A Model for Combined Remedies

Well 12A Superfund Site, Tacoma, Washington

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Introduction – Combined Remedies

Jim Cummings

Combined Remedies – The 'New Normal'

- Growing awareness that different tools may be most suitable to address different contaminant phases/ concentrations in different site 'compartments'

Examples (Not Exhaustive)

- Thermal + Thermal
- Thermal + Bio
- Thermal + ISCO + Bio
- ISCO + ISCO
- ISCO + Bio
- ISCO + ISCR...   (Say What...?)
- Surfactant + ISCO
- ISS + ISCO//ISS + Ex Situ Thermal Desorption
- Ex Situ + In Situ

Desired End State/Least Cost Solutions

- Adequate Use of Robust Source Term Removal Technologies
- Timely transition to cost-effective ‘polishing’ step(s)
- Reduce/Eliminate Need for ‘Pump and Treat’
- Appropriate Reliance on Monitored Natural Attenuation (MNA)

Approaches

- **Temporal – Adjust/change technologies at appropriate changeover points**

- **Spatial – Treat different zones with different technologies**

- **'Package Deals' – Some tools have more than one mechanism of action ('two-fers' and 'three-fers'...)**

In Situ Chemical Oxidation (ISCO) + Bio

- **‘…it is now clear to many that chemical oxidation is best coupled with accelerated bioremediation for more successful site management.’**

  - *Regenesis ReGenOx Product and Design Manual*

IMPORTANT NOTE: How You Do It Is As Important as What You Do

- **“Remedy implementation is just the next phase of site characterization”**

- **“Sources begin to reveal themselves as the remedy progresses’**

  - Many/Most ISCO remedies have a smaller footprint for subsequent injections

- **Therefore: *Flexible*, *Adaptive*, *Attentive*…**

Attentive…

- **Even system <u>installation</u> can be informative**
  - AECOM webinar discussed ERH installation found top of confining unit topology which resulted in completely different GW flow regime
- **Process Control!!!!**
  - Initially an advantage for In Situ Thermal
  - ISCO vendors now monitoring reagent presence, DO, ORP, conductivity, color, etc on a frequent basis
    - At least one vendor reports doing MIP probes between ISCO injections

Attentive… (Especially)(Bio)

- ‘It has become standard practice on our projects to do microbial evaluation throughout the remedial process.“

- *Jack Sheldon*

Antea Group

Remaining Challenges

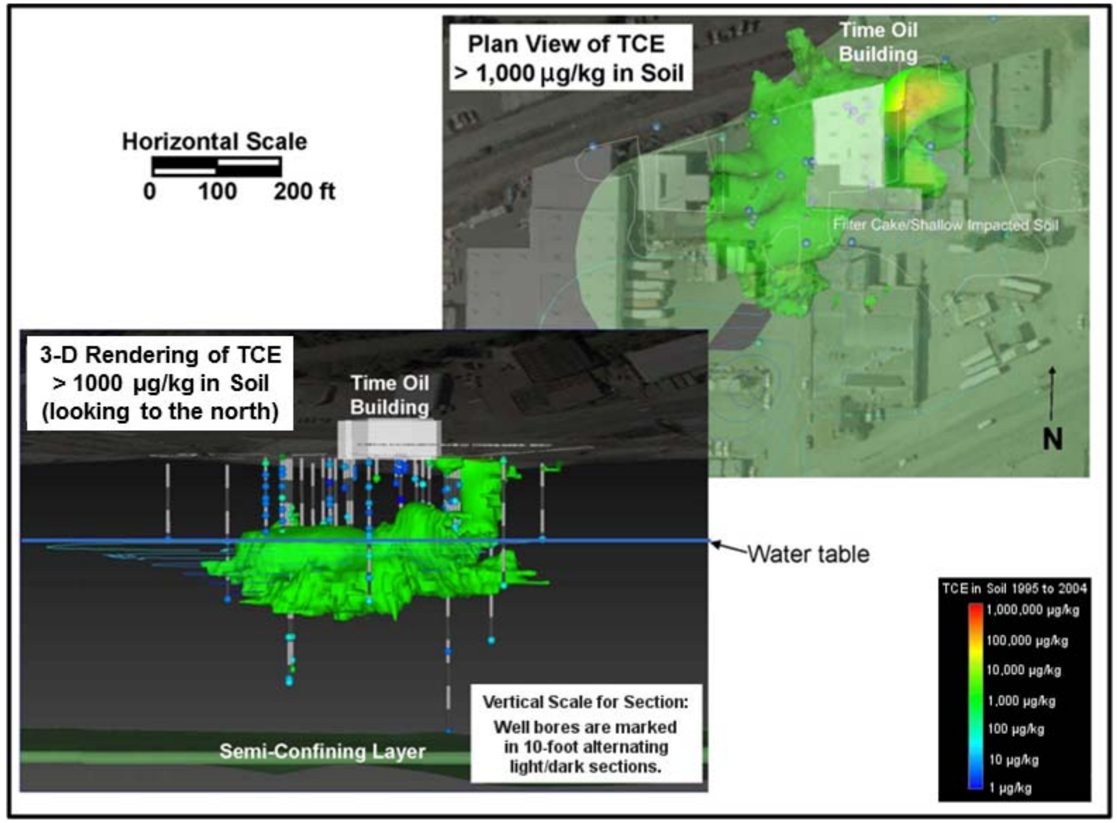
- **Tools to Predict Resource Restoration Timeframes**
  - And tools to QA/QC calculations

- **Decision Rules to delineate boundaries/temporal transition points among remedial components**
  - ‘How much to heat/how much to eat…’

Site Overview and History
Tamzen Macbeth, PhD

Site Background

- Tacoma Supply Well 12A identified to be contaminated in 1981.
- 3,000 ft x 1,500 ft chlorinated volatile organic compound plume and identified source area, Time Oil Property.



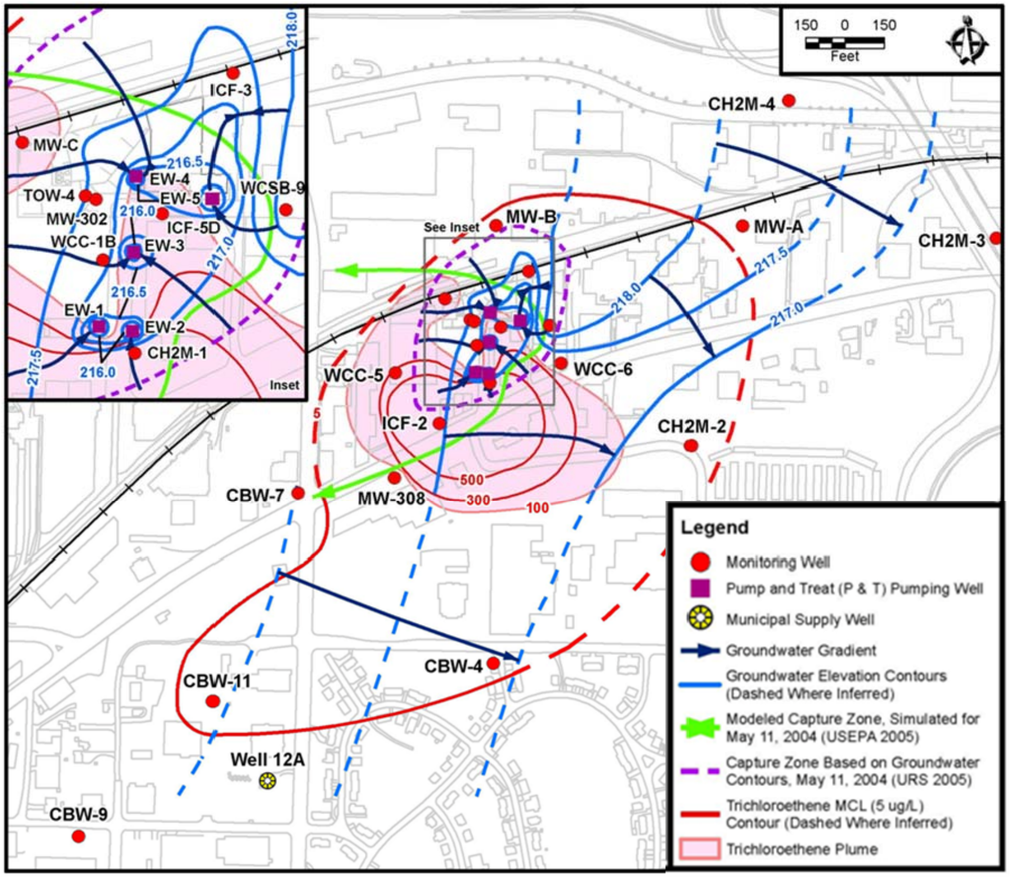
Time Oil Site Contamination Summary

- Paint and lacquer thinner manufacturing (1924-1964)
- Waste oil recycling (1924-1976)
- Oil canning (1976-1991)
- 6 primary COCs in soil and groundwater
  - 1,1,2,2-Tetrachloroethane (PCA)
  - Tetrachloroethene (PCE)
  - Trichloroethene (TCE)
  - cis- and trans-1,2-dichloroethene (DCE)
  - Vinyl Chloride (VC)
- TCE contamination is impacting the City of Tacoma municipal supply Well 12A

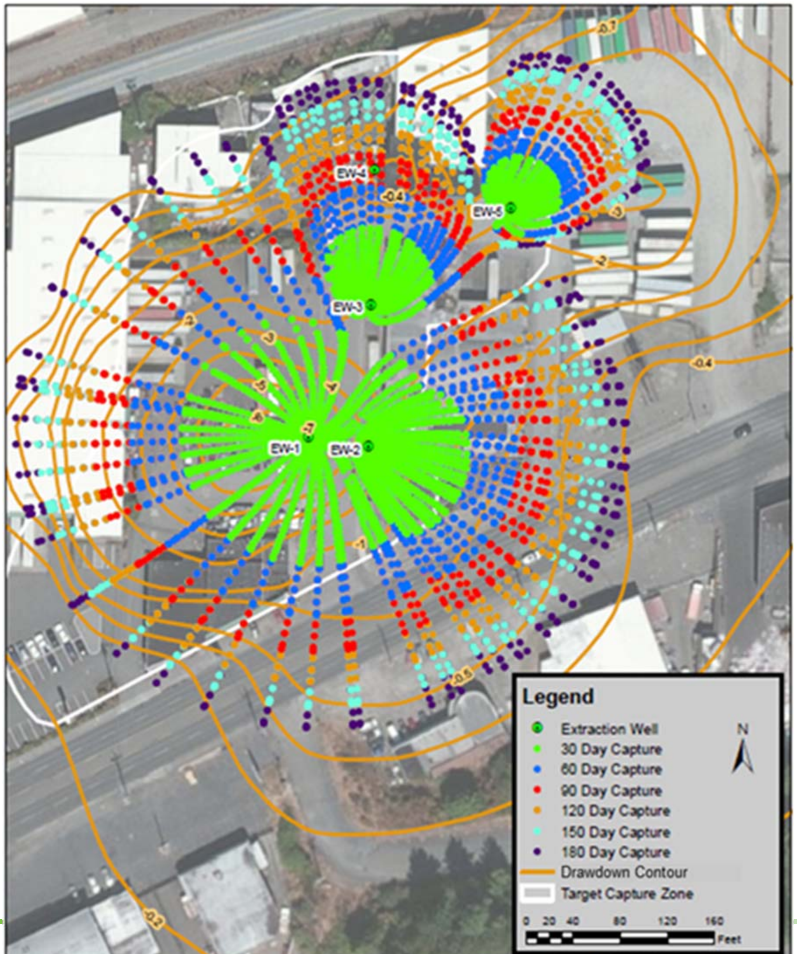
CDM Smith TRS

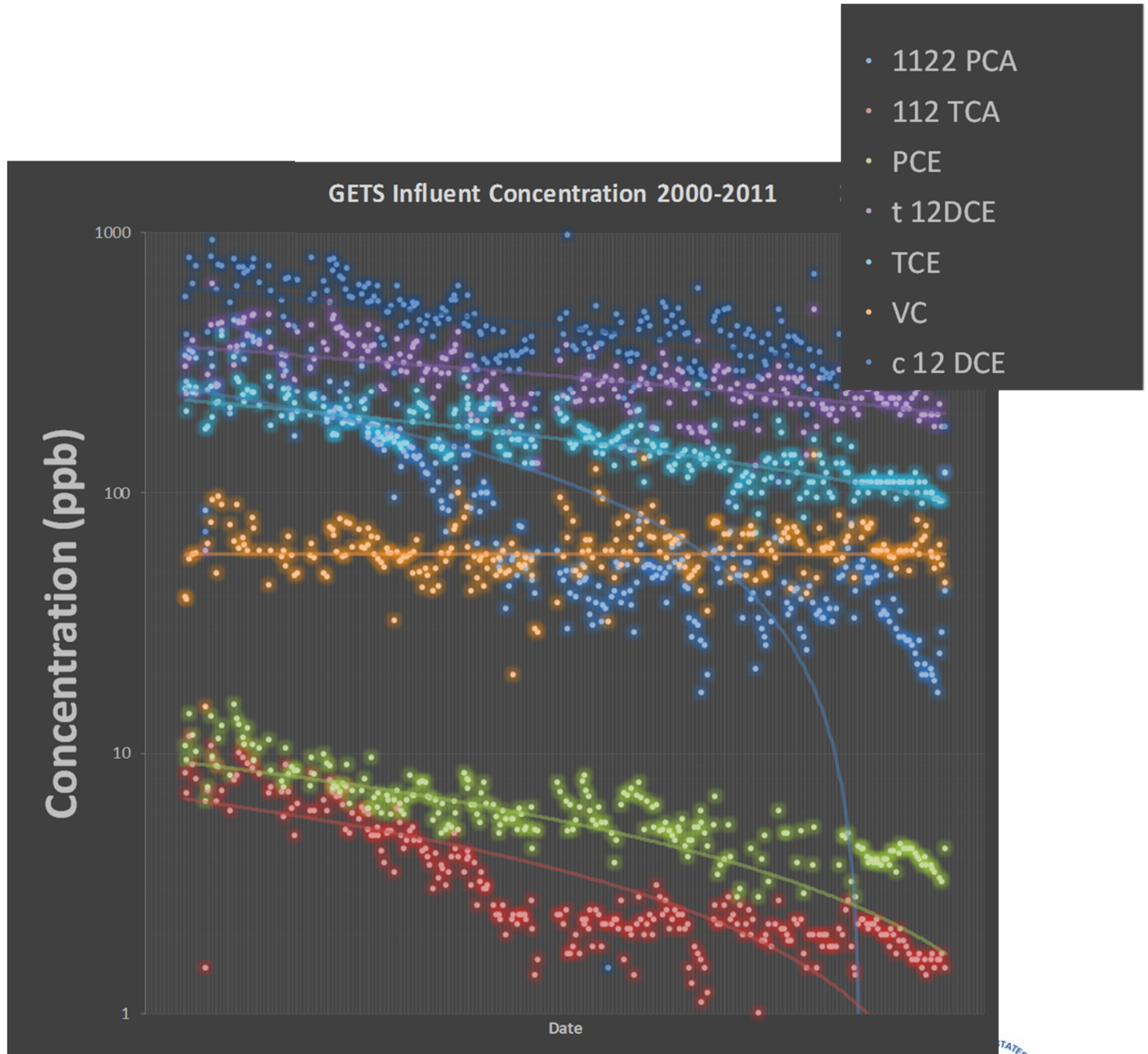
Historical Remedial Action Summary

- 1983- Original signed ROD
  - Wellhead treatment system at Well12A
- 1985- ROD-Amendment #1,
  - Groundwater Extraction Treatment System (GETS)
    - 1988 – 2001/550 million gallons of groundwater extracted/treated, removing 16,000 pounds VOCs
  - Vapor Extraction System (VES)
    - 1993 – 1997/Removed 54,100 pounds VOCs
  - Filter cake/contaminated soil removal
    - BNRR excavated 1,200 cy along rail line
    - VES construction/removed 5,000 cy of filter cake



GETS Performance





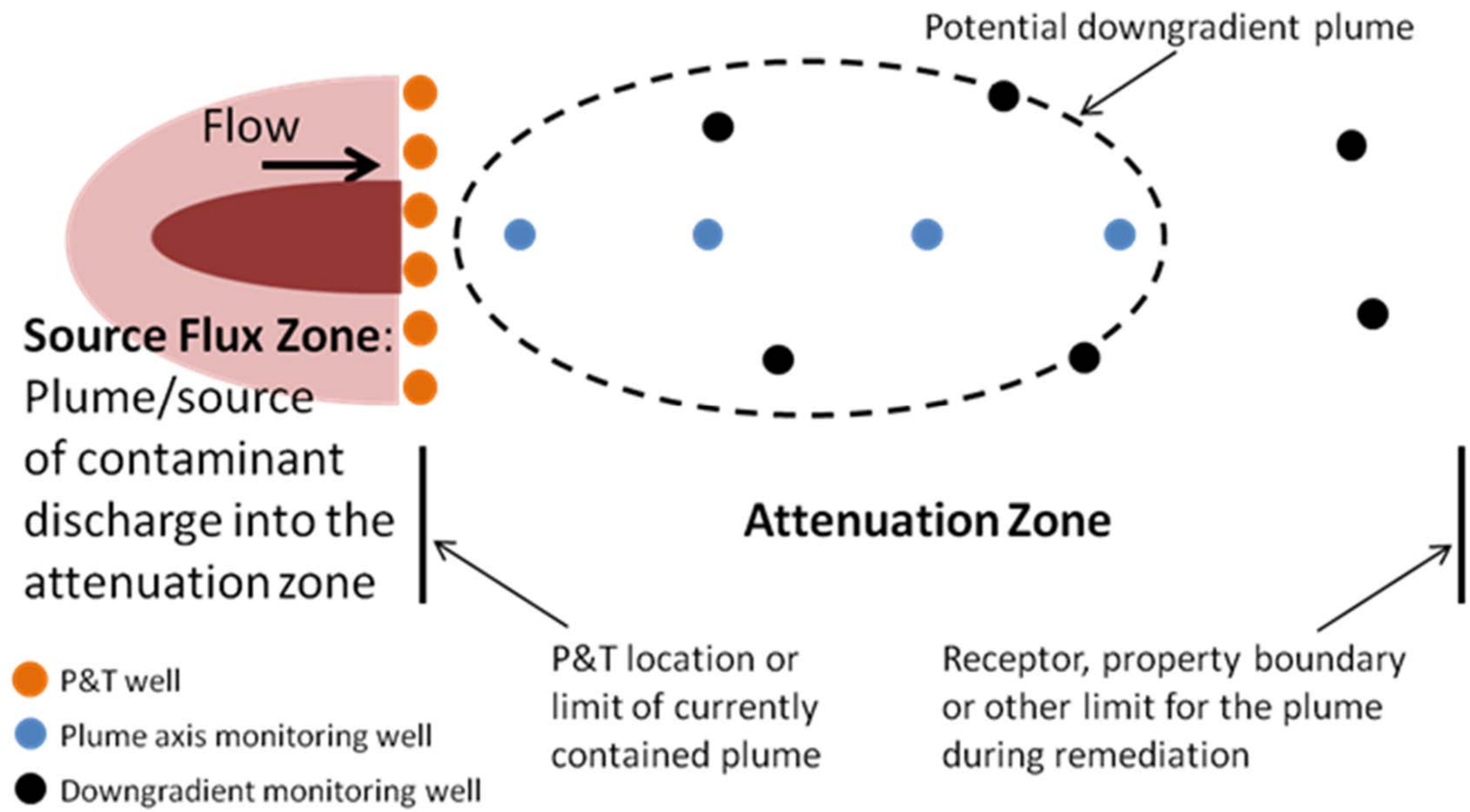
Desired End State

- Adequate use of robust source removal technologies.
- Timely transition to cost-effective ‘polishing’ step(s).
- Reduce/eliminate need for pump and treat.
- Appropriate reliance on monitored natural attenuation (MNA).
- Adaptive, flexible implementation
  - *“Sources begin to reveal themselves as remediation progresses”*

