

# Quantifying Diffuse Recharge to the Edwards Aquifer using Micrometeorology and Remote Sensing

Todd Caldwell<sup>1</sup>, Tara Bongiovanni<sup>1</sup>, Michael Young<sup>1</sup>, and Marcus Gary<sup>2</sup>

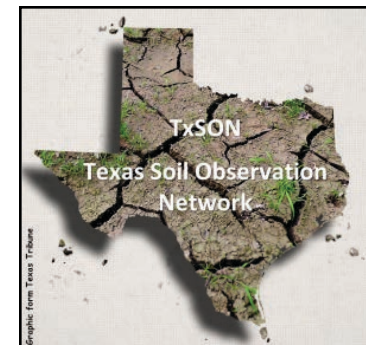
The 2018 MOISST Workshop

6 June 2018

<sup>1</sup>Bureau of Economic Geology, Jackson School of Geosciences

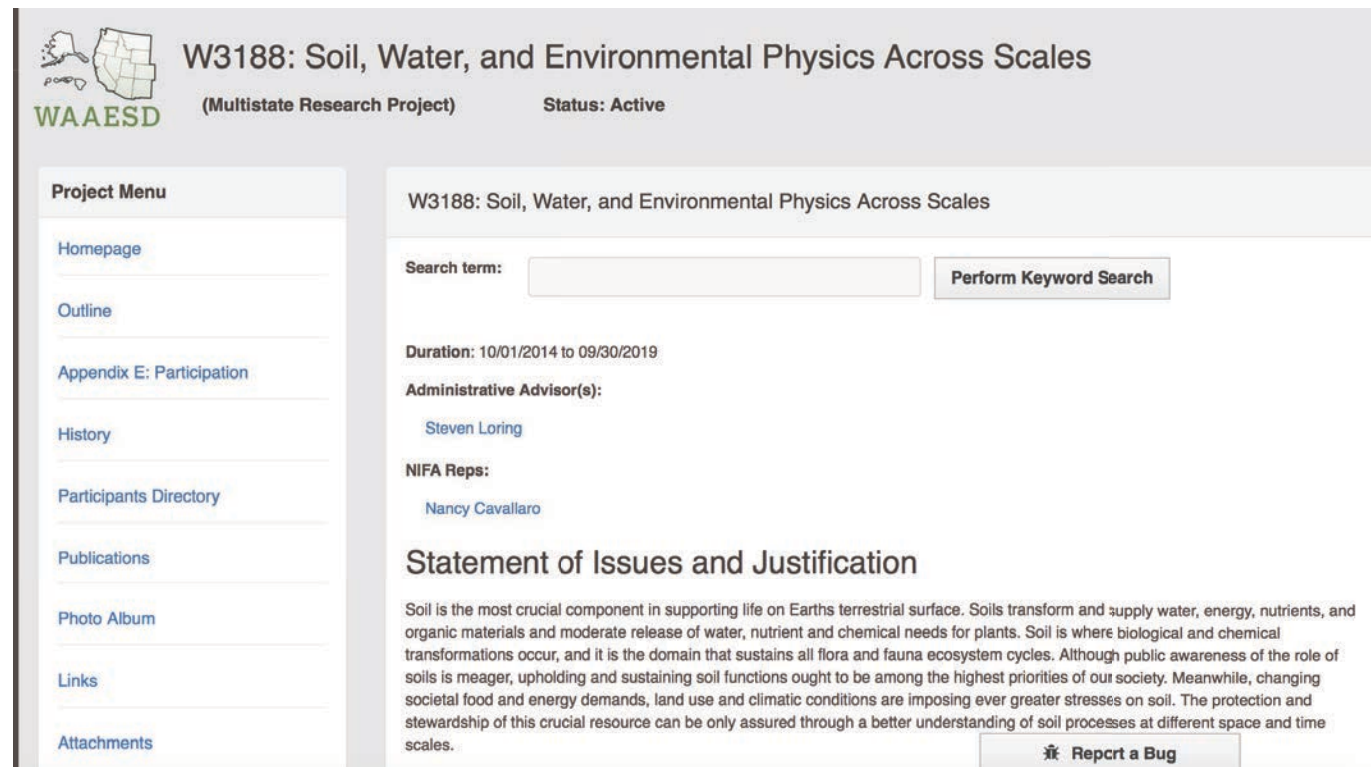
<sup>2</sup>Edwards Aquifer Authority, San Antonio, TX

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# W3188 Meeting: January 9-12, Riverside, CA

- Began in 1980's as W188
- USDA Sponsored with annual reporting from each Land Grant
- Now in it's 4<sup>th</sup> iteration
- Meeting will follow SSSA Annual Meeting in San Diego
- Could we formalized MOISST in such a way?



The screenshot shows the website for the W3188 project, titled "W3188: Soil, Water, and Environmental Physics Across Scales". The website is part of the WAAESD (Western Agricultural Experiment Station) and is a Multistate Research Project. The status is listed as "Active".

**Project Menu**

- [Homepage](#)
- [Outline](#)
- [Appendix E: Participation](#)
- [History](#)
- [Participants Directory](#)
- [Publications](#)
- [Photo Album](#)
- [Links](#)
- [Attachments](#)

**W3188: Soil, Water, and Environmental Physics Across Scales**

Search term:

**Duration:** 10/01/2014 to 09/30/2019

**Administrative Advisor(s):**

- [Steven Loring](#)

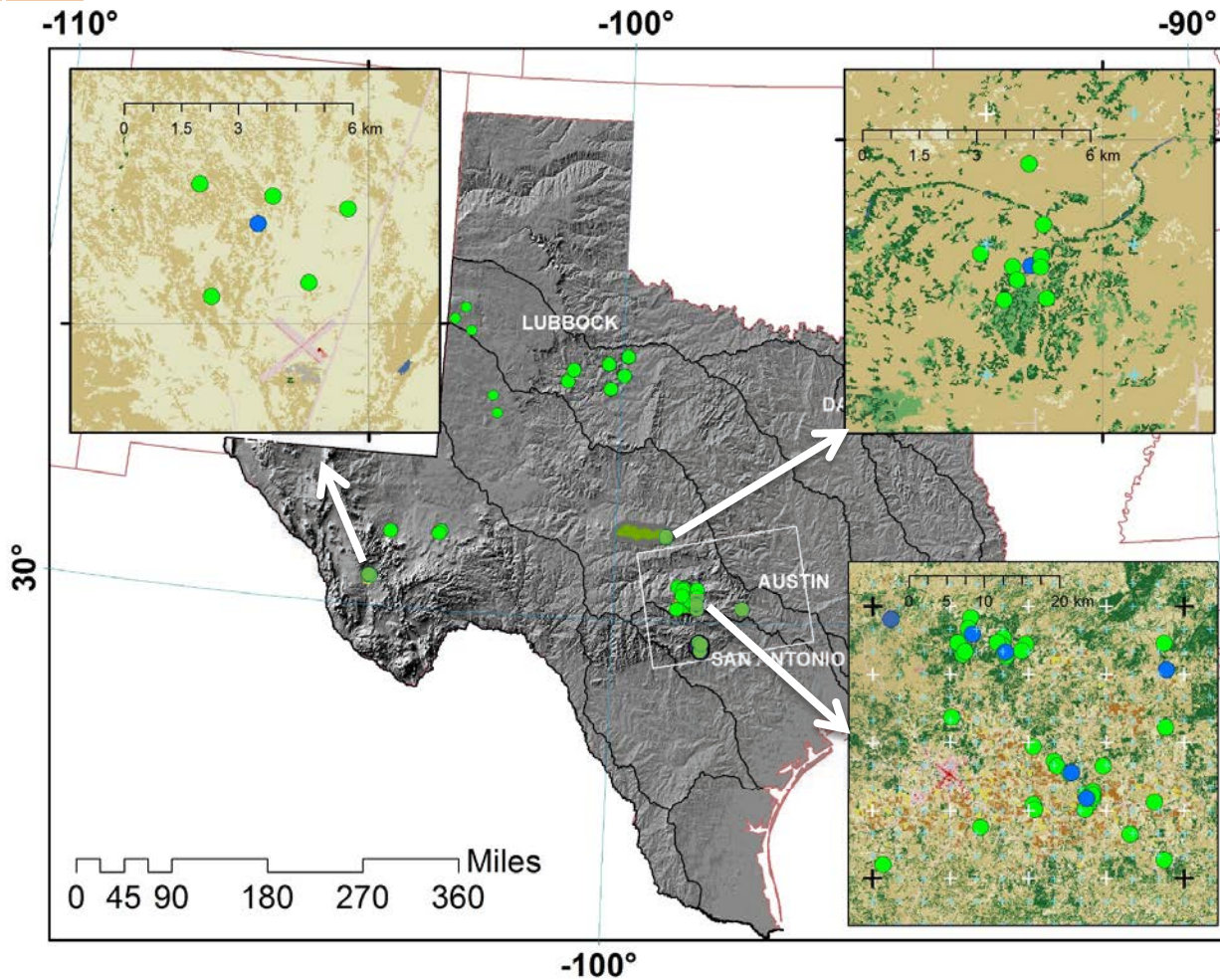
**NIFA Reps:**

- [Nancy Cavallaro](#)

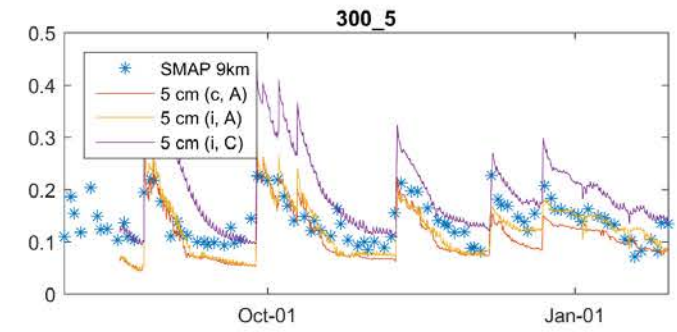
**Statement of Issues and Justification**

Soil is the most crucial component in supporting life on Earth's terrestrial surface. Soils transform and supply water, energy, nutrients, and organic materials and moderate release of water, nutrient and chemical needs for plants. Soil is where biological and chemical transformations occur, and it is the domain that sustains all flora and fauna ecosystem cycles. Although public awareness of the role of soils is meager, upholding and sustaining soil functions ought to be among the highest priorities of our society. Meanwhile, changing societal food and energy demands, land use and climatic conditions are imposing ever greater stresses on soil. The protection and stewardship of this crucial resource can be only assured through a better understanding of soil processes at different space and time scales.

