BIOREMEDIATION OF DEEP CONTAMINATION – DEEPER IS NOT ALWAYS MORE DIFFICULT

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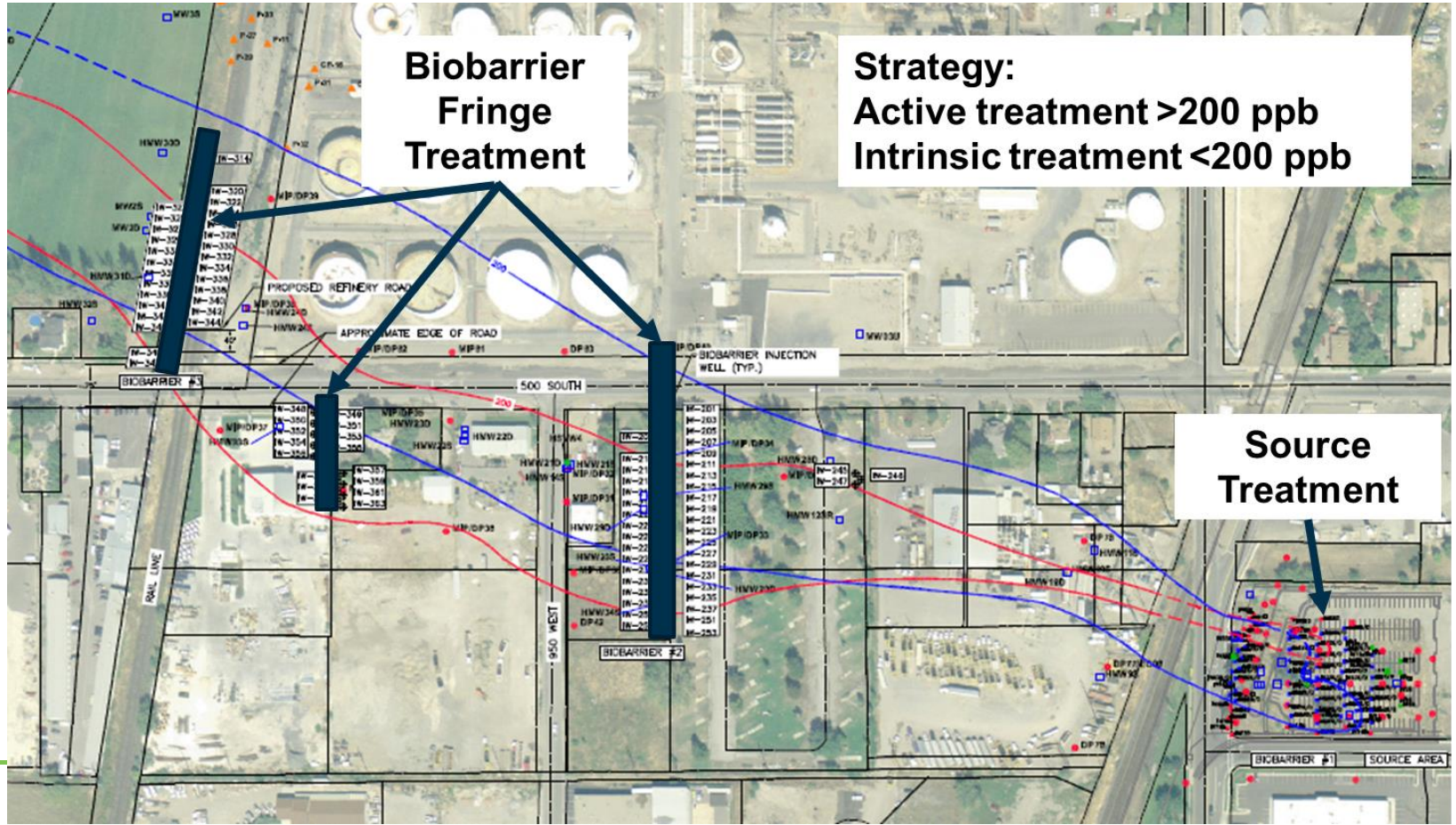
Introduction/Outline

- Thousands of sites have used bioremediation for a wide variety of contaminants
- At sites with contamination present at depths greater than tens of feet, creative approaches may be needed
- Deeper sites can actually be easier to inject amendment, while very shallow sites can be more difficult
- This presentation shows five short case examples

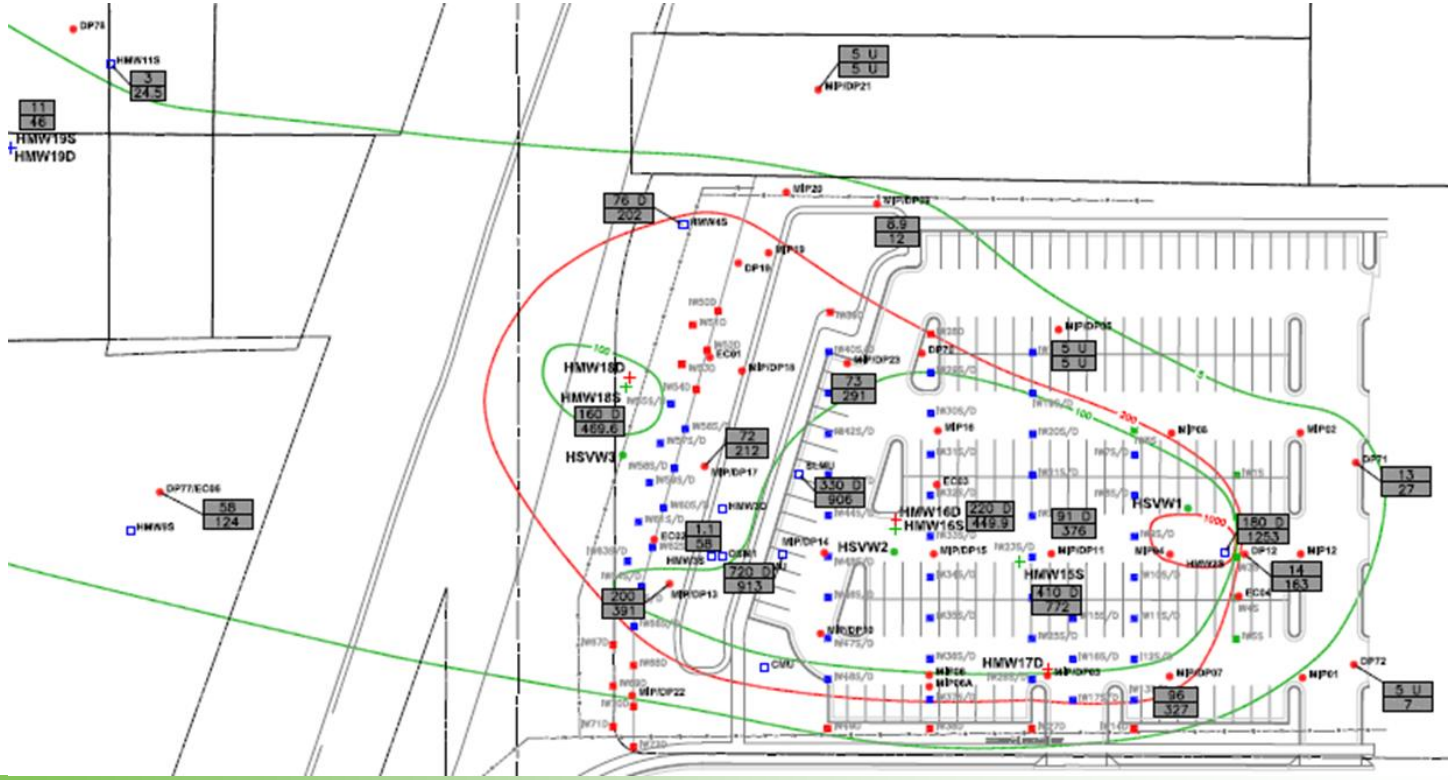
Site 1 - Bountiful OU1

- Extensive deep contamination, present as source and large dilute plume
- Strategy: Aggressive source remediation and biobarriers downgradient

