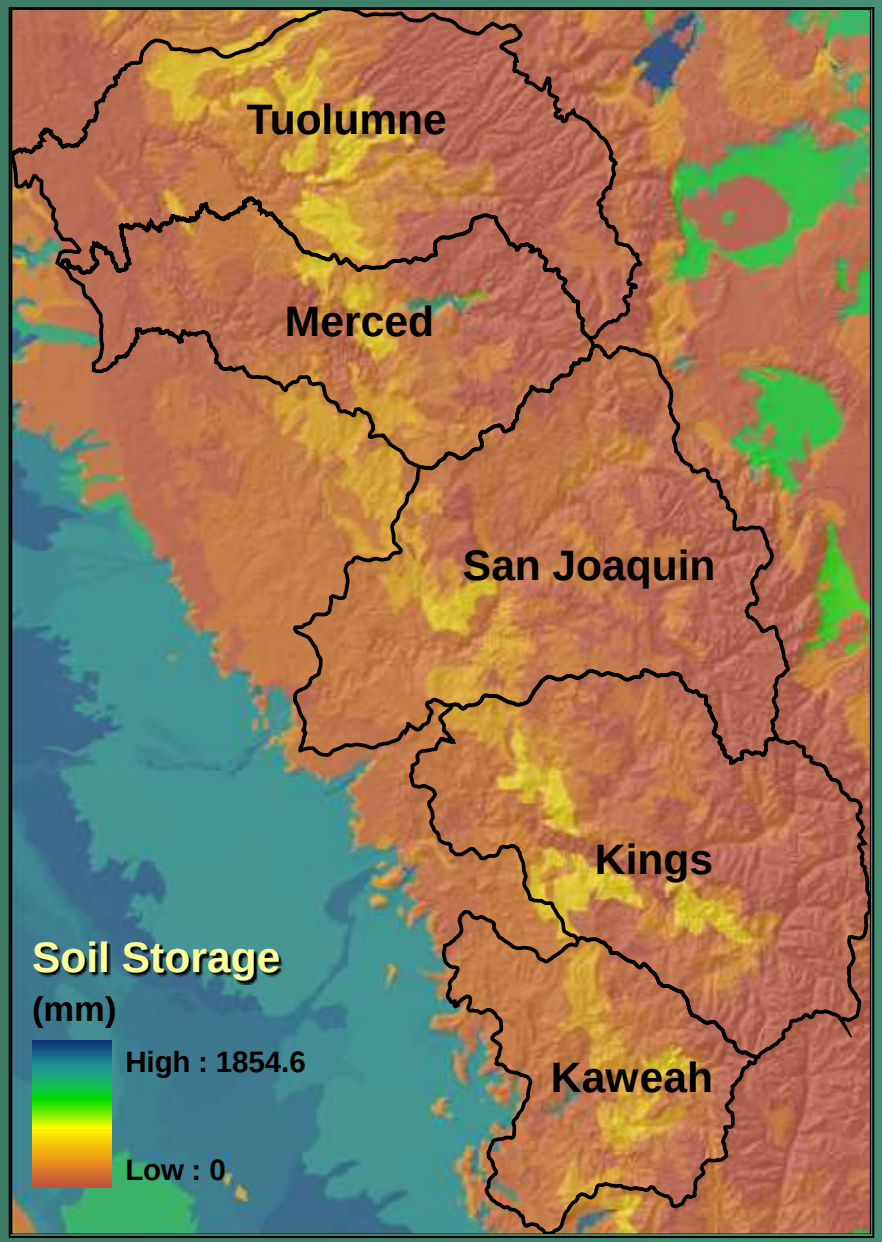


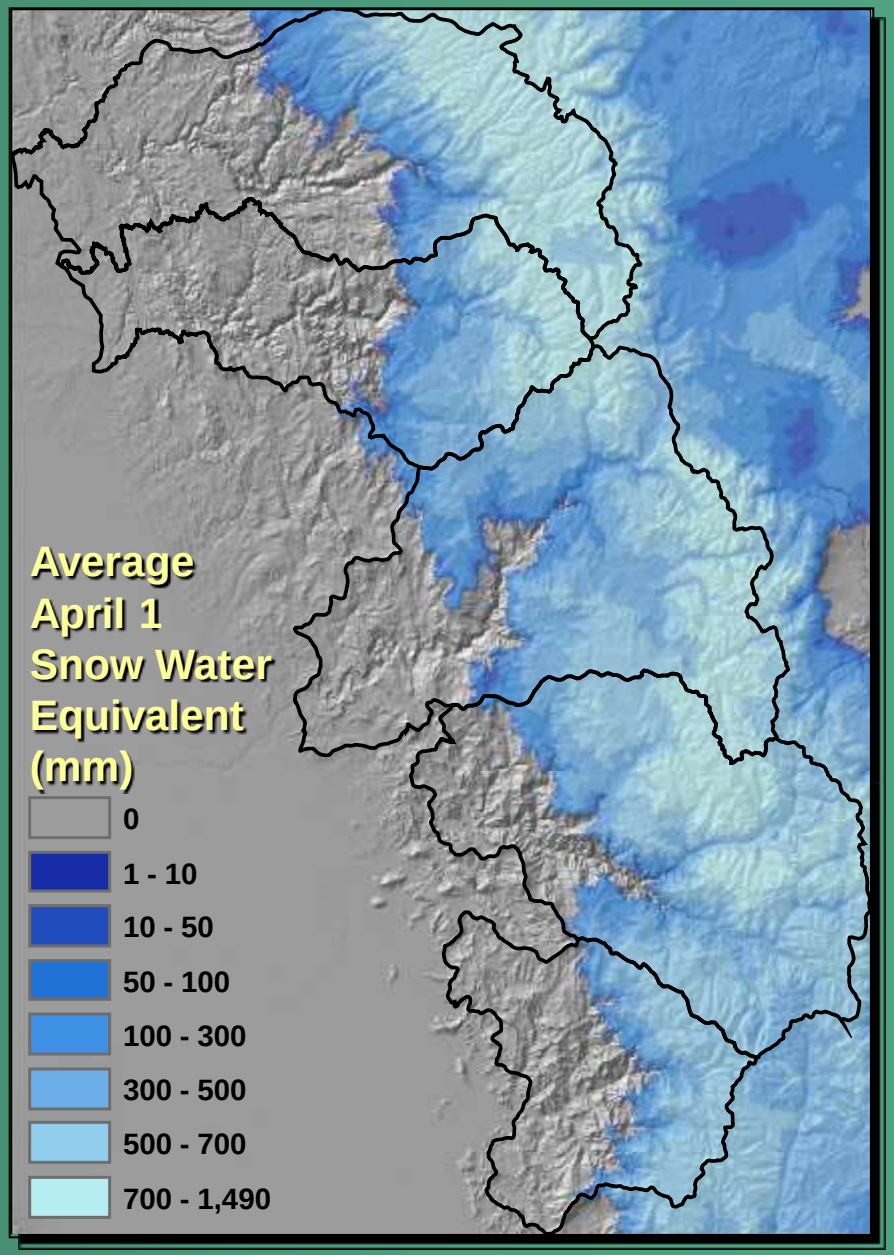
Dana Soil Water Content and Water Potential

	2007	2008	2009
Onset of snowmelt	3/31	3/15	4/1
Lag time to rise in flow (days)	0	24	18
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 full saturation	7	11	8