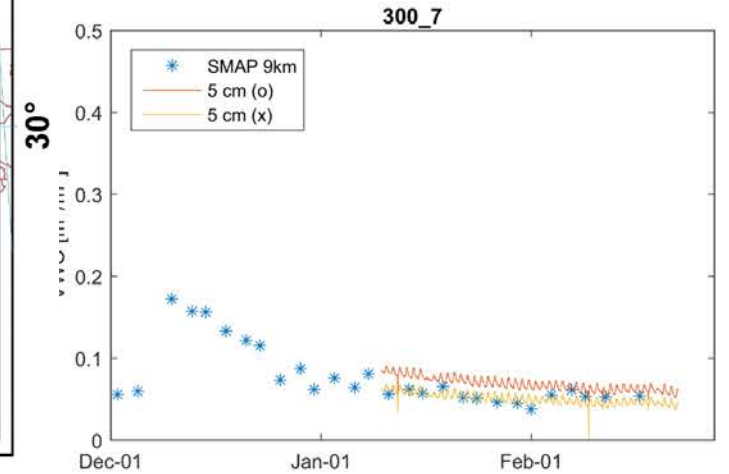
# TxSON Update: SMAP/Sentinel Validation



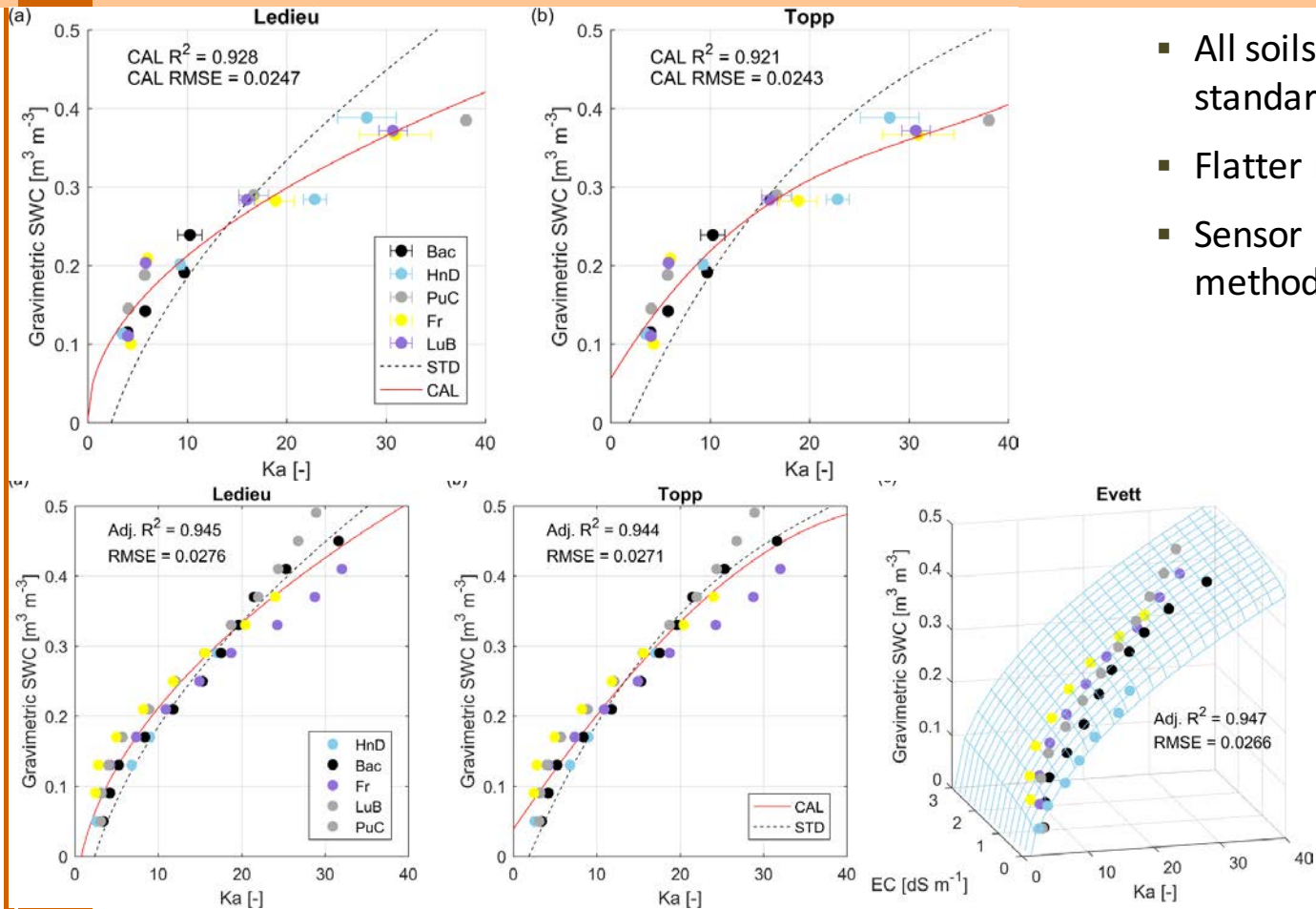
Brady, TX: shrub/scrub & evergreen



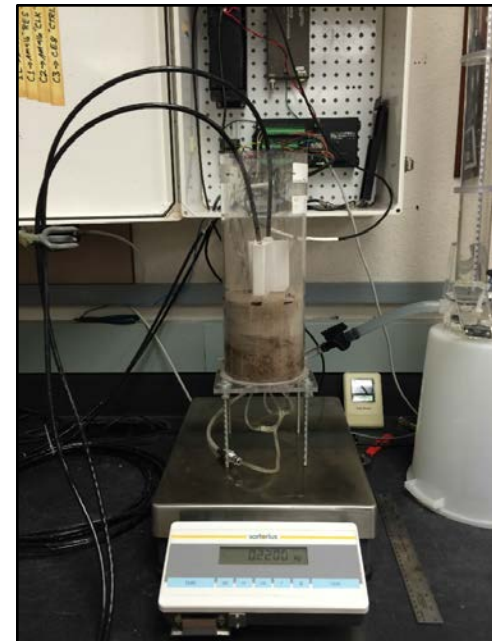
Marfa, TX: herbaceous & shrub/scrub



# CS655 Lab calibrations – downward infiltration



- All soils show a significant deviation from standard Topp et al., 1980
- Flatter response than Topp
- Sensor response affected by methodology (batch or infiltration)



Caldwell et al., 2018, *Vadose Zone J.*

# Quantifying Diffuse Recharge (QDR) in the Edwards Aquifer

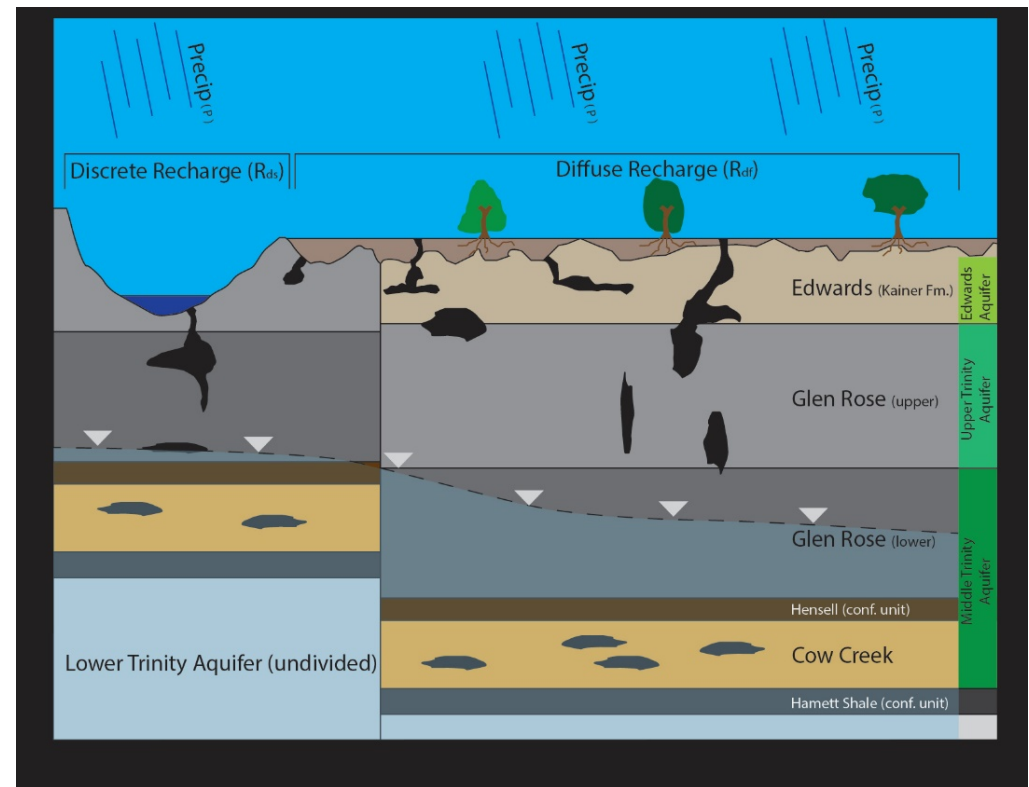
- I. Diffuse recharge through epikarst could represent substantial amount of groundwater recharge across the Edwards Aquifer drainage area
- II. Substantial variability in time and space, plus effects of vadose zone “memory” make estimates difficult to quantify

Vadose zone water storage impacted by interannual variability of precipitation

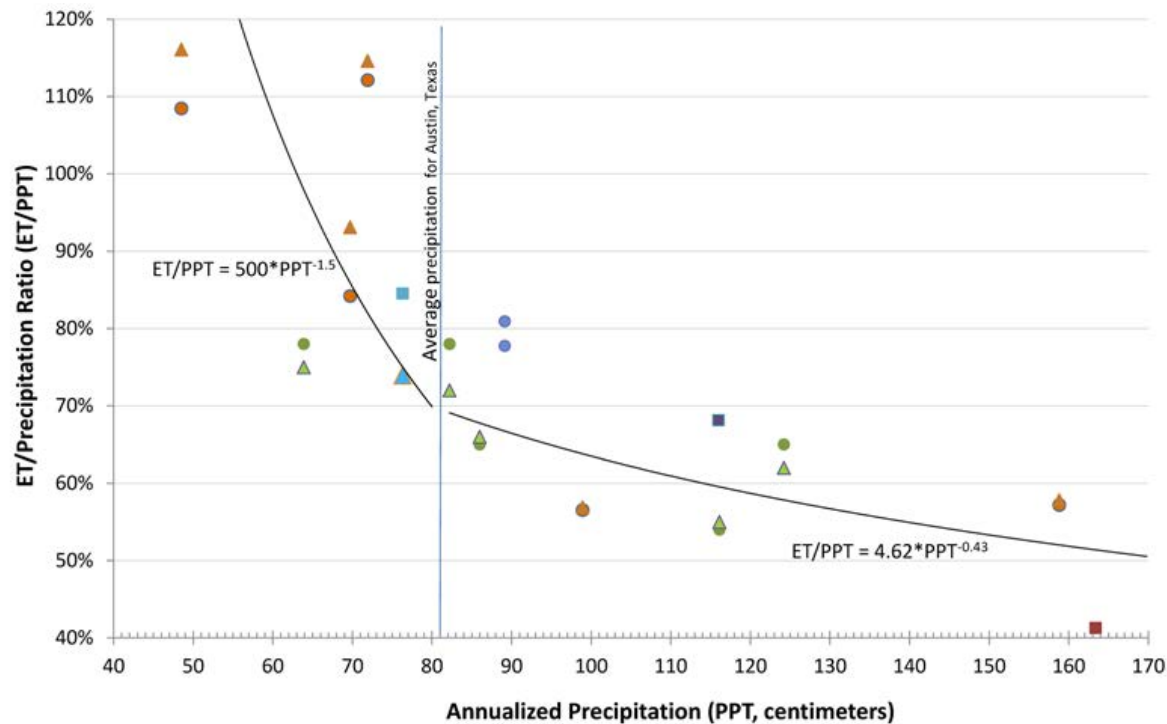
- III. Reports of recharge percentages (R/P) often suffer from short-term data sets or scaling effects

Incorporating longer-term observations will increase confidence

- IV. Camp Bullis - existing data in project area: soil characterization, 23 weather towers, karst feature maps, geophysics, and cave drip studies
- V. Combine in-situ sensors, micro-meteorology (e.g. eddy covariance) and remote sensing to basin-level estimates