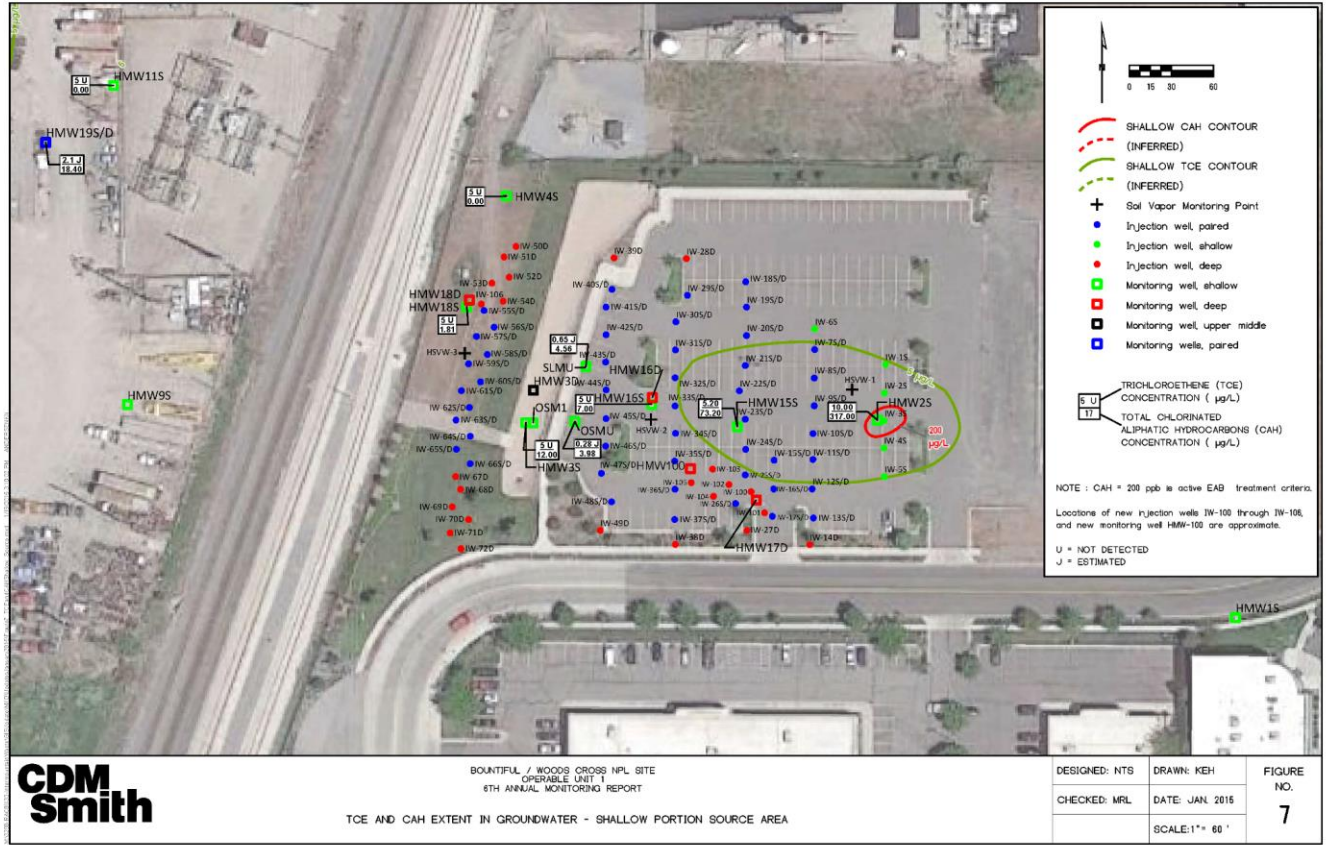
Full-Scale Design



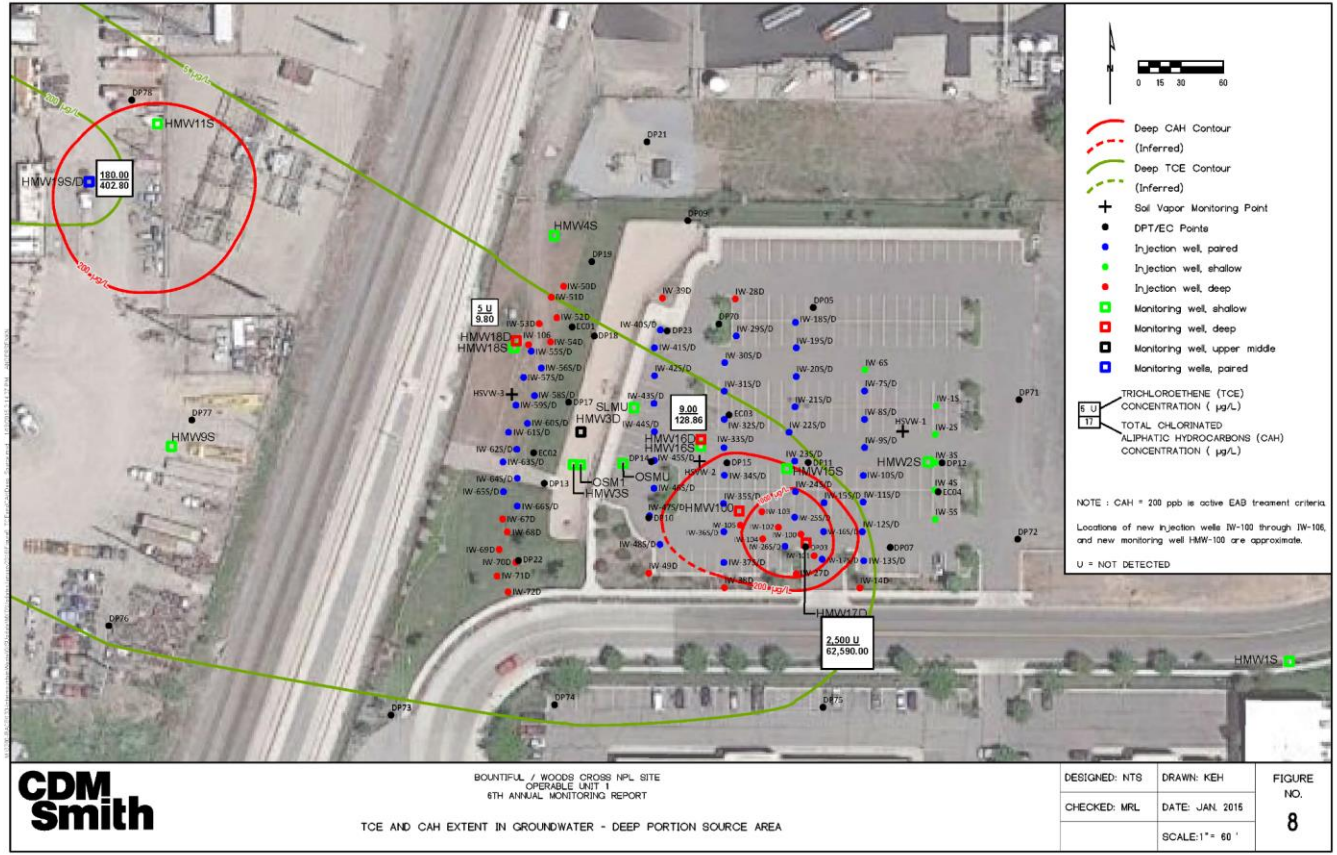
Baseline Shallow Zone Concentrations



Source Area – Shallow Contaminant Plume

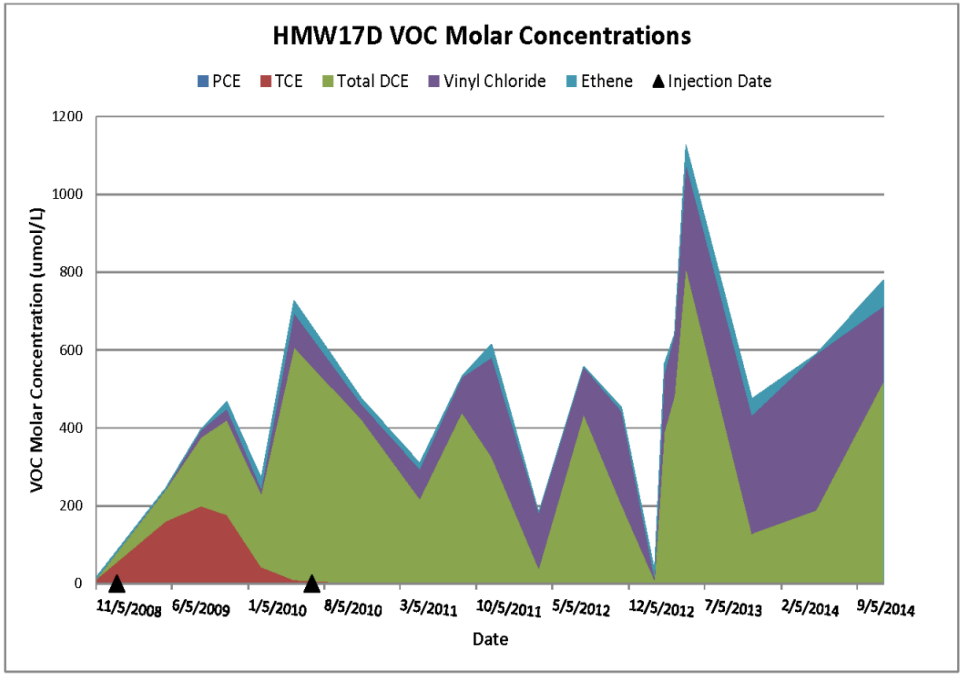


Source Area – Deep Contaminant Plume



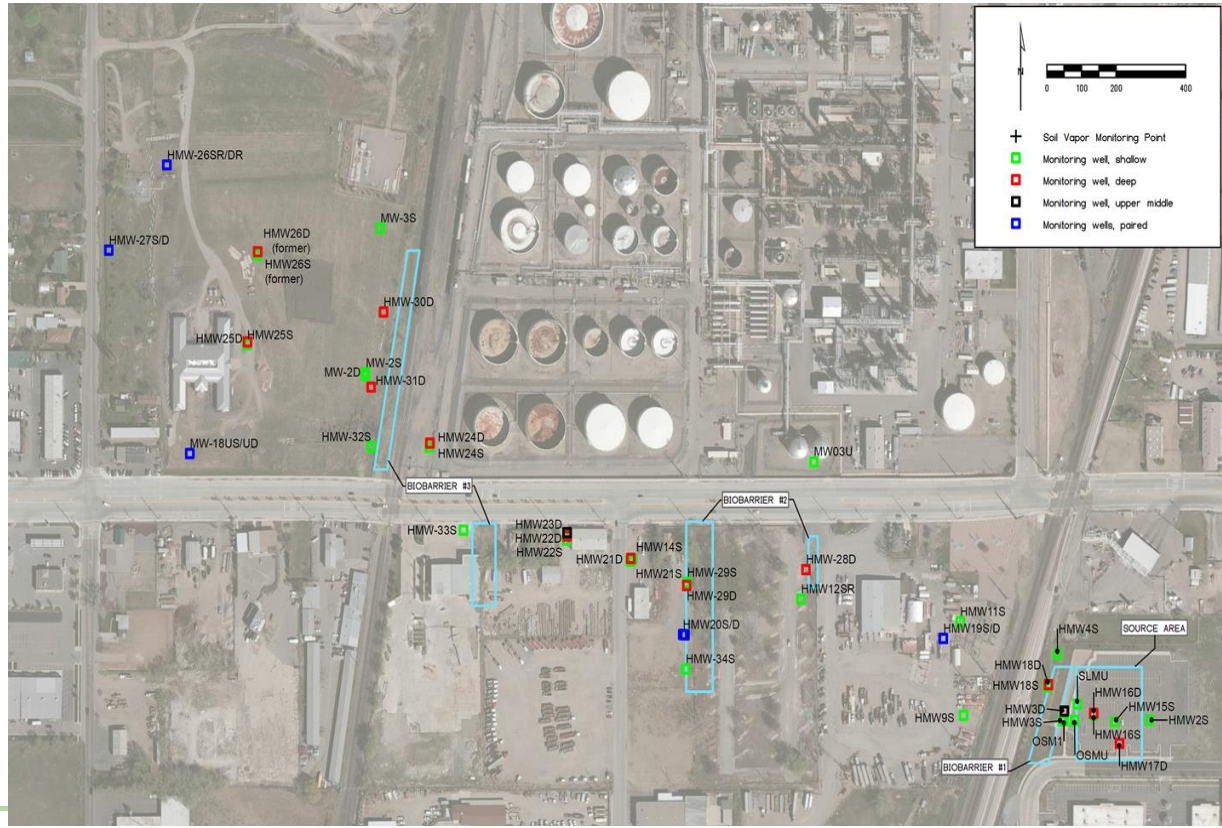
Source Area Deep Zone Hotspot – MW-17D

- Targeted injections ongoing since 2011
- Pilot study of Electrochemically Induced Reduction (EIR) initiated in 2015
- Initiating ZVI/biorecirculation in 2017