Basin-scale Application

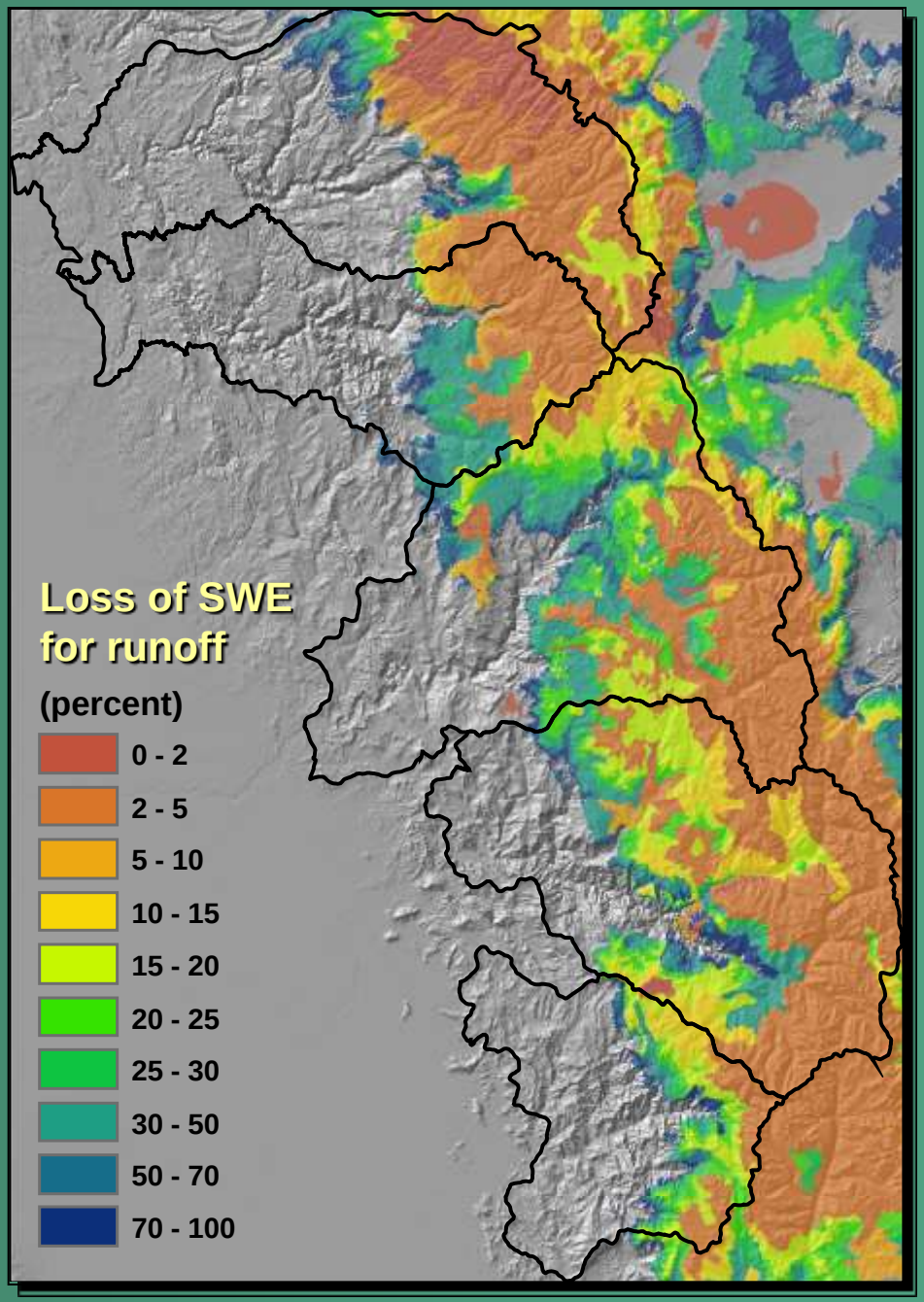
- Measurements provide point locations that support a conceptual model
- Distribution of processes and calculation of basin impacts require models


Tuolumne
Merced
San Joaquin
Kings
Kaweah
Soil Storage
(mm)
High : 1854.6
Low : 0


