Refining regional recharge estimates: considering the water balance and recharge processes

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U.S. Geological Survey
Yosemite Hydroclimate, Oct 5, 2016

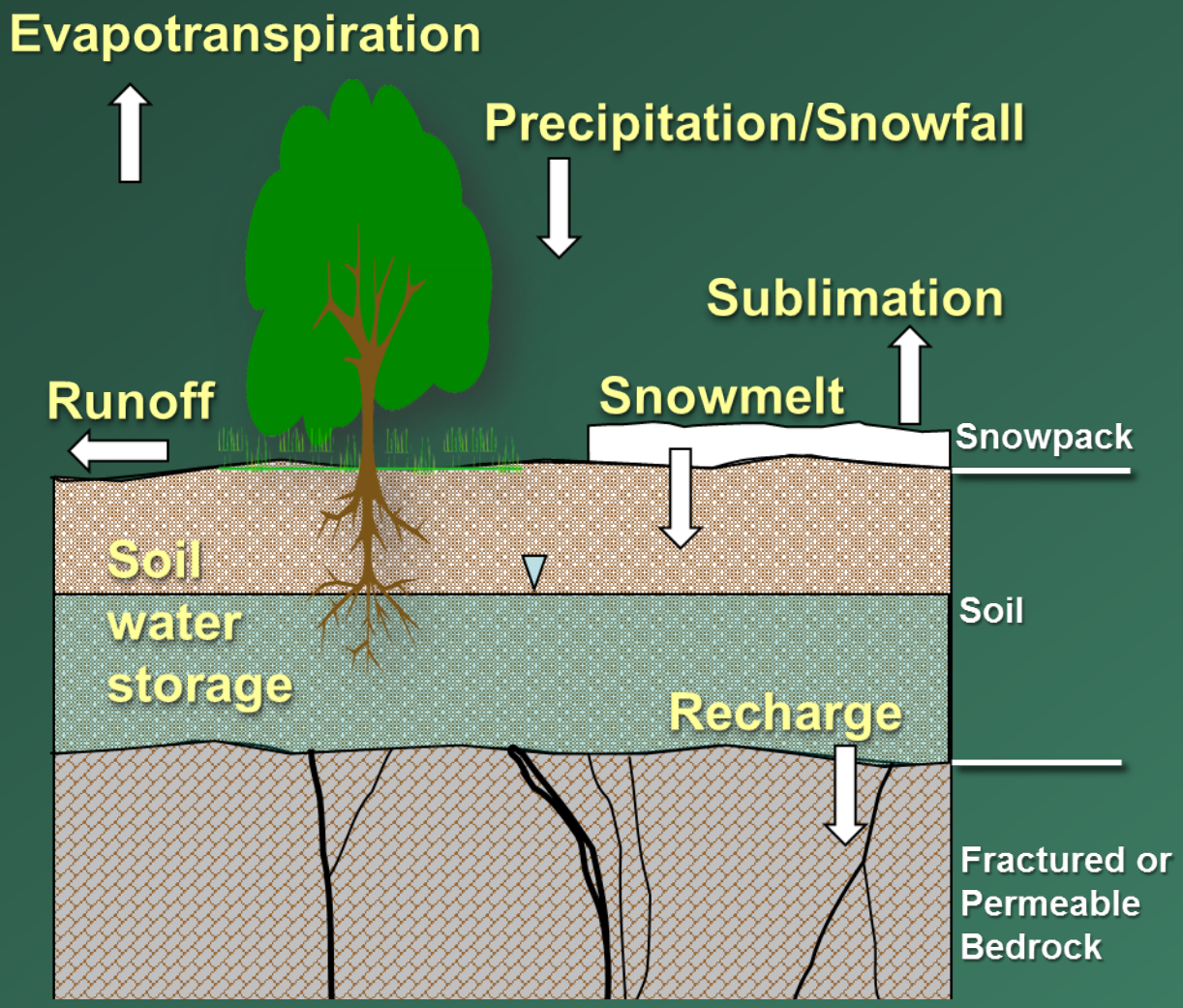
Estimating Recharge

- Recharge is difficult to accurately estimate
- Hydrologic modeling typically makes recharge the error term
- Water balance modeling can be used to improve estimates with calibration of all hydrologic components

Outline of talk

- **Water balance**
- **Conceptualizing a simple water balance model that describes hydrologic processes across large regions**
- **Model refinements to improve water balance and recharge**
  - **PET**
  - **Snow parameterization**
  - **Soil properties**
  - **Vegetation seasonality and actual evapotranspiration**
  - **Groundwater flow modeling**

The Water Balance



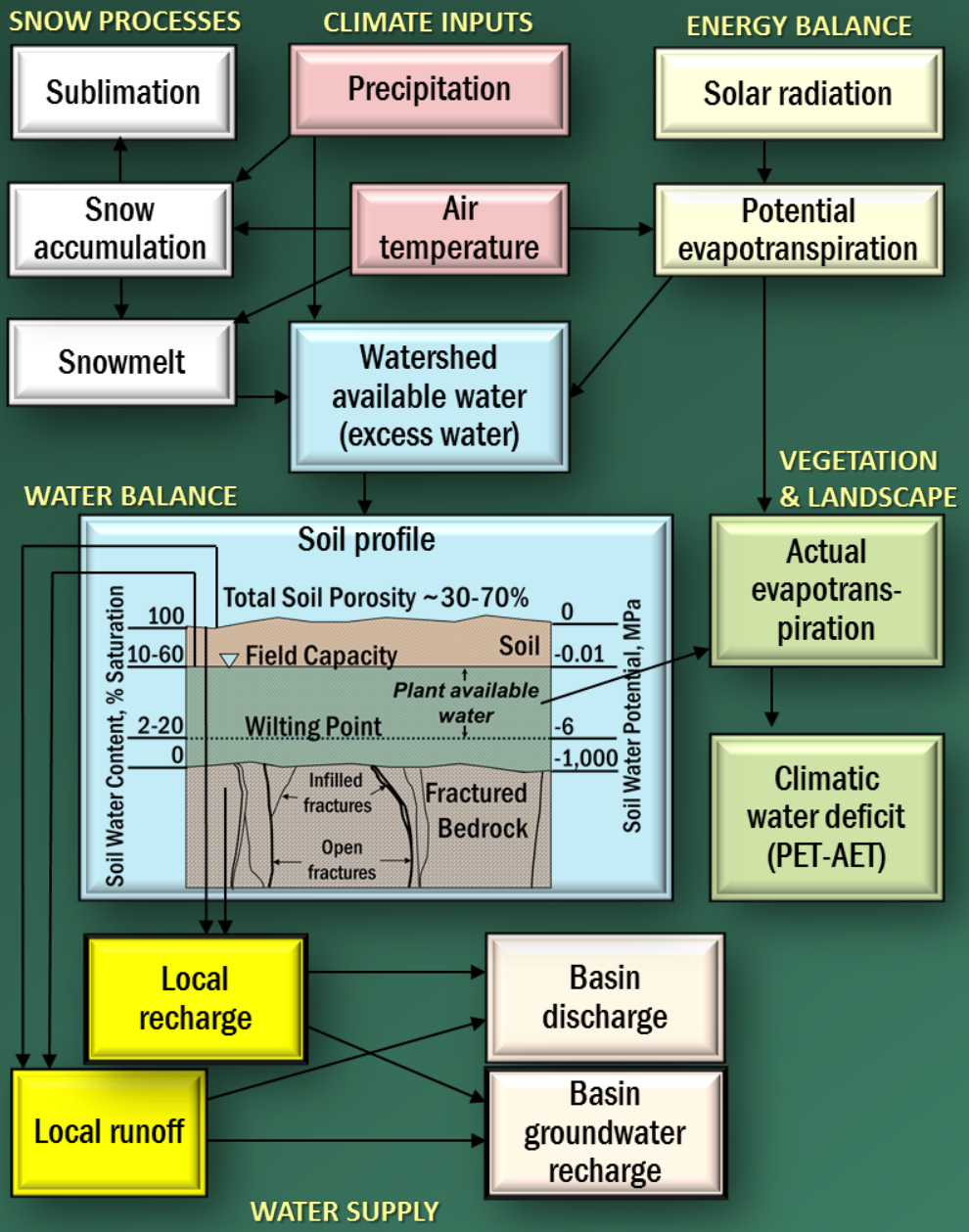
Precipitation = Evapotranspiration + Runoff + Sublimation + Recharge + ▲Soil Water Content

Transient regional scale modeling for the southwest

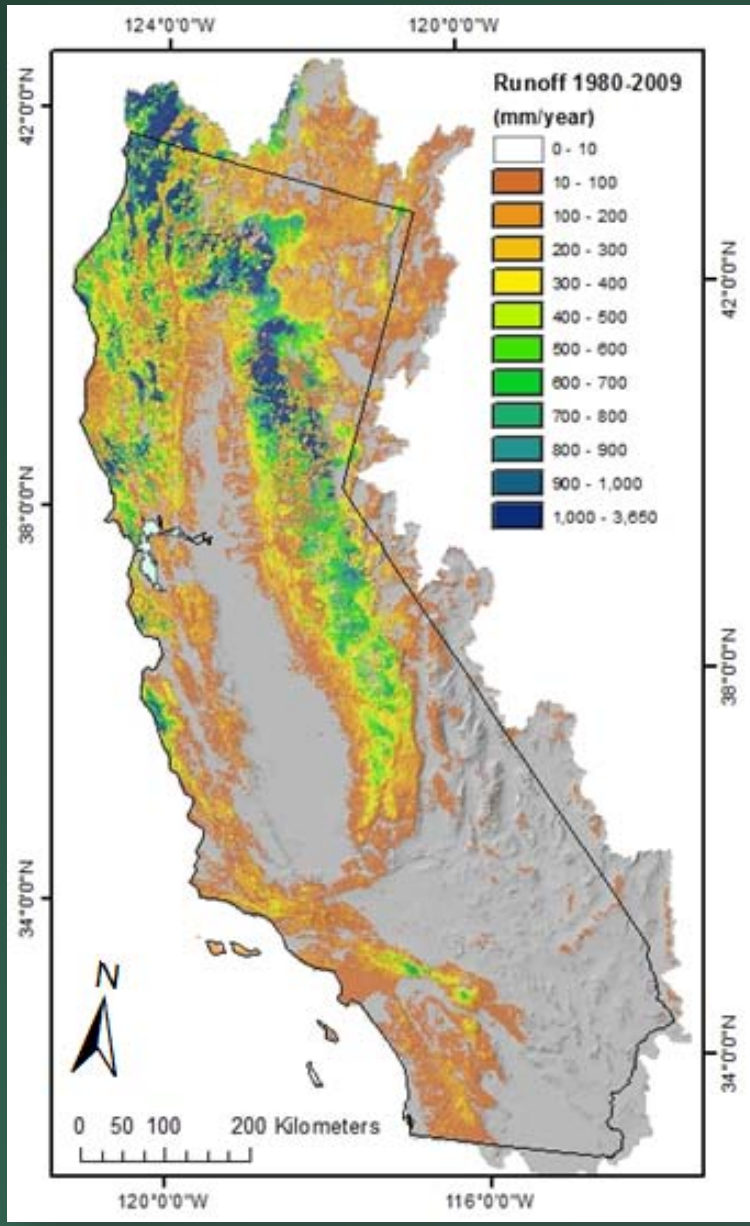
- Develop a model for basin characterization based on the conceptual model
- Geospatial dataset of the physical and climatic setting
  - Digital Elevation Model
  - Geology
  - Soils
  - Potential Evapotranspiration
  - Air Temperature
  - Precipitation

Basin Characterization Model

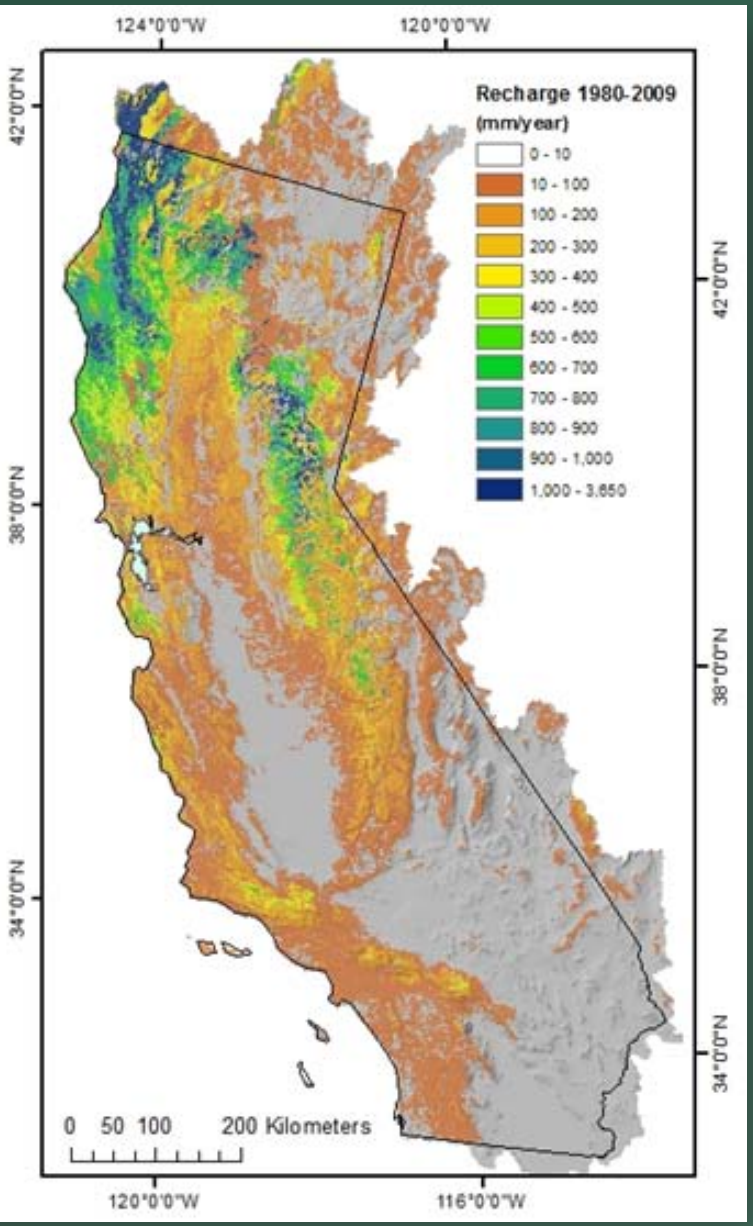
The soil profile is central to calculating the water balance



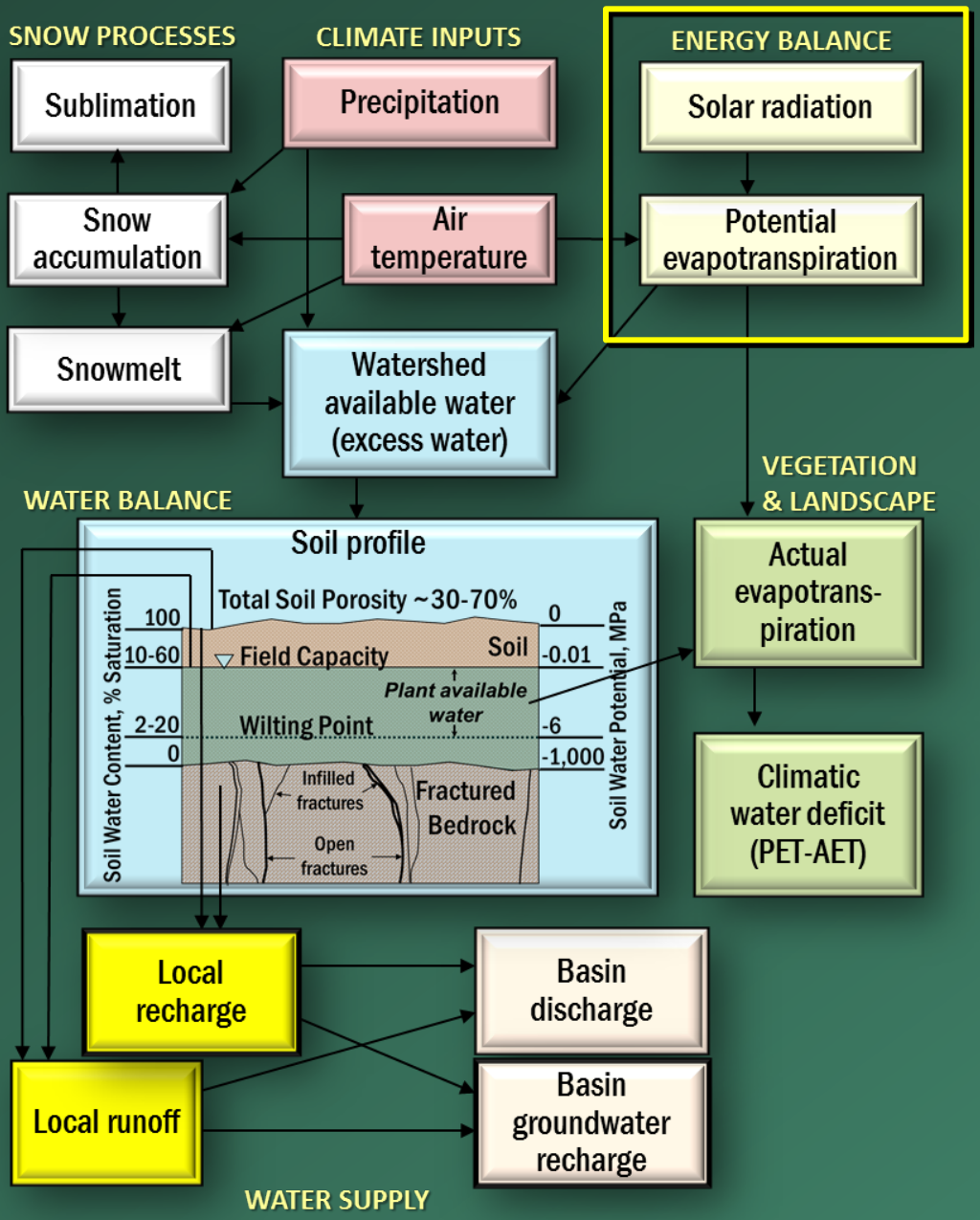
Runoff



Recharge



Basin Characterization Model



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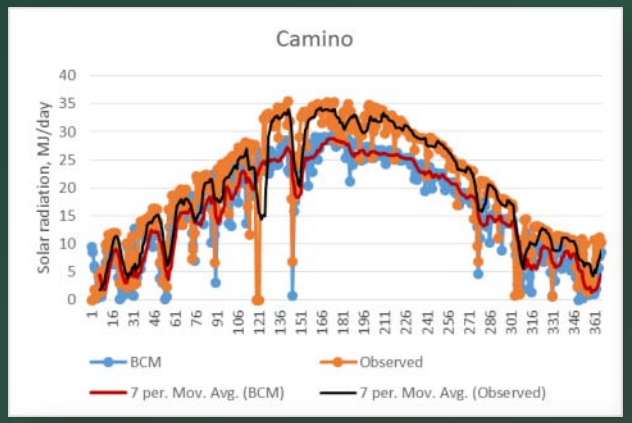
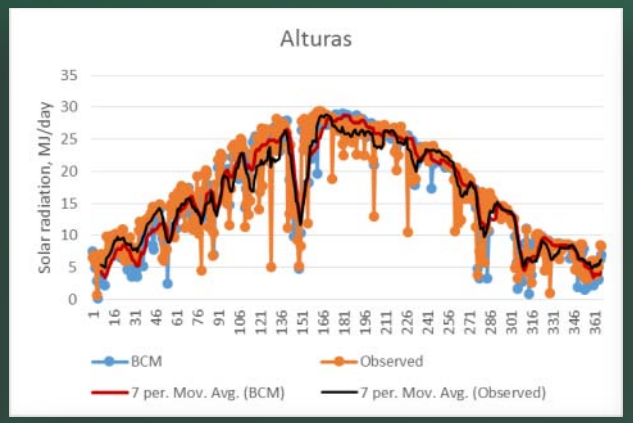
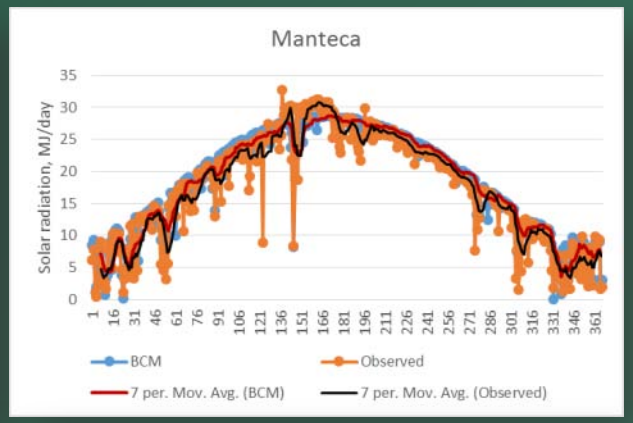
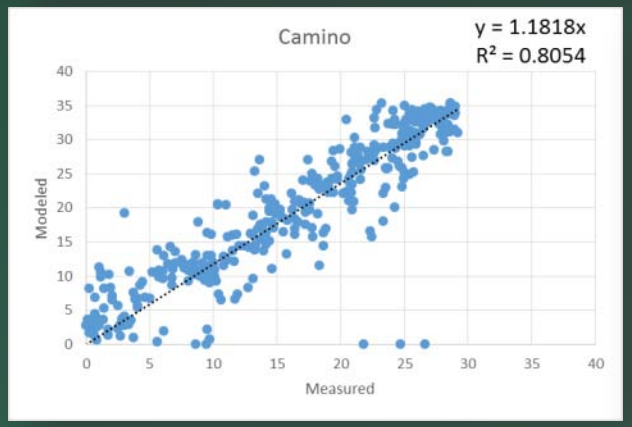
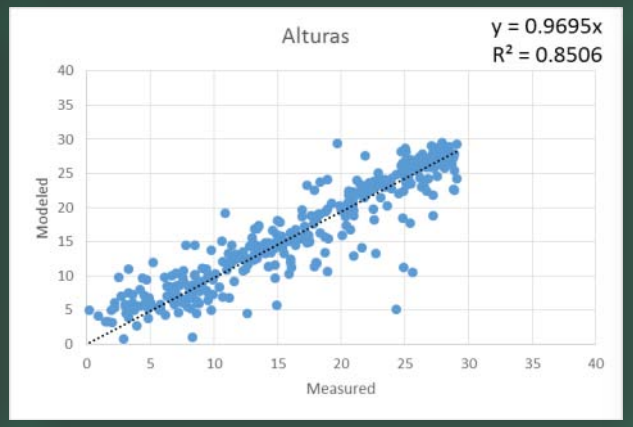
Solar Radiation