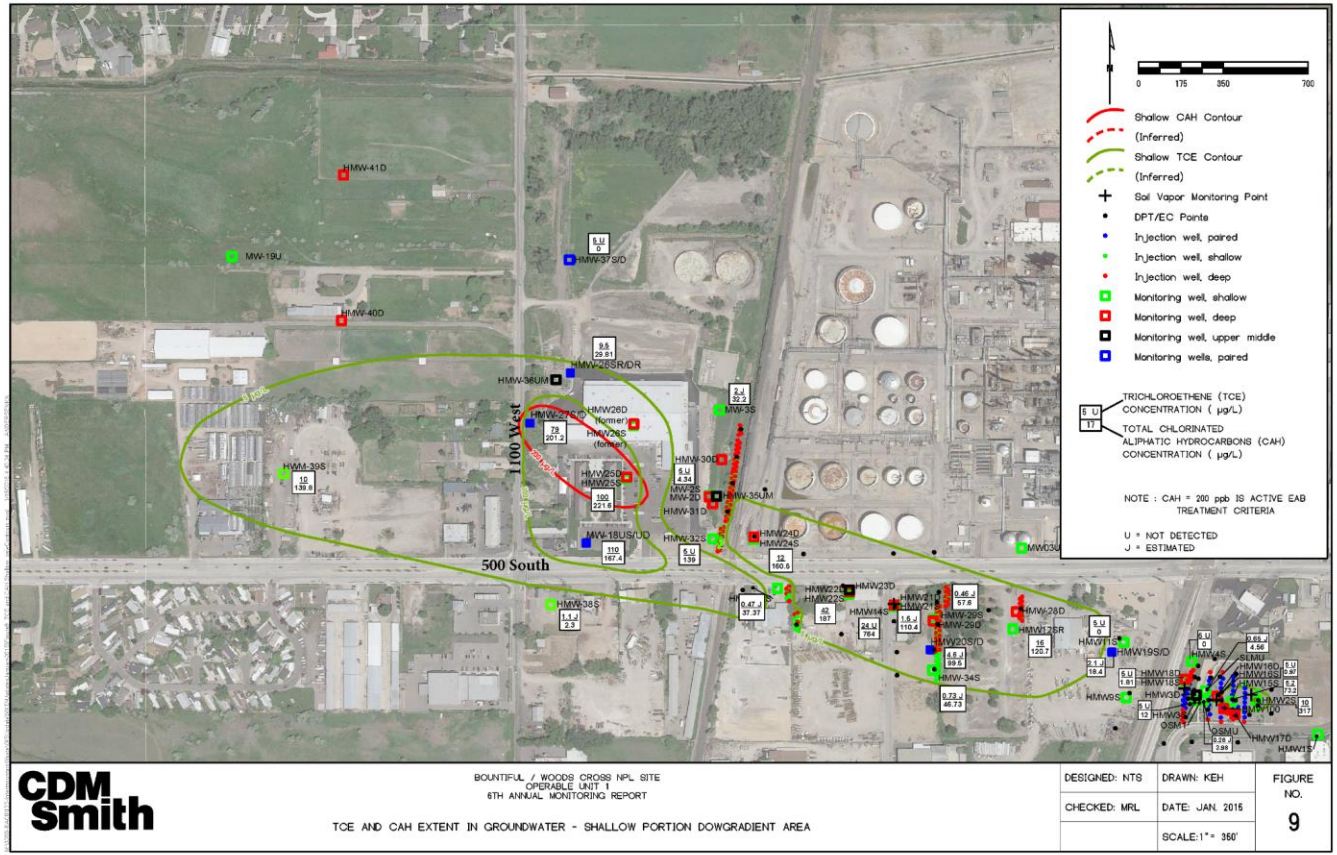


Biobarriers

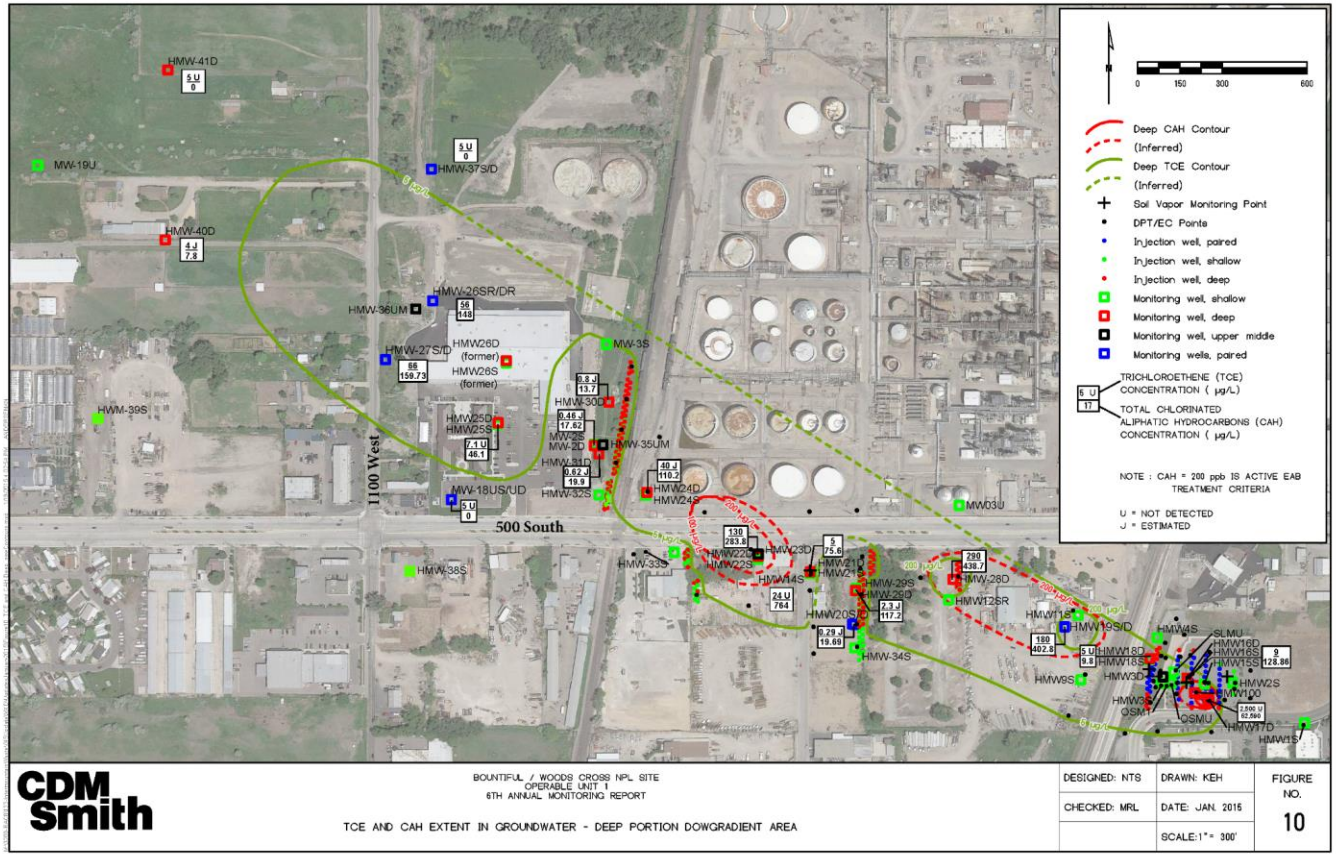
- Biobarrier wells: Used DPT to install 1.5” pre-pack injection wells
- Geoprobe® 7822 and 8040 direct push drill rigs – capable of pushing 3.25” or 3.5” casing to depths of 50 feet and 75 feet, respectively



Shallow Zone Results



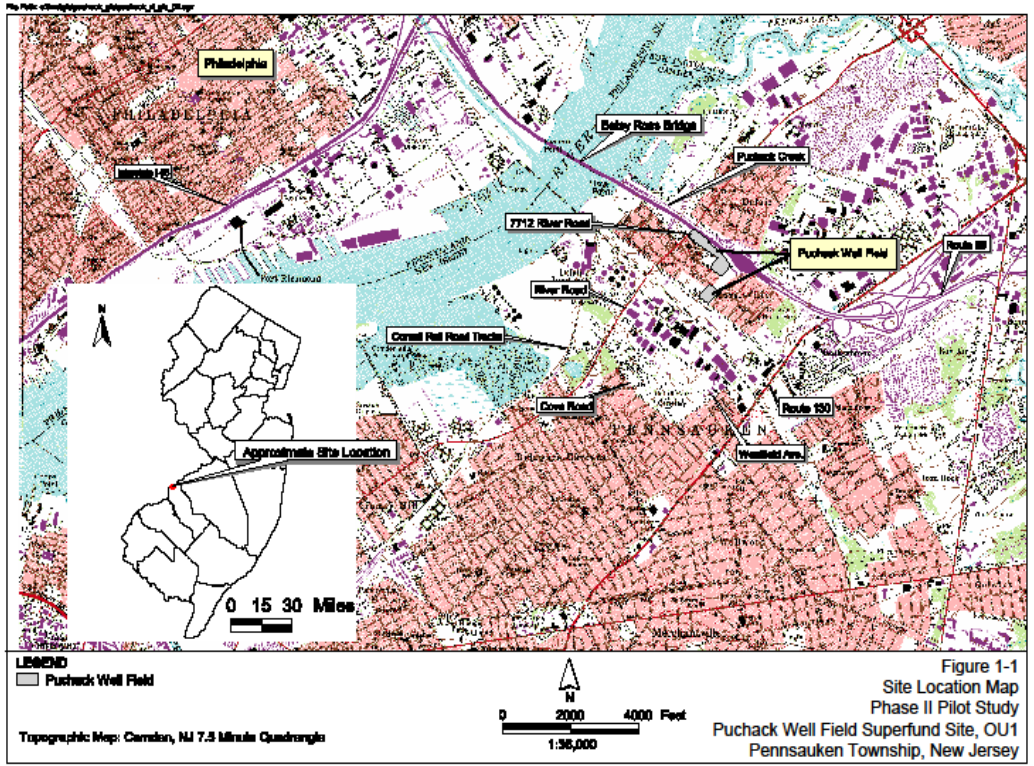
Deep Zone Results



Site #2: Puchack – Chromium Remediation

Puchack Wellfield Site
Camden, NJ

- Chromium plumes in multiple aquifer layers
- Strategy: active recirculation and horizontal wells for injection into deeper zones
- Completed RI/FS and bench studies
- Conducted two pilot scale field demonstrations
- Completed full scale design and implementation of the in situ reduction system



Conceptual Site Model

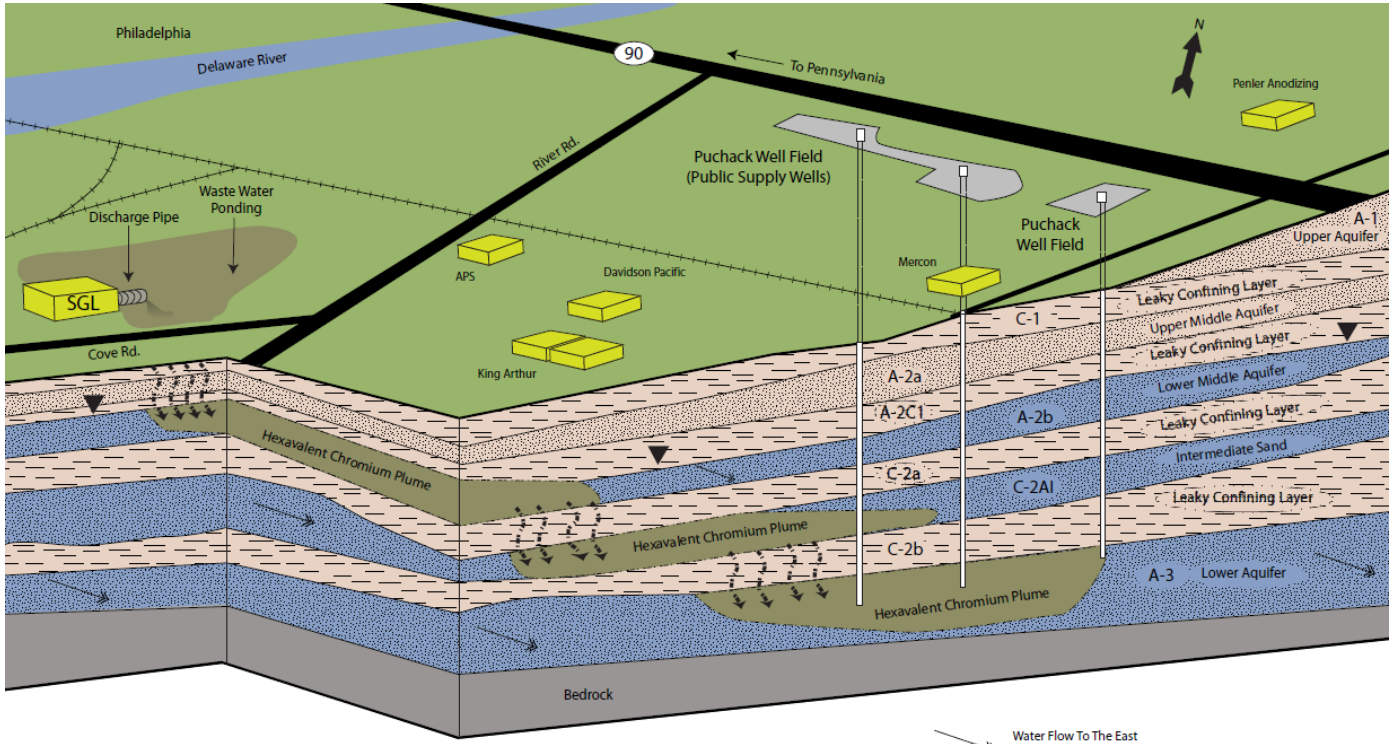
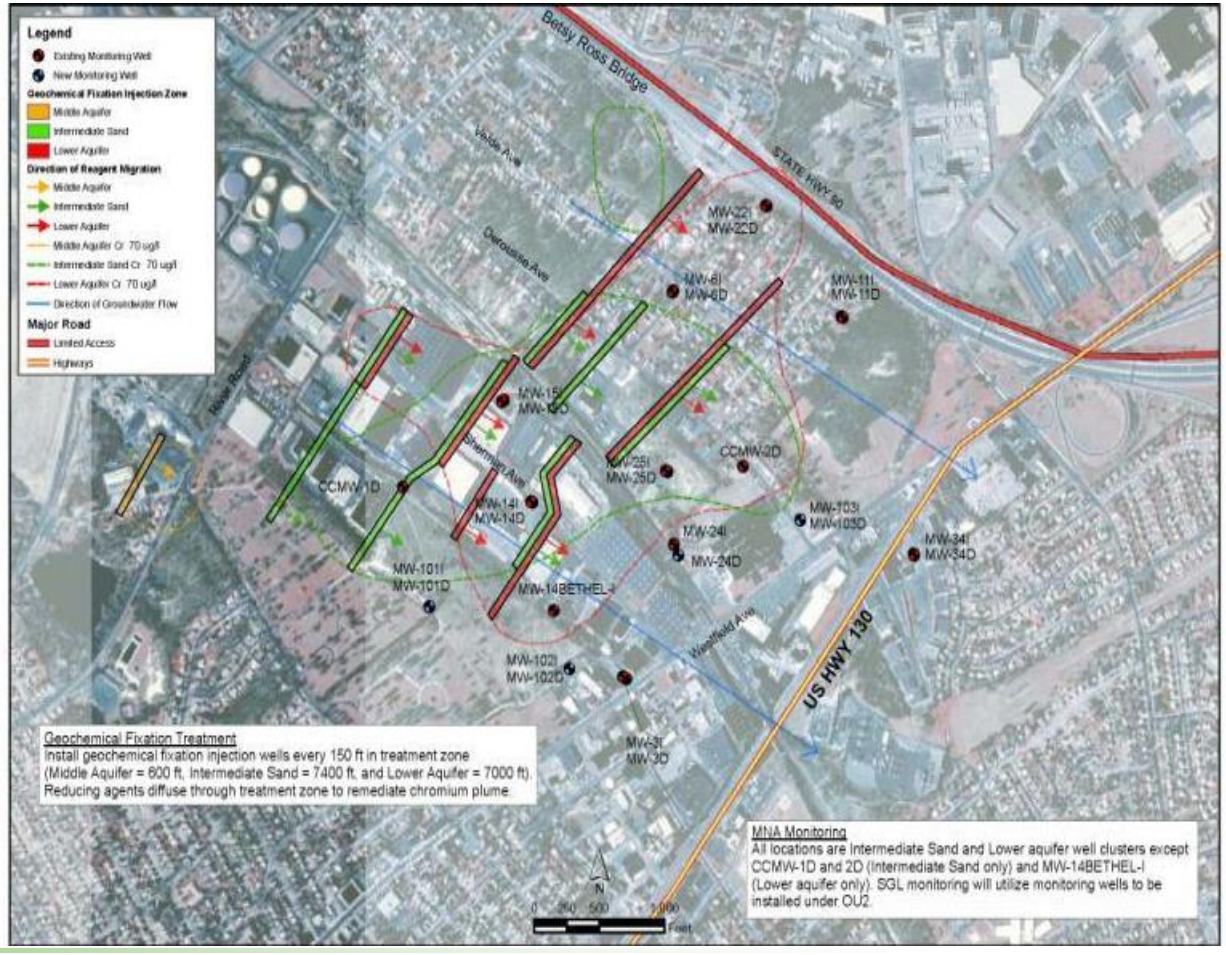


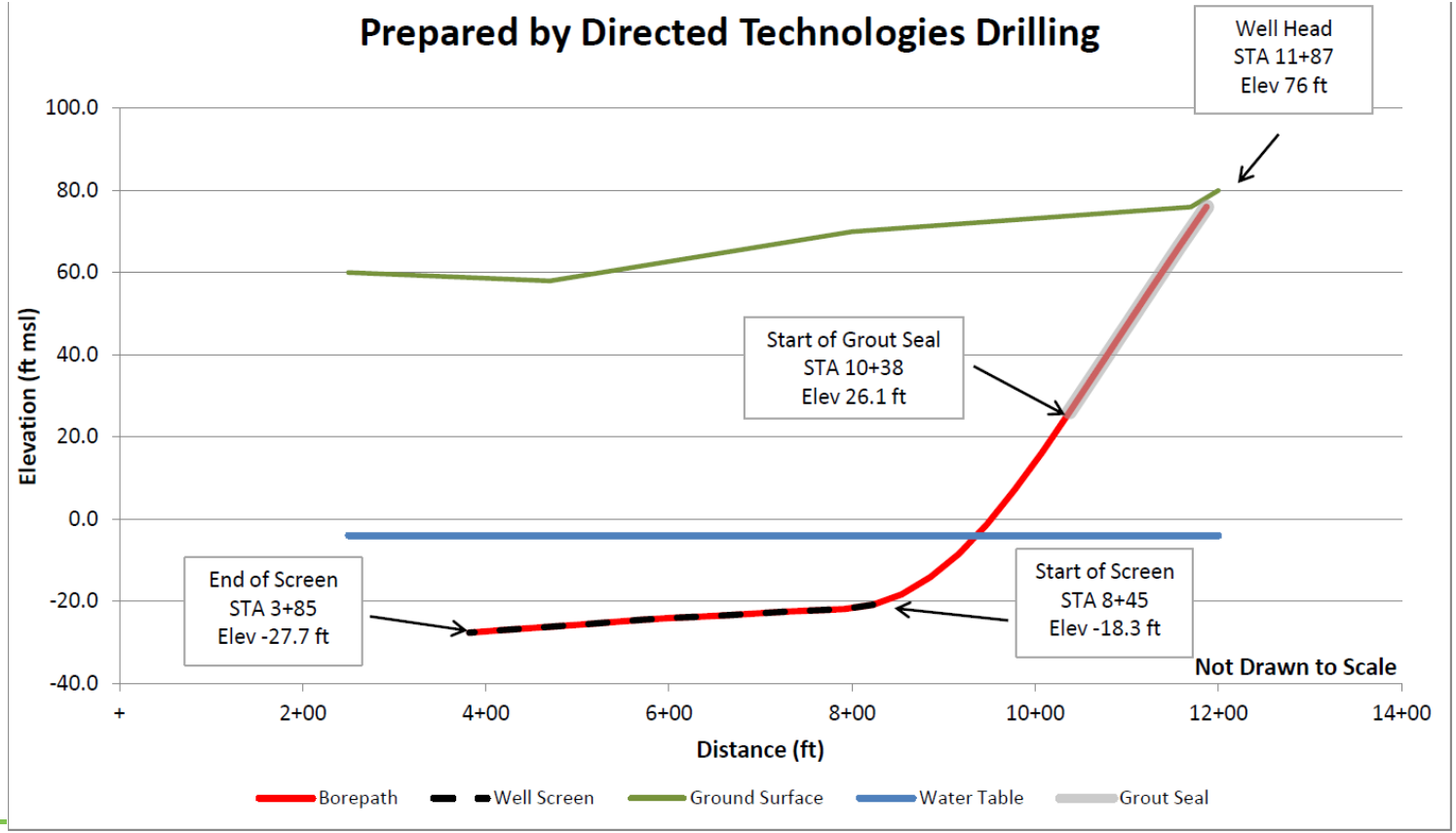
Figure 5-6
Conceptual Site Model
Puchack Well Field Site, OU2
Pennsauken Township, New Jersey

Full Scale Design

- **Three aquifers**
  - Orange: shallow (called middle aquifer) – 51 DPT wells, 10 – 30 ft deep
  - Green: intermediate aquifer – 17 injection wells (63 -73 ft), 5 downgradient extraction wells
  - Red: lower aquifer – 27 injection wells (103 – 113 ft), 8 extraction wells
- **General**:
  - 125 ft between injection wells in each row; 400 ft between rows; over 15,000 ft of barriers.
  - 1.63 million lb. of Na Lactate



Schematic of Horizontal Pilot Well



Horizontal Well Drilling

Intermediate Sand Injection Scheme Overview

Site 3: ESTCP Delivery Demonstration Grand Forks AFB

Technical Objectives ER 2014-30

- Demonstrate the amendment distribution performance of permeability enhancement technology in three geologic settings
  - Effective radius
  - Volume
  - Orientation
  - Vertical distribution
- Demonstrate and validate high-resolution sensing and mapping techniques
- Collect sufficient cost and performance data to develop guidance
- Presentation in Session A1 by Dr. Kent Sorenson
- Strategy: use permeability enhancement to deliver amendment at tight, shallow sites

Test Design – GFAFB

- Main objective: direct comparison between hydraulic permeability enhancement (HPE) and conventional injection techniques
- Site info:
  - Silts from 0 to 3 ft bgs followed by clays from 3 to 30 ft bgs
  - Shallow water table at 4 to 8 ft bgs
  - Groundwater flow ~ 13 ft/year in shallow unit
- Selected delivery technologies:
  - HPE with EVO (LactOil), no sand emplacement via DPT
  - 4-8 permeability enhancement points
  - 3 vertical intervals per permeability enhancement point

Demonstration Layout

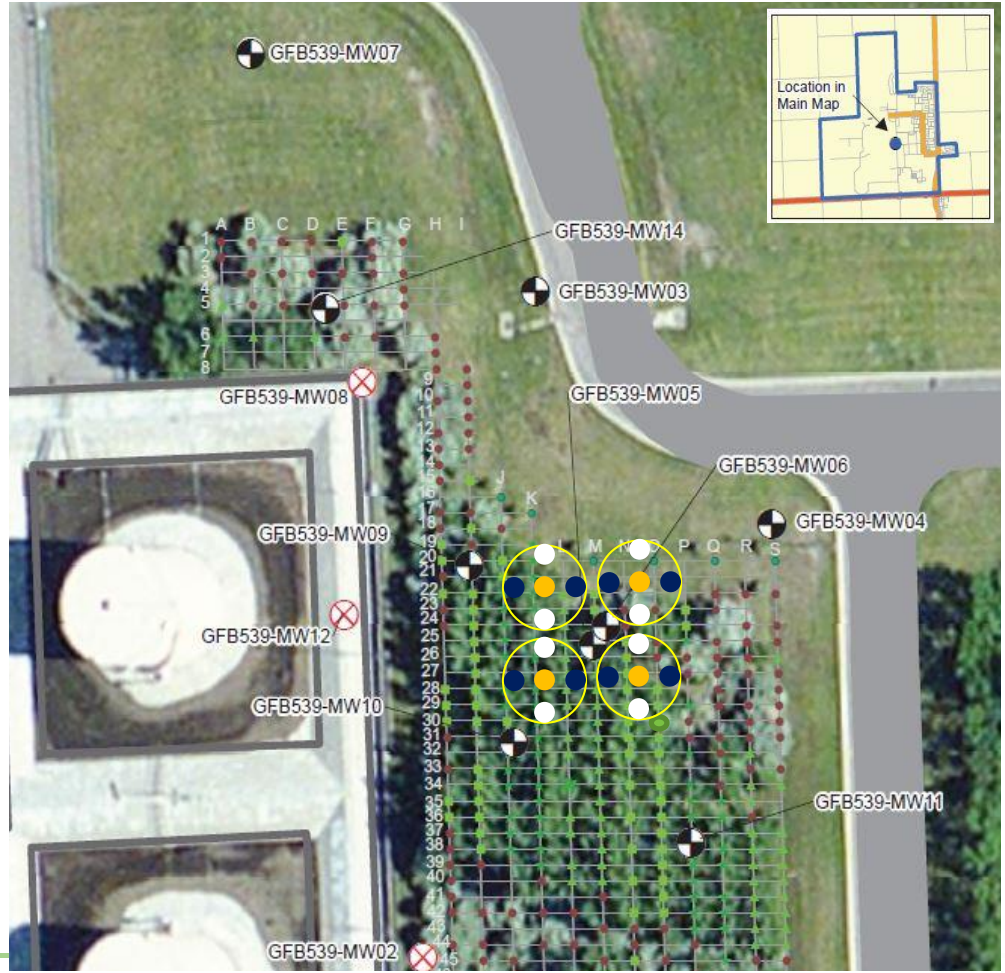


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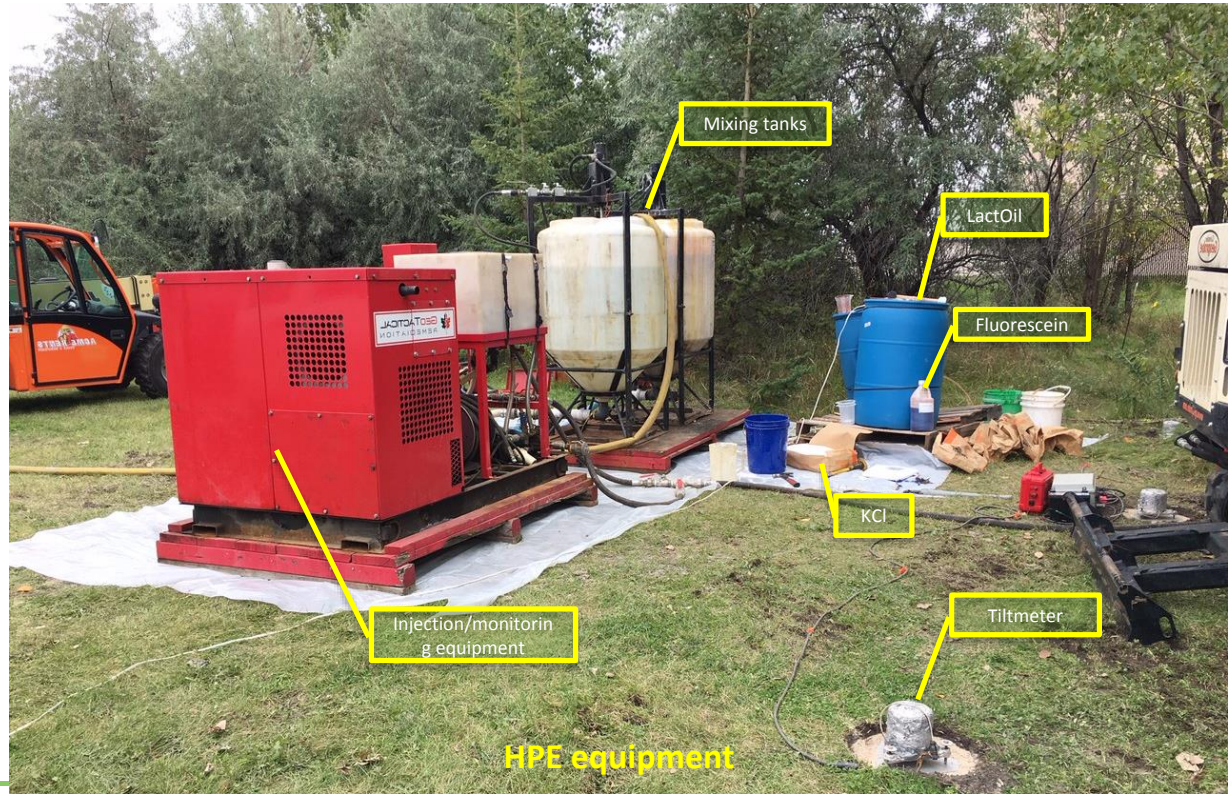
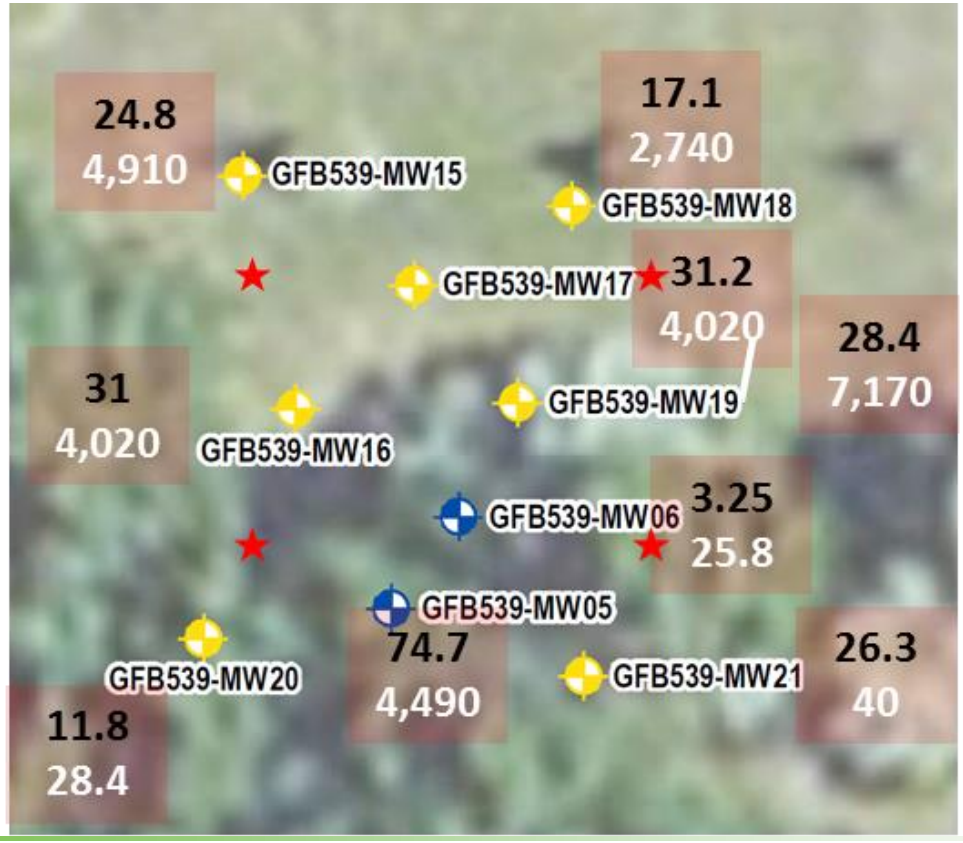
Figure courtesy of ARGO/ LRS JV

Field Implementation Photos – GFAFB

Implementation



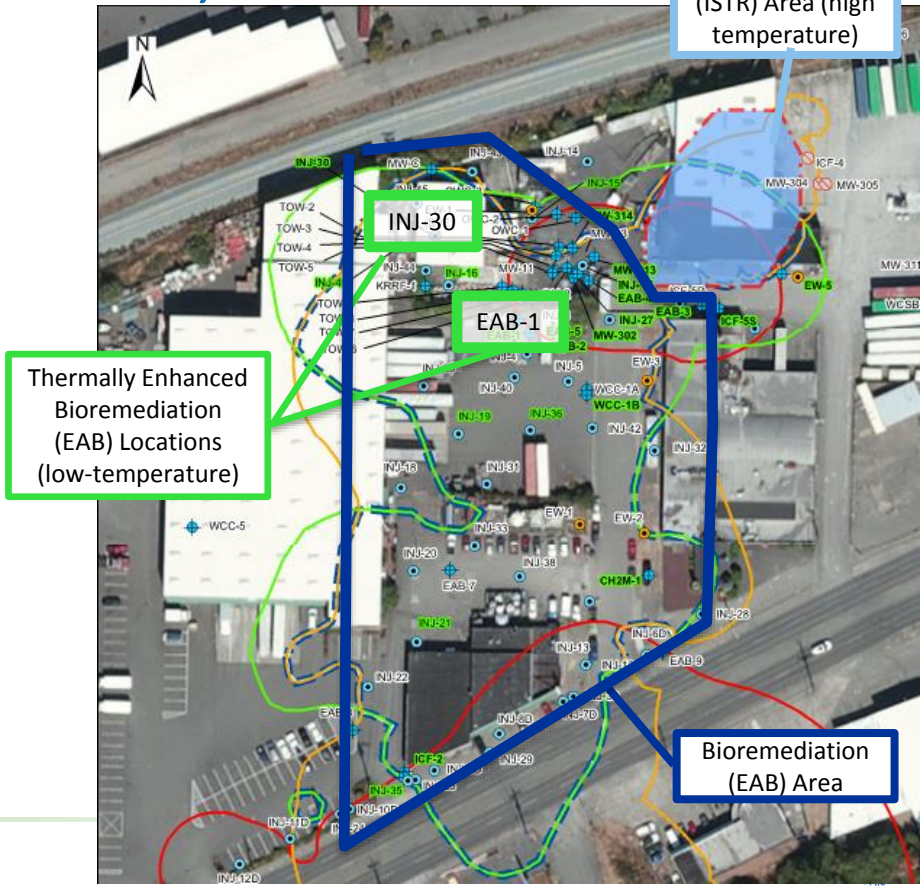
Groundwater Results – TOC (mg/L)



Site #4: Well 12A Superfund Site

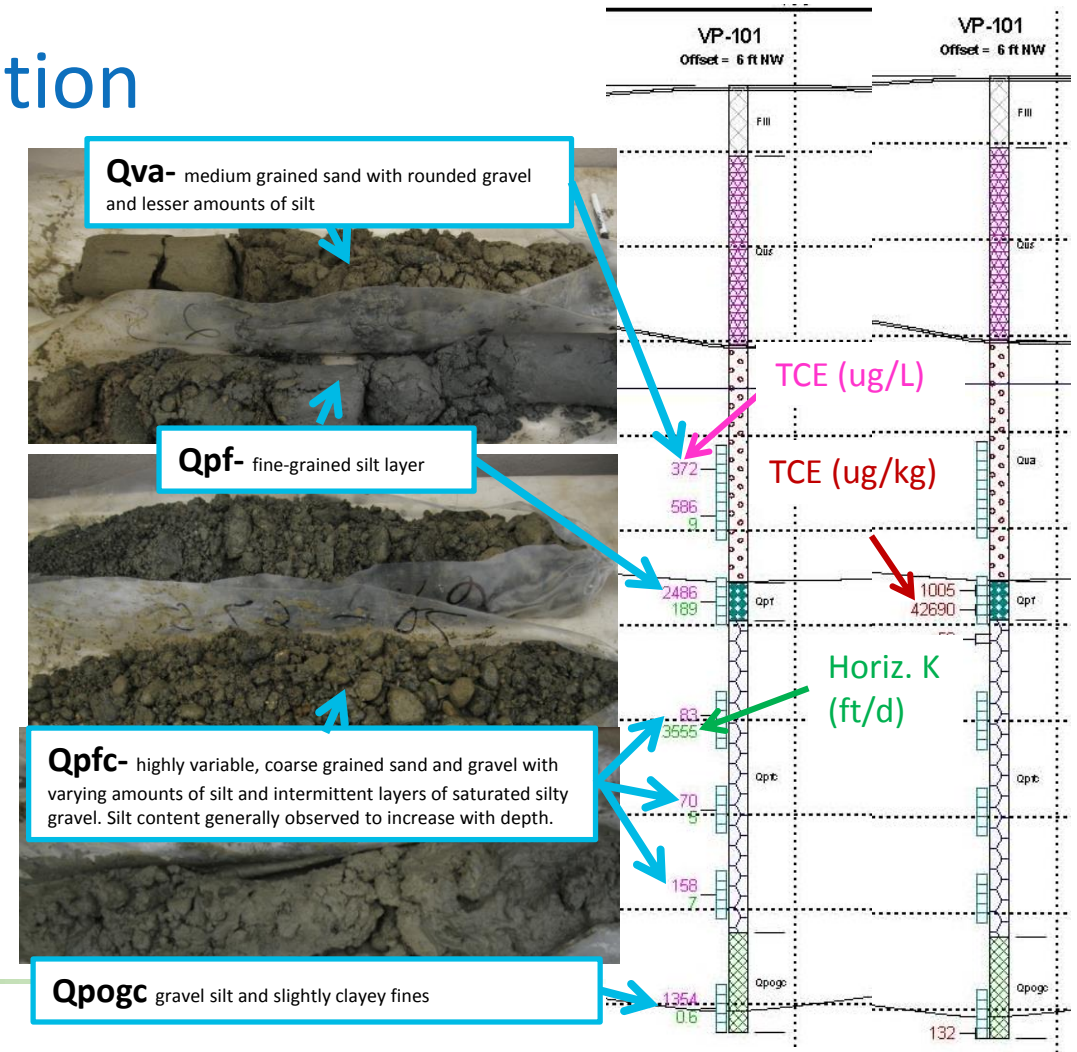
Commencement Bay/South Tacoma Channel Well 12A Superfund Site, Tacoma, WA

- Six primary contaminants of concern (COCs) in soil and groundwater at depths greater than 100 ft
  - PCE, TCE, cis and trans 1,2-DCE, vinyl chloride, 1,1,2,2-tetrachloroethane
- Remedial strategy:
  - Multi-component remedy including EAB and in situ thermal remediation
  - High resolution site characterization to refine target treatment interval
  - Incorporation of shear thinning fluids

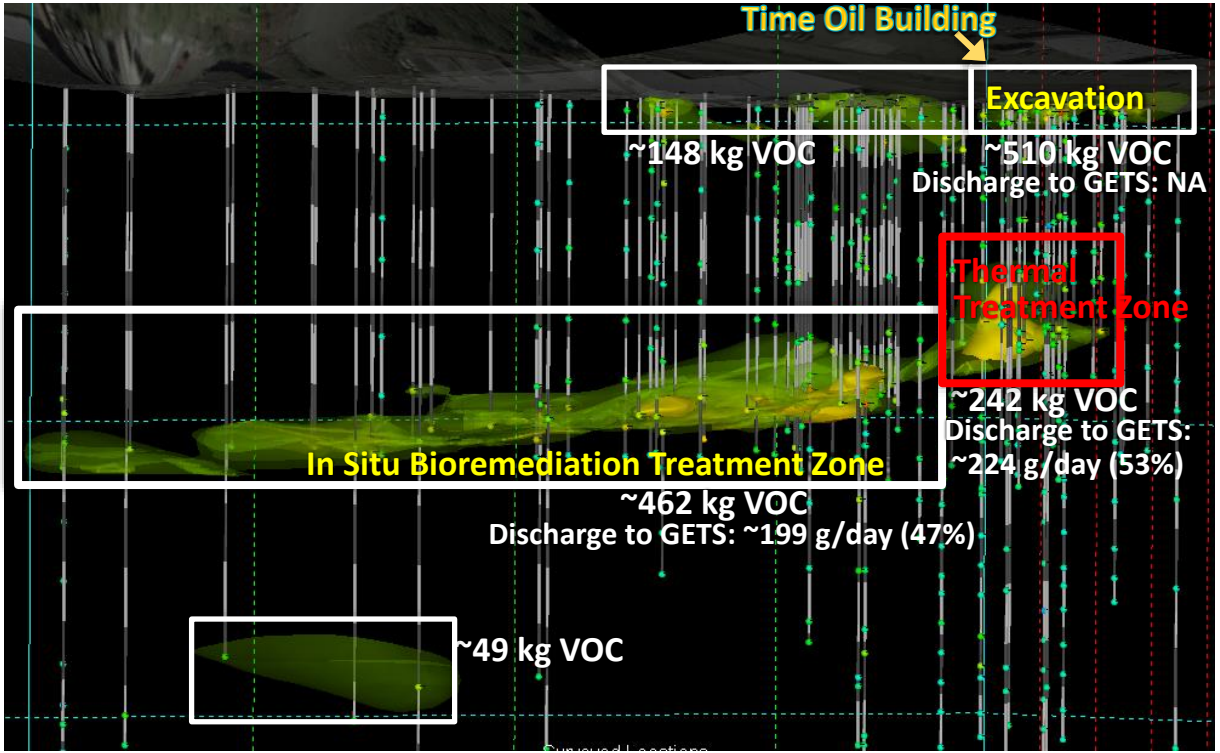


Vertical Characterization

- Vertically discrete sampling showed that ~ 95% of the mass discharge was occurring within 20 feet of the 75 foot vertical extent

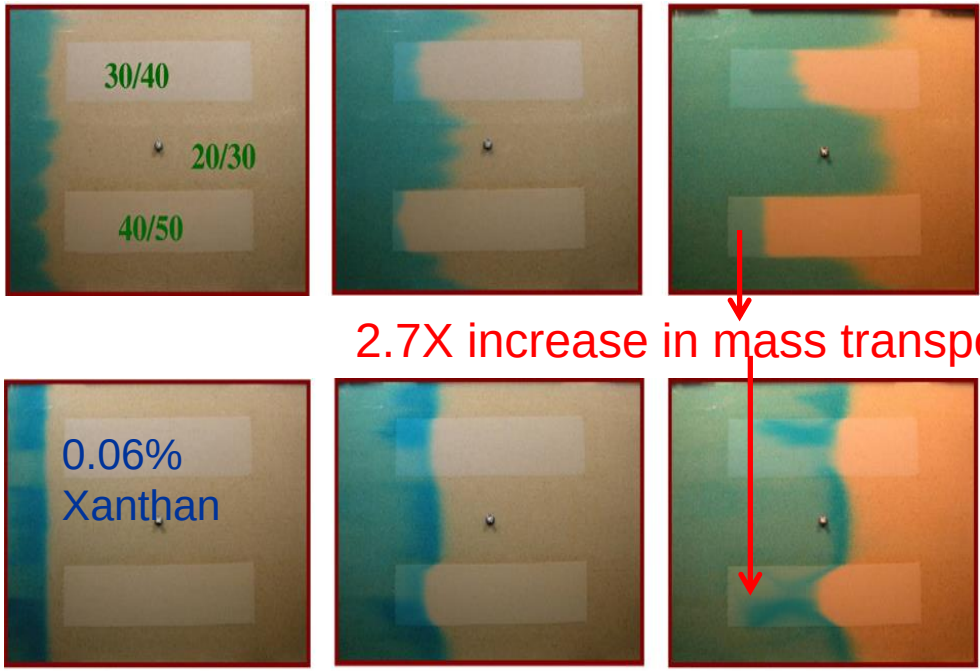


EAB is Targeting Mass in Low Permeability Zones



Remedy Optimization Step – Shear Thinning Fluids

- Shear-thinning fluids exhibit lower viscosity as greater shear force is applied
- During injection, shear force is higher in low-permeability zones
  - Viscosity lower in fine-grained soil
- Shear-thinning fluids increase relative flow through low permeability zones
  - Can deliver greater proportion of remedial amendments to low-permeability units
- Injection testing and confirmation sampling confirmed amendment delivery into silt



Zhong (2008)

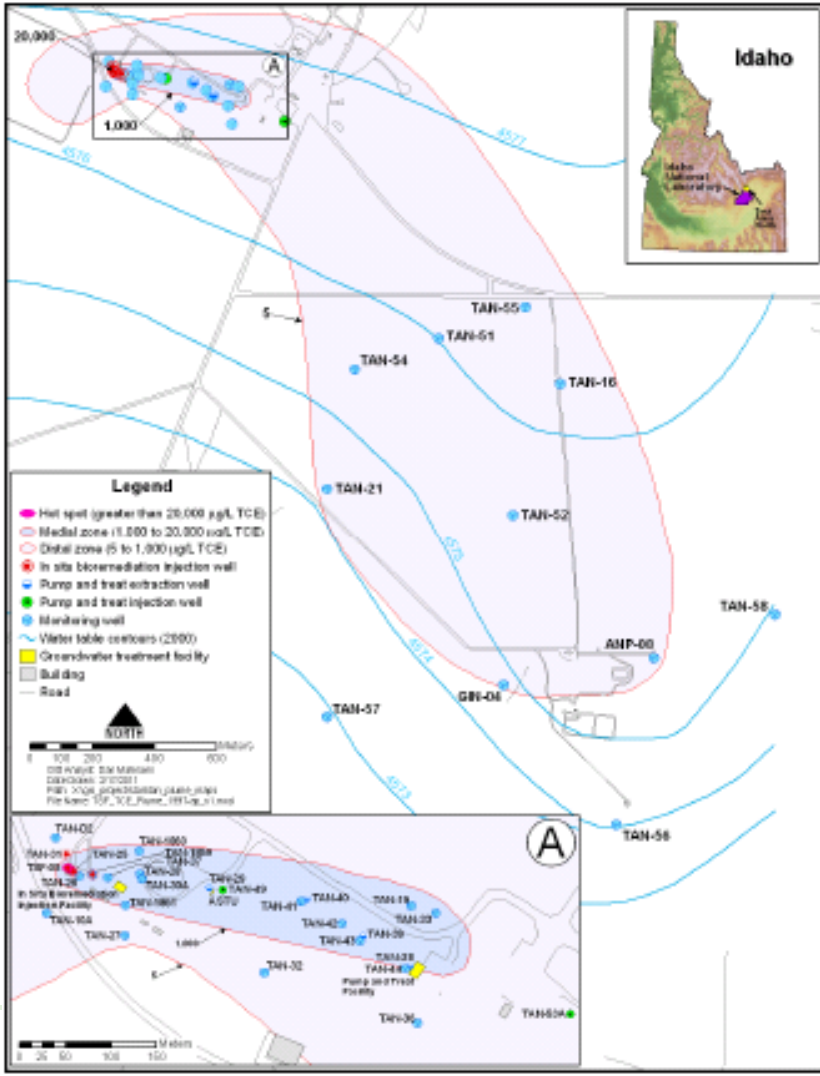
Full-Scale EAB Implementation with Shear Thinning Fluids

- Over 850,000 gallons of shear-thinning fluid amendments with emulsified oil injected into 43 injection wells
- Emulsified oil concentrations varied from 3% to 5% depending on total VOC concentrations in soil and groundwater
- Xanthan gum concentrations varied from 0% to 0.125% depending on specific capacity of wells
- Injection completed using multiple amendment tanks and pumps/manifolds to allow simultaneous injection of different amendment mixtures

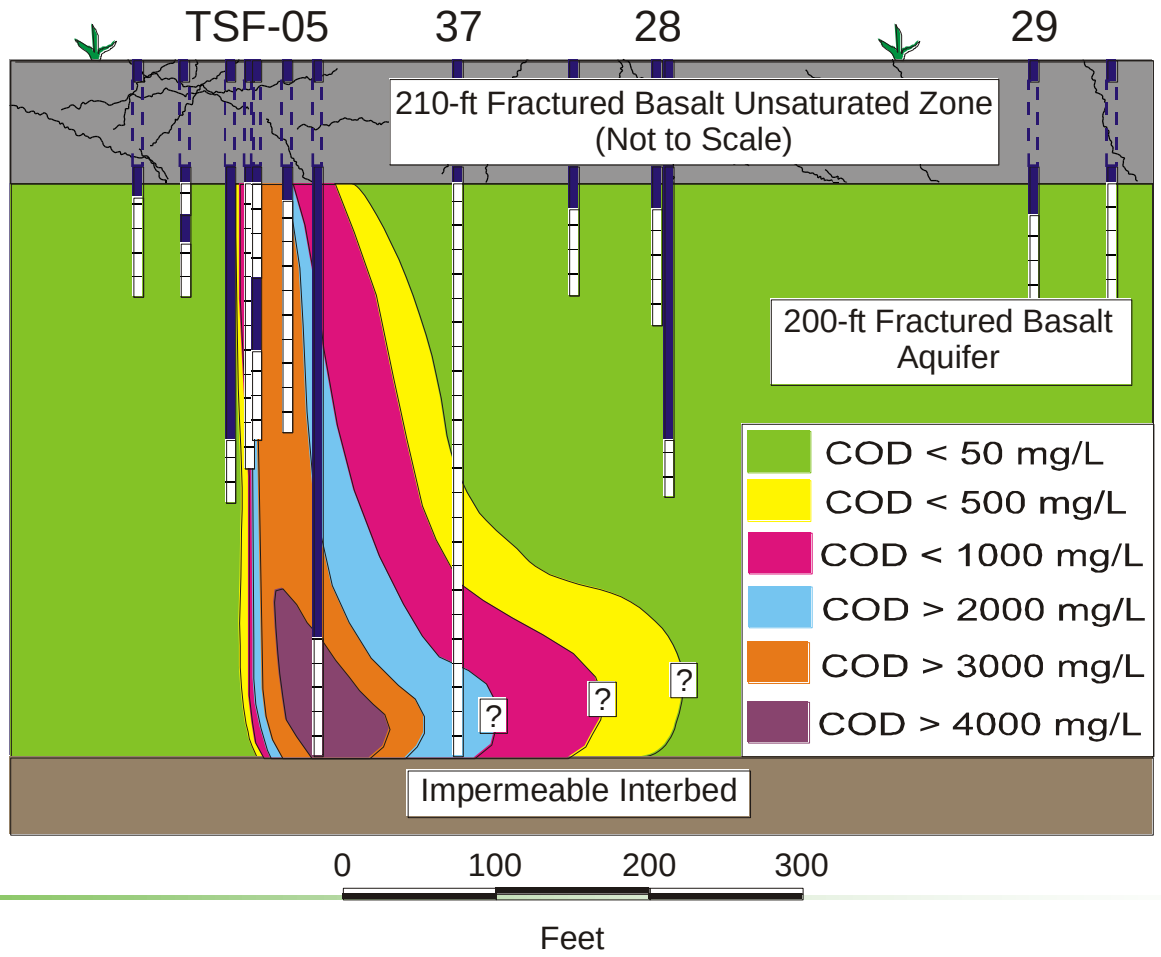
Site #5: Test Area North

Test Area North

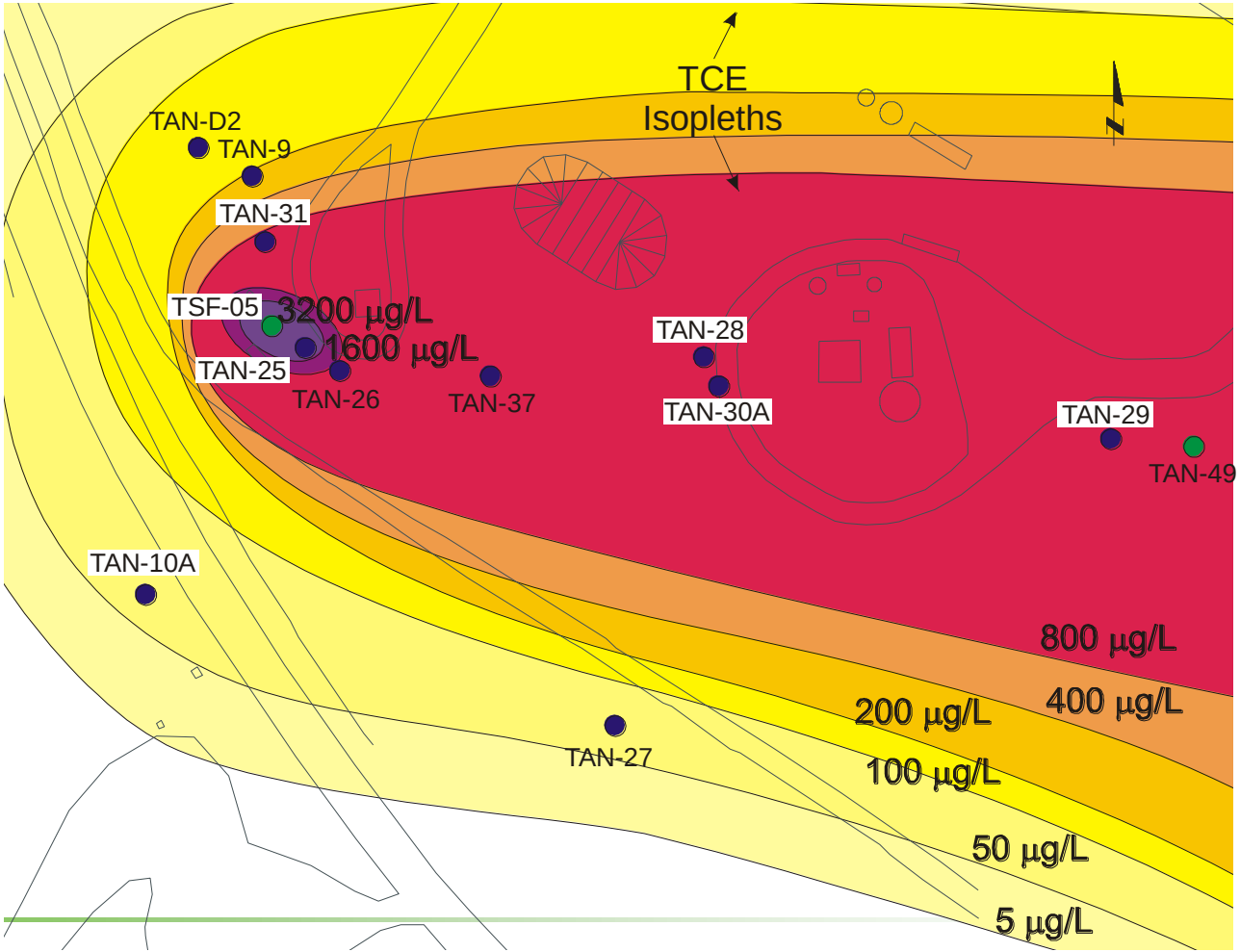
- 1.5-mi TCE plume emanating from sludge disposal well
- 200 ft to water; 200-ft contaminated thickness
- EAB selected for source area
  - Sodium lactate initially, whey also used
  - Use former sludge injection well for amendments
  - Single injection events of thousands of gallons of amendments performed at ~40 gpm
  - Donor distributed with ROI approaching 75 to 100 ft



Chemical Oxygen Demand Sept. 13, 1999



Pre-Lactate


TCE
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TAN-28
TAN-30A
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200 µg/L
100 µg/L
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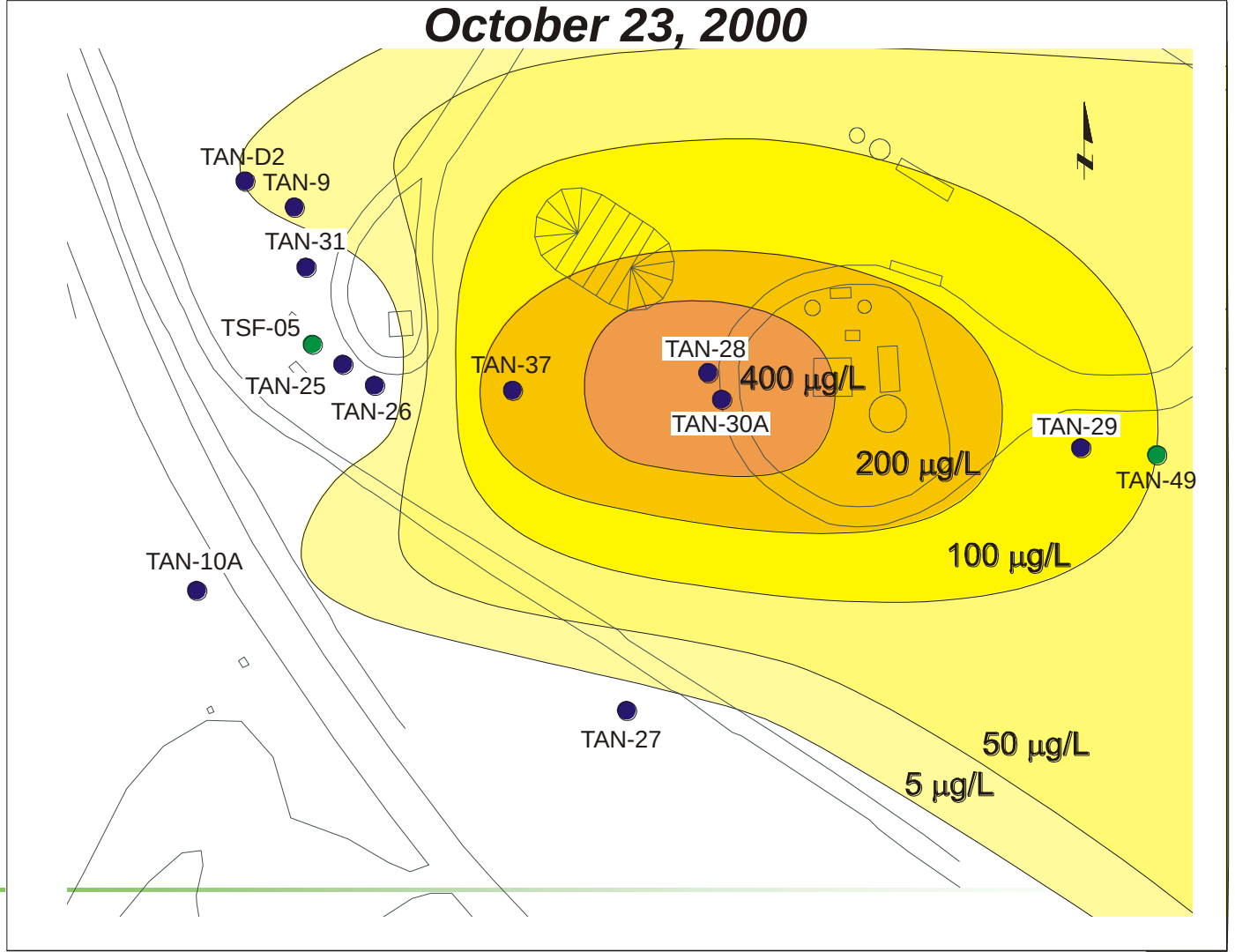
October 23, 2000
TAN-D2
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400 µg/L
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200 µg/L
TAN-29
TAN-49
100 µg/L
TAN-10A
TAN-27
50 µg/L
5 µg/L
N

Summary and Conclusions

- Depth is not inherently a limitation for implementation of bioremediation
  - Deeper sites allow for more mounding and higher injection pressures
- While injection and monitoring infrastructure are more expensive, creativity can be used to maximize cost effectiveness:
  - Active recirculation to extend injection well spacing
  - Invest in characterization
  - Combined remedies

Acknowledgements

- Kent Sorenson
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