

# Fracturing Methods to Deliver Liquid Amendments to Low Permeability and Heterogeneous Settings – Methods and Case Studies



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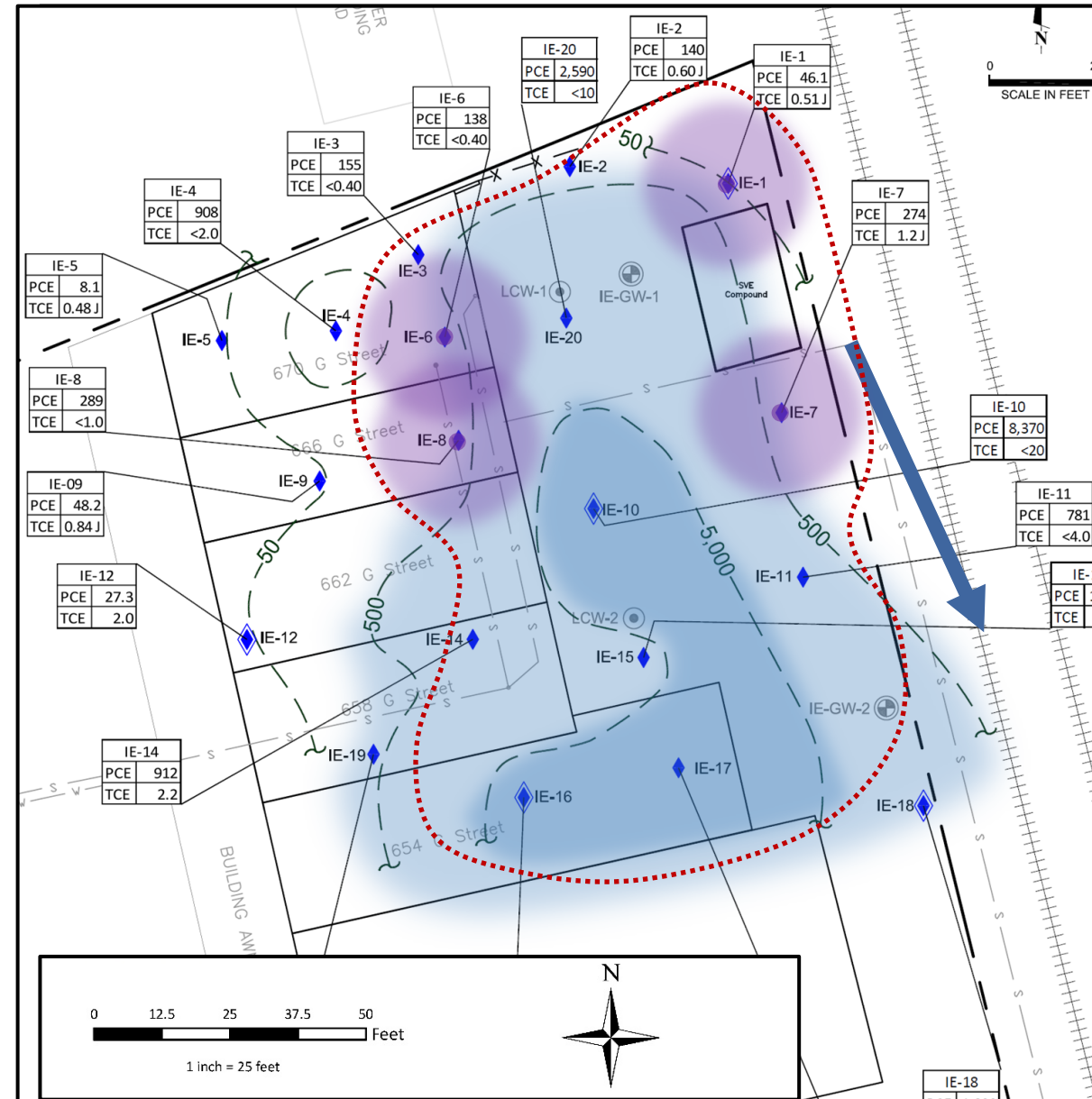
# Case Study #1: Confidential California Site

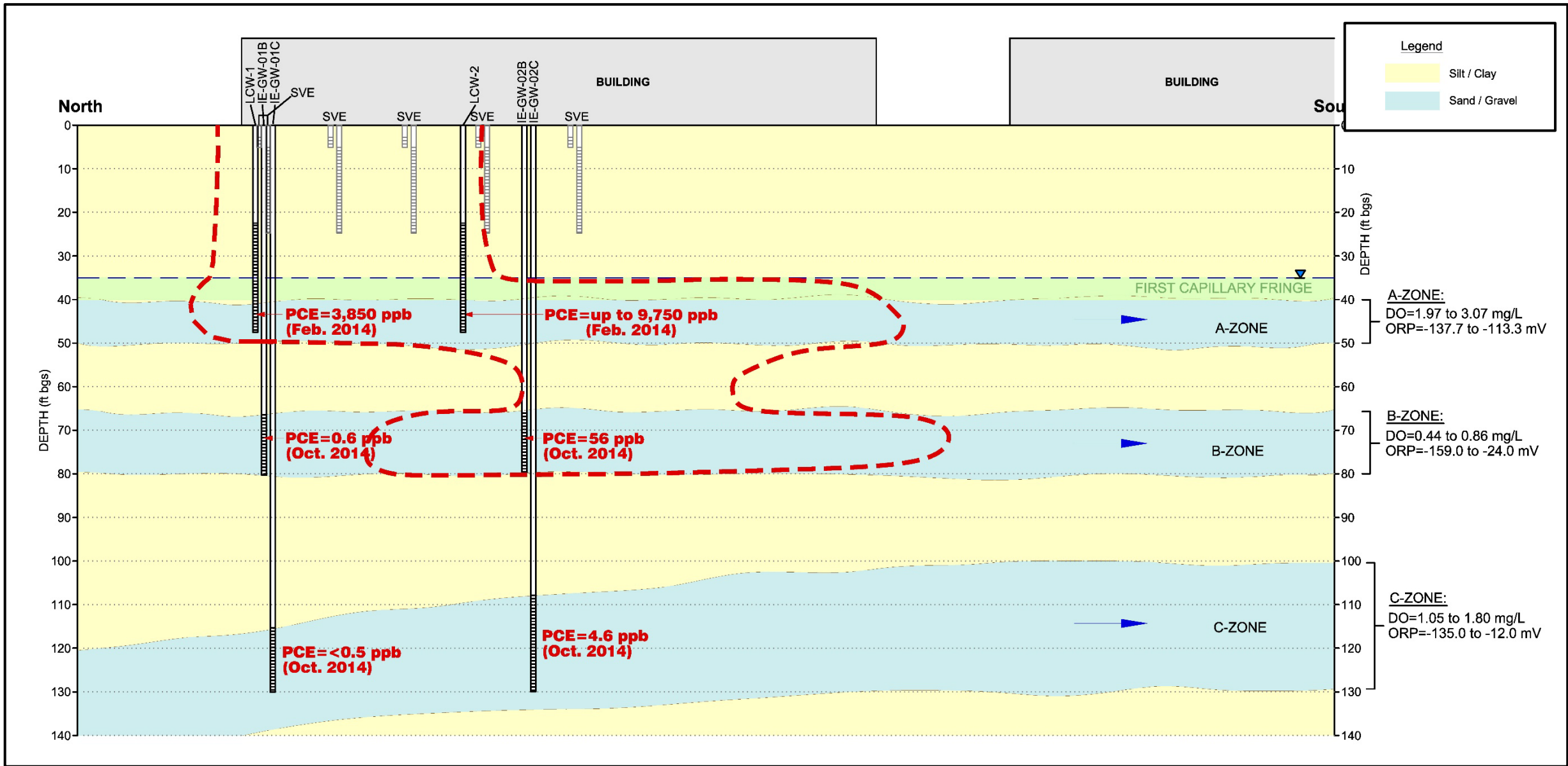
ZVI and Electron Donor  
Injections for CVOCs