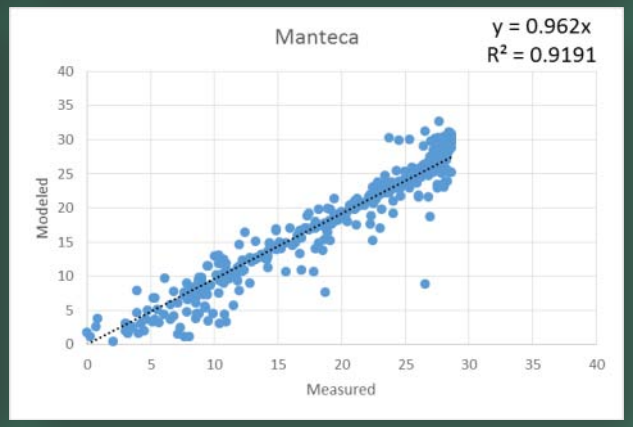




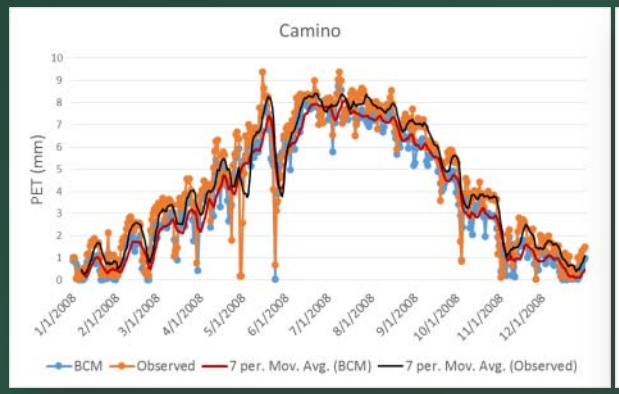


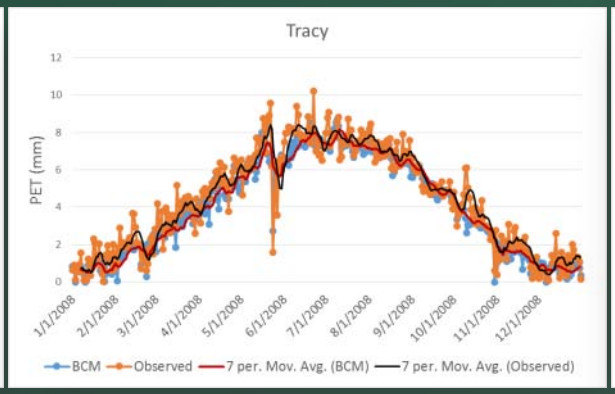


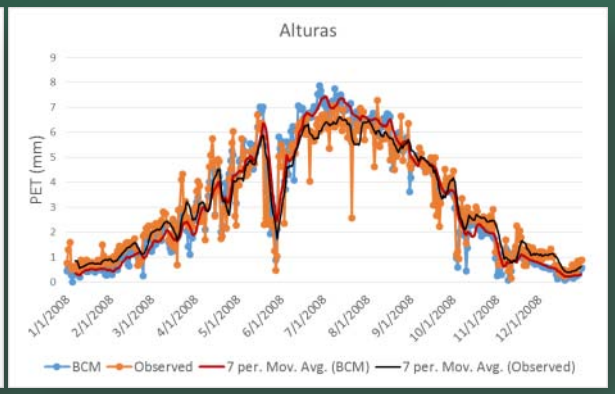


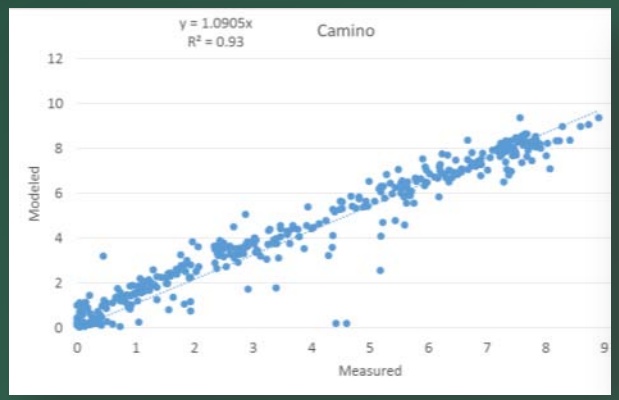


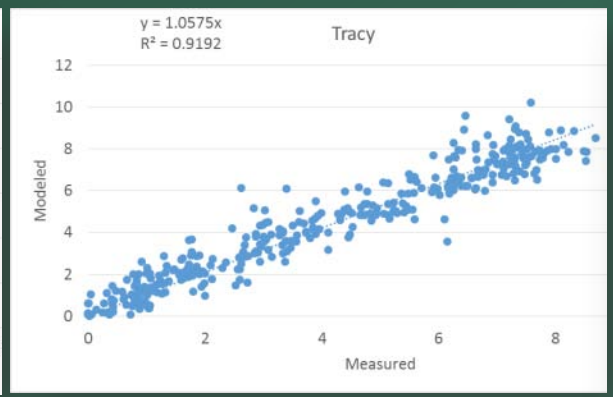
Daily Potential Evapotranspiration

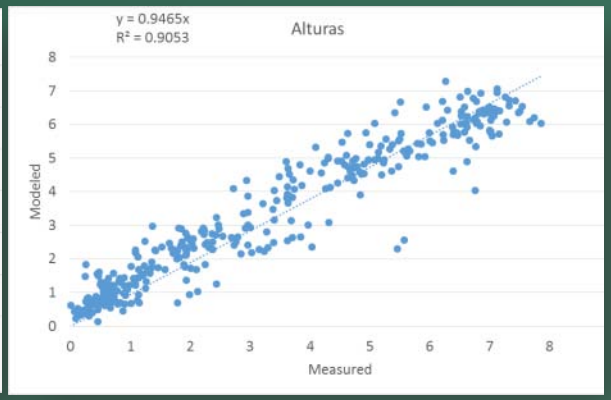




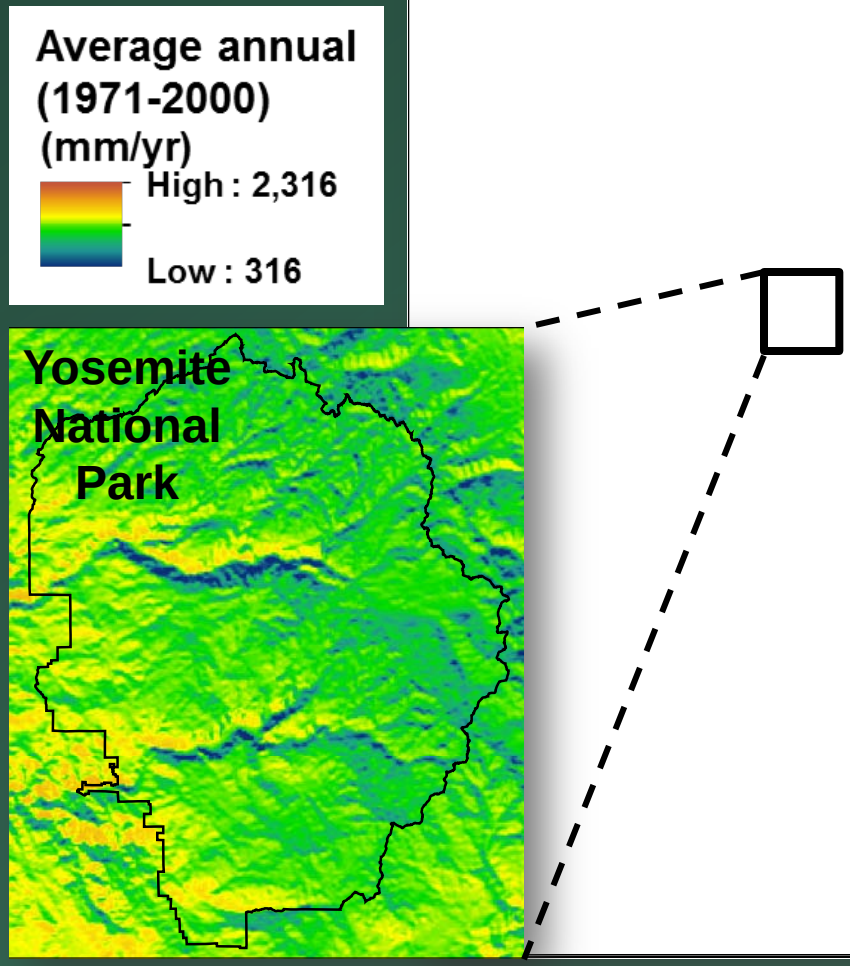


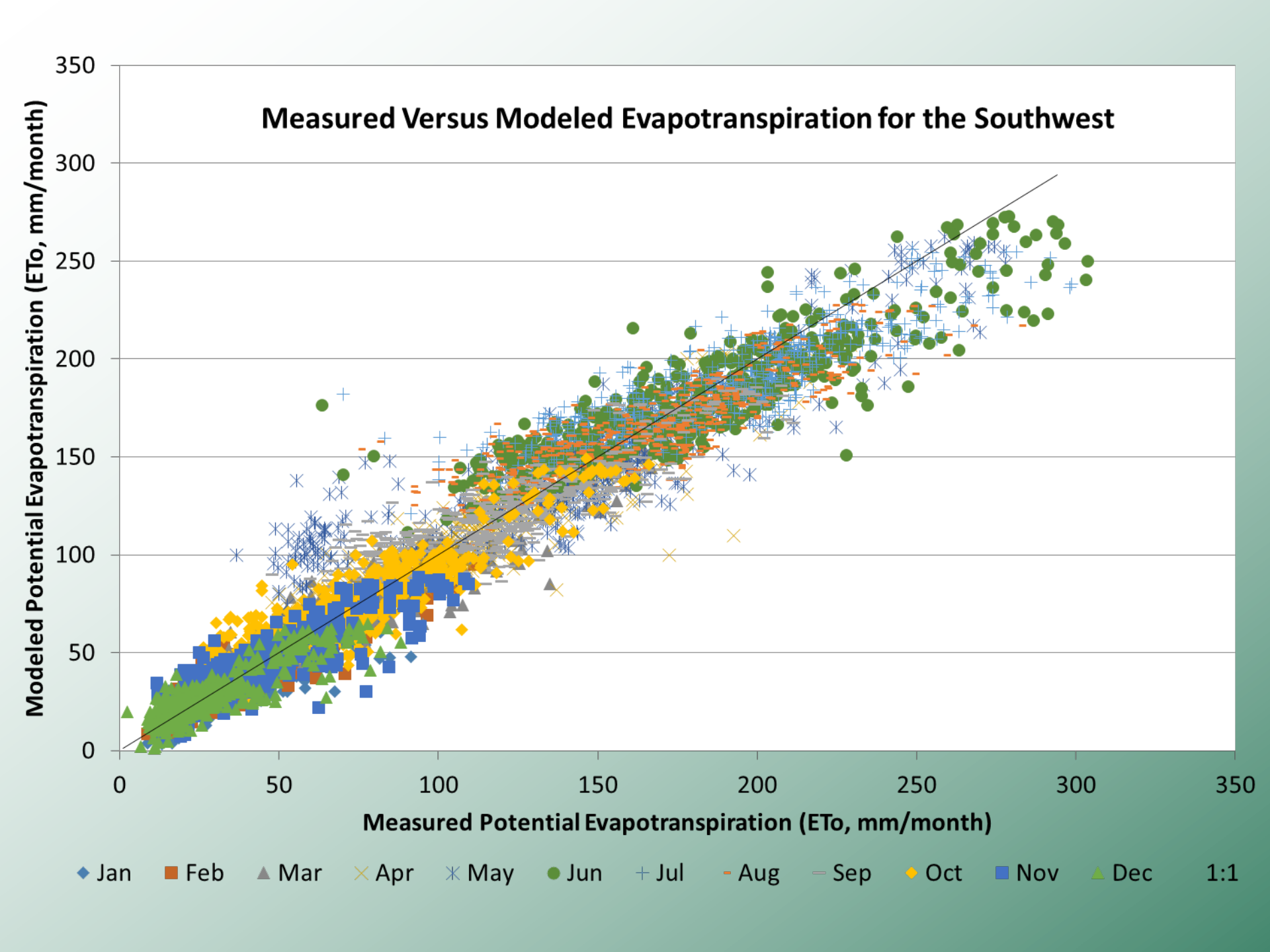




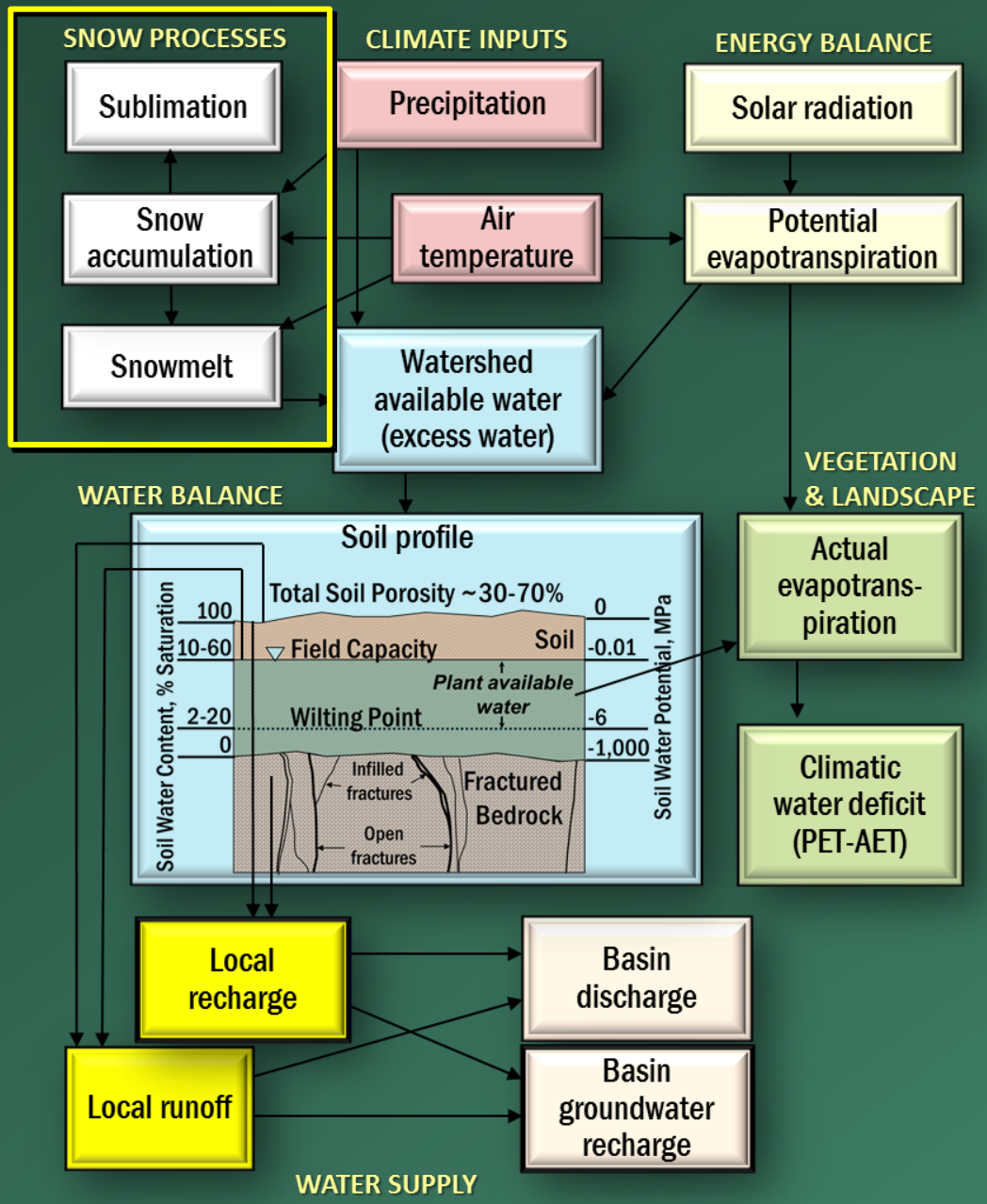


Potential Evapotranspiration




Measured Versus Modeled Evapotranspiration for the Southwest
Modeled Potential Evapotranspiration (ETo, mm/month)
Measured Potential Evapotranspiration (ETo, mm/month)
0
50
100
150
200
250
300
350
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1:1

