Department of
LAND, AIR AND WATER RESOURCES
University of California, Davis
Climate Change • Sustainable Agriculture
Environmental Quality • Landscape Processes

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Feasibility of Agricultural Groundwater Banking and its impact on groundwater storage

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OCTOBER 12, 2017

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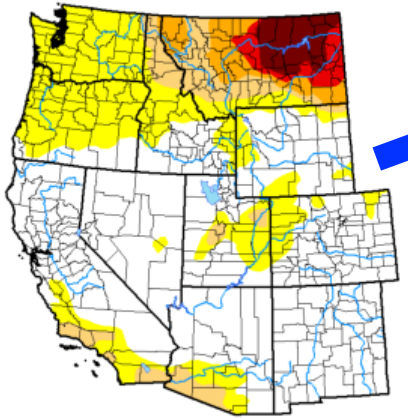
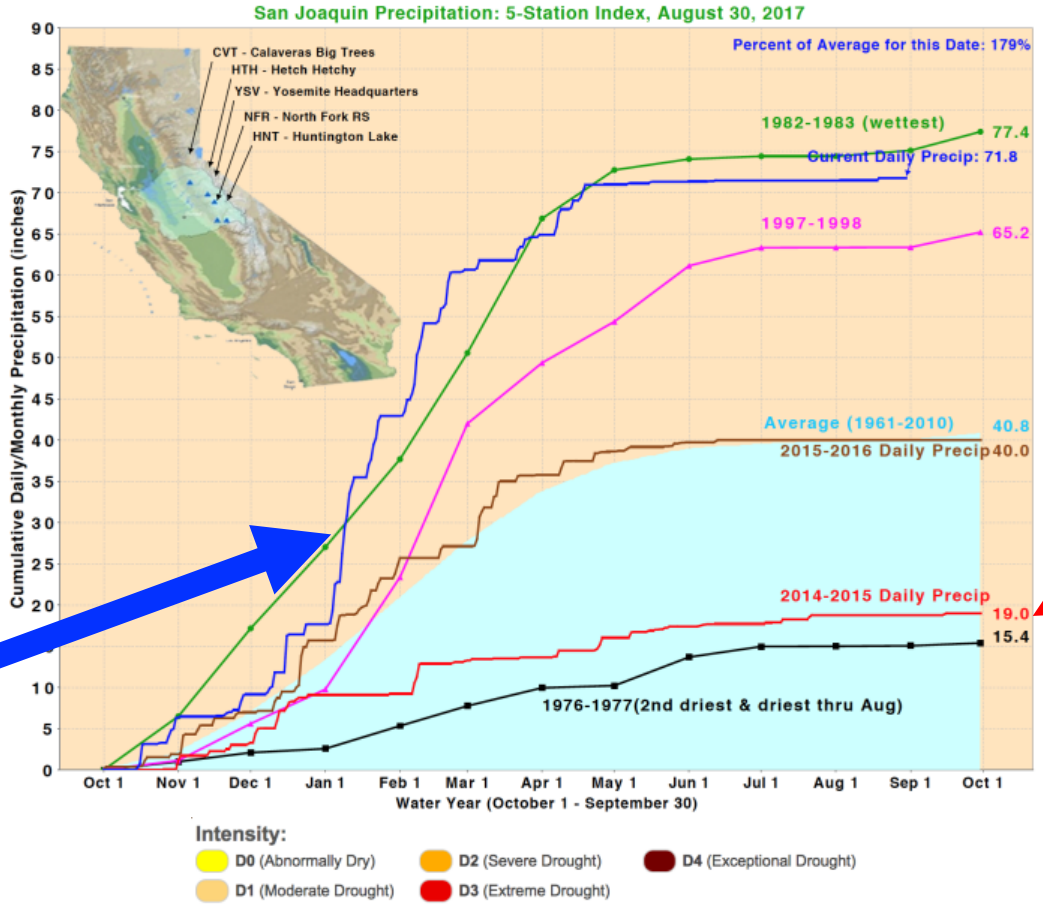
California Extremes

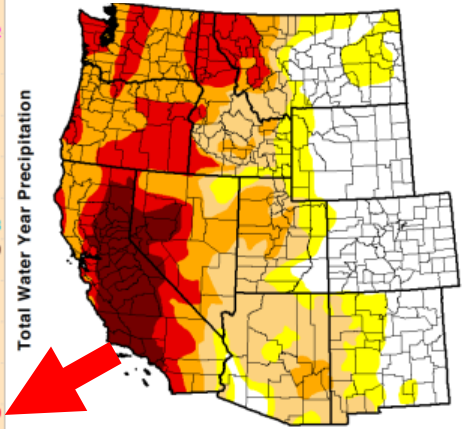
2017 FLOODS





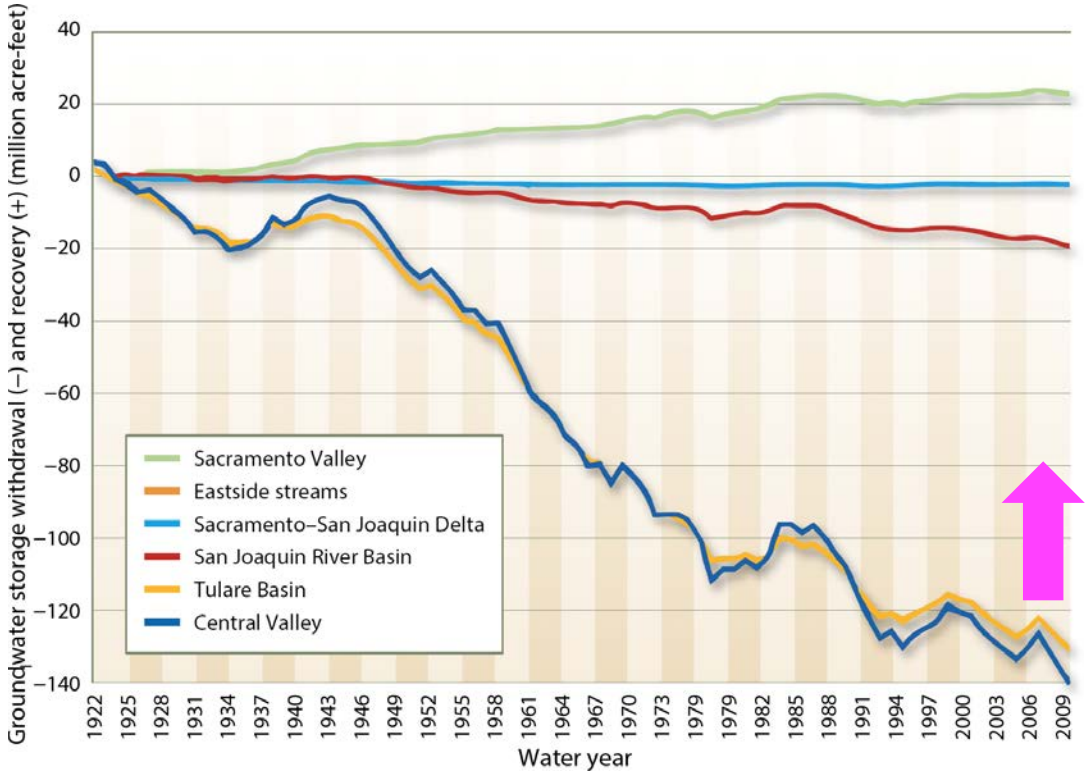
2012-2016 DROUGHT

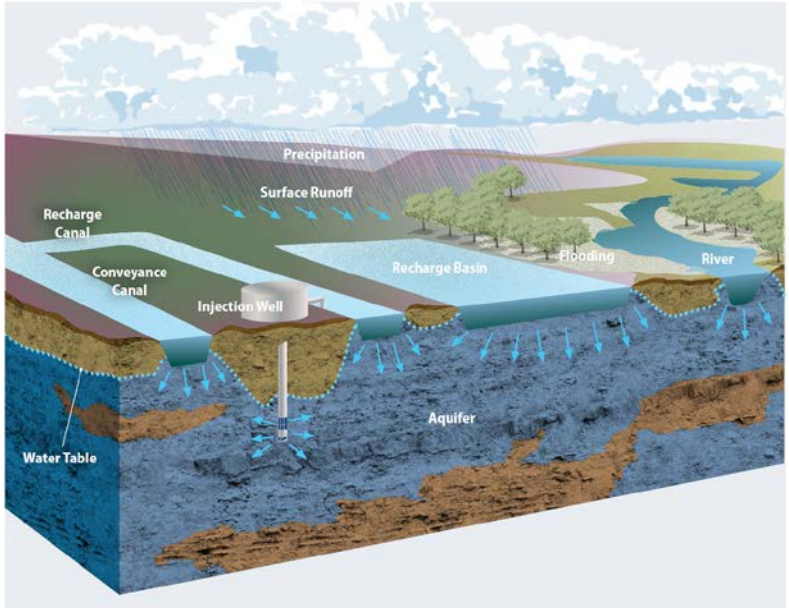
U.S. Drought Monitor
October, 2015



Sources: DWR 2017, temblor.net, droughtmonitor.unl.edu

State of groundwater resources in the Central Valley, California



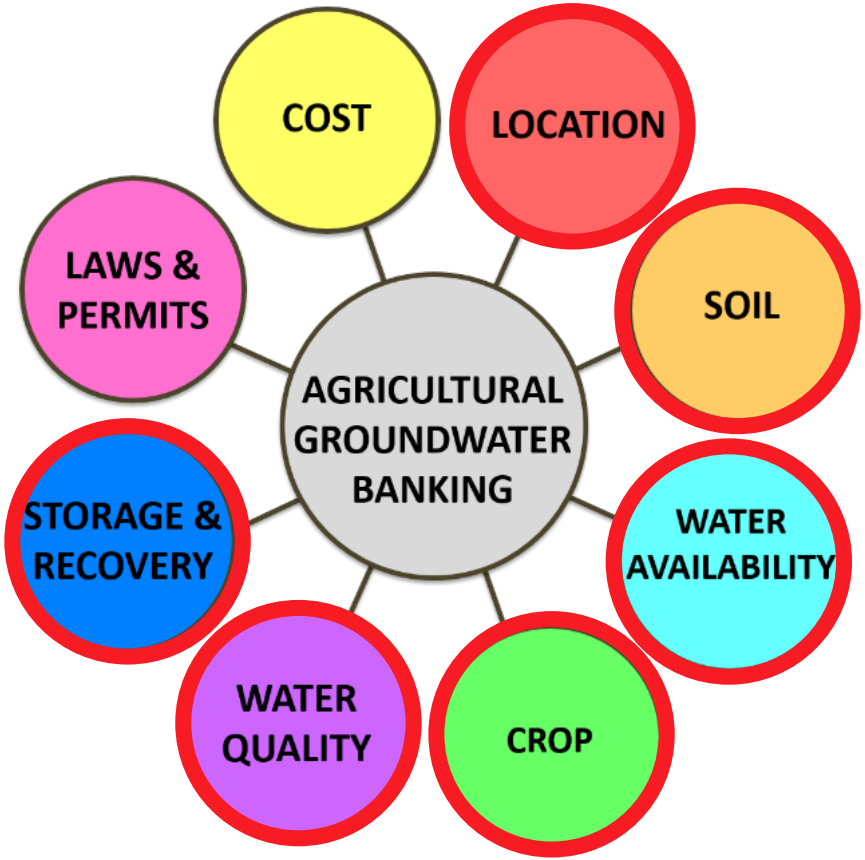


Harter 2015, CalAg

Agricultural Groundwater Banking

- Farmland is flooded during the winter using surface water to recharge the underlying groundwater
- Large spreading areas are needed to capture runoff from the few (6-10) storms that bring rainfall in California
- 8 million acres of farm land that could serve as spreading grounds
- Existing irrigation infrastructure could be used to move water from streams to farmland