Best Practices

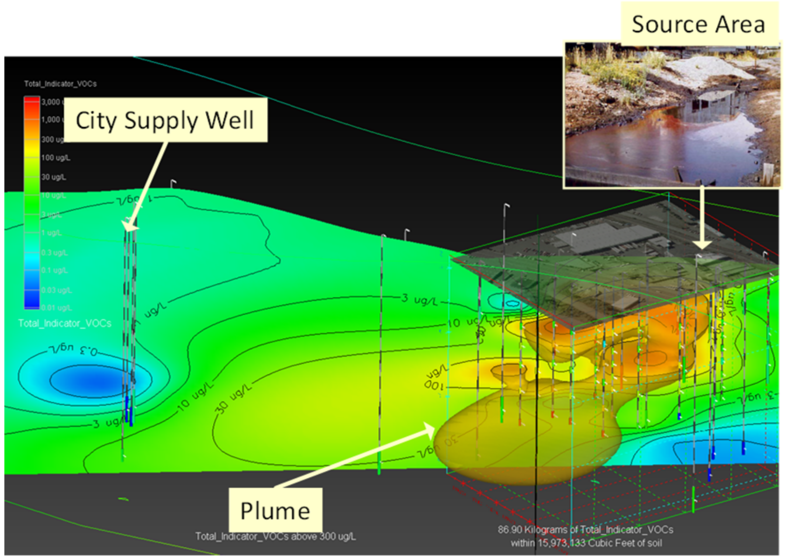
- Utilize a thorough systematic planning process, which includes participation of all stakeholders, to determine:
  - Performance goals
  - Metrics
  - Decision logic for optimizing and terminating a response action
- Manage uncertainty with dynamic work strategy (DWS) that is continually refined throughout the project lifecycle
- Transparent, open, honest discussion of uncertainty management, data representativeness, and site closure strategies

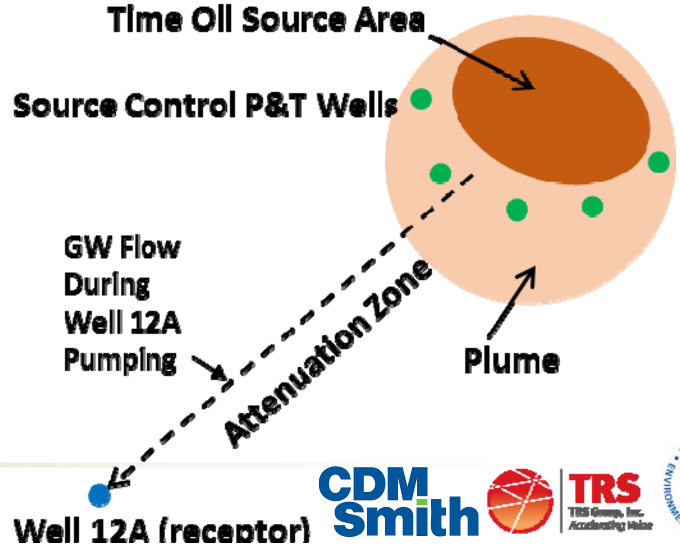
Re-Evaluating the Remedy: New Basis



Well 12A: Basis for Setting Goals

- Develop model for plume attenuation capacity
- Source- Anaerobic
- Plume- Aerobic
  - Modeling Degradation Rates: 1.5-8 years
- 50-80% reduction in TCE mass discharge result in concentrations to be less than 5 μg/L





CDM Smith
TRS

2009 ROD-Amendment #2, Remedial Action Objectives

Tier 1: reduce risk from contaminated surface soils and achieve a contaminant discharge reduction of at least 90% from the high concentration source area near the Time Oil building to the dissolved-phase contaminant plume.

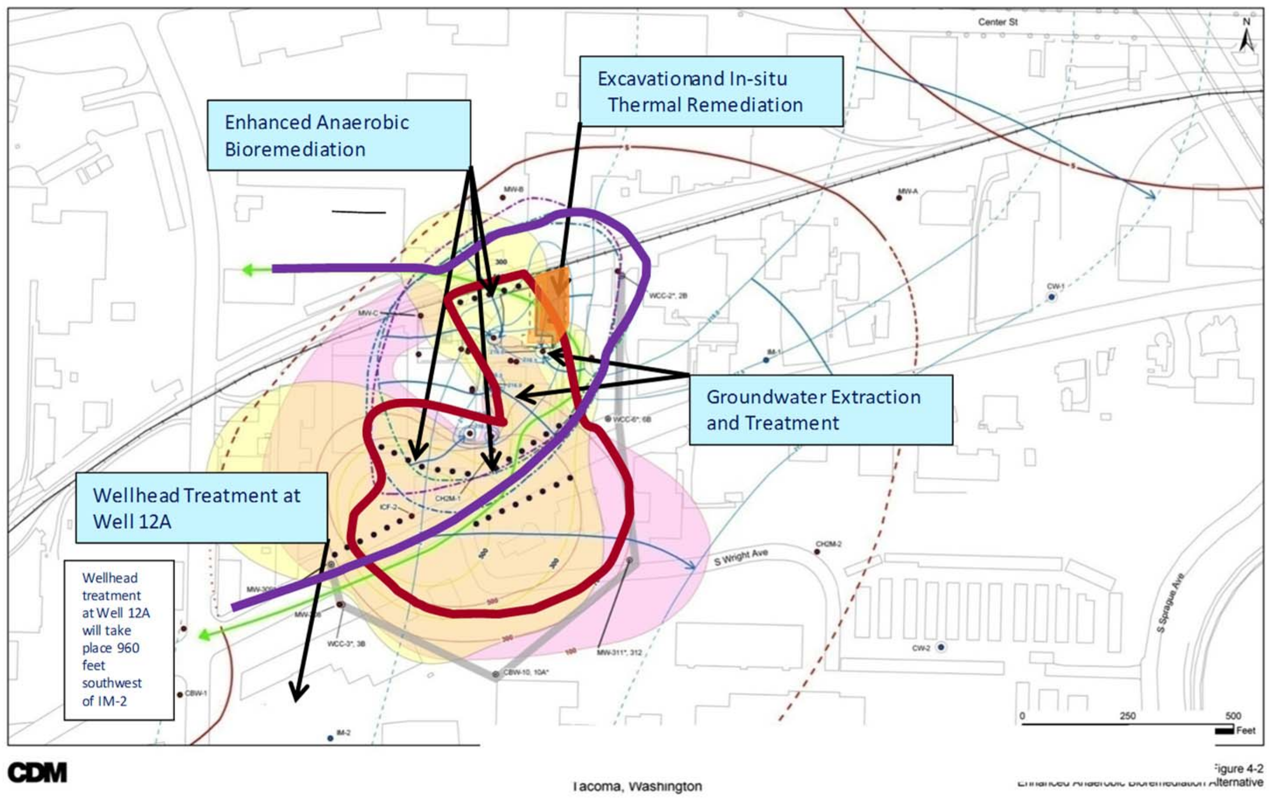
- Remedy operational and functional.
- Operations and maintenance of the Well12A OU1 will be turned over to the State of Washington

Tier 2: Achieve chemical-specific ARARs measured at proposed interim performance monitoring points.

Tier 3: Determine if ARARs can be achieved throughout the plume, using monitored natural attenuation.

Remedy: Amendment #2

- Multi-component remedy technologies to achieve this goal:
  - Excavation- remove filter cake and underground storage tanks
  - In situ thermal remediation (ISTR)- address NAPL
  - Enhanced anaerobic bioremediation (EAB)- address concentrated plume
  - Groundwater extraction and treatment system (GETS)- existing source pump and treat

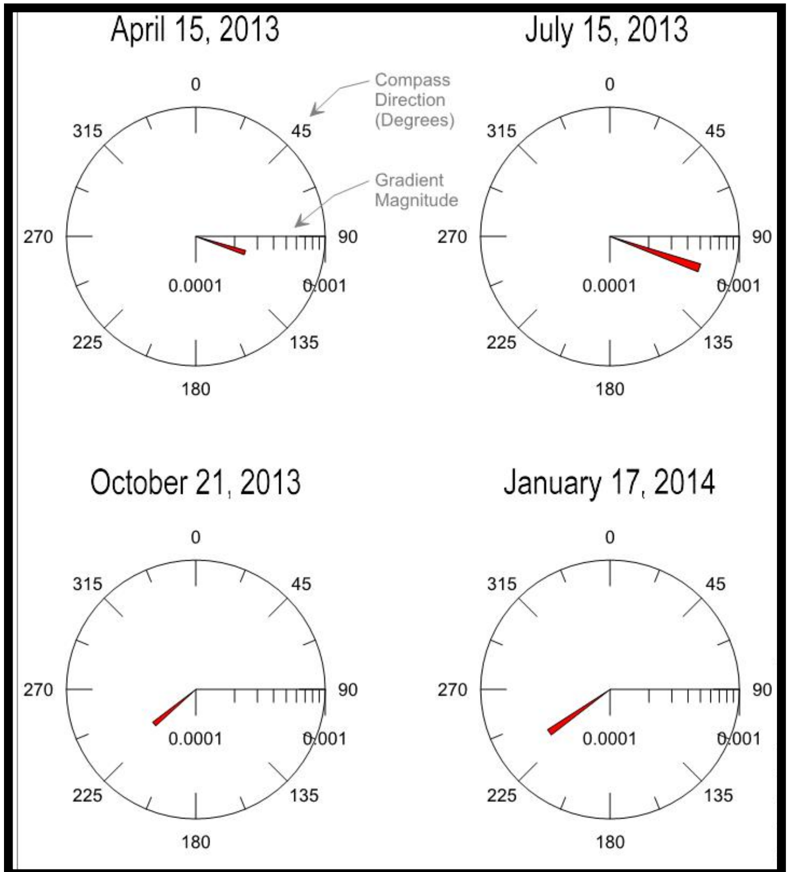


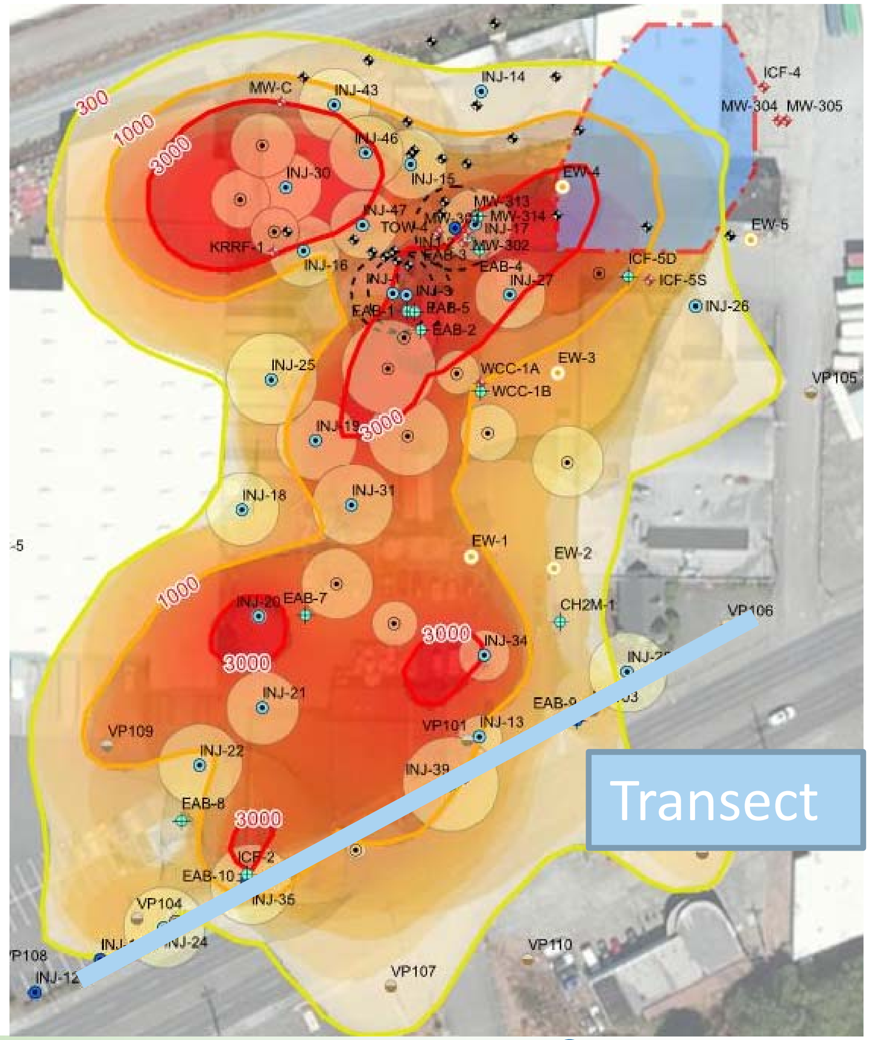
Summary of Site Characterization

- 34 soil borings to reduce uncertainty and delineate sources
- 12 locations for vertical profiling
- Depth discrete samples:
  - Groundwater
  - Soil
  - Slug testing
  - Stratigraphy
- Gradient assessment

Smith

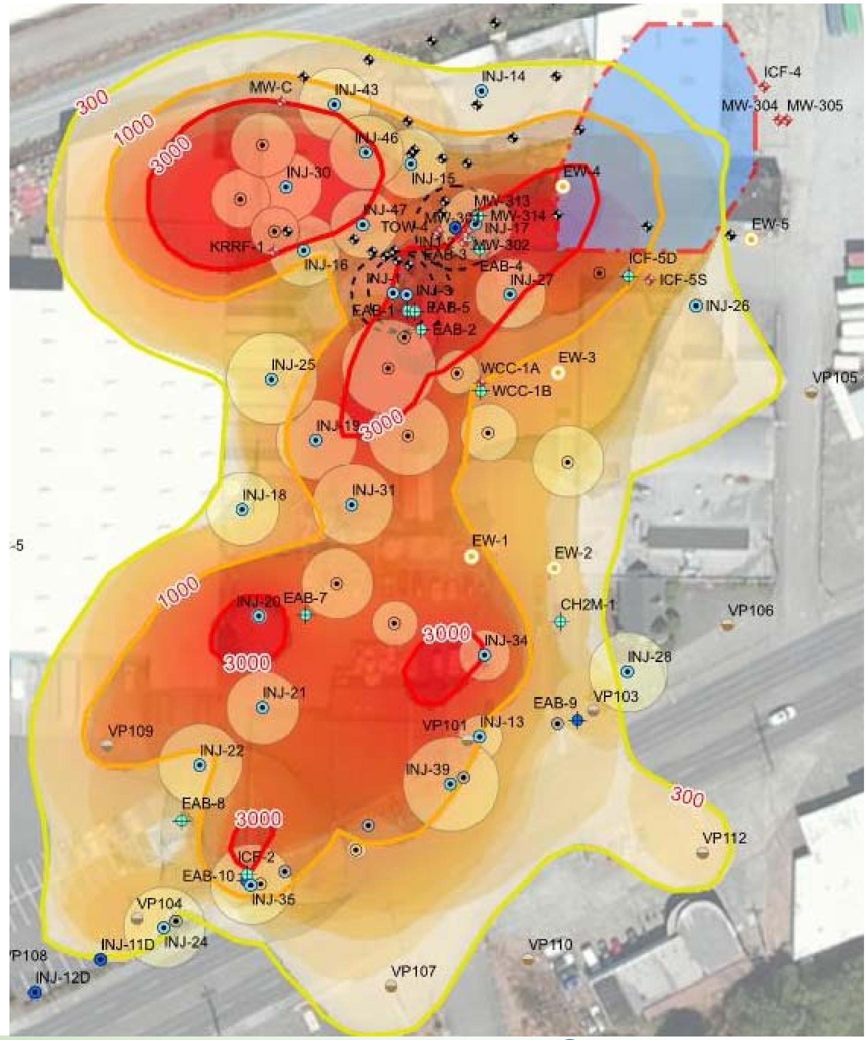
Site Gradient





Mapping Technologies

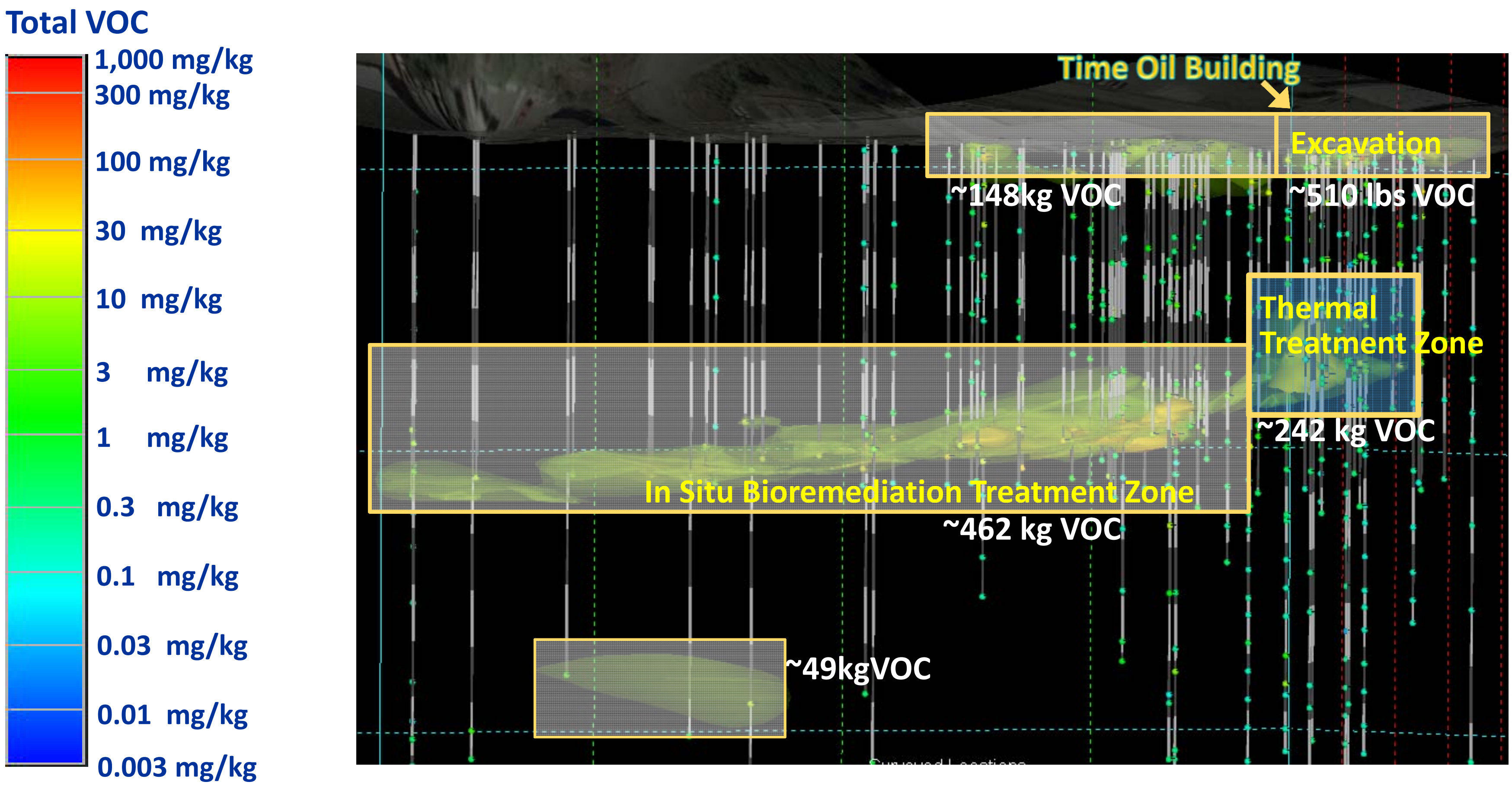
Zone	Surface Area (ft²)	VOC Mass (kg)	Discharge to GETS
Excavation Zone	3819	510	NA
Thermal Treatment Zone	13,000	~242	224 g/day (53%)
In Situ Bioremediation Zone	162,000	~462	199 g/day (47%)



Legend

- Monitoring Well
- Injection Well
- GETS Extraction Well
- In Situ Thermal Treatment Area
- Total VOCs in Soil >5,000 ug/kg
- Union of TCE and cis-DCE > 300 ug/L above Qpf silt
- Amendment Injection Location
- Pilot Study Injection Well