Average
April 1
Snow Water
Equivalent
(mm)
0
1 - 10
10 - 50
50 - 100
100 - 300
300 - 500
500 - 700
700 - 1,490

Percentage of SWE lost to soil storage during snowmelt in a year with dry preceding fall

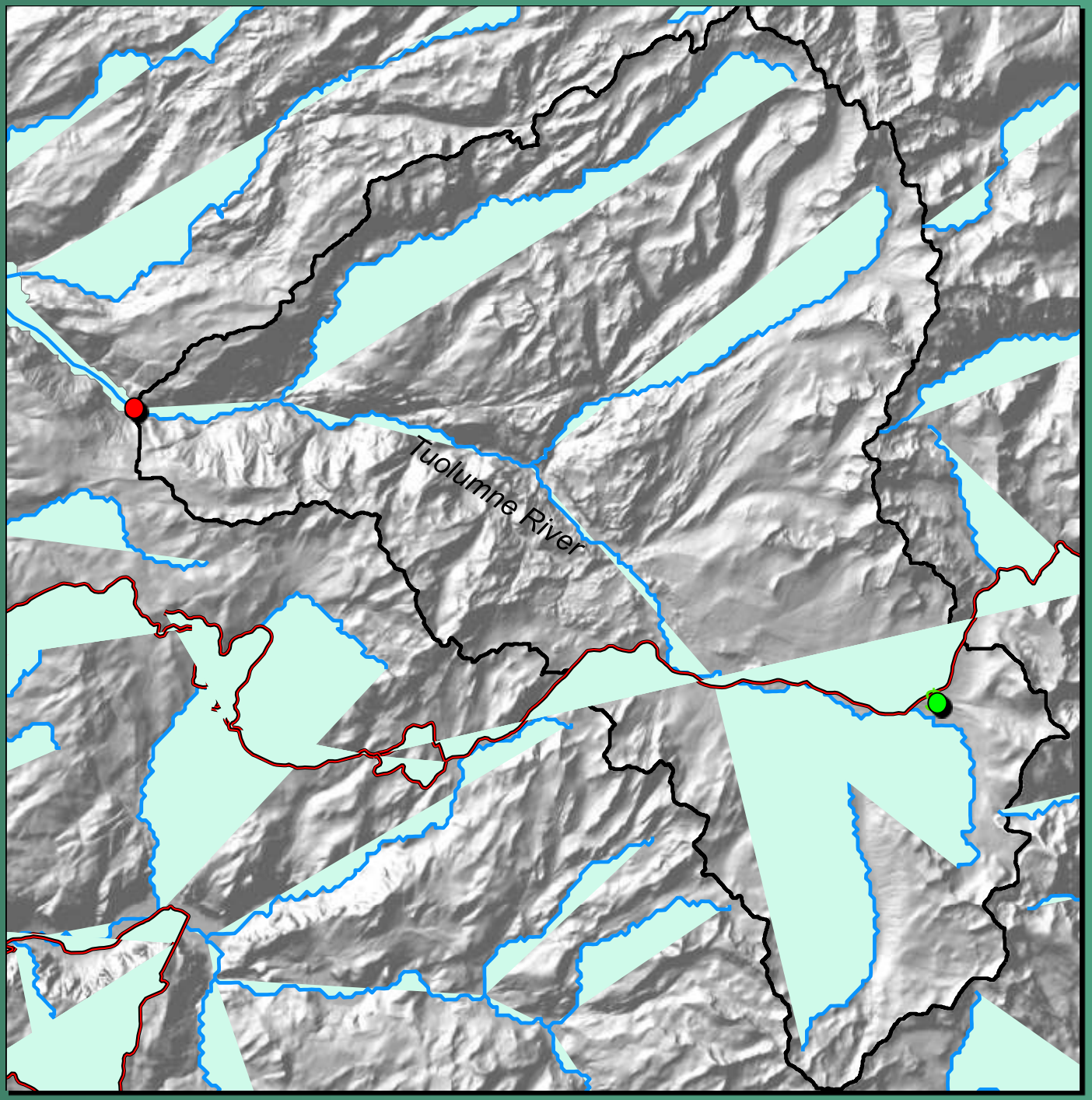
Tuolumne	7%
Merced	12%
San Joaquin	13%
Kings	12%
Kaweah	19%