# CA Site – Data Gap Investigation

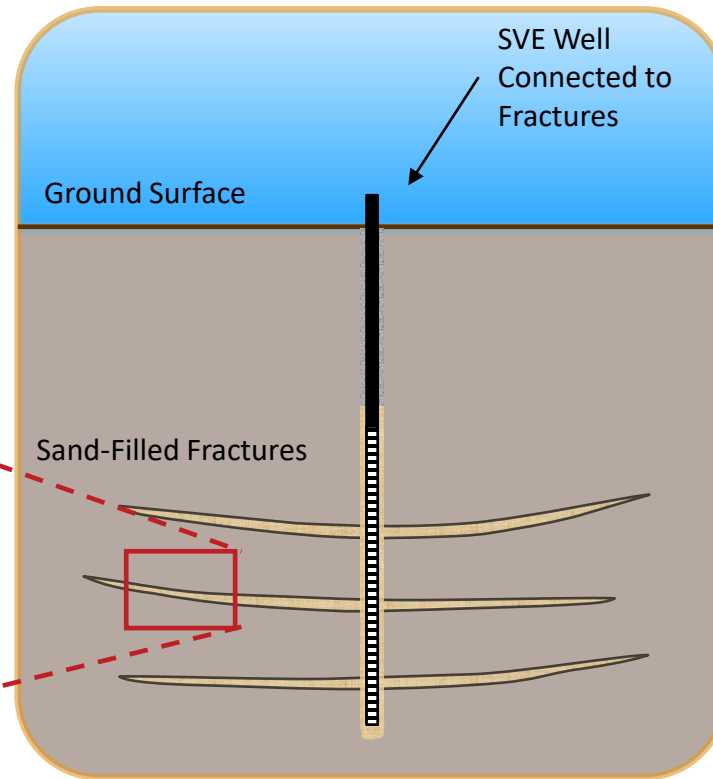
- Groundwater grab samples
- MIP investigation
- Treatment area defined by
  - PCE in groundwater
  - MIP response





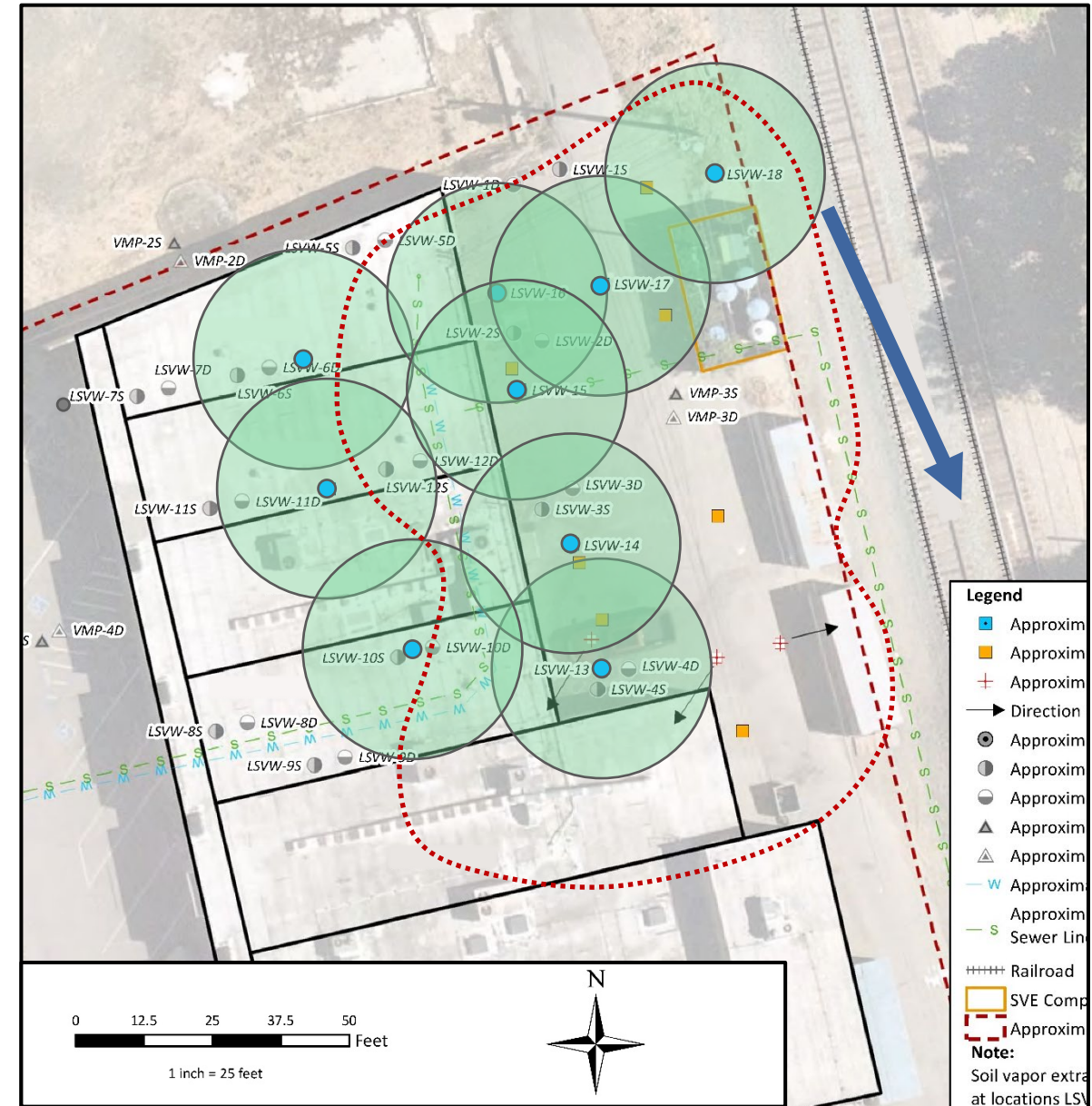
# CA Site – Fracturing Methods

- Sand-filled fracture-enhanced wells for SVE
- High velocity water jetting and liquids injection into cased hole wells