Treatment Zones: Selecting Vertical Intervals

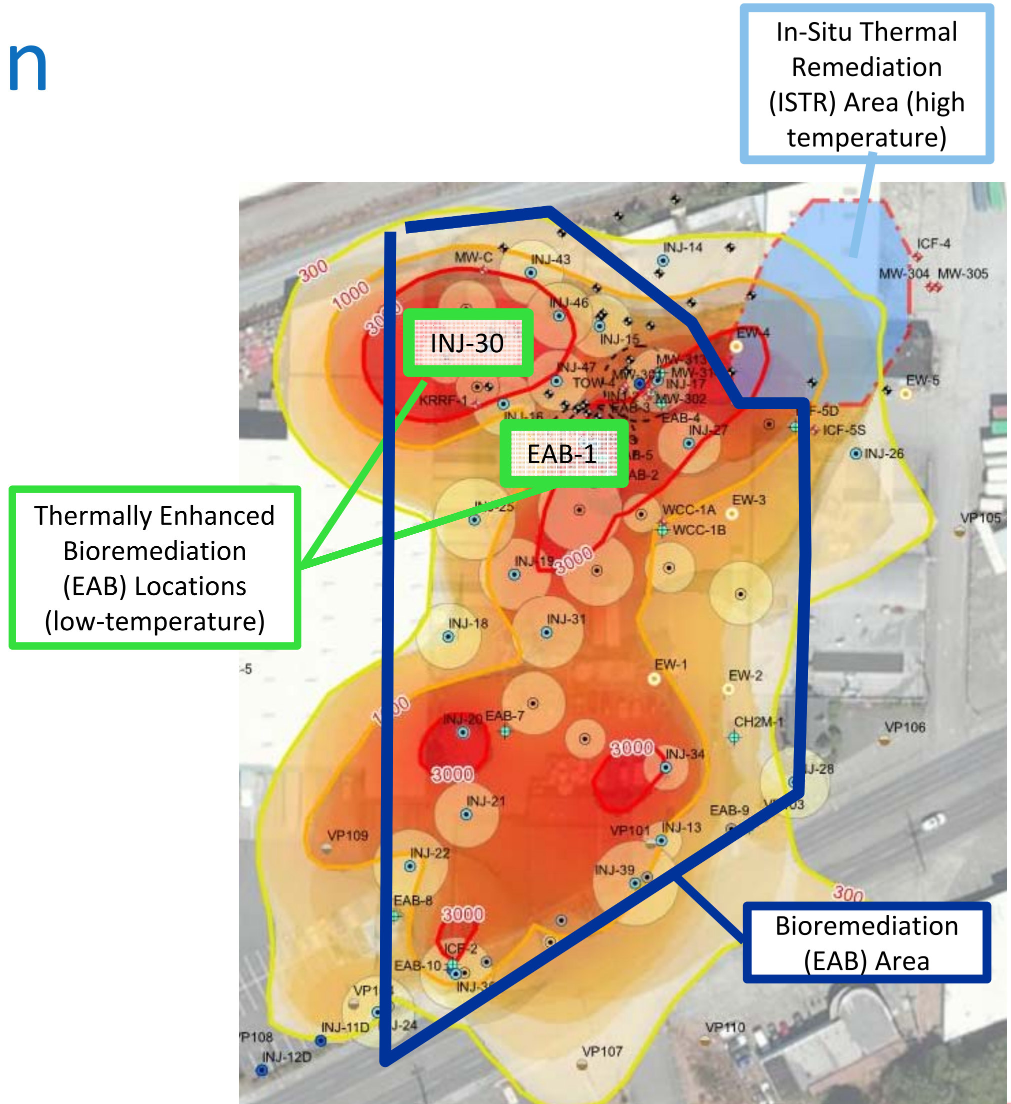


Overcoming Challenging Geology during Bioremediation

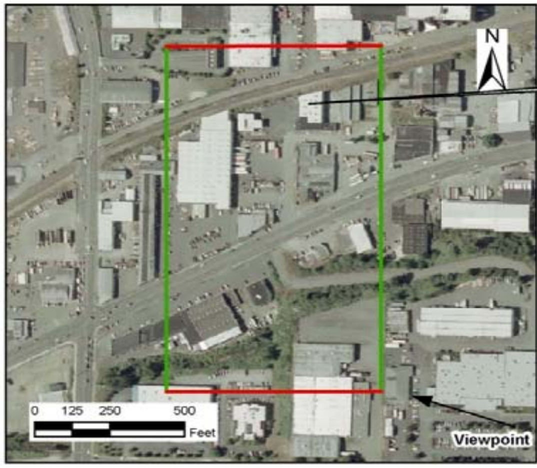
Neil Smith

Extent of Bioremediation Treatment Area

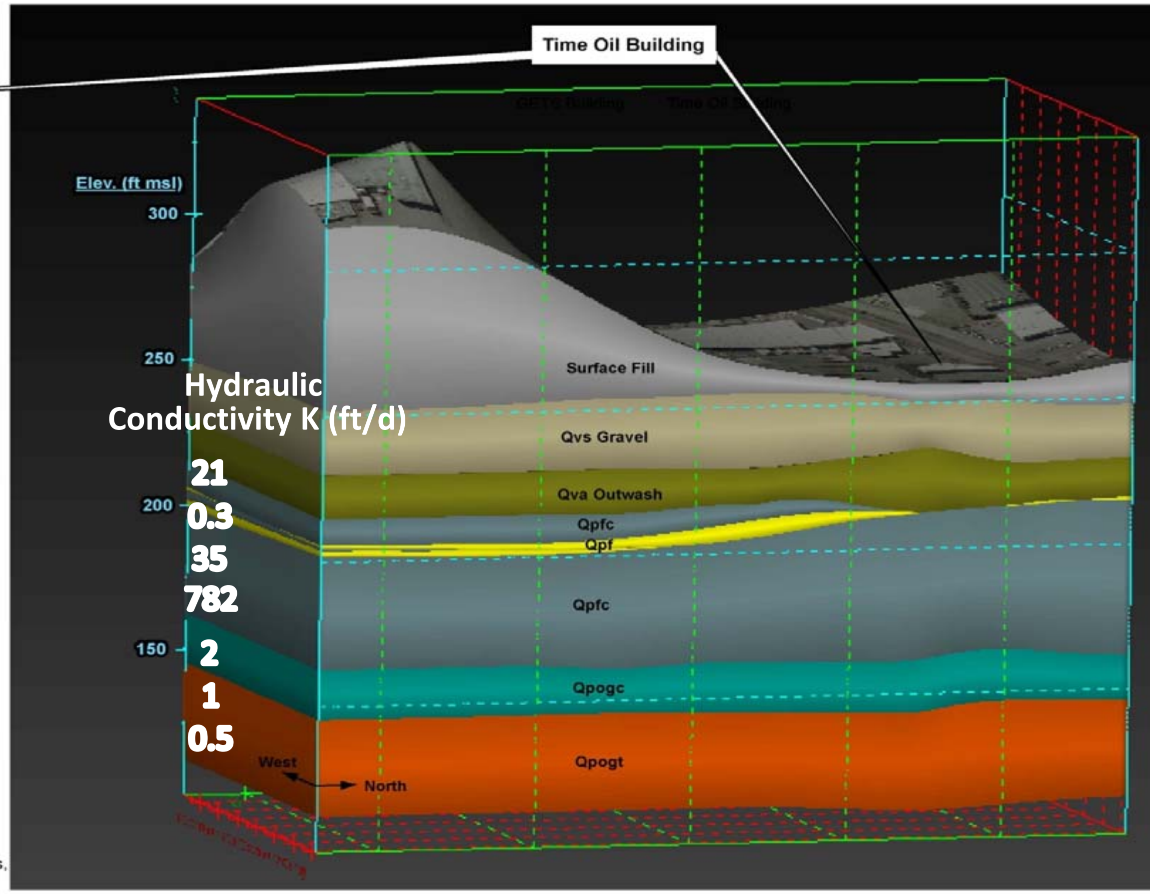
- 162,000 square foot area
- Source mass present in Qpf Silt unit, and diffusing to Qpfc sand/gravel units above and below
  - Target treatment interval generally between 40-55 feet bgs
- 47% of mass discharge estimated to originate from the EAB treatment area



Summary of Site Stratigraphy



Plan View of 3D Visualization



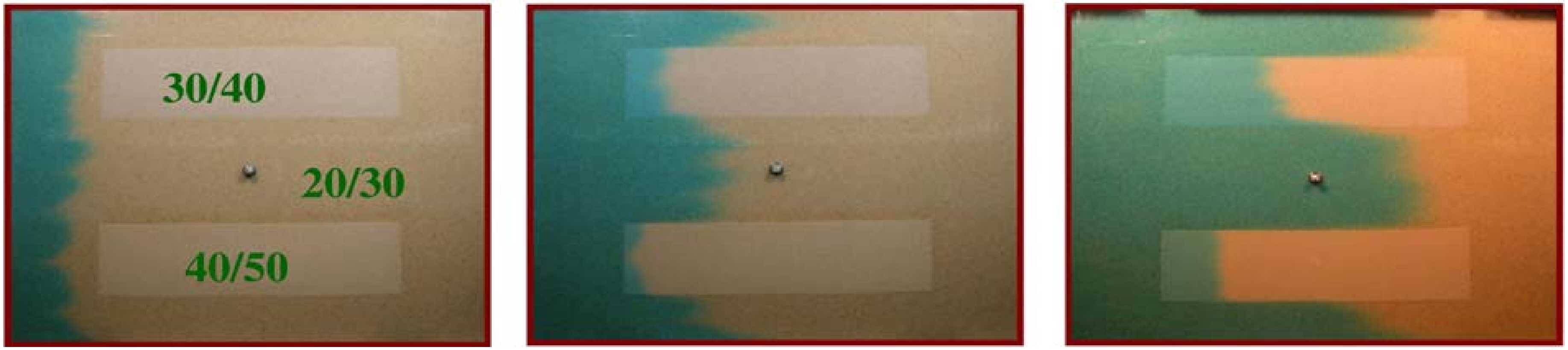
Legend

- Surface Fill
- Filter Cake
- Qvs Gravel
- Qvt Till
- Qva Outwash
- Qpfc
- Qpf
- Qpogc
- Qpogt

Note: The hill south of the site is modeled as surface fill, but likely includes a combination of Qva, Qvt, Qvs, and younger glacial deposits, as well as surface fill.

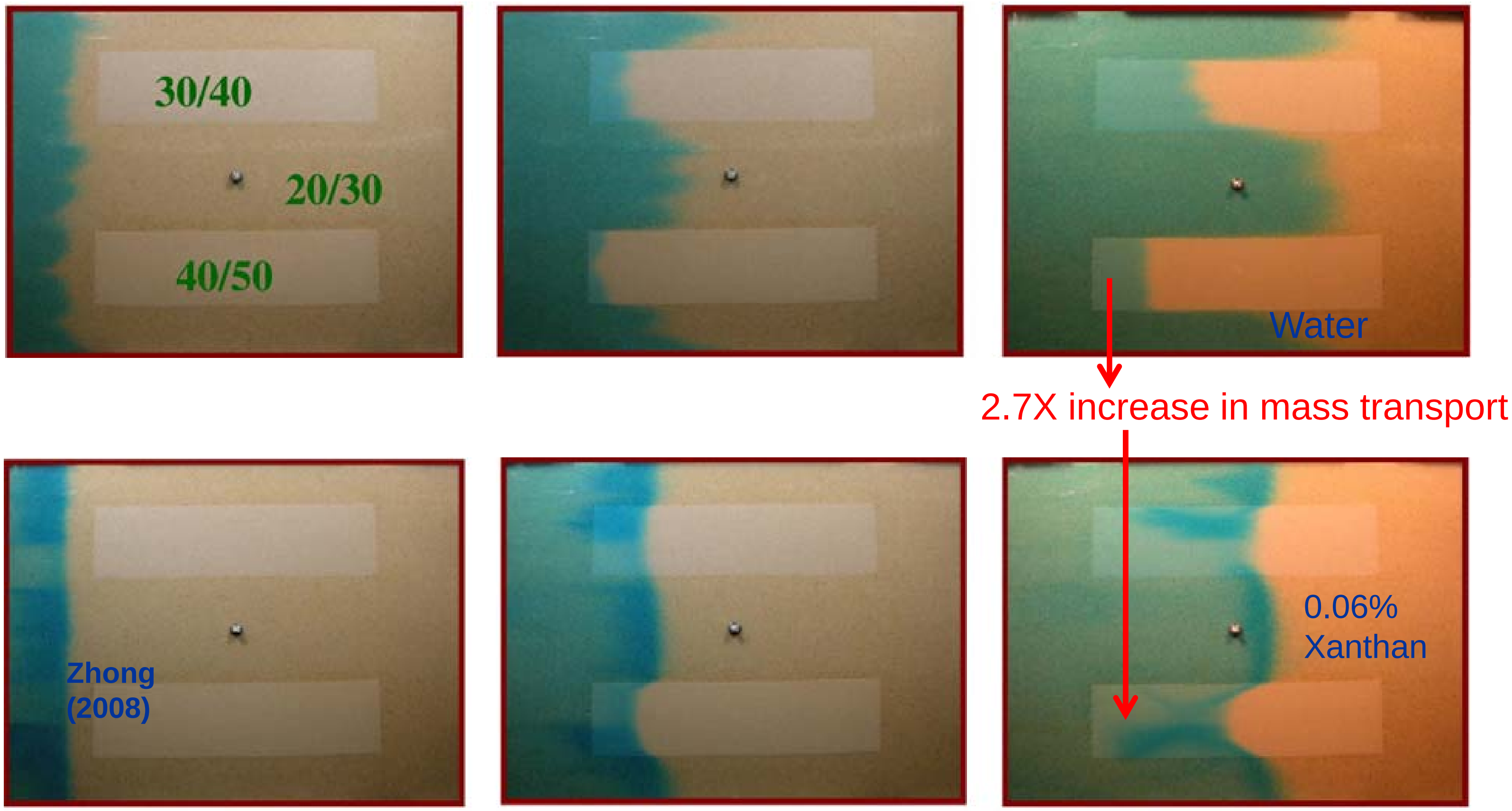
Problem – Amendments are preferentially delivered to high-permeability zones

- Key attribute of success for in-situ remediation of groundwater is the ability to deliver substrate to the contaminated zone
- Heterogeneity in aquifers causes fluid bypass of low permeability zones via flow in preferential pathways
- A persistent (matrix back diffusion) and more costly to remediate source remains in low permeability lithology



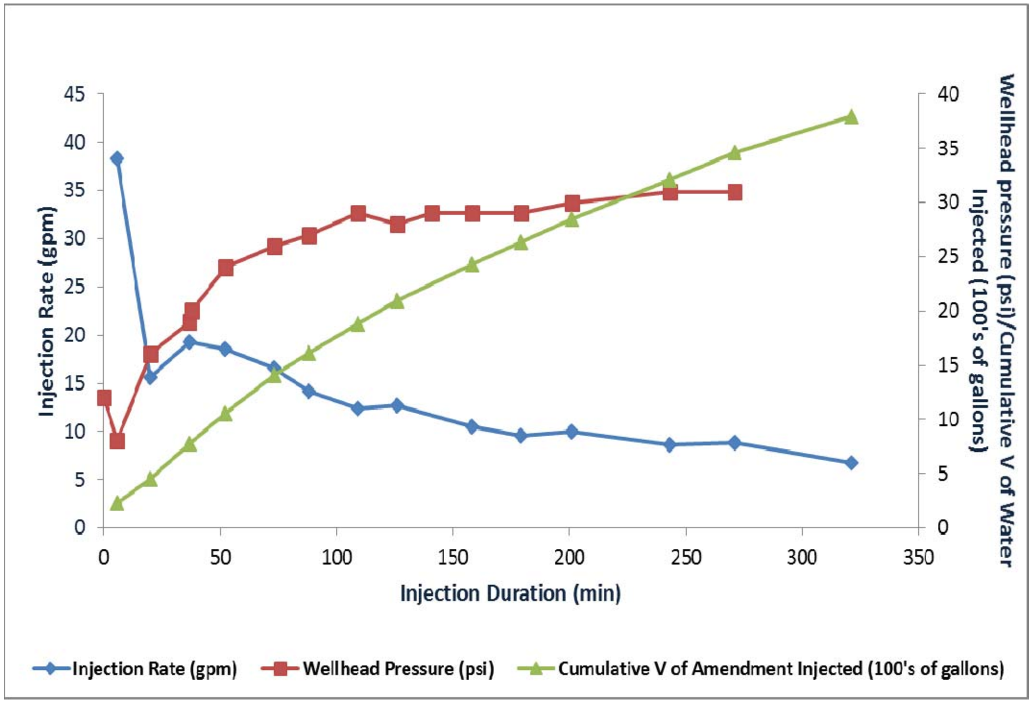
Zhong (2008)

Shear-thinning fluid allows greater amendment transport into low permeability regions



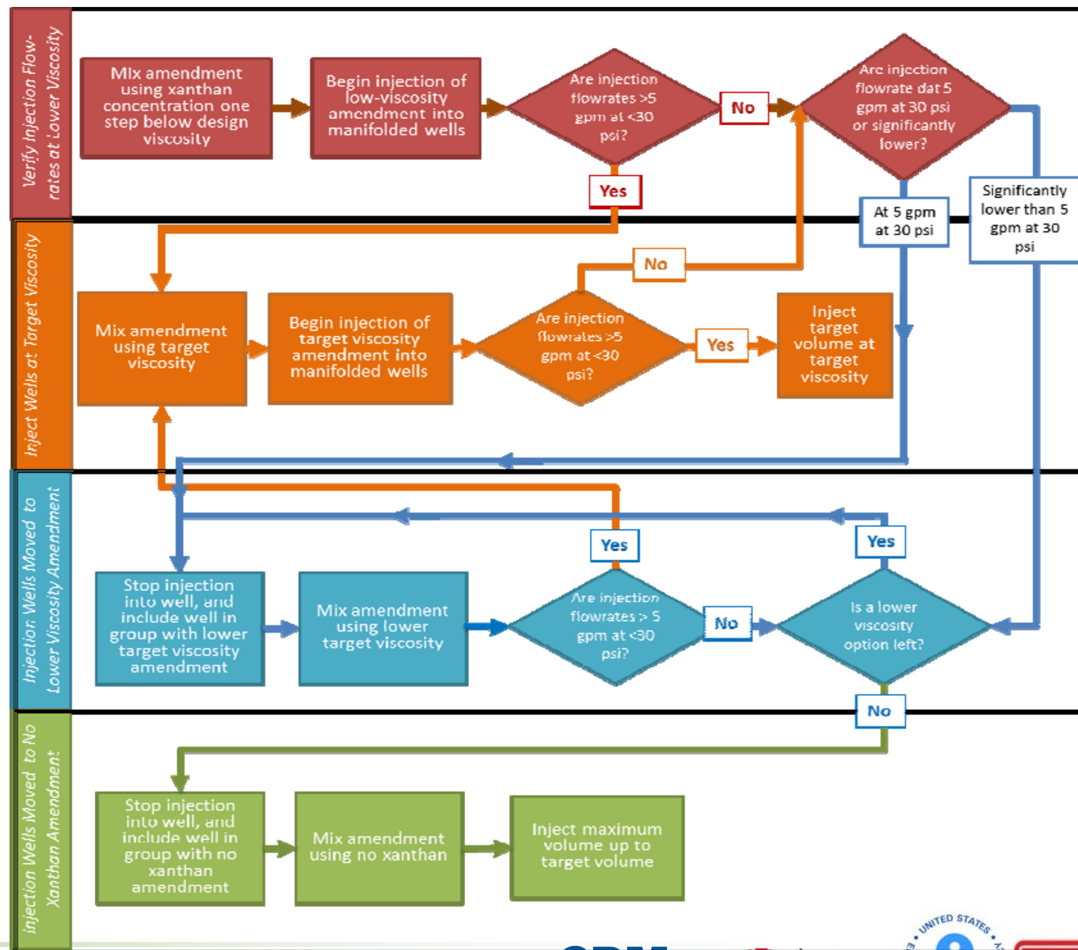
Shear-Thinning Fluid Amendment Injection Strategy

