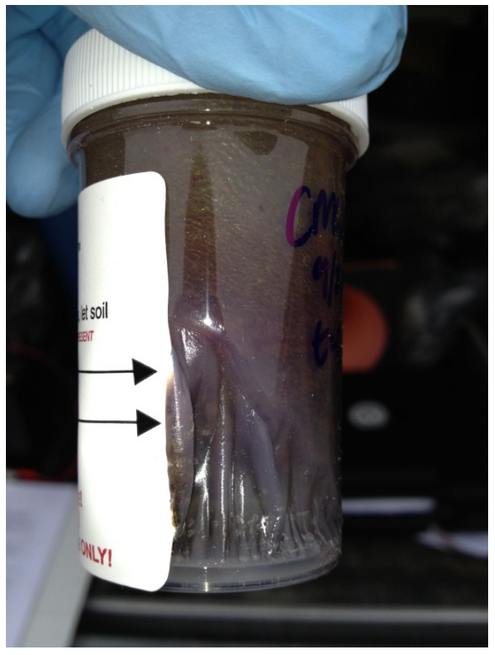
A Dual Biorecirculation System to Facilitate VOC Mass Reduction and Hydraulic Control in Fractured Bedrock

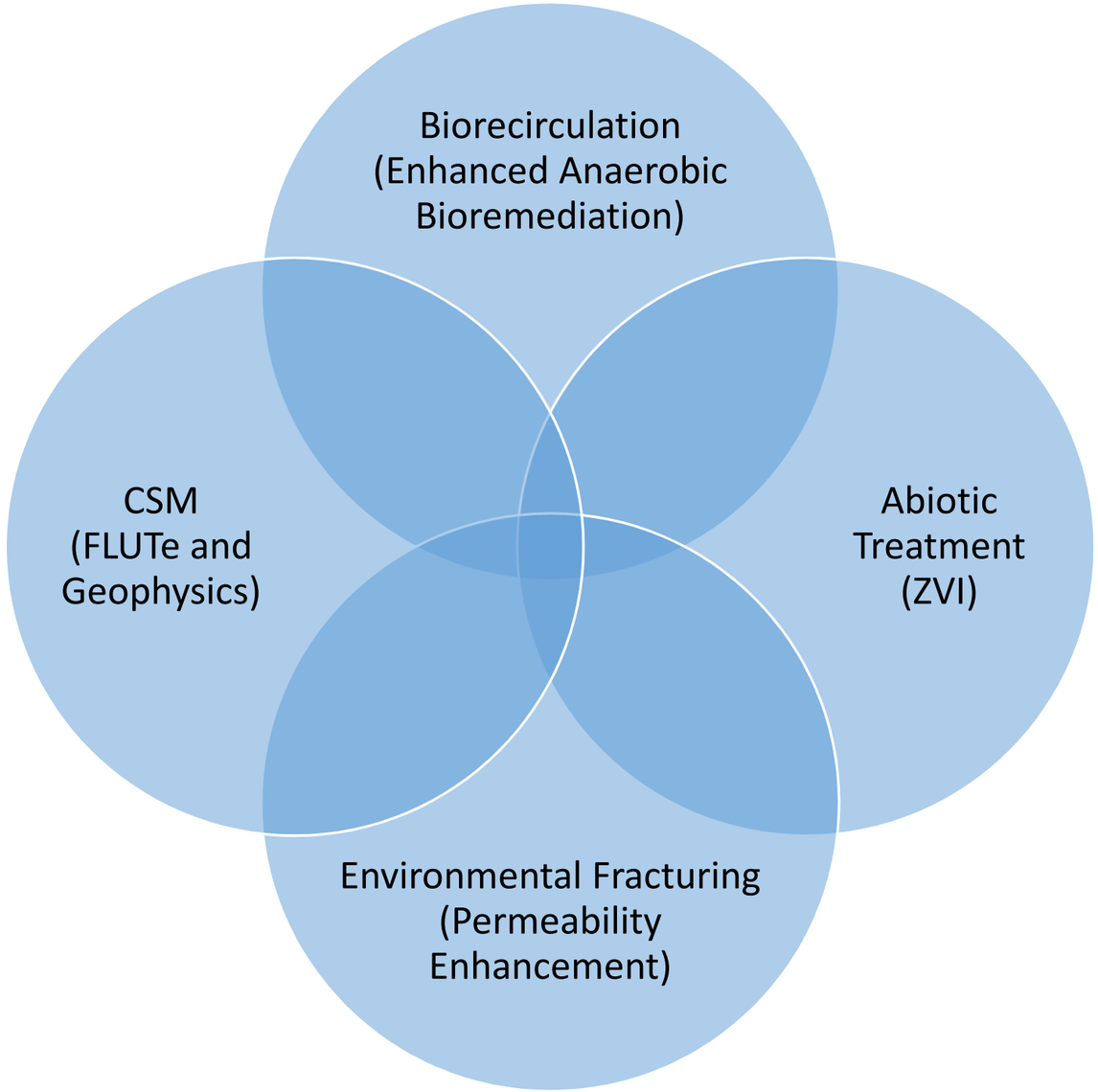


Jeff Bamer

CDM Smith

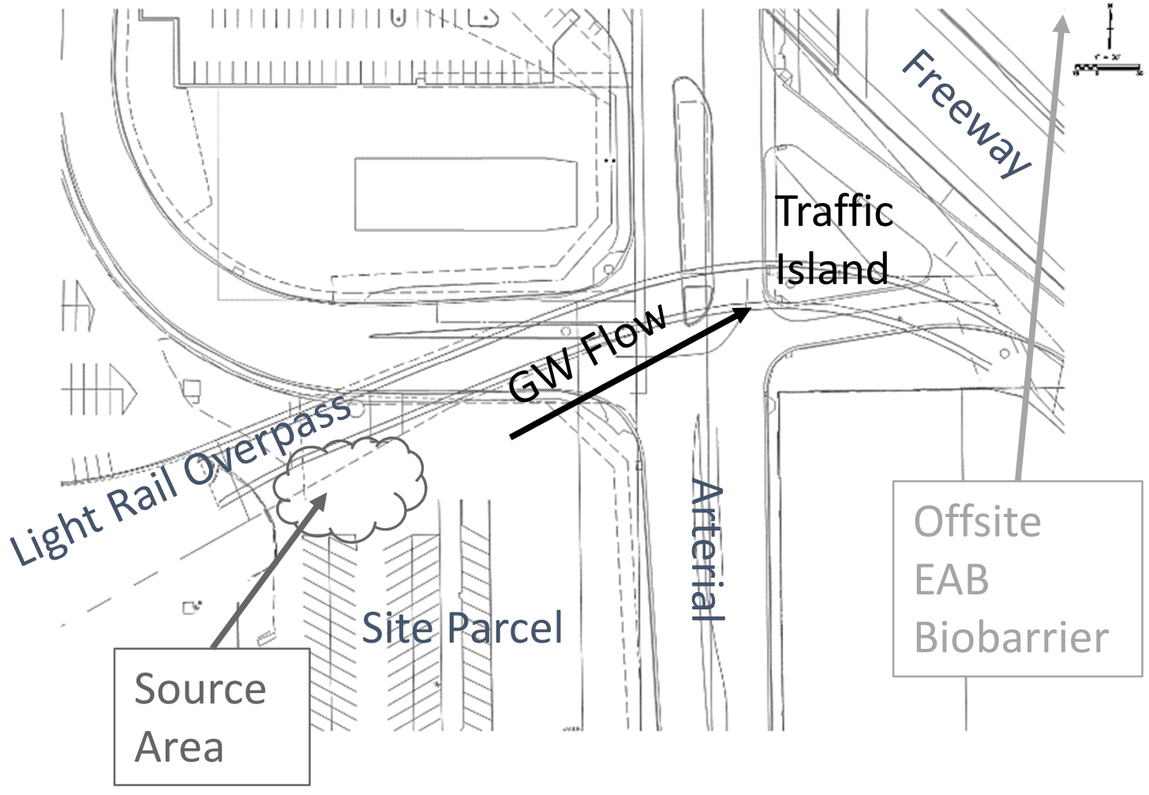
Presentation Overview

- Site Background
- Remediation Objectives
- Remedy Design (Concept and Locations)
- Remedy Installation
- Results
- Critical Success Factors