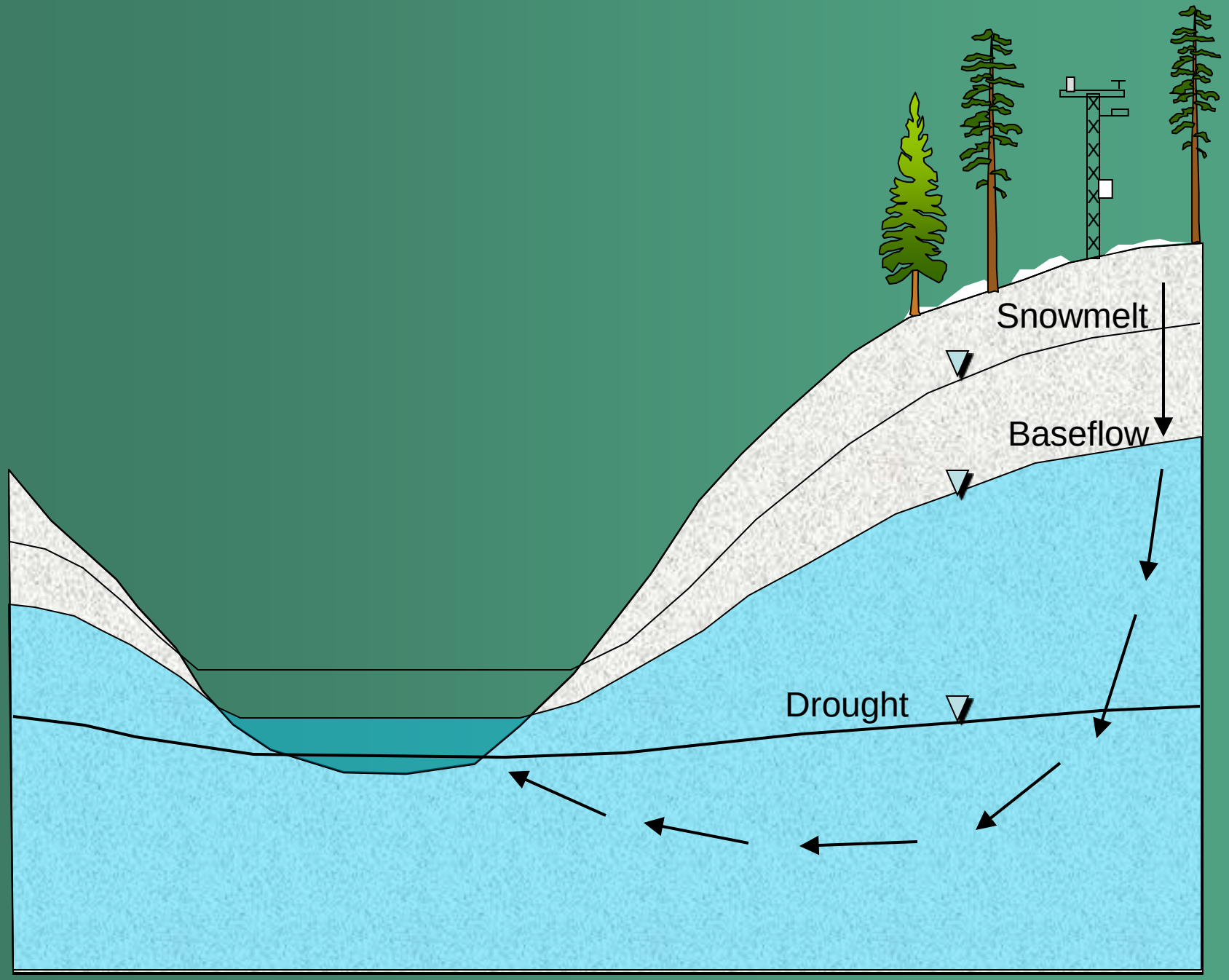


- Tuolumne at Grand Canyon gage

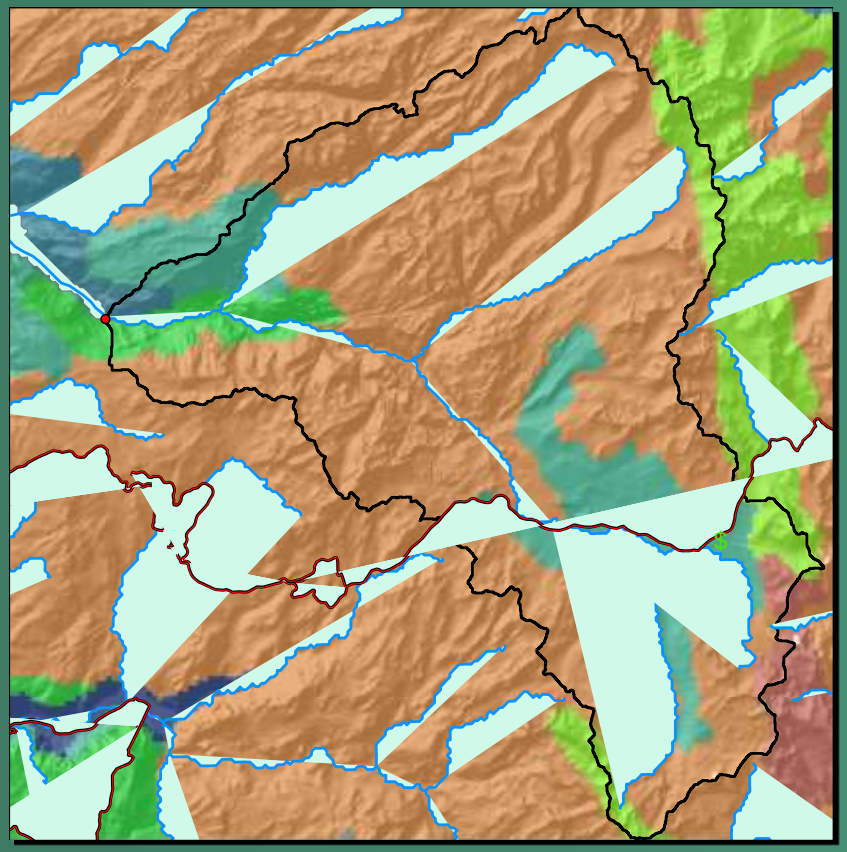
  775 km^2 basin area

