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Monitoring CO2 at an enhanced oil recovery and carbon capture and storage project, Farnsworth unit, Texas

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SCIENCE-ENGINEERING-RESEARCH-UNIVERSITY

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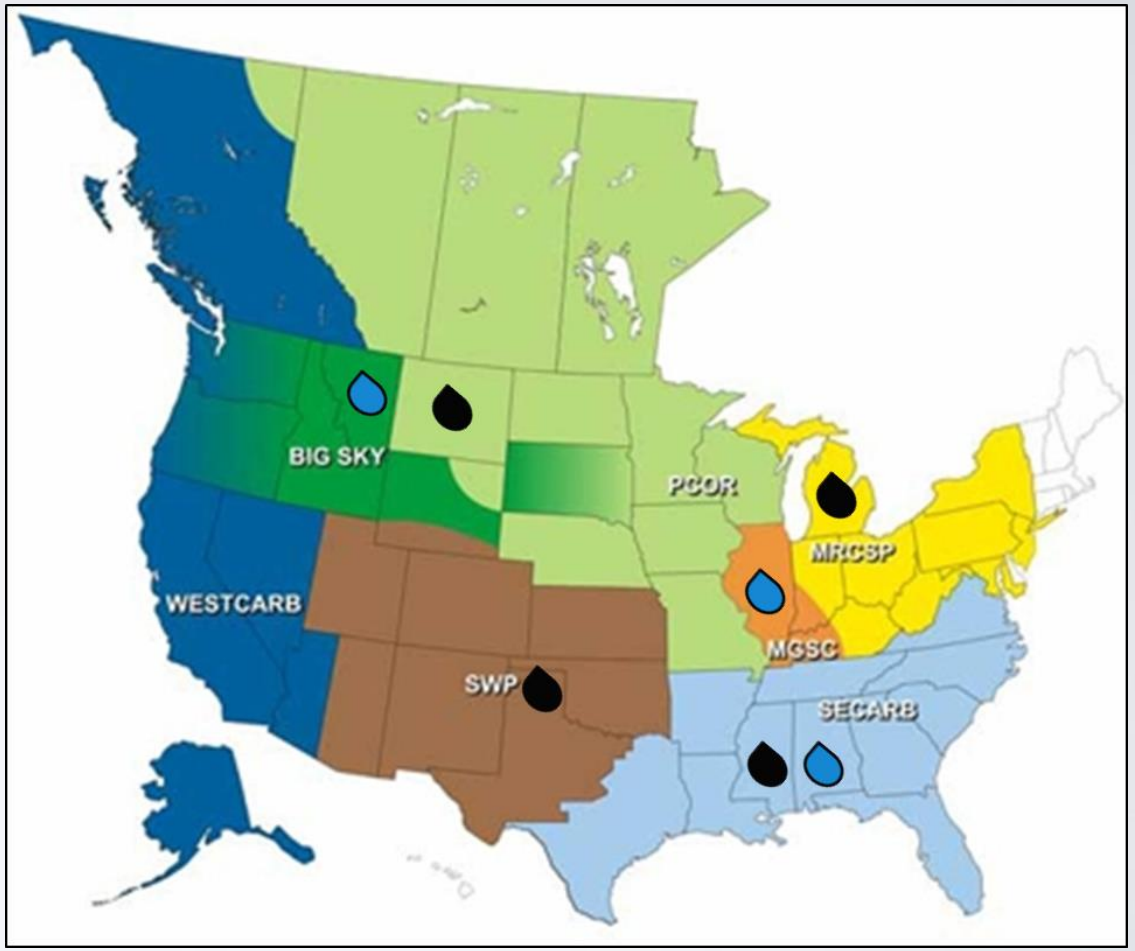
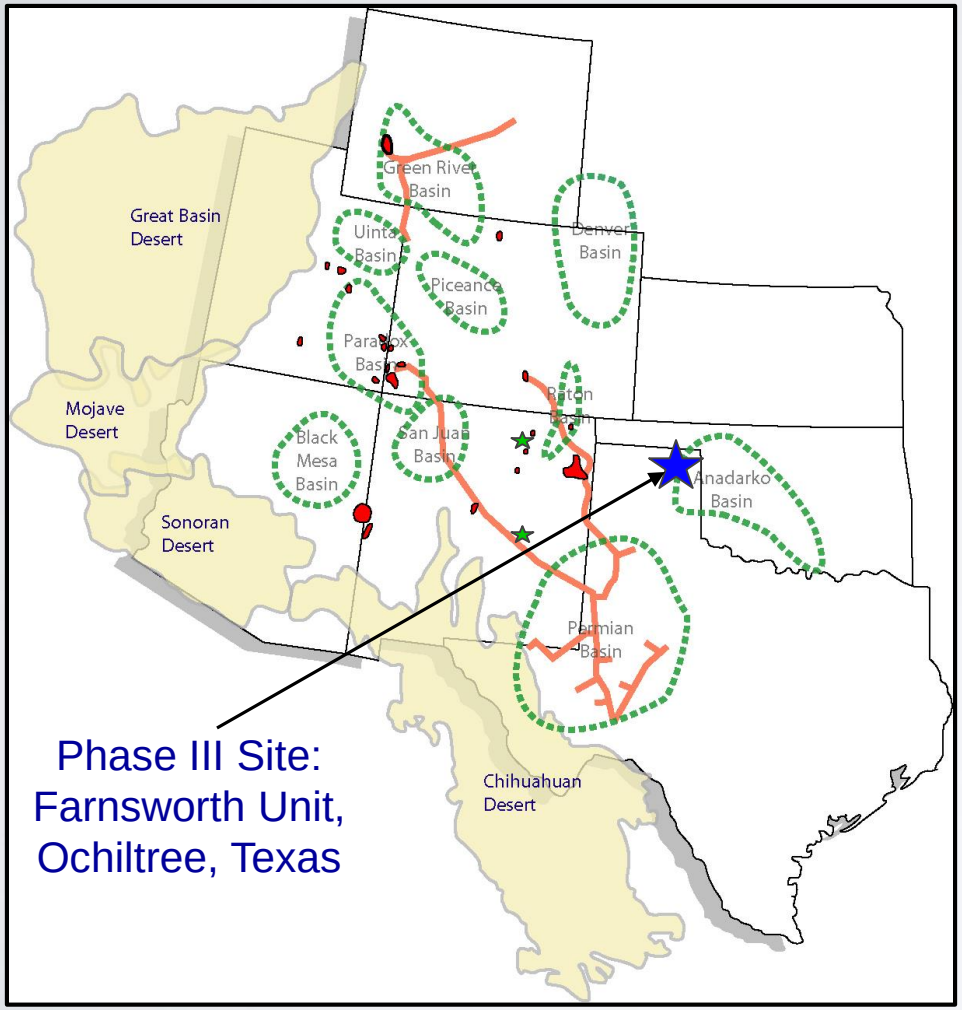
USA Case Studies for CCS

- US Department of Energy Regional Carbon Sequestration Partnerships
  - Seven regional partnerships
- Each demonstrating injection of at least 1,000,000 metric tons of CO_2
- Four of these projects are demonstrating storage in conjunction with EOR
- Developing “best practices” for utilizing captured CO_2



Modified from http://energy.gov/fe/science-innovation/carbon-capture-and-storage-research/regional-partnerships

Southwest Partnership Goals



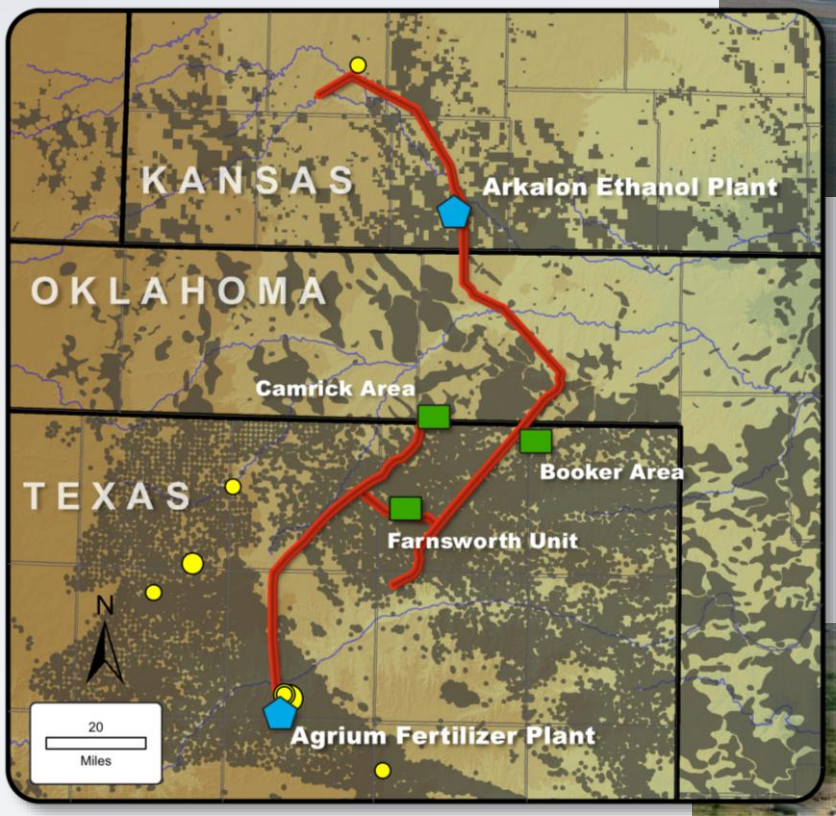
The SWP's Phase III project is a large-scale EOR-CCUS test

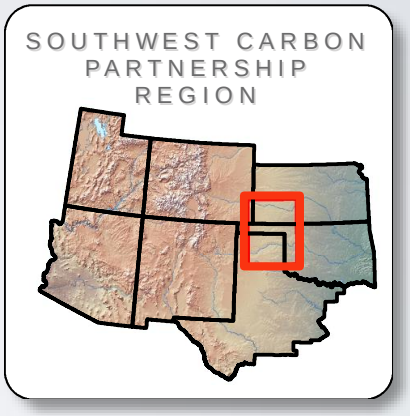
- **General Goals:**
- One million tons CO_2 injection
- Optimization of storage engineering
- Optimization of monitoring design
- Optimization of risk assessment
- Blueprint for CCUS in southwestern U.S.