Site Overview

- Former industrial site
- Public infrastructure
- CVOCs (TCE) in GW follow paleochannel to northeast
- Mobile DNAPL present onsite in bedrock wells
- Historical EAB injections
  - Traffic island infrastructure
  - Offsite biobarrier



Site Geology

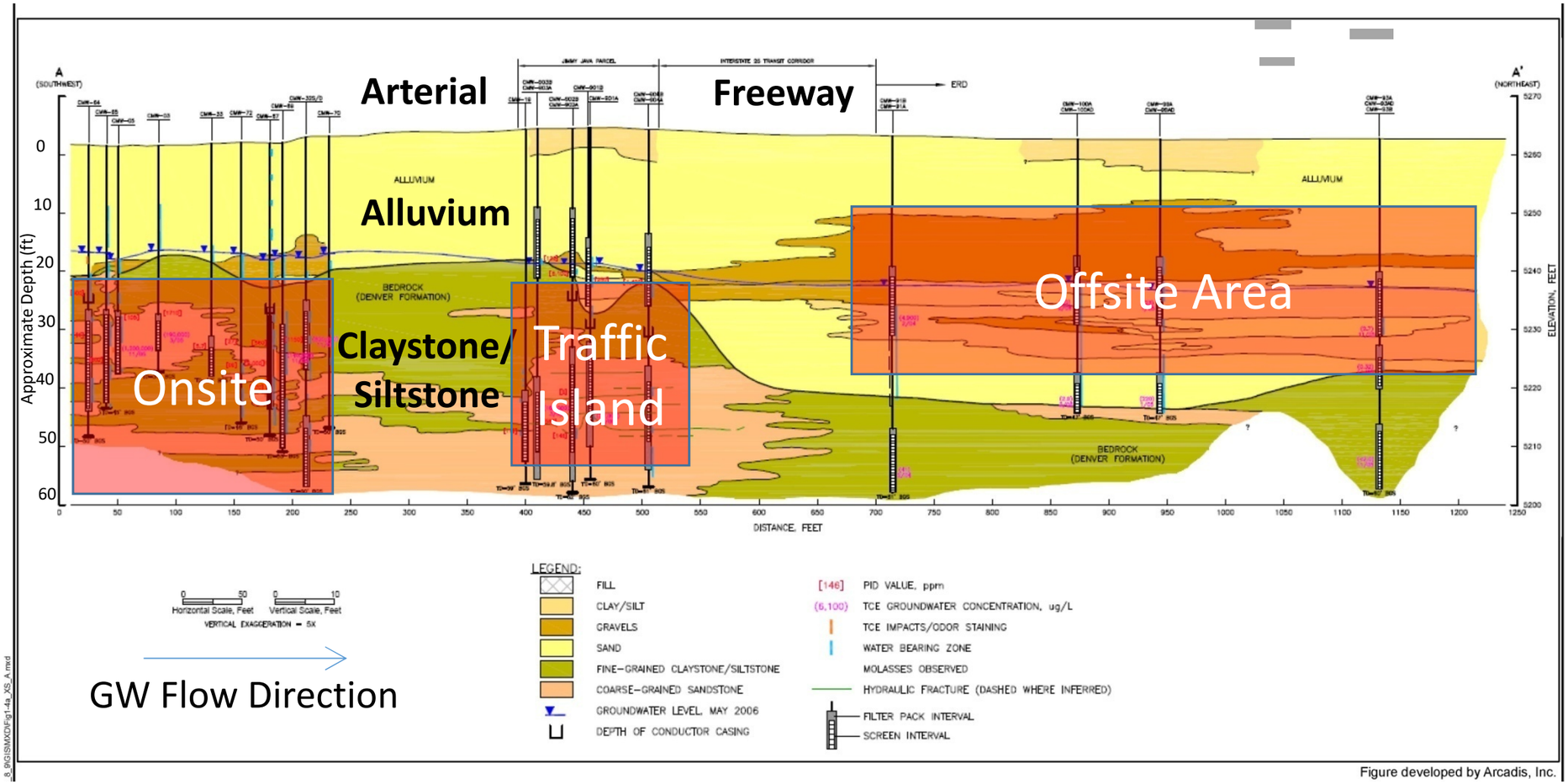
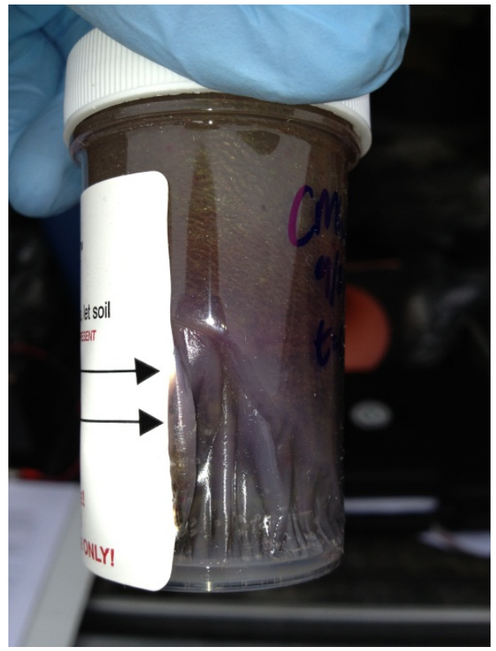


Figure developed by Arcadis, Inc.

Remediation Objectives

- Objectives
  - Hydraulic control (stop downgradient mass flux)
  - Onsite mass removal
- Considerations and Constraints
  - Significant VOC mass
  - Difficult hydrogeology
  - Numerous surface access constraints (e.g. streets, overpass)
  - Data gaps



Combined Approach

CSM and Geophysical Methods

- Improved remedial targeting
- Reduced risk of enhanced NAPL migration

Biorecirculation

- Reductive dechlorination of dissolved-phase VOC
- DNAPL treatment
- Hydraulic control