- Observations during typical shear-thinning fluid injection
  - Gradual increase in wellhead pressure
  - Gradual decrease in injection flow rate
  - Pressure and flow rate tend to stabilize after approximately 2 hours
- If xanthan gum concentration is too high, will not be able to inject amendment



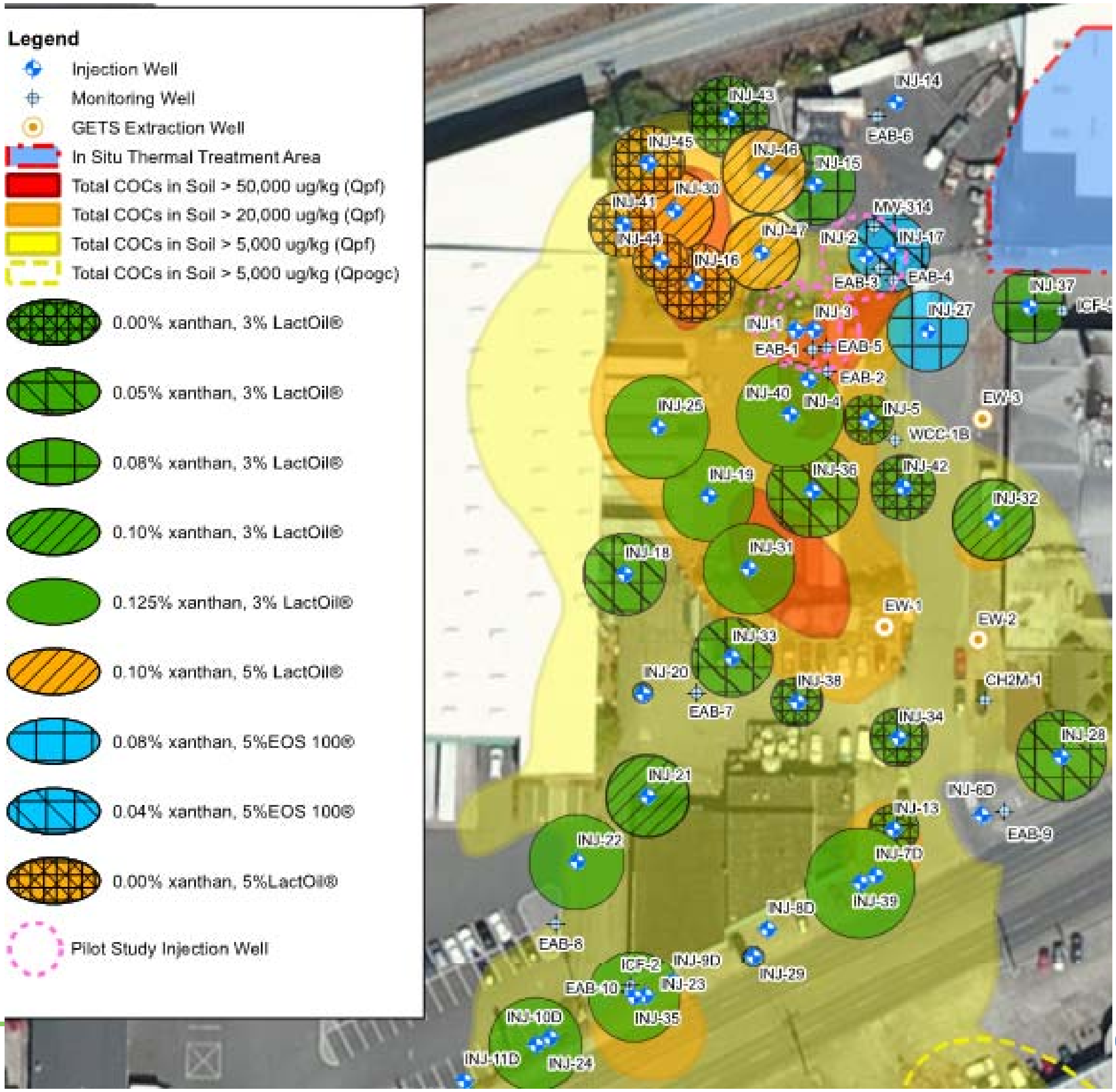
Decision Process for Shear-Thinning Injections

- Dynamic approach to injection
  - Start injection with lower-viscosity (low % xanthan gum)
  - Increase xanthan % based on observed response during injections
    - If low pressure and high flow rate, increase the xanthan concentration
  - If injection flow rate slows, then switch to lower % xanthan amendment
- In total, more than 850,000 gallons of shear-thinning amendments injected



Full-Scale EAB Implementation

- Emulsified oil concentrations varied from 3% to 5%
- Xanthan gum concentrations varied from 0% to 0.125% depending on specific capacity of wells
- Continuous monitoring of amendment properties
  - Evaluate consistency of mixed amendment batches over time and suitability for injection at specific well
- Parameters measured in field
  - Quantities of all ingredients (emulsified oil, water, xanthan gum, sodium bicarbonate)
  - pH
  - Conductivity
  - Viscosity using Zahn cup



Legend
Injection Well
Monitoring Well
GETS Extraction Well
In Situ Thermal Treatment Area
Total COCs in Soil > 50,000 ug/kg (Qpf)
Total COCs in Soil > 20,000 ug/kg (Qpf)
Total COCs in Soil > 5,000 ug/kg (Qpf)
Total COCs in Soil > 5,000 ug/kg (Qpogc)
0.00% xanthan, 3% LactOil®
0.05% xanthan, 3% LactOil®
0.08% xanthan, 3% LactOil®
0.10% xanthan, 3% LactOil®
0.125% xanthan, 3% LactOil®
0.10% xanthan, 5% LactOil®
0.08% xanthan, 5%EOS 100®
0.04% xanthan, 5%EOS 100®
0.00% xanthan, 5%LactOil®
Pilot Study Injection Well

Benefits of Using Shear-Thinning Fluids at Well 12A

- More uniform vertical distribution of amendment
  - Verified during pilot study
  - Delivery of amendment into and at interface with low-K zone
- Prevented migration of amendment through high-permeability pathways during injection
  - Observed carbon concentrations at monitoring points
  - Even during heavy municipal pumping, sufficient amendment remained within treatment area

Technology Synergies with In Situ Thermal Remediation

Emily Crownover, PhD

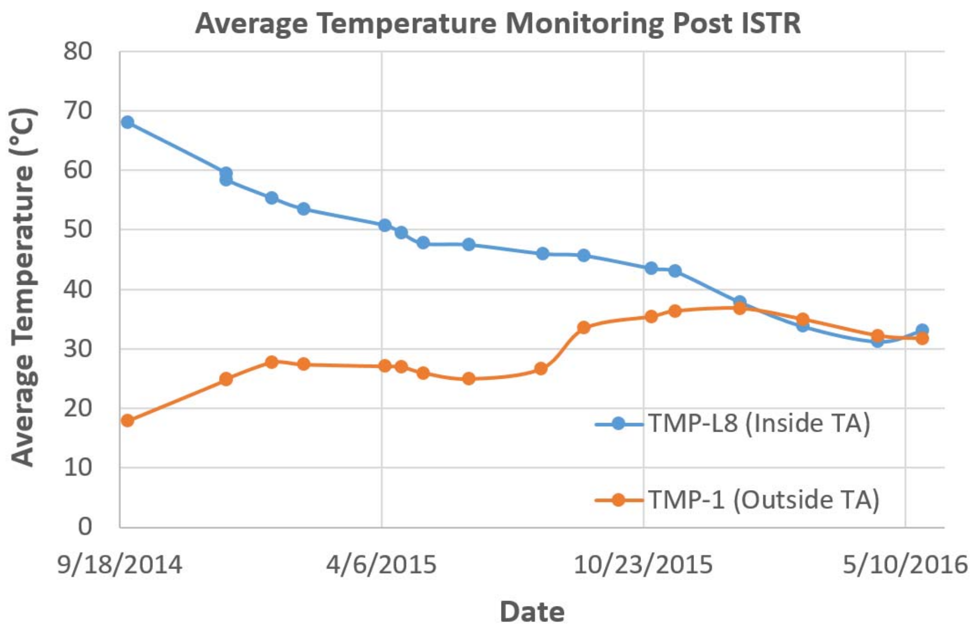
Thermal Technology Synergies Outline

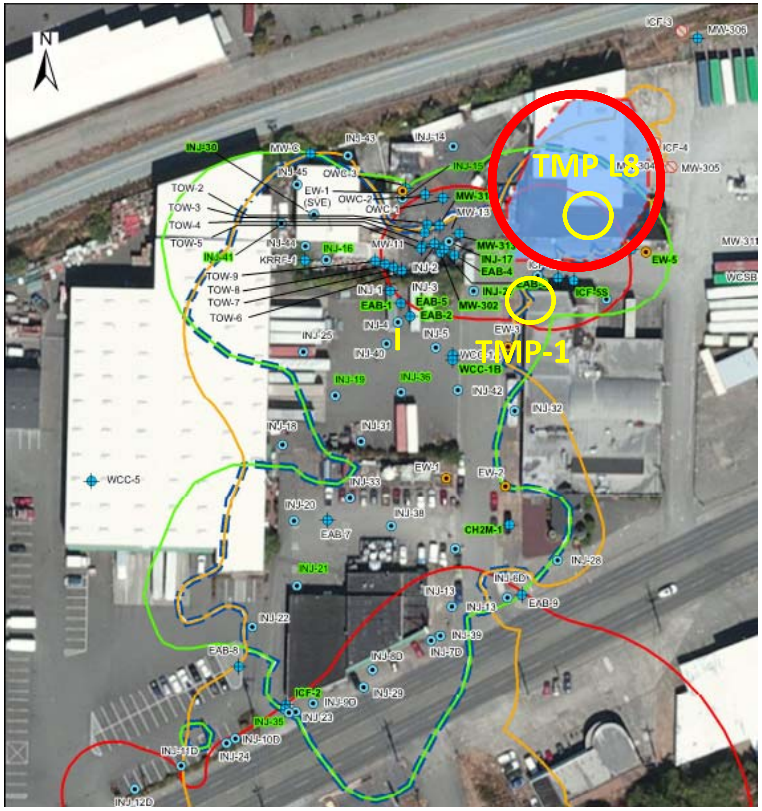
- In Situ Thermal Remediation
- Thermally Enhanced Processes
  - Hydrolysis
  - Chemical Oxidation
  - Bioremediation
- ROD Amendment Flexibility
- Evaluating Thermal Synergies

In Situ Thermal Remediation
Electrical Resistance Heating

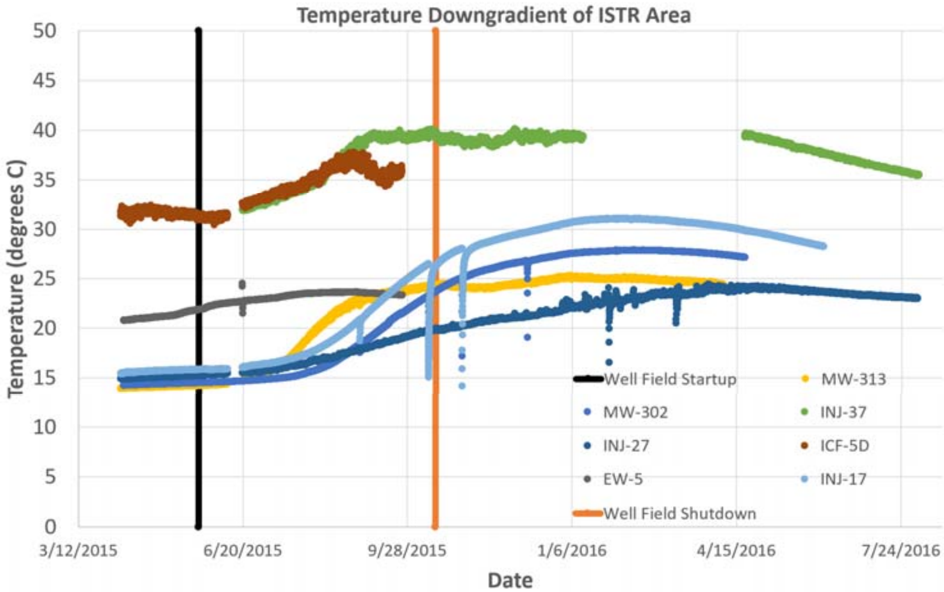
- Steam stripping temperatures targeted for source zone remediation
- ISTR Treatment Zone
  - 13,700 ft^2, 2 to 55 ft bgs
  - 27,900 yd^3
  - 71 electrodes
- Dual phase extraction system
- 117 days operation
- ~400 lbs CVOCs removed
- 22,000 lbs total mass removed

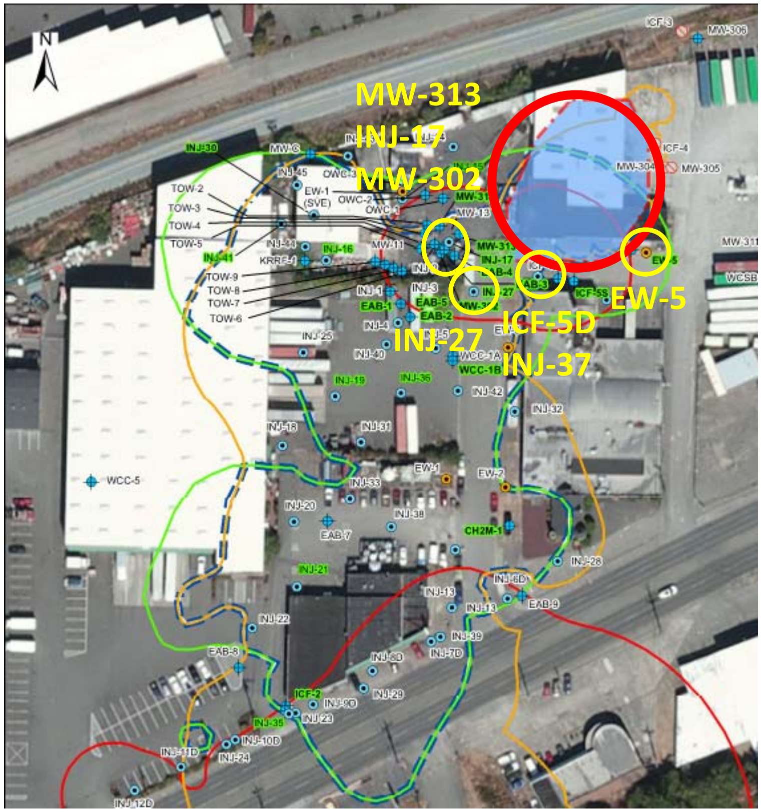
In Situ Thermal Remediation Synergies
Sustained Temperature Increases Post ERH





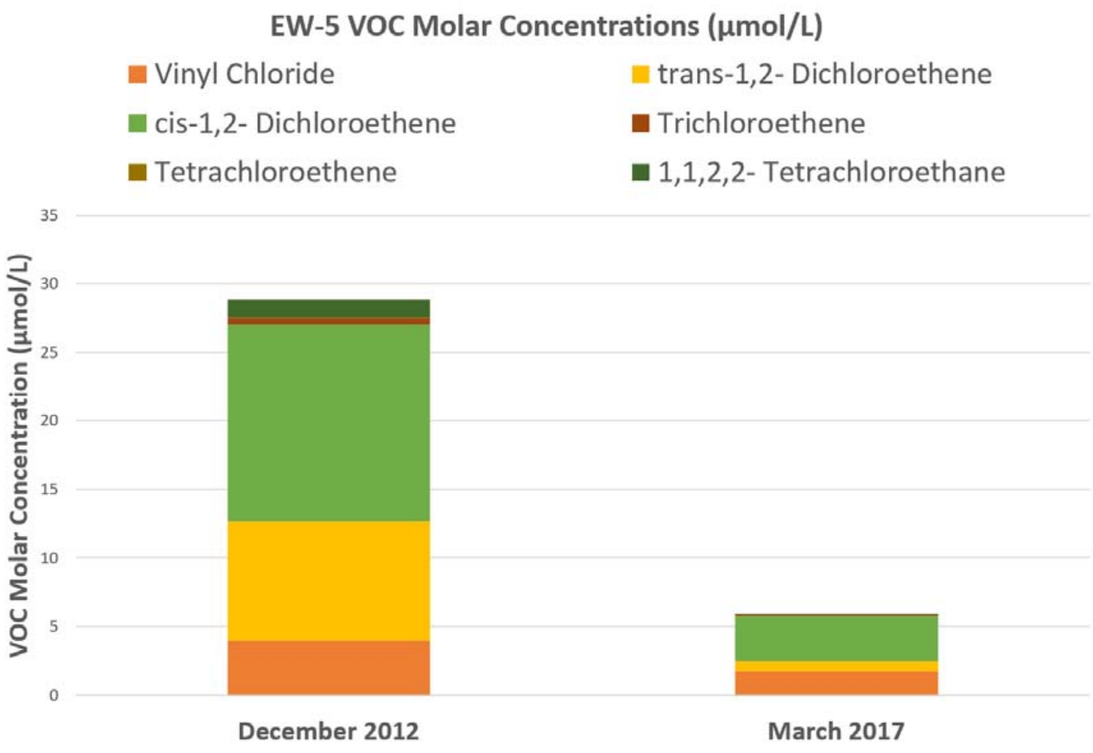
In Situ Thermal Remediation Synergies
Temperature Increases Downgradient of ISTR

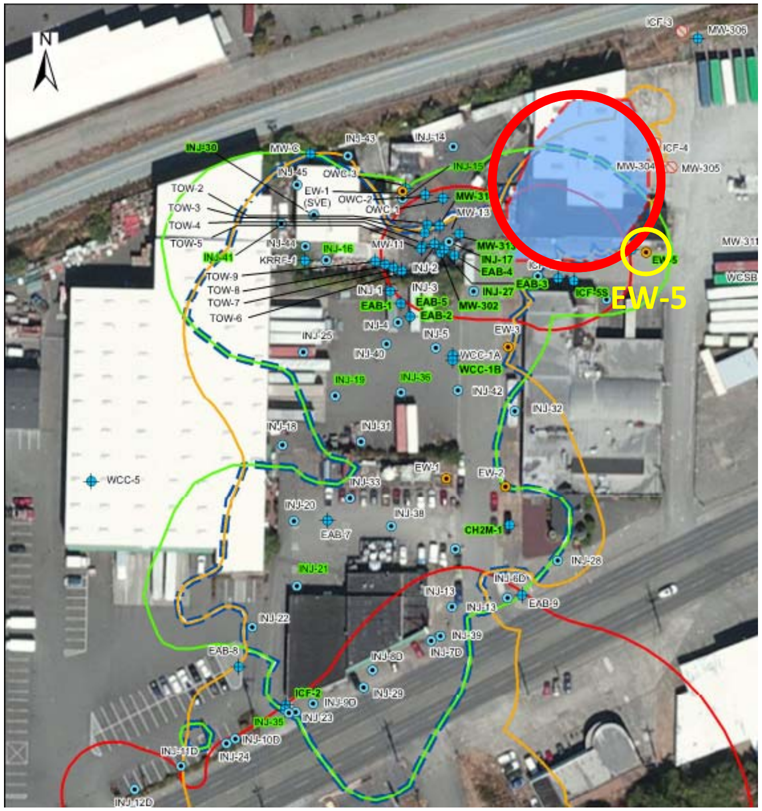




- Sustained temperature increases south of ISTR area
- Heightened temperatures in range for biodegradation enhancement (25-40°C)