# CA Site – FRx Injections Fracture-Enhanced SVE

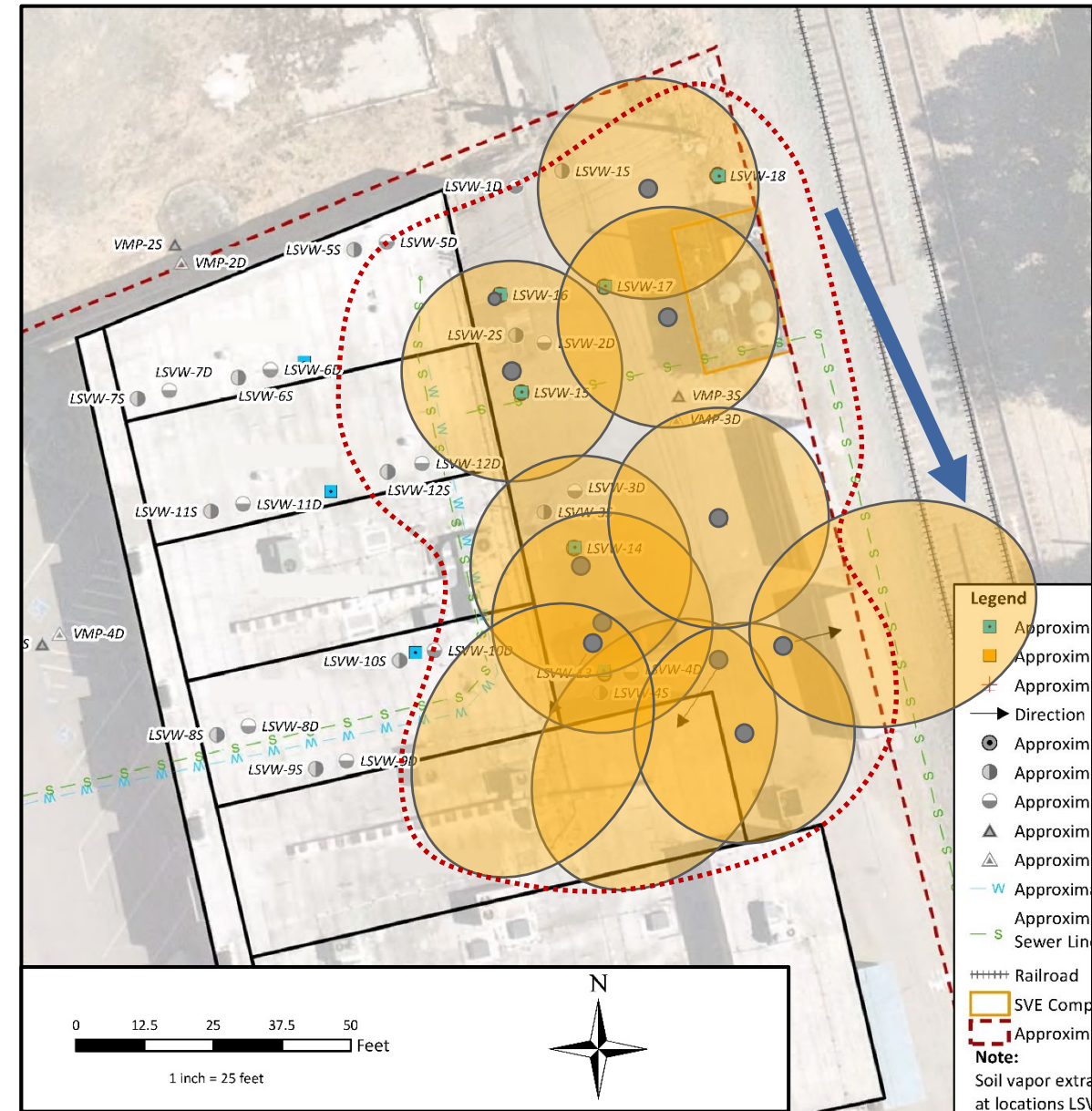
- 9 Locations
- 10 to 25 ft bgs
- 3 sand-filled fractures per location
- Wells constructed with engineered connection to fractures



# CA Site – FRx Injections Enhanced Bio/ISCR

- 11 Locations
- 25 to 80 ft bgs
- High velocity water jetting combined with hydraulic fracturing
- Total amendment loading:

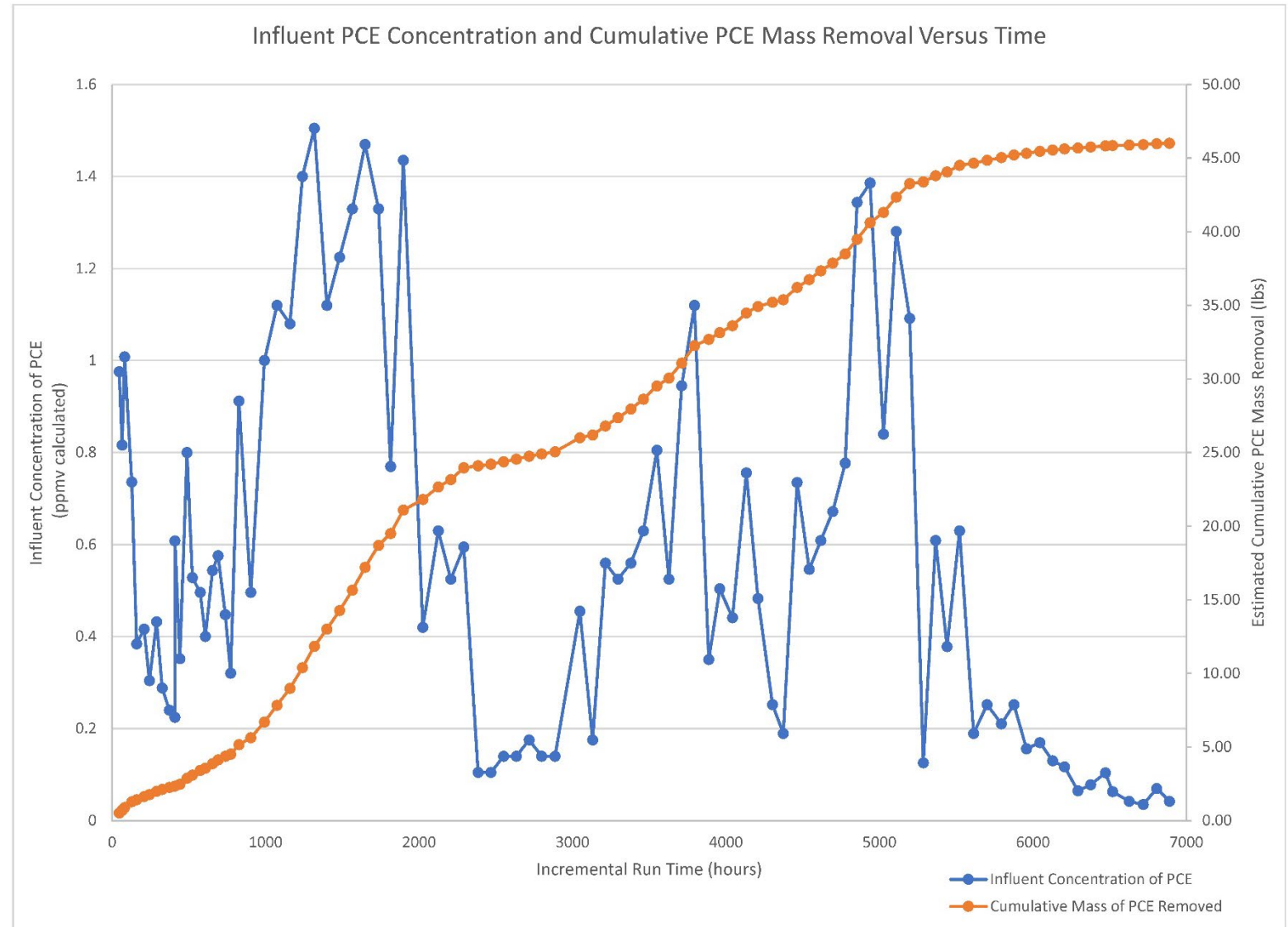
Newman Zone 55	Totes	30,400	lbs
Newman Zone QR	500-lb drums	3,700	lbs
Regenesis S-Micro ZVI	