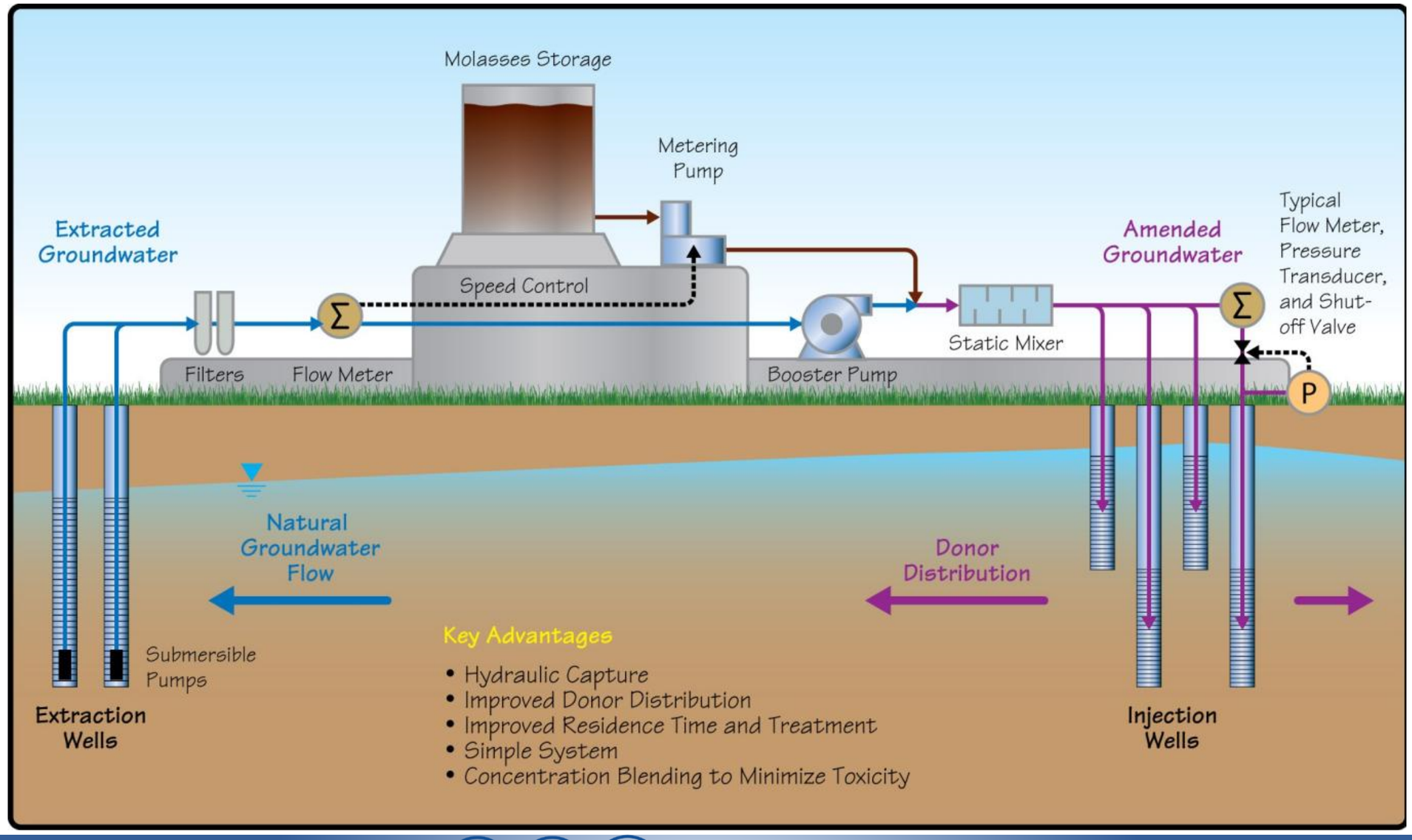
Environmental Fracturing

- Drastically improved delivery and contact with VOCs
- Reduced surface access limitations

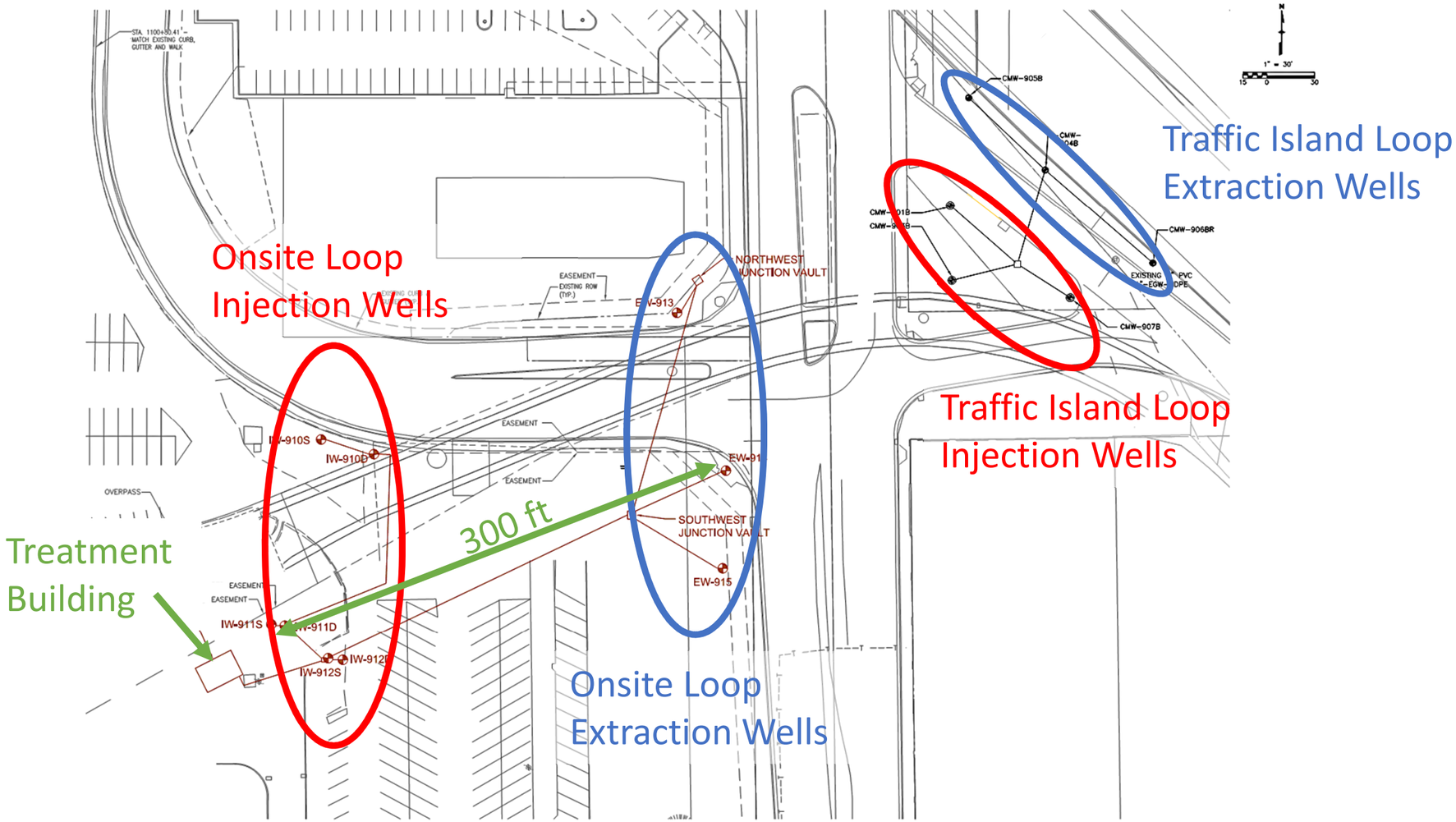
Abiotic Treatment (ZVI)