Agricultural Groundwater Banking



Flooding Tolerance Studies

Crop Suitability - Alfalfa

- Alfalfa supports $7.6 billion dairy industry
- In 2013 largest acreage crop in CA (~ 1 million acres)
  → high likelihood to find land on suitable soils
- Relatively low use of fertilizers, pesticides
  → low risk for leaching
- Flood irrigation with surface water most common (75%)
  → allows fast spreading of large water amounts
- Conducted flooding experiments in two locations in winter of 2014/15; repeated experiments in Scott Valley in 2015/16

On-Farm recharge experiments - Alfalfa

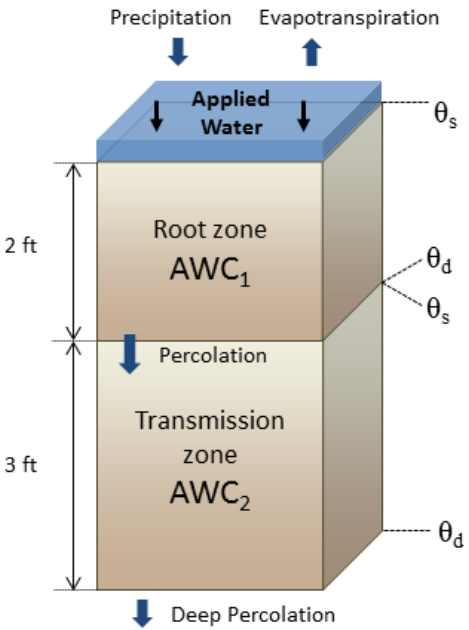
Scott Valley, Siskiyou County, 15 acre field

- Three winter water application rates:
  - ***Continuous*** – every day
  - ***High*** – 3-5 water applications per week
  - ***Low*** – 1-3 water applications per week
  - **Standard** - no winter water application

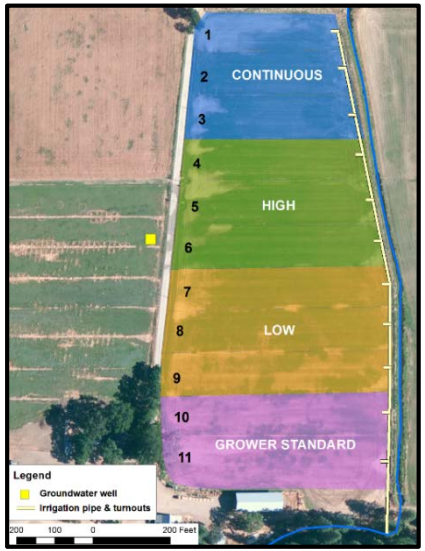
- Use Thornthwaite-Mather soil water balance model to estimate deep percolation and losses to evapotranspiration and soil storage

- Use 1D van Genuchten-Mualem model to estimate recharge into deeper soil

Soil water balance model



AWC = available water content



Water Boards

Media Release

State Water Board Issues its First Temporary Groundwater Storage Permit to Capture Rain Season High Flows

FOR IMMEDIATE RELEASE
Jan. 15, 2016

Contact: Miryam Barajas
miryam.barajas@waterboards.ca.gov

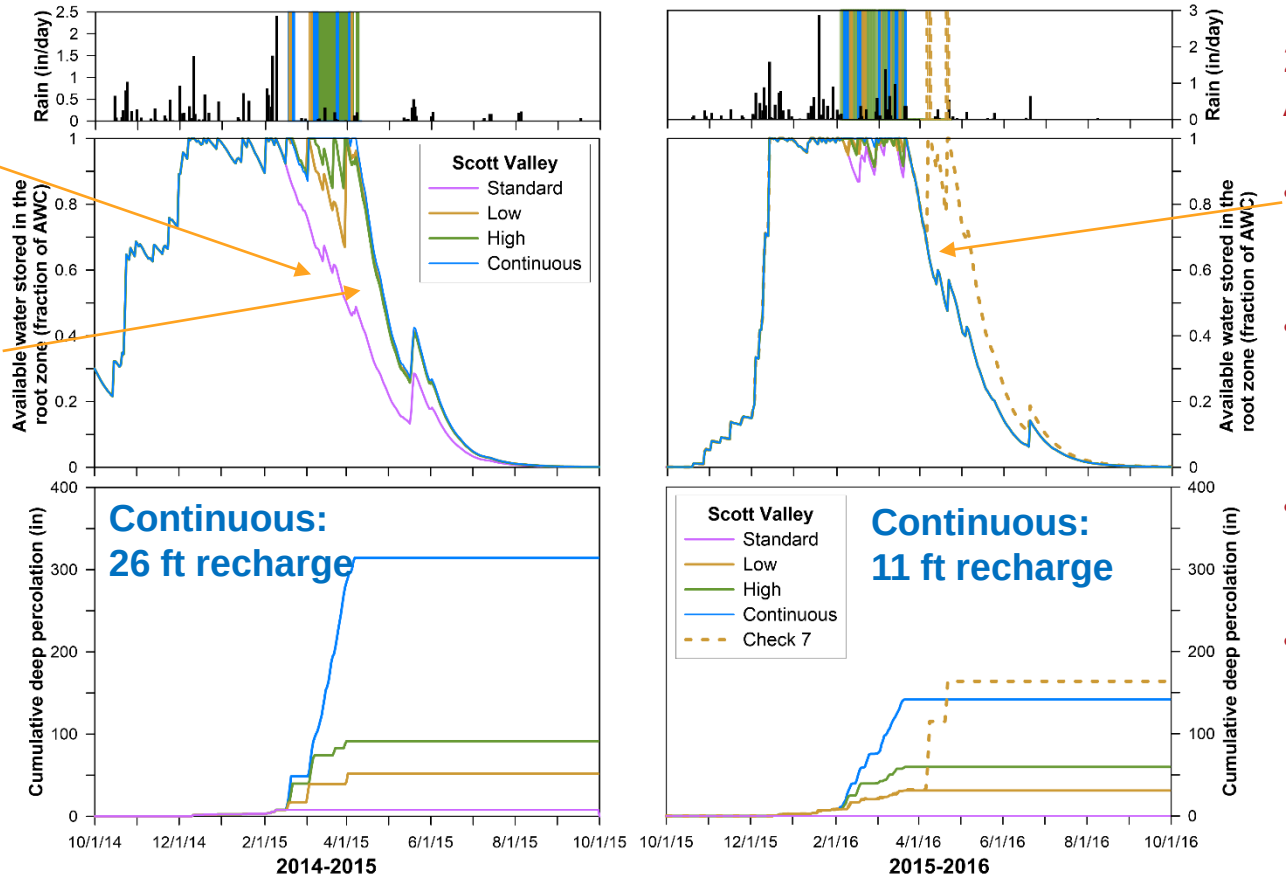
SACRAMENTO – Today the State Water Resources Control Board (State Water Board) issued its first temporary groundwater storage permit to the Scott Valley Irrigation District to capture high winter and spring flows for local groundwater storage and recharge. The permit is the first in what is expected to be a series of temporary permits issued for this type of water diversion and use.

Dahlke et al. 2017, CalAg

On-Farm recharge experiments - Alfalfa

2014/15 dry year:

- Early dry-out in standard plot
- Recharge increases plant available water
- Loss to ET, soil storage is 1-7%
- Total recharge was 135 AF



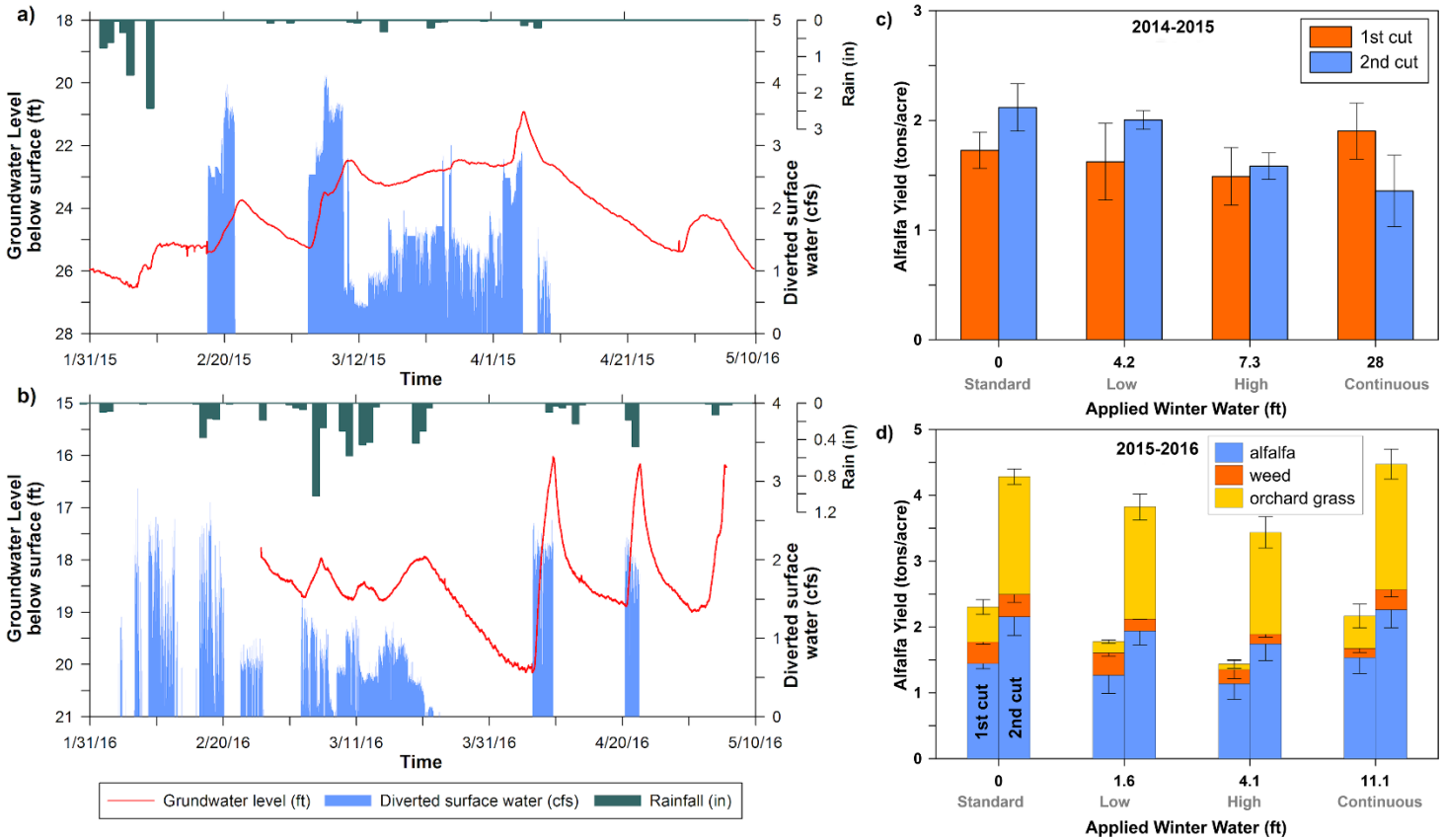
2015/16
Above normal year:

- Late dry-out
- No benefit for plant available water
- Loss to ET soil storage is 1-2%
- Total recharge was 107 AF