# Autogenic recharge from miscellaneous methods and micromet

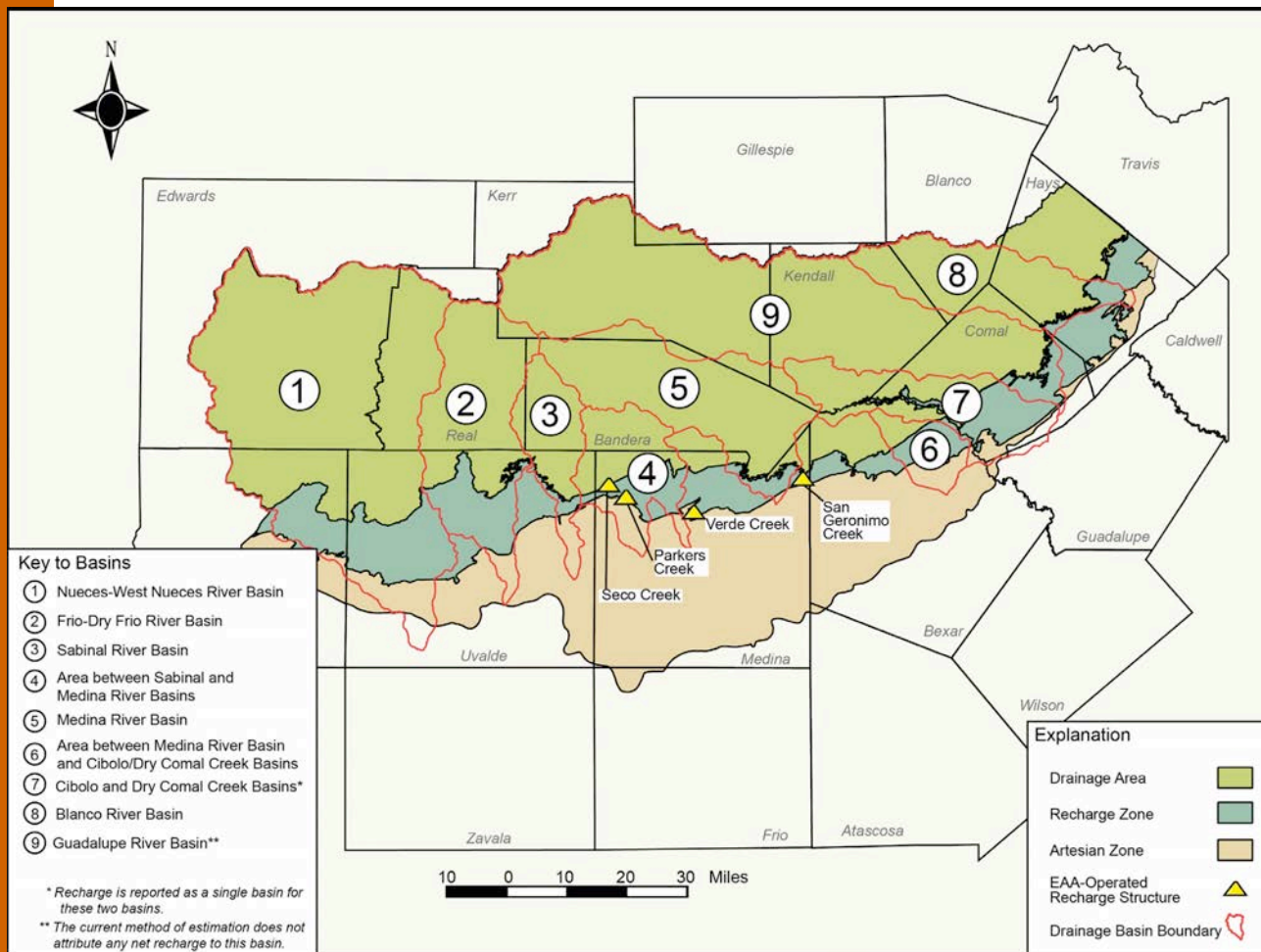


- Seco Creek Wooded 1991-1995 (Dugas et al., 1998)
- Freeman Ranch Wooded 2005-2009 (Heilman et al., 2012)
- Honey Creek 2002-2003 (Slattery et al., 2006)
- Honey Creek Wooded 2005-2010 (Banda et al., 2011)
- HQ Flat Sink (2004-2005, this study)
- ▲ Seco Creek Savana 1991-1995 (Dugas et al., 1998)
- ▲ Freeman Ranch Savana 2005-2009 (Heilman et al., 2012)
- Honey Creek Wooded 2002-2004 (Banda et al., 2011)
- ▲ Honey Creek Savana 2005-2010 (Banda et al., 2011)

## Diffuse Recharge in TX

- Direct measurement of ET<sub>a</sub> from eddy covariance/Bowen Ratio
- ET<sub>a</sub> 68% of PPT over 505 days
- Focused recharge 6%
- Diffuse recharge 26% of PPT
- Annual and inter-annual variability may change this ratio

# Quantifying Recharge to the Edwards Aquifer



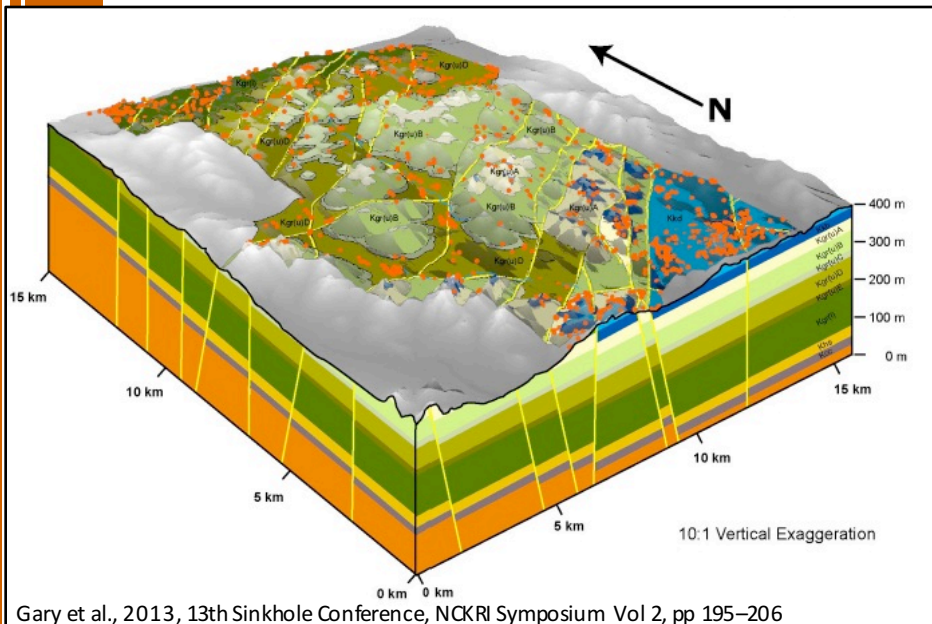
## Recharge to the Edwards

- 9 Drainage Basins
- USGS water-balance method for Basin 1-8 (1934 to pres.)
- EAA also uses HSPF model
- Interflow between Edwards and Trinity Aquifers

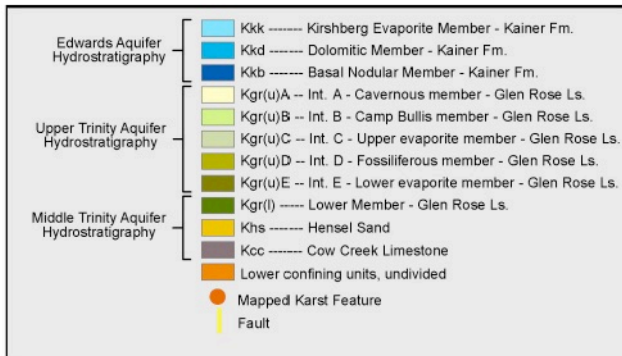
## Camp Bullis

- 30 km NW of San Antonio
- 10,000 ha - DOD controlled (1906)

# Quantifying Diffuse Recharge (QDR) - Camp Bullis, TX

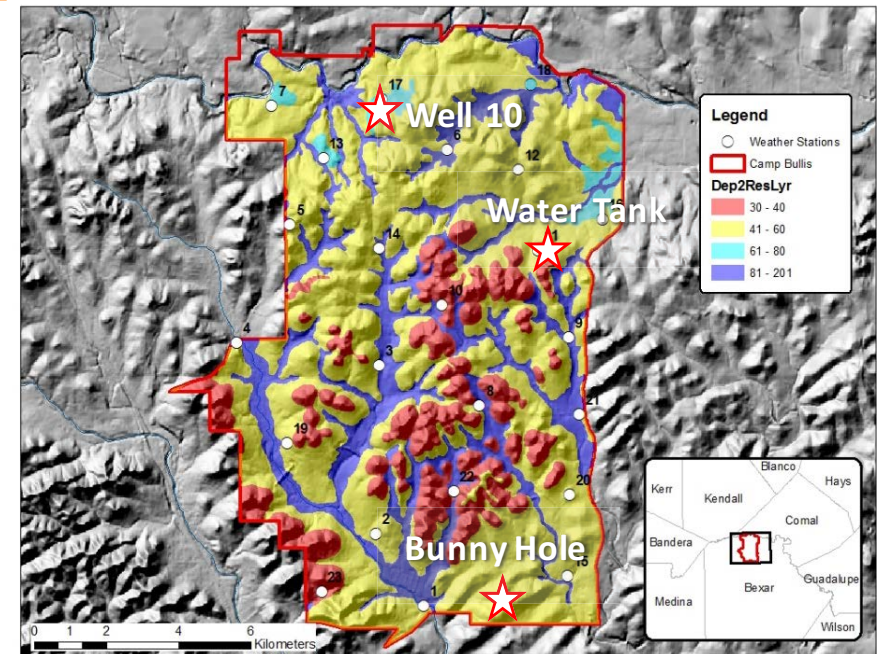


Gary et al., 2013, 13th Sinkhole Conference, NCKRI Symposium Vol 2, pp 195-206



## Surficial Geology Edwards Plateau

- Cretaceous carbonates: Edwards and Glen Rose Ls
- NE trending faults



## Vadose zone:

- Shallow soils (<40 cm) in uplands (Brackett, Eckrant, Krum)
- Thicker soils (<100 cm) in valley bottoms
- Epikarst of varying thickness (10-100 m)

# Quantifying Diffuse Recharge (QDR) - open path eddy covariance



- I. **Bunny Hole: closed cedar woodland**
  - CSI Irgason at 8.6 m
  - Installed and operational on May 24, 2016
  - Soil depth: 5-10 cm
- II. **Well 10: open oak savanna**
  - CSI Irgason, at 7.3 m
  - Installed on February 3, 2016
  - Fully operational on April 26, 2016
  - Soil depth: 40-70 cm
- III. **Water Tank: open grassland**
  - Licor Li-7550 at 3 m
  - Installed on January 2017
  - Fully operational on March 25, 2017
  - Soil depth: 40-60 cm