- Dana Meadows snow pillow and soil moisture sensors



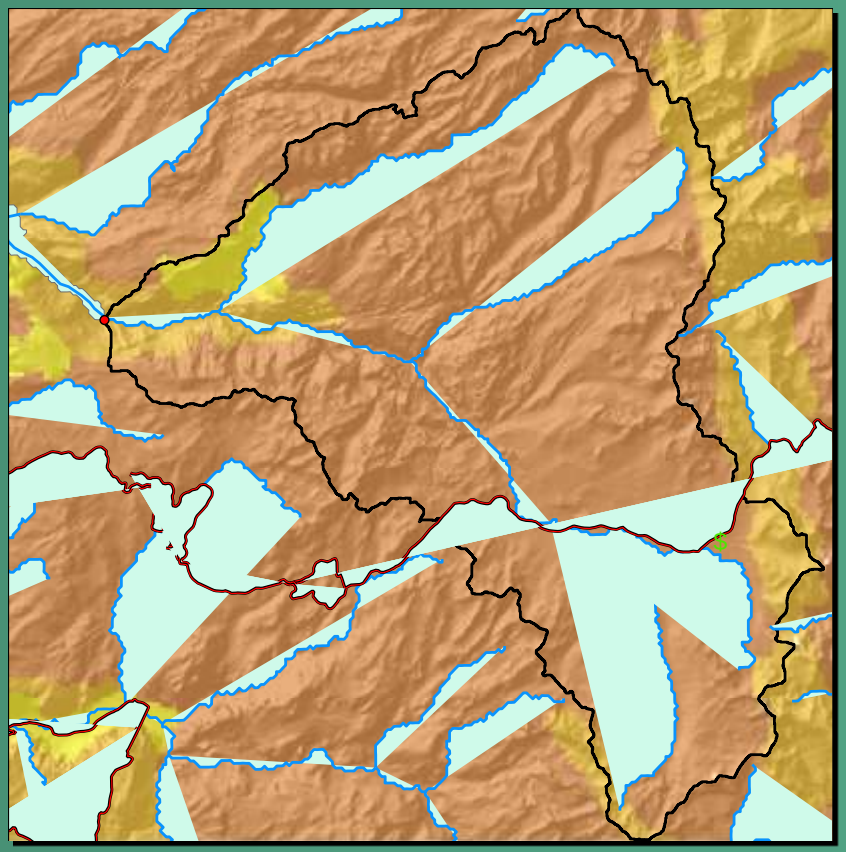

Snowmelt
Baseflow
Drought

Soil Thickness



X

Field Capacity