Dahlke et al. 2017, CalAg

On-Farm recharge experiments - Alfalfa

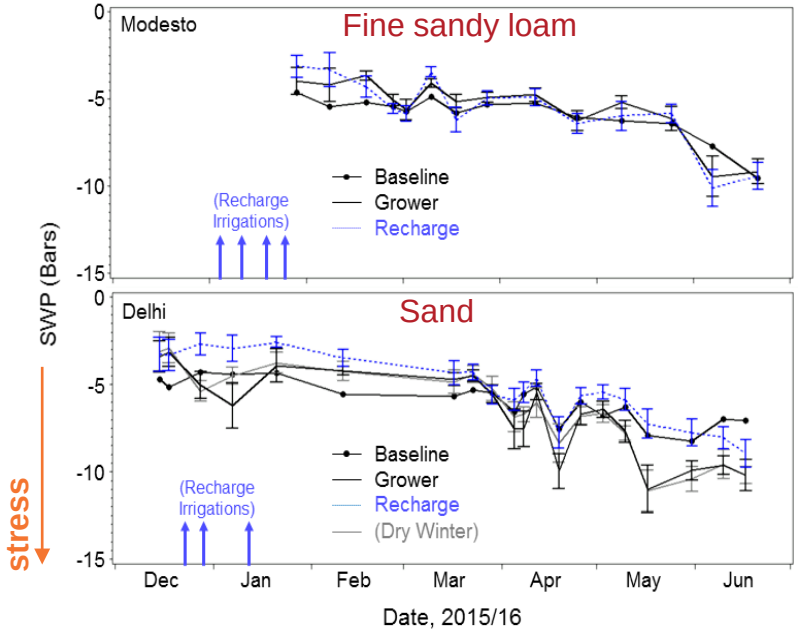
- Water table rose up to 6 ft in response to winter recharge
- Application of up to 26 ft of water caused no discernible difference in alfalfa yield

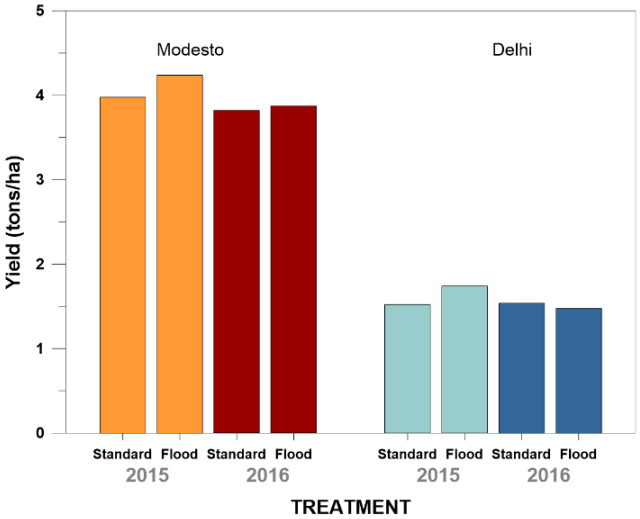


Dahlke et al. 2017, CalAg

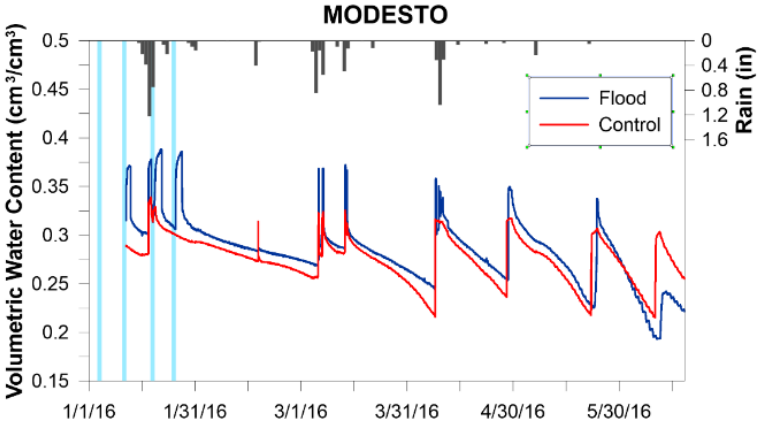
Crop Suitability - Almonds

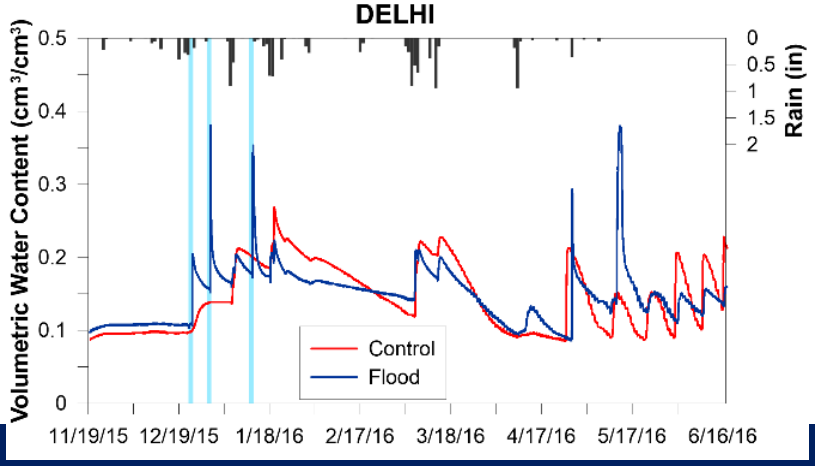
- Tree stem water potential (SWP) indicates that trees in the flood treatment remained more hydrated than the control trees
- There were no statistically significant differences in yield (Nonpareil almond variety)



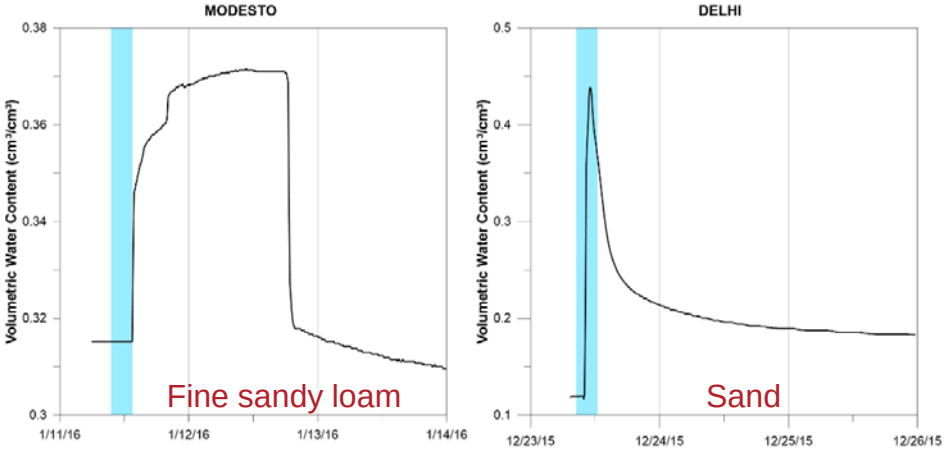


Crop Suitability - Almonds

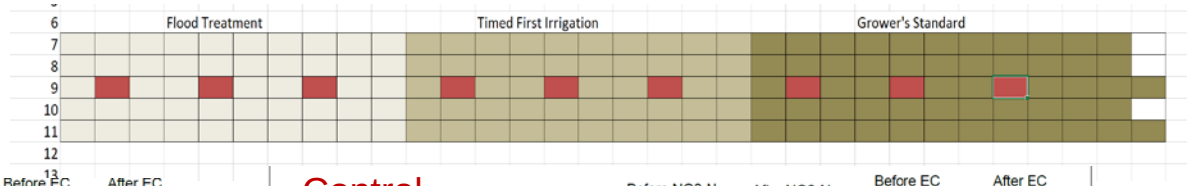




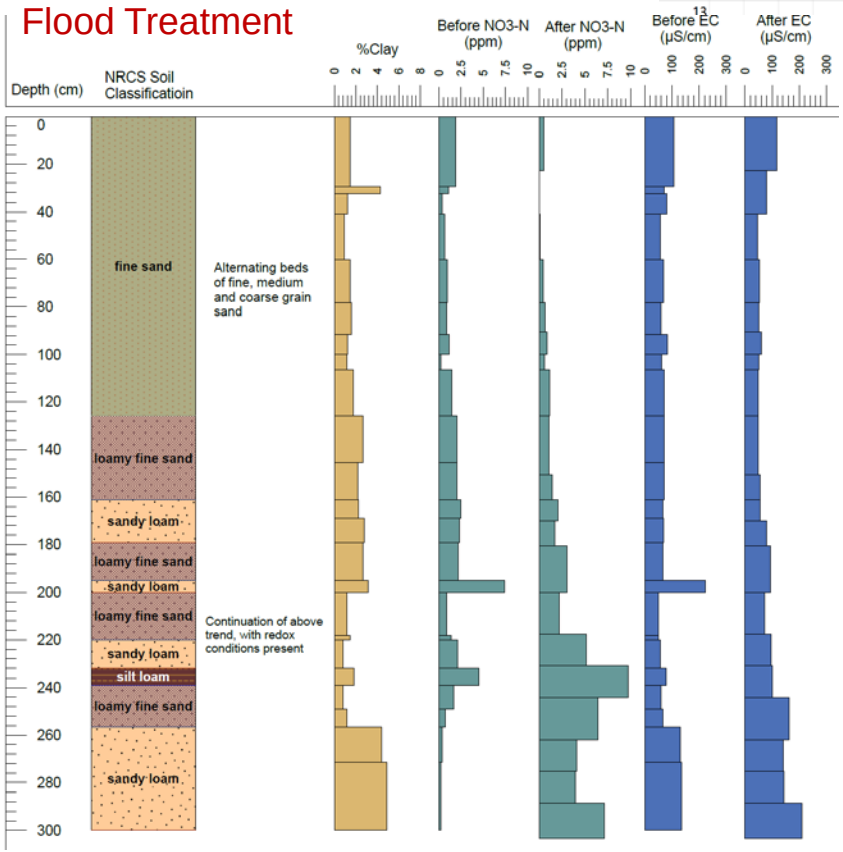
- Application of 60 cm (2 ft) of water in Dec.-Jan.
- Root zone remained saturated up to 48 hr after recharge events