Farnsworth Field

Anthropogenic Supply: 500-600,000 Metric tons CO_2/year supply

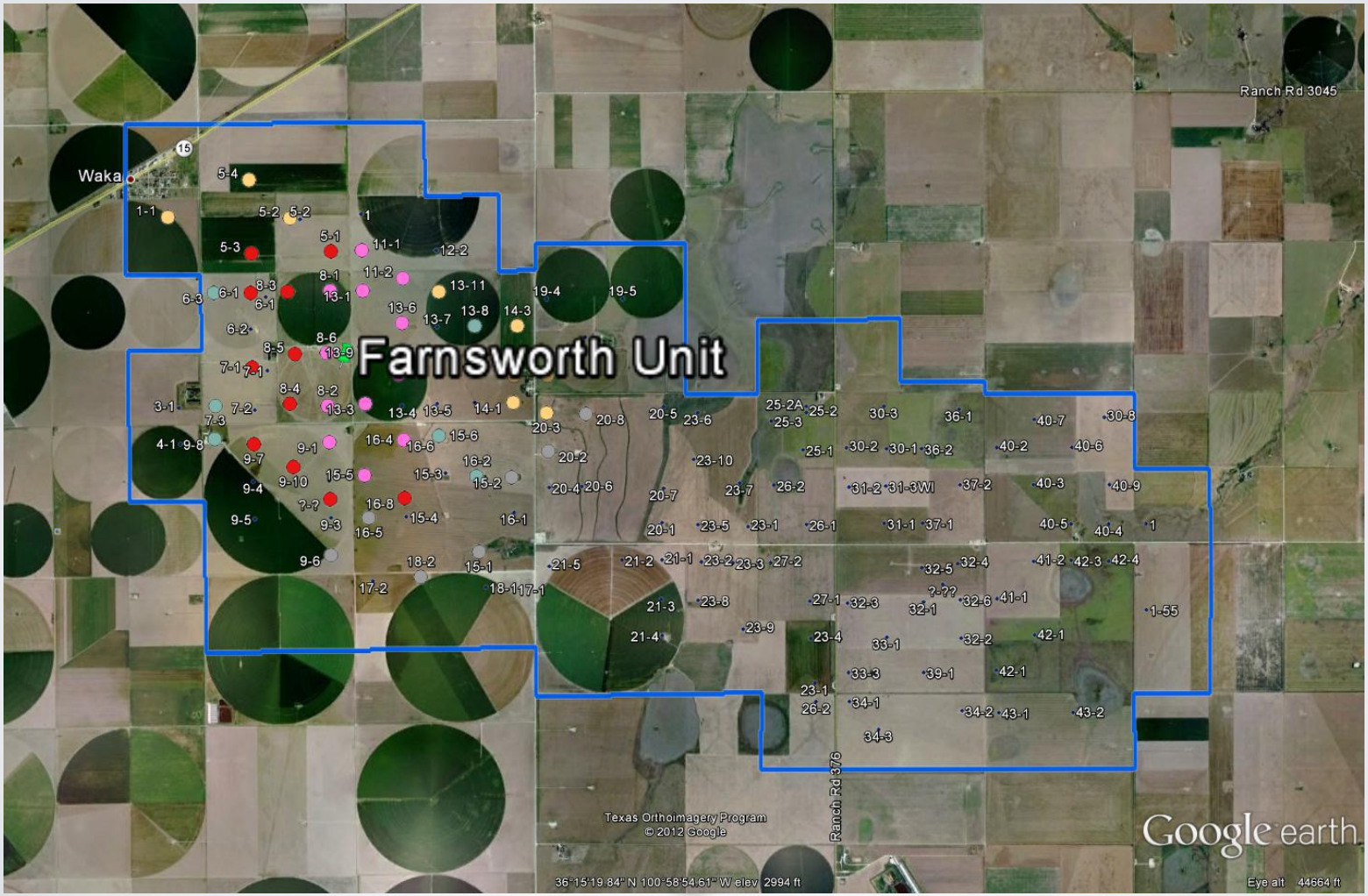
- Field discovery
  - 1955
- 100 wells by
  - 1960
- Unitized 1963
  - Waterflood
- CO2 flood started in 2010





Project Site

Actively farmed land,
West half being developed for CO2 EOR



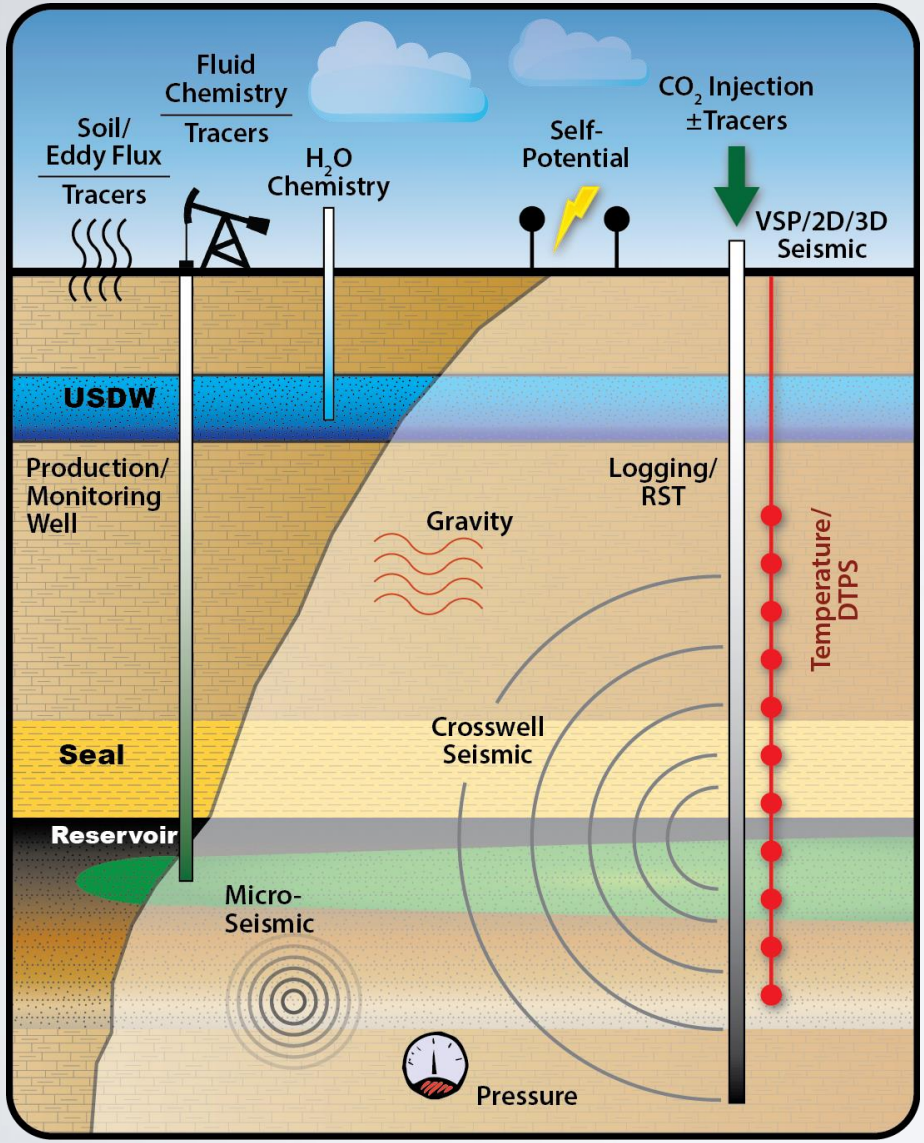
SWP Monitoring, Verification, and Accounting

SWP MVA Objectives at the Farnsworth Unit

- Collect and analyze data needed to characterize injected CO_2 Volumes
- Study CO_2 Migration (temporal and spatial)
- Understand trapping mechanisms
- Monitor pathways for potential leakage (USDW and atmosphere)
- Facilitate storage security predictions using simulation

Monitoring is accomplished with direct and indirect methods

SWP MVA Methods



Detecting CO_2 at Surface:

- Surface soil CO_2 flux
- Atmospheric CO_2/CH_4 eddy flux
- Gas phase tracers

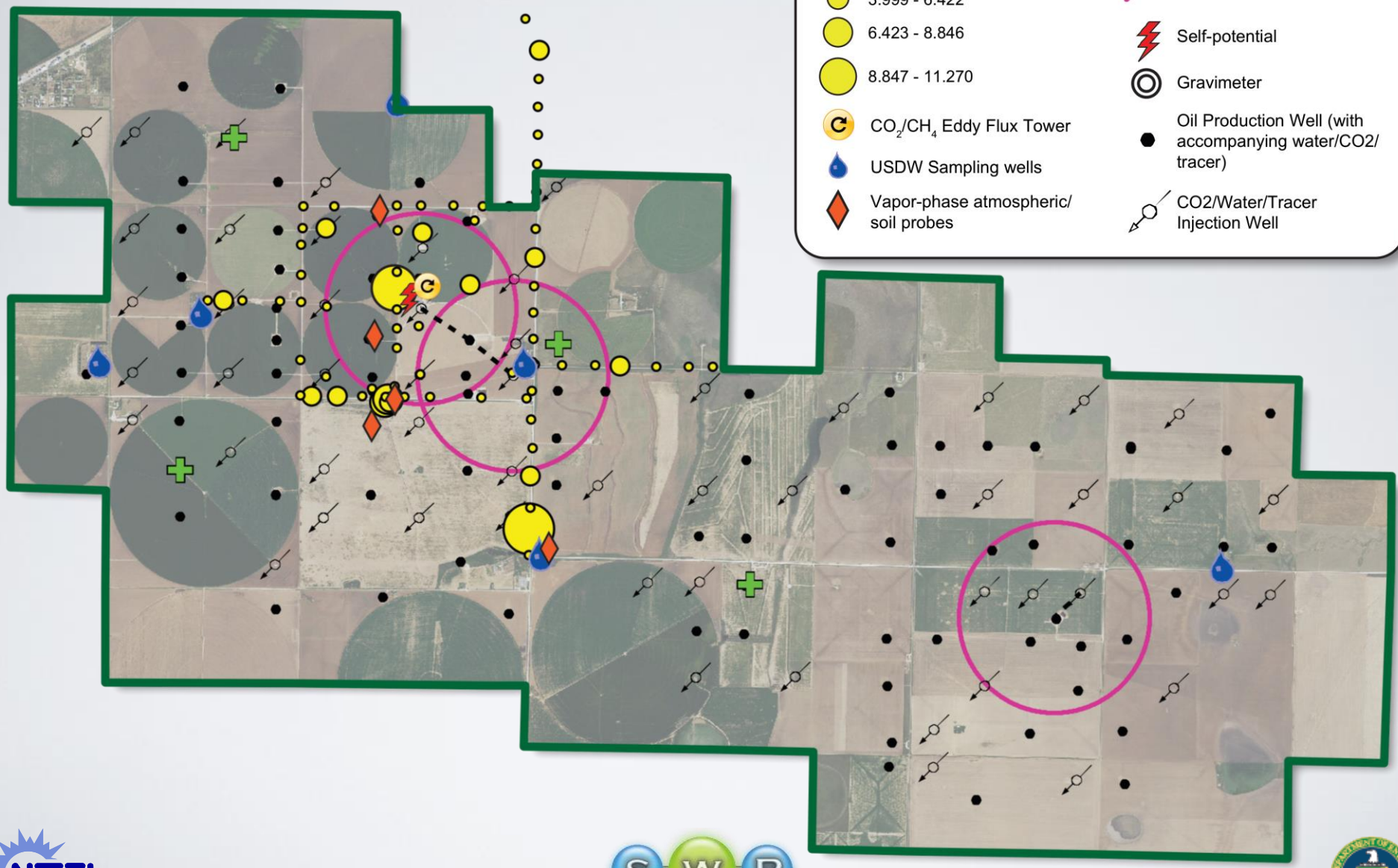
Detecting CO_2 and/or other fluid migration in Target/Non-Target Reservoirs:

- Groundwater chemistry (USDWs)
- Water/gas phase tracers
- Self-potential

Tracking CO_2 Migration and Fate:

- *In situ* pressure & temperature
- 2D/3D seismic reflection surveys
- VSP and Cross-well seismic
- Passive seismic
- Fluid chemistry (target reservoir)
- Water/gas phase tracers
- Microgravity surveys
- Water/gas isotopes

SWP - MVA Methods



Surface Monitoring – Soil Flux

CO_2 Soil & Eddy Flux

Identify and quantify any increase of CO_2 flux and/or concentration due to injection or surface activities (diffusive leakage from shallow subsurface or point source leaks).