0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 1
1 - 1.3
1.3 - 1.7
1.7 - 6

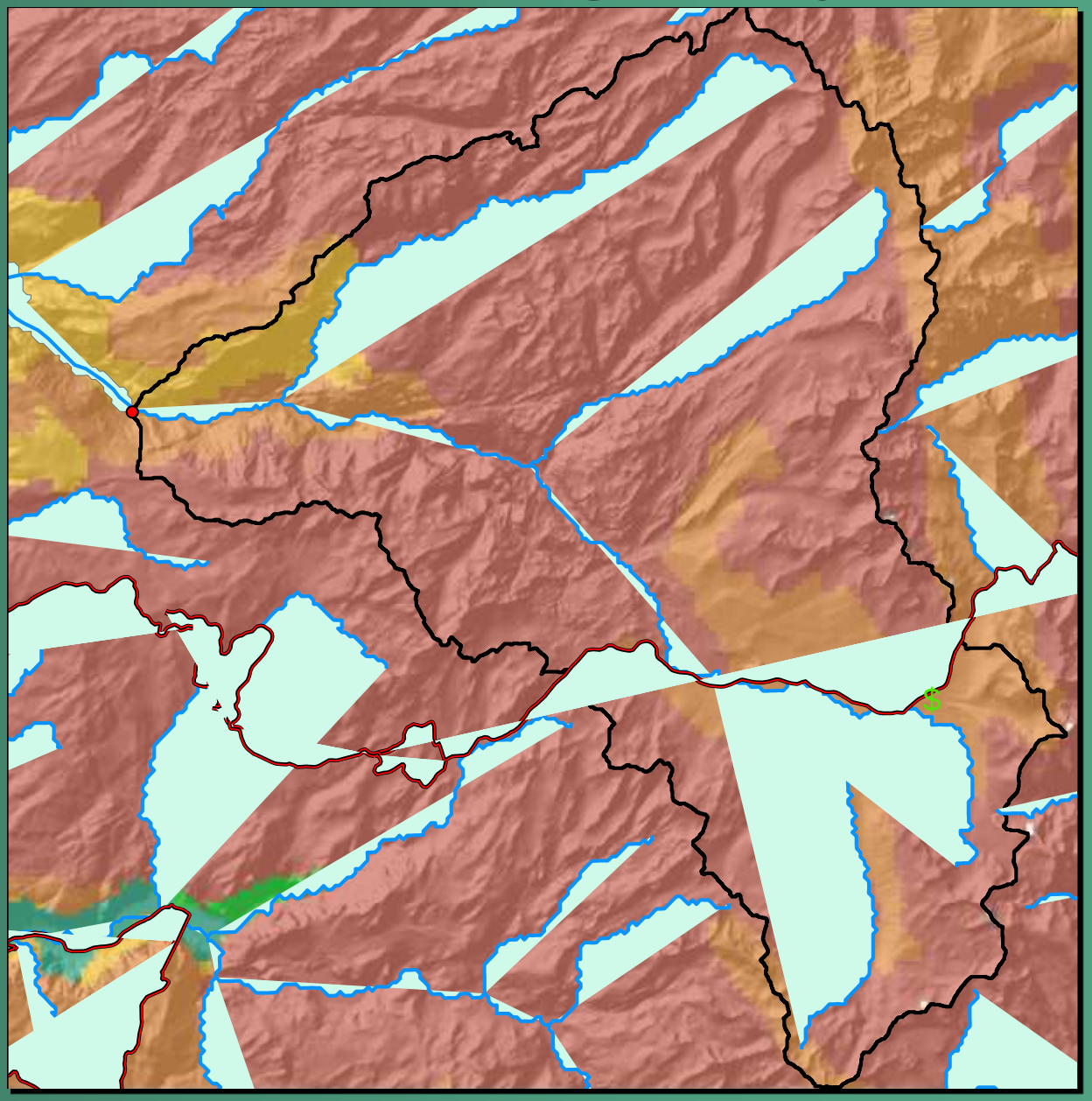
Thickness (meters)