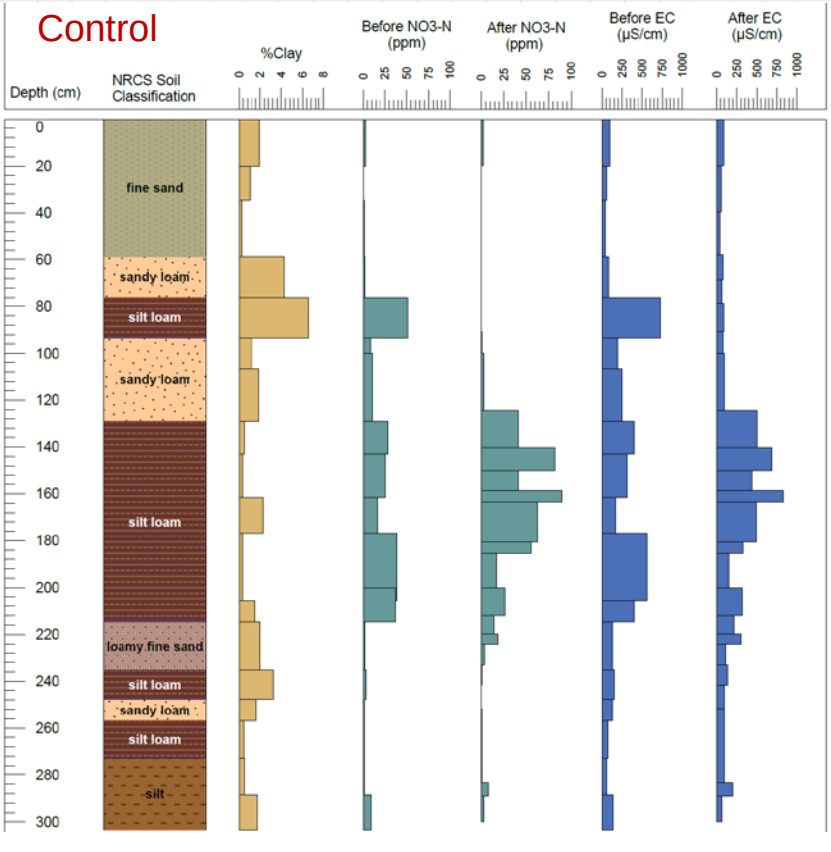
Crop Suitability - Almonds



Flood Treatment



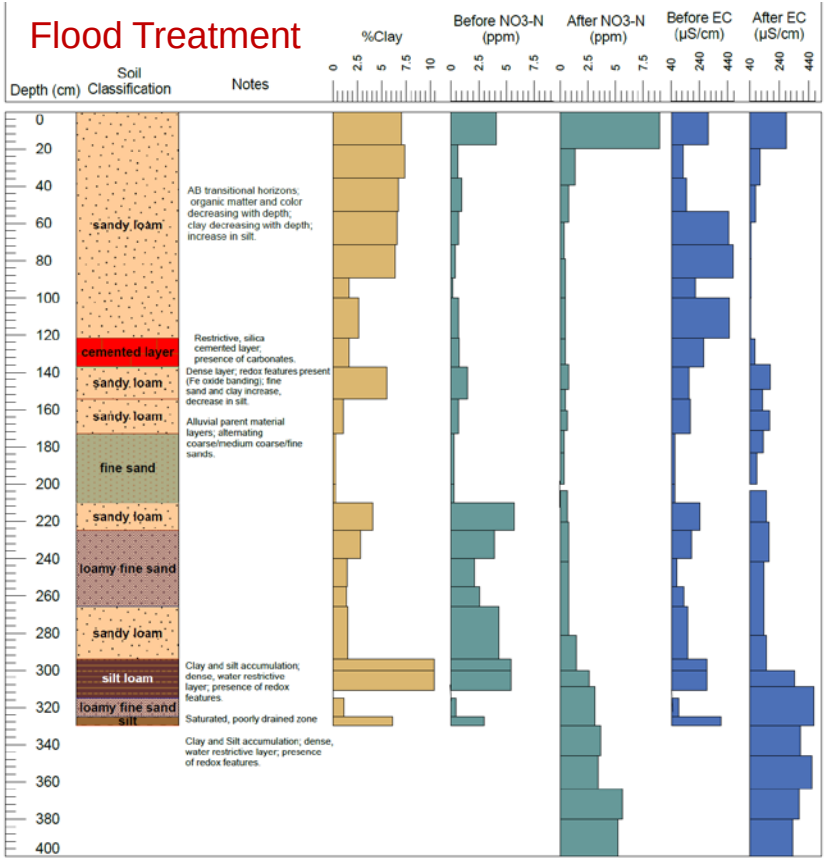
Control

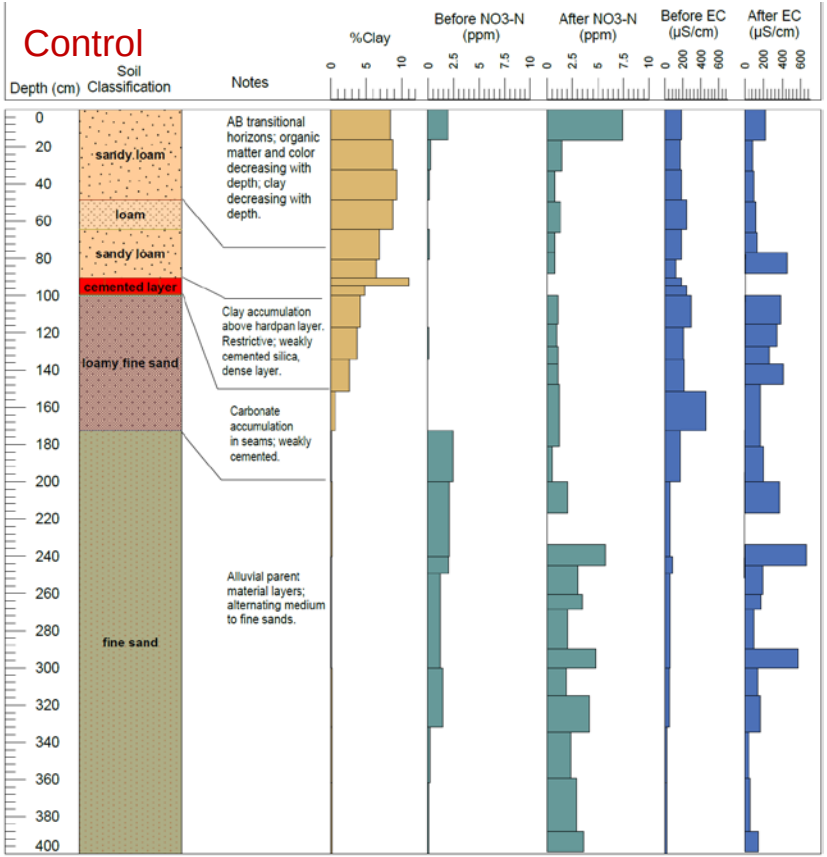


$$NO_3^- = NO_3^-\text{-}N*4.43$$

Delhi site

Crop Suitability - Almonds





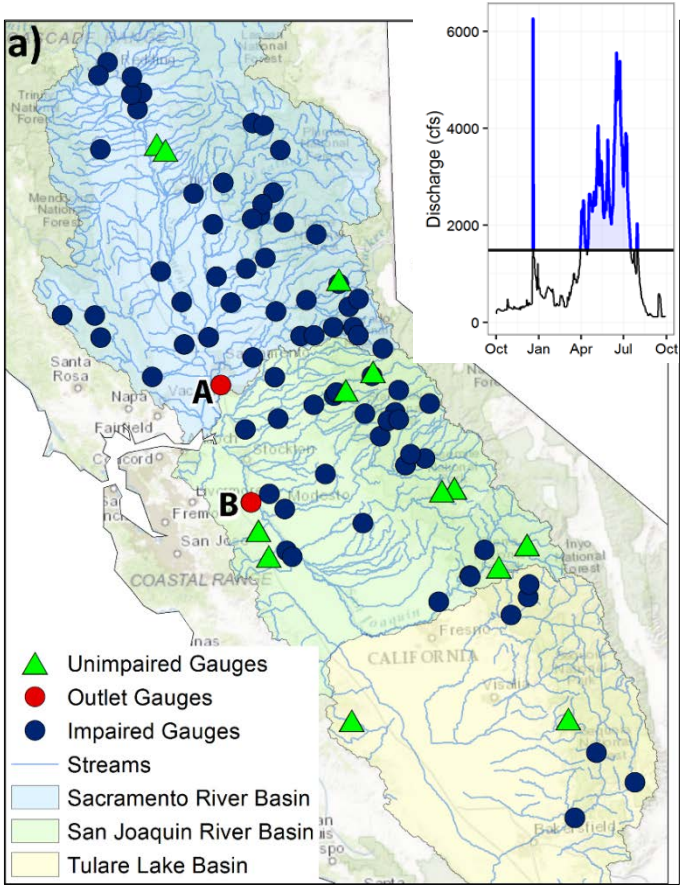
$NO_3^- = NO_3^-\text{-}N*4.43$

Modesto site

Surface Water Availability for Recharge

High-magnitude streamflow assessment for groundwater recharge

- Historical daily streamflow records for 93 stream gauges (13 unimpaired, 80 impaired)
- 90th percentile used to designate high-magnitude flows (HMF), determined from full historical record
- Metrics: magnitude, duration, frequency and timing
- Analysis is conducted for:
  - different time periods (annual, Nov – Apr, Dec – Feb)
  - record lengths (Sac Valley: 1970 – 2014, San Joaquin Valley: 1989 – 2014)



Kocis and Dahlke, 2017, ERL

Metrics for Time Series Analysis

Magnitude:

- Volume of flow above the 90th percentile

Duration:

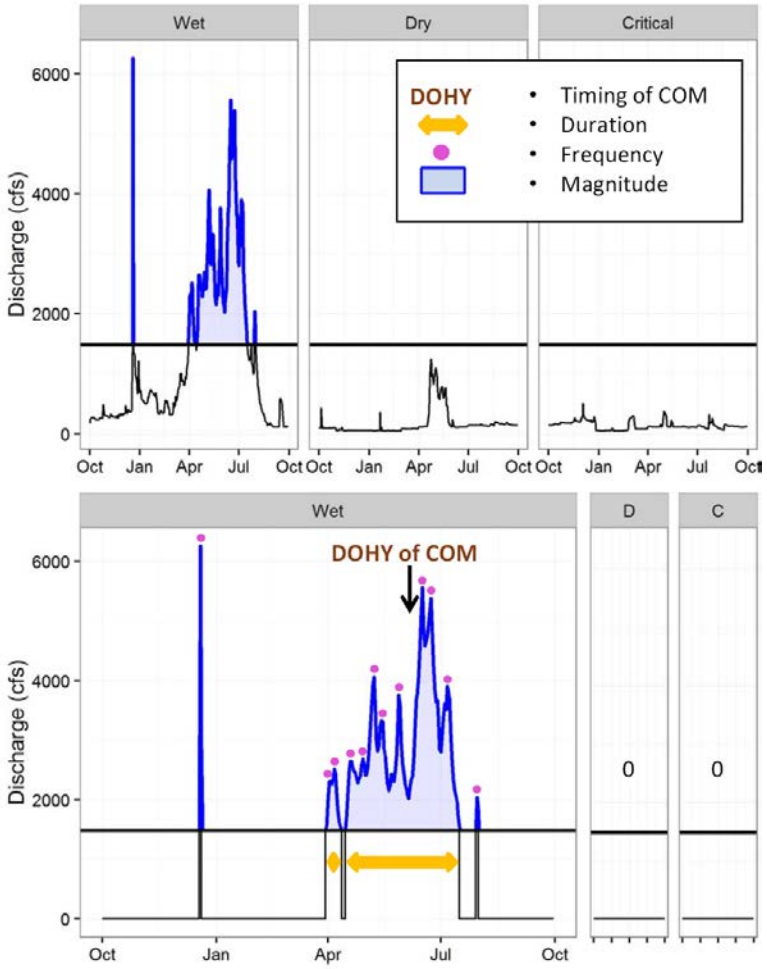
- Number of days above the 90th percentile per time period

Frequency:

- Number of peaks above the 90th percentile within period (intra-annual)
- Number of years with flow above the 90th percentile (inter-annual)

Timing:

- Day of Hydrologic Year (DOHY) that peak event occurs



Kocis and Dahlke, ERL, submitted

High-magnitude flows for groundwater recharge

Average total flow above 90th percentile

Outlet	Dec-Feb	Nov-Apr
Sac Valley	1.15 MAF	1.88 MAF
SJ Valley	0.5 MAF	0.97 MAF

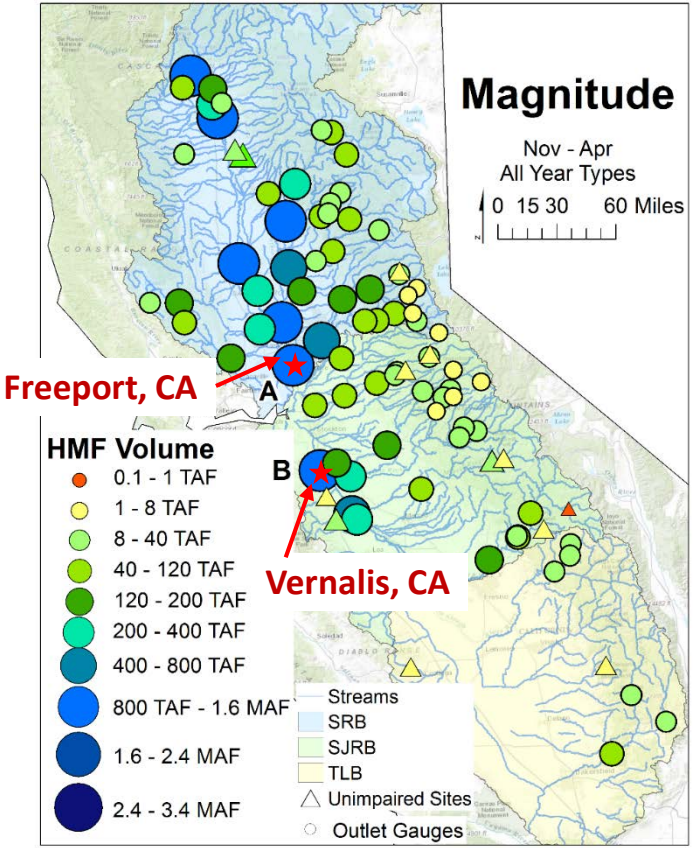
Average flow above 90th percentile during wet years

Outlet	Dec-Feb	Nov-Apr
Sac Valley	1.75 MAF	3.01 MAF
SJ Valley	0.65 MAF	1.21 MAF

- A single, average wet year in the Sacramento Valley can provide two-times the annual groundwater overdraft.

  30% of years are “wet” (post-impairment record)

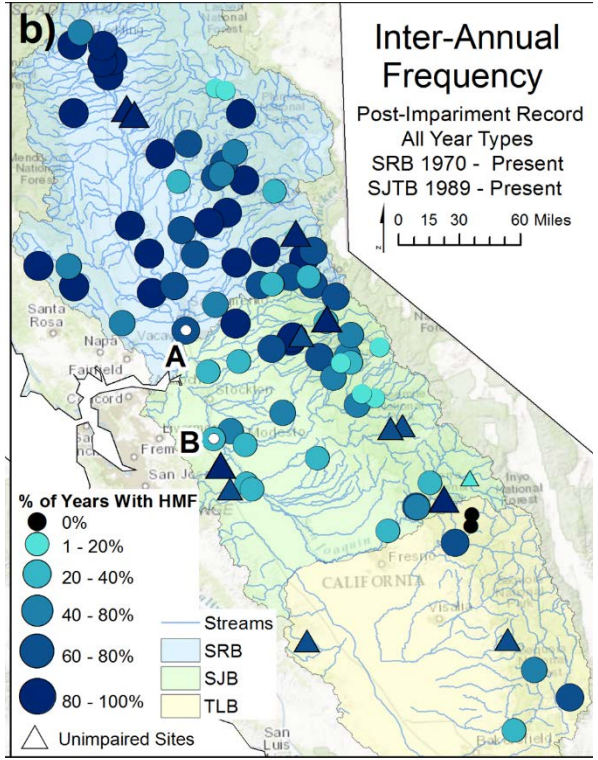
Full Period of Record
Average Volume Above 90th Percentile
November to April, Years with Non-zero Flows



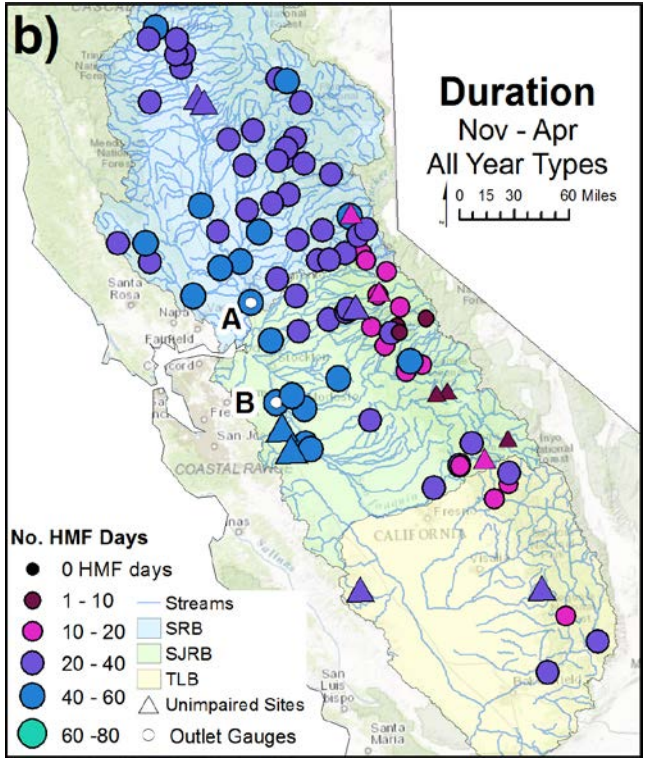
Kocis and Dahlke, 2017, ERL

Caveat – True Availability of High-Magnitude Flows, Timing, Frequency

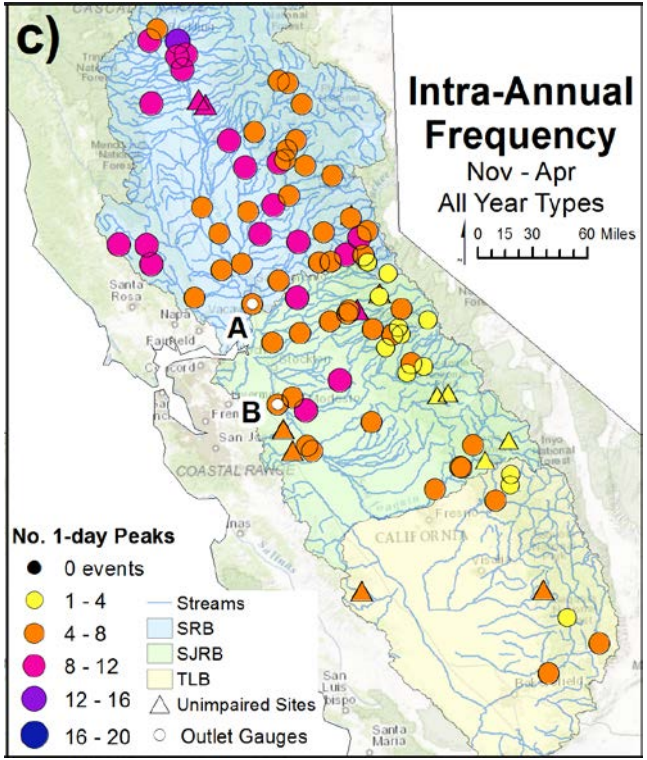
Number of years with HMF



Number of HMF days per time period

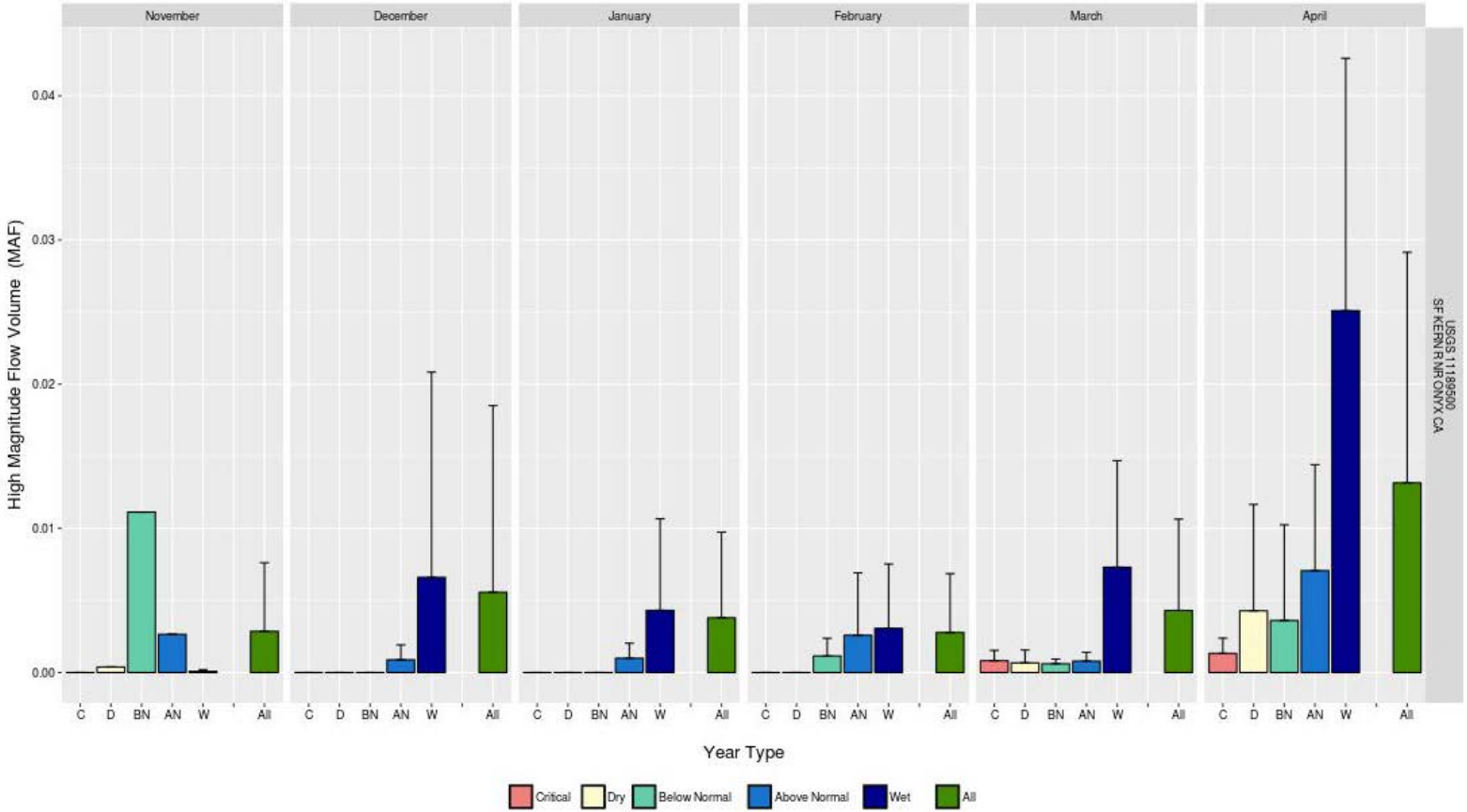


Number of peak events



Kocis and Dahlke, ERL, submitted

Kern River HMF availability

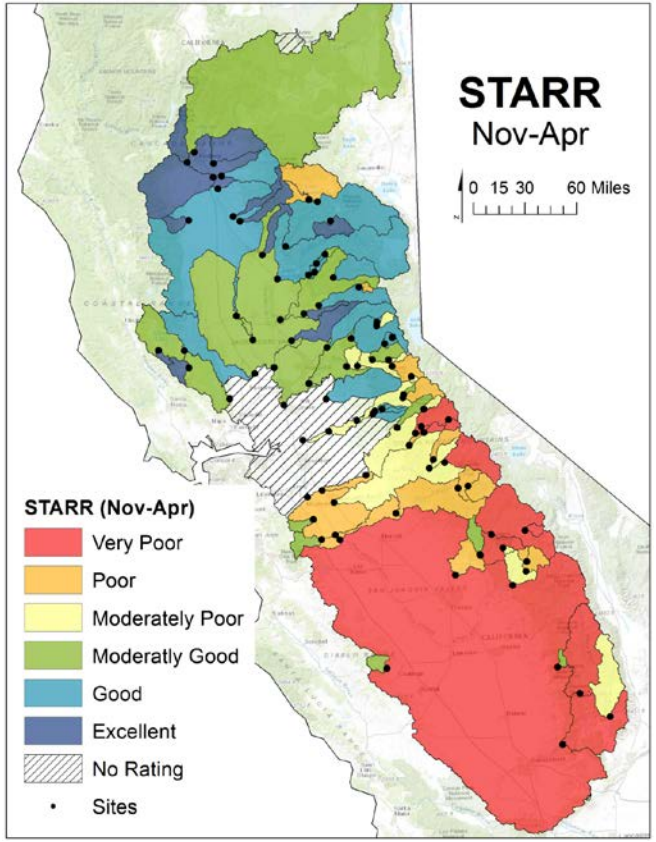


Streamflow Availability Rating for Recharge (STARR)