## QDR biometeorological sensors

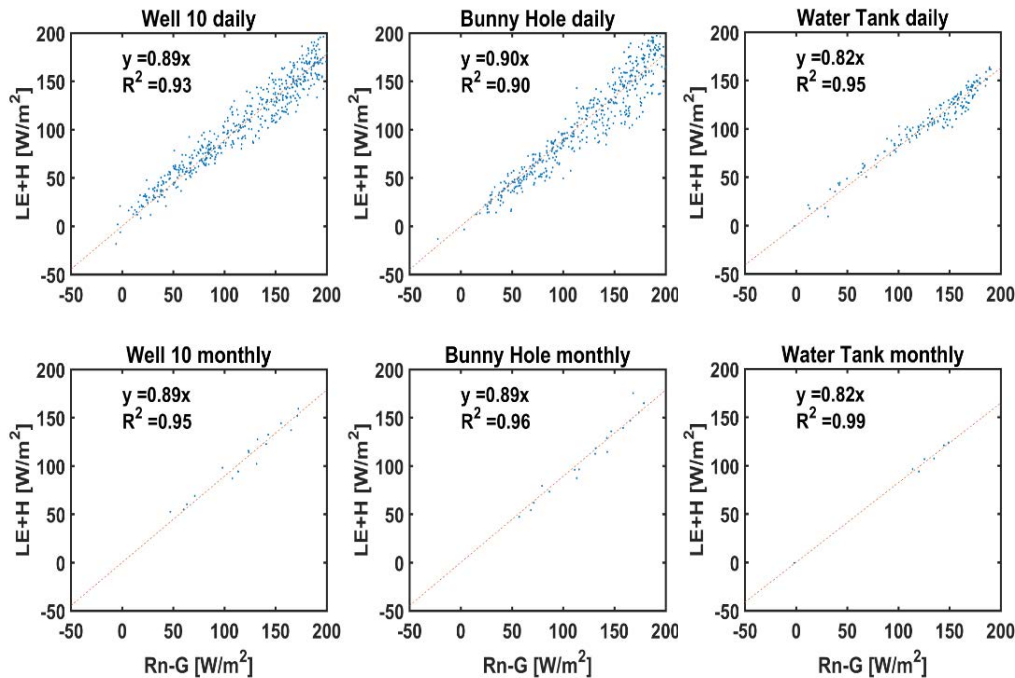


- Soil heat flux plates (3) at 8cm
- Averaging thermocouples (2) at 2 and 8cm
- Soil moisture and temperature sensors at 5 (2), 10, and 20 cm depth at 2 locations
- Additional meteorological sensors
  - Four-component net radiometer
  - Rain gage
- Additional data collection, 100 m transects (6)
  - 400 MHz ground penetrating radar
  - Electromagnetic induction DUALEM-2S
  - Portable water content sensor (1 m)
  - Soil depth probe (battery powered drill with 36" bit)

# QDR Evapotranspiration: Data processing

## 10 Hz corrections (EddyPro and EasyFlux)

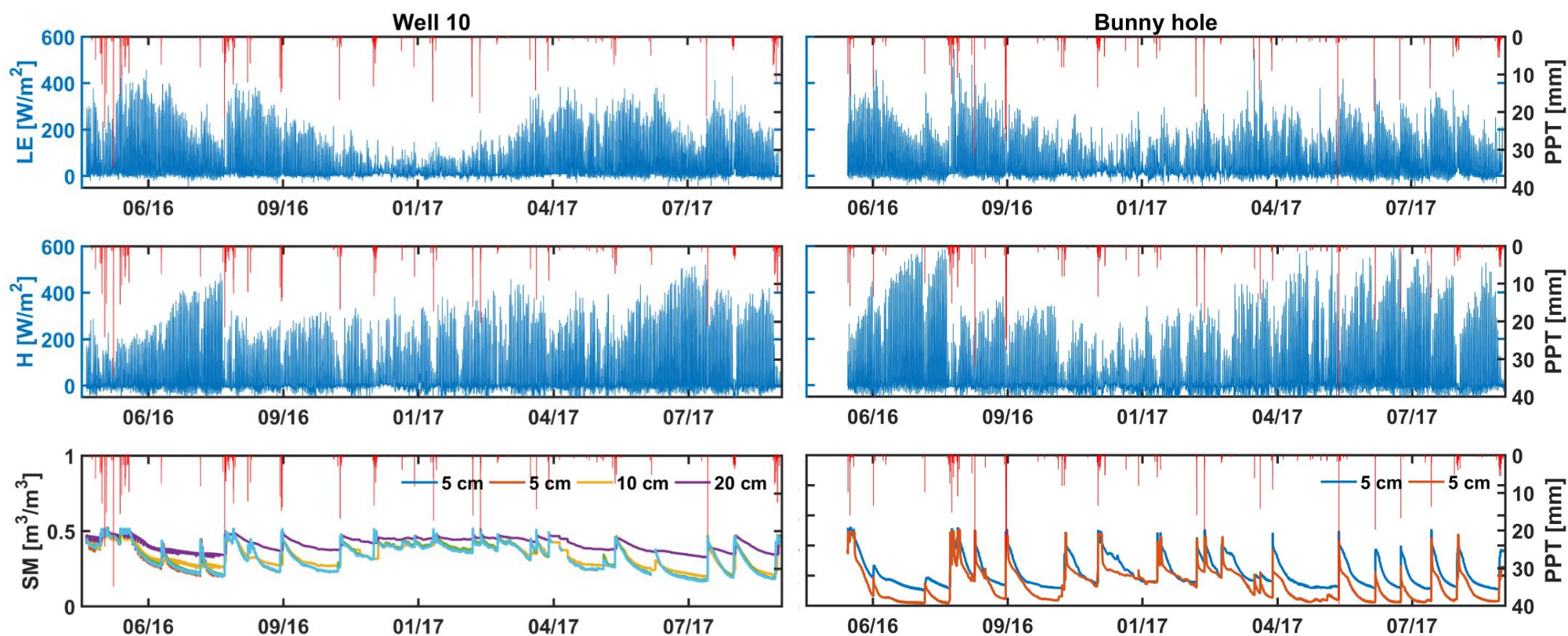
- Statistical screening (Vickers and Mahrt, 1997), despiking and filter anemometer and gas analyzer
- Covariance maximization for time lags compensation
- Block average for extracting turbulent fluctuation
- Linearly fill if <1% or remove data with >10% missing



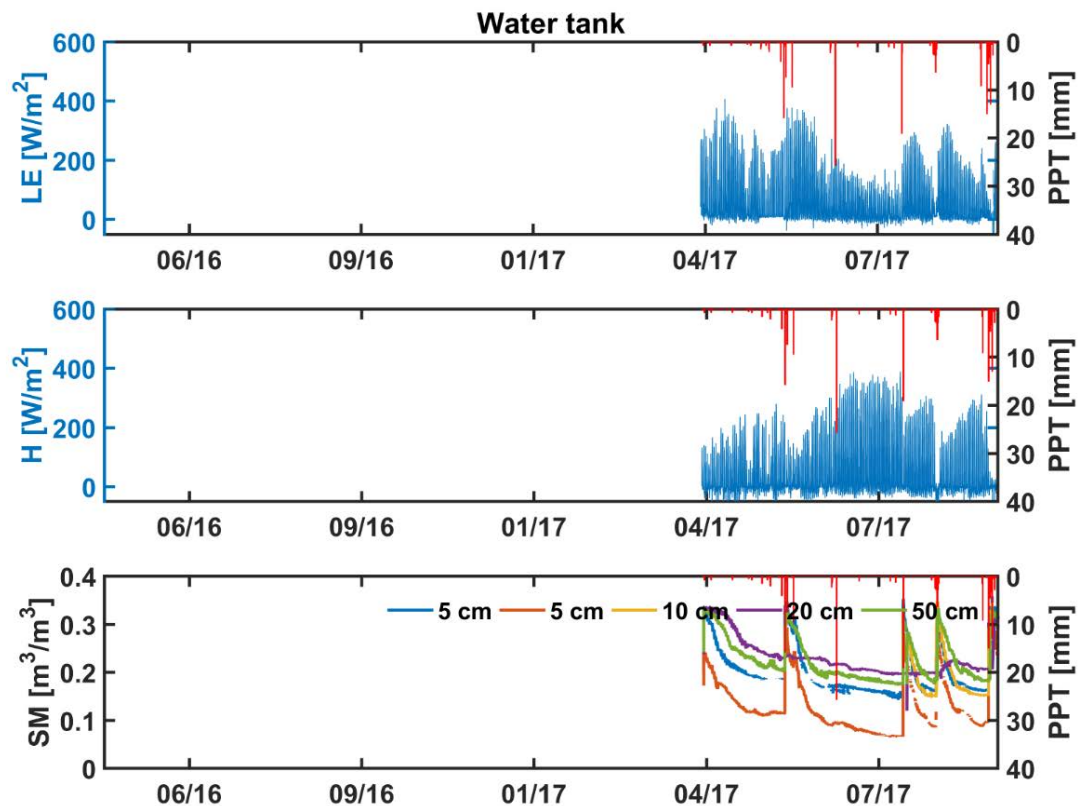
## 30 Minute Mean Fluxes

- Coordinate rotations for tilt, double rotation corrections
- Apply frequency corrections using cospectra
- Humidity correction of sonic temperature
- Low-pass frequency and high-pass frequency correction
- Apply correction for air density fluctuations using WPL equations
- Assign quality check (Mauder and Foken, 2004)
- Calculate footprint characteristics using Kljun et al. (2004) and Kormann and Meixner (2001)
- Spike detection of 30 minute data (Papale et al 2006)
  - For 13 day window use based on the double-differenced time series, using the median of absolute deviation about the median (MAD)
- Gap filling, 30 minute data
  - If gap  $\leq 2$  hrs then linearly interpolate
  - If gap  $> 2$  hrs then use  $R_n$ ,  $T_{air}$ , VPD to find data similar within a  $\pm 7$  day period
  - If data missing for station use  $R_n$  from other station
- Bowen Ratio correction for day time
  - $LE_{corr} = (R_n - G) / (1 + B)$
  - $H_{corr} = LE_{corr} * B$

# Corrected 30-minute flux data: Well 10 and Bunny Hole



## Corrected 30-minute flux data: Water Tank



### 30 Minute Mean Flux Summary

- Energy balance closure is biased low for LE+H
- $R = P - LE \Rightarrow R$  will be +
- Force closure through linear correction (future)

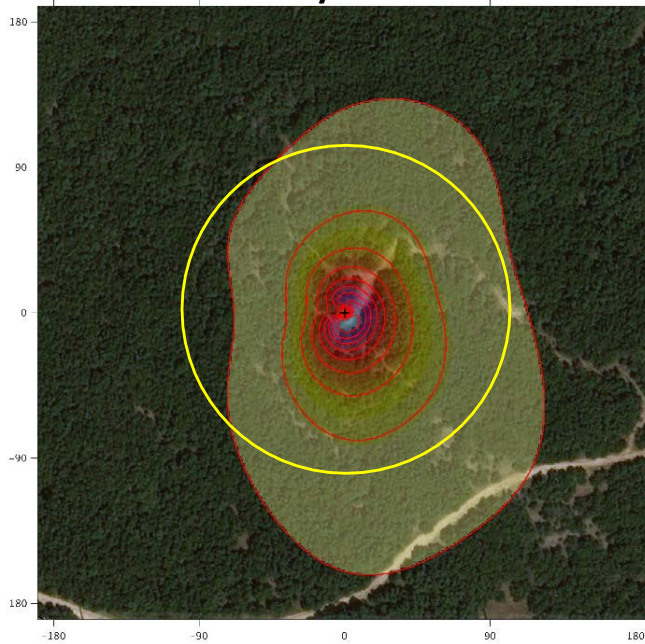
### 30 Day Cumulative Flux Summary

- Aggregate 30 min fluxes into monthly total
- Assume 100-m footprint
- Extract Landsat vegetation indices
- Develop regression between actual Evapotranspiration (ETa) and monthly indices

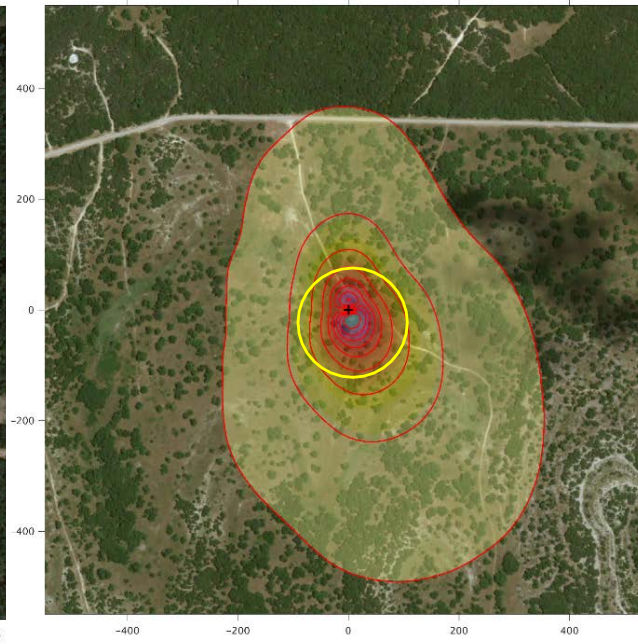
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## Eddy covariance footprint analyses – upscaling with Landsat