0 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.25
0.25 - 0.3
0.3 - 0.35
0.35 - 0.4
0.4 - 0.45
0.45 - 0.5

Field capacity (meters)

STATSGO national soils dataset

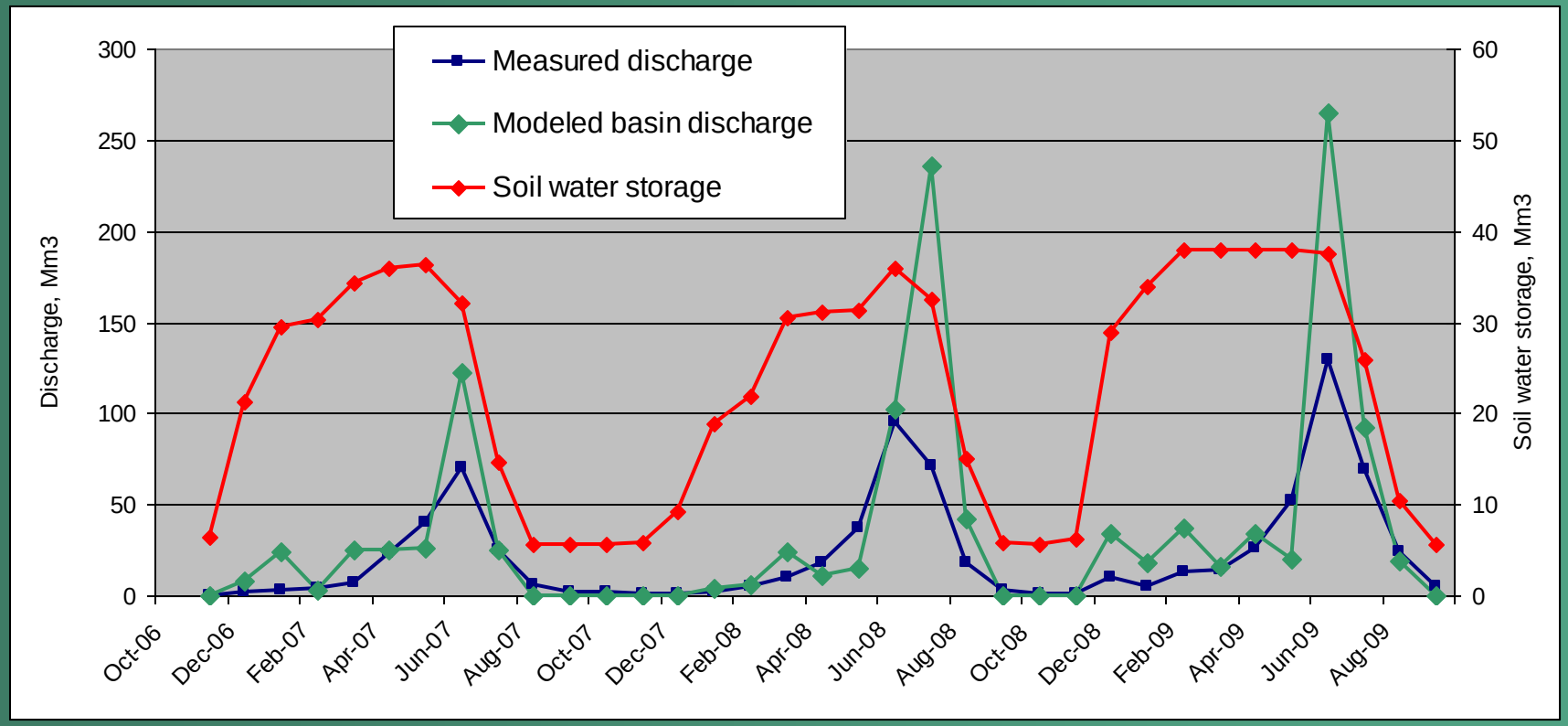
Soil Water Storage Capacity



Storage Capacity (meters)