Surface Monitoring – Soil Flux

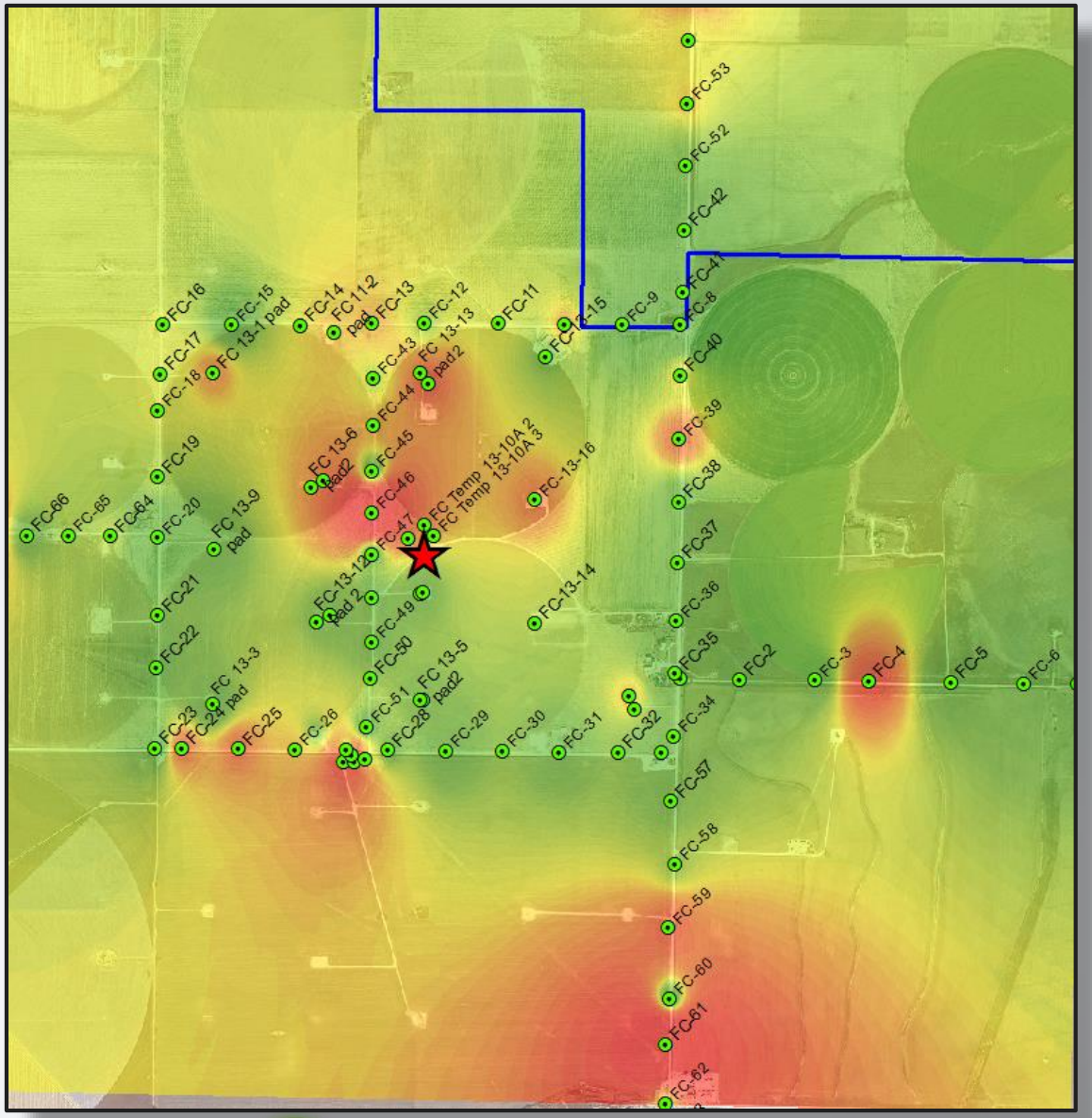
CO_2 Soil Flux

- Accomplished by: Quarterly measurements at >93 semi-permanent sites.
- Soil collars “planted” and surveyed at safe locations around 13-10A.
- Visit collar grid once per quarter.
- 5 to 10 minutes per station with human-portable infrared (CO2) gas analyzer with recirculating chamber records flux.
- Compile and analyze data; look for trends.

Surface Monitoring - Soil Flux

CO_2 Soil Flux

- Soil collars located around main project CO_2 injection well (13-10A)



CO_2 Flux
(µmol/m^2/sec)

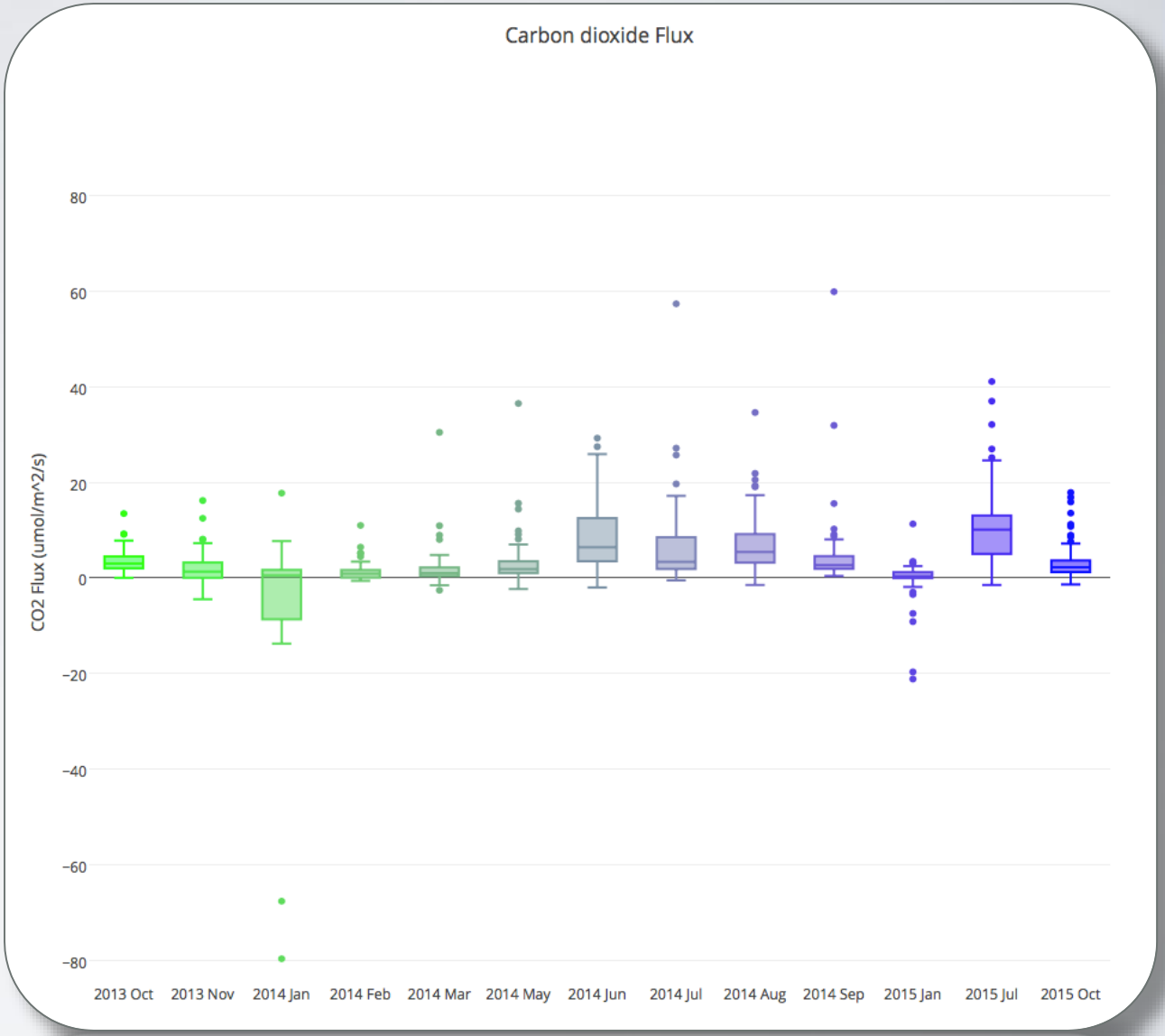
High : 11.3

Low : -0.8

Surface Monitoring – Soil Flux

CO_2 Soil Flux

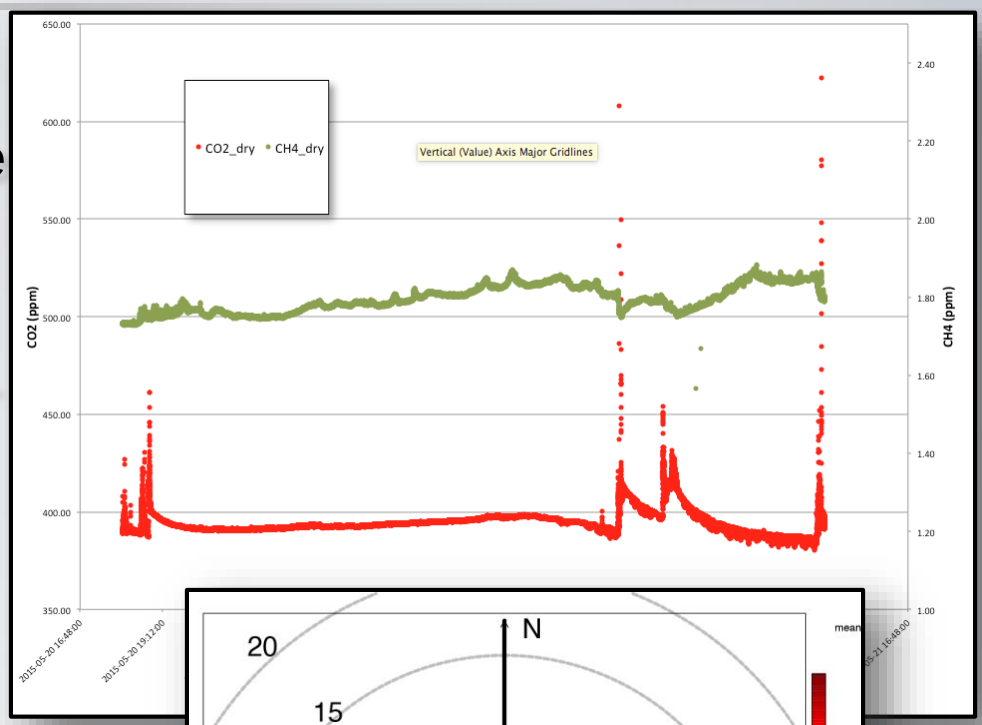
2+ years of soil flux collar surveys around well #13-10A have detected no significant increase in CO_2 levels.