Basin Characterization Model



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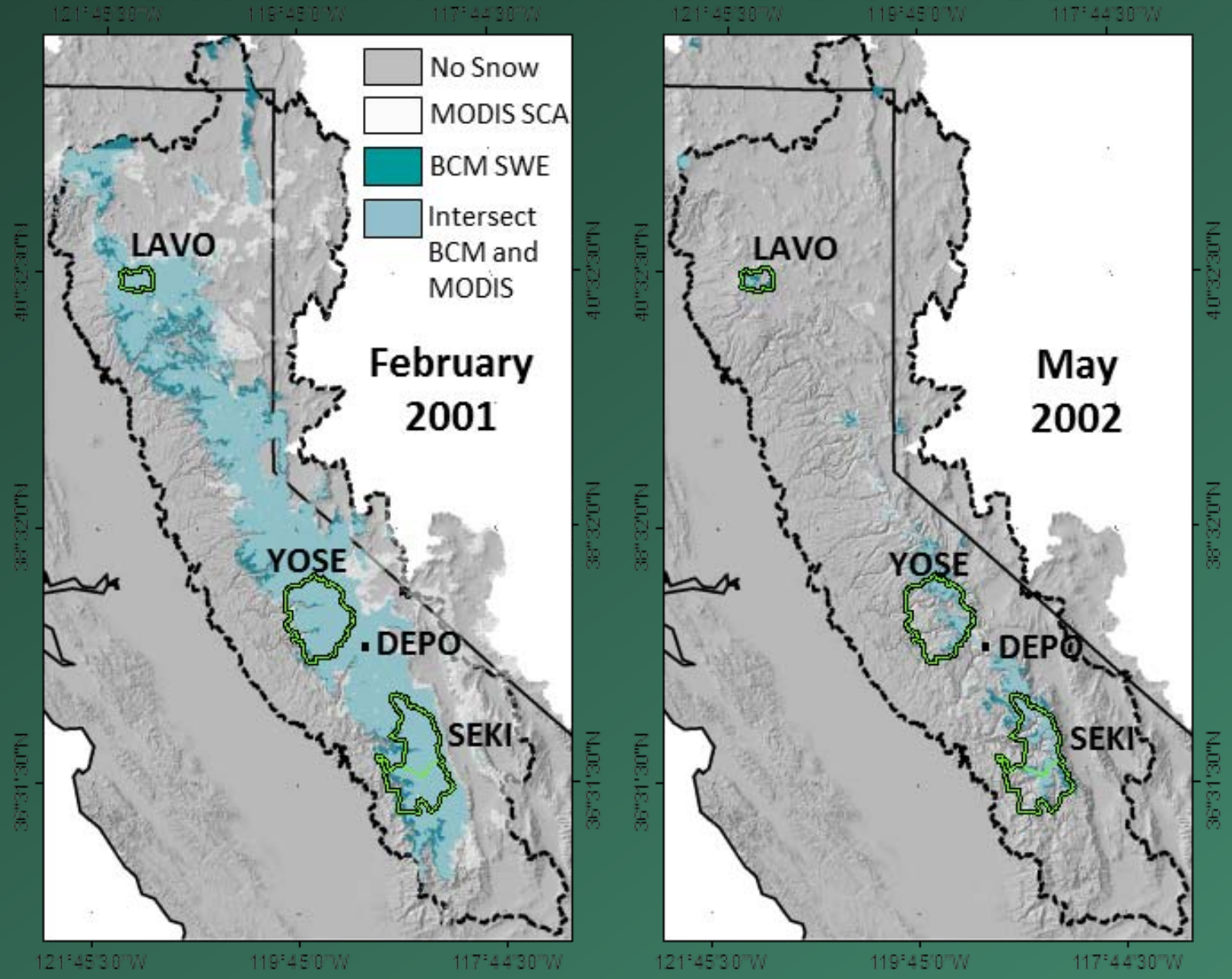
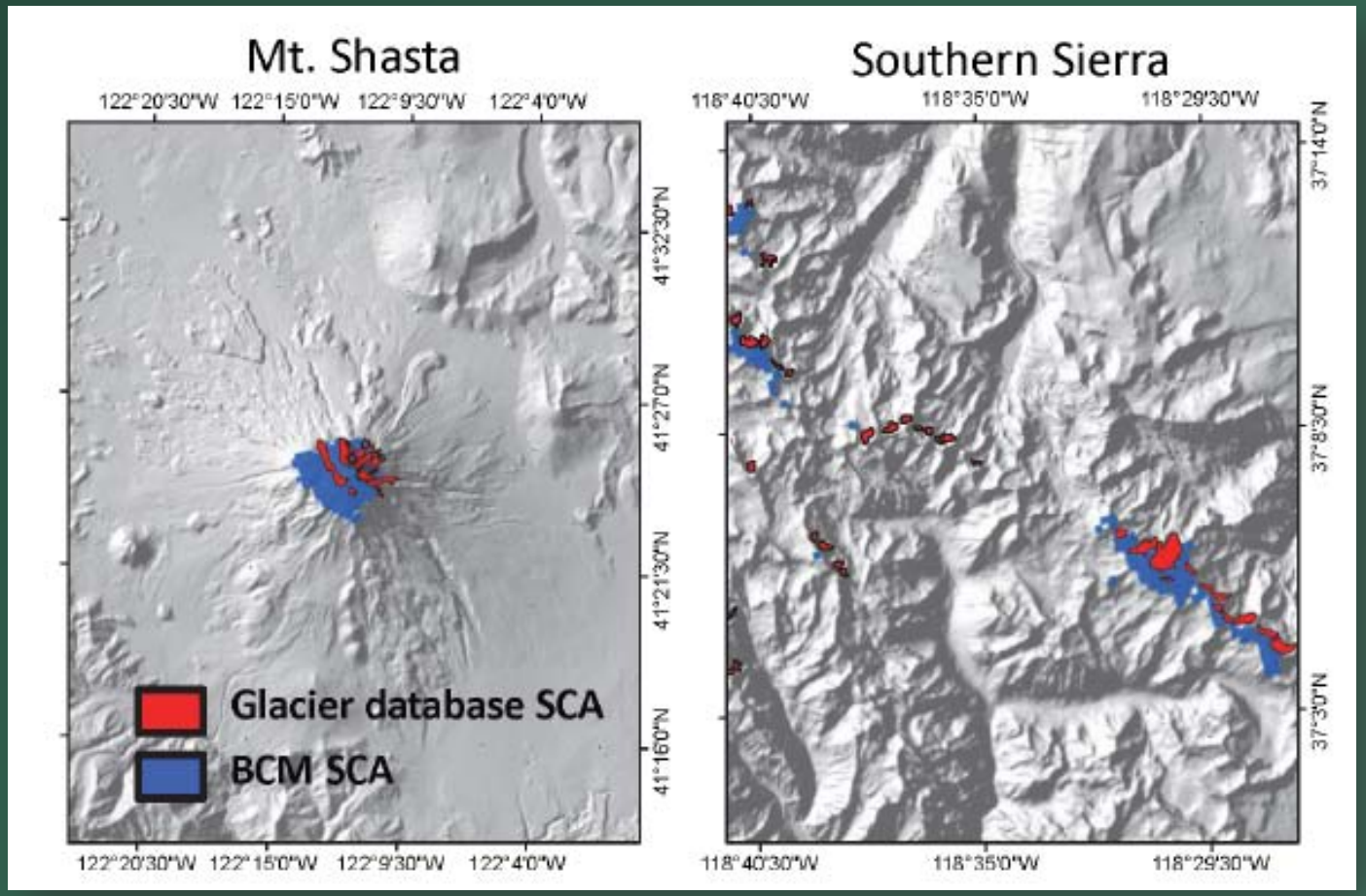
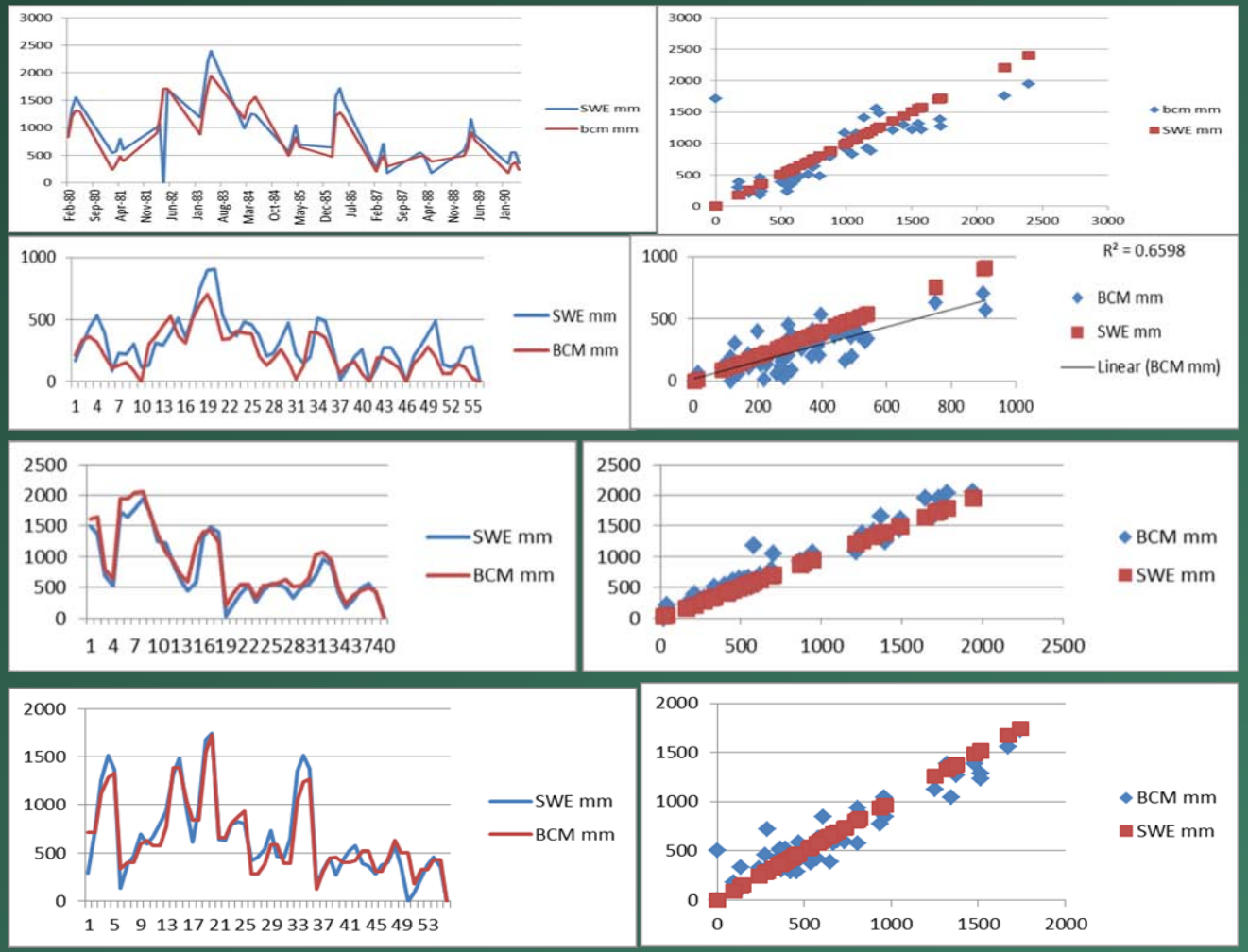
Snow covered area: accumulation and melt seasons

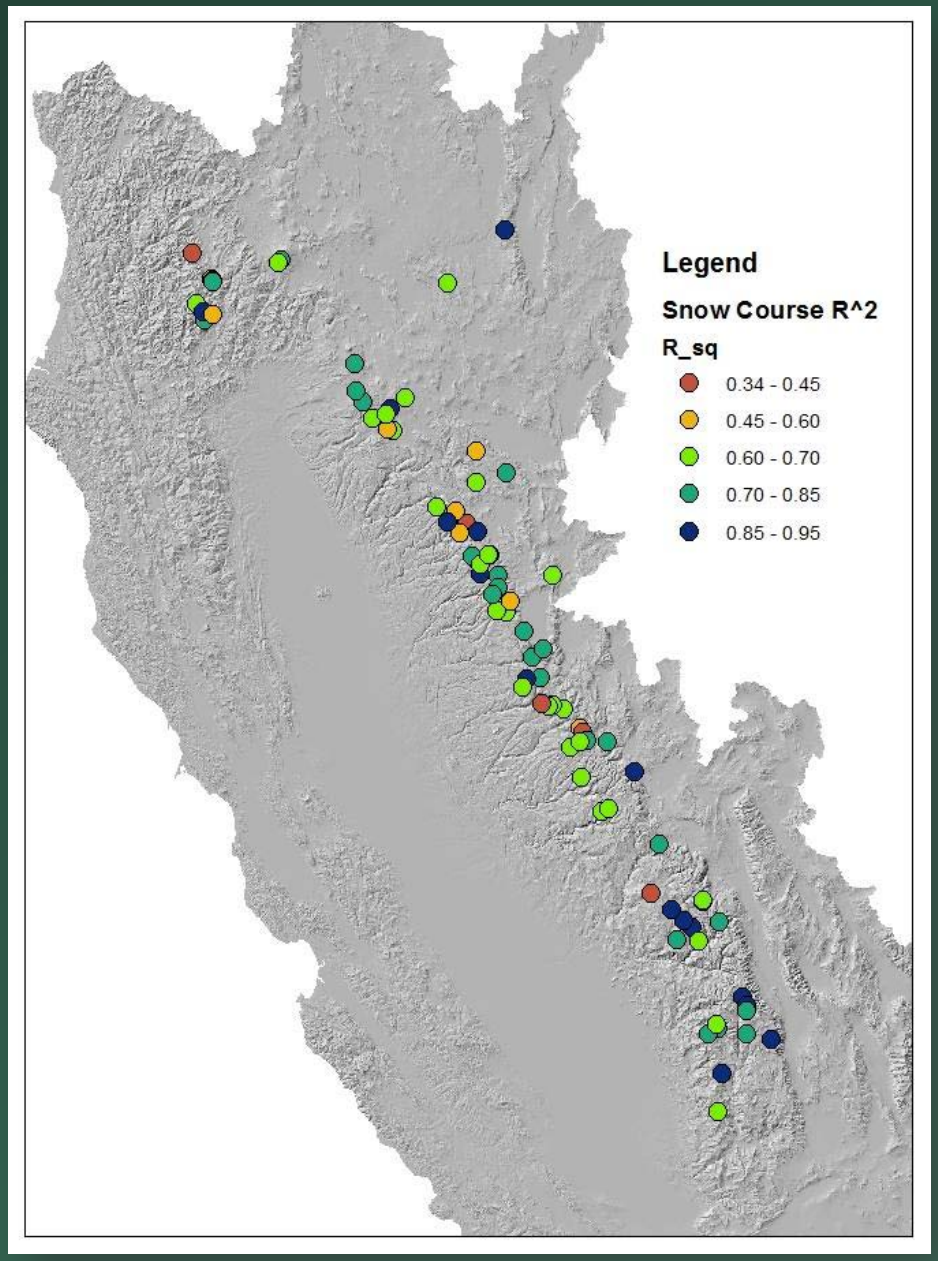


Year round snow: glaciers



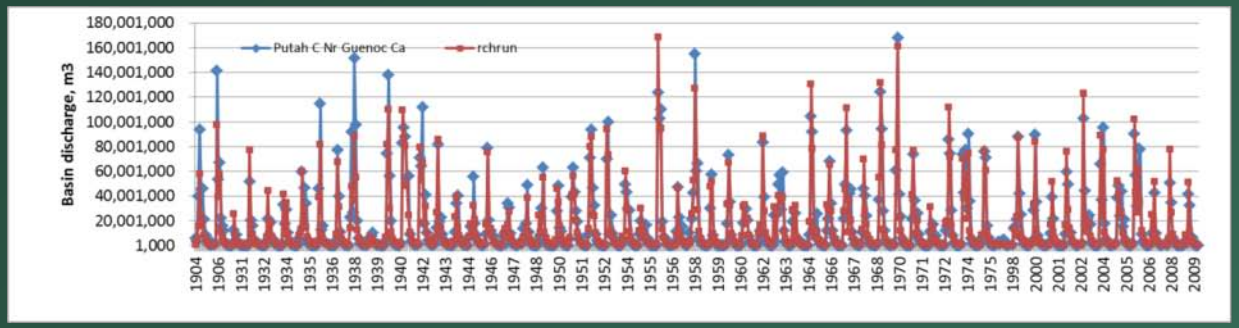
NWS Snow 17 Parameter Calibration
Spatially distributing coefficients (87 courses)

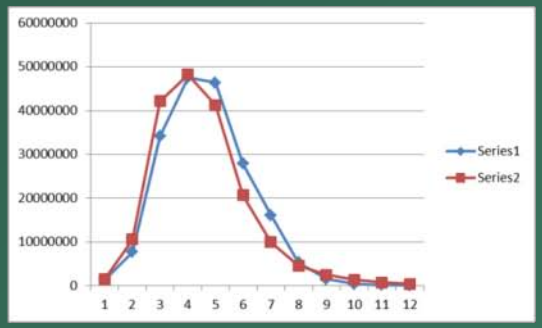


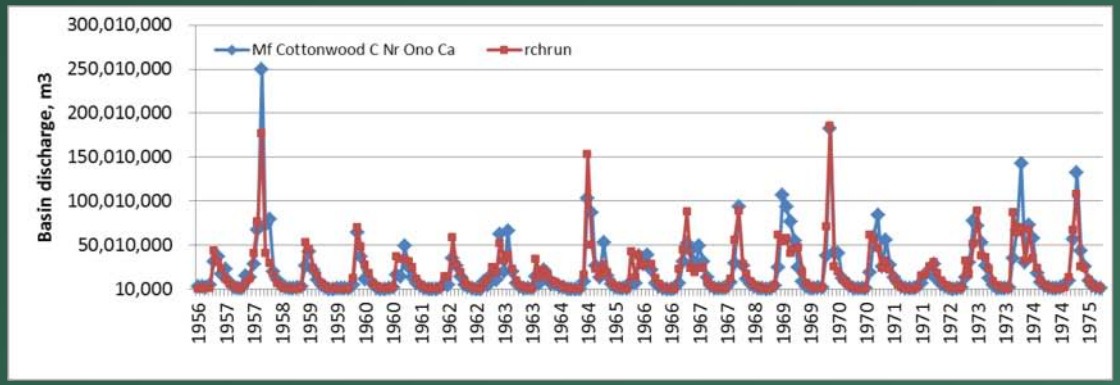


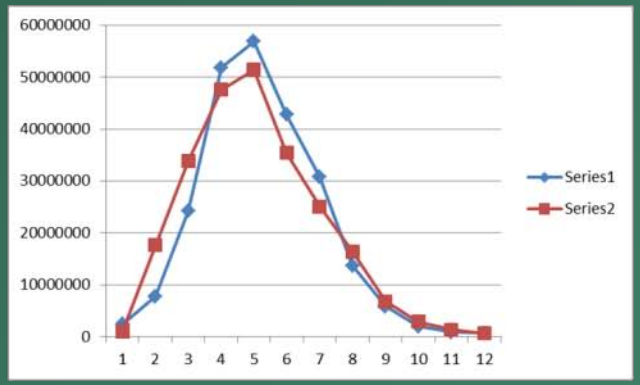
Spatially distributing snow accumulation and melt parameters to capture the range of snow conditions throughout California

Seasonal Timing of Runoff for Proofing Snow Module



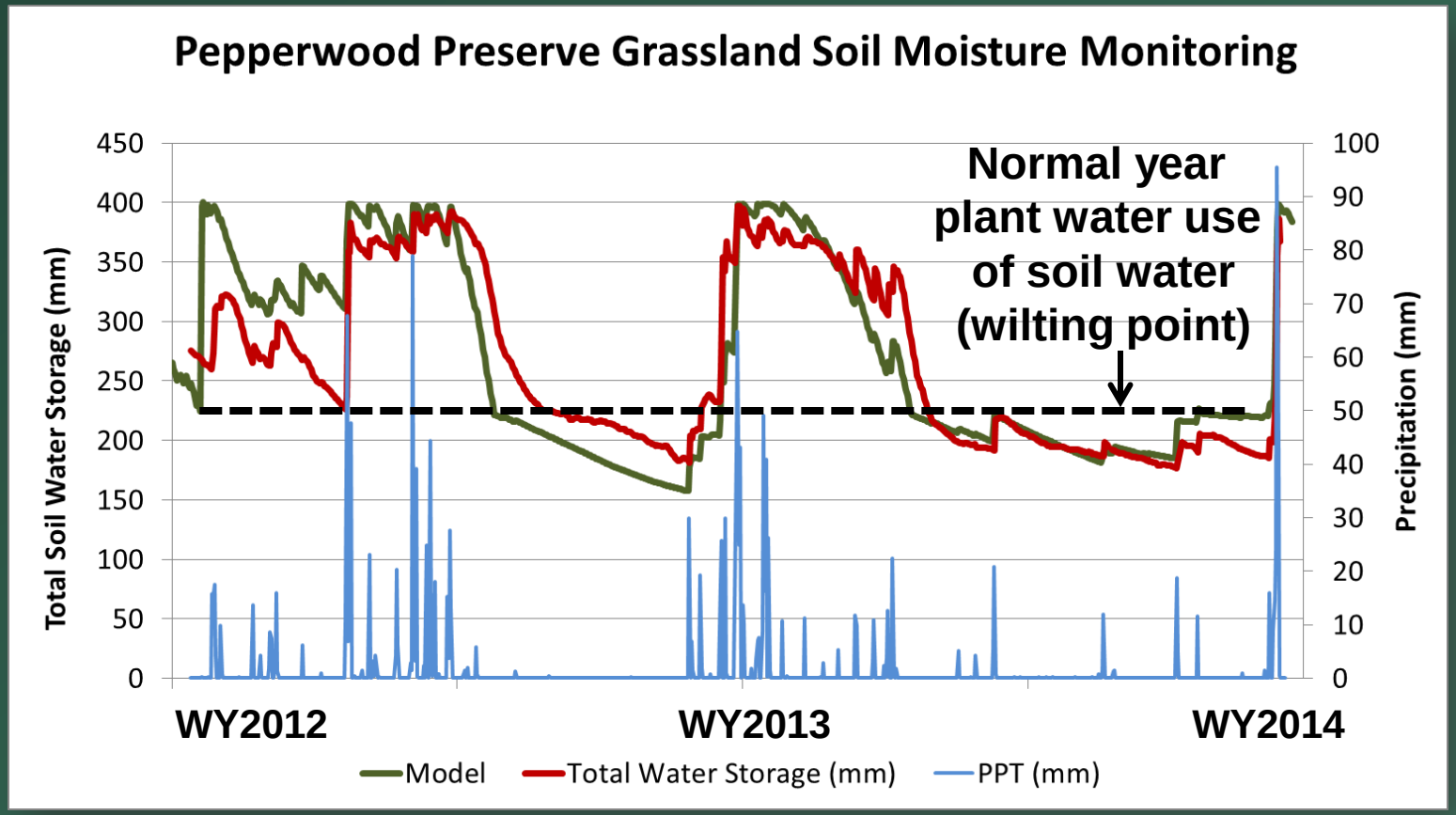






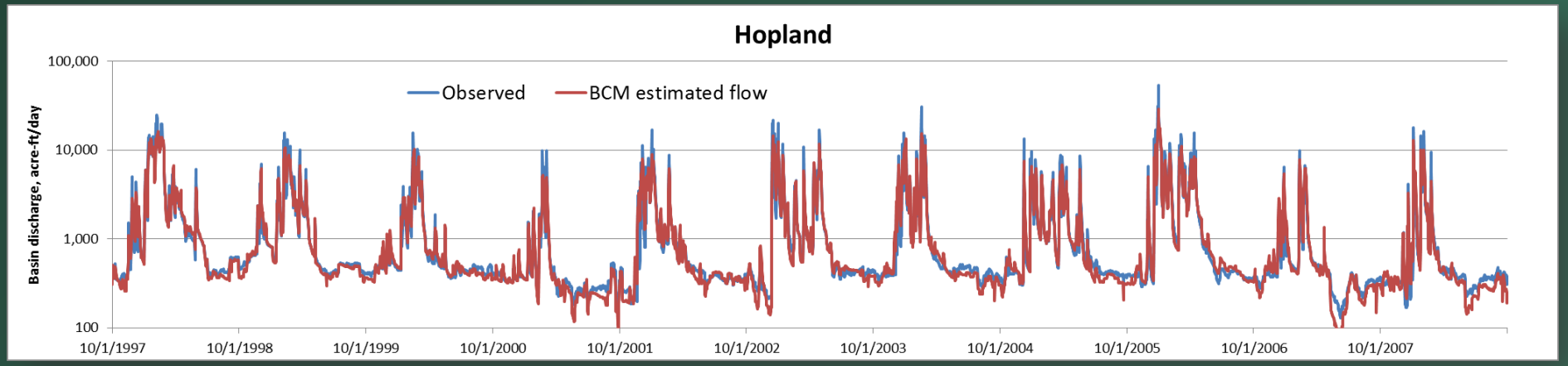
Soil Moisture Monitoring

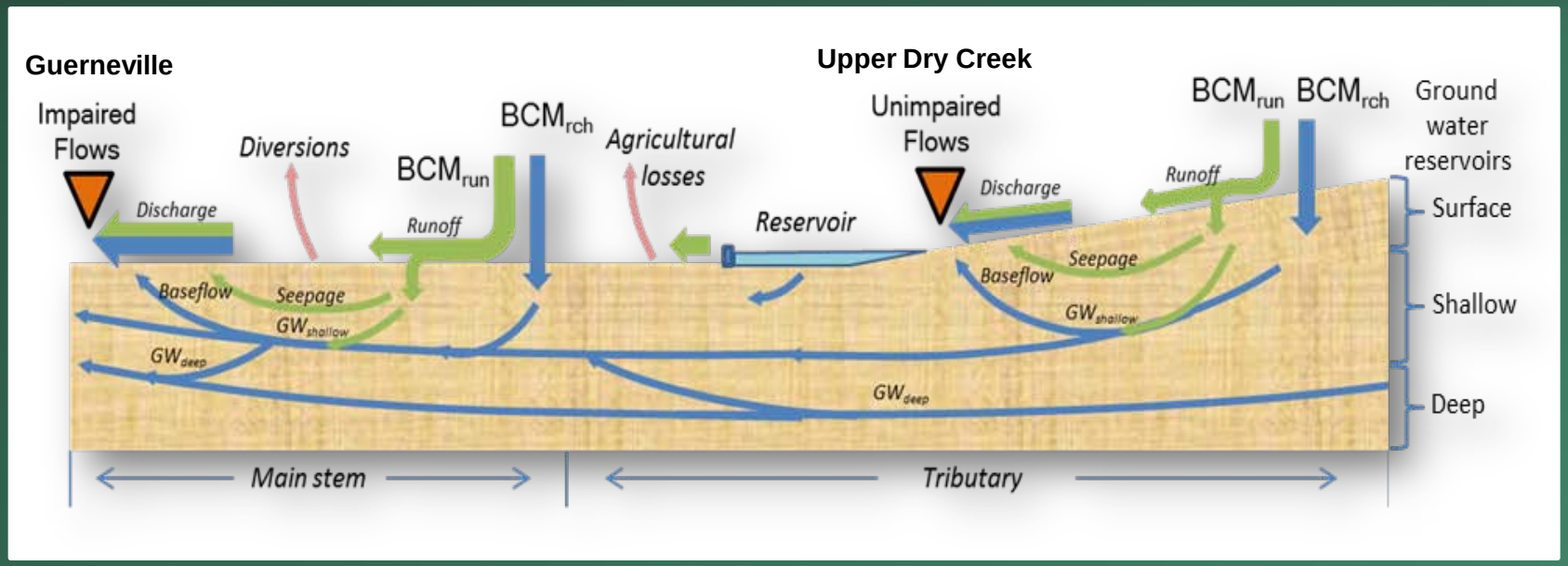
(headwaters of Mark West Creek)