- STARR index indicates the most suitable watersheds for ag-recharge in terms of water availability relatively to other watersheds
- Uses 3 terms:
  - V/A = HMF volume / watershed area
  - D/P = number of HMF days / number of days in period
  - YWF = fraction of years with HMF
- Terms are ranked individually into six equal-area classes and weighted using Rank Ordered Centroid method:

$$\textbf{STARR} = 0.61 * \text{ranked(YWF)} + 0.28 * \text{ranked}\left(\frac{V}{A}\right) + 0.11 * ranked\left(\frac{D}{P}\right)$$

- STARR values are divided into 6 equal-interval classes from excellent to poor surface water availability
- Created for the same time periods as the metric analyses



Kocis and Dahlke, in prep.

Decision Support Tools on Soil Suitability

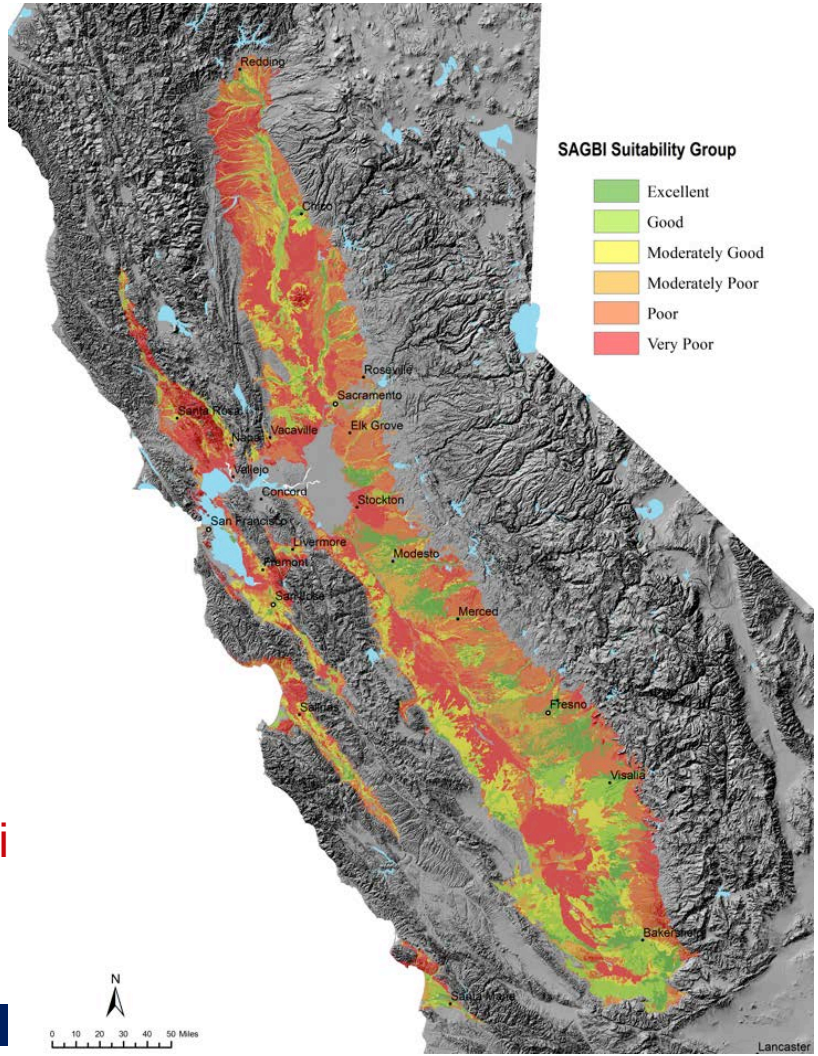
Good groundwater banking locations?

Soil characteristics:

- **Hydraulic conductivity**
- **Occurrence of restrictive layers**
- **Topographic Limitations (slope)**
- **Chemical Limitations**
- **Surface Condition (e.g. crusts, erodibility)**

http://casoilresource.lawr.ucdavis.edu/sagbi

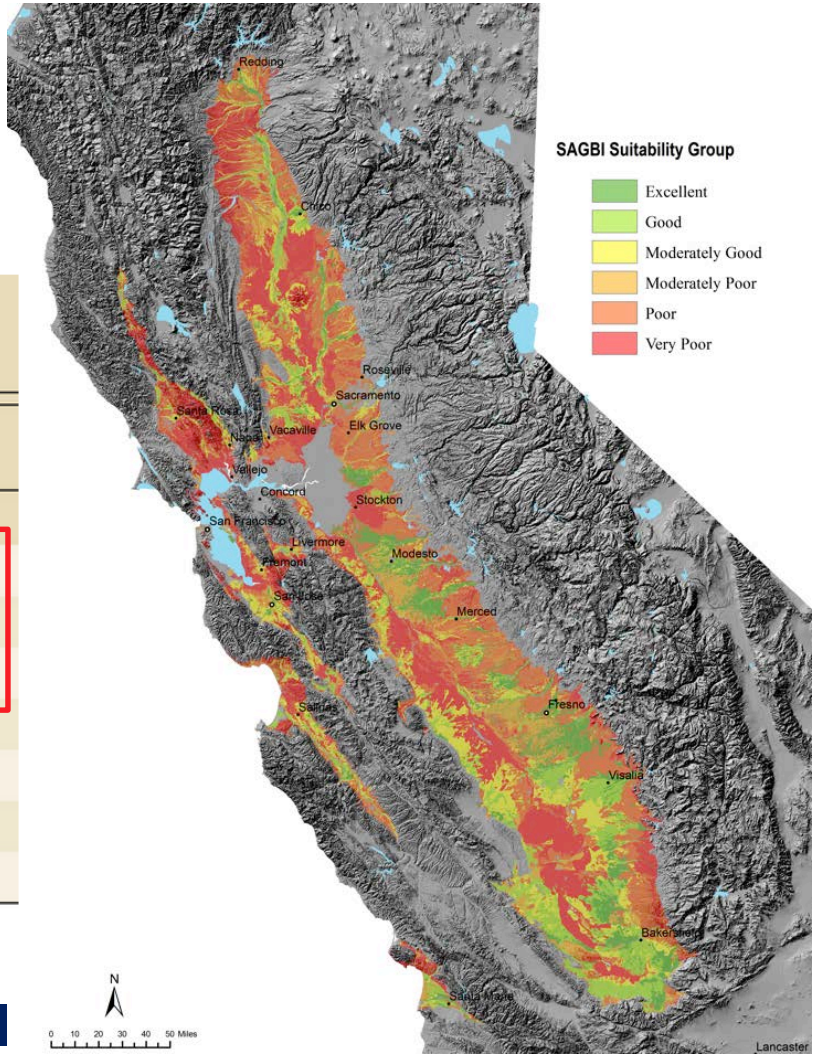
O'Geen et al. 2015, CalAg



Soil Agricultural Groundwater Banking Index

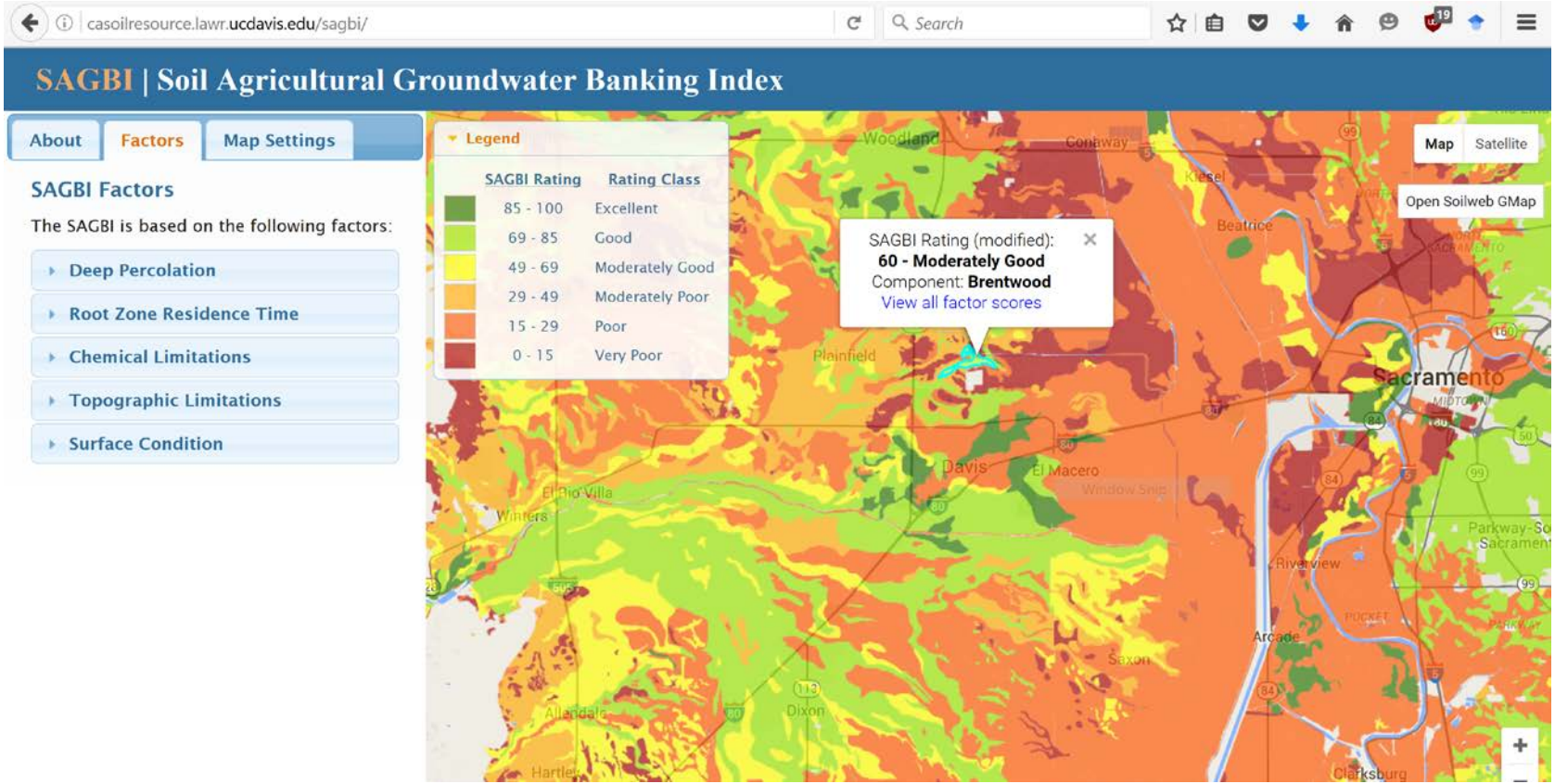
TABLE 2. Summary of the areal extent of Soil Agricultural Groundwater Banking Index groups generated from soil survey data

