Breaking the Uncertainty Logjam: Leveraging CSMs to Make Remedial Progress in Bedrock Aquifers

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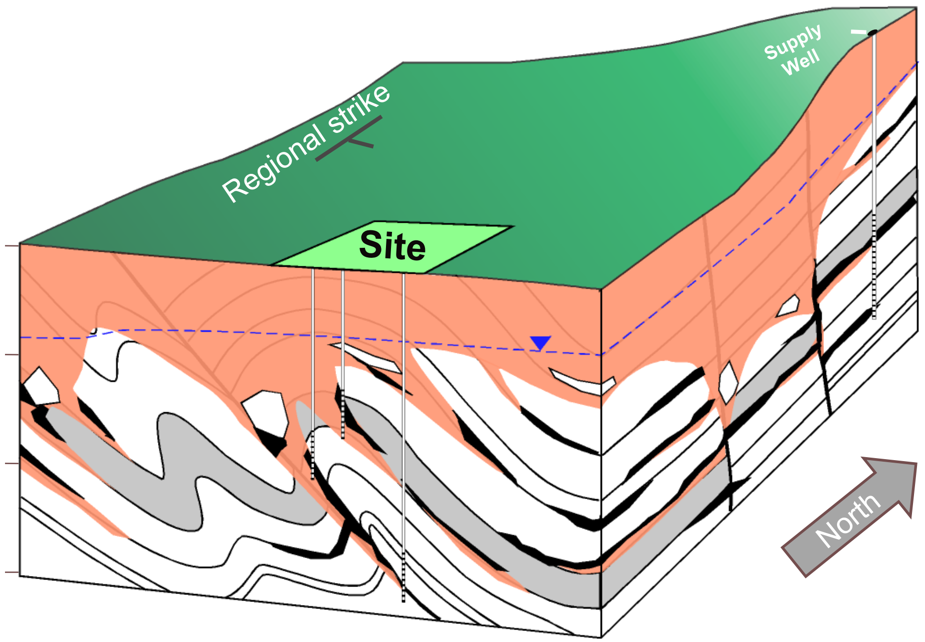
Urvi Tulsiani

Remediation Approach

- ❑ Construct a CSM that integrates regional and local bedrock environment into known site conditions to interpret site data.
- ❑ Use the CSM to effectively define transport in the bedrock environment.
- ❑ Set site-specific achievable remedial goals based on the CSM that reduces risks and focuses on high flux zones.
- ❑ Account for how matrix diffusion affects both plume advancement and remediation.



Build the CSM. Find the Gaps.

Large to Small Scale

- Physiographic Province
- Hydrostratigraphic Families
- Regional-Local Bedrock Environment
- Site Specific Bedrock Conditions

All focused on these characteristics

- Rock Type
- Structure
- Porosity Type
- Fracture Networks
- Nature of Bedrock Surface
- Groundwater Flow & Hydraulic Connectivity
- Source mass and flux zones

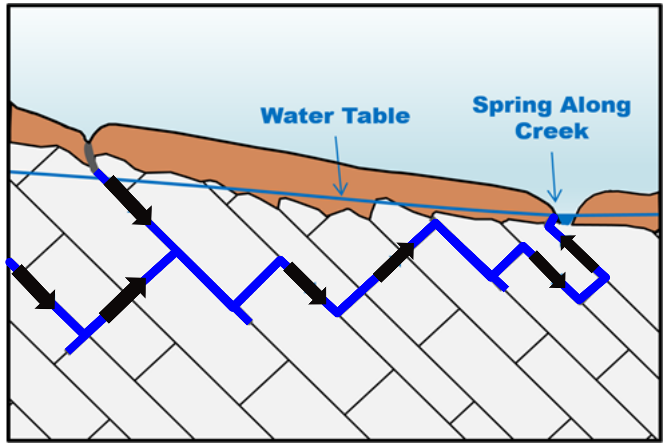
CSM based on monitoring well data?

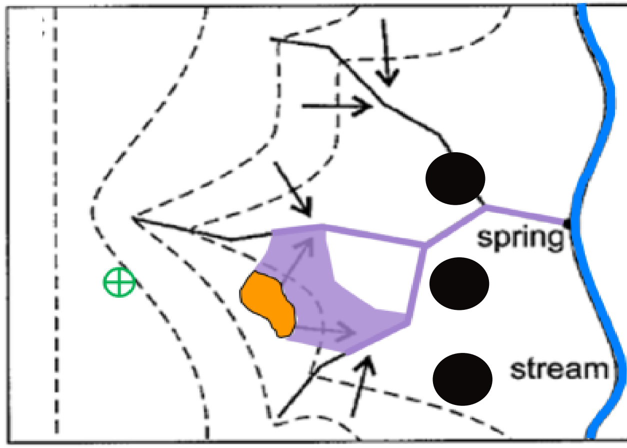
CSM based on targeted tools to reduce uncertainty:

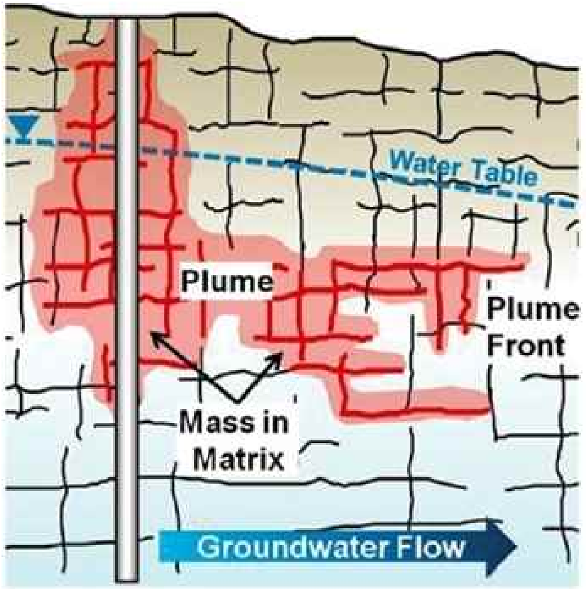
- Geophysical Methods
- Grab Groundwater Sampling
- Rock Coring
- Hydraulic Testing
- Tracers Analysis

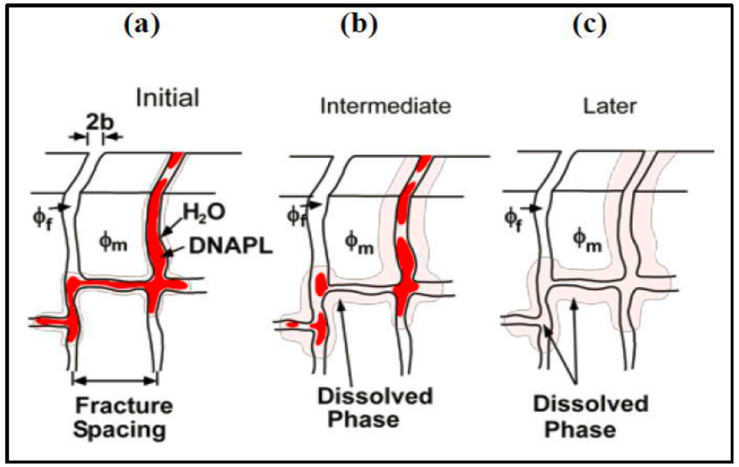
A Path Through Complexity

- Bedrock fracture network variable and unpredictable
- High investigation cost in bedrock resulting in limited data and greater uncertainty
- Matrix diffusion challenges