2,000-lb totes	3,700	lbs





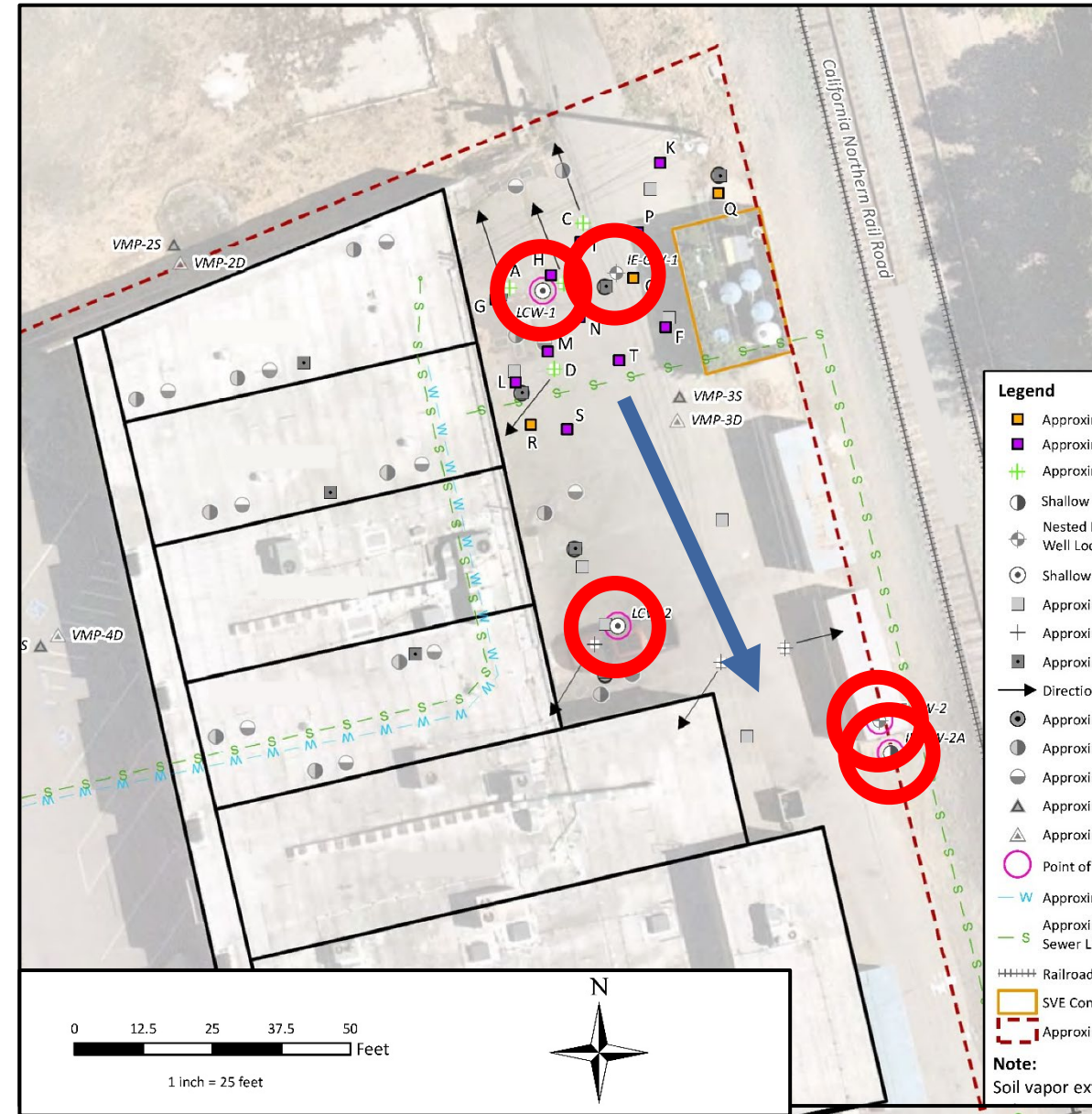
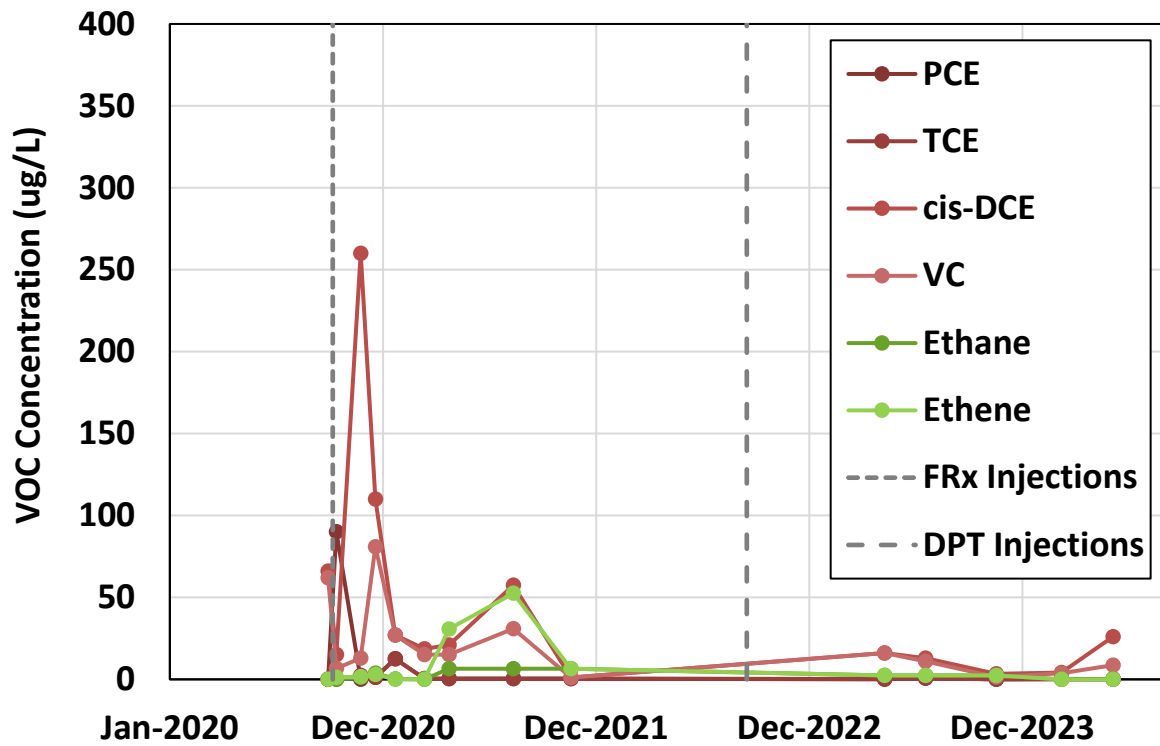
# CA Site – SVE Mass Removal