SAGBI group	Original SSURGO data		SSURGO modified by deep tillage	
	acres	*%**	*acres*	*%**
Excellent	1,477,191	8	1,557,035	9
Good	1,747,712	10	2,020,921	11
Moderately Good	1,786,972	10	1,984,414	11
Moderately Poor	1,343,250	8	1,364,066	8
Poor	4,866,942	28	4,586,645	26
Very Poor	6,375,277	36	6,084,142	35
Total†	17,597,345		17,597,222	



O'Geen et al. 2015, CalAg

Soil Agricultural Groundwater Banking Index (O'Geen et al. 2015, CalAg)

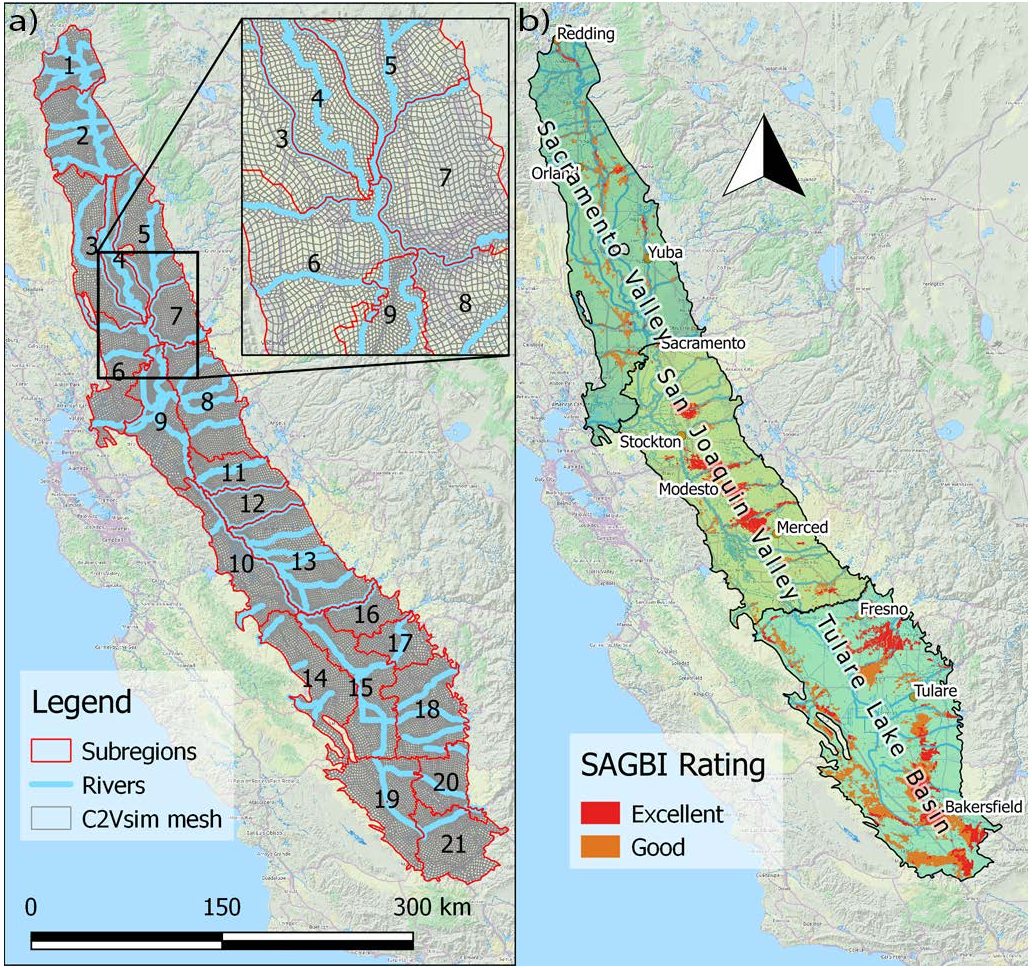


O'Geen et al. 2015, CalAg

Groundwater Modelling

Groundwater Modeling

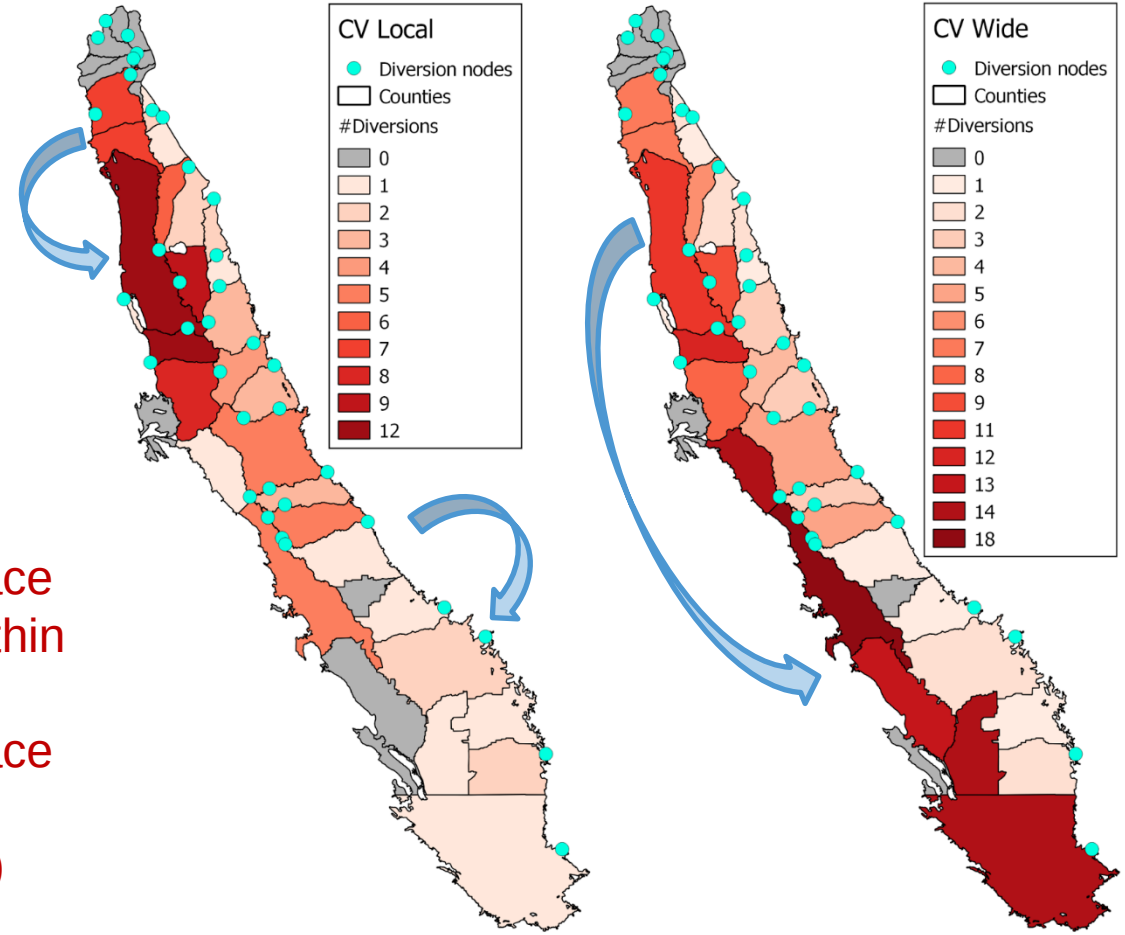
- California Central Valley Groundwater-Surface Water Simulation Model
- Fine-mesh version (>35,000 elements), 1921-2009
- Diversion of high-magnitude flows onto soils rated as Excellent and Good in SAGBI



Groundwater Modeling

Diversion of high-magnitude flow (flow > 90th percentile) at 42 nodes

The color ramp shows the number of diversion nodes each subregion receives water from.



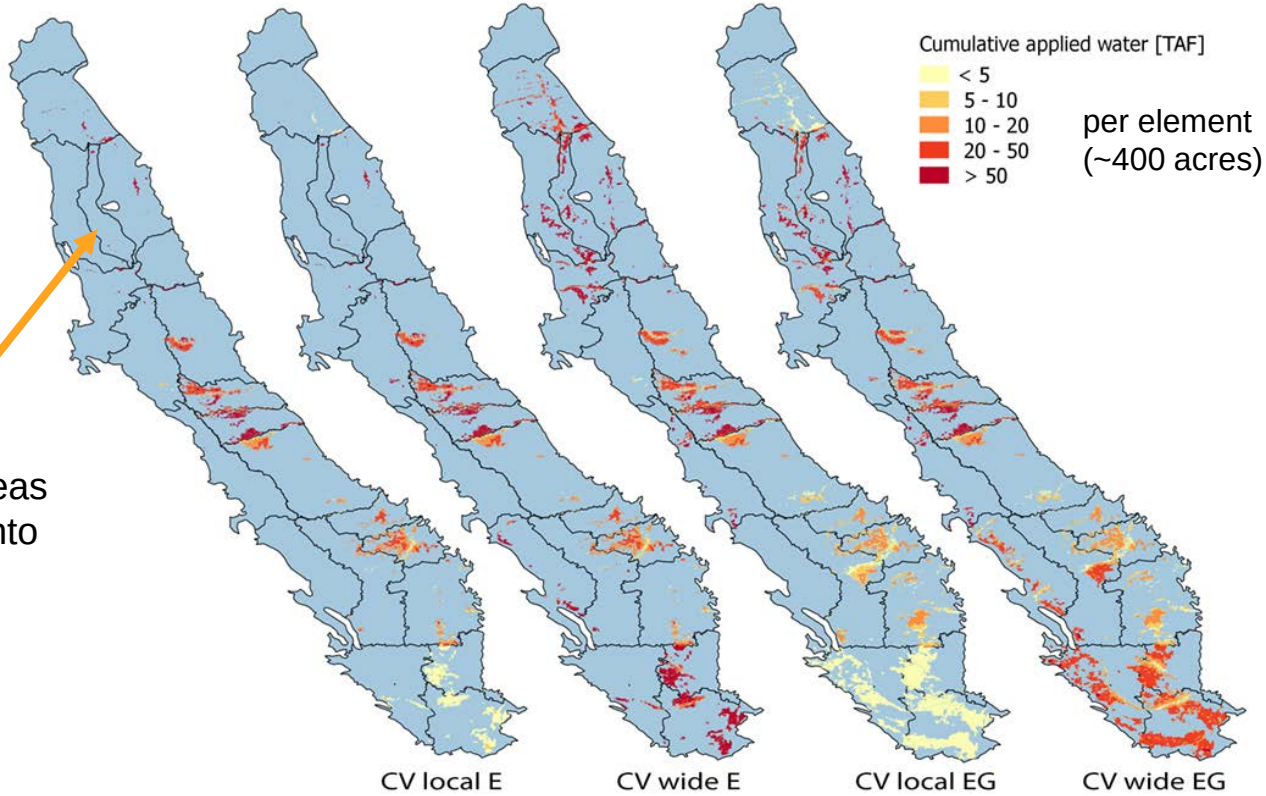
Two scenarios:

1. Recharge of excess surface within local basin (e.g. within Sacramento River basin)
2. Recharge of excess surface water Central-Valley-wide (export through the Delta)