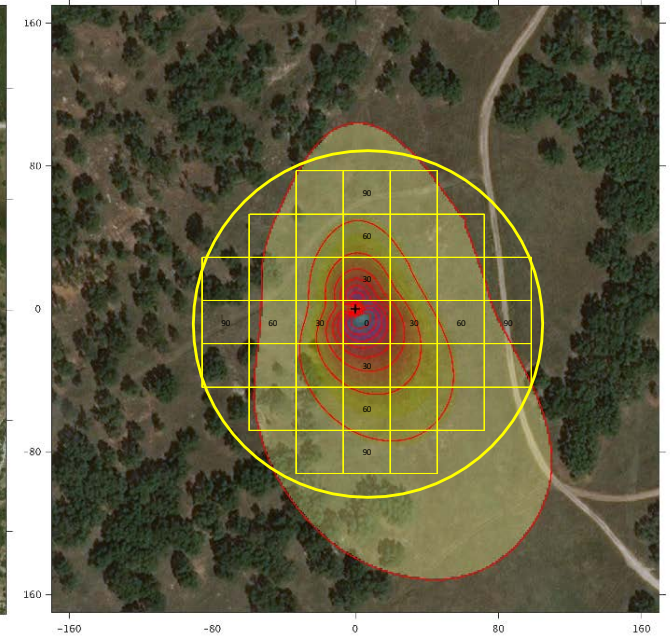
**Bunny Hole**



**Well 10**



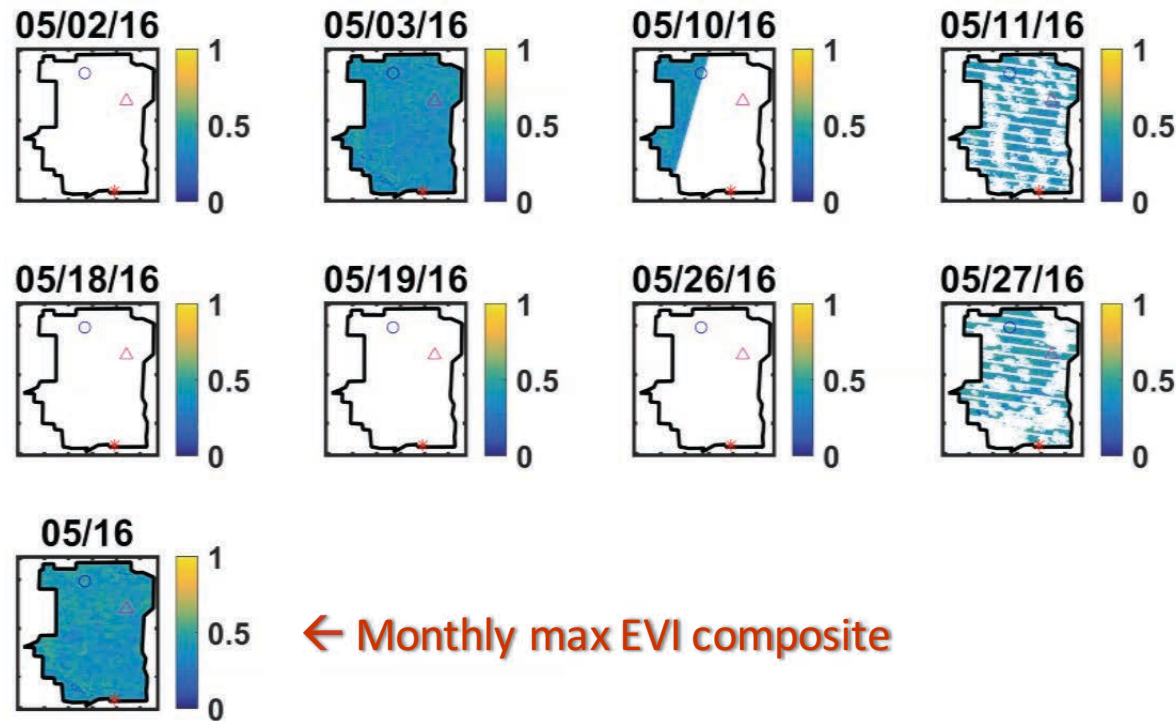
**Water Tank**



### Landsat (7/8) Surface Reflectance-Derived Indices

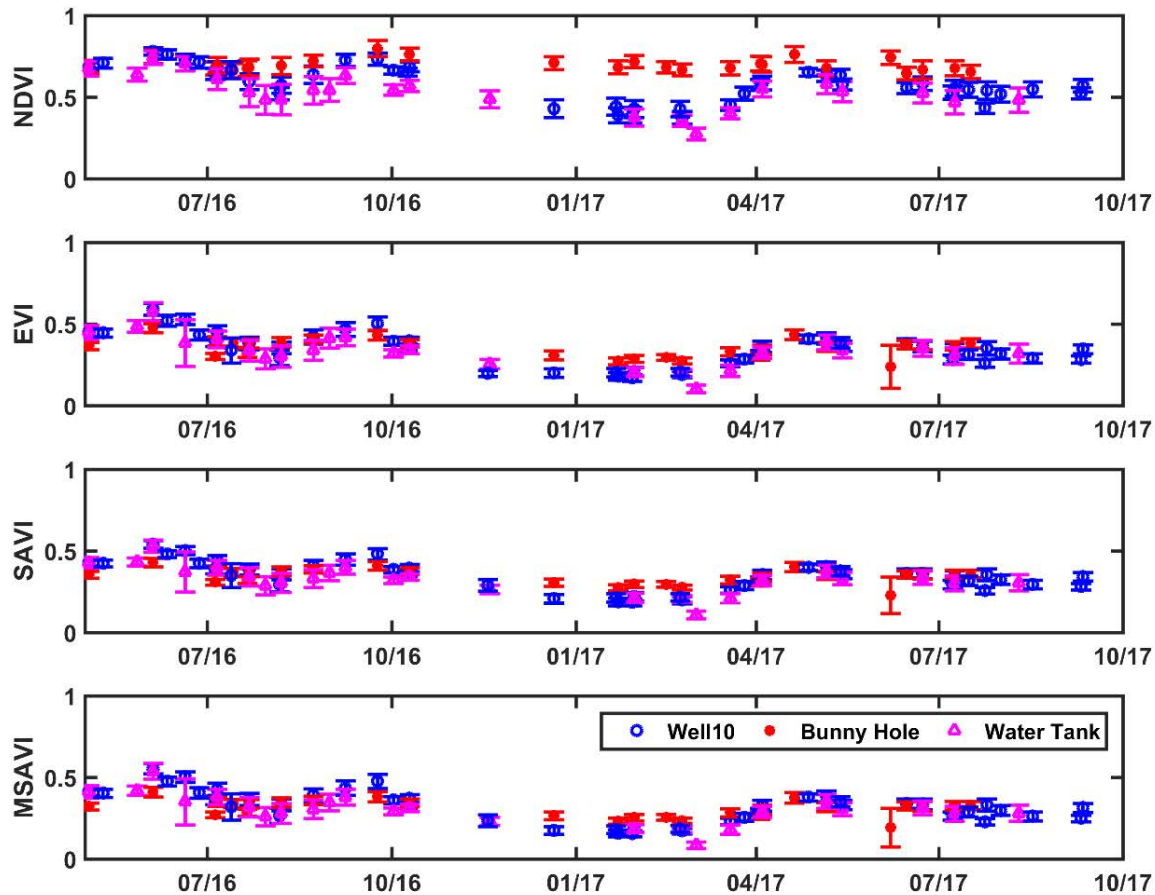
- 30 m resolution
- Need cloud-free images
- 4-7 images per month

# Eddy covariance footprint analyses – upscaling with Landsat



Monthly Composite EVI Camp Bullis				
	mean	std	max	min
16-May	0.413	0.068	0.707	-0.044
16-Jun	0.447	0.083	0.845	-0.066
16-Jul	0.389	0.062	0.661	0.02
16-Aug	0.379	0.069	0.806	-0.046
16-Sep	0.421	0.073	0.962	0.007
16-Oct	0.378	0.054	0.656	-0.037
16-Nov	0.299	0.06	0.635	-0.154
16-Dec	0.259	0.057	0.527	0.003
17-Jan	0.263	0.05	0.555	-0.026
17-Feb	0.255	0.045	0.478	-0.08
17-Mar	0.298	0.062	0.674	-0.047
17-Apr	0.388	0.078	1.108	0.002
17-May	0.376	0.07	0.725	-0.038
17-Jun	0.386	0.073	0.799	-0.019
17-Jul	0.371	0.07	0.712	-3E-04
17-Aug	0.356	0.077	0.723	-0.004
17-Sep	0.358	0.061	0.627	0.05