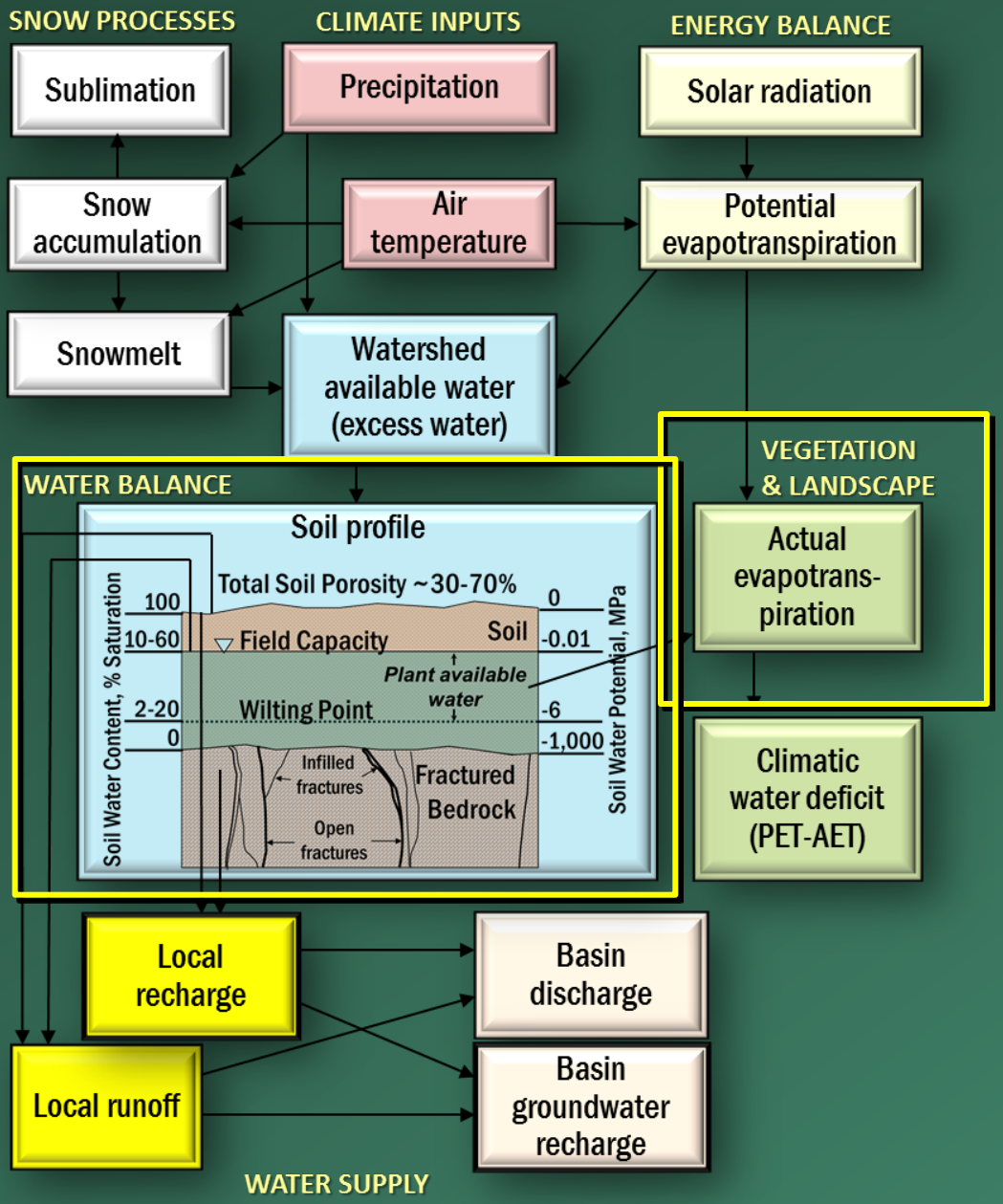
Data US Geological Survey

Calculating Basin Discharge from Recharge and Runoff to Match Streamflow Measurements





Basin Characterization Model



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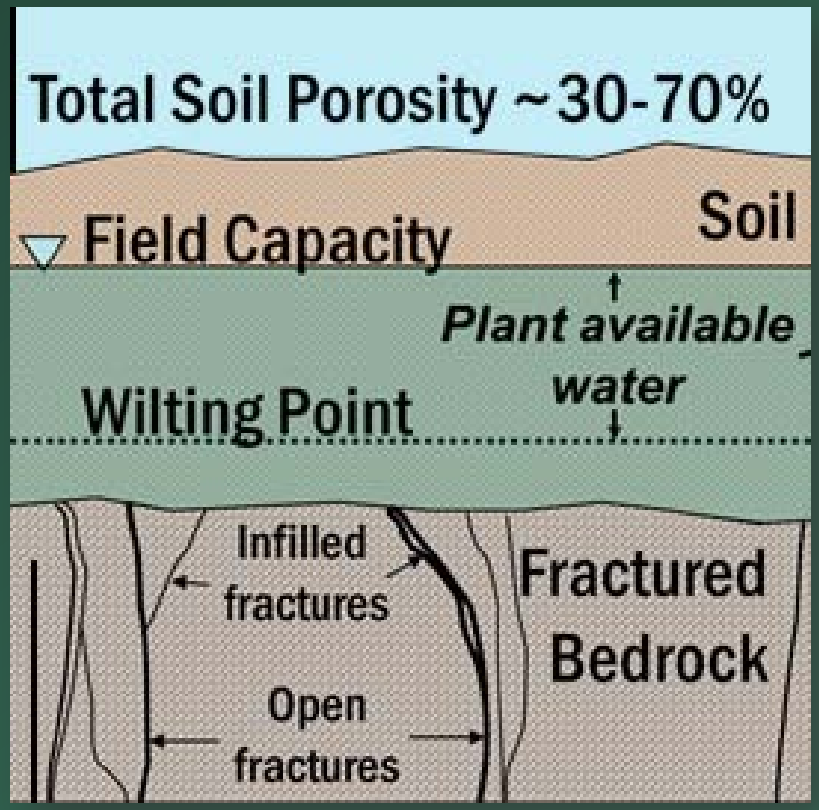
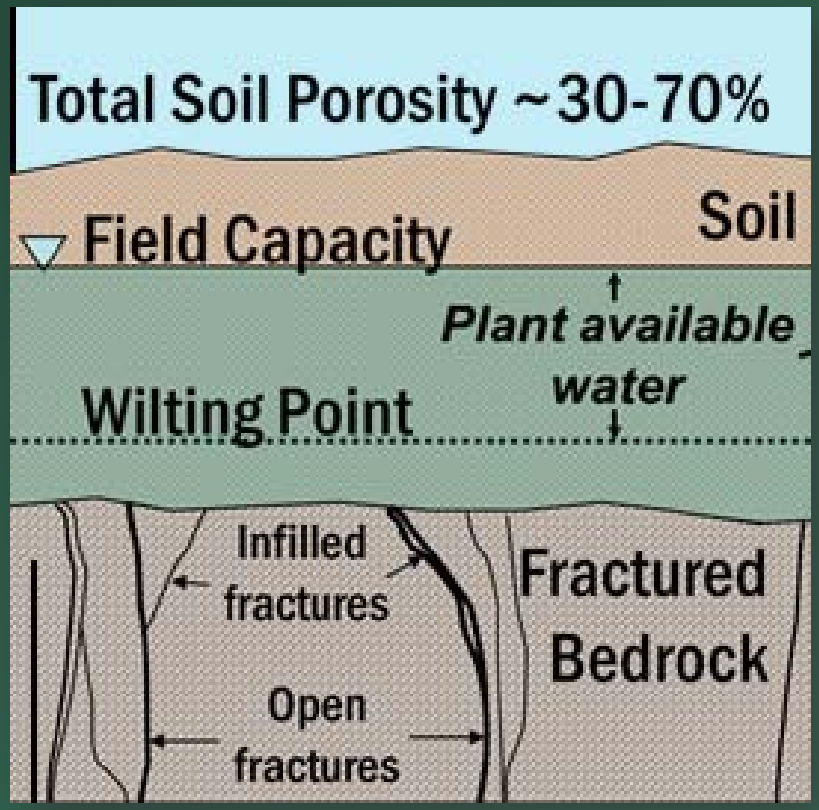
Soil Properties



- SSURGO soils have field capacity of -0.03 MPa and wilting point of -1.5 MPa
- Plant available water is between these values

Soil Properties



- SSURGO soils have field capacity of -0.03 MPa and wilting point of -1.5 MPa
- Texture can be used to estimate field capacity and wilting point
- We used -0.01 MPa for field capacity and -3.0 MPa for wilting point to increase water holding capacity

Using Soil Physics Equations to Develop New Soil Properties

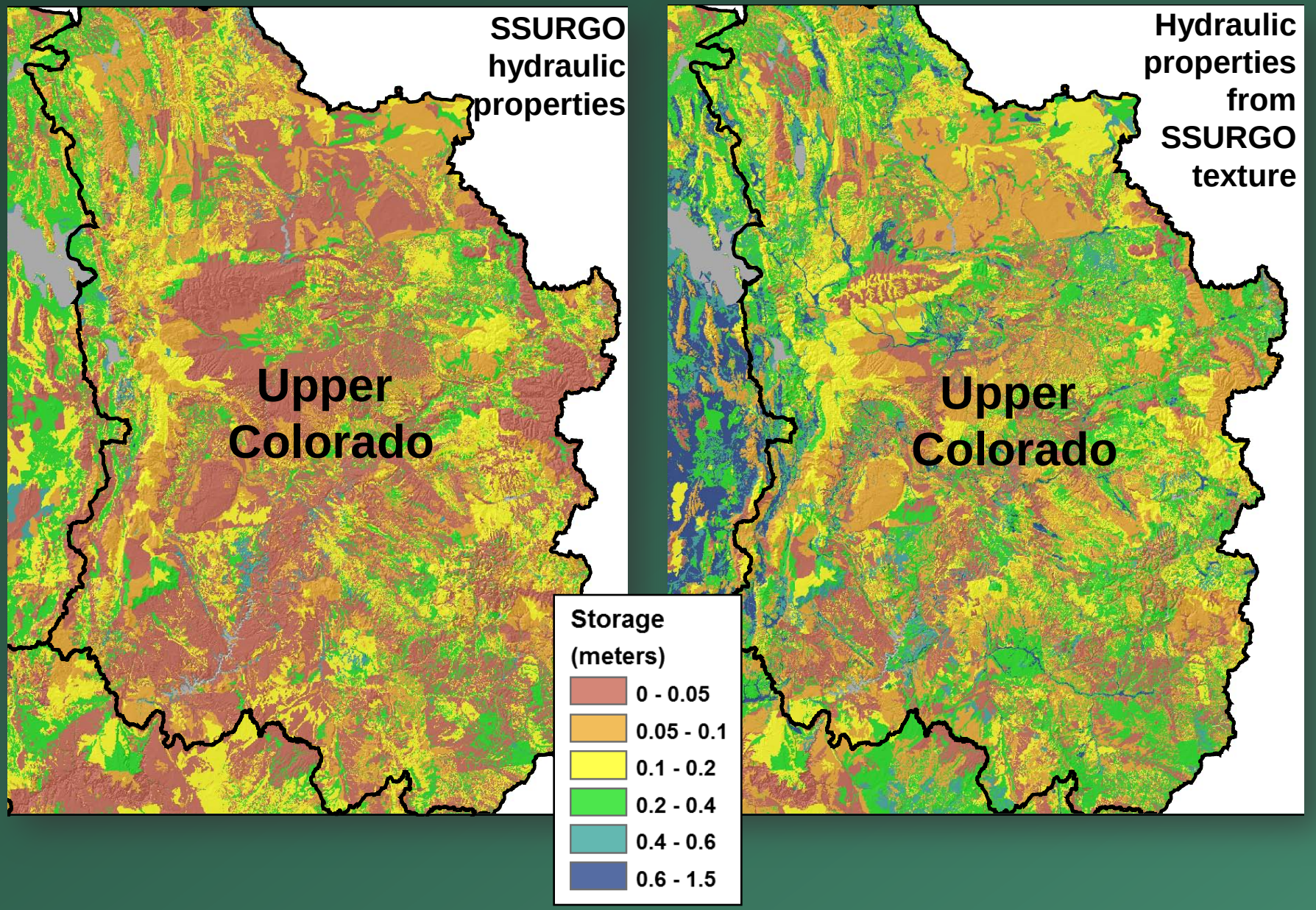
Campbell, G.S., 1985) Soil physics with basic, transport models for soil-plant systems, Elsevier, New York, 150pp.

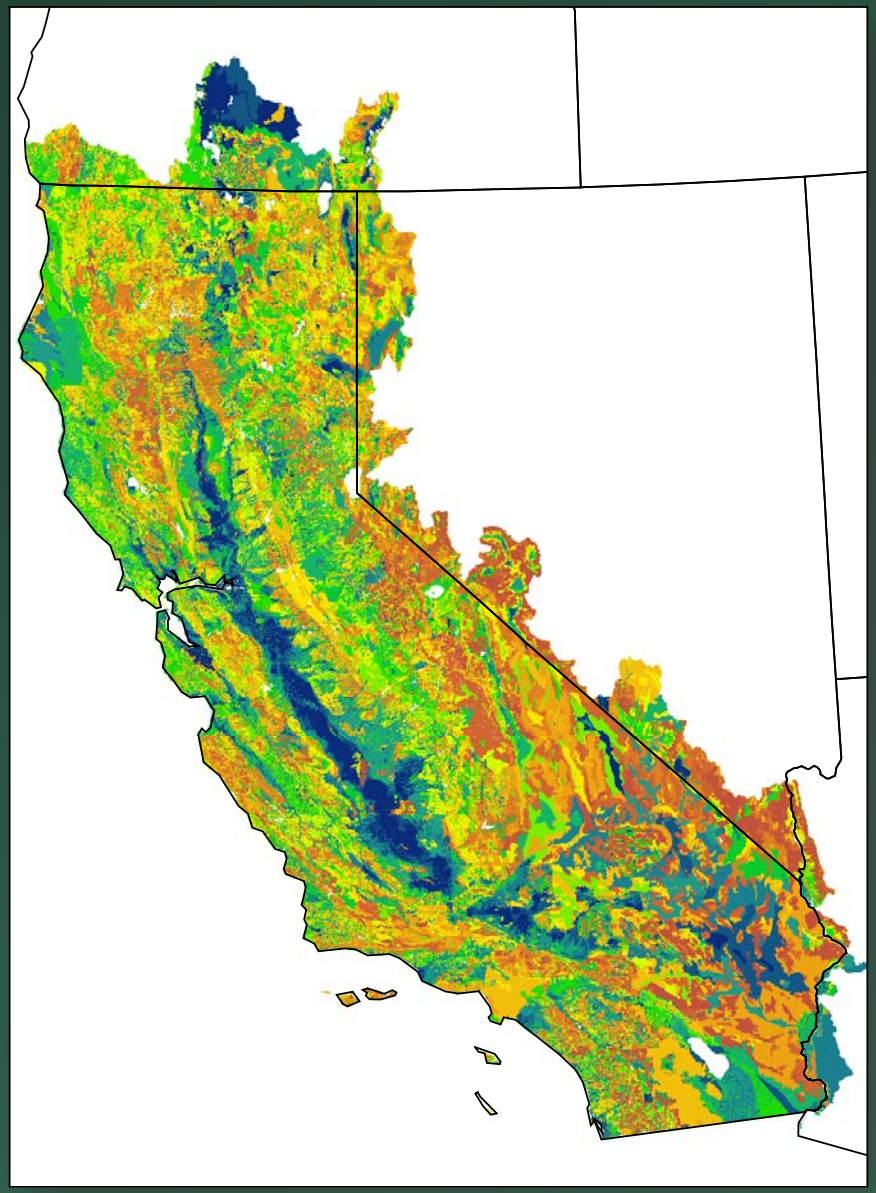
Gupta, S.C. and Larson, W.E., 1979, Estimating soil water retention characteristics from particle size distribution, organic matter percent, and bulk density, Water Resources Research Vol. 15, No.6.

Rawls, W.J., Pachepsky, Y.A., Ritchie, J.C., Sobecki, T.M., and Bloodworth, 2003, Effect of soil organic carbon on soil water retention, Geoderma, 116, pp61-76.

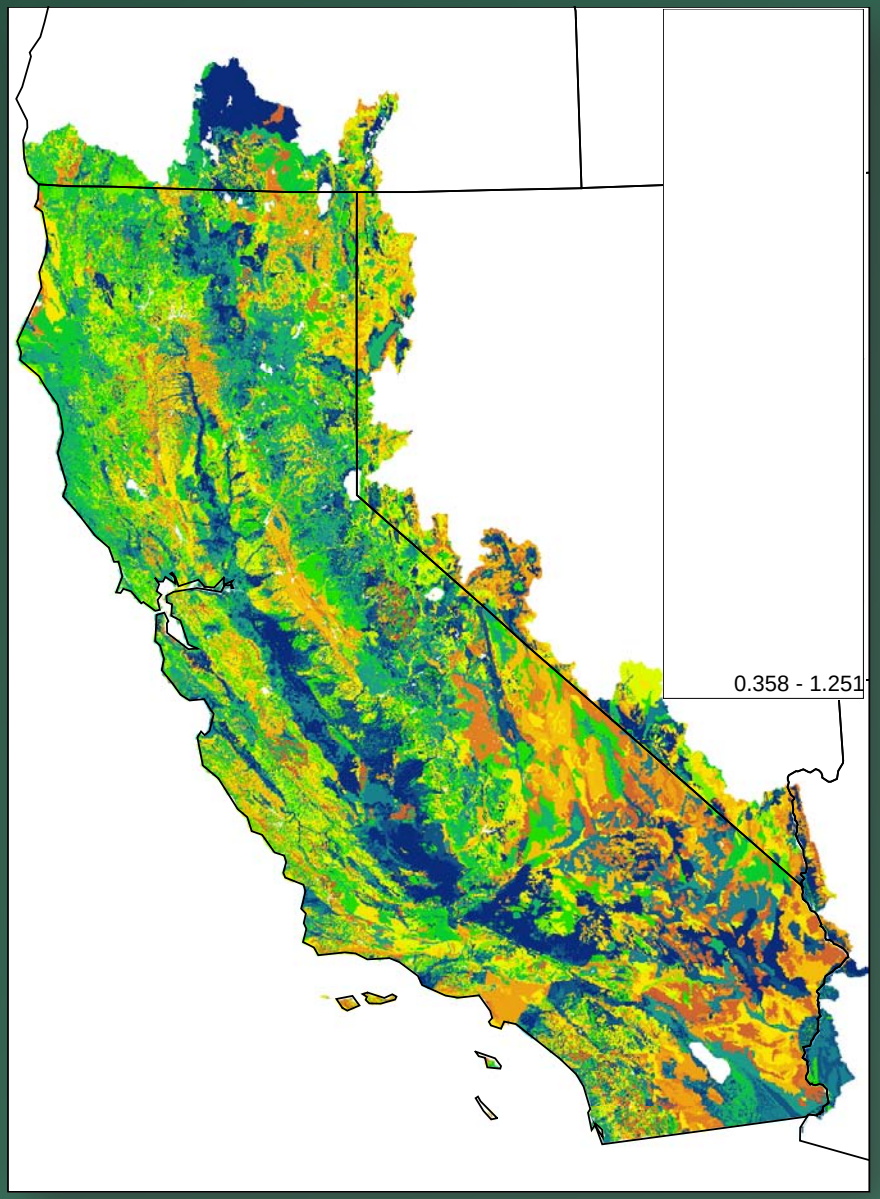
Saxton, K.E. and Rawls, W.J., 2006, Soil water characteristic by texture and organic matter for hydrologic solutions, Soil Sci. Soc. Am. J. 70:1569-1578.