- Reducing conditions
- Additional treatment pathways

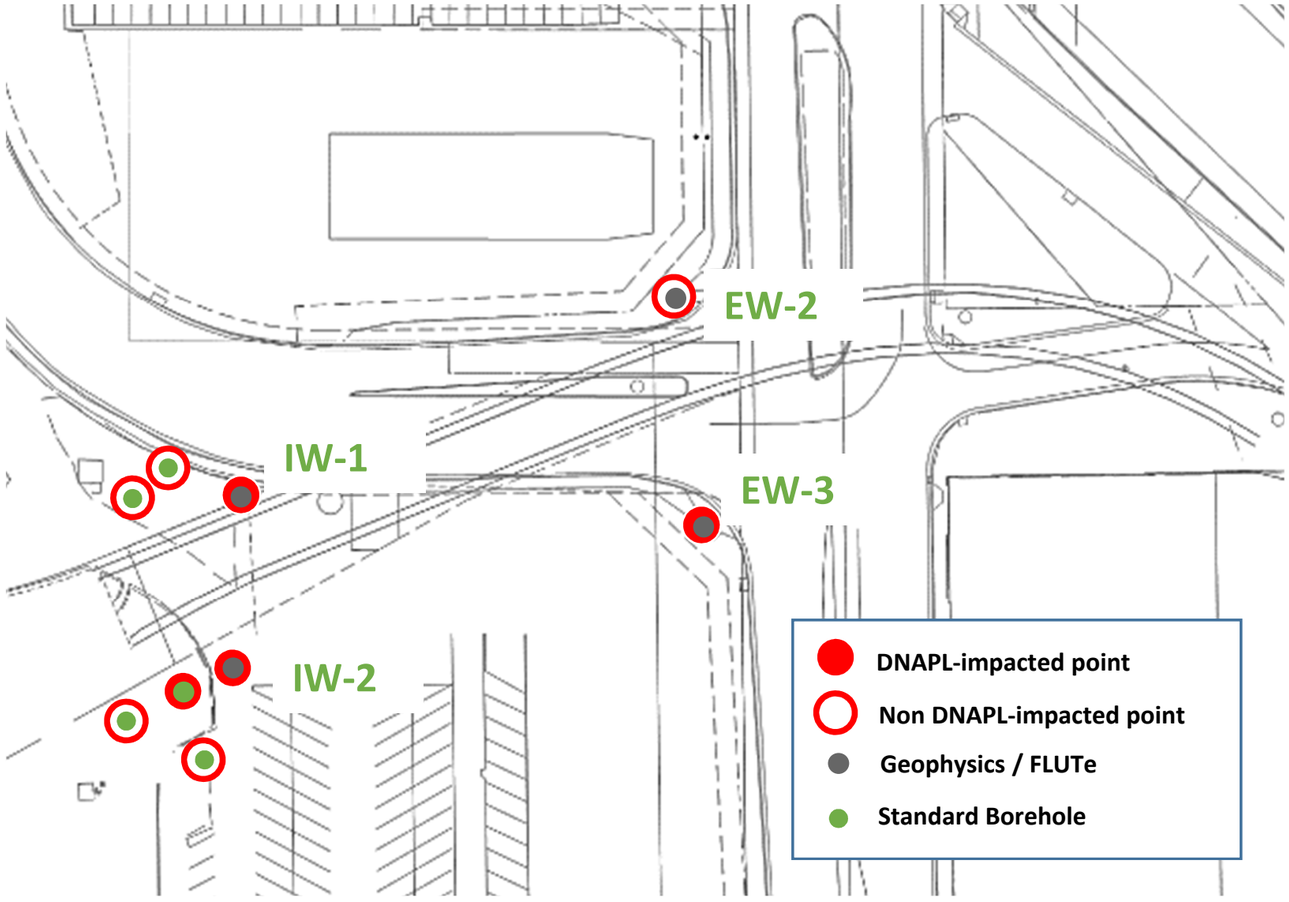
Biorecirculation Process



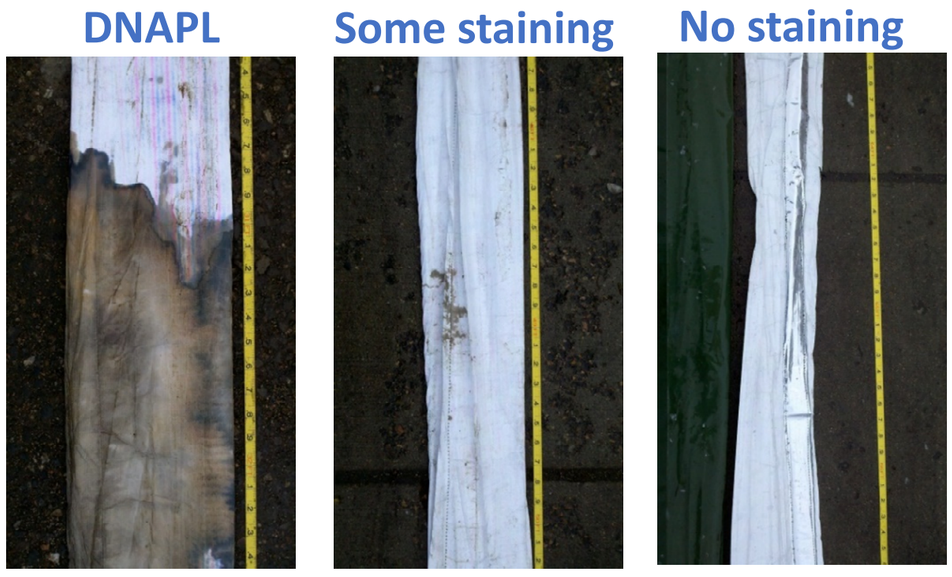
Remediation Approach – Two Loops



Geophysics, FLUTe, and DNAPL Delineation



- Geophysical investigation
  - Fracture location
  - Fracture transmissivity
- FLUTe liners
  - NAPL location



Environmental Fracturing

- Forced tensile parting of the subsurface
- Increase hydraulic conductivity
- Inject water, sand, and guar polymer, with zero valent iron (ZVI)
- Initiate with high pressure (90 to 3,000 psi) and high flow
- Propagate an injection plane (85 to 400 psi)
- Specialized equipment required
- Real-time pressure and flow data
- Fracture mapping (tilt meter)
- ESTCP Project ER-201430

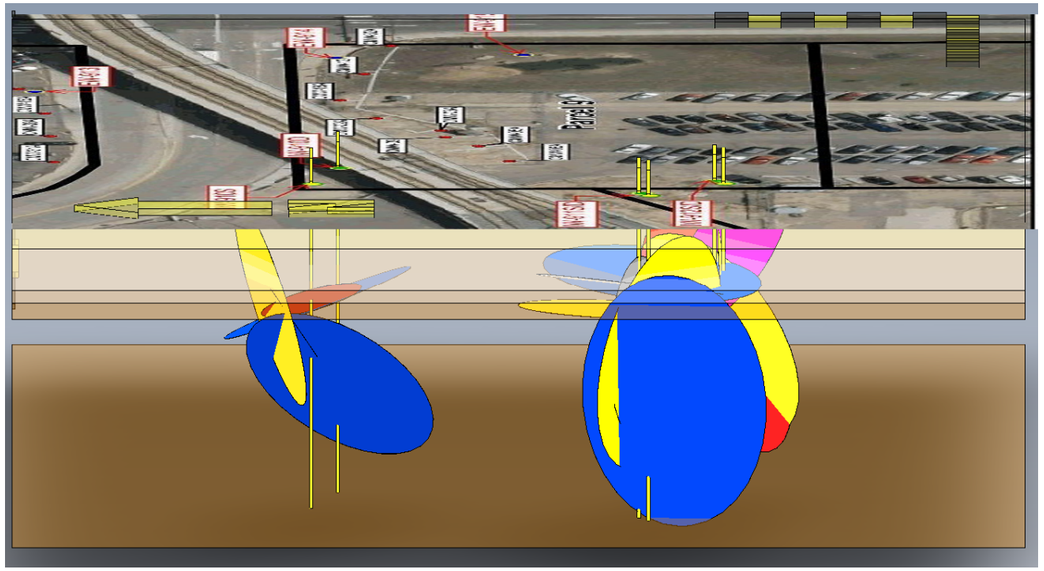
Fracturing Results

- 20 fractures (and 12 conjugate fractures) into 9 boreholes
- Emplacement volumes (98% of target):
  - ~60,800 lbs of sand
  - ~47,600 lbs of ZVI
- Fracture width: 0.13” to 0.48” (0.37” average)
- ZVI emplacement radius: 12 ft to 90 ft (40 ft average)

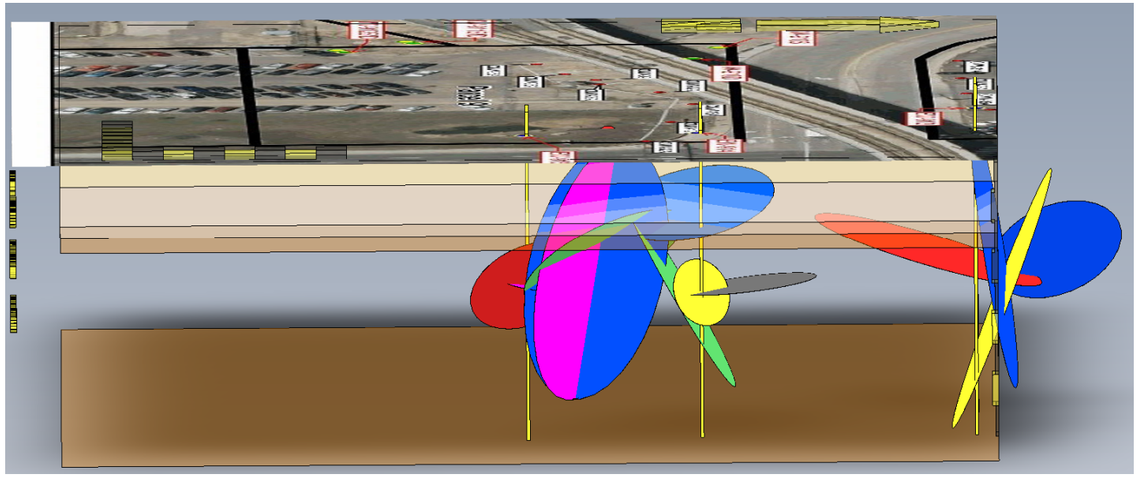
Fracturing Results

- Overlapping fracture network
- Greatly expanded network from conjugate fractures
- Some fracture penetration into the upper alluvium
- Imagine connectivity without the new fractures…

Injection Wells - Looking East/Downgradient (from the treatment building)