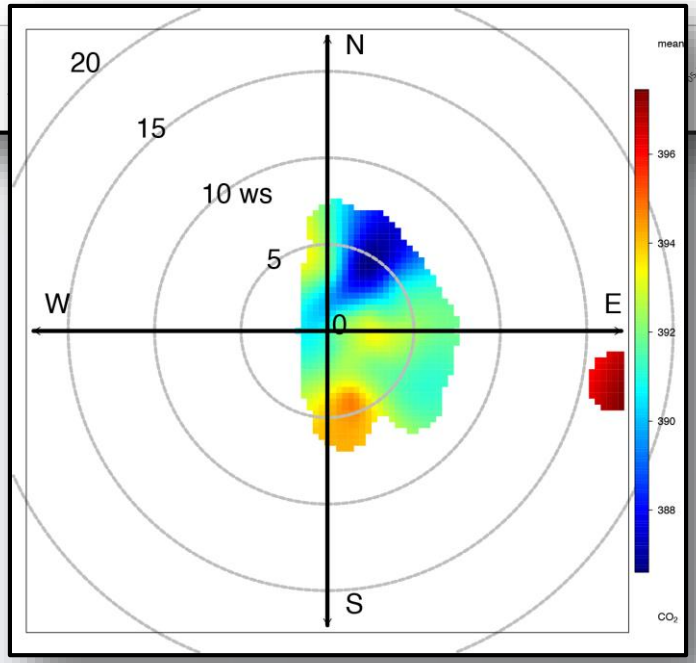


Surface Monitoring – Eddy Flux

CO_2 Eddy Flux

- Continuous, wide-area coverage and point-source leak detection.
- Initial installation of eddy flux system at the 13-10A data shed.
- Continuous acquisition of CO_2 (CH_4 and H_2O) flux/concentration and wind (speed and direction)
- Probability estimates of leak sources
- “Triangulation” of sources with multiple eddy flux systems (second system will be deployed summer 2016)

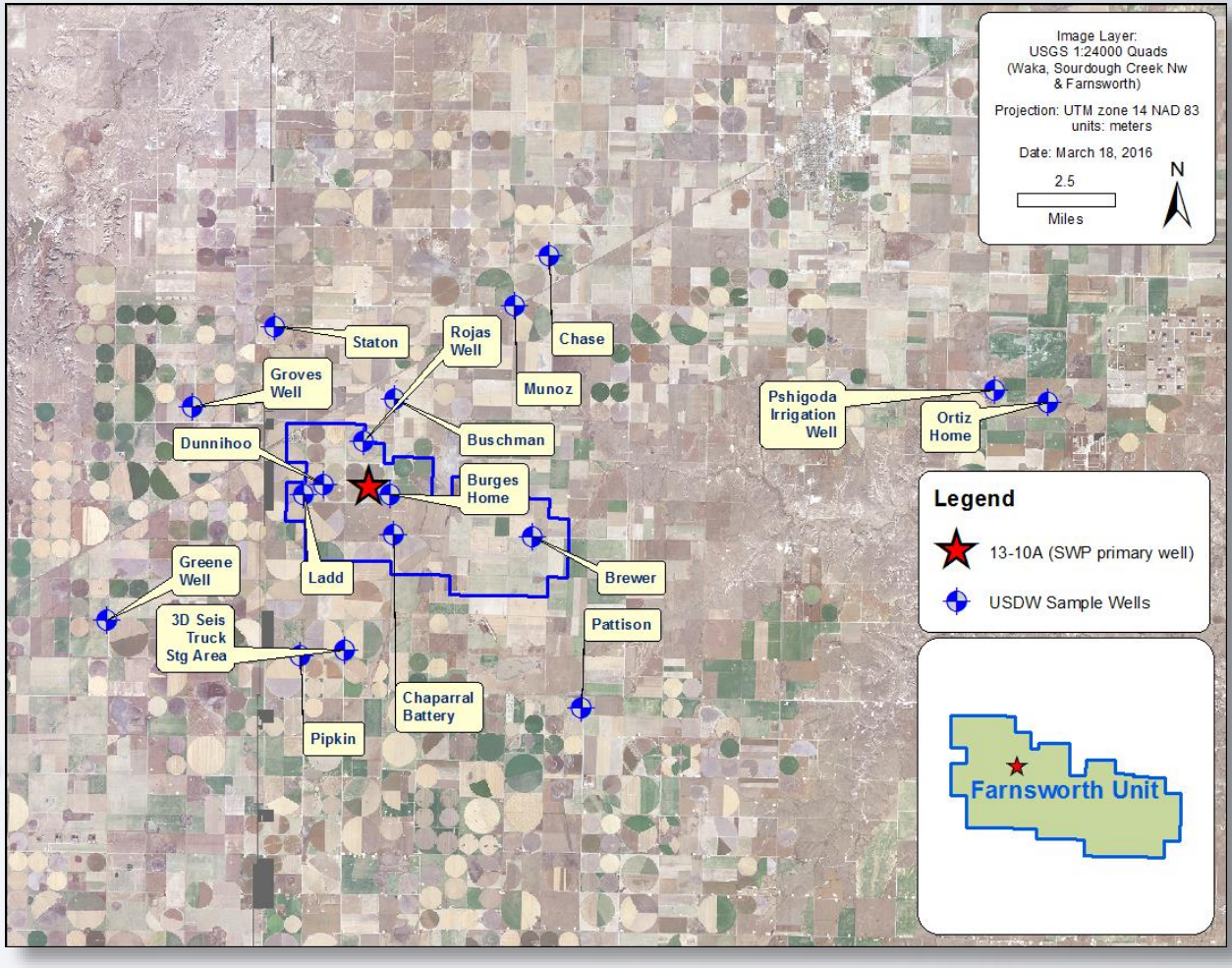




Near Surface Monitoring – USDW

USDW

- Quarterly sampling of Ogallala aquifer to monitor for brine, oil and/or CO_2 leakage from depth.
  - Major ions
  - pH
  - Conductivity
  - Alkalinity
  - Oxidation and
  - Reduction Potentials
  - Inorganic/organic
  - Carbon
  - Trace Metals
  - Isotopes (^{13}C,^{18}O, and D)



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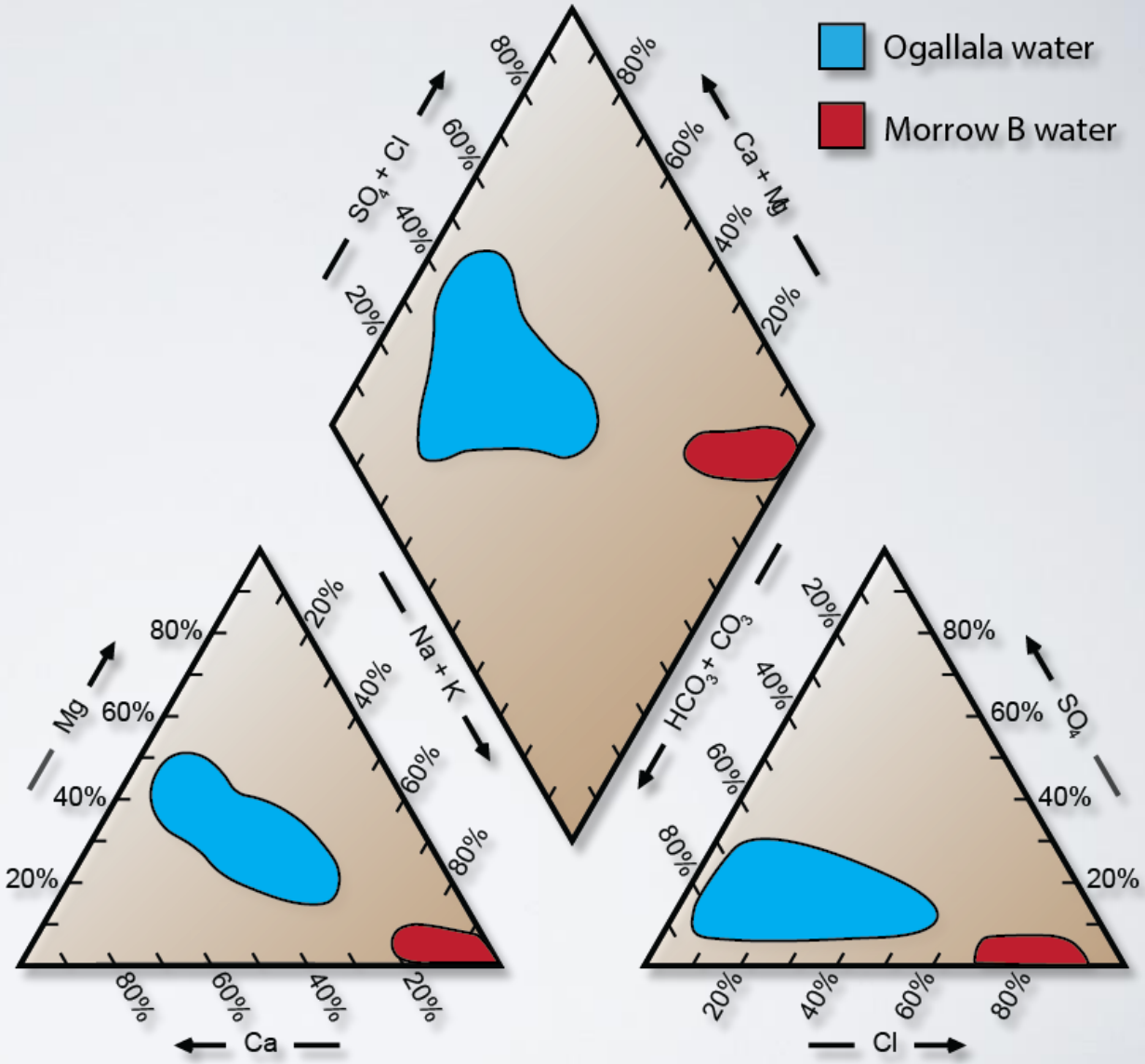