Soil Water Storage Capacity

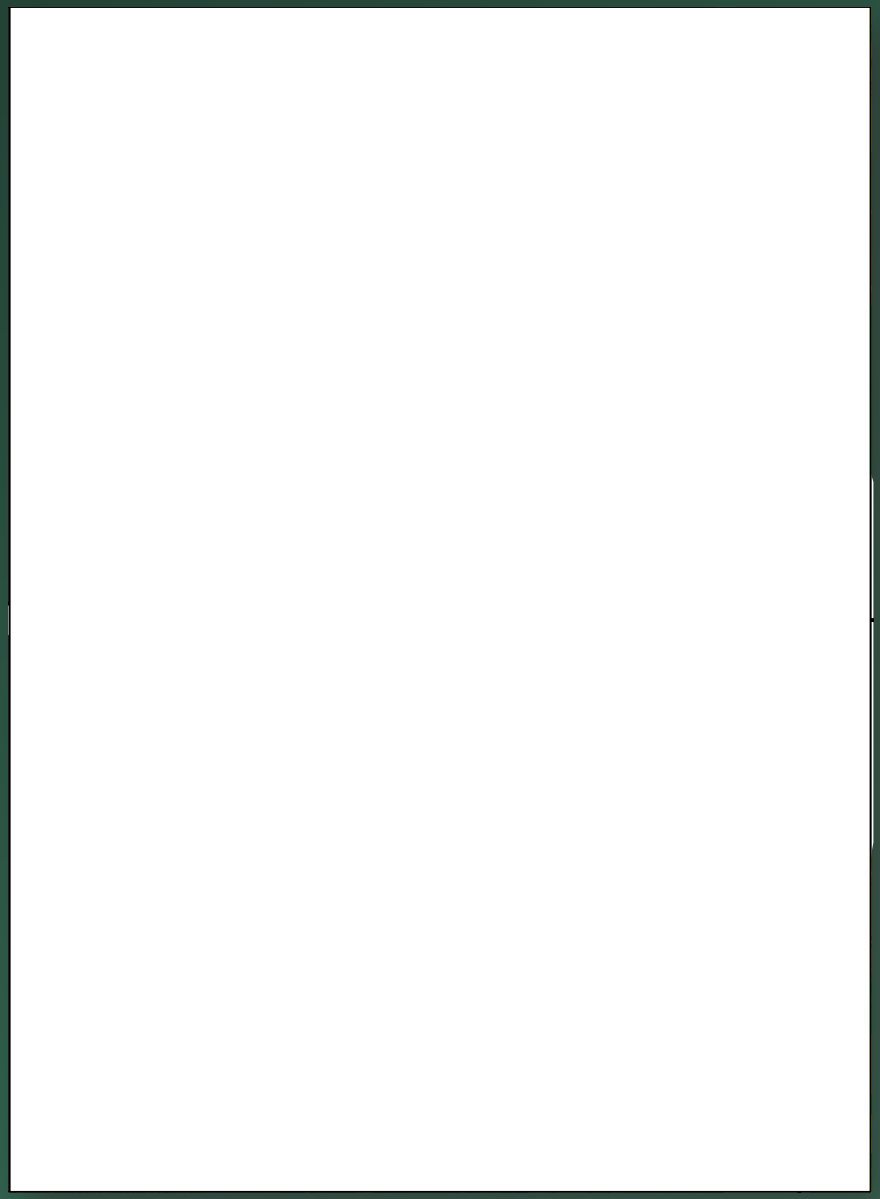




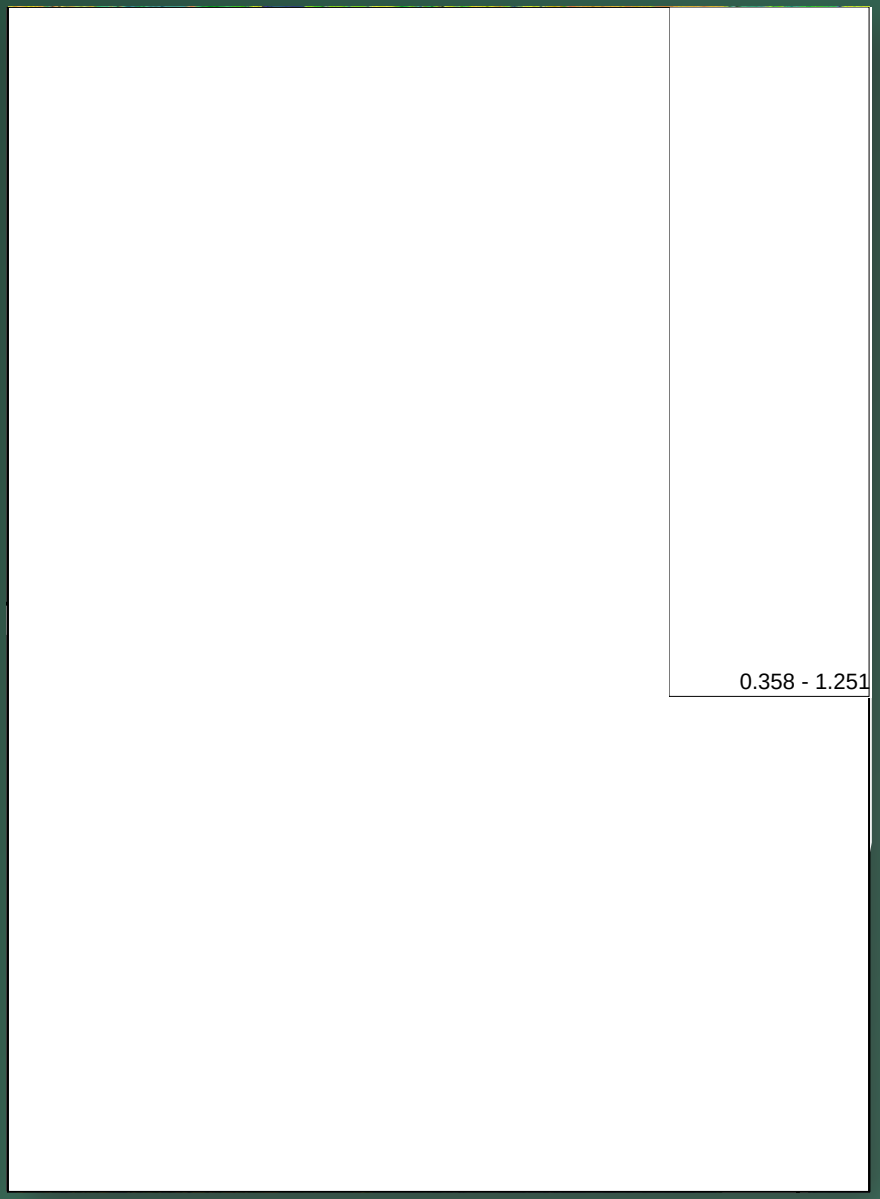
SSURGO hydraulic properties



Hydraulic properties from SSURGO texture



SSURGO hydraulic properties



Hydraulic properties from SSURGO texture

Testing Recharge Results

- Comparing new results against estimates of basin recharge
  - Chloride Mass Balance
  - ModFlow
    - Death Valley Regional Flow System
    - Lower Walker Valley, Tooele Valley, Utah Valley
  - Discharge Measurements
  - California ModFlow Model

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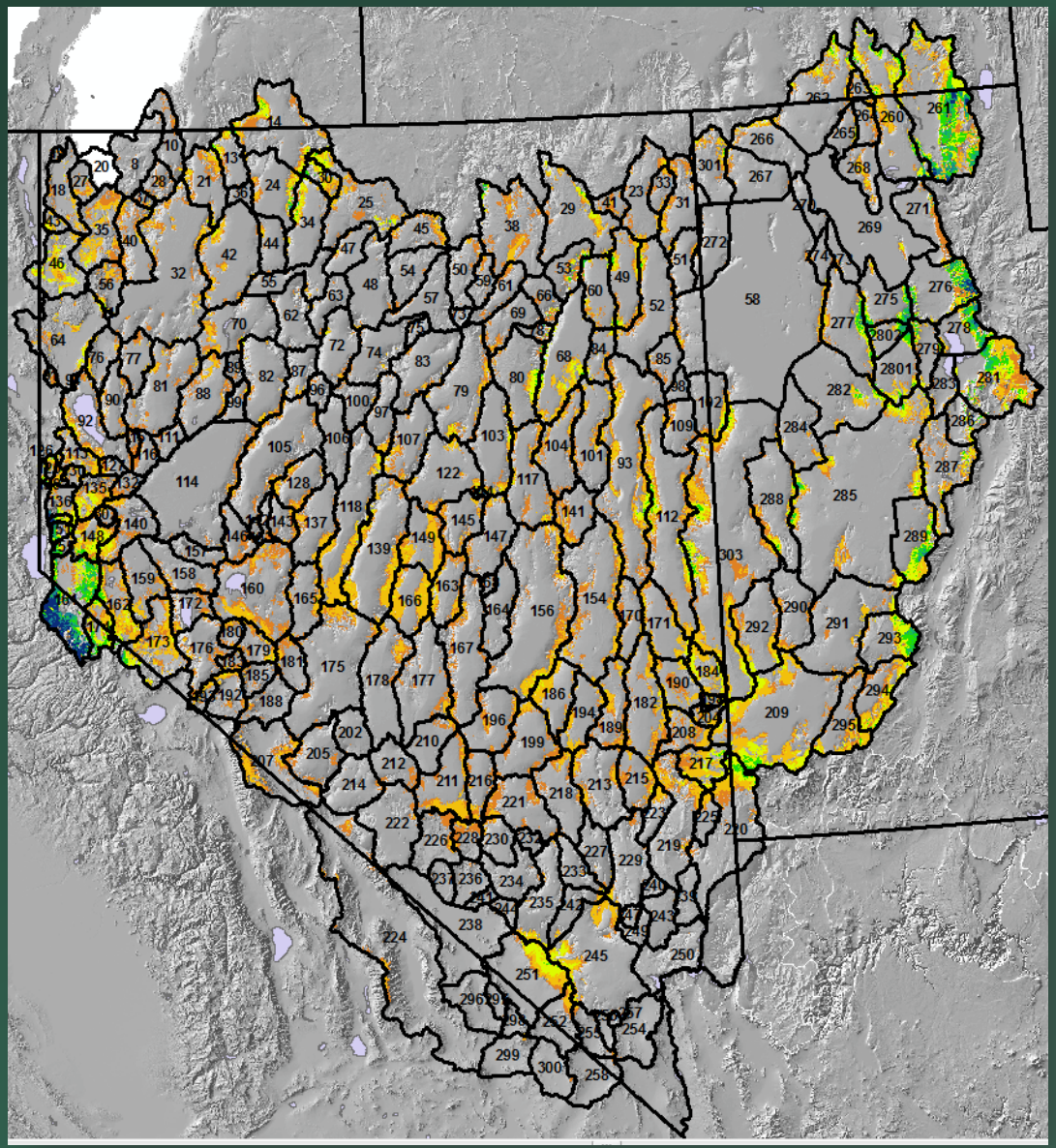
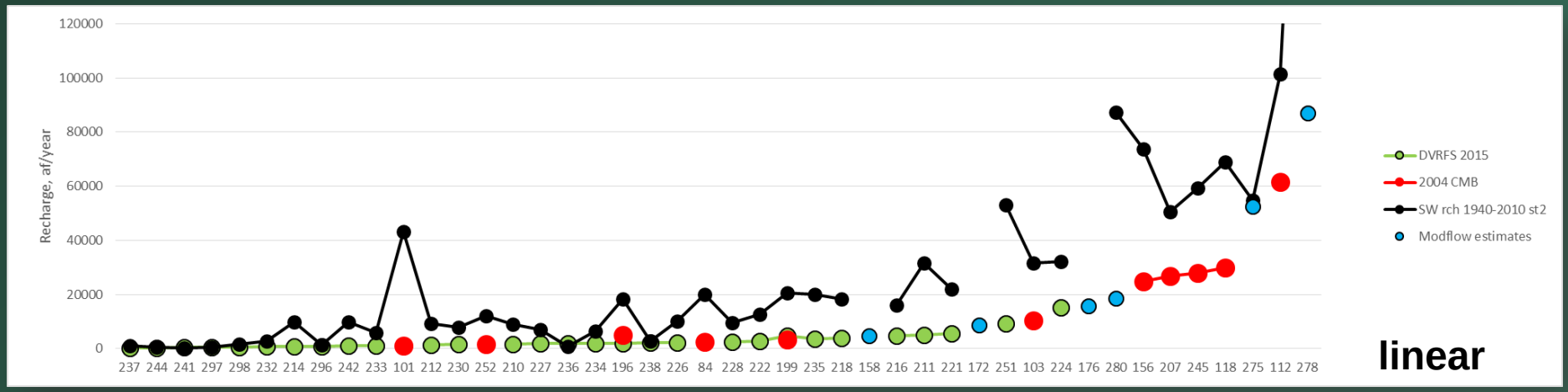
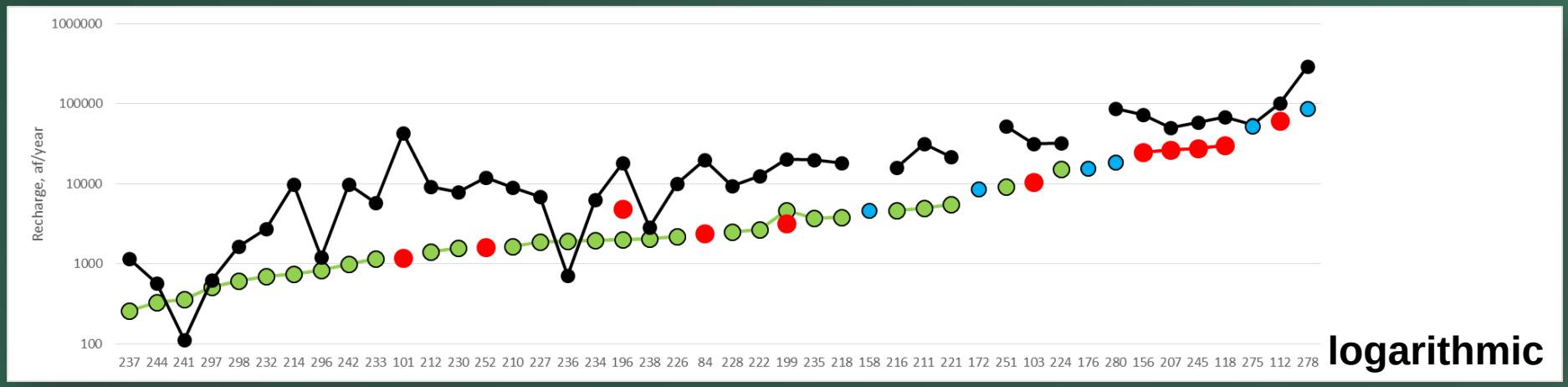


Great Basin Recharge

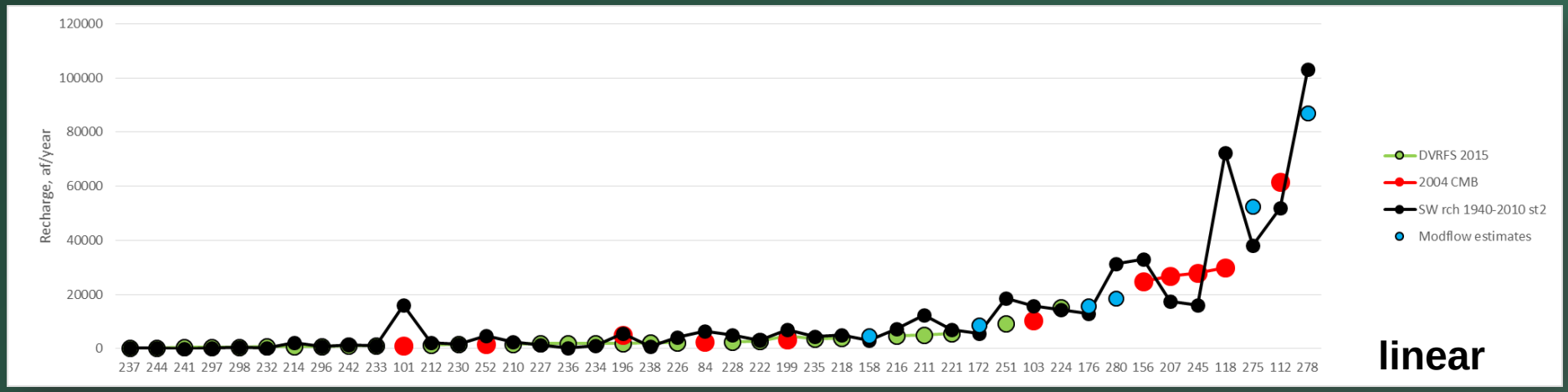
Great Basin Recharge

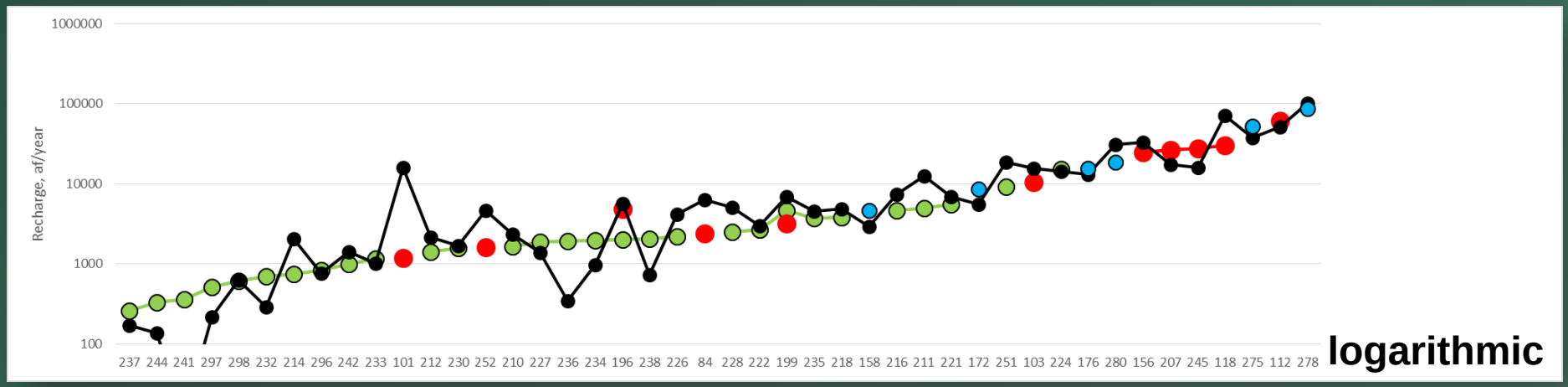




Alluvial valleys 2.01 m soil depth
SSURGO hydraulic properties

Great Basin Recharge





Alluvial valleys 4 m soil depth
SSURGO texture for hydraulic properties

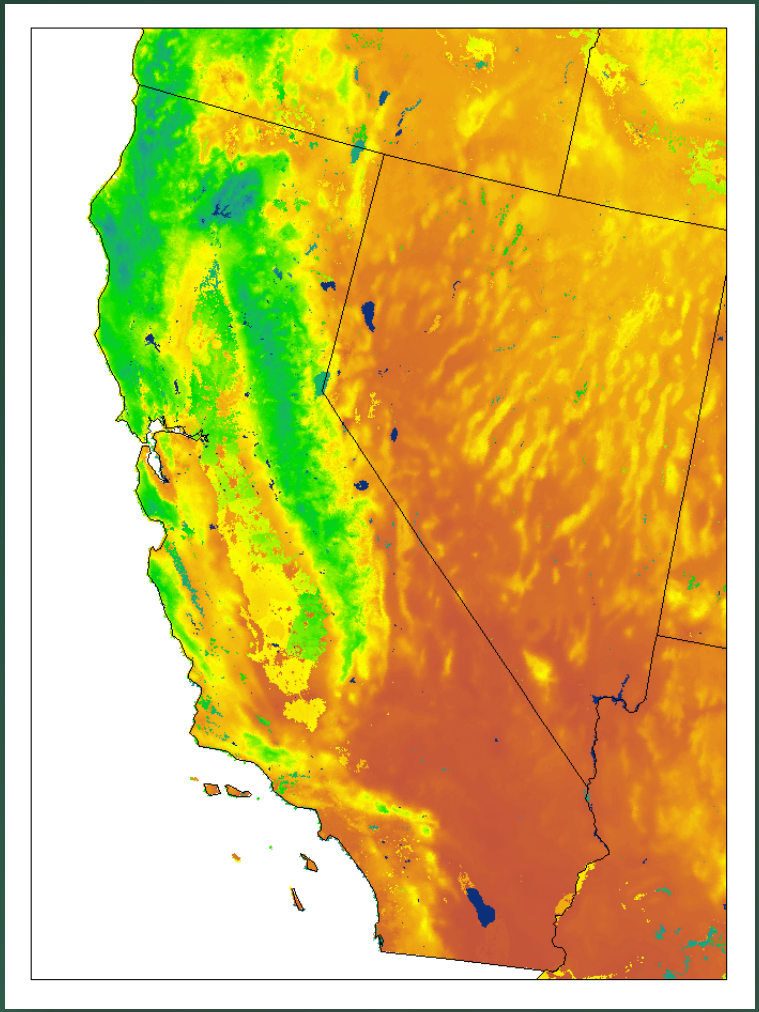
Ongoing Model Development

- Recent research to provide gridded estimates of actual evapotranspiration are allowing the incorporation of vegetation specific seasonal evapotranspiration
- This serves to constrain another component of the water balance, reducing uncertainty in recharge estimates