In Situ Thermal Remediation Synergies
Molar Concentrations at EW-5

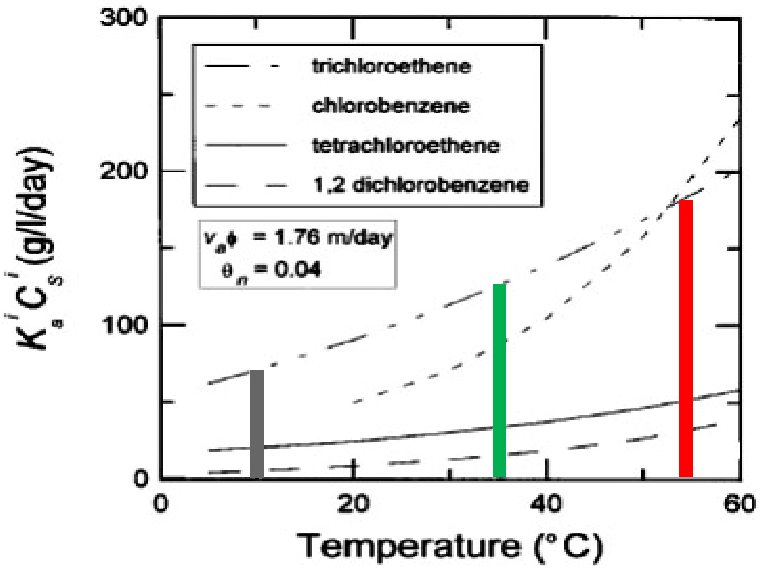




Thermal Treatment Synergies

HEPA® Remediation

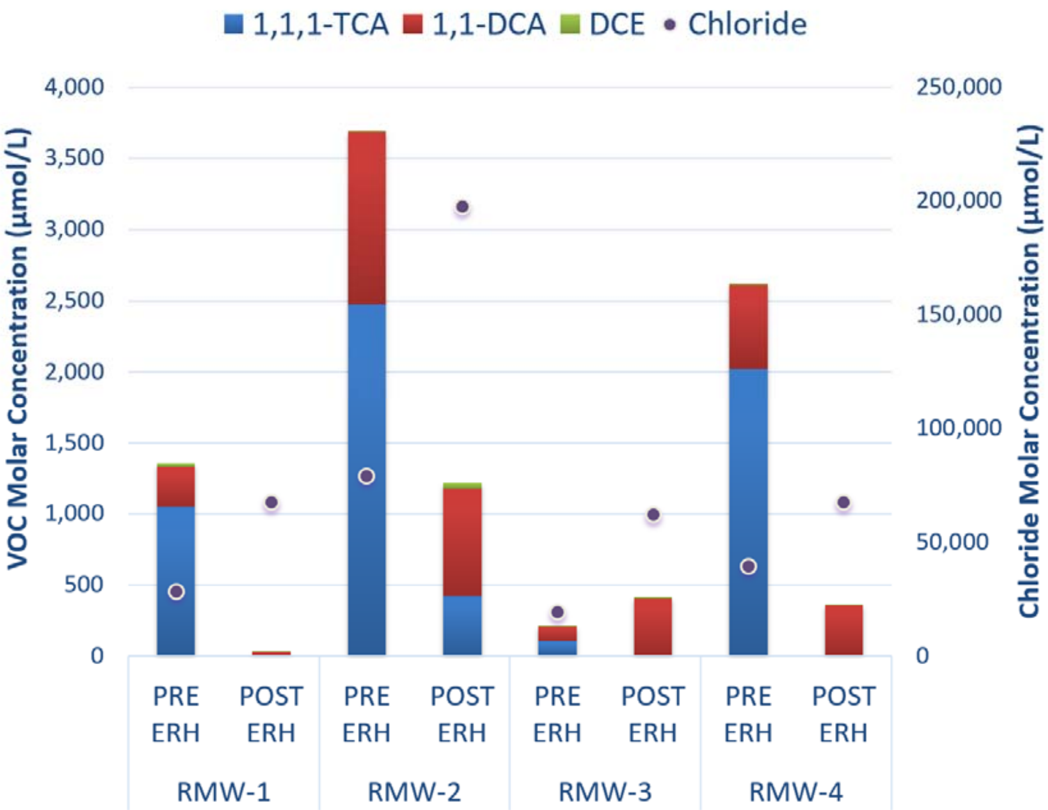
- Electrical resistance heating allows for more even heating in target treatment interval
- Target temperatures vary for thermally enhanced processes
  - Rate enhancement of reactions (e.g. hydrolysis, oxidation)
  - Heightened biodegradation kinetics
  - DNAPL dissolution enhancing biotic and abiotic reactions in aqueous phase



Imhoff, et al. (1997)

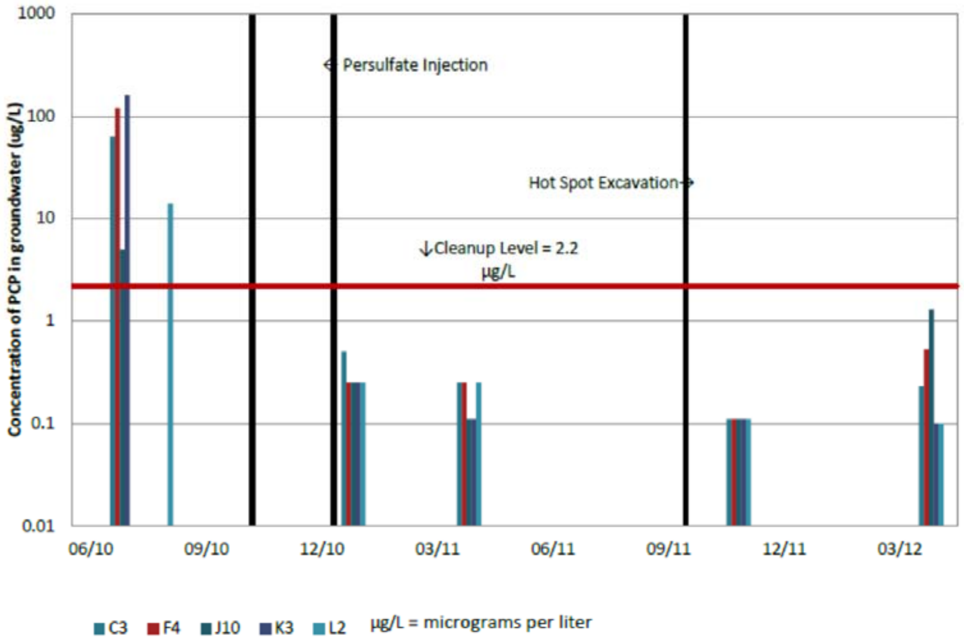
Thermally Enhanced Hydrolysis
Orland Park, IL

- COCs: 1,1,1-TCA, 1,1-DCA, DCE
- 51 days ERH operations
- Subsurface design temperatures below steaming conditions
- Temperature milestones for sampling: 25°C, 40°C, 60°C, 77°C
- Peak site average temperature: 80°C
- Overall VOC reduction: 93%



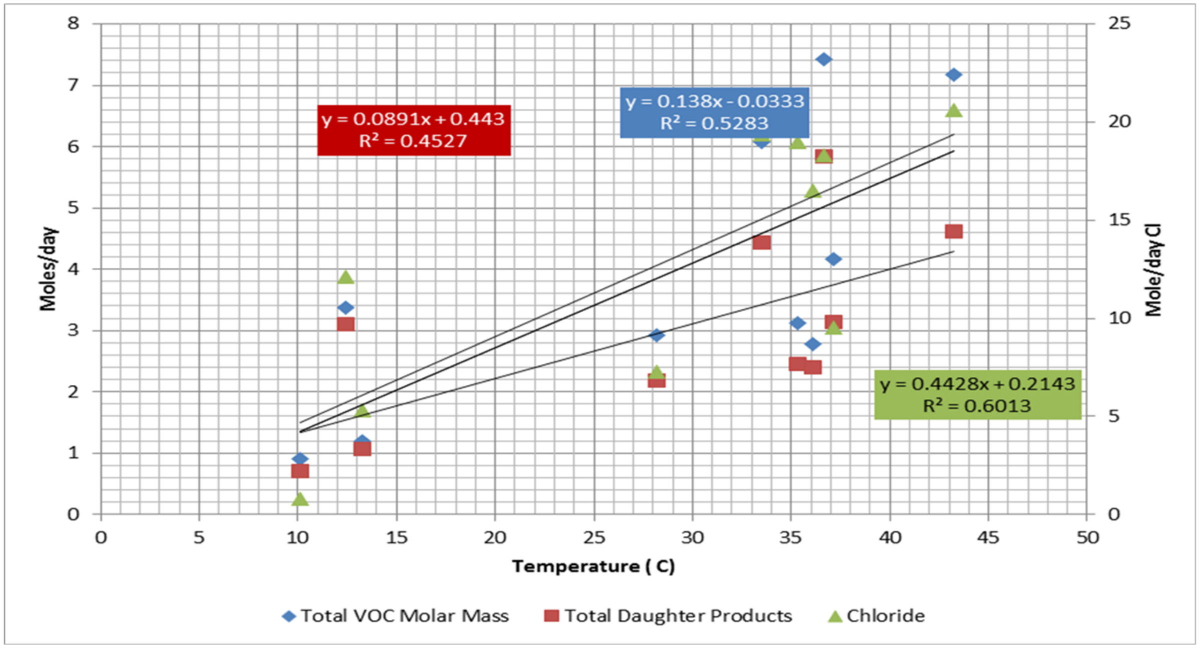
Thermally Enhanced Chemical Oxidation
Seattle, WA

- Subsurface design target temperature: 50 °C
- 3 months ERH Operations
- Sodium persulfate injections post ERH
- 2.2 µg/L pentachlorophenol goal achieved (max 160 µg/L PCP baseline concentration)



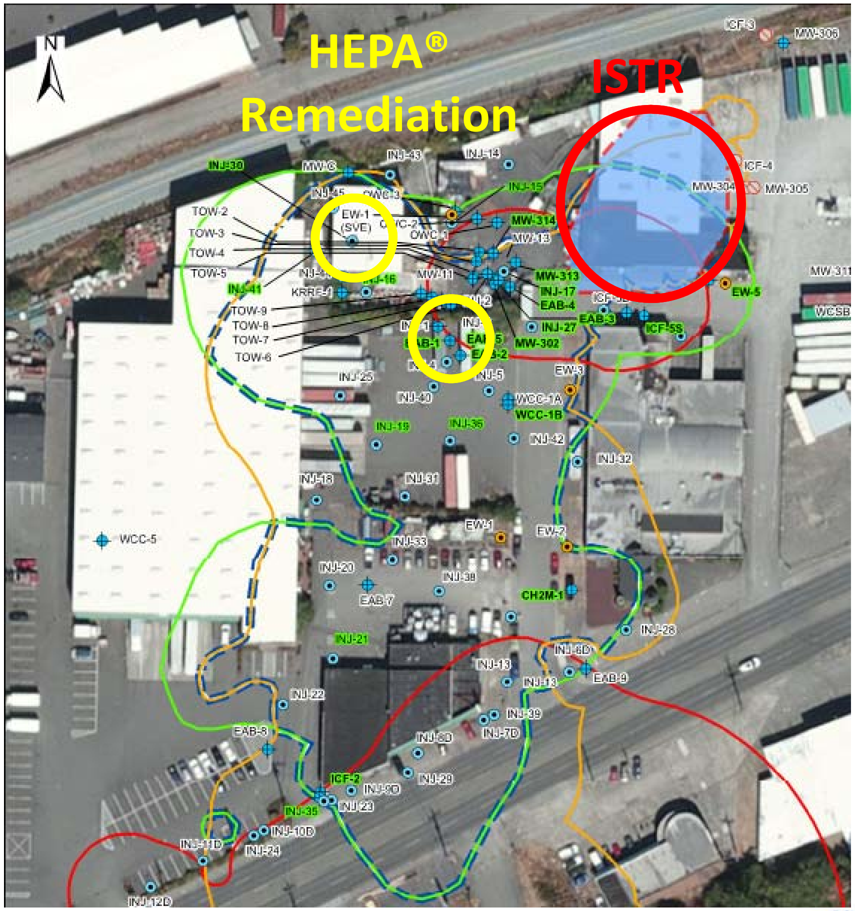
Thermally Enhanced Bioremediation
Fort Lewis, WA

- In Situ Bioremediation
  - Increased temperature 10°C to 35-45°C
  - 2-4 fold increase dechlorination
- Zero Valent Iron
  - Increased temperature 10°C to 35-45°C
  - 4-8 fold increase dechlorination



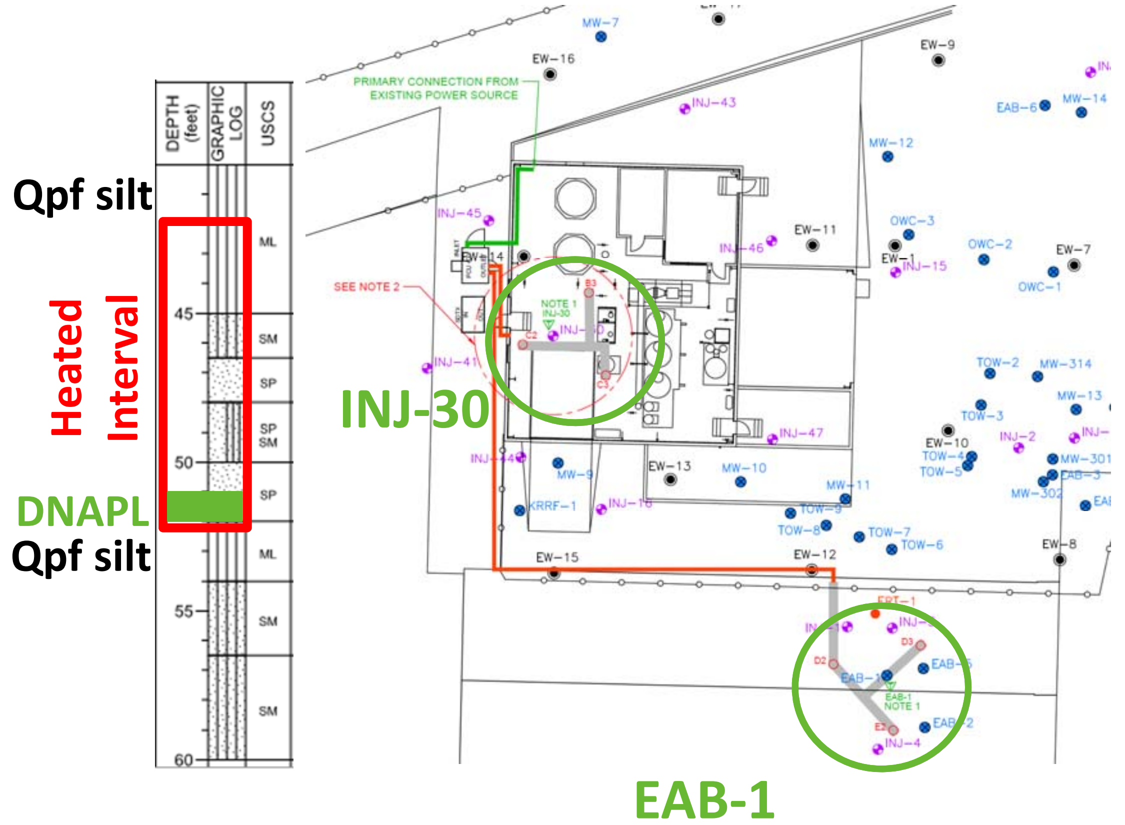
ROD Amendment Flexibility

- ROD Amendment enabled flexibility in remedy approach
- Order and location of technology implementation flexible
  - In situ thermal remediation and bioremediation
  - Thermally enhanced bioremediation
  - No change in ROD Amendment
- Temperature increases downgradient of ISTR coincided with thermally enhanced bioremediation

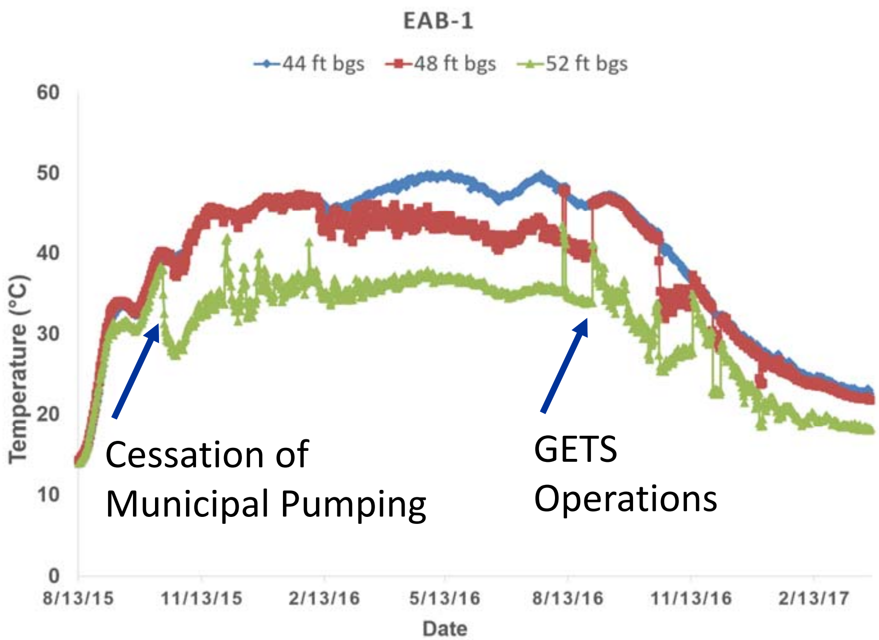


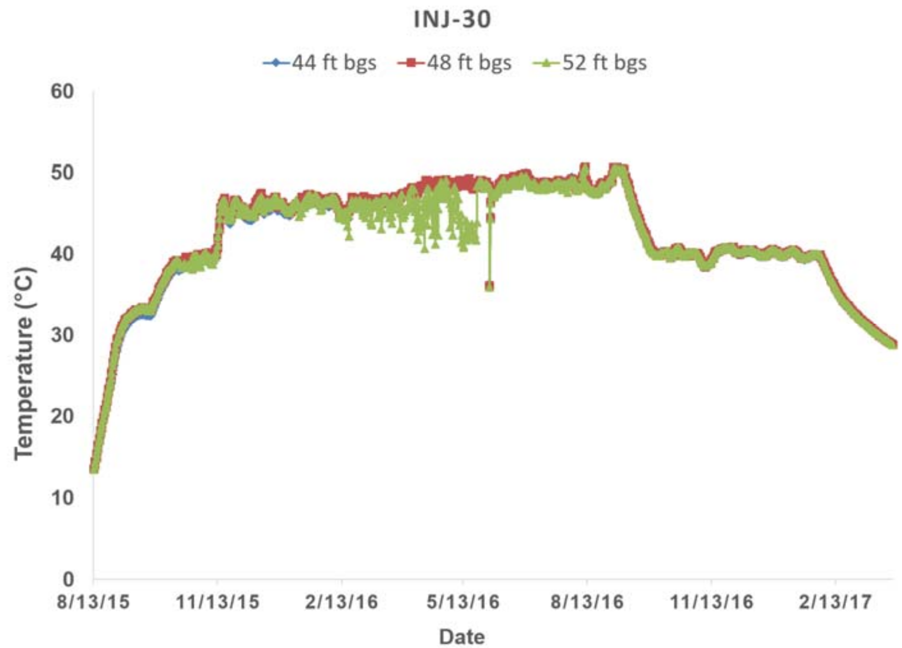
Thermally Enhanced Bioremediation
HEPA® Remediation

- Three electrode array installed surrounding each DNAPL hot spot, treatment interval above silt unit
  - INJ-30 Lower silt: 52-54 ft bgs
    Heated interval: ~42-52 ft bgs
  - EAB-1 Lower silt: 49-54 ft bgs
    Heated interval: ~40-50 ft bgs
  - Temperature monitoring point depth intervals: 44, 48, 52 ft bgs
- DNAPL extraction wells installed as precaution but not operated
- Utilized existing 3 phase, 480V electrical service at site