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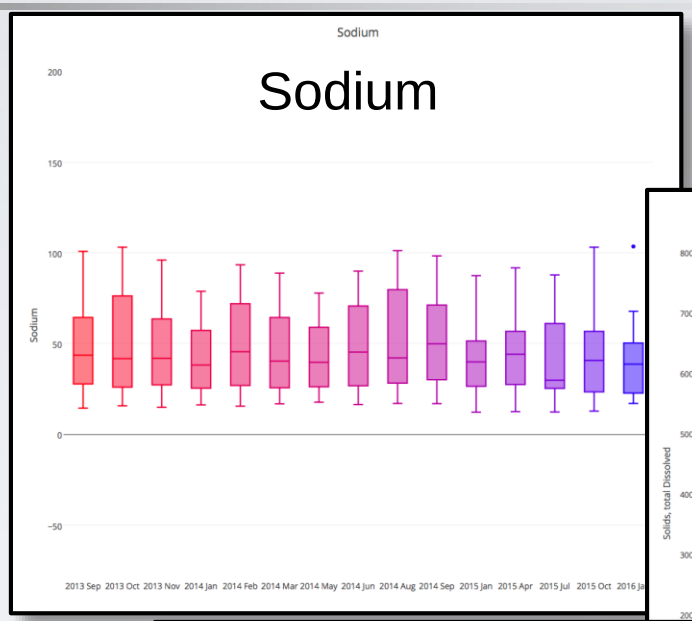
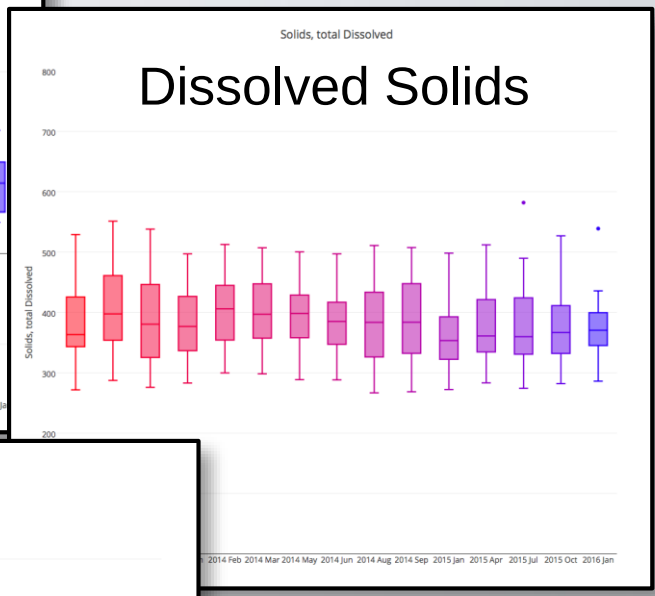
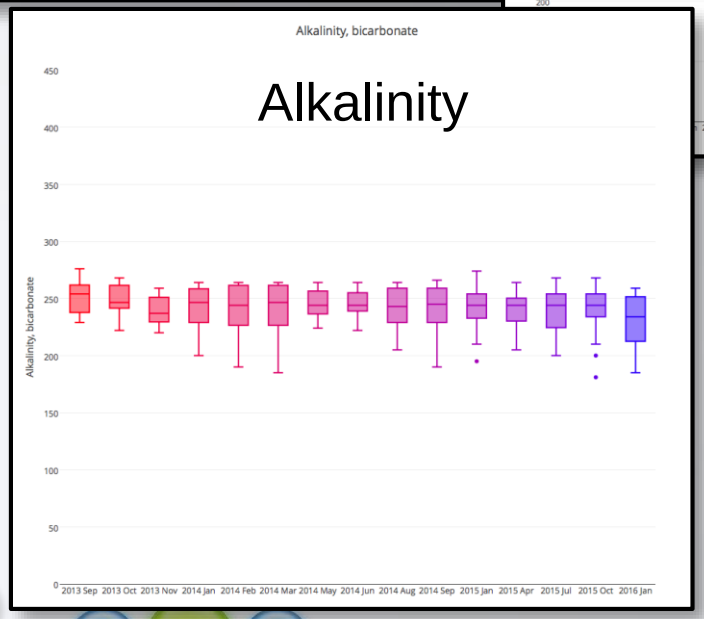
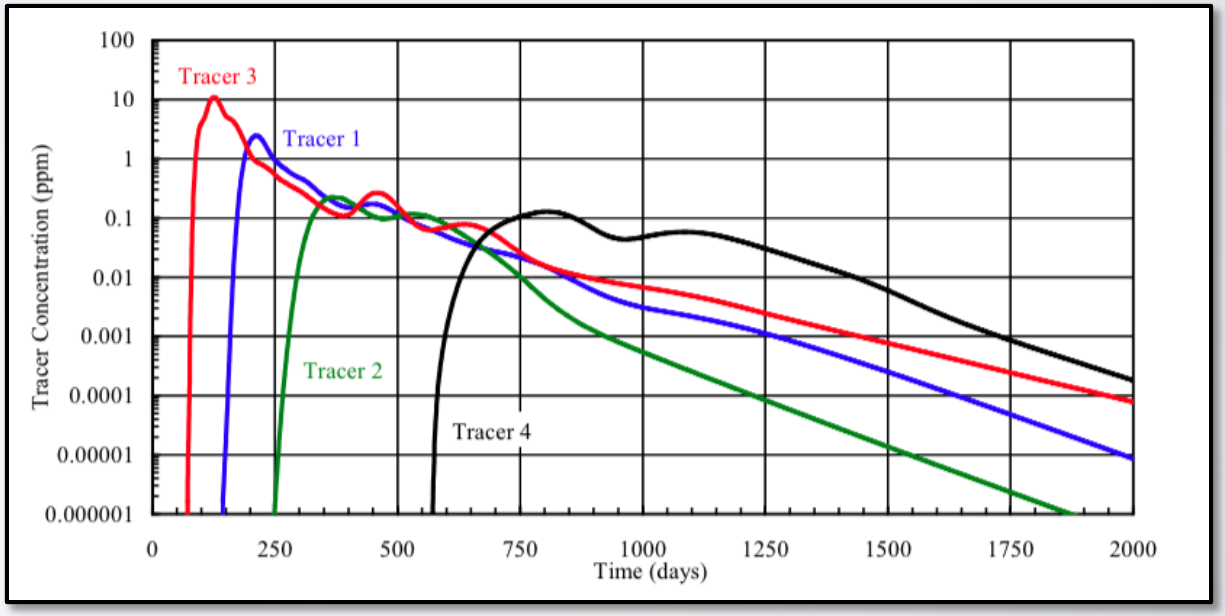






Sub Surface Monitoring – Tracers

- Determine fluid-flow patterns & travel time between injection & production wells
- Constrain and calibrate flow models; predict the fate of the injected CO_2
- Detection and quantify CO_2/brine leakage to subsurface/atmosphere
- Attempt to determine CO_2 saturation levels and storage capacity
- Attempt to determine sweep efficiency (tracer concentration history)
- Confirm other verification methods (e.g. seismic)



Example tracer recovery plot

Sub Surface Monitoring – Tracers

Tracers – Aqueous- and Vapor-Phase

- **Aqueous Phase:** naphthalene sulfonates; conservative tracers that follow water phase (Pete Rose – University of Utah).
  - Up to 8 unique aqueous-phase tracers available.
- **Vapor Phase:** perfluorocarbons; conservative tracers that follow gas phase (Rod Diehl – NETL).
  - Up to 7 unique vapor-phase tracers available.
- **Oil Phase:** Not planned at this time.

- Aqueous Phase (n=8)
  - 1-naphthalenesulfonic acid, sodium salt
  - 2-naphthalenesulfonic acid, sodium salt
  - 1,5-naphthalenedisulfonic acid, disodium salt
  - 1,6-naphthalenedisulfonic acid, disodium salt
  - 2,6-naphthalenedisulfonic acid, disodium salt
  - 2,7-naphthalenedisulfonic acid, disodium salt
  - 1,3,5-naphthalenetrisulfonic acid, trisodium salt
  - 1,3,6-naphthalenetrisulfonic acid, trisodium salt
- Vapor Phase (n=7)
  - Perfluoro-dimethylcyclobutane (PDCB)
  - Perfluoro-methylcyclopentane (PMCP)
  - Perfluoro-methylcyclohexane (PMCH)
  - Perfluoro-ethylcyclohexane (PECH)
  - Perfluoro-1,2-dimethylcyclohexane (o-PDCH)
  - Perfluoro-1,3,5-trimethylcyclohexane (PTCH)
  - Perfluoro-isopropyl-cyclohexane (i-PPCH)

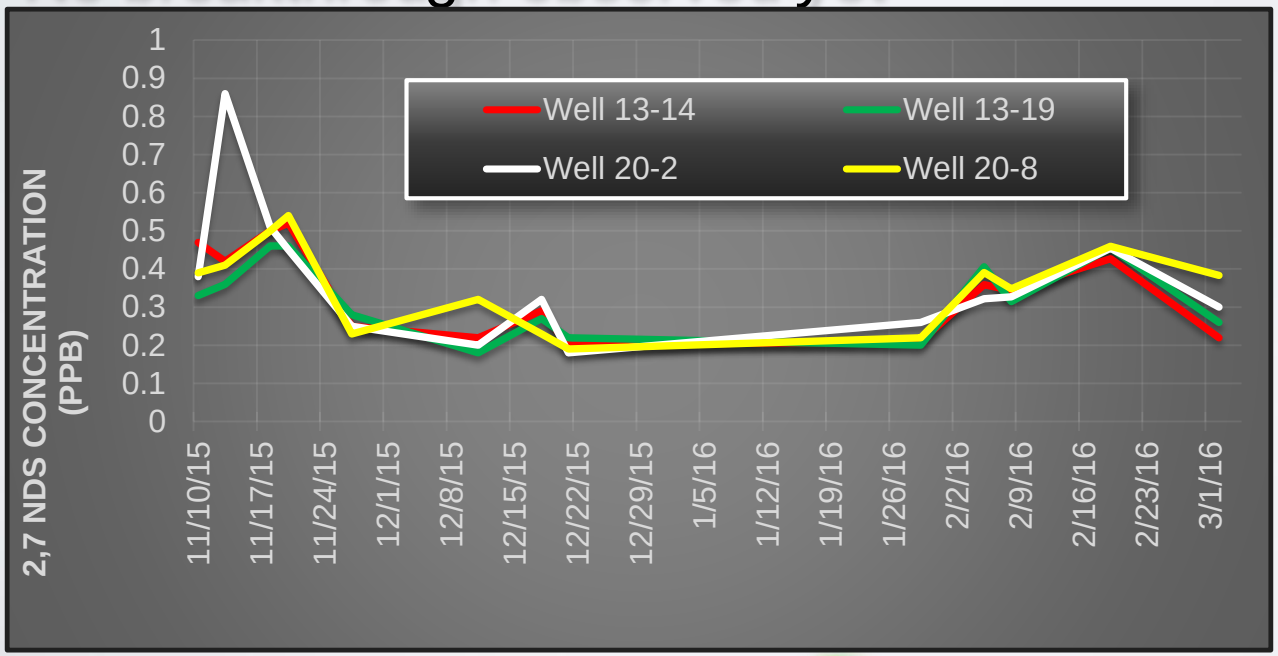
Tracer suite available for use at the FWU; green highlighted tracers already injected at FWU.

Sub Surface Monitoring – Tracers

- **Tracers – Aqueous-phase Injection #1**
  - FWU wells (on water flood) tagged with unique tracers in May, 2014
    - Well #13-13: 1-naphthalenesulfonic acid, sodium salt
    - Well #13-10A: 2-naphthalenesulfonic acid, sodium salt
    - Well #13-5: 1,5-naphthalenedisulfonic acid, disodium salt
  - Additional ~3 days of water injection, followed by CO_2 flood
  - **Never observed breakthrough!**

Sub Surface Monitoring – Tracers

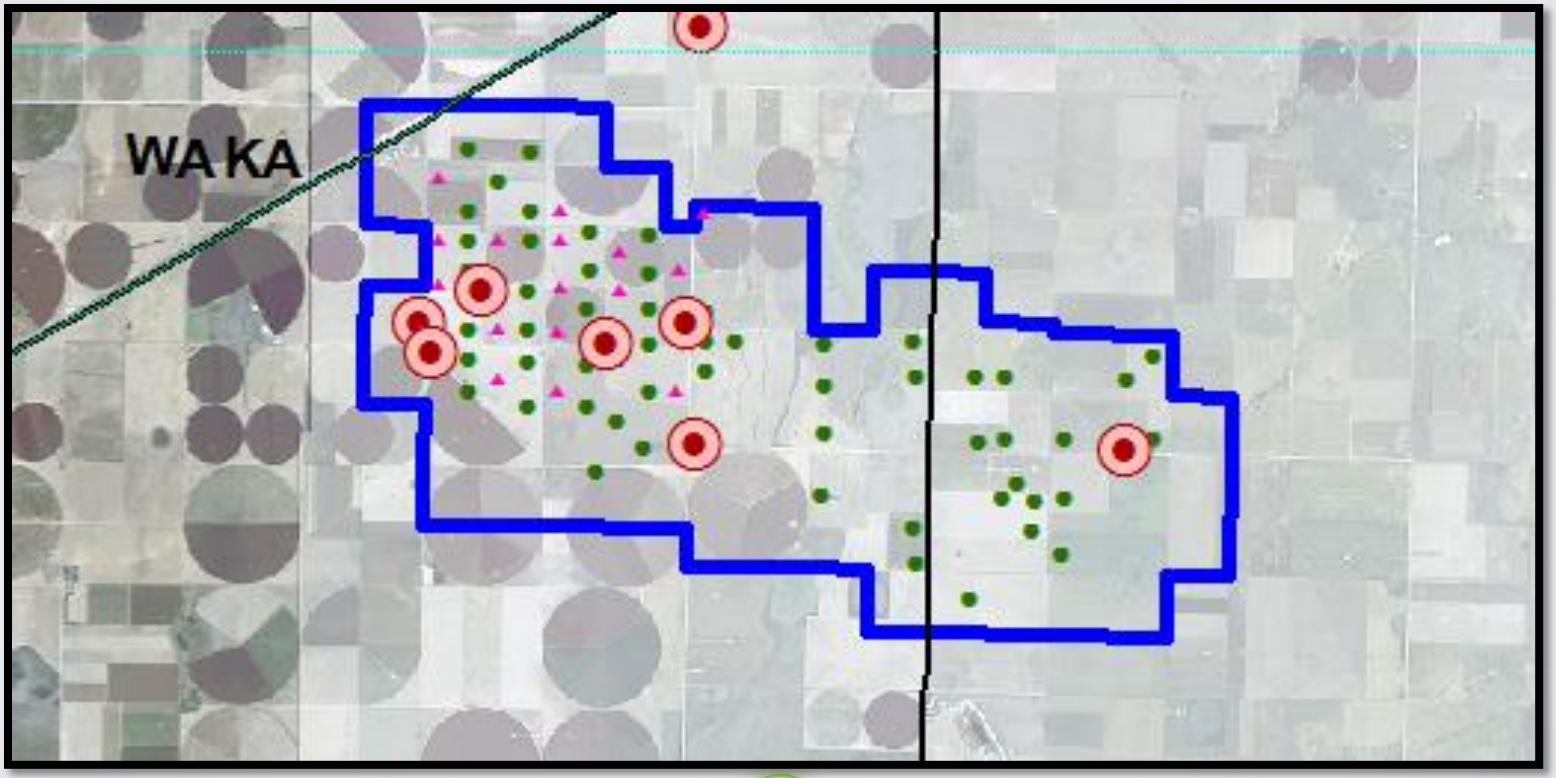
- **Tracers – Aqueous-phase Injection #2**
  - FWU well (on water flood) tagged with tracer in October, 2015
    - Well #14-1: 2,7-Naphthalenedisulfonic acid, disodium salt
    - 2 to 4 times the amount of NPT injected into previous wells
  - No switch to CO_2
  - No breakthrough observed yet*