Cumulative applied water in each scenario

Excellent soils only

Excellent and good soils

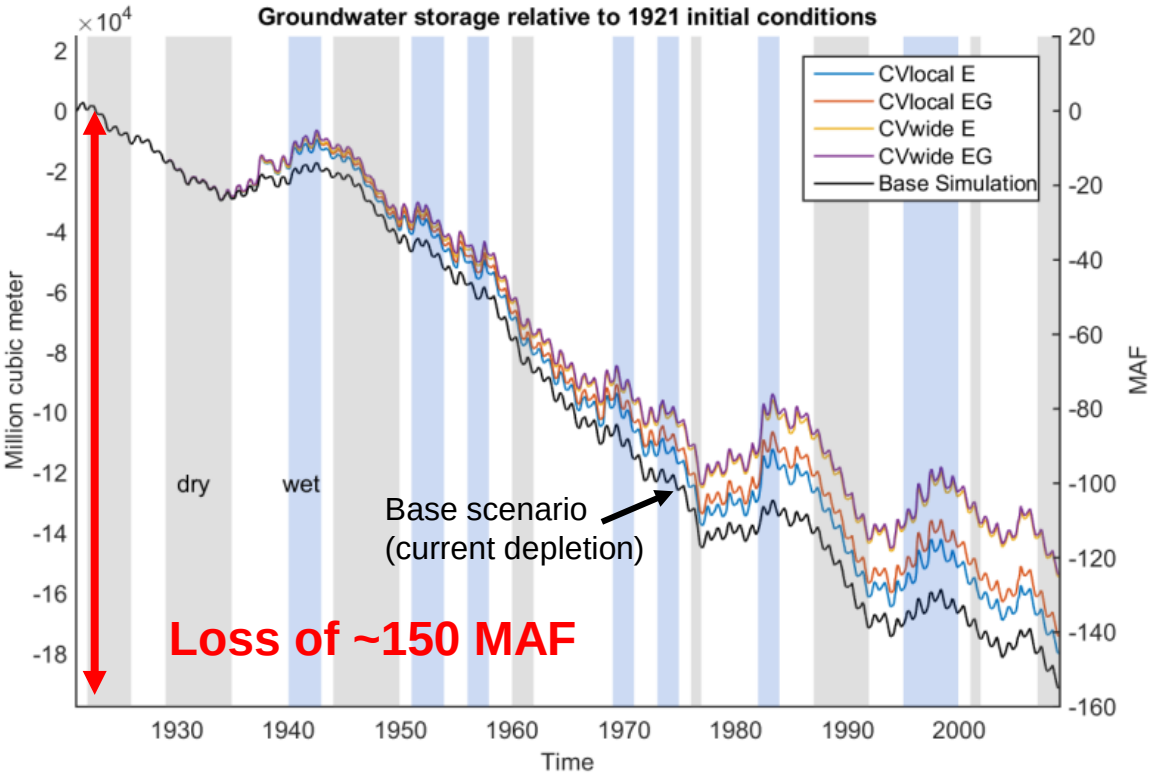


per element
(~400 acres)

Very few excellent recharge areas in Sacramento Valley

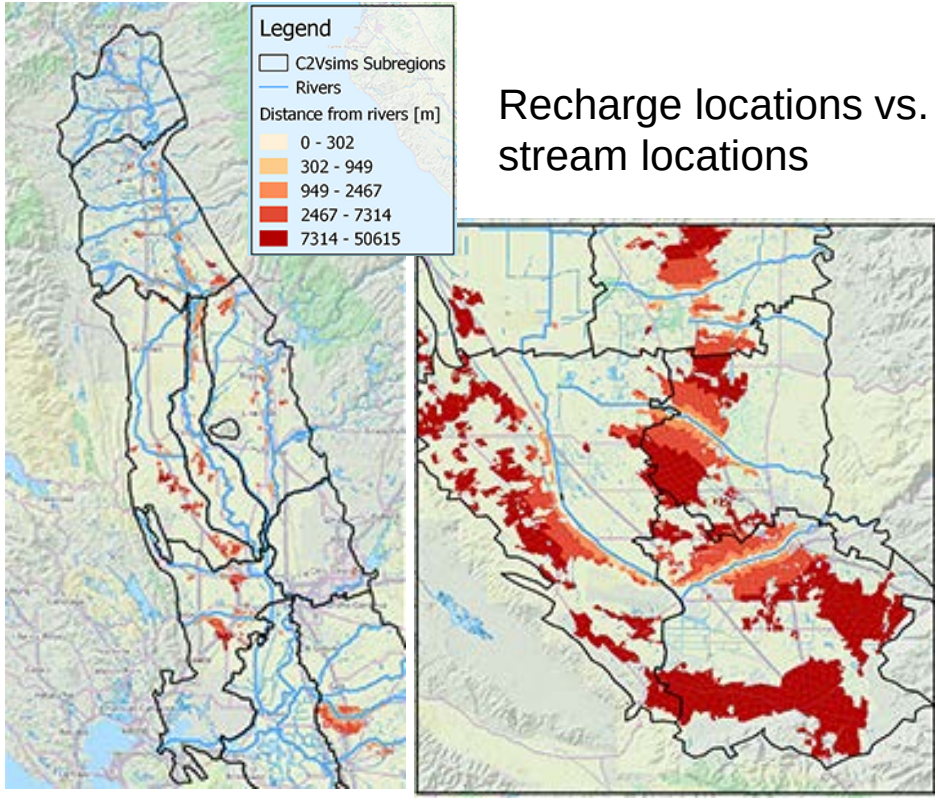
Change in groundwater storage

- 120 MAF – total excess surface flows diverted between 1921-2009 for recharge
- Groundwater storage gain over same period is about 30 MAF (1/5th of depletion)
- Most of recharged water returns back to stream

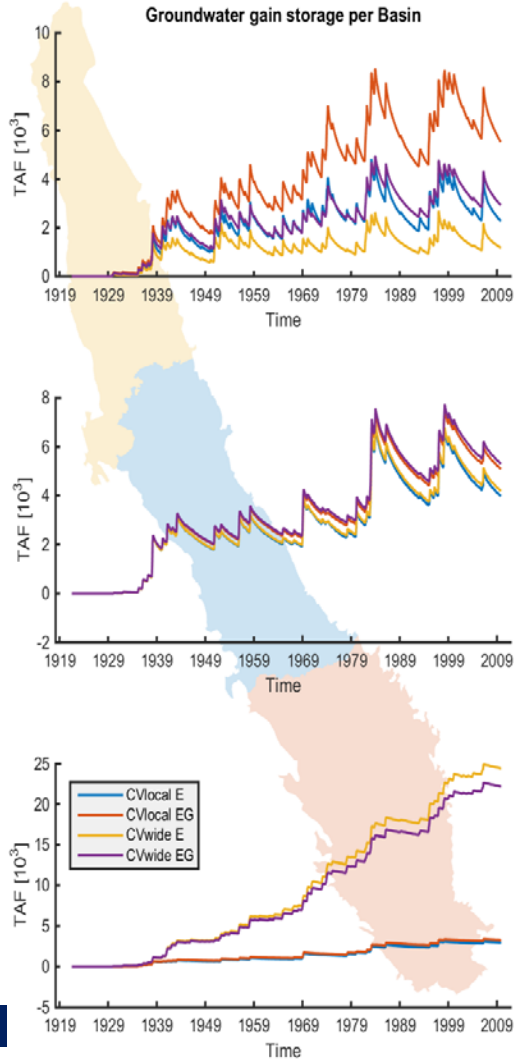


Relative gain in groundwater storage by region

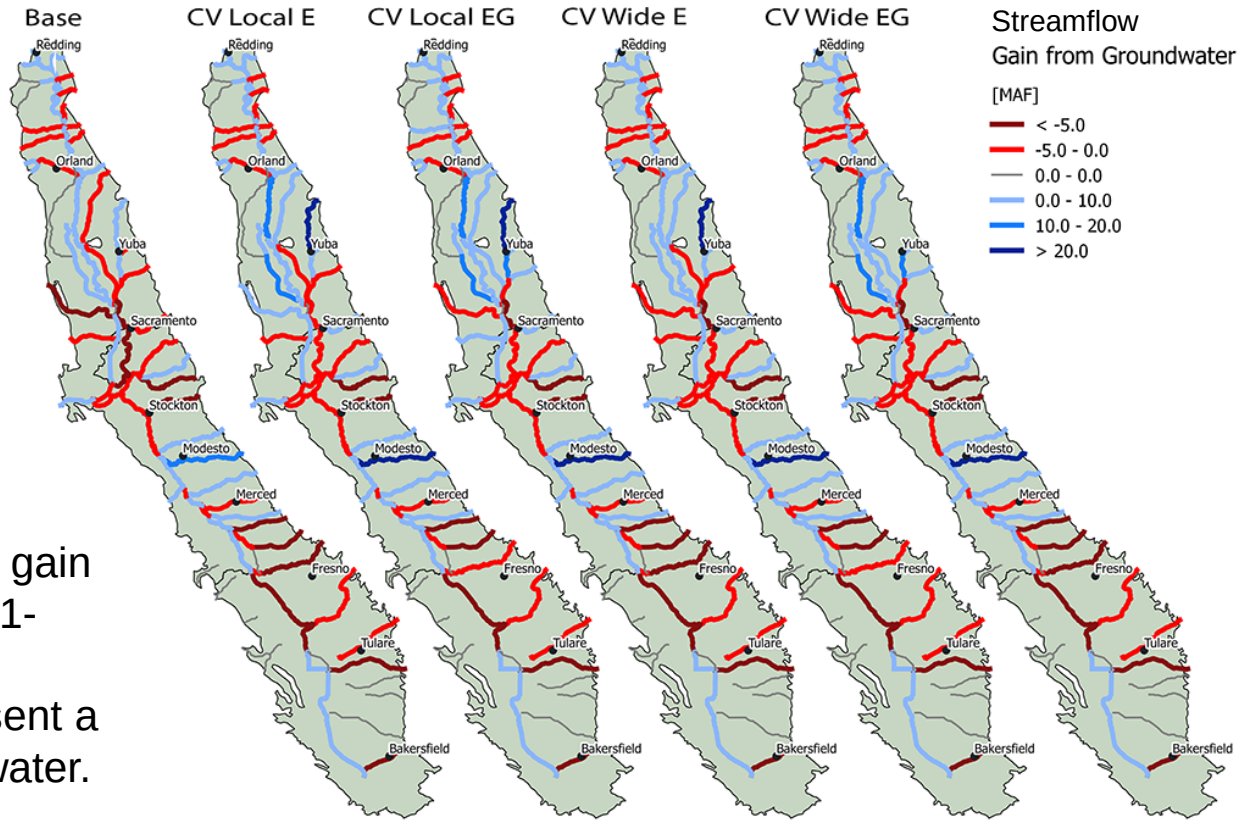
- Difference between base scenario and recharge scenario



Recharge locations vs. stream locations



Where does all the water go?



- Cumulative streamflow gain from groundwater (1921-2009).
- Negative values represent a stream loss to groundwater.

Conclusions

- Alfalfa, almonds, pecans are promising crops if grown on suitable soils with high percolation rates
- In some alfalfa fields 26 ft of water could be recharged in 30 days without decline in yield
- High-magnitude flows potentially provide an untapped source of water during the winter months
- Short duration events and low frequency of high-magnitude flows suggests a need for coordinated efforts for the local-scale utilization
- Agricultural groundwater banking can increase instream flows, help mitigate floods, and improve groundwater supply for disadvantaged communities

THANKS!!

hdahlke@ucdavis.edu

Acknowledgments:

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