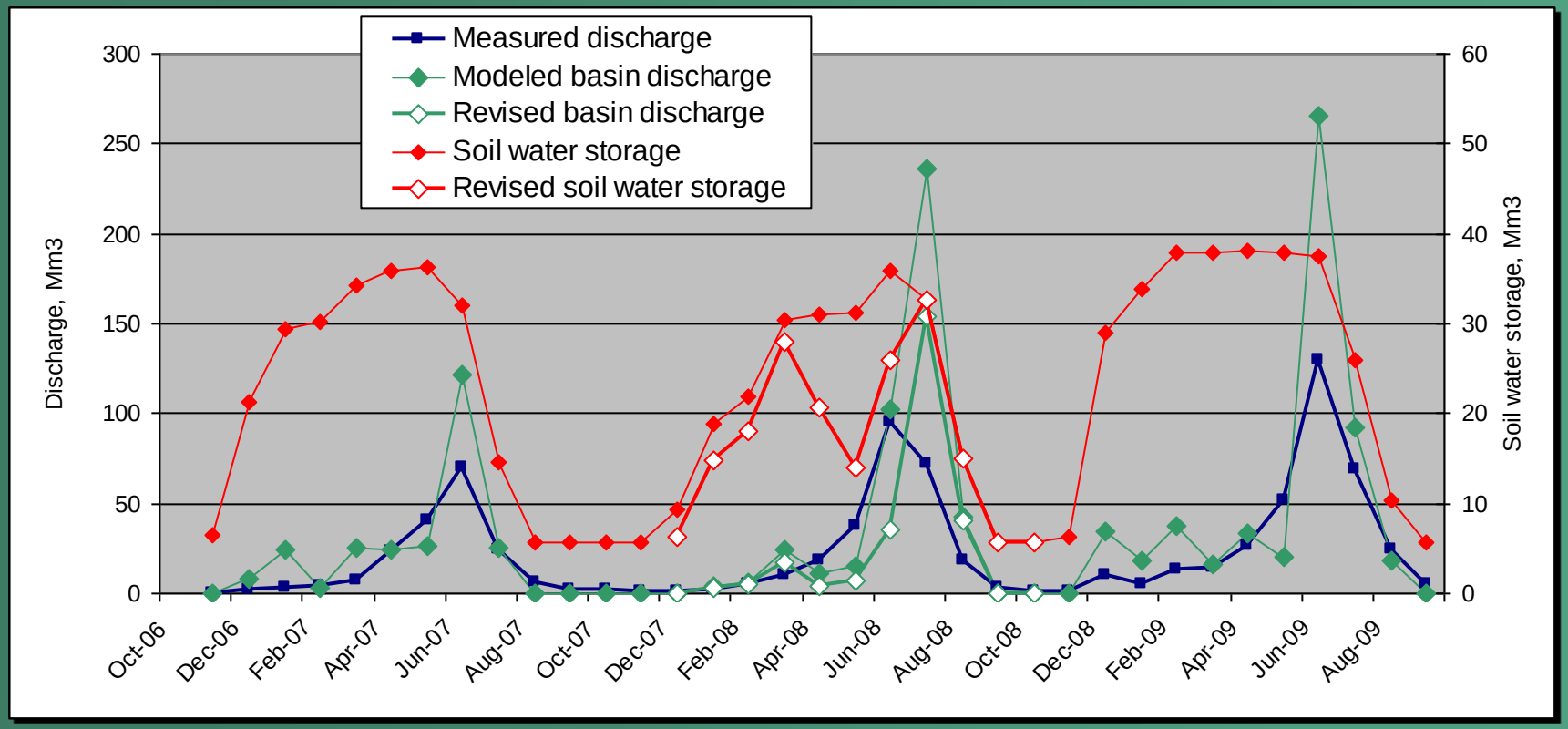
- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3.5

Modeled basin discharge and soil water storage Upper Tuolumne Basin above TGC



	Maximum Snowpack	Soil Storage at Onset	Annual Discharge
	(Mm3)		
2007	239	36	183
2008	482	36	350
2009	396	38	457

Modeled basin discharge and soil water storage Upper Tuolumne Basin above TGC



	Maximum Snowpack	Soil Storage at Onset	Annual Discharge
	(Mm3)		
2007	239	36	260
2008	**482**	**33**	**267**
2009	396	38	536

Summary for Soil Moisture Measurements

- Laboratory calibration necessary for every sensor, coupled with field checks
- Recommended configuration includes duplication, water content and water potential, and multiple depths
- Consider what you are trying to answer

Ongoing Work and Soil Moisture Considerations

- Snowpack is critical but not always the whole story
- Point measurements help us understand the state of the system at that location
- Need a model to distribute and quantify processes for watersheds
- Continuing model refinements rely heavily on field observations
- Daily time step is necessary to reflect snowmelt and soil moisture processes at the watershed scale