Tracer production curve for current injection (14-1)

Sub Surface Monitoring – Tracers

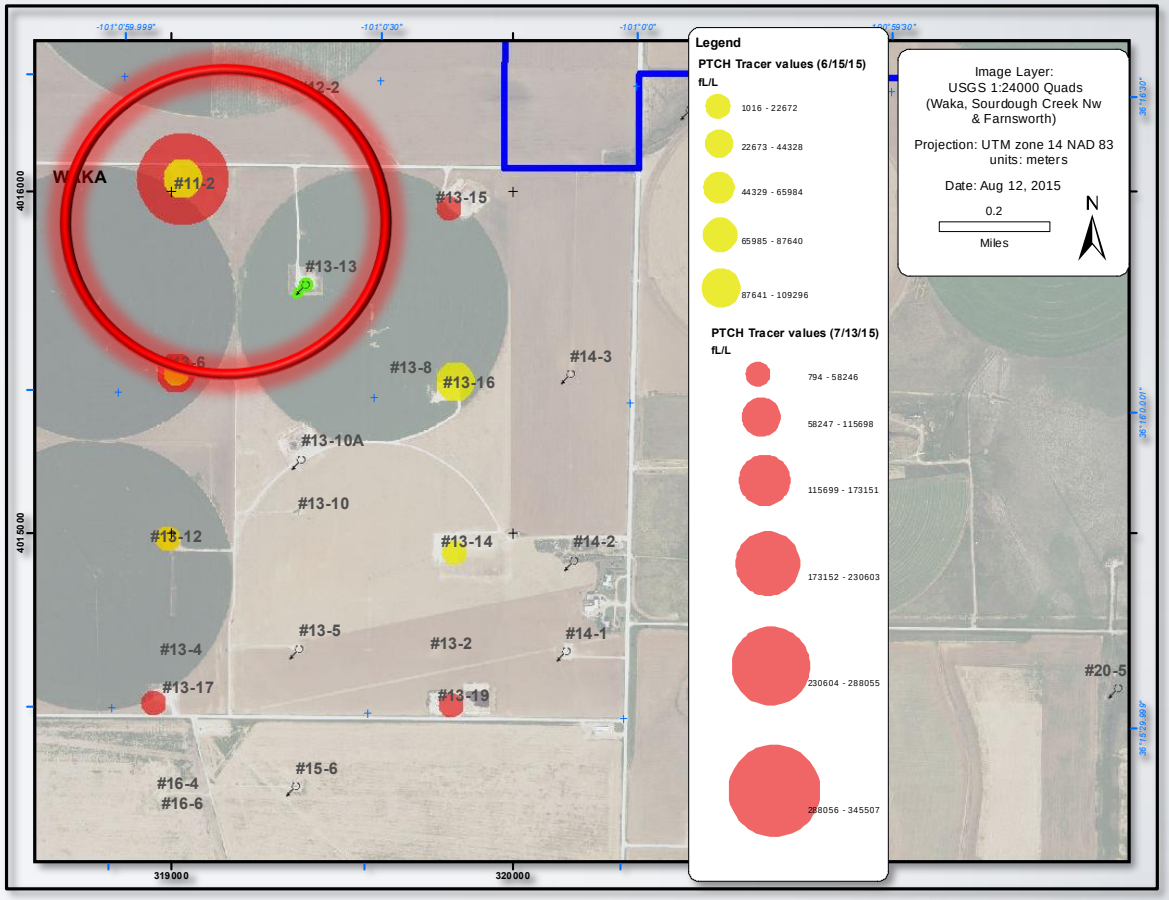
- Tracers – Additional Sampling
  - Because of the low detectability of the NPTs (<ppb), select USDW samples/wells (see map below) are analyzed quarterly for the injected water-phase tracers as well (monitoring for brine leakage from reservoir)
  - **No USDW NPT signals above background.**



Sub Surface Monitoring – Tracers

Tracers – Vapor-Phase Injection #1

- FWU well (on CO_2 flood) tagged with tracer in May, 2015
  - Well #13-13: PTCH (2 kg)
- Additional ~30 days of CO_2 injection
- Every other week to weekly sampling of production wells
- **"Breakthrough" after 2 to 4 weeks!**
  - (fast path or "short circuit" between 13-13 and 11-2)



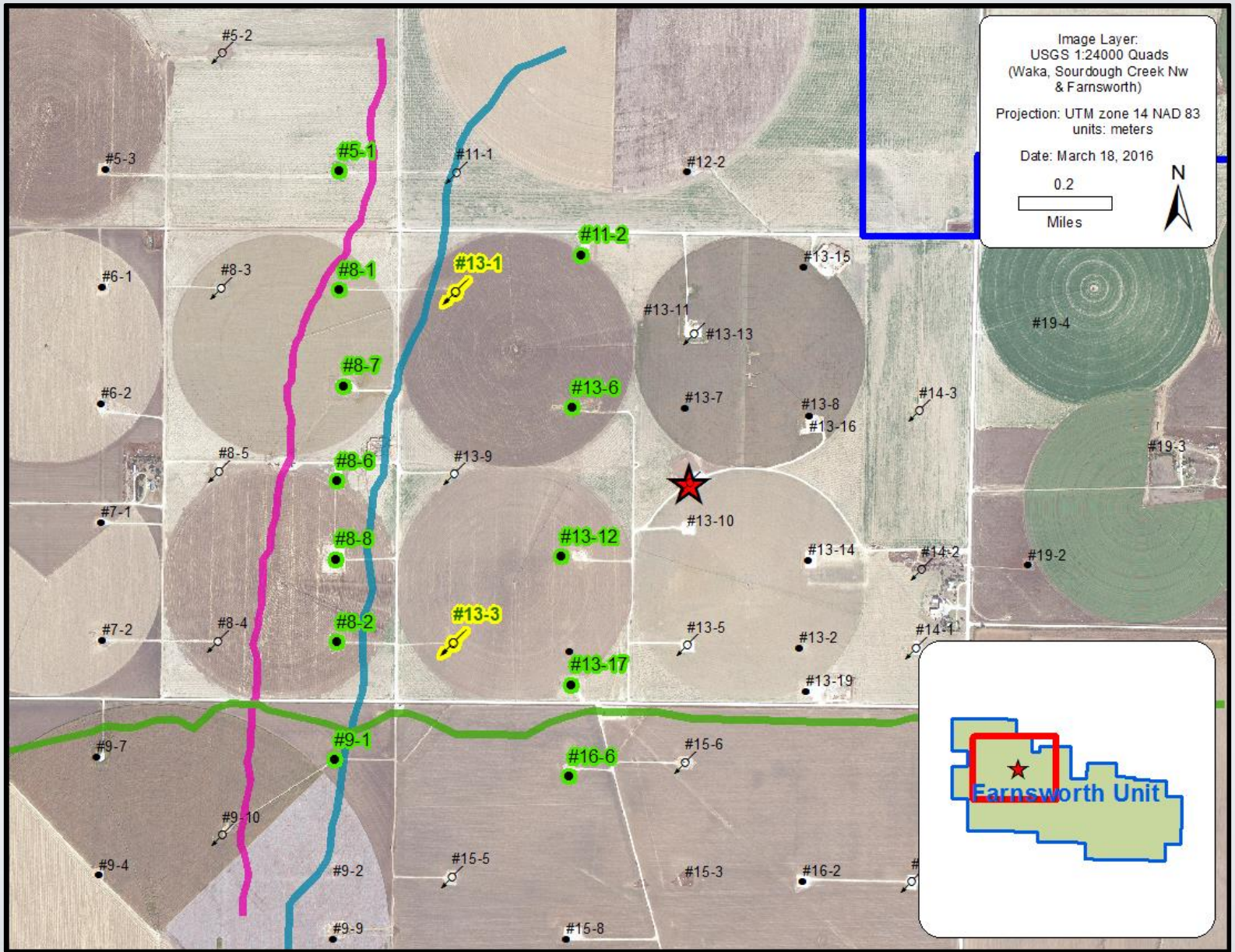
Sub Surface Monitoring – Tracers

Tracers – Vapor-Phase Injection #2

- FWU well (on CO2 flood) tagged with tracer in November, 2015
  - Well #13-10A: PDCB (1kg)
- Additional ~30 days of CO_2 injection
- High frequency sampling (wells & recycled CO_2)
- Modification of sampling procedures
- No significant sample data yet.

Sub Surface Monitoring – Tracers

Tracers – Vapor-Phase Injection #3-4 (planned May 2016)



Sub Surface Monitoring – Tracers

Tracers – Additional Sampling

- Because of the low detectability of the PFTs (<<ppb), surface sensors (carbon adsorption tubes) have been placed at the surface, at strategic locations around the Farnsworth Unit. These sensors are periodically surveyed for injected PFTs that may be indicative of a (CO_2) leak from the subsurface and/or surface infrastructure.