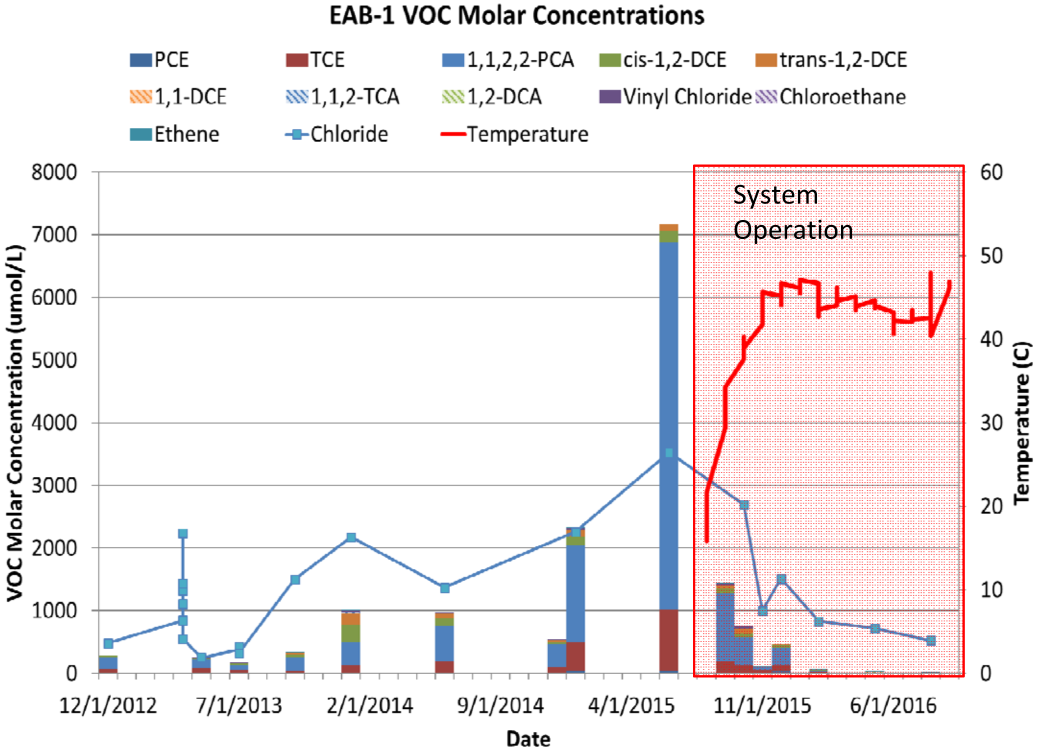
HEPA® Remediation System Operation

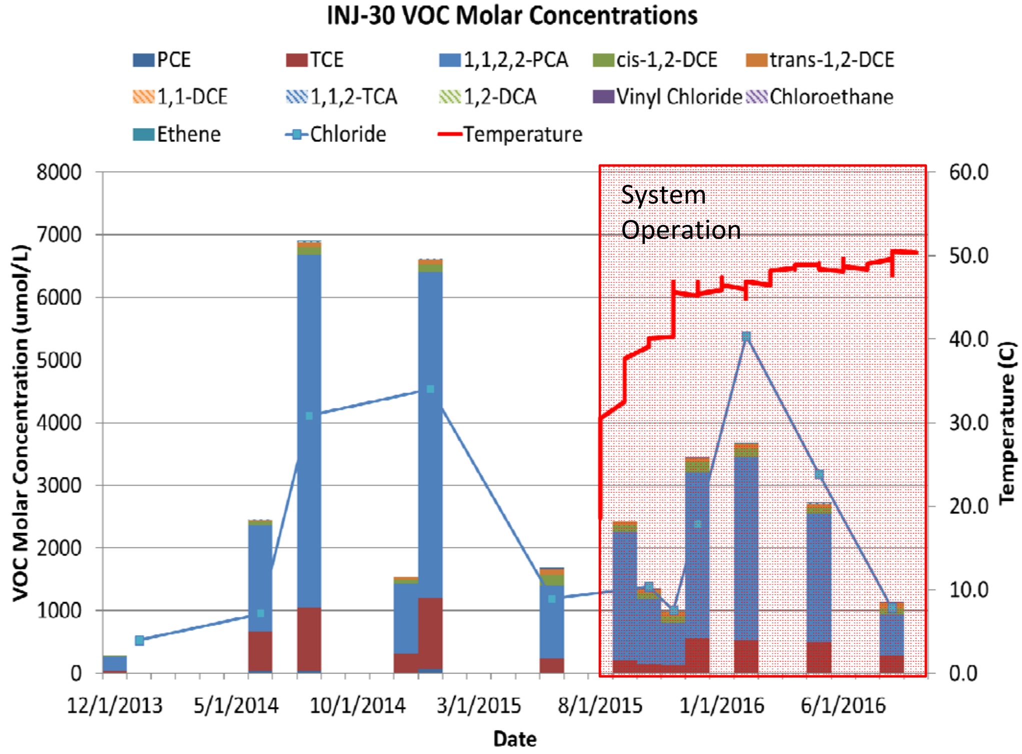




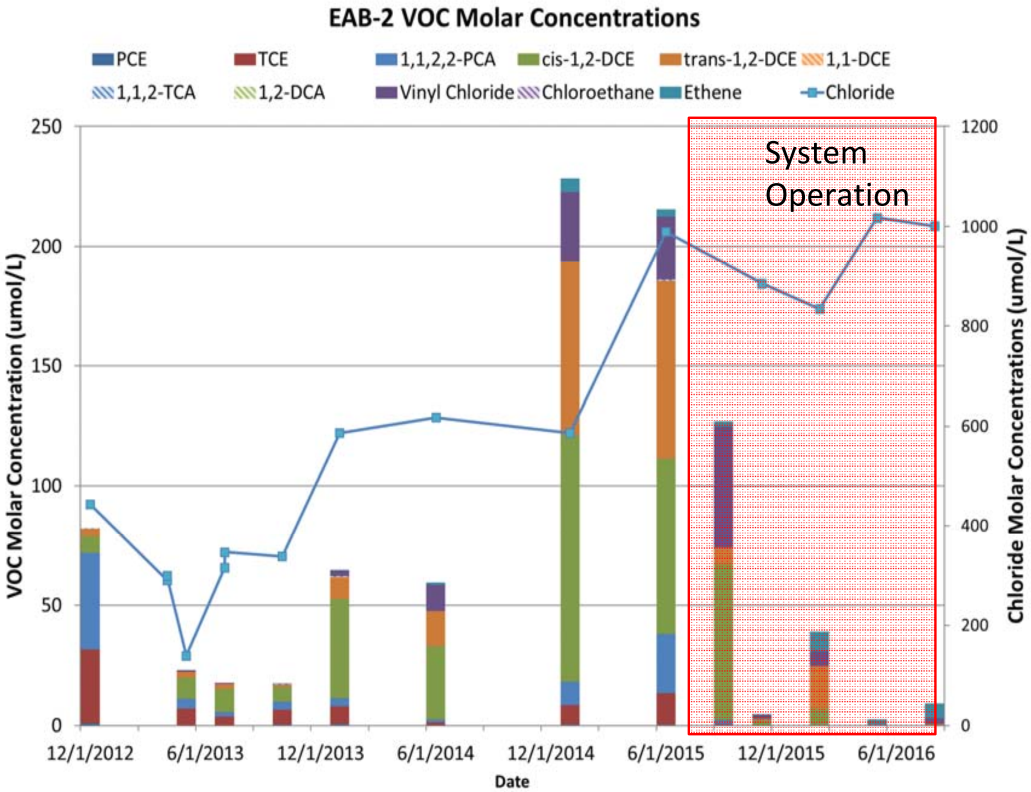
- Temperatures are able to be controlled within a 5°C specified range
- Incremental changes in target temperatures during operations
- EAB-1: August 2015 – October 2016, INJ-30: August 2015 – February 2017
- Biodegradation enhancing temperatures at EAB-1 post heating

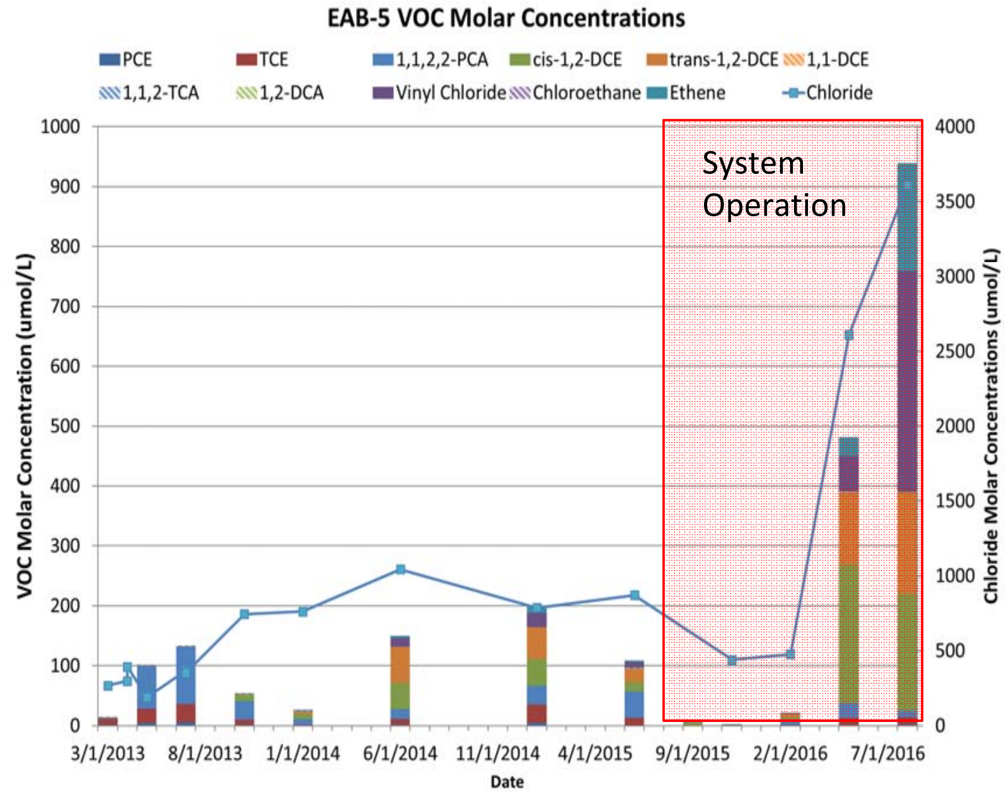
COPC Molar Concentrations at DNAPL Wells



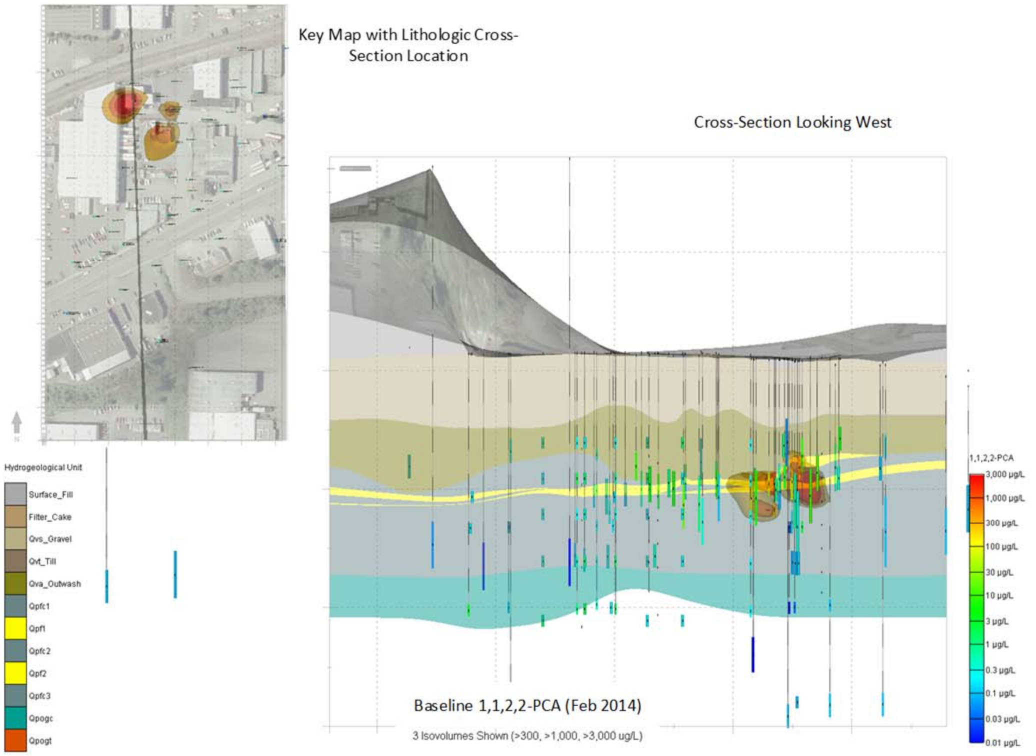


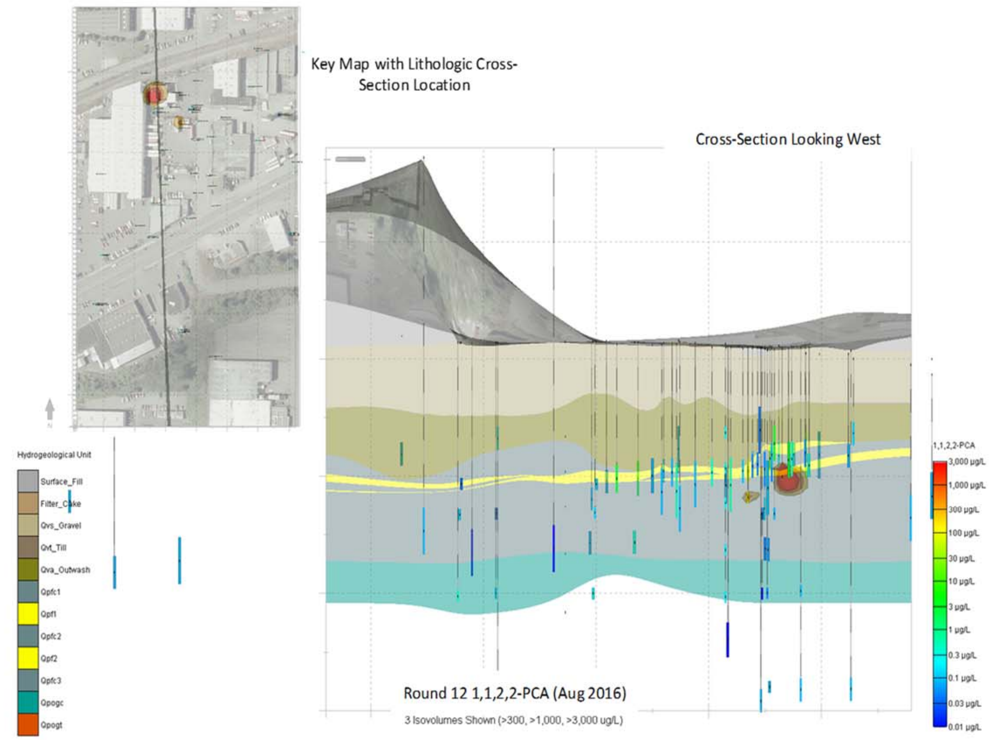
COPC Molar Concentrations at Nearby Wells