- Initial SVE pilot testing was unsuccessful
- Fracture-enhanced wells allowed full-scale SVE implementation
- ~46 lbs of PCE was ultimately removed by the SVE system and asymptotic conditions were realized



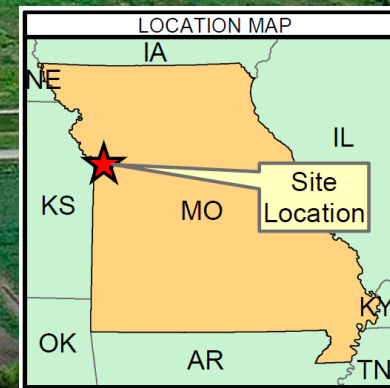
# CA Site – GW Monitoring Program

IE-GW-2B

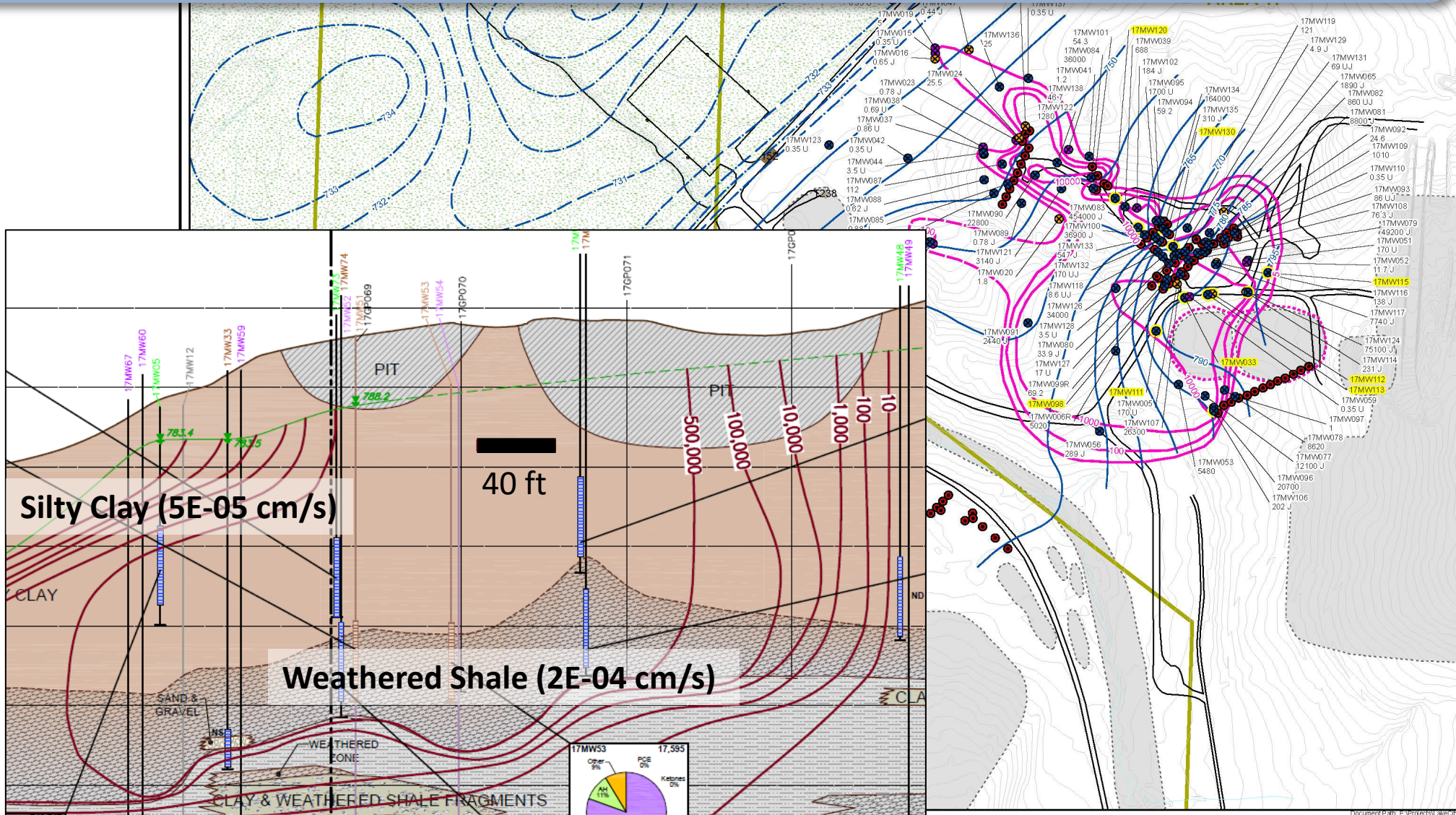


# Case Study #2: Lake City Army Ammunition Plant

Electron Donor Injections for CVOCs



# Area 17B: Oil & Solvent Waste Pits



**LEGEND**

- Silty Clay Overburden, Monitoring Well
- Lake City Aquifer, Monitoring Well
- Bedrock Aquifer, Monitoring Well
- Weathered Bedrock, Monitoring Well
- Injection Well
- Production Well
- NAPL Present in Well
- Silty Clay Aquifer (HSU1) potentiometric surface 202021 (ft MSL)
- Lake City Aquifer (HSU2) potentiometric surface 202021 (ft MSL)
- 2020 Trichloroethene (TCE) Isoconcentration Line (ug/L) (Cleanup Goal = 5 ug/L)
- 2020 Trichloroethene (TCE) Isoconcentration Line (ug/L) (Inferred) (Cleanup Goal = 5 ug/L)
- Inferred Area of Contamination Based on Historical Disposal Practices (Current Data not Available)
- Paleochannel Boundary
- PRW (Permeable Reactive Well)
- Paved Roads
- Streams
- Surface Elevation (10 ft Interval)
- LCAAP Boundary
- OU / Area Boundaries
- Area of Concern / Interest
- Buildings
- Lake

**LOCATION MAP**

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**NOTES & SOURCES**

- All data in micrograms/liter (ug/L)
- Unless otherwise noted, analytical results are from the 2021 Annual Groundwater Monitoring event (2nd quarter 2021).
- ft MSL - feet above Mean Sea Level
- J - Compound was positively identified, but the numerical value is an estimated concentration only.
- U - Non-detect at detection limit
- NAPL - Non-aqueous phase liquid
- TCE - trichloroethene
- OU - operable unit

All concentrations and contours are shown in micrograms per liter (ug/L).

**TITLE**

**Area 17B  
Trichloroethene (TCE)  
Groundwater Results**

2021 Annual O&M Report  
Lake City Army Ammunition Plant  
Independence, Missouri

0 120 240 Feet

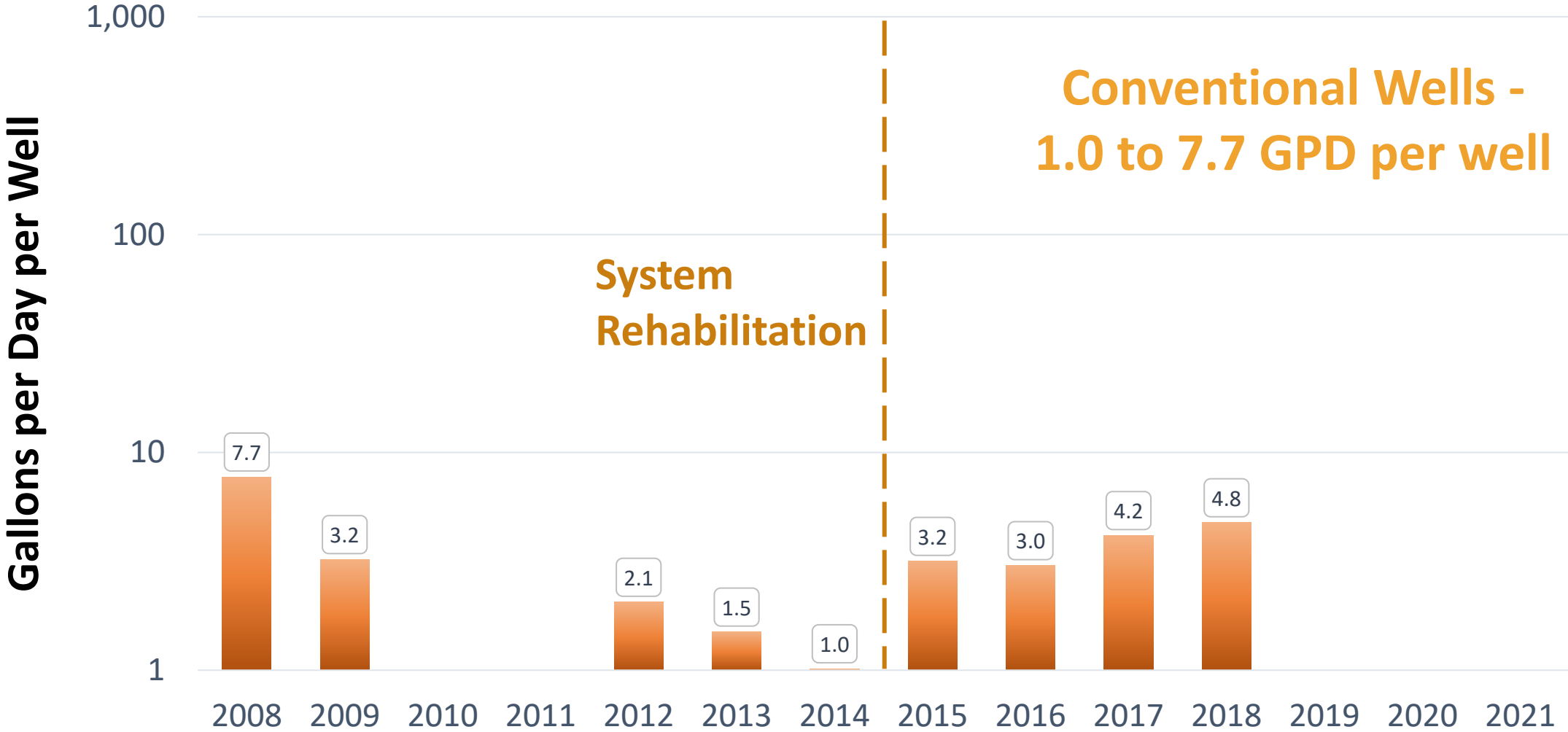
Map Coordinates:  
NAD 1983 SP  
Missouri West (US Feet)  
ECC DENVER  
1746 Cole Blvd.  
Bldg. 21, Site 360  
Lakeview, CO 80401