## Eddy covariance footprint analyses – upscaling with Landsat



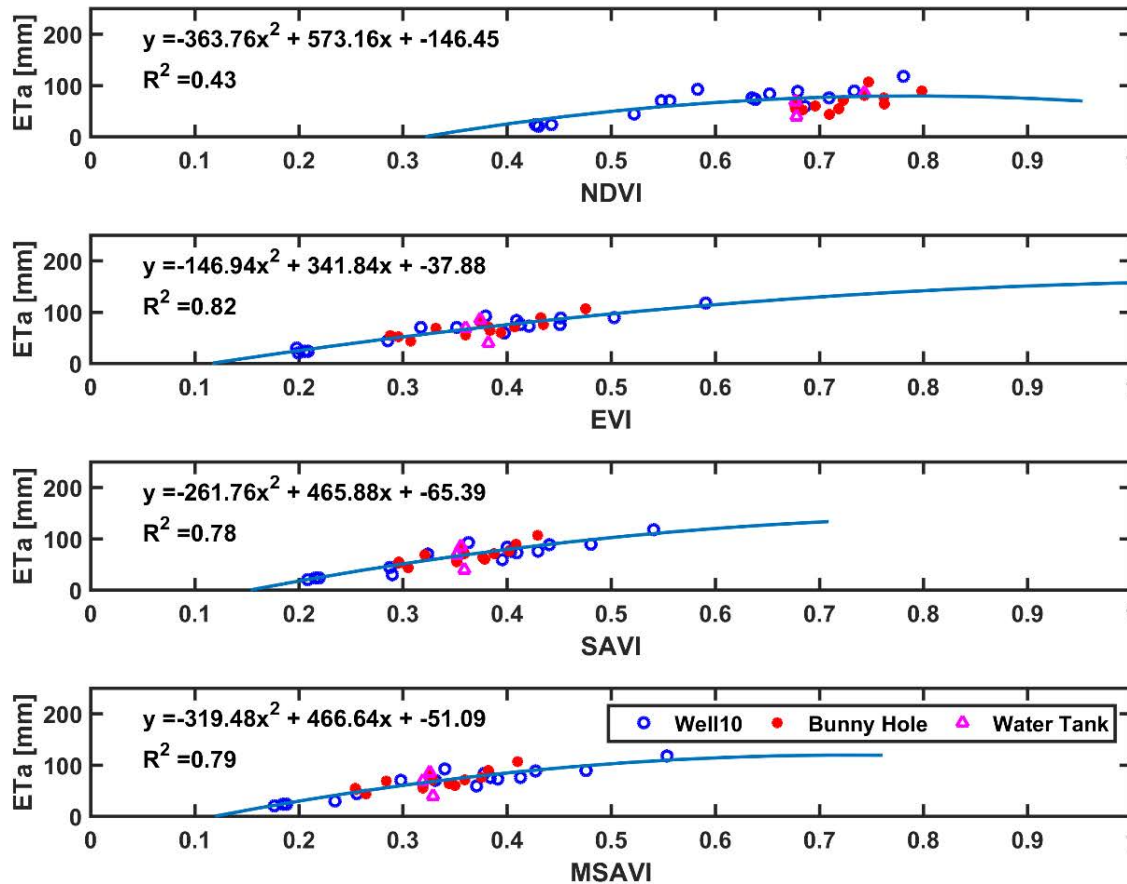
$$NDVI = \frac{NIR - R}{NIR + R}$$

$$EVI = G \frac{NIR - R}{NIR + C1 * R - C2 * B + L}$$

$$SAVI = (1 + L) \frac{NIR - R}{NIR + R + L}$$

$$MSAVI = \frac{2NIR + 1 - \sqrt{(2NIR + 1)^2 - 8(NIR - R)}}{2}$$

## Eddy covariance footprint analyses – upscaling with Landsat

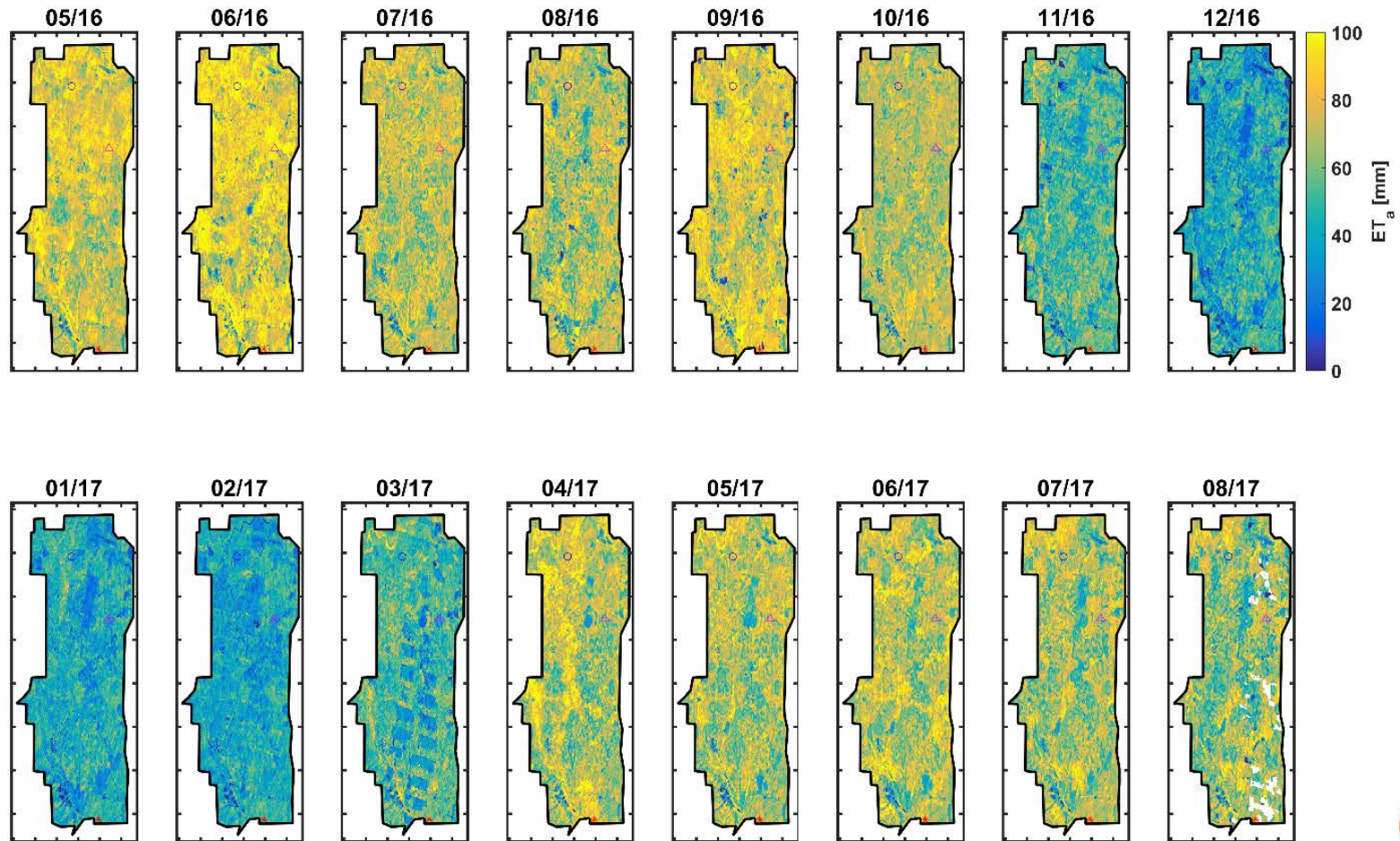


### Footprint Flux Summary

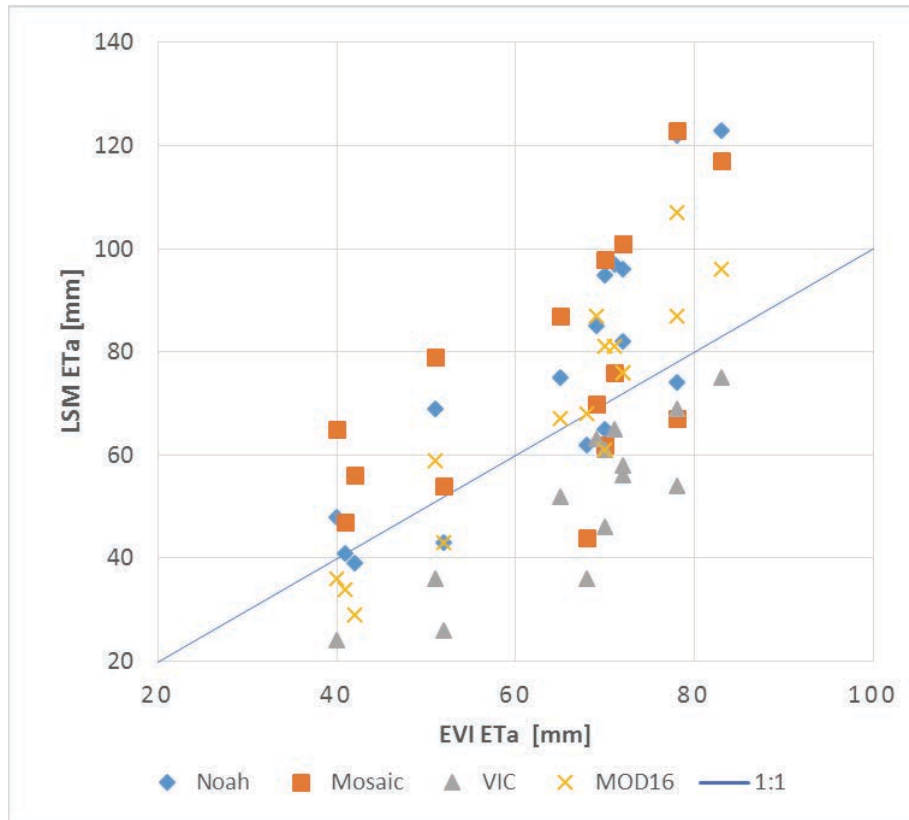
- Enhanced Veg Index
  - captures wider dynamic range
  - more robust statistics
- Normalized Veg Difference Index
  - Significantly higher values
  - tends to saturate at higher levels
- SAVI/MSAVI also show promise
- Future work (2019) will find higher/lower EVI locations to guide ET<sub>a</sub> sites

Based on annual groundwater discharge approach from Beamer et al., 2013, *JAWRA*.

# Monthly $ET_a$ based on satellite composite EVI for Camp Bullis, TX



## Monthly $ET_a$ inter-comparisons to Land Surface Models and Modis

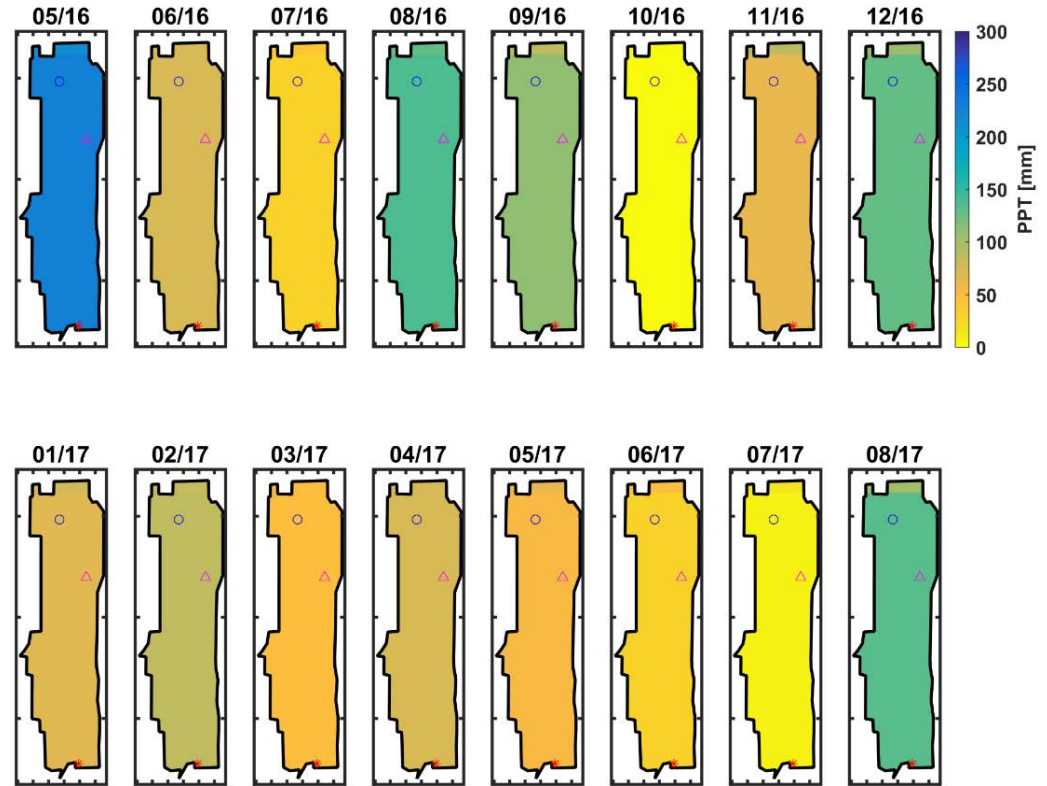
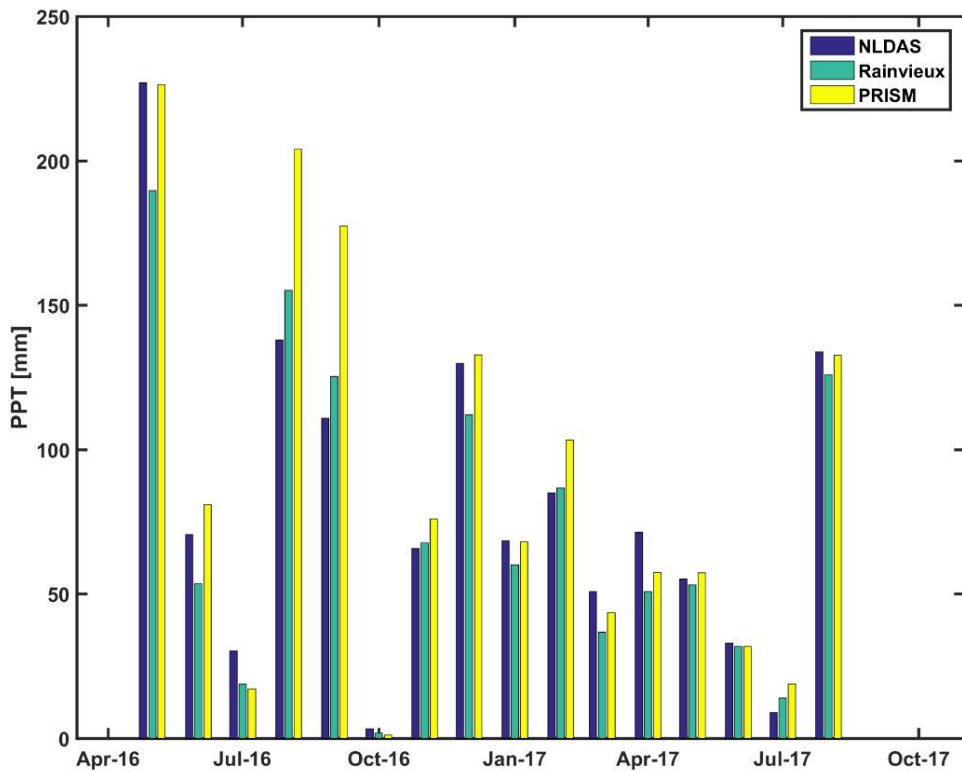