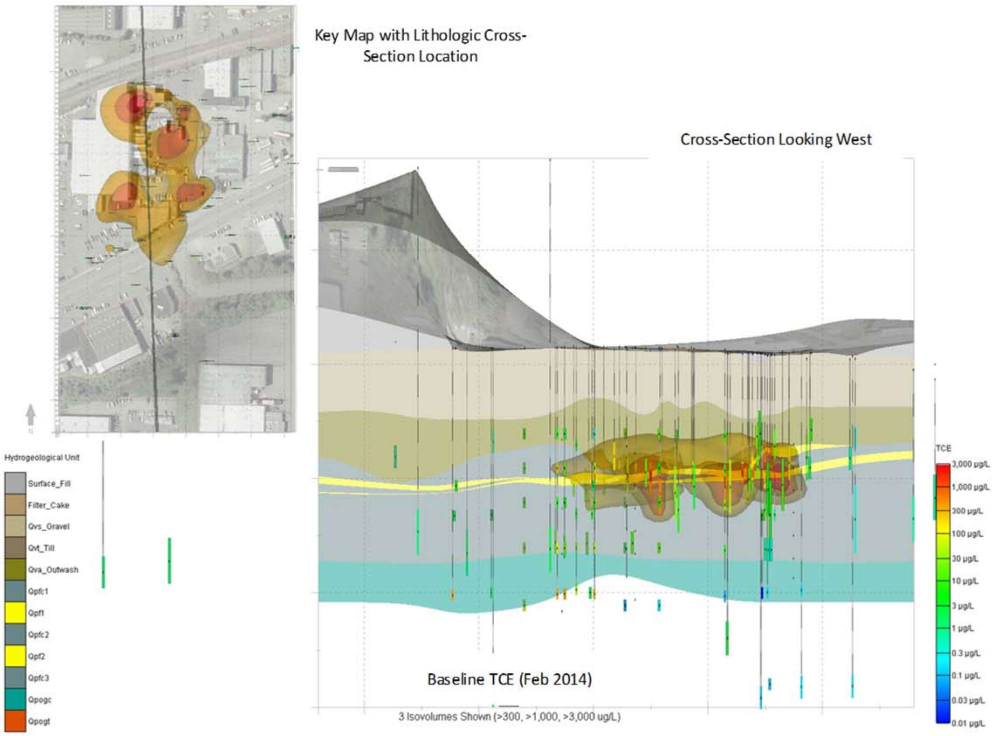


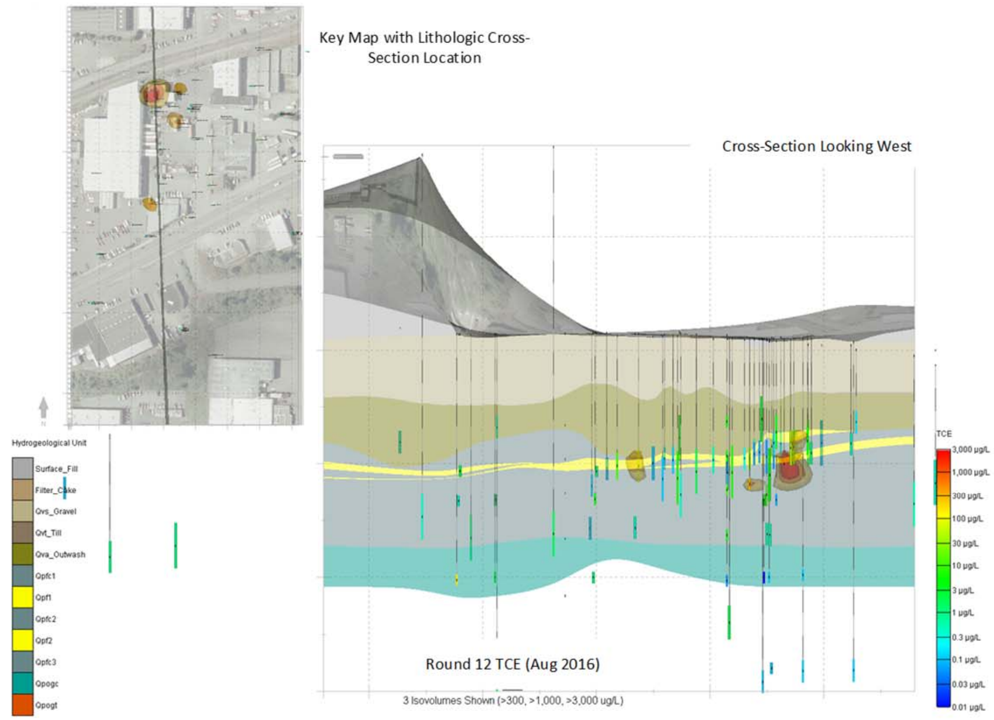
1,1,2,2-PCA Extent





TCE Extent

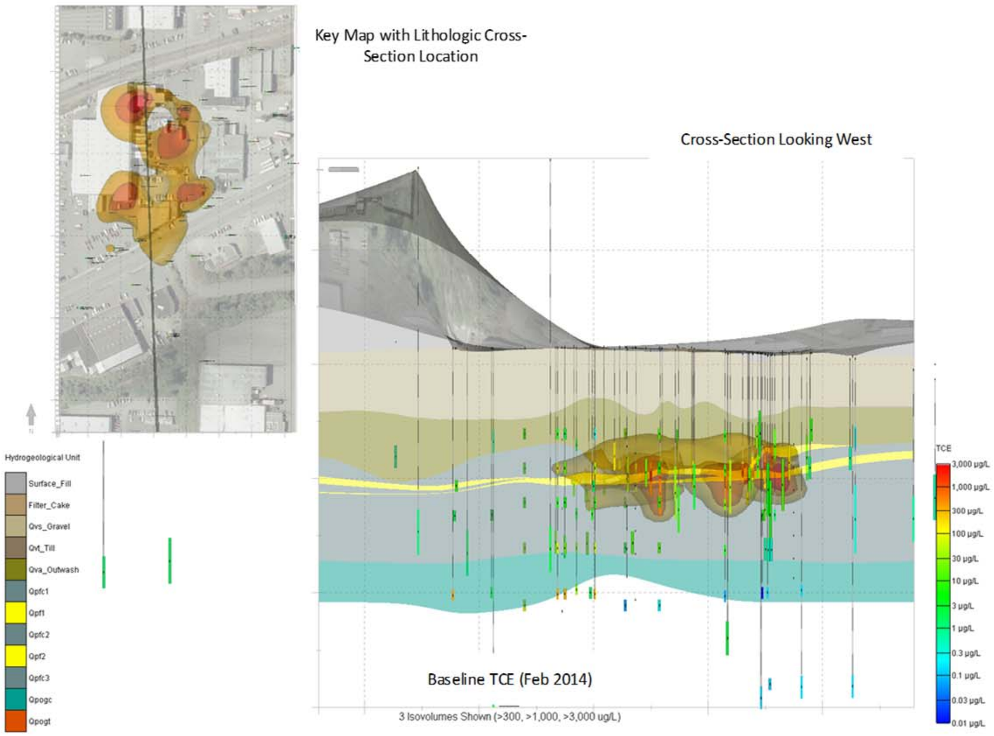


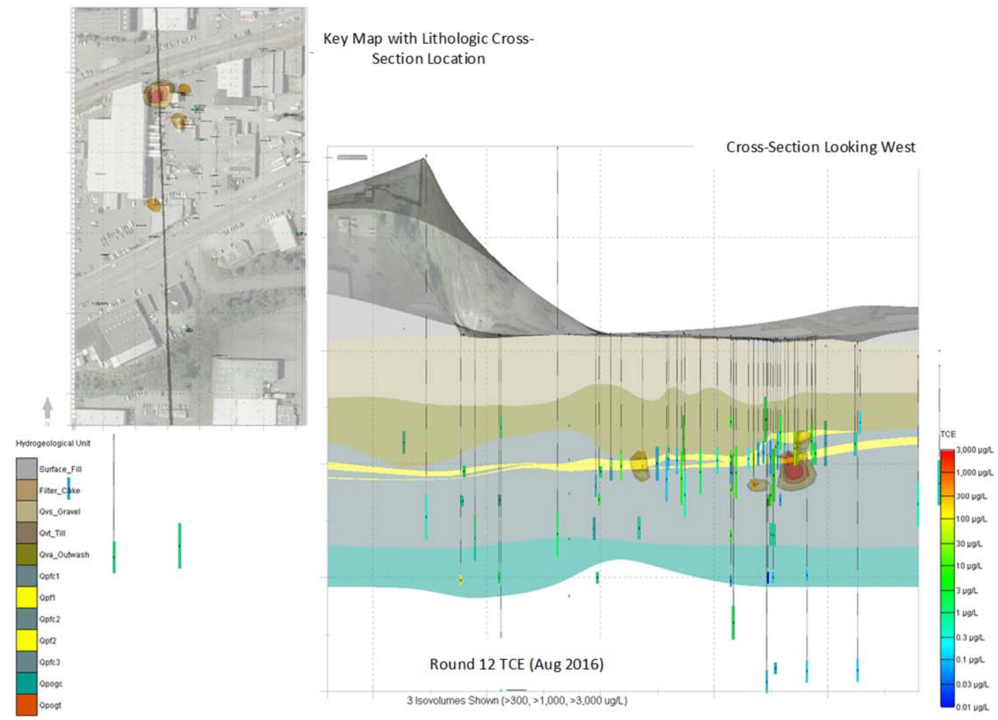


CDM Smith TRS Group, Inc. Accelerating Value

Summary

- Synergy through residual remediation temperatures from in situ thermal remediation
- Thermally enhanced bioremediation implemented to synergistically accelerate degradation rates within DNAPL hot spots and surrounding monitoring wells
- Flexible ROD Amendment allowed for adaptation and quick implementation


Key Map with Lithologic Cross-Section Location
Cross-Section Looking West
Hydrogeological Unit
Surface_Fill
Filter_Cake
Qvs_Gravel
Qvt_Till
Qva_Outwash
Qpfc1
Qpf1
Qpfc2
Qpf2
Qpfc3
Qpogc
Qpogt
TCE
3,000 µg/L
1,000 µg/L
300 µg/L
100 µg/L
30 µg/L
10 µg/L
3 µg/L
1 µg/L
0.3 µg/L
0.1 µg/L
0.03 µg/L
0.01 µg/L
Baseline TCE (Feb 2014)
3 Isovolumes Shown (>300, >1,000, >3,000 ug/L)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1 µg/L
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0.1 µg/L
0.03 µg/L
0.01 µg/L
Round 12 TCE (Aug 2016)
3 Isovolumes Shown (>300, >1,000, >3,000 ug/L)

Mass Discharge Performance Metric

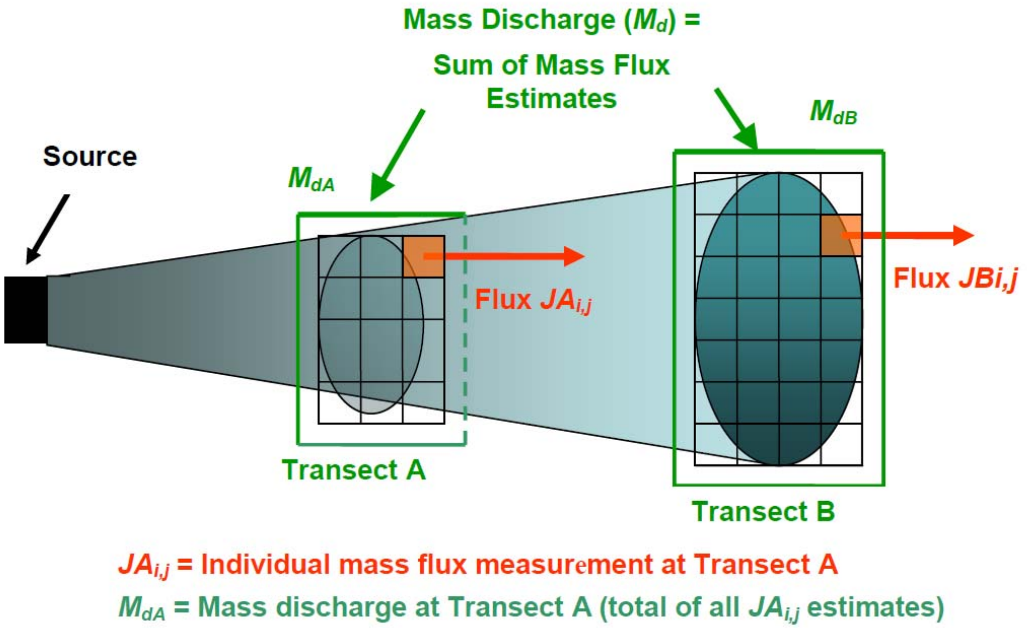
Dominic Giaudrone

Presentation Overview

- Use of mass discharge at the Well 12A Superfund Site
  - Mass flux and mass discharge used during site characterization to improve the CSM and optimize the treatment strategy for the combined remedy
  - Contaminant mass discharge reduction compliance goal in the ROD
- Mass discharge reduction results
- Lessons learned associated with use of mass discharge as a compliance metric

Mass Flux and Mass Discharge

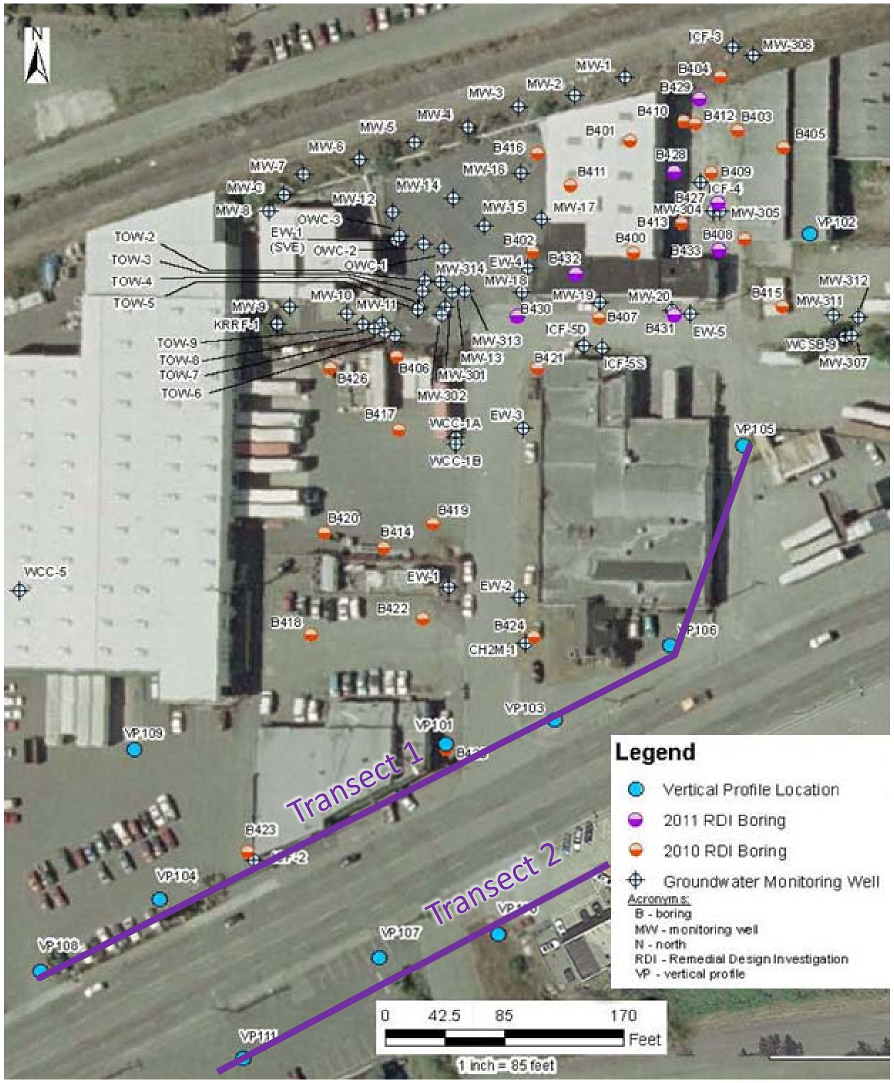
- Mass Flux (J) is the mass moving past a plane of given area per unit time (e.g., $g/d/m^2$)
- Mass Discharge (M_d) is the total mass flux integrated across the entire area of a transect (e.g., g/d)



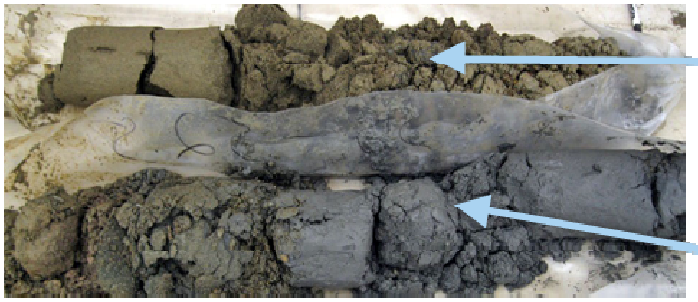
ITRC 2010. *Use and Measurement of Mass Flux and Mass Discharge.*

Pre-RA Supplemental Site Characterization

- 34 soil borings to reduce uncertainty and delineate sources
- 12 locations for vertical profiling
- Depth discrete samples:
  - Groundwater
  - Soil
  - Slug testing
  - Stratigraphy
- Gradient assessment
- Transect-based mass discharge evaluation



Vertical Profiling

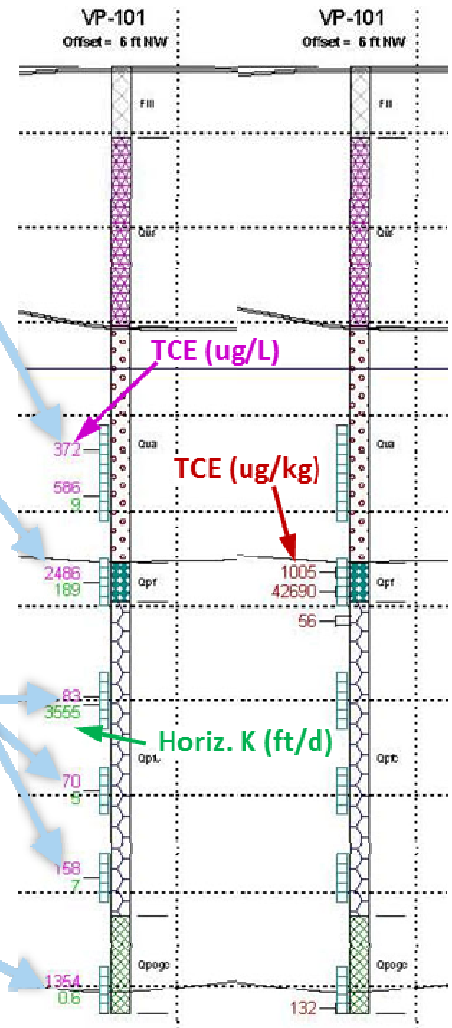


Qva: medium grained sand with rounded gravel and lesser amounts of silt

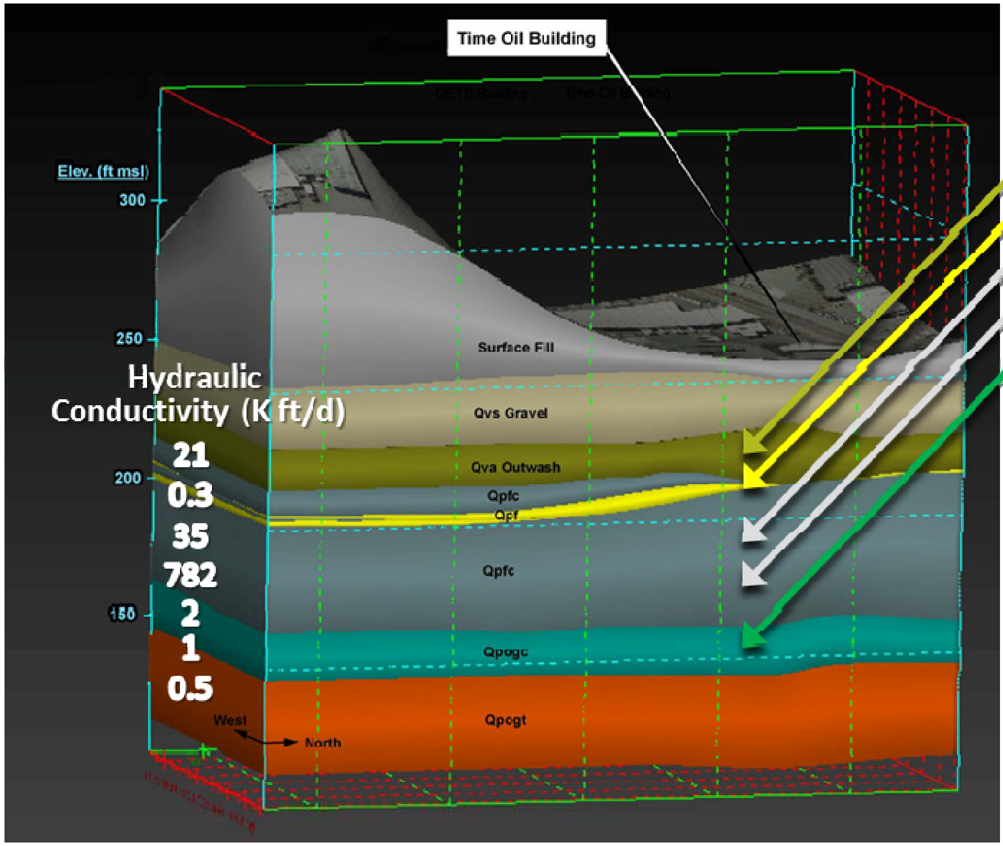
Qpf: fine-grained silt layer

Qpfc: highly variable, coarse grained sand and gravel with varying amounts of silt and intermittent layers of saturated silty gravel. Silt content generally observed to increase with depth.

Qpogc: gravel silt and slightly clayey fines

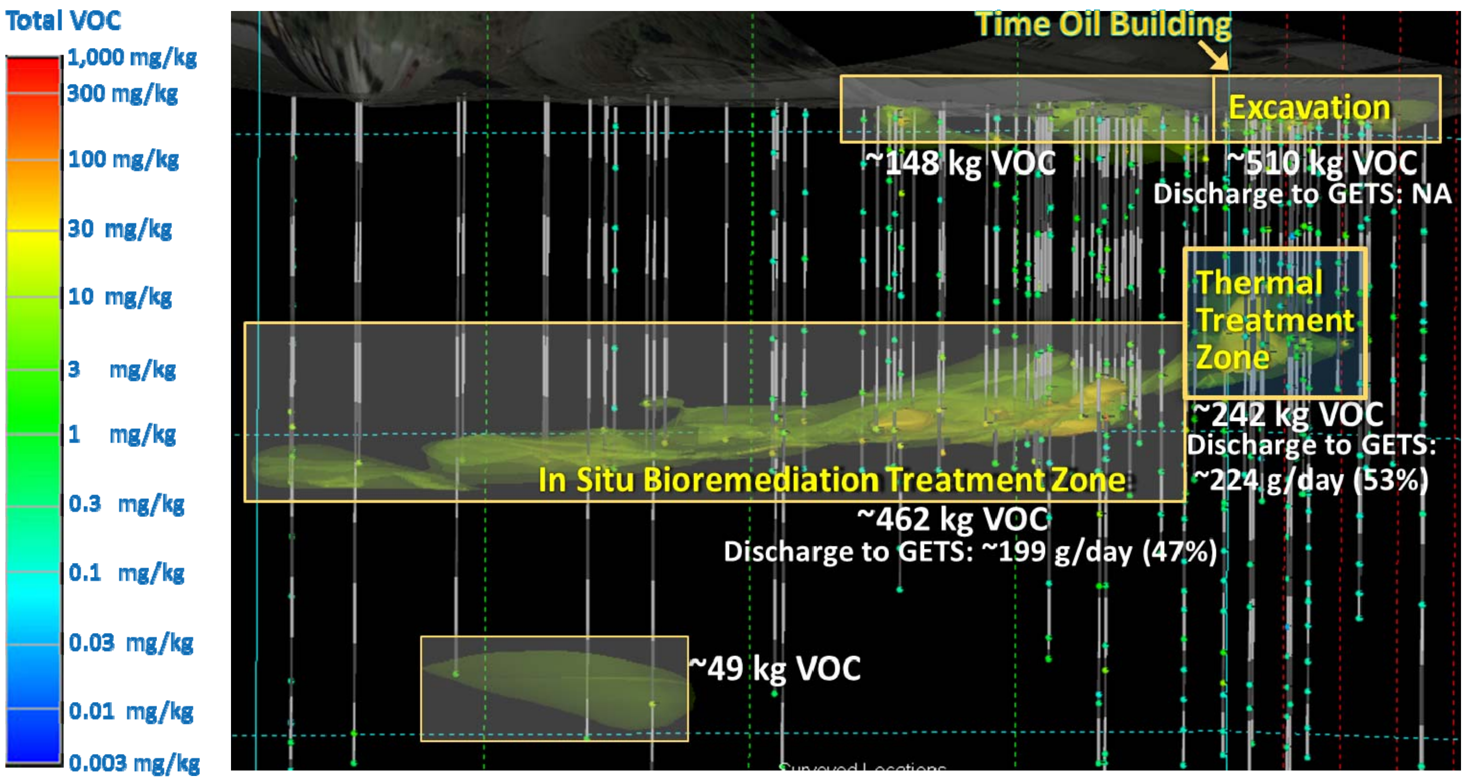


Mass Discharge – Vertical Intervals Refined



	Total VOC MD (kg/yr)	% of Total MD
Transect 1		
Qva	0.1	1%
Qpfc1/Qpf	2.9	31%
Qpfc2	5.9 96%	64%
Qpfc3	0.06	1%
Qpogc	0.3	4%
Total	9.3	
% of Total		
Transect 2		
Qva	0.01	0.4%
Qpfc1/Qpf	0.2	7%
Qpfc2	1.7	57%
Qpfc3	0.1	3%
Qpogc	1.0	33%
Total	3.0	