- **No surface PFT signals above background have been detected to date.**

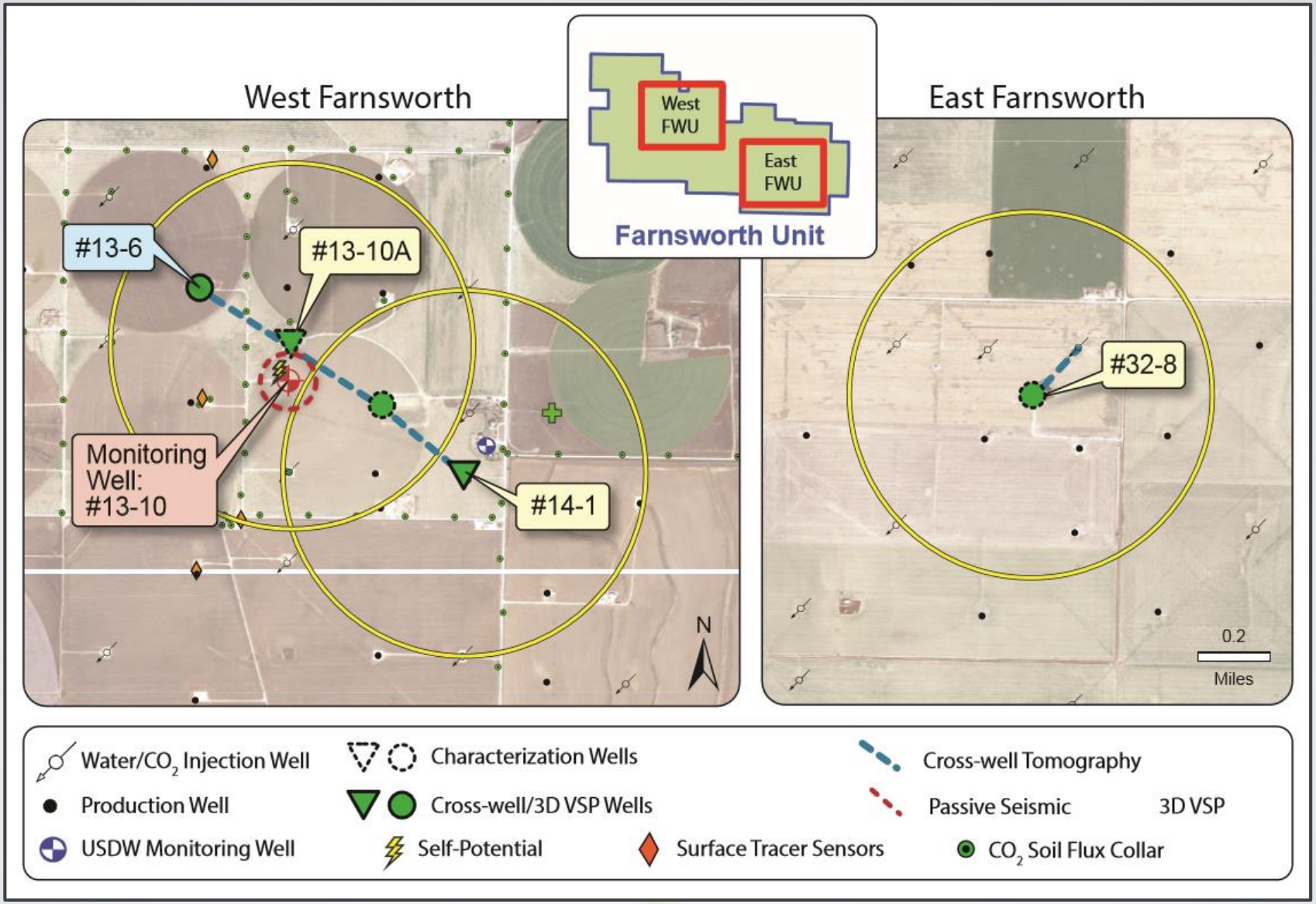
Additional Direct Monitoring

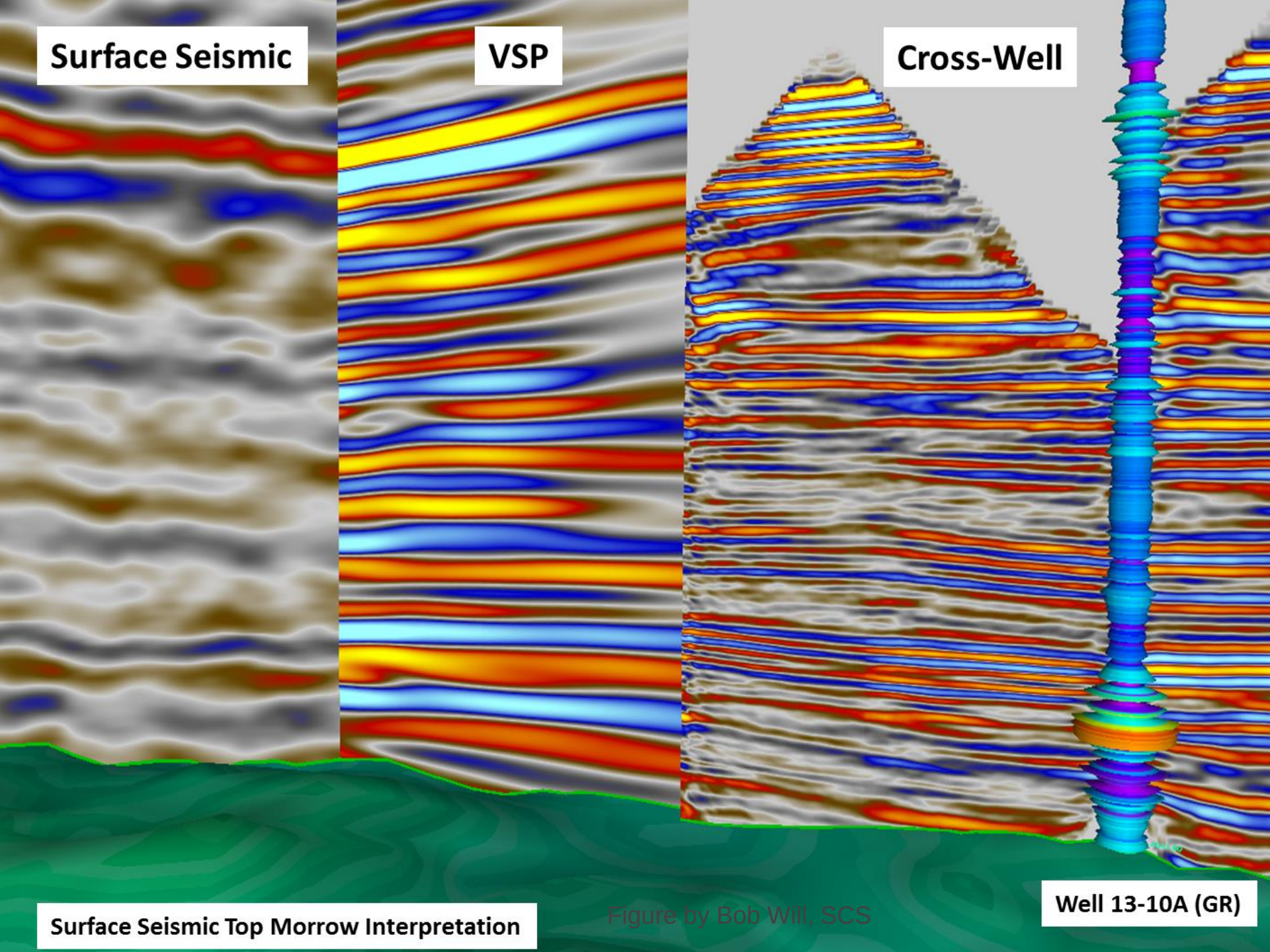
- **Downhole Temperature and Pressure**
  - Downhole pressure gauges and a distributed temperature sensor (DTS) array are installed in monitoring well 13-10 to record injection pressure fronts, fluid sweep and any fluid rising near the wellbore.

- **Reservoir Fluid Chemistry**
  - Morrow B brine, oil and gas composition are monitored, primarily for reactive transport simulation efforts.

- **Geophysical (AIST)**
  - Gravity Monitoring at AWT3
  - Self-potential Monitoring at 13-10

Seismic Monitoring

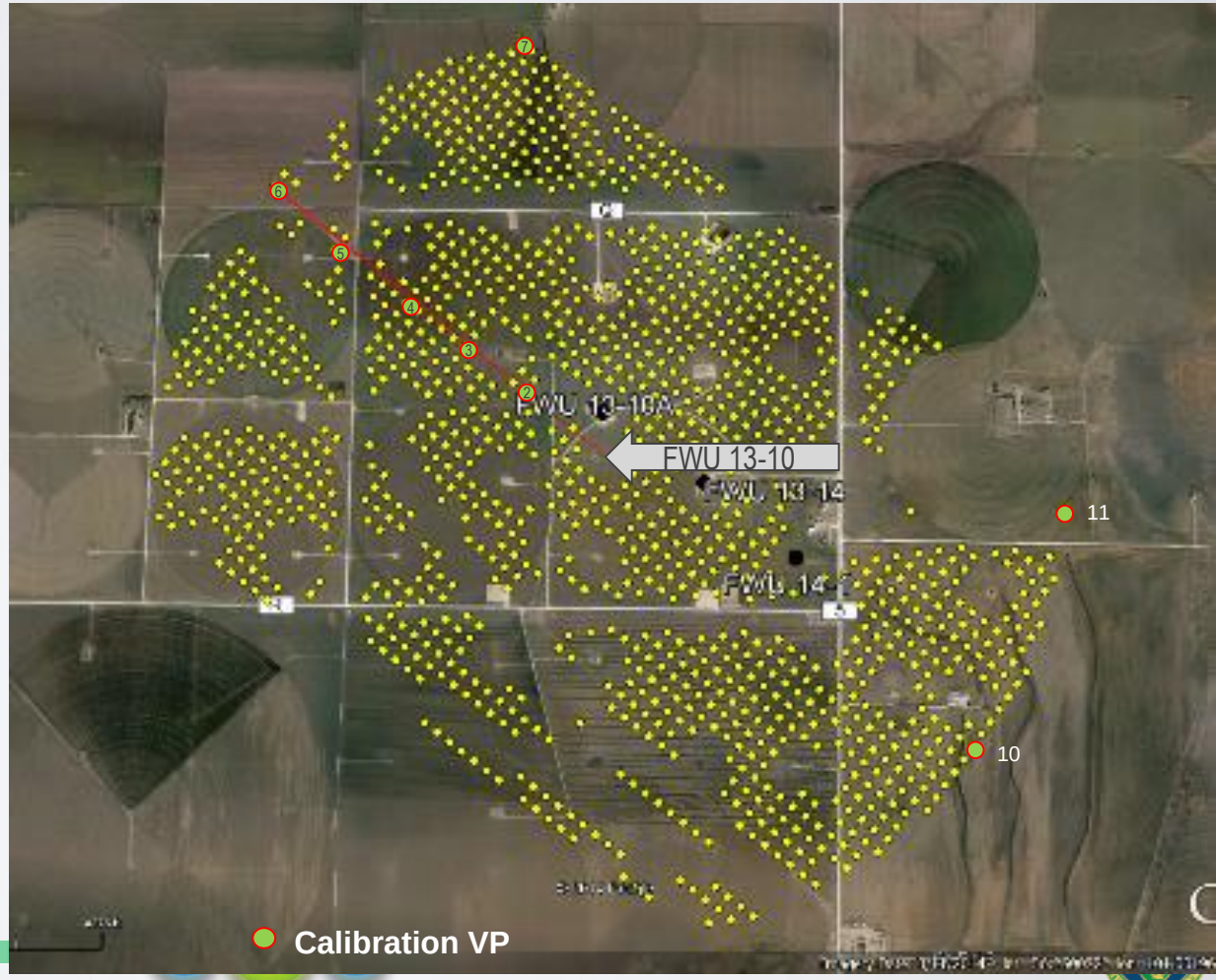



Surface Seismic
VSP
Cross-Well
Surface Seismic Top Morrow Interpretation
Figure by Bob Will, SCS
Well 13-10A (GR)