		Noah	Mosaic	VIC	MOD16
$R^2$	[-]	0.71	0.39	0.84	0.87
RMSE	[mm]	20.0	23.1	18.3	11.5
Bias	[mm]	12.1	14.1	-16.7	4.13

- Noah, Mosaic and VIC from North American Land Data Assimilation (NLDAS-2) model ensemble
- MOD16 based on Modis LAI, Albedo, FPAR, land cover, and additional soil-bio-atmo modeling

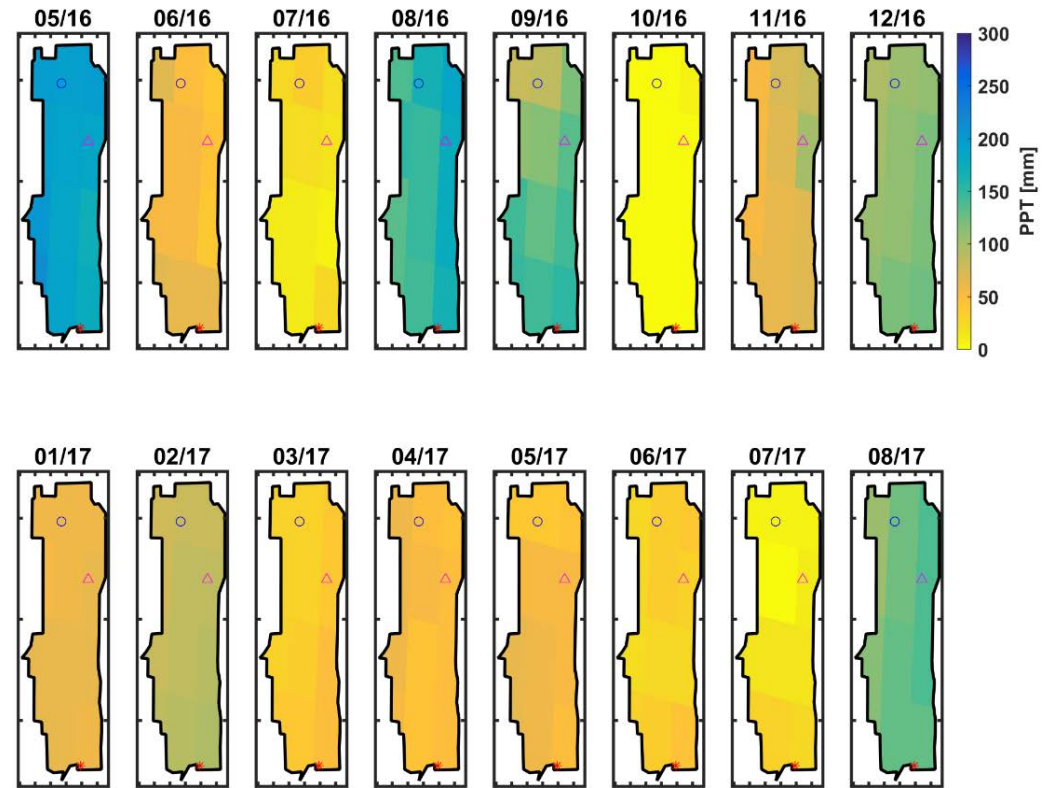
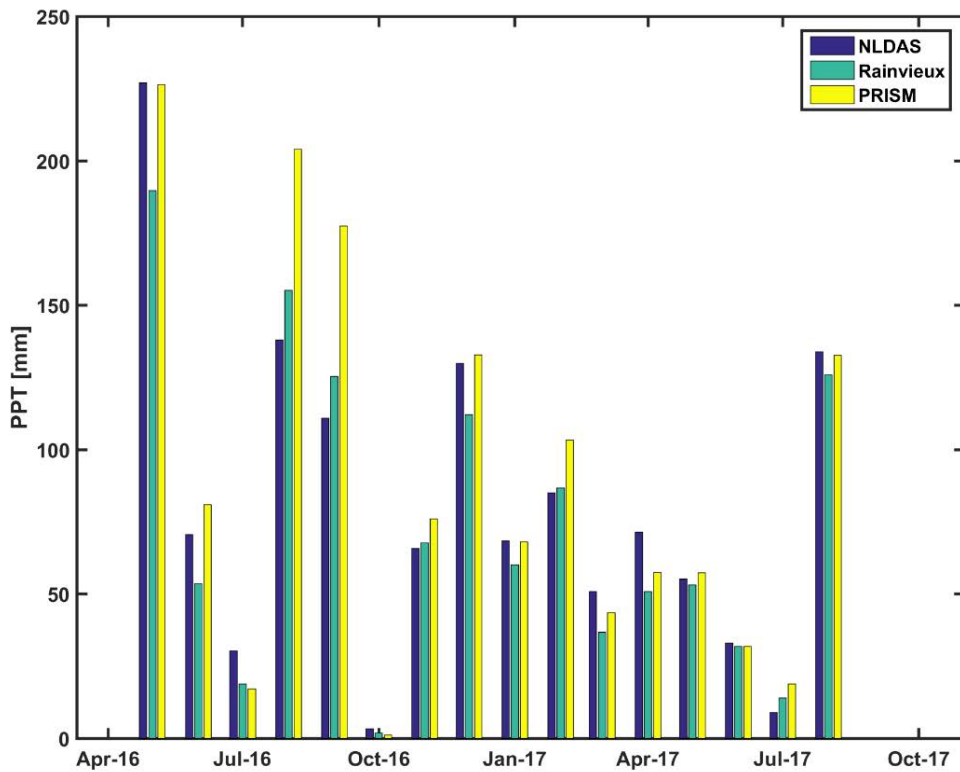
# Monthly Precipitation for Camp Bullis, TX

NLDAS (NARR) 1/8° (16 km)

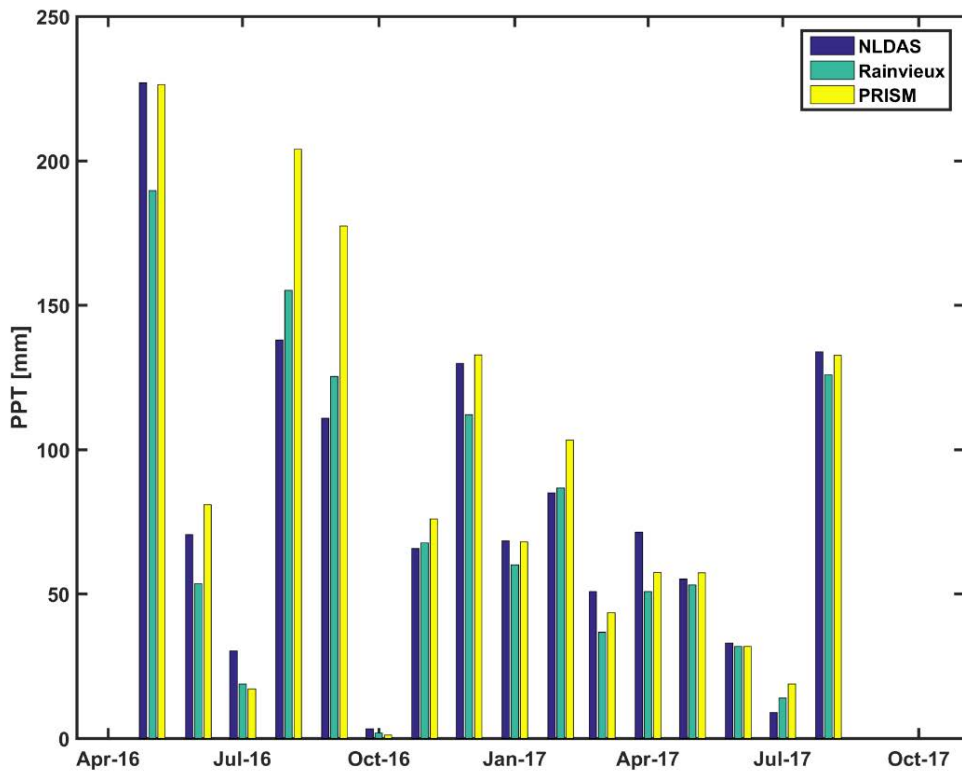


# Monthly Precipitation for Camp Bullis, TX

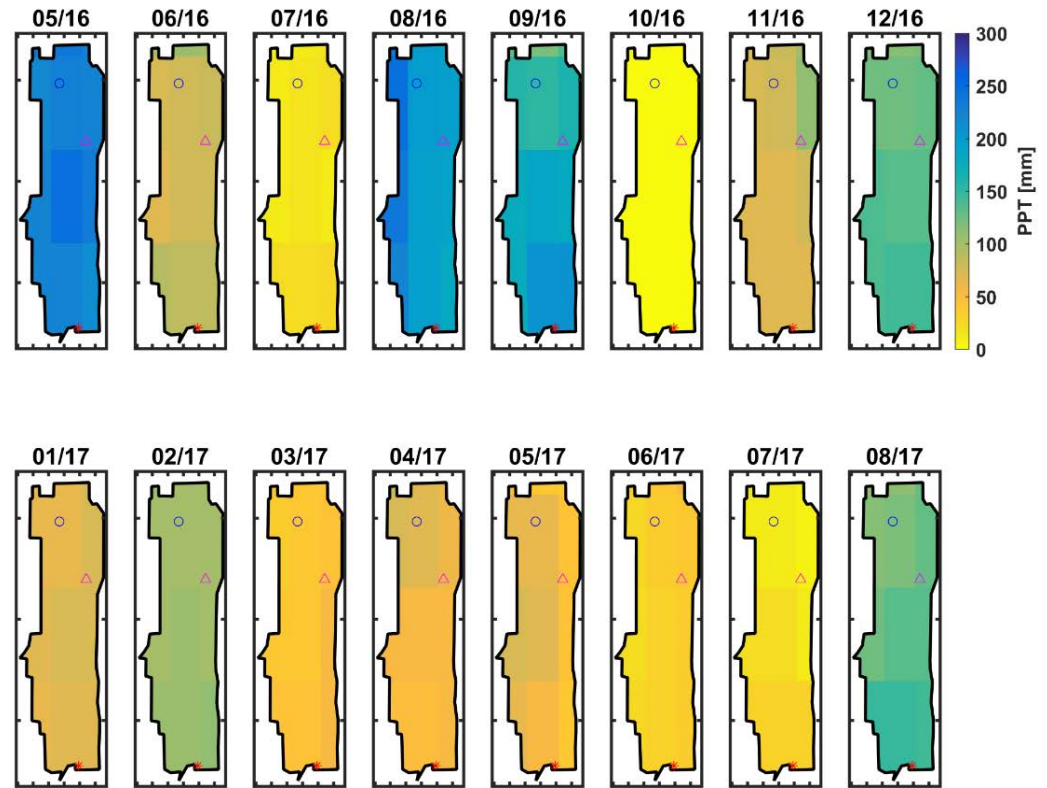
RainVieux (~4 km)