Mapping Treatment Technologies

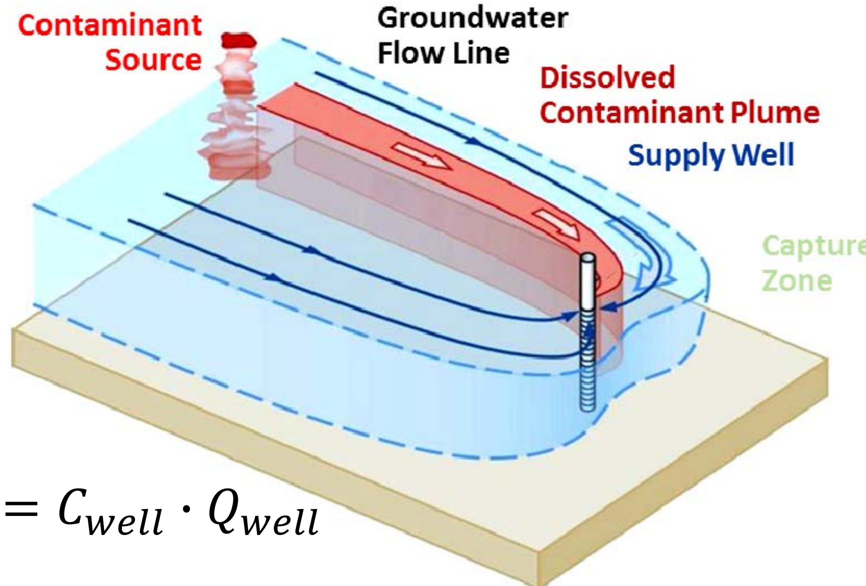


Mass Discharge Reduction Compliance Metric

- ROD Amendment #2 RAOs – Tiers of Compliance
  - **Tier 1:** Reduce risk from contaminated surface soils and achieve a contaminant mass discharge reduction of at least 90% from the high concentration source area near the Time Oil building to the dissolved-phase contaminant plume.
    - Remedy will be considered operational and functional.
    - O&M of Site will be turned over to the State of Washington.
    - Transition to LTM
- Basis for 90% mass discharge reduction objective
  - Fate and transport modeling of TCE from source to Well 12A
  - 50-80% reduction in TCE concentrations along the 300 µg/L plume boundary required for TCE to attenuate to below the 5 µg/L MCL prior to reaching Well 12A
- Ideal metric to evaluate source strength reduction from the combined remedy

Mass Discharge Measurement Methodology

- Pumping method using existing GETS selected over a transect method
  - Heterogeneous glacial stratigraphy
  - Horizontal gradient is strongly influenced by pumping
  - Gradient shift complicates the transect method
- M_d captured by the GETS is representative of mass that would otherwise discharge to the plume under pumping conditions



Nichols and Roth 2004

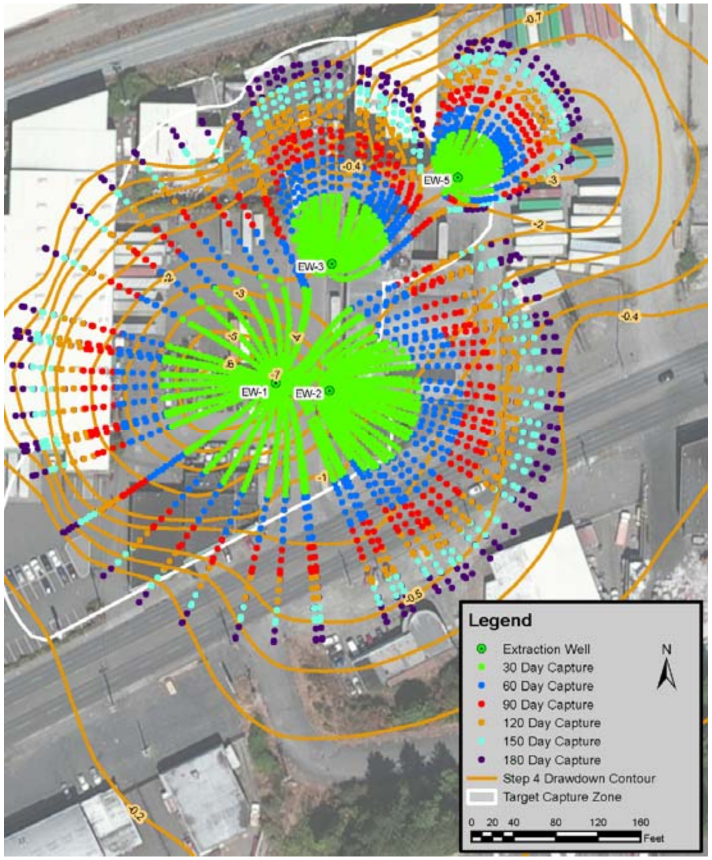
$$M_d = C_{well} \cdot Q_{well}$$

where

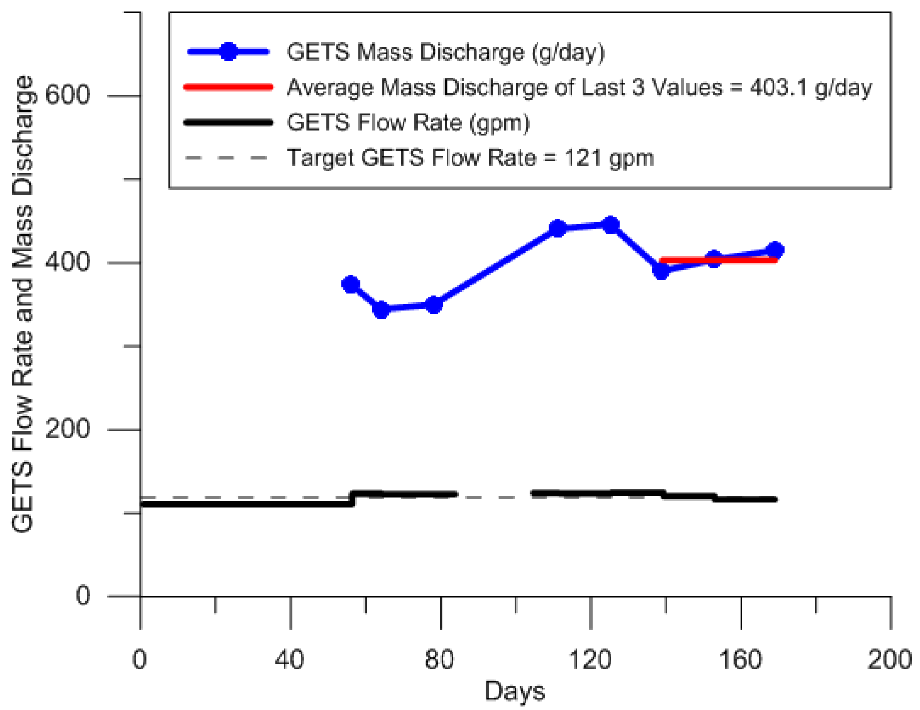
$C_{well} = concentration\ in\ pumping\ well$
$Q_{well} = flow\ rate\ of\ pumping\ well$

Baseline Mass Discharge Measurement Steps

1. Define target capture zone and verify representative capture
2. Used historical GETS data to evaluate variability in sampling and analysis and determine tolerance for variability in the measurement
   - Target flow rates: ± 10%
   - TVOC concentration: ± 18.5%
3. Maintain steady state pumping conditions until concentrations stabilize within acceptable range of variability
4. Calculate M_d using mean TVOC concentration in GETS influent from 3 consecutive M_d sampling events once concentrations stabilize



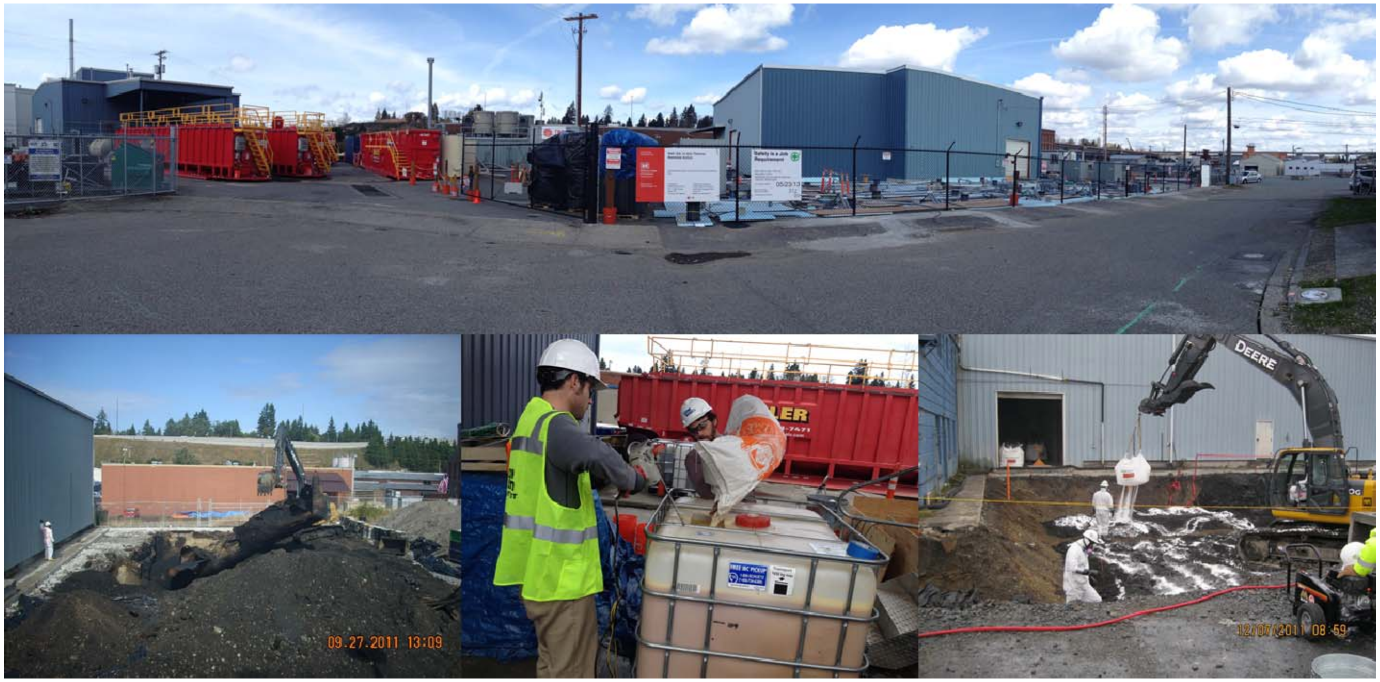
Baseline Mass Discharge Measurement Results



- Steady state conditions achieved
- All values within the expected range of variability
  - RPDs for last 3 data pairs <6%
- Baseline M_d = 403.1 g/day

Remediation Summary 2011-2016

- 2,130 tons of contaminated shallow soil and filter cake removed
- 2 USTs removed
- Building demolition
- ISTR of ~400 lbs. COCs and >22,000 lbs. non-target petroleum compounds
- Bioremediation of high concentration GW plume
- Thermally enhanced bioremediation of 2 DNAPL areas

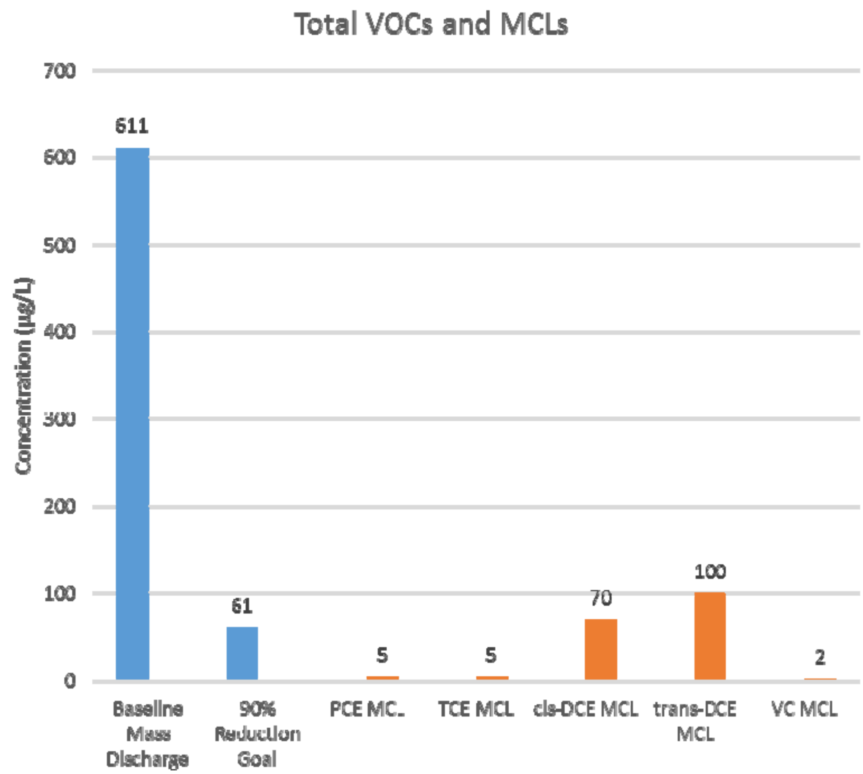


Post-RA Mass Discharge Measurement

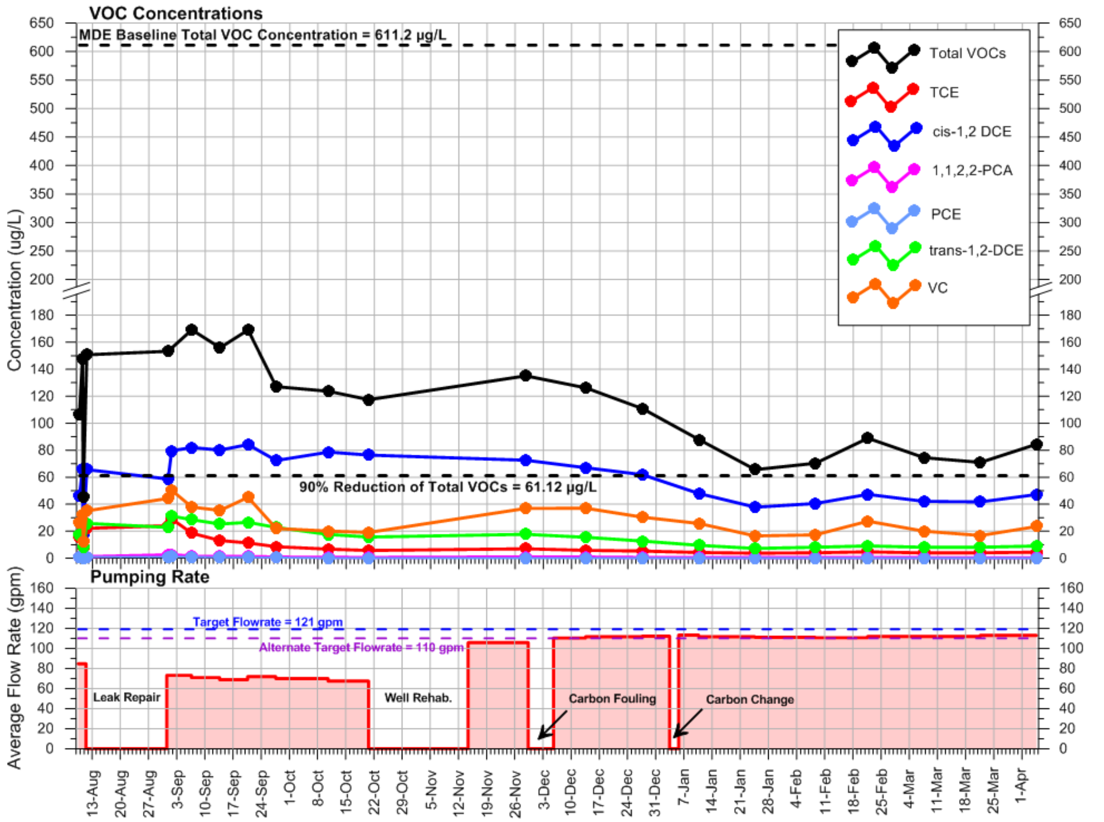
- Post-RA M_d measurement initiated August 2016
  - Favorable concentration trends observed
  - 3 of 4 wells unable to achieve target flow rates
  - Well rehabilitation performed
  - Unable to achieve 22 gpm target flow rate at EW-2
    - Established 11 gpm alternate target flow rate
  - Verified similar representative capture of the Target Capture Zone
  - Steady state conditions achieved
- Post-RA M_d measurement completed April 2017

Post-RA Mass Discharge Considerations

- 90% mass discharge reduction goal
  - ~40 g/day
  - ~61 µg/L TVOCs
- Requires GETS influent concentrations below MCLs for some compounds



Post-RA GETS Influent VOC Concentrations and Flow Rates



SP-1 VOC Concentrations and Pumping Rates

- 87.5% M_d reduction achieved
- 5 of 6 COCs reduced to below MCLs in GETS influent

Mass Discharge Reduction by Compound

	MCL	2012/2013 Baseline Mass Discharge (SP-1)			2017 Post-RA Mass Discharge (SP-1)			
	µg/L	µg/L	g/d	% of Total	µg/L	g/d	% of Total	% Reduction
1,1,2,2- PCA	NA	226.7	149.5	37.1%	0.4	0.2	0.5%	99.8%
PCE	5	8.9	5.9	1.5%	ND	0.0	0.0%	100%
TCE	5	160	105.5	26.2%	4.1	2.7	5.4%	97%
Parent Compounds Total		**395.6**	**260.9**	**64.8%**	**4.5**	**2.9**	**5.8%**	**99%**
cis-1,2- DCE	70	130.0	85.7	21.3%	43.7	28.8	57.0%	66%
trans-1,2- DCE	100	71.0	46.8	11.6%	8.4	5.5	11.0%	88%
VC	2	14.7	9.7	2.4%	20.1	13.3	26.2%	-37%
Degradation Compounds Total		**215.7**	**142.2**	**35.3%**	**72.2**	**47.6**	**94.2%**	**67%**
Overall Total		**611.2**	**403.1**	**100%**	**76.7**	**50.6**	**100%**	**87.5%**

Results Summary

- Mass Discharge Reduction
  - 87.5% total COCs
  - 99% parent compounds
  - 67% degradation compounds
- Intent of 90% M_d reduction RAO has been met
- 5 of 6 COCs reduced to below MCLs in GETS influent
- GETS shutdown after 29 years of operation

Next Steps

- Install compliance wells
- MNA evaluation
- Update F&T analysis for degradation compounds DCE and VC
- Develop and initiate LTM plan
- O&F determination

Conclusions and Lessons Learned

- Evaluation of mass flux and mass discharge during site characterization
  - Contributed to a more successful and cost-effective remedy
  - Discrete hydrogeologic zones targeted to maximize source strength reduction
- M_d was an appropriate metric to evaluate performance of the combined remedy
- GETS pumping method was appropriate for the site
  - Overcome challenging hydrogeologic conditions
  - Cost effective because of existing GETS
  - M_d captured by the GETS is representative of mass that would otherwise discharge to the plume under pumping conditions
- Consider how the makeup of COCs will change through RA implementation
  - 90% M_d reduction objective was based on F&T of TCE
  - Post-RA M_d >94% degradation compounds
  - DCE and VC will rapidly degrade in the aerobic portion of the aquifer beyond the EAB treatment zone and are not expected to impact Well 12A.
- Consider the M_d reduction objective in terms of concentration
  - M_d reduction goal: ~61 µg/L TVOCs
  - MCLs for site COCs: 2 to 100 µg/L
  - Concentrations outside source treatment zone