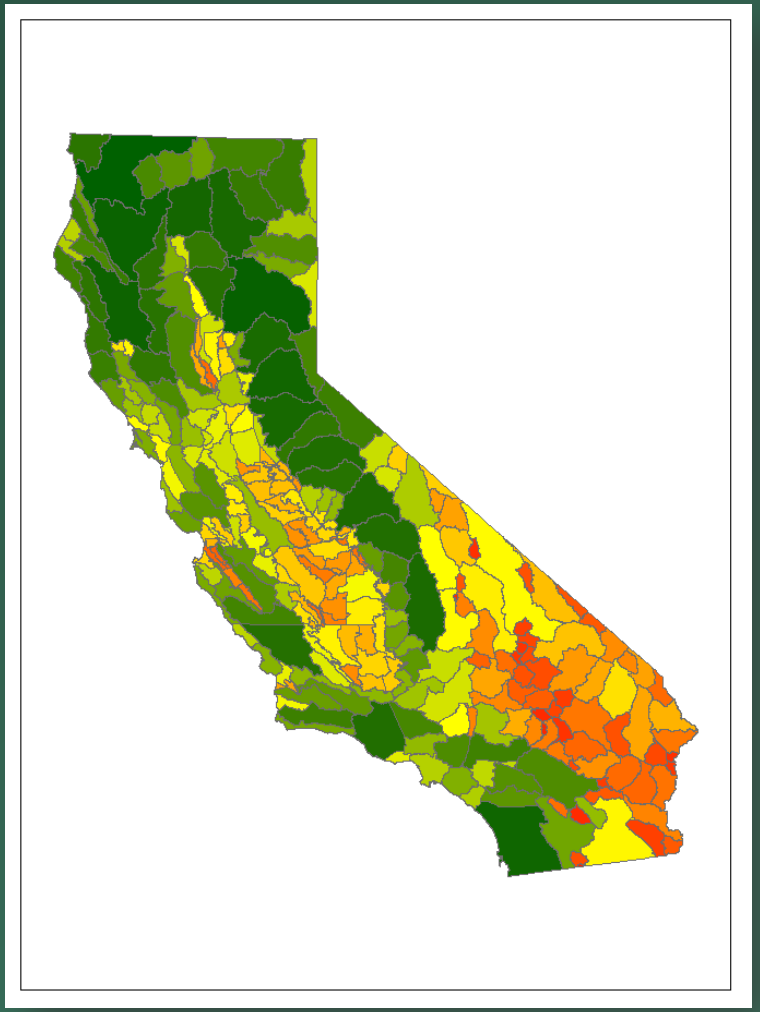
AET Data Sets Available for Analysis

Data Sets	Time Period	Time	Domain	Scale
BCM	1896-2015	Monthly	SW BCM	270m
Reitz	2000-2013	Yearly	US	1km
NASA	2007	Daily	SW BCM and Global	5km
DAU	2010-2015	Monthly	CA State	watershed
Jim Roche	2003-2011	Yearly	Tuolumne-Merced	270m

Estimates of Actual ET

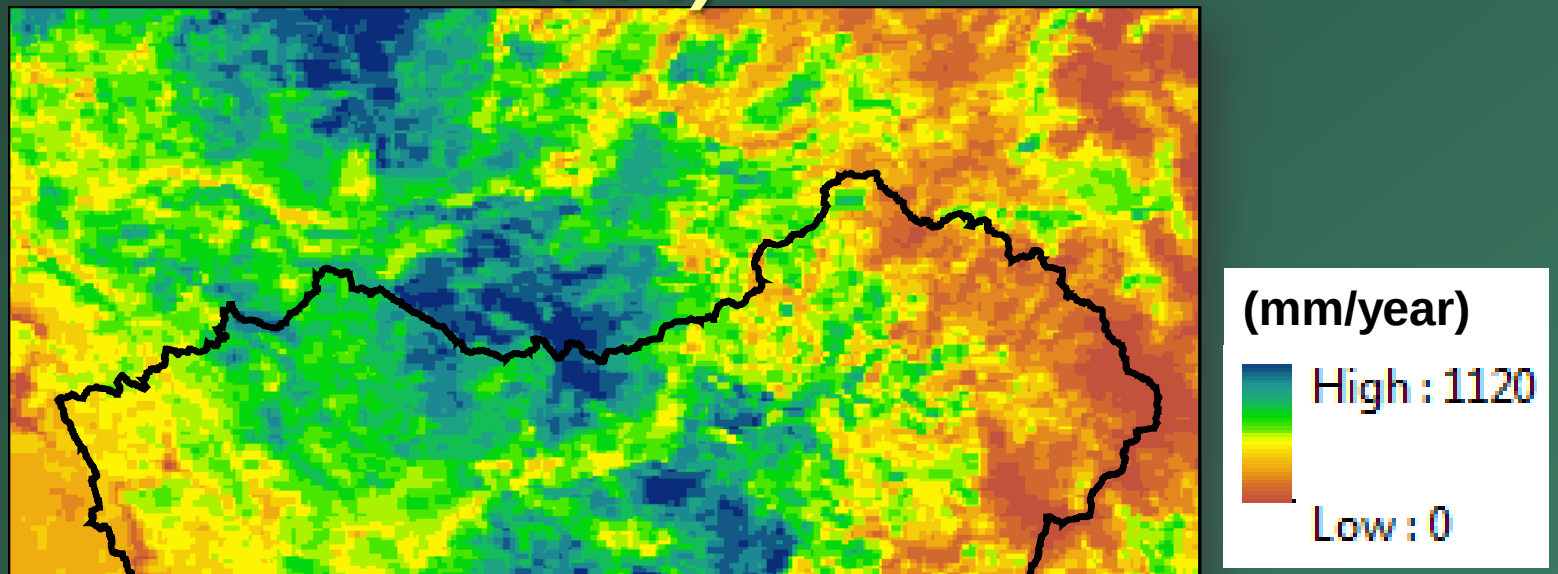


Annual, Meredith Reitz, USGS Reston



Monthly 2010-2015 Formation Environmental LCC

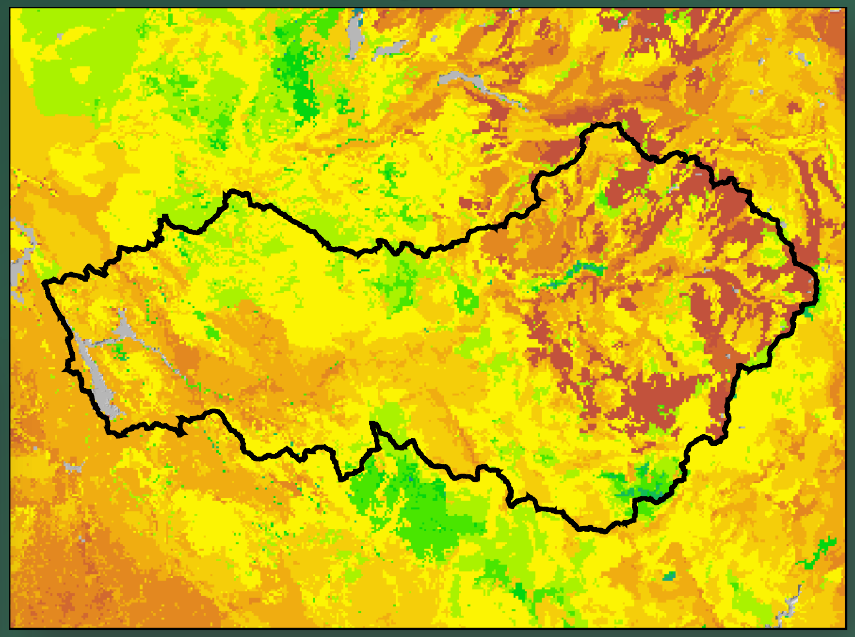
Actual ET calculated from NDVI and flux towers (Goulden and Bales 2014)