Date Served: June 29 2022  
DWN BY: MJ /CHK BY:

**FIGURE 4-10**

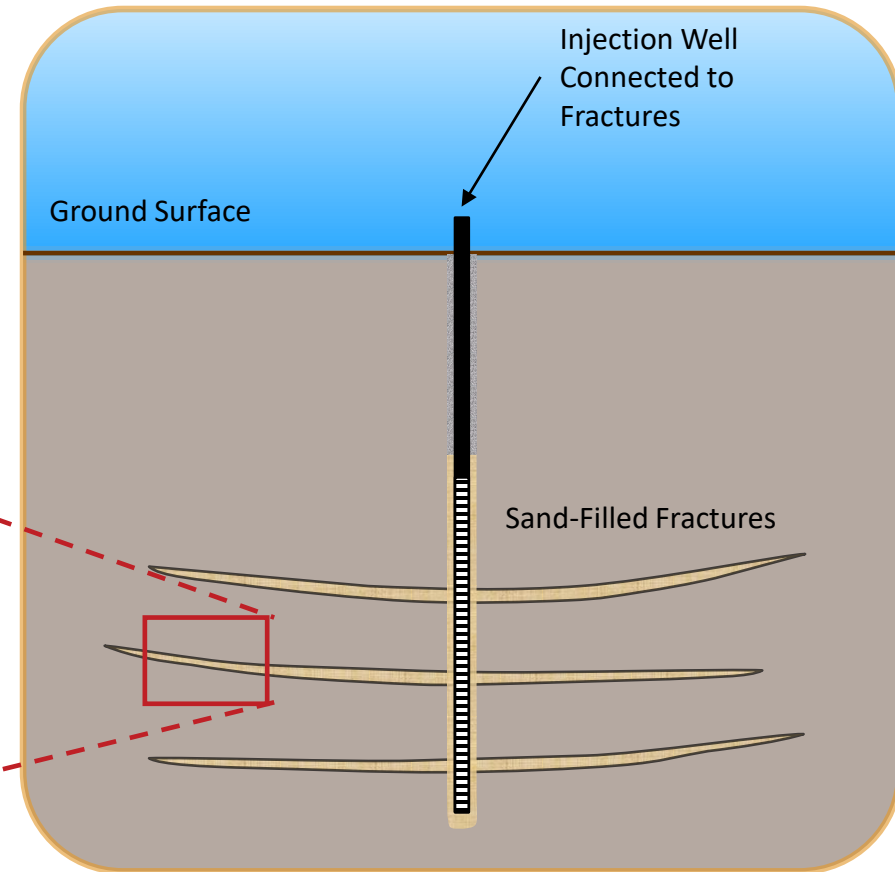


# Normalized Flow into Injection Wells – Before Fracturing

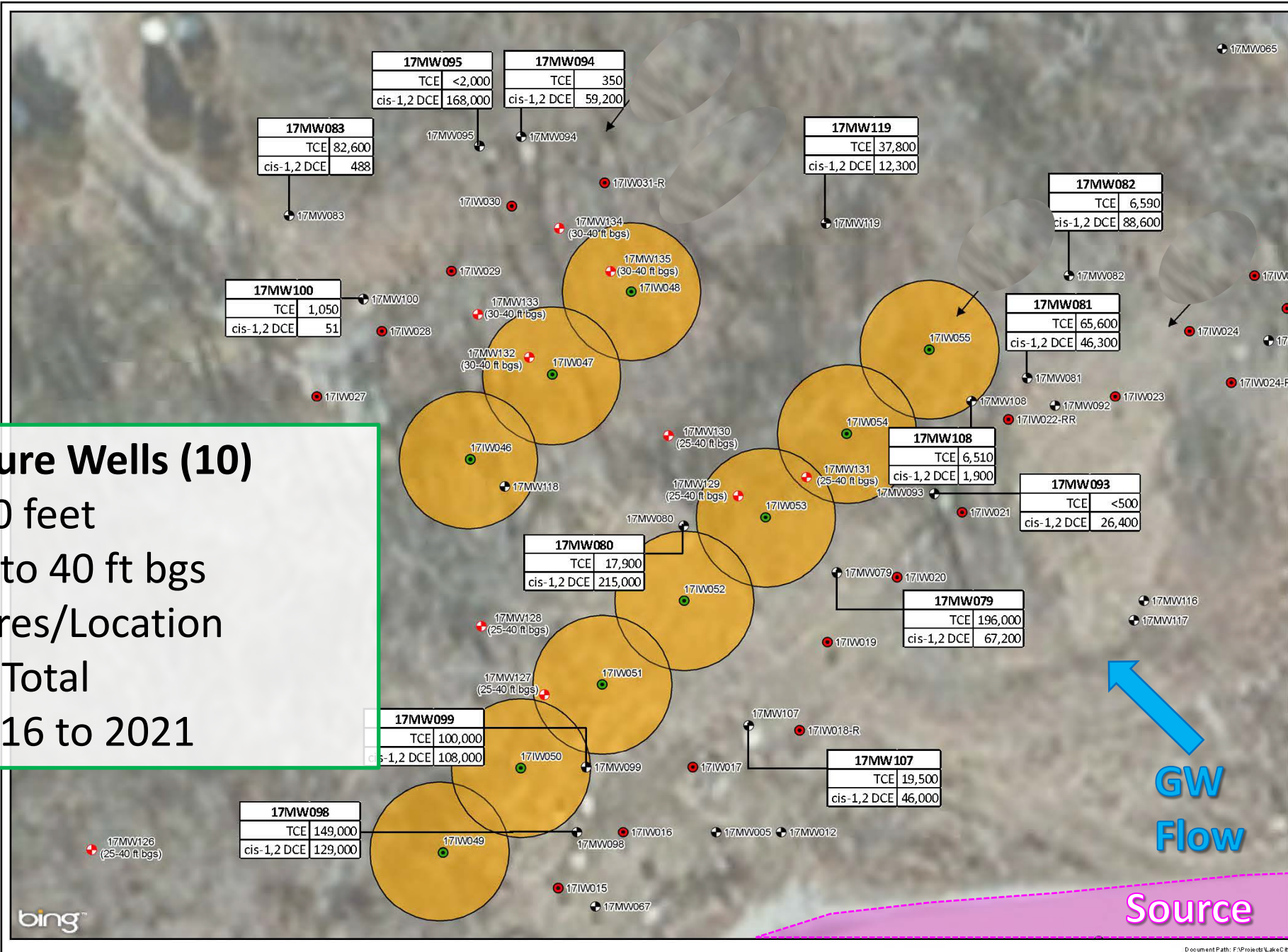


# LCAAP – Fracturing Methods

- Sand-filled fracture-enhanced wells for liquid injections

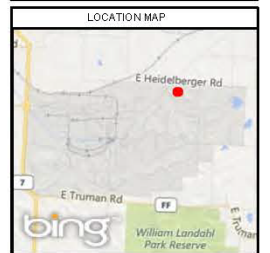


**2015: Fracture Wells (10)**  
 Spanning 260 feet  
 Targeting 25 to 40 ft bgs  
 3 to 4 Fractures/Location  
 37 Fractures Total  
 Injections 2016 to 2021



**LEGEND**

- Proposed Monitoring Well
- LCAAP Monitoring Well
- LCAAP Injection Well
- Proposed Injection Location
- Sand Lens
- NECOU AREA
- Buildings



- NOTES & SOURCES**
- LCAAP = Lake City Army Ammunition Plant
  - NECOU = Northeast Corner Operable Unit
  - Data shown is 2nd quarter 2014 data and is in units of micrograms per liter (µg/L).
  - TCE = trichloroethylene
  - cis-1,2 DCE = cis-1,2-dichloroethene

**TITLE**

**Area 17B  
 Injection Wells with  
 Emplaced Sand Lenses**