Time-Lapse 3D VSP Surveys

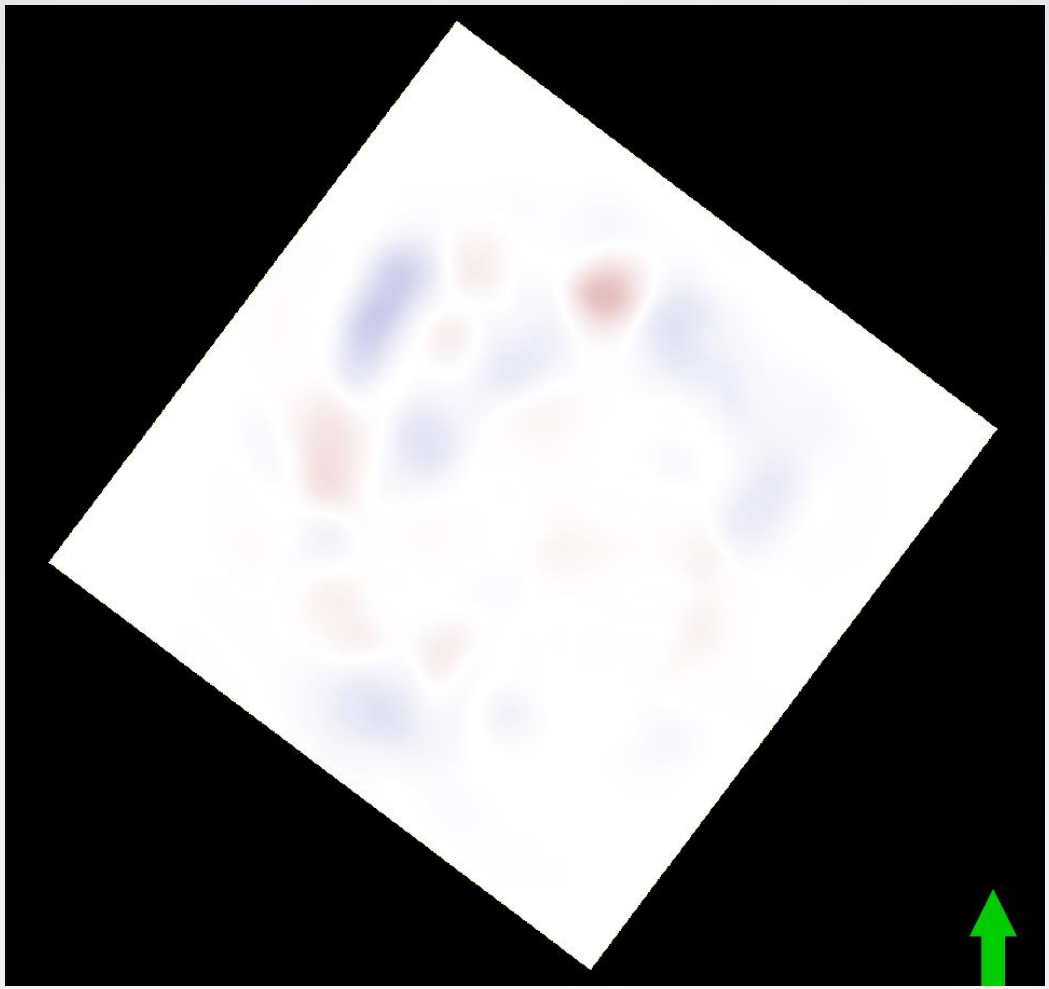
Data Acquired February 2014, January 2015

- Processed by WesternGeco and delivered June 2015
- Processing 1st and second 13-10a VSPs with ~30,000 Metric tonnes CO2 injected
- Excellent repeatability
- Acquired calibration VSP data for micro-seismic array
- Cursory differencing inconclusive
- Plans for acoustic imp-dance volume on VSP
- Fluid substitution model to determine expected difference



13-10a 3D VSP Time Lapse Difference Image

Image Difference Slices at SRD Depth 7800 ft.

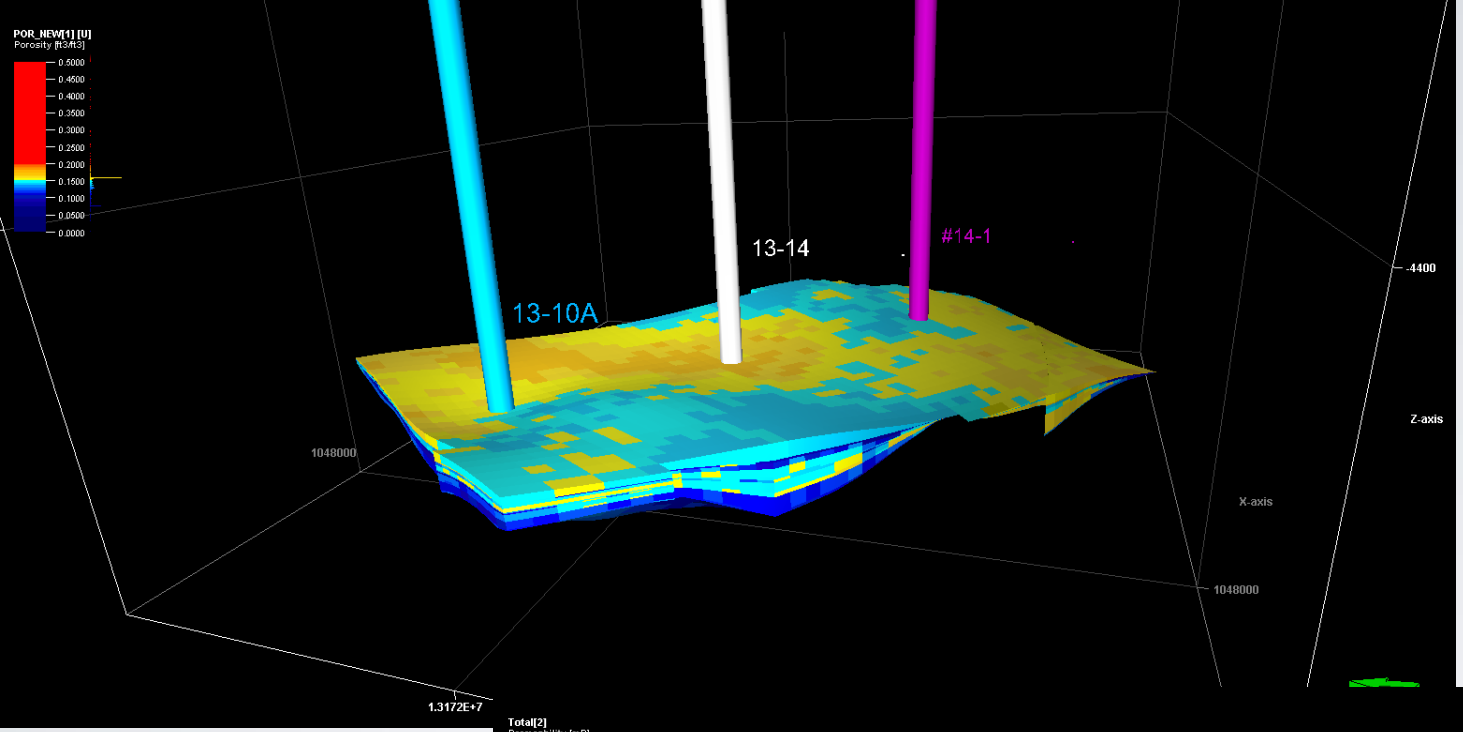


Difference = Baseline - Monitor

Fluid Substitution Modeling

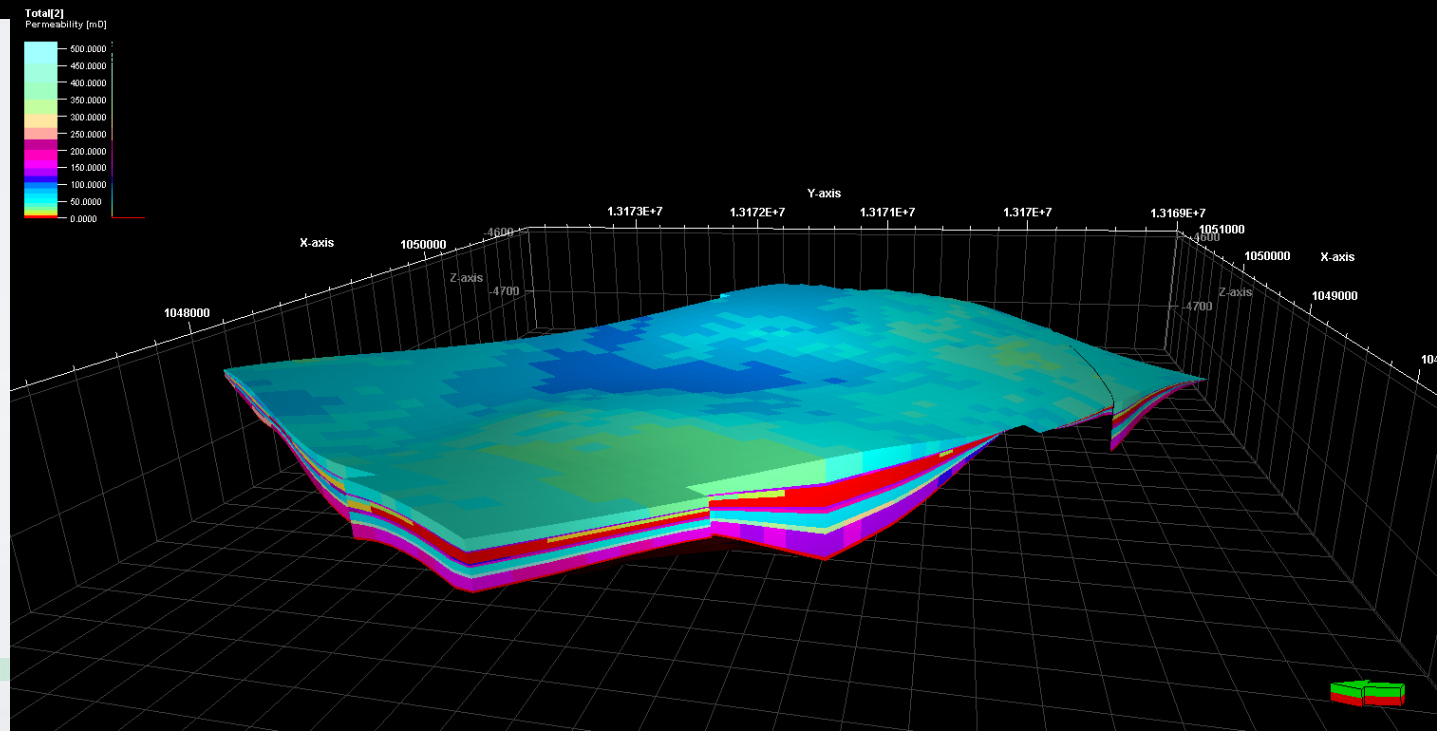
- **Model can be populated with fluids for multiple cases**
  - Post waterflood
  - Post 30,000 tonnes injection, etc.

- **Fluid filled models can have synthetic seismic generated from them**
  - Can difference to find expected response at varying CO2 injection levels
  - Useful for determining detection thresholds
  - Help determine timing of future VSP repeats



Porosity

Matched to well and core data based facies and distributed by geostatistics



Permeability

Computed using relationships from log analyses

Conclusions

- Effective best practices for CCS must include an adequate monitoring program which addresses:
- **Monitoring** – understand CO_2 plume movement over short and long time periods
  - ***Direct monitoring*** tests repeat air and water samples for seeps, leaks, and well-bore failures
  - ***Seismic MVA*** utilizes time lapse seismic data at a variety of scales to image the CO_2 plume over time
- **Verification** – assurance that CO_2 stays in target reservoir, doesn't make it back to atmosphere
- **Accounting** – Accurately measure amount of stored carbon including storage mechanisms
- ***To date and after 2+ years of monitoring no leaks to the atmosphere, ground water, or secondary reservoirs have been detected at Farnsworth using a wide array of detection technologies***

Acknowledgements

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