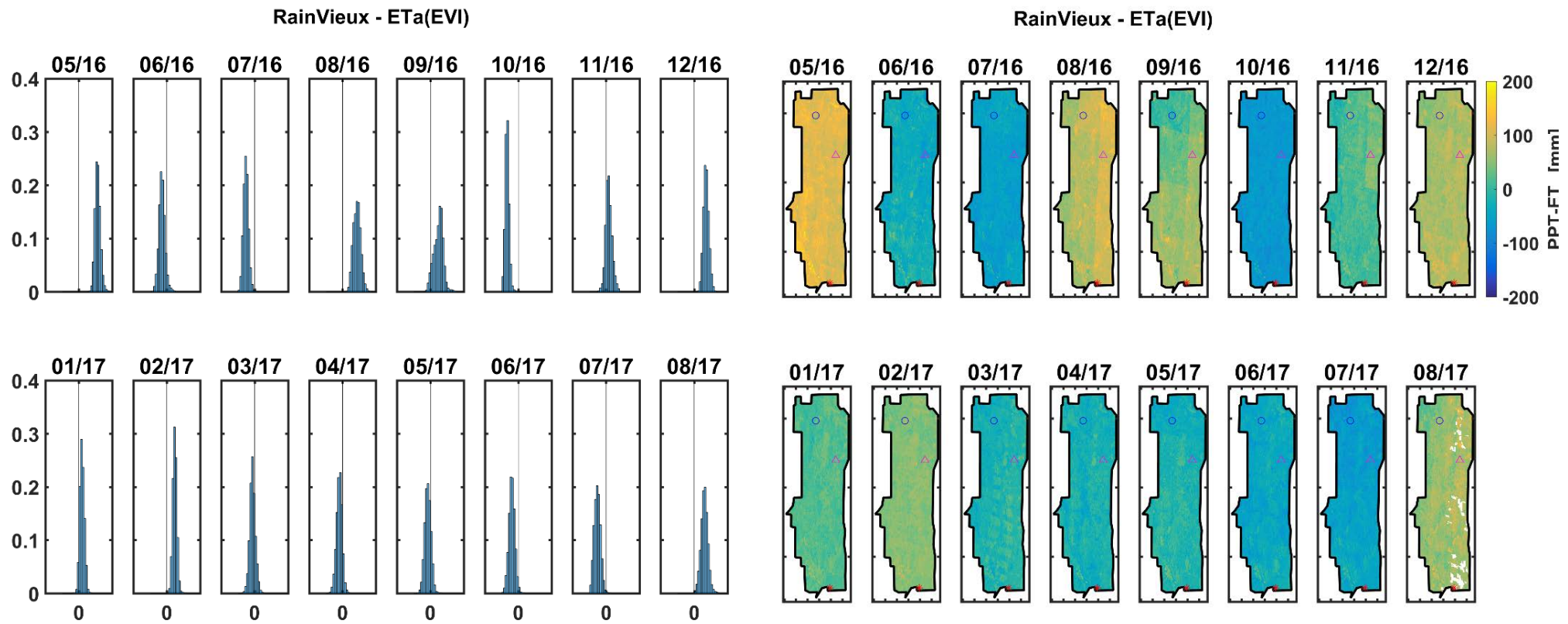
# Monthly Precipitation for Camp Bullis, TX



PRISM (4 km)



# Monthly $R_{df}$ based on satellite composite EVI for Camp Bullis, TX



# Quantifying Diffuse Recharge (QDR) - Conclusions

## Results to date:

- Three EC stations are fully operational
  - Good diversity of variable vegetation indices
  - Combined nearly 36 months of data
  - LE+H is ~90% of G+RN – our  $ET_a$  is biased low
- Four vegetation indices produce consistent regional  $ET_a$
- Inter-comparisons of monthly  $ET_a$  are reasonable
- For our 12-month window  $ET_a/P$  ranged from 0.70 to 0.86
- Is  $ET_a/P$  appropriate? And at what time-scale?

	12-month window	Annual PPT [mm]	Eta (EVI) [mm]	$R_{df}$ [mm]	$ET_a/P$ [-]	$R_{df}/P$ [-]
NLDAS-NARR		931		179	0.81	0.19
RainVieux		877	752	125	0.86	0.14
Prism		1070		318	0.70	0.30

## Future plans:

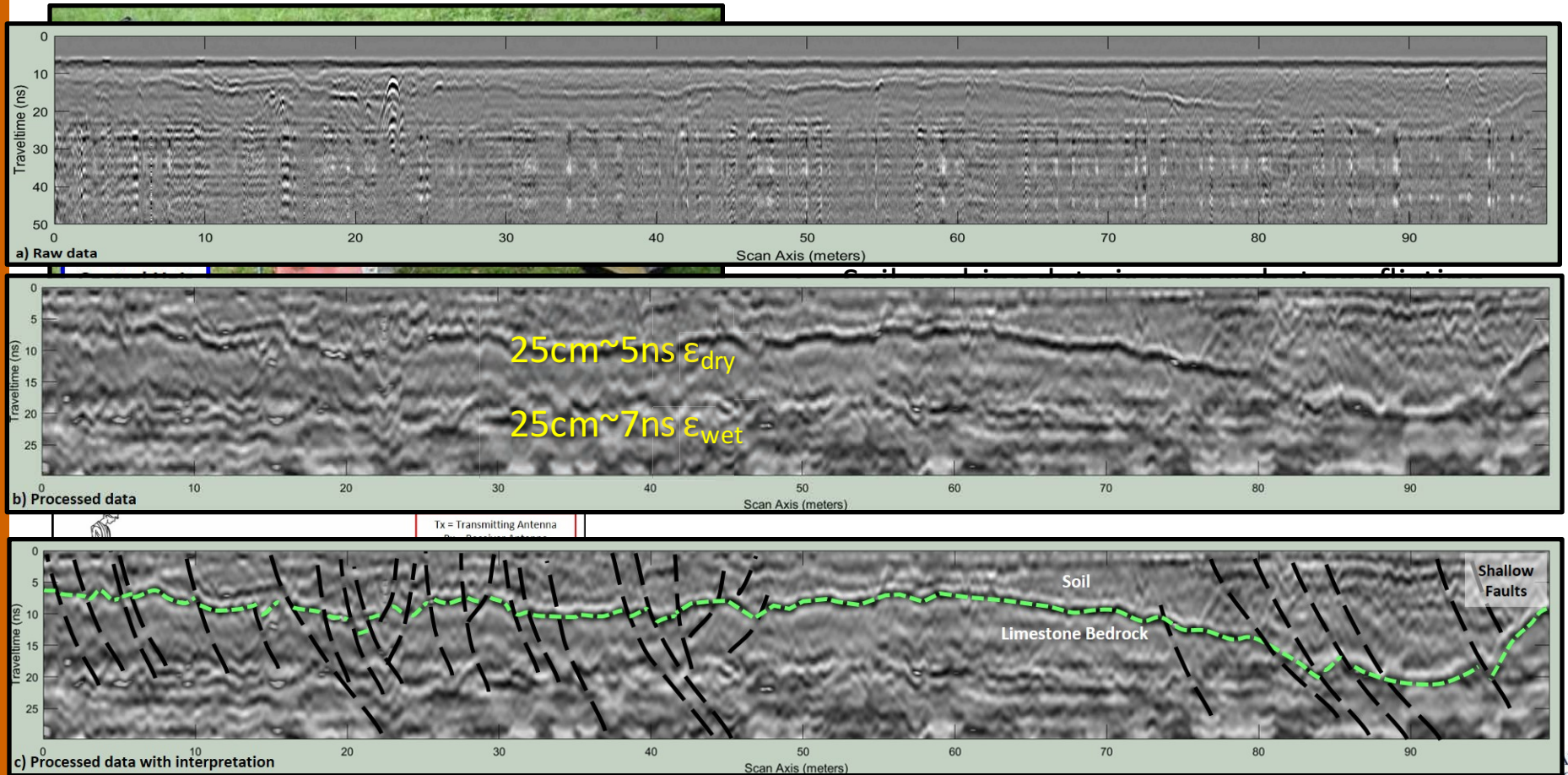
- Recharge estimates from a distributed vadose zone model (Hydrus)
- Improve soil mapping using EM/GPR and digital soil mapping
- Integrate  $ET_a$  into EAA-HSPF recharge model
- Integrate into HEM conduit flow model

# Camp Bullis extra slides

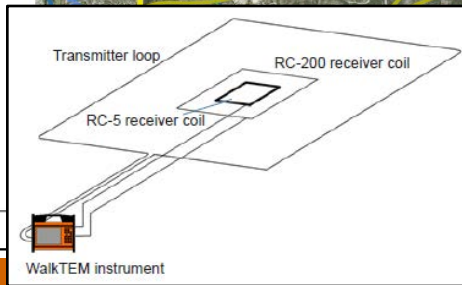
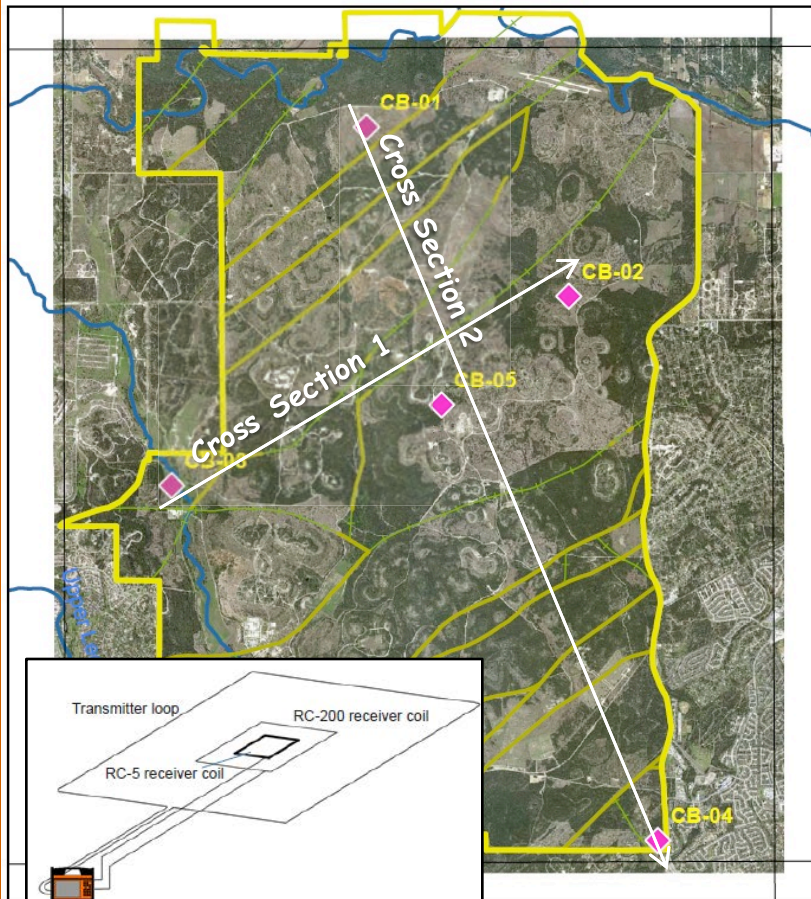
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# QDR geophysical sensors - GPR



# QDR geophysical sensors - TDEM



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