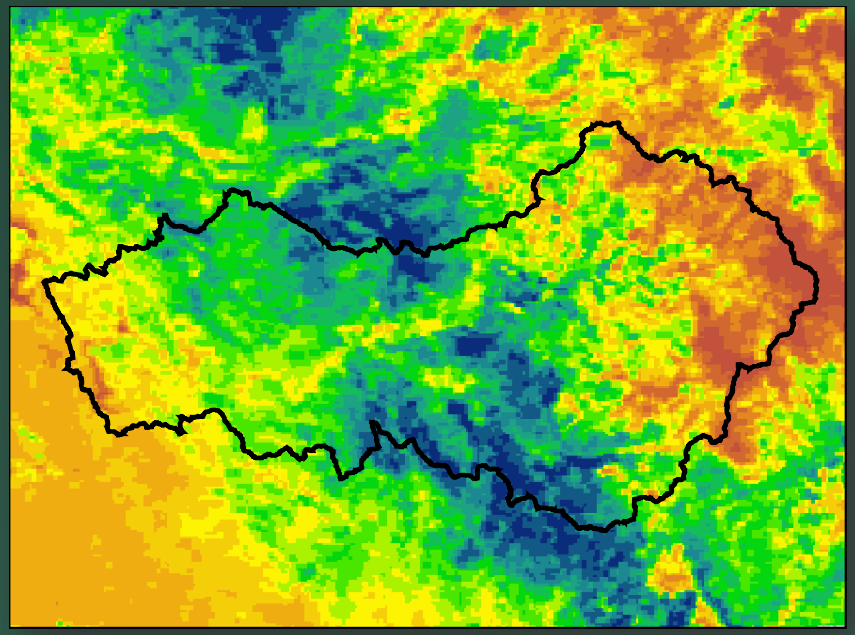
Merced River Basin 2003-2011

Actual ET

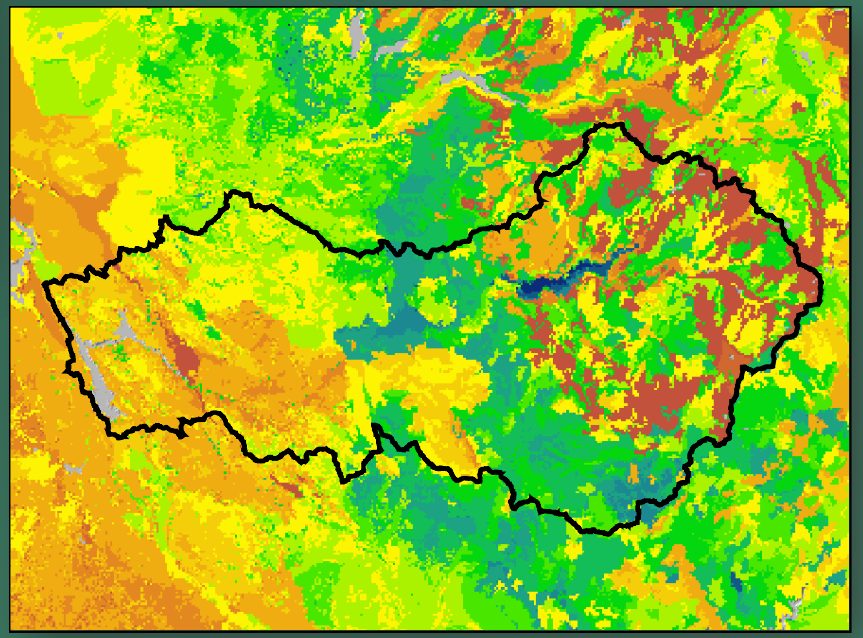
BCM SSURGO hydraulic properties

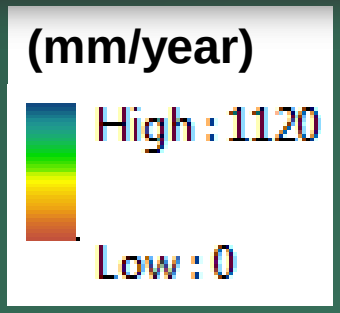


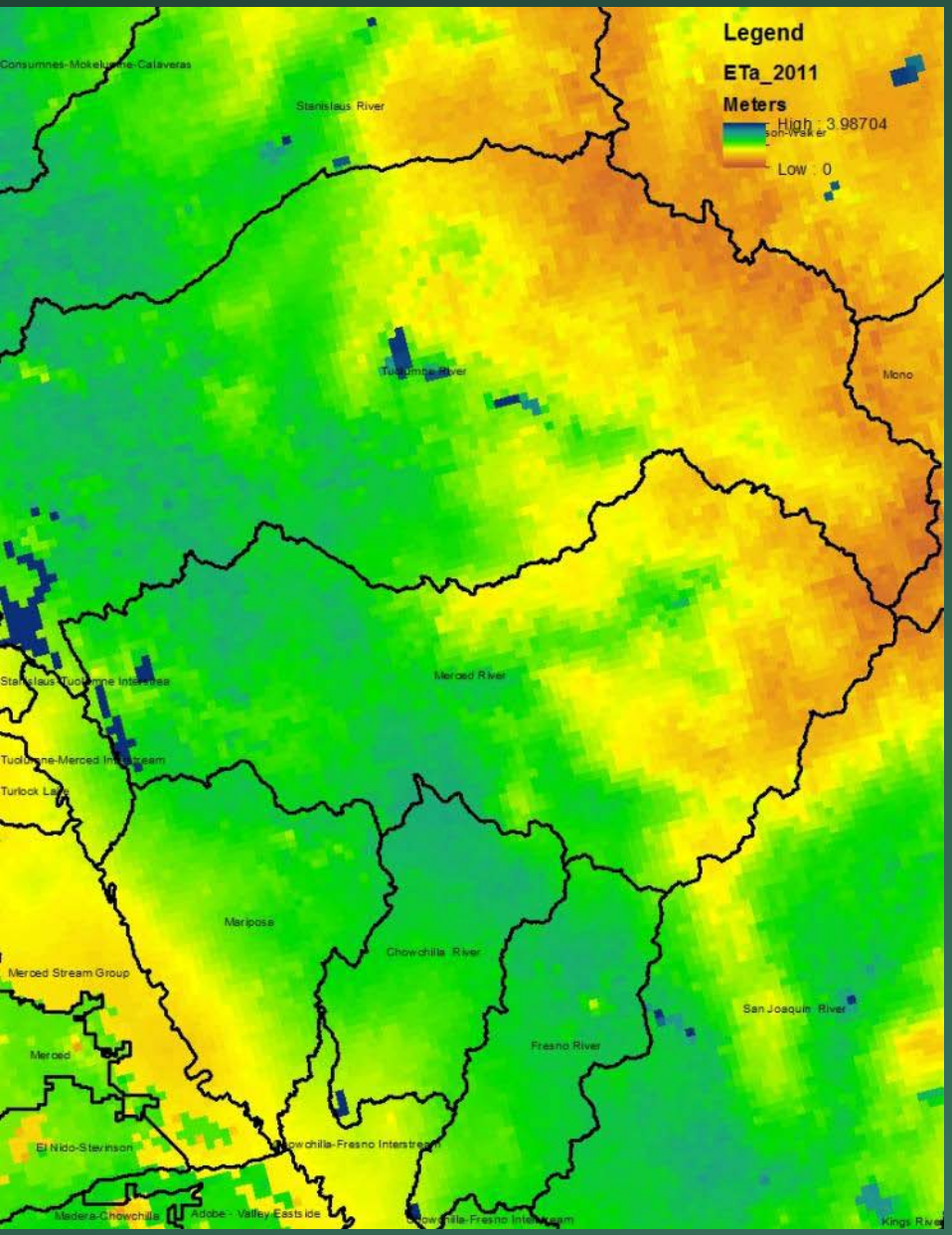
NDVI and flux measurements

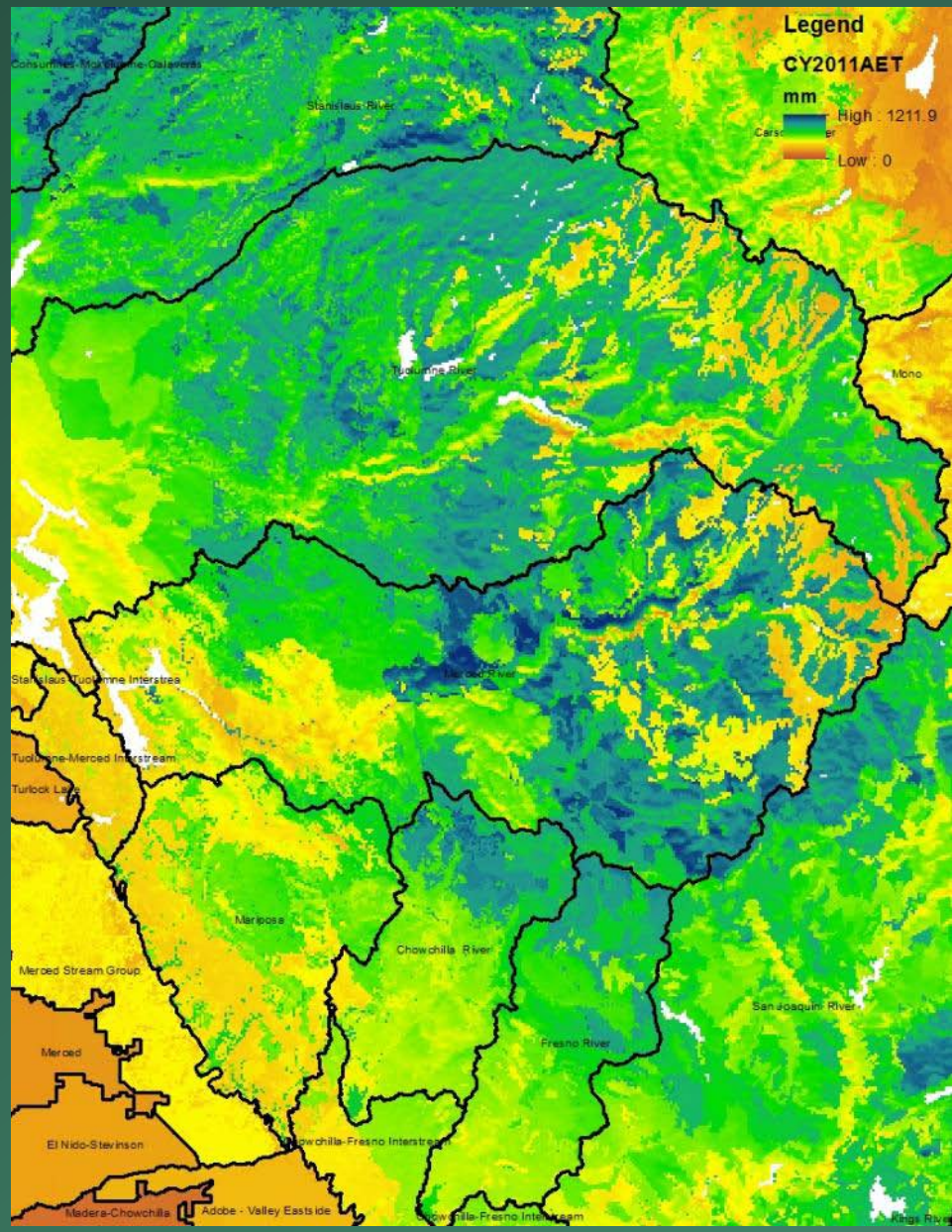


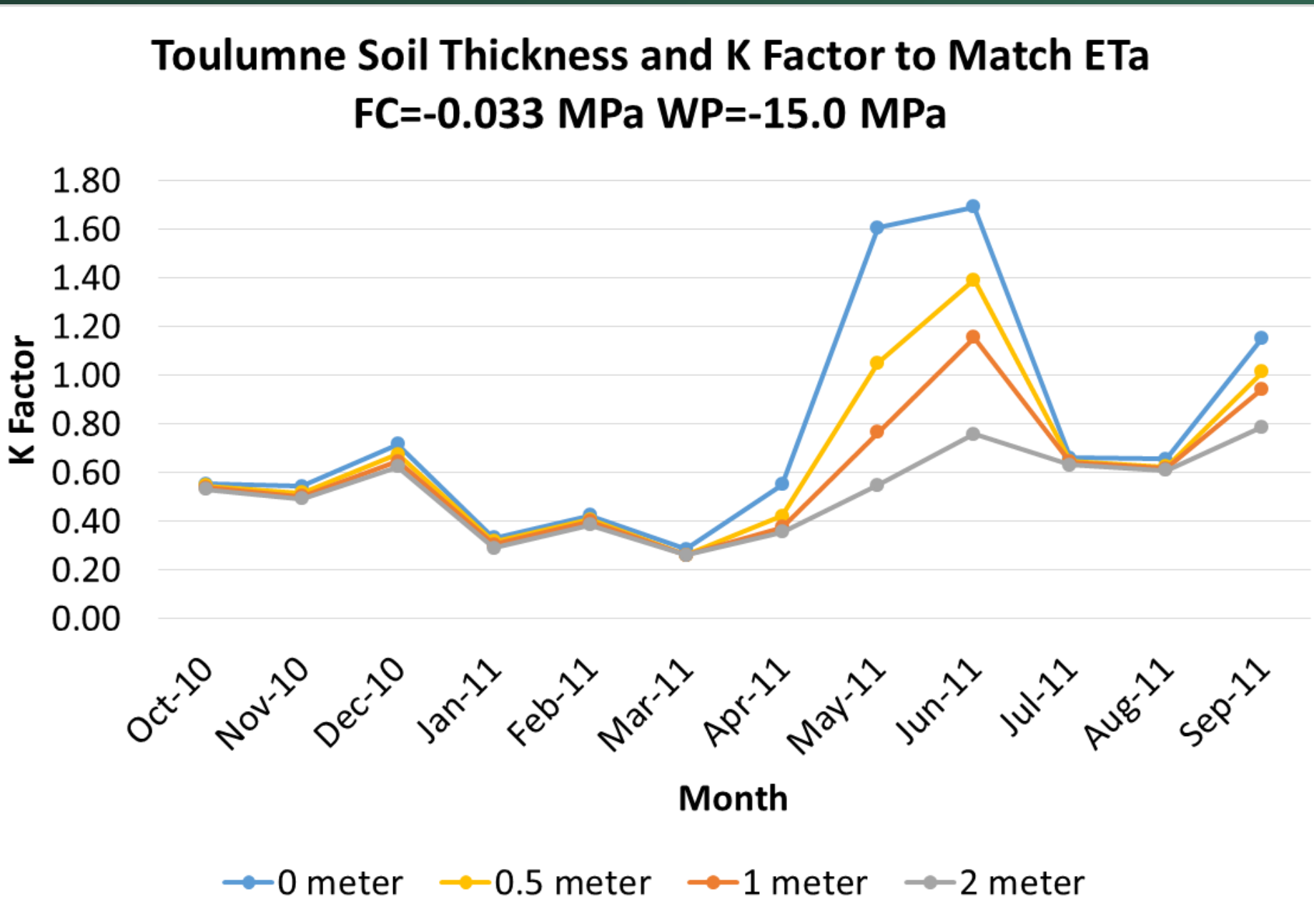
BCM SSURGO properties from texture

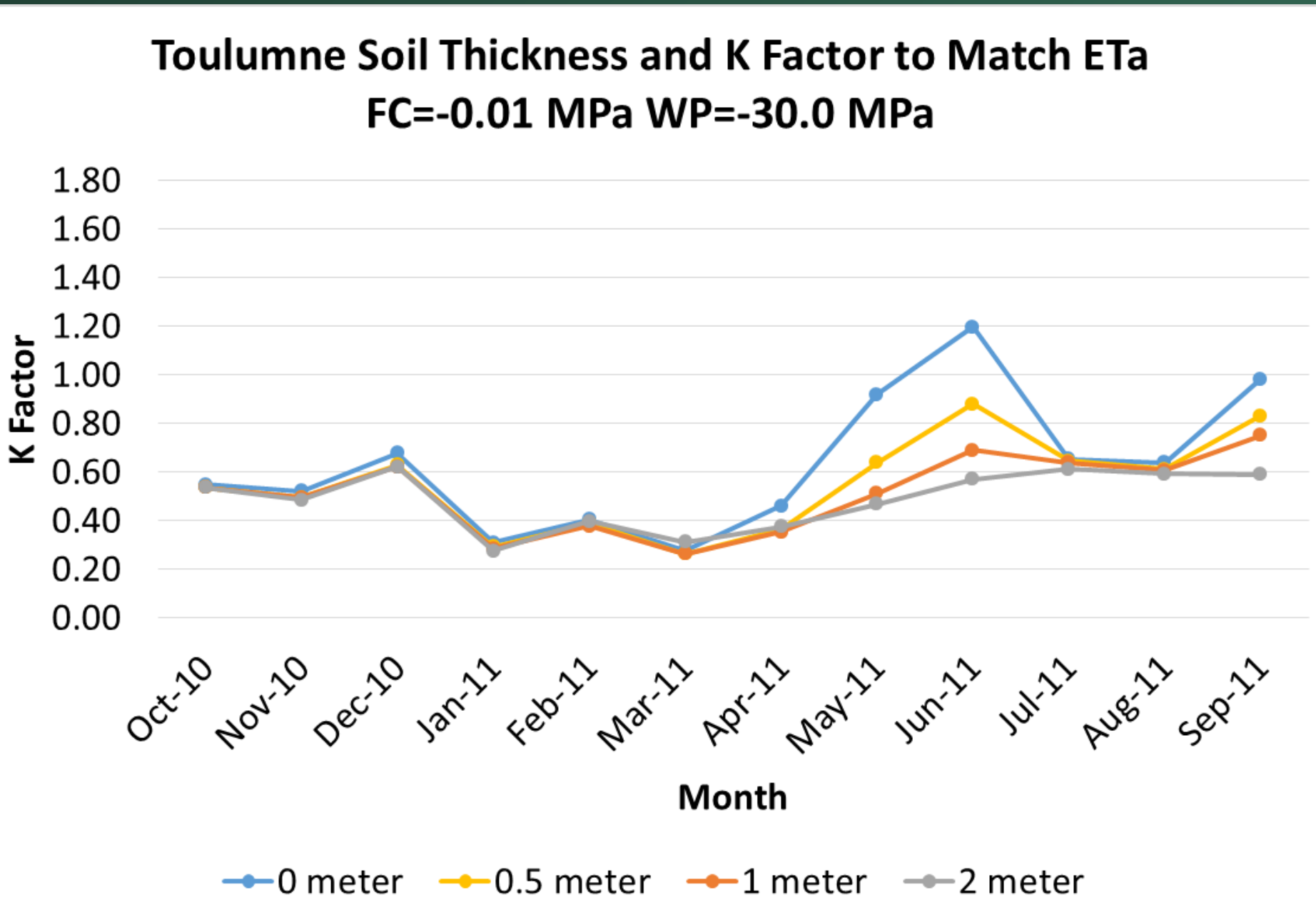


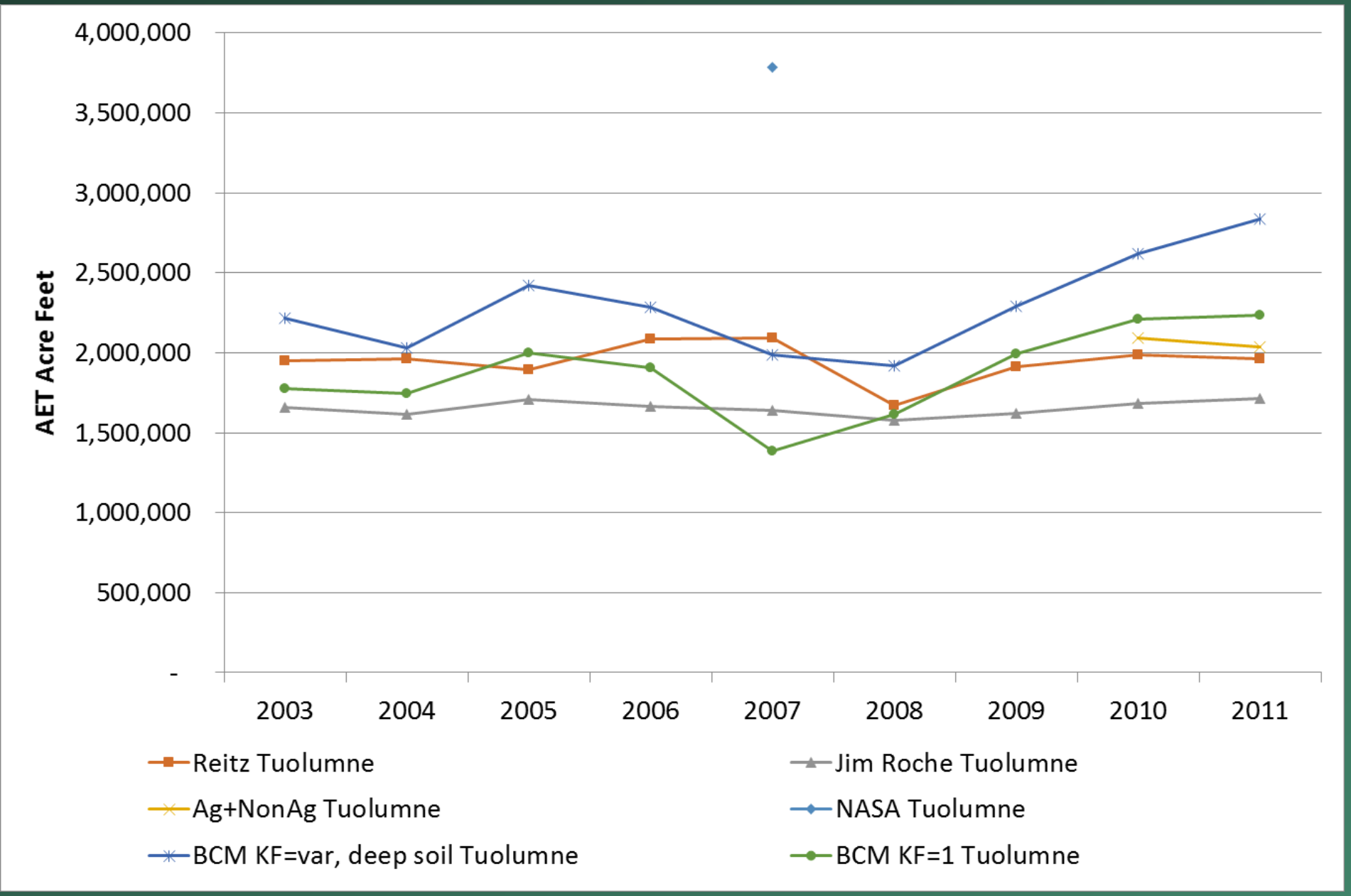


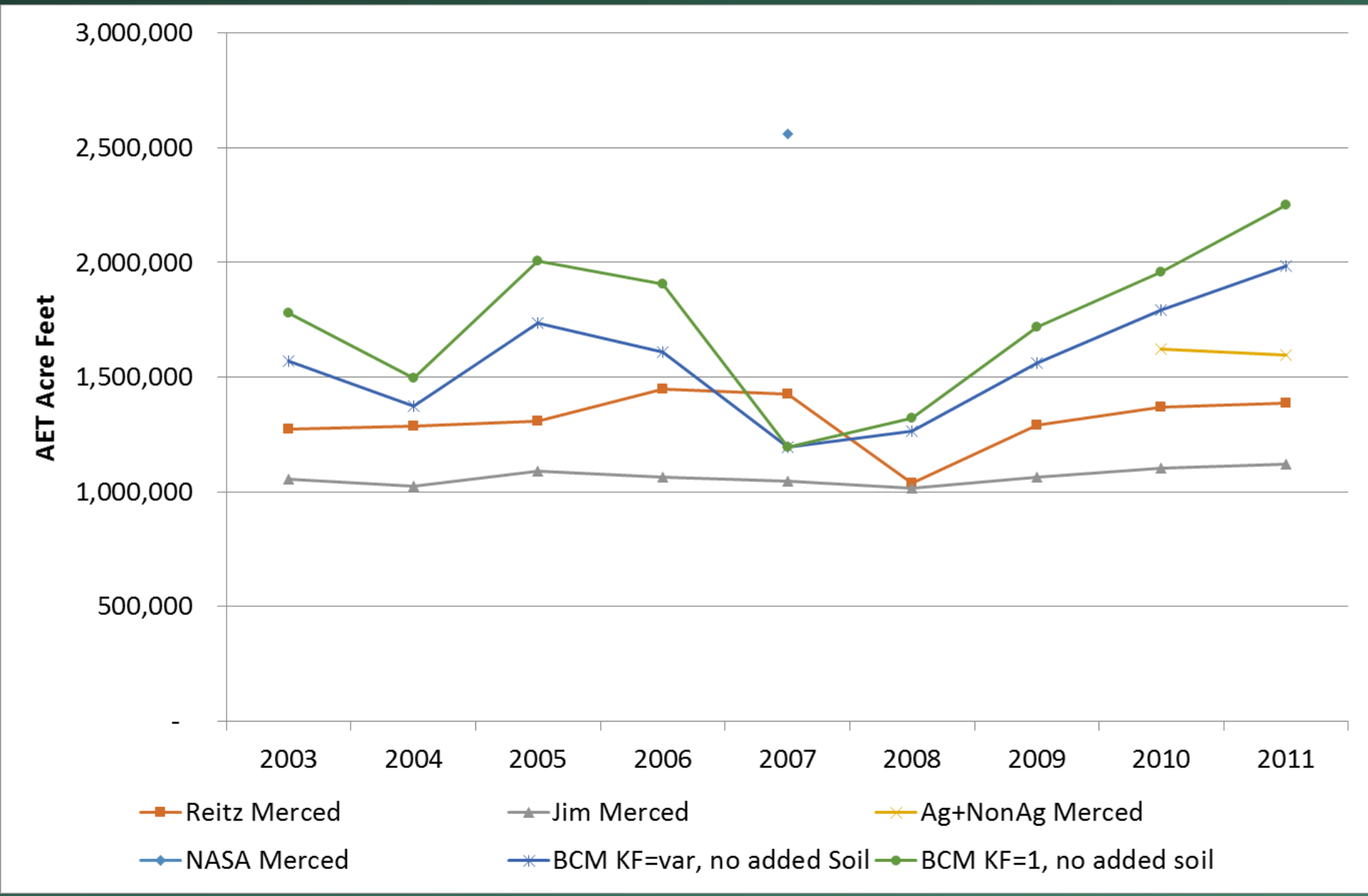

Legend
ETa_2011
Meters
High : 3.98704
Low : 0
Consumnes-Mokelumne-Calaveras
Stanislaus River
Tuolumne River
Mono
Merced River
Stanislaus-Tuolumne Interstrea
Tuolumne-Merced Interstream
Turlock Lake
Mariposa
Chowchilla River
Merced Stream Group
San Joaquin River
Fresno River
Merced
El Nido-Stevinson
Chowchilla-Fresno Interstream
Madera-Chowchilla
Adobe - Valley Eastside
Kings River


Legend
CY2011AET
mm
High : 1211.9
Low : 0
Consumnes-Mokelumne-Calaveras
Stanislaus River
Tuolumne River
Mono
Stanislaus-Tuolumne Interstrea
Tuolumne-Merced Interstream
Turlock Lake
Mariposa
Chowchilla River
Merced Stream Group
San Joaquin River
Fresno River
Merced
El Nido-Stevinson
Chowchilla-Fresno Interstream
Madera-Chowchilla
Adobe - Valley Eastside
Kings River

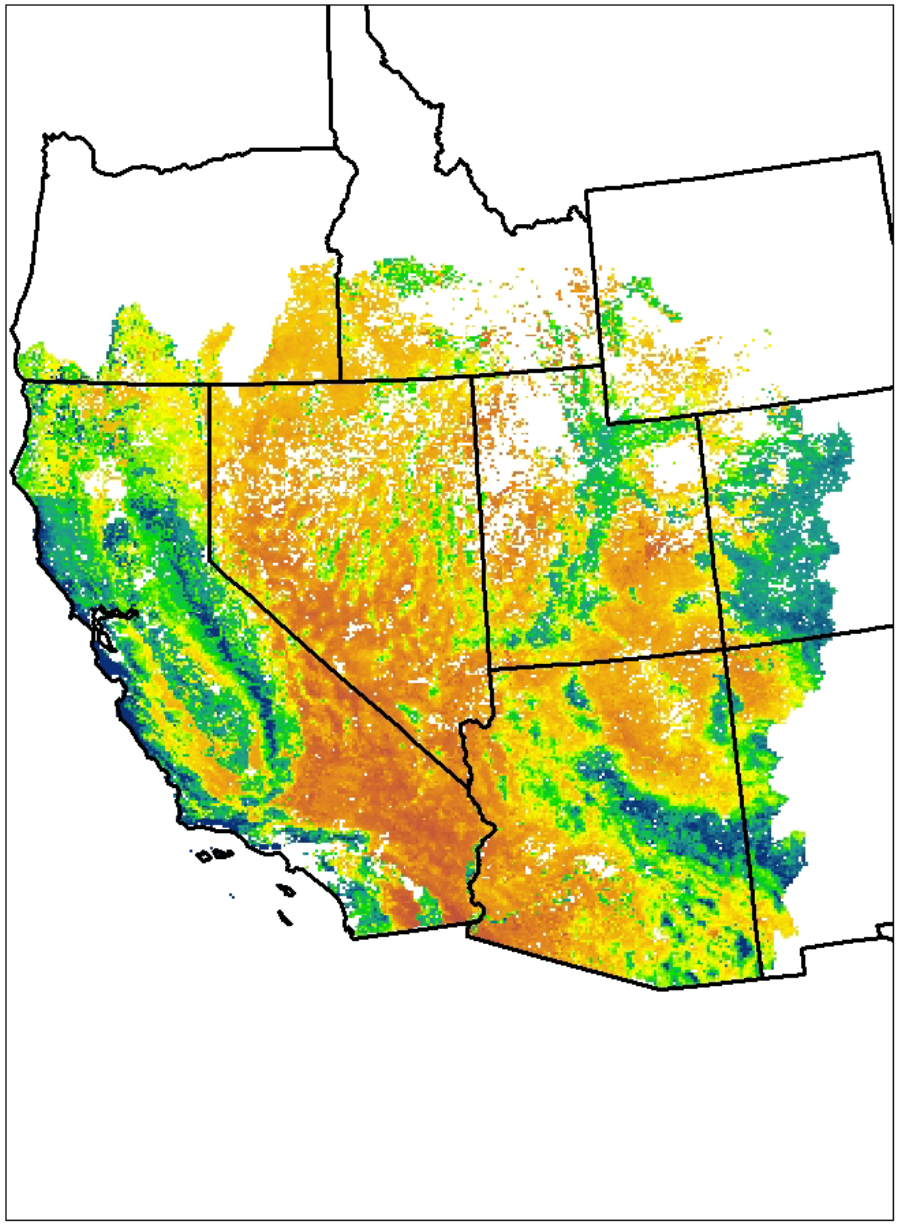

Toulumne Soil Thickness and K Factor to Match ETa
FC=-0.033 MPa WP=-15.0 MPa
K Factor
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Month
0 meter
0.5 meter
1 meter
2 meter


Toulumne Soil Thickness and K Factor to Match ETa
FC=-0.01 MPa WP=-30.0 MPa
K Factor
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Month
0 meter
0.5 meter
1 meter
2 meter

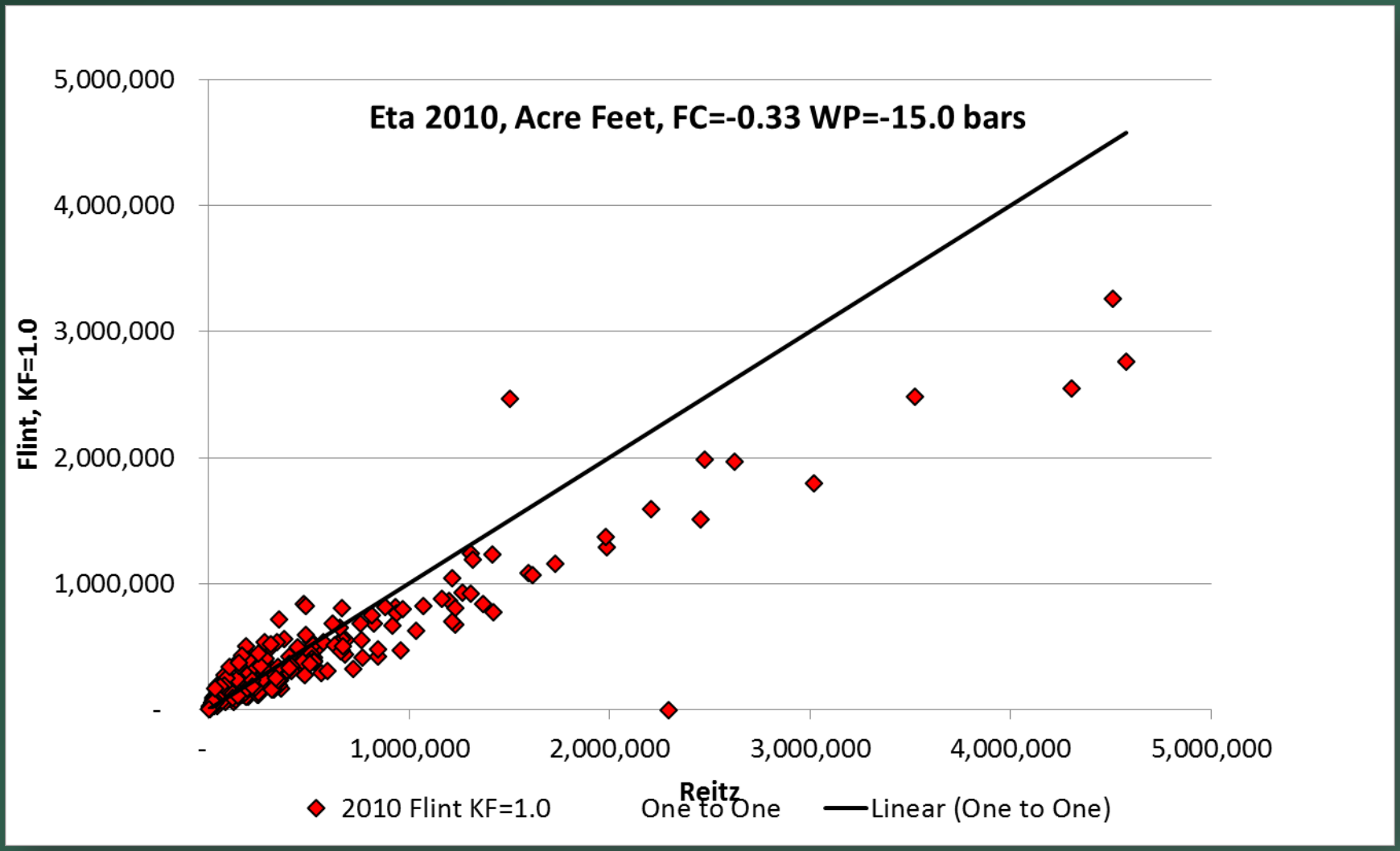

4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-
AET Acre Feet
2003
2004
2005
2006
2007
2008
2009
2010
2011
Reitz Tuolumne
Jim Roche Tuolumne
Ag+NonAg Tuolumne
NASA Tuolumne
BCM KF=var, deep soil Tuolumne
BCM KF=1 Tuolumne