Optimization Addendum 2  
 Lake City Army Ammunition Plant  
 Independence, Missouri

0 10 20 Feet

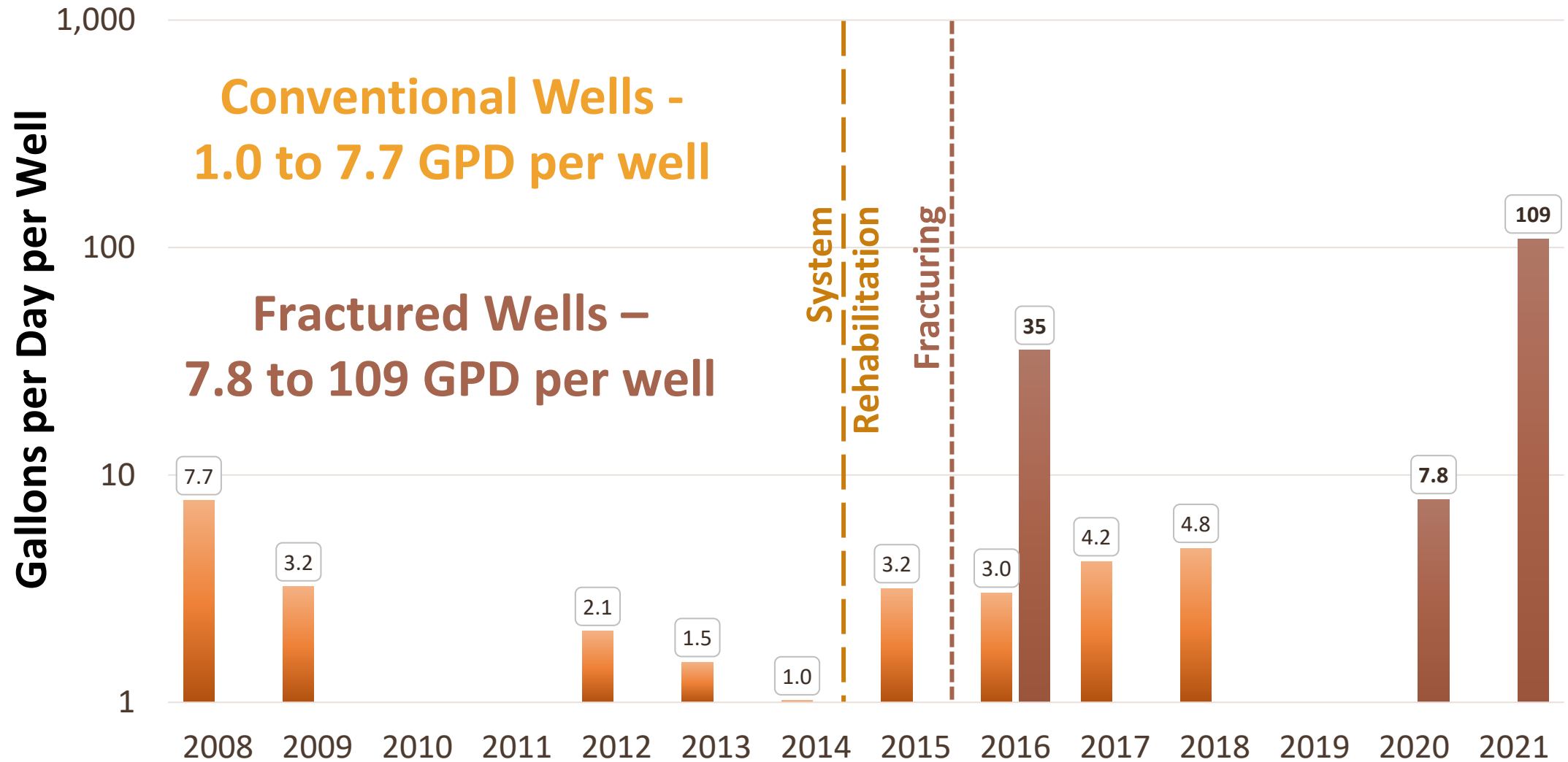
EDC DENVER  
 1745 Cole Blvd.  
 Bldg 21, Ste. 300  
 Lakewood, CO 80401

FIGURE  
**5**

DATE: 09/16/2015  
 DRAWN BY: BU CHANG BY:

**GW  
 Flow  
 Source**

# Normalized Flow into Injection Wells – After Fracturing





# Conclusions

- High velocity water jetting (applying kinetic energy to the formation in combination with liquids injection using positive displacement pumps provided excellent distribution of liquid amendments and addressed issues at all but one well. (case study #1)
- Sand-filled fracture-enhanced SVE wells (case study #1) and liquid injection wells (case study #2) facilitated higher flow rates (>10X) and larger ROI.
- These wells vastly improved performance over the traditional wells tested during earlier phases of both projects while also reducing operating costs.
- Site closure is imminent for both case studies.