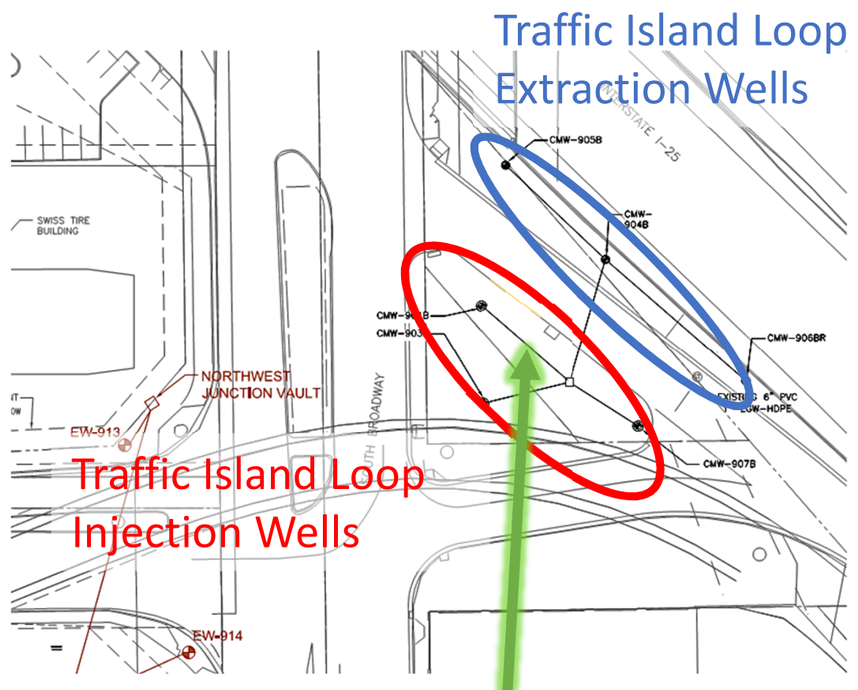


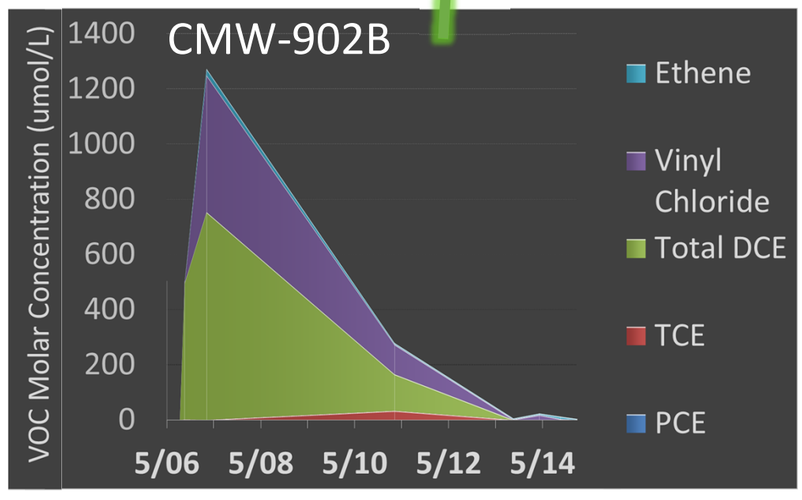
Extraction Wells - Looking West/Upgradient (from the street)



Performance Data – Traffic Island Loop

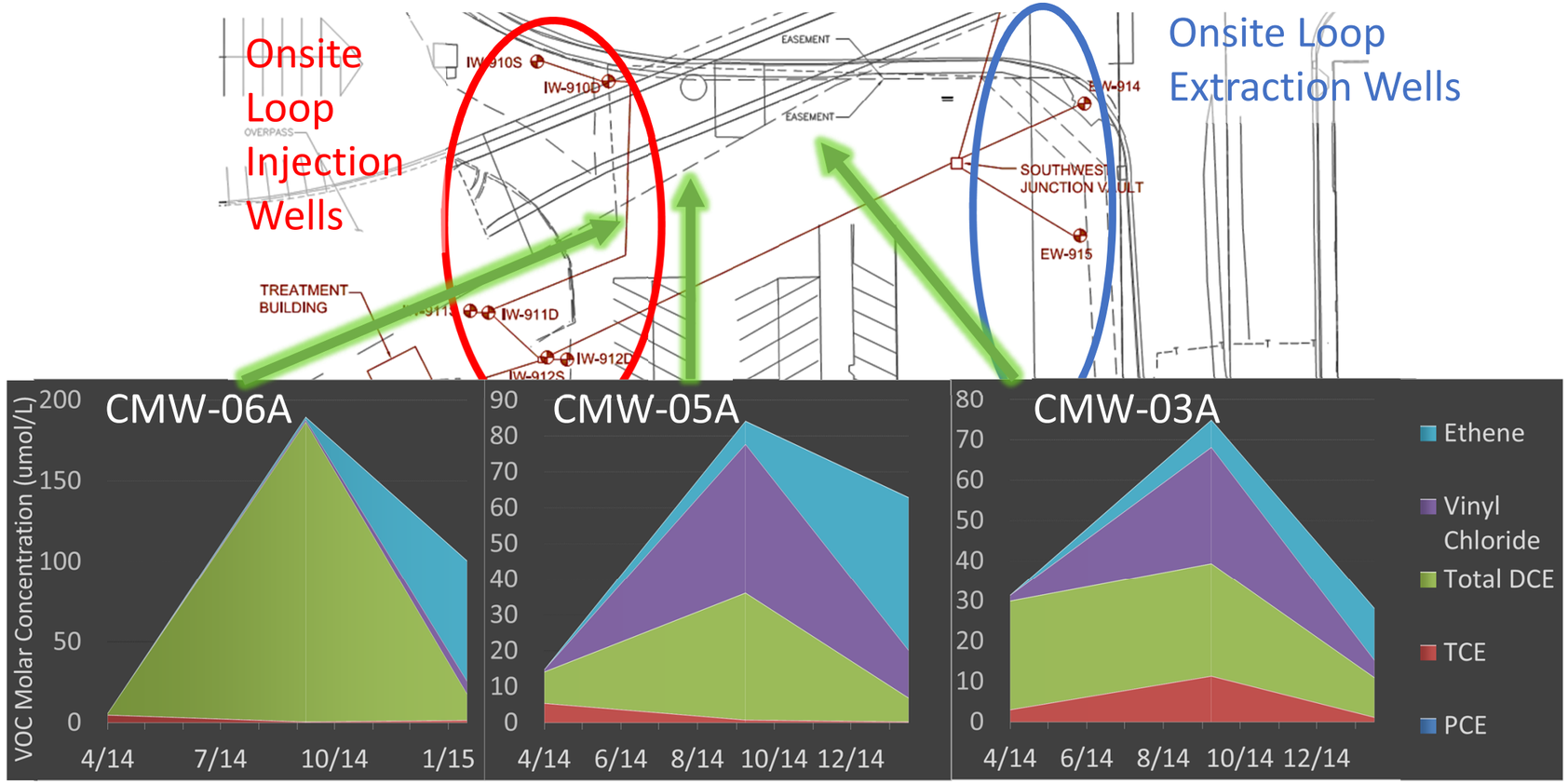
- Historical standard EAB injections (molasses)
- Biorecirculation operation since August 2012
- Intermittent operation
  - Based on TOC concentrations
  - Hydraulic control
- Limited monitoring network
- Complete dechlorination