3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-
AET Acre Feet
2003
2004
2005
2006
2007
2008
2009
2010
2011
Reitz Merced
Jim Merced
Ag+NonAg Merced
NASA Merced
BCM KF=var, no added Soil
BCM KF=1, no added soil

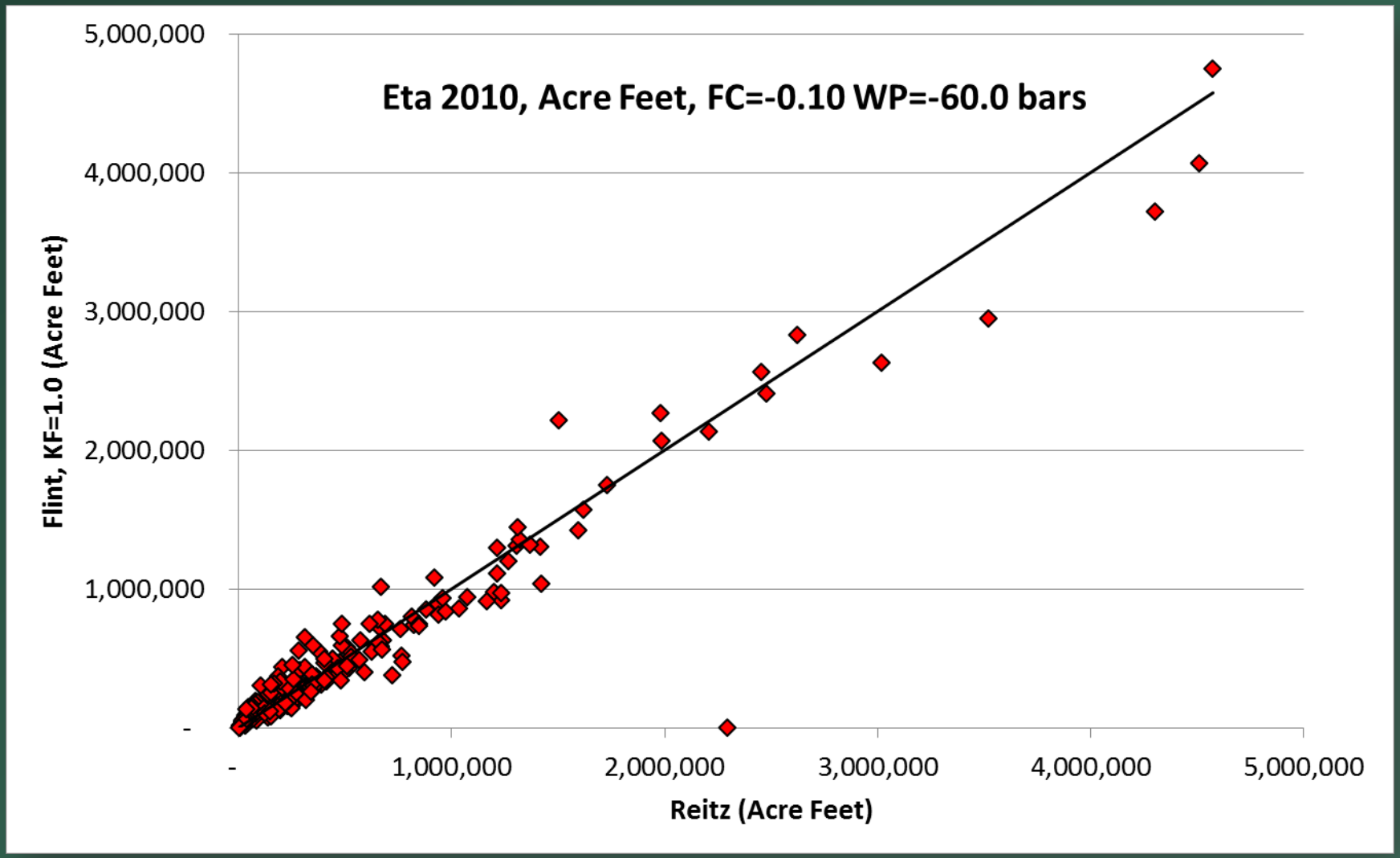
NASA ETA, 2007



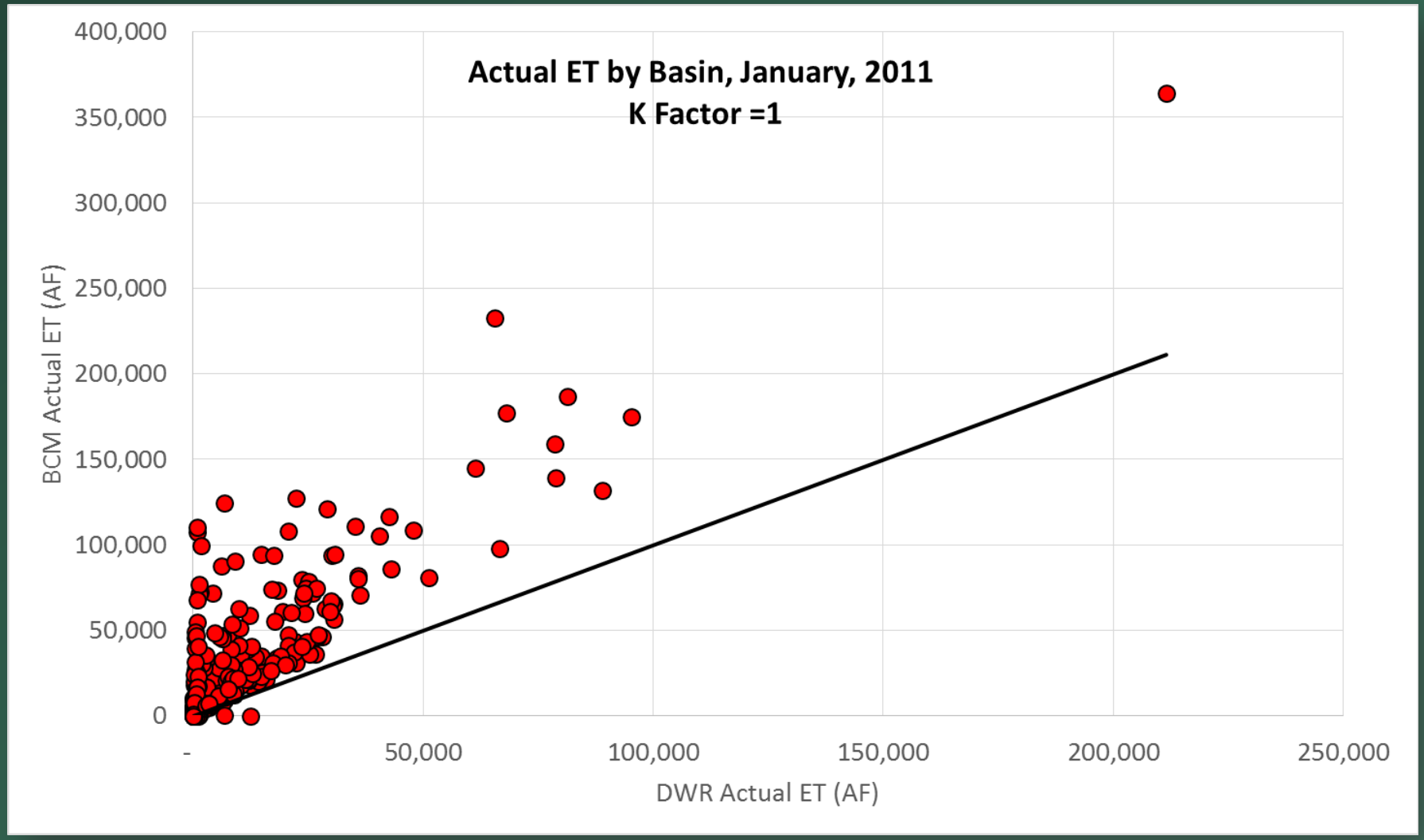
Matching Annual Estimates of Actual ET



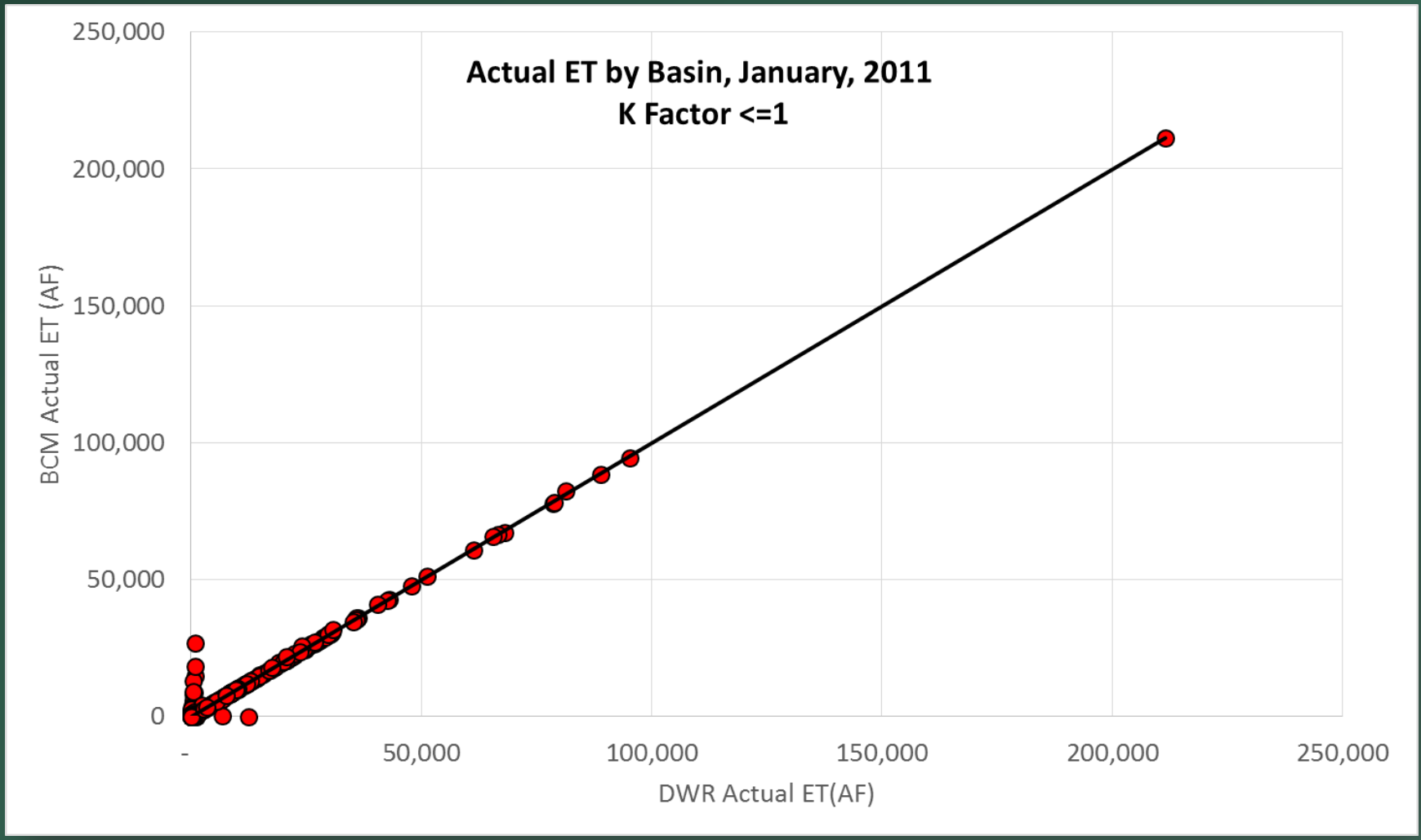
Matching Annual Estimates of Actual ET

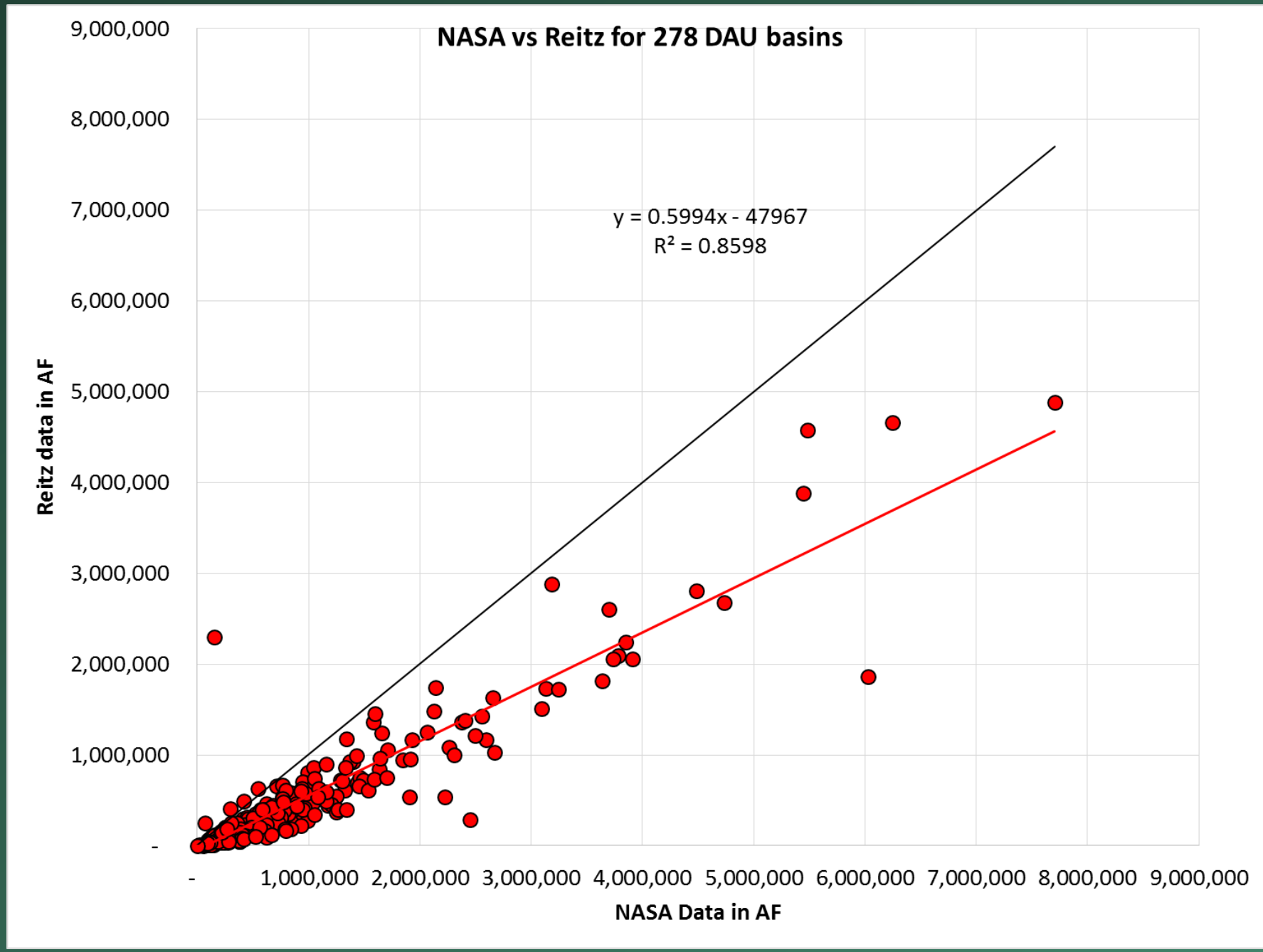


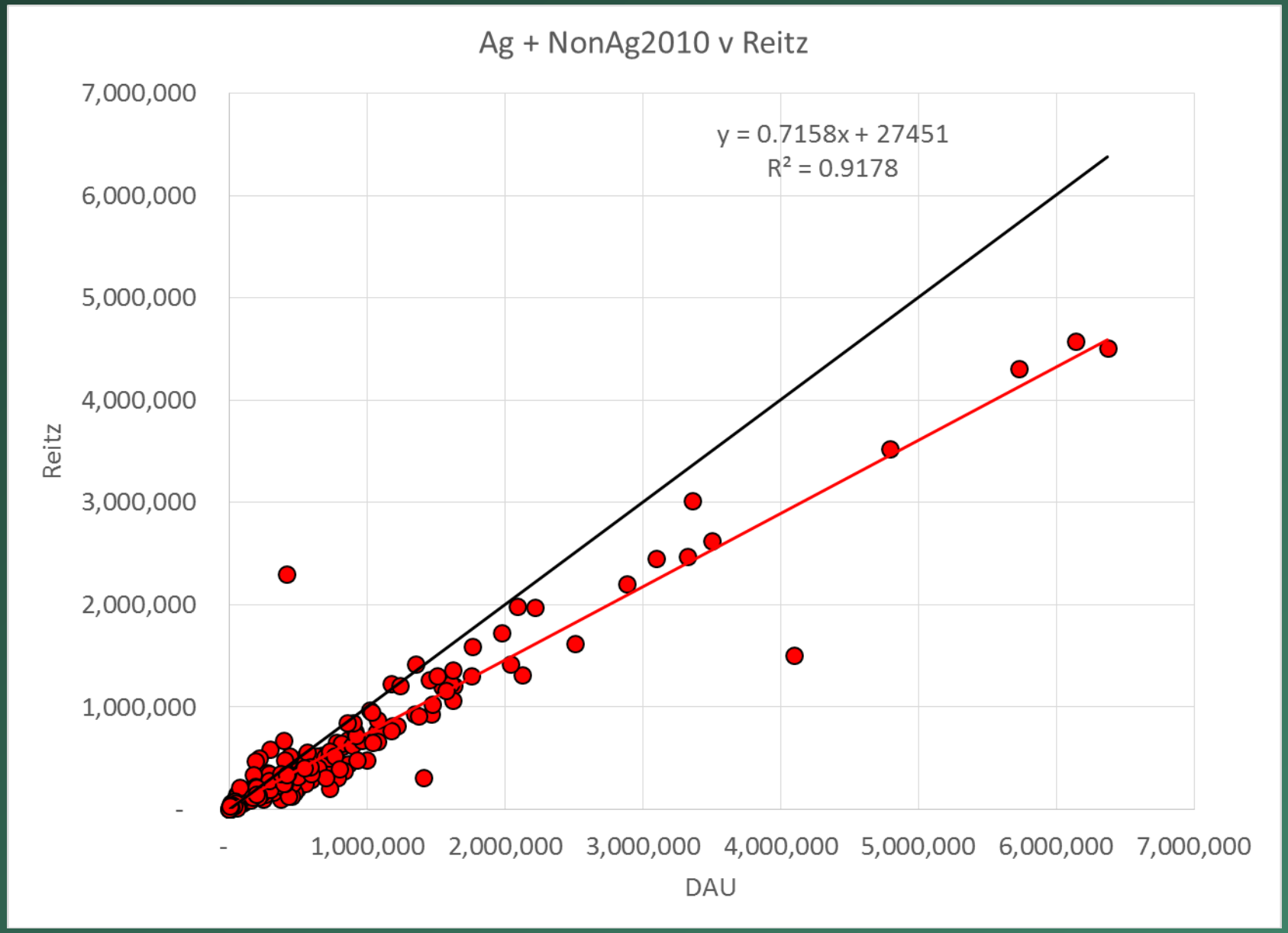
Allowing Actual ET to Equal PET



Limit Actual ET using variable K Factor <=1




NASA vs Reitz for 278 DAU basins
y = 0.5994x - 47967
R² = 0.8598
Reitz data in AF
NASA Data in AF
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
-
1,000,000
2,000,000
3,000,000
4,000,000
5,000,000
6,000,000
7,000,000
8,000,000
9,000,000


Ag + NonAg2010 v Reitz
y = 0.7158x + 27451
R² = 0.9178
Reitz
DAU
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
-
1,000,000
2,000,000
3,000,000
4,000,000
5,000,000
6,000,000
7,000,000

Ongoing Refinements

- Incorporation of species' specific monthly evapotranspiration
  - To enable more realistic seasonality
  - To enable the representation of disturbance
- Modeled soil water content at multiple measurement locations statewide
- Recharge comparisons to Modflow model estimates

Summary

- The BCM was developed on the basis of fundamental processes, observations, and physics
- Calibration of the various components are used to improve the estimates of the water balance and recharge
- Mapped soil properties do not represent the rooting zone, they underestimate actual ET and overestimate recharge
- Combining remote sensing and field measurements can help develop actual rooting depth and soil water storage
- Increasing soil water holding capacity improves estimates of actual ET and recharge