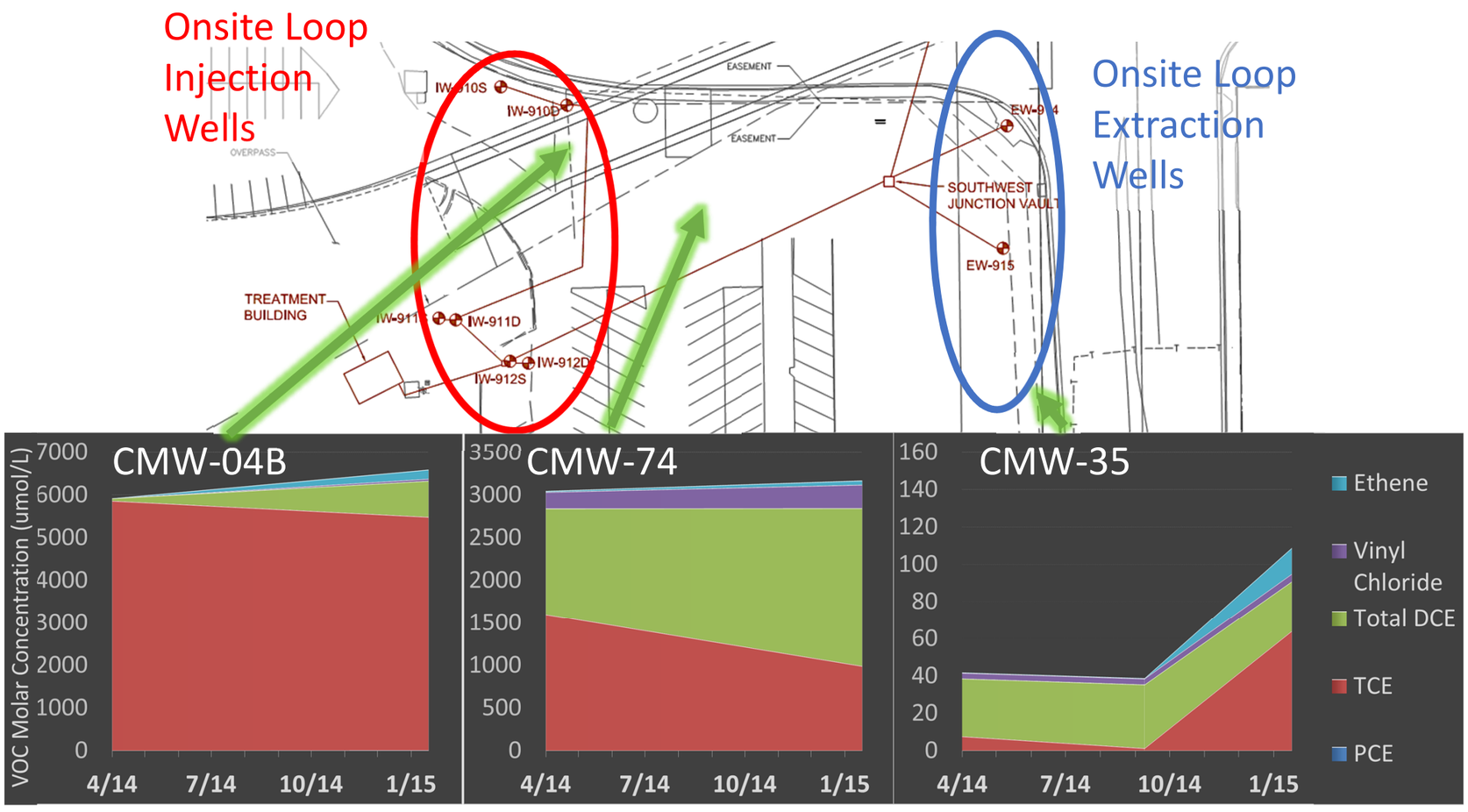
Performance Data – Onsite Loop (Alluvium)

- TOC (donor) generally low (<100 mg/L)
  - Limited alluvium influence by injection wells
- Some VOC mass here (from bedrock or desorption in alluvium)
- Conditions are suitable for complete dechlorination



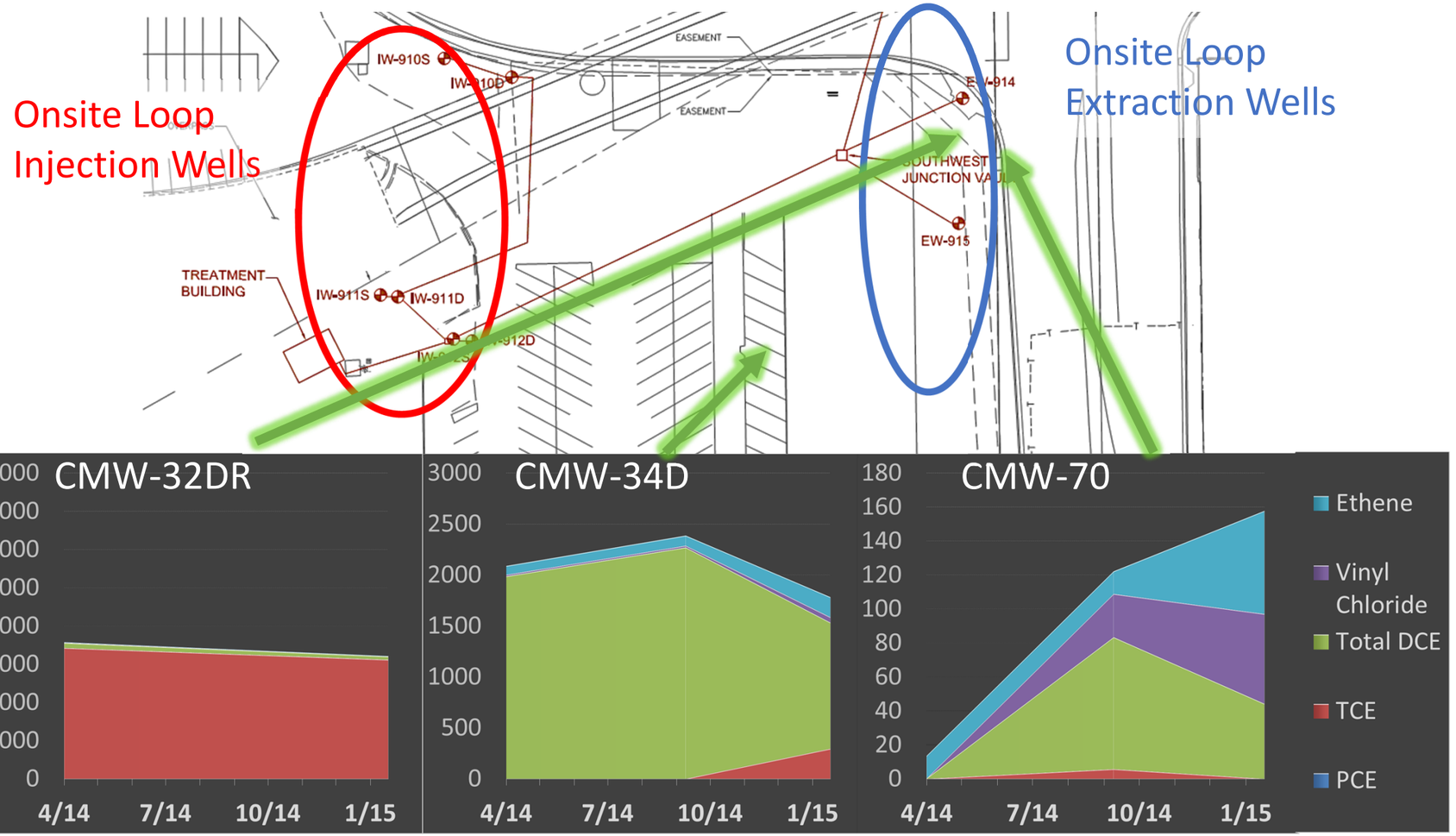
Performance Data – Onsite Loop (Shallow Bedrock)

- TOC increases at MWs adjacent to injection wells, limited elsewhere
- Sulfate reducing to methanogenic conditions
- Conversion to ethene observed within 6 months
- Concentrations remain elevated due to source area mass



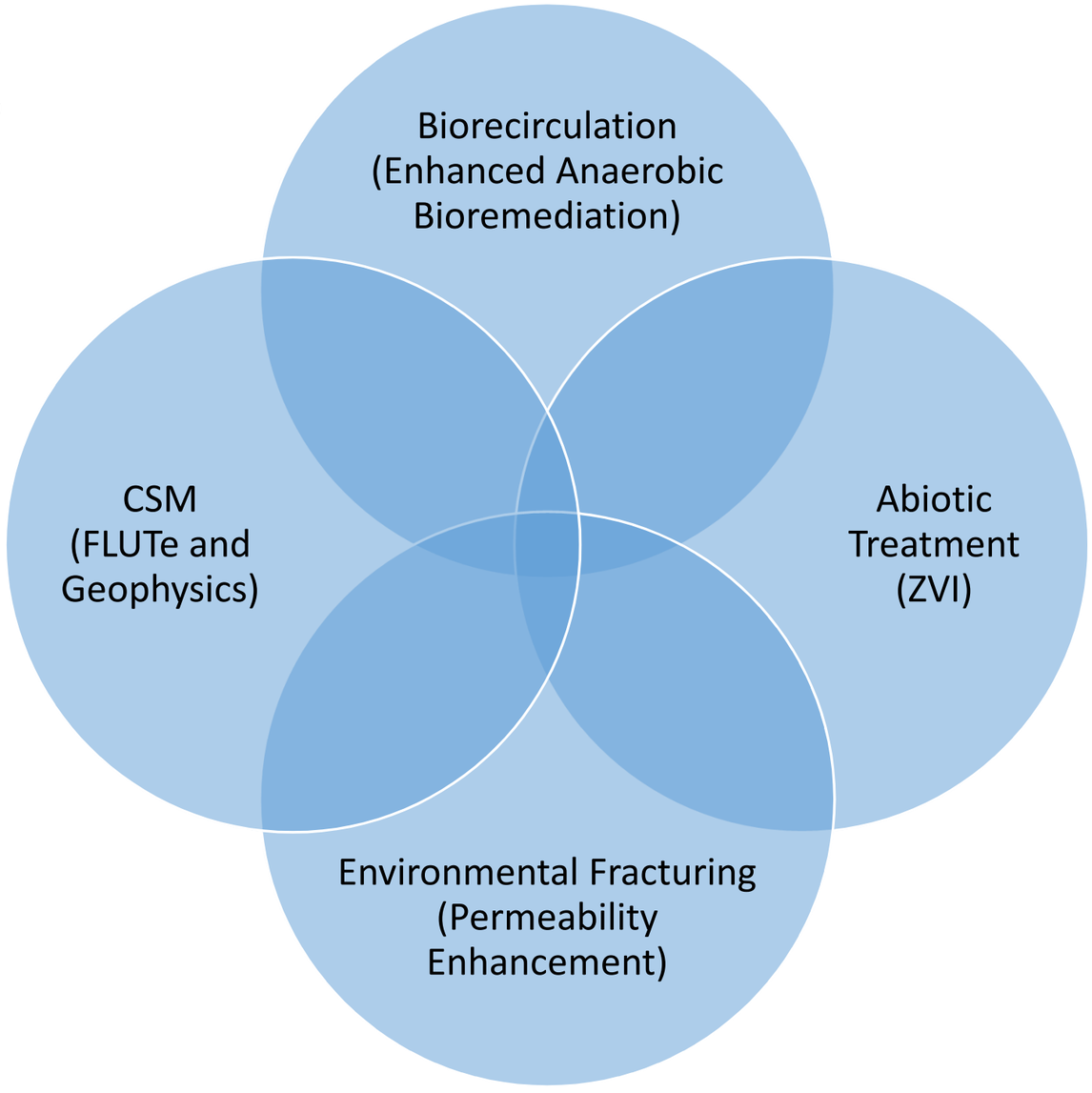
Performance Data – Onsite Loop (Deep Bedrock)

- TOC elevated downgradient at 34D, increased at 32DR
- Concentrations remain elevated, but complete dechlorination underway (even at 32DR)



Critical Success Factors

- Experience in similar geology
- Environmental fracturing expertise and equipment
- Injection and extraction well location selection
- Injection well control strategy
- Dynamic water flushing strategy
- Intermittent operation



Thank you!

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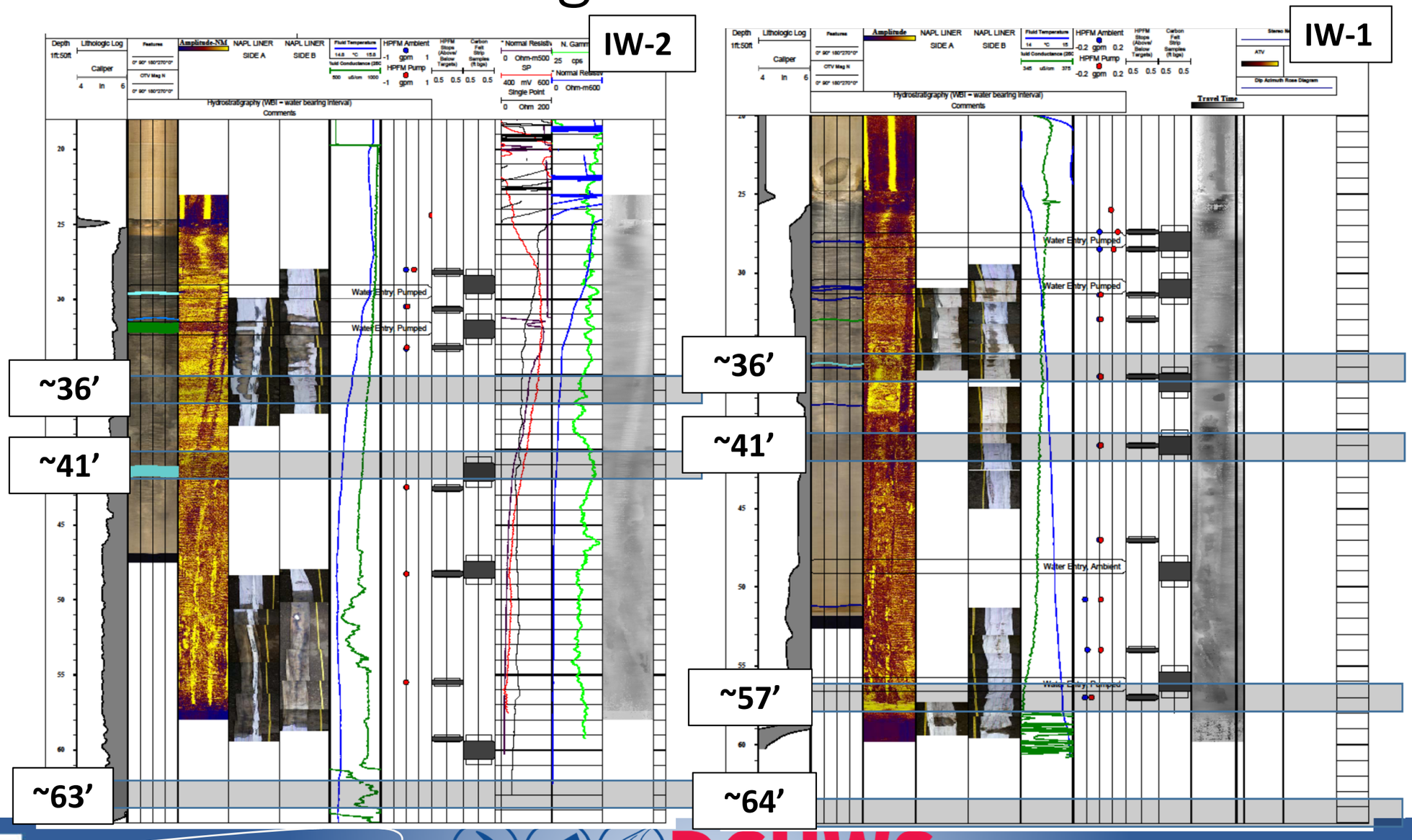
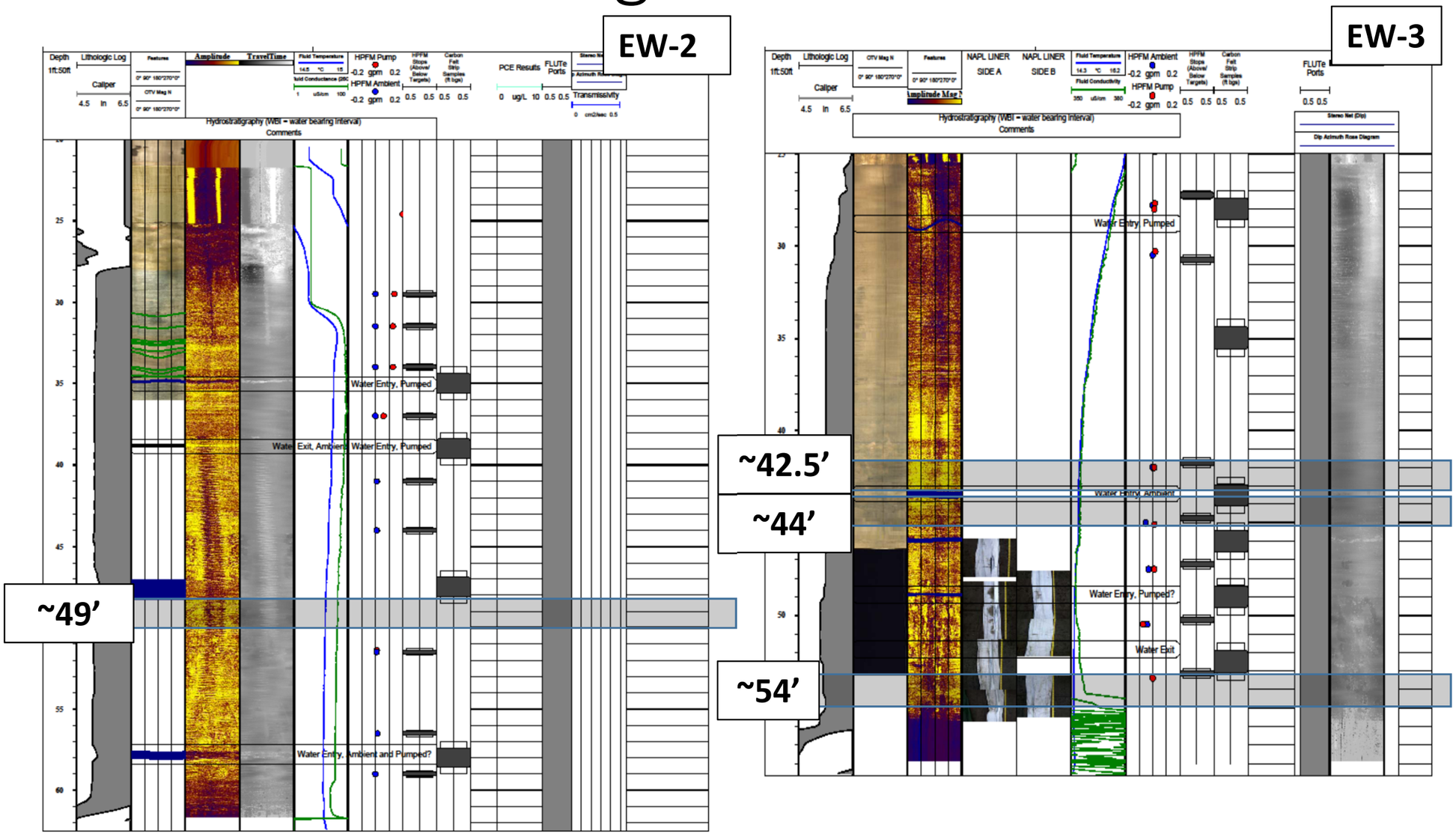
Injection Well Findings

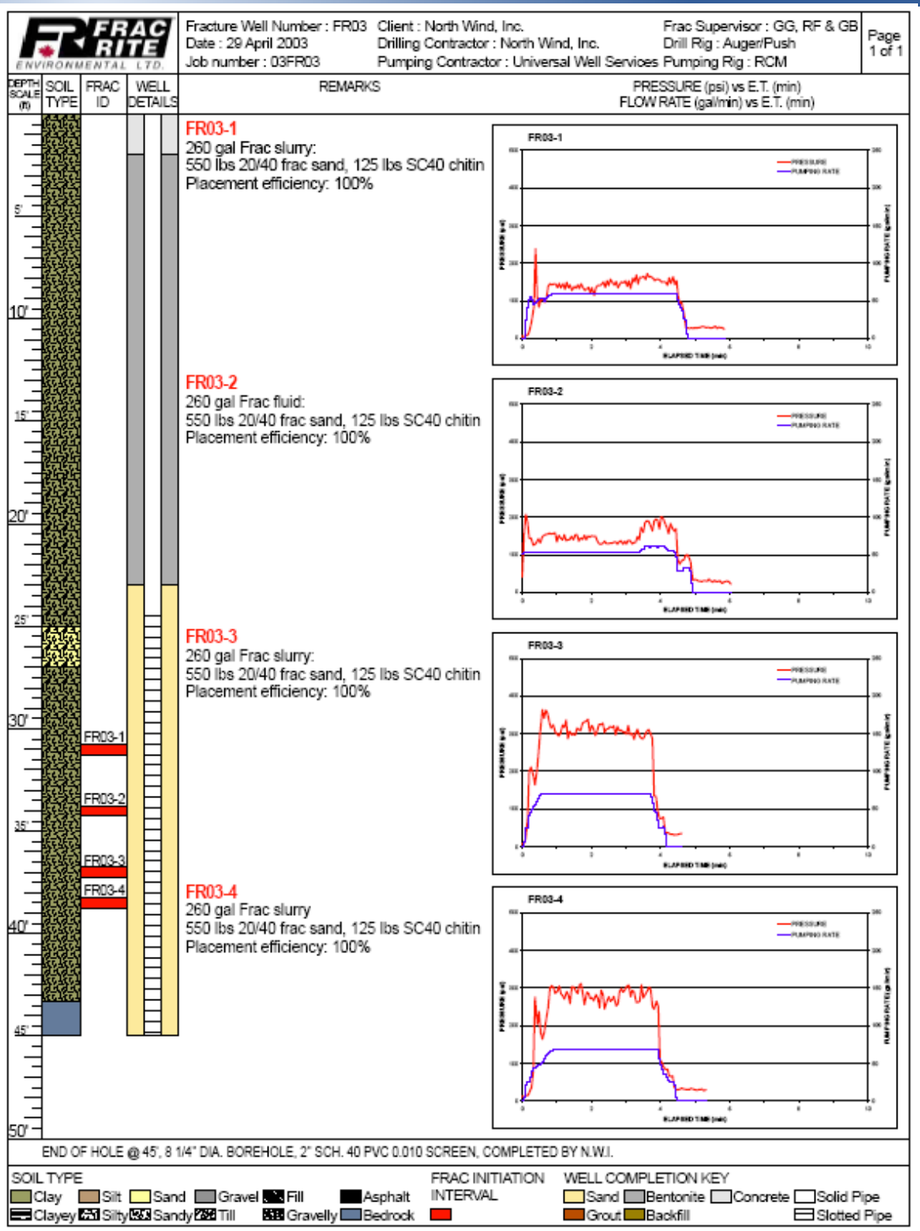


Extraction Well Findings



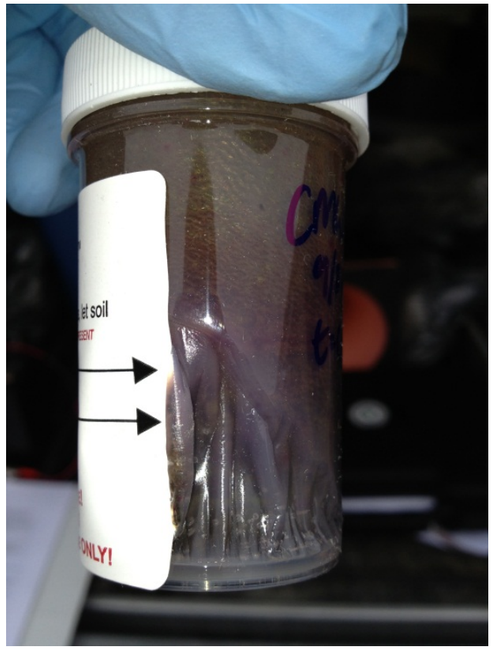
Fracture Borehole Log

- Pressure vs. time characteristics indicate operational fracture pressures:
- “Break” Pressure – indicates pressure at which bedrock breaks (i.e. fractures)
- “Propagation” Pressure – indicates pressure required to radiate fracture outward from borehole



Site DNAPL

NAPL test kit - TCE melted plastic



DNAPL coming up with cuttings during drilling

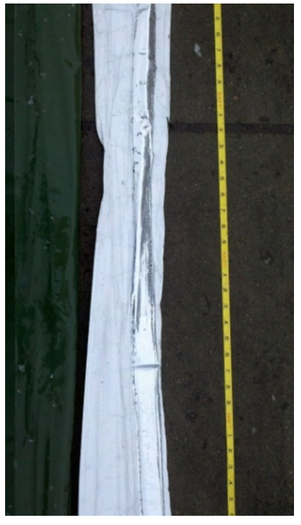
DNAPL recovery during ethanol push-pull test

FLUTe Investigation

- FLUTes are impermeable liners that are installed by pushing the liners into a borehole with water
  - Pressure of water on liner forces liner to conform to the borehole wall
  - A NAPL-reactive fabric is attached to liner
  - Liner is pulled and NAPL fabric shows any reaction with NAPL
- FLUTe liners successful to show discrete units where DNAPL is present in subsurface
  - DNAPL present 30-40’ and 50-60’ bgs near former source area
  - DNAPL present 45-60’ downgradient

DNAPL

Some staining



No staining

Operational Data

	Injection Wells	Extraction Wells	Weeks of Operation	Average Flow (gpm)	Total Water Volume (gal)	Total Molasses Volume (gal)
Traffic Island Loop	3	3	12	2.0	~132,000	~500
Onsite Loop	6	3	13	1.2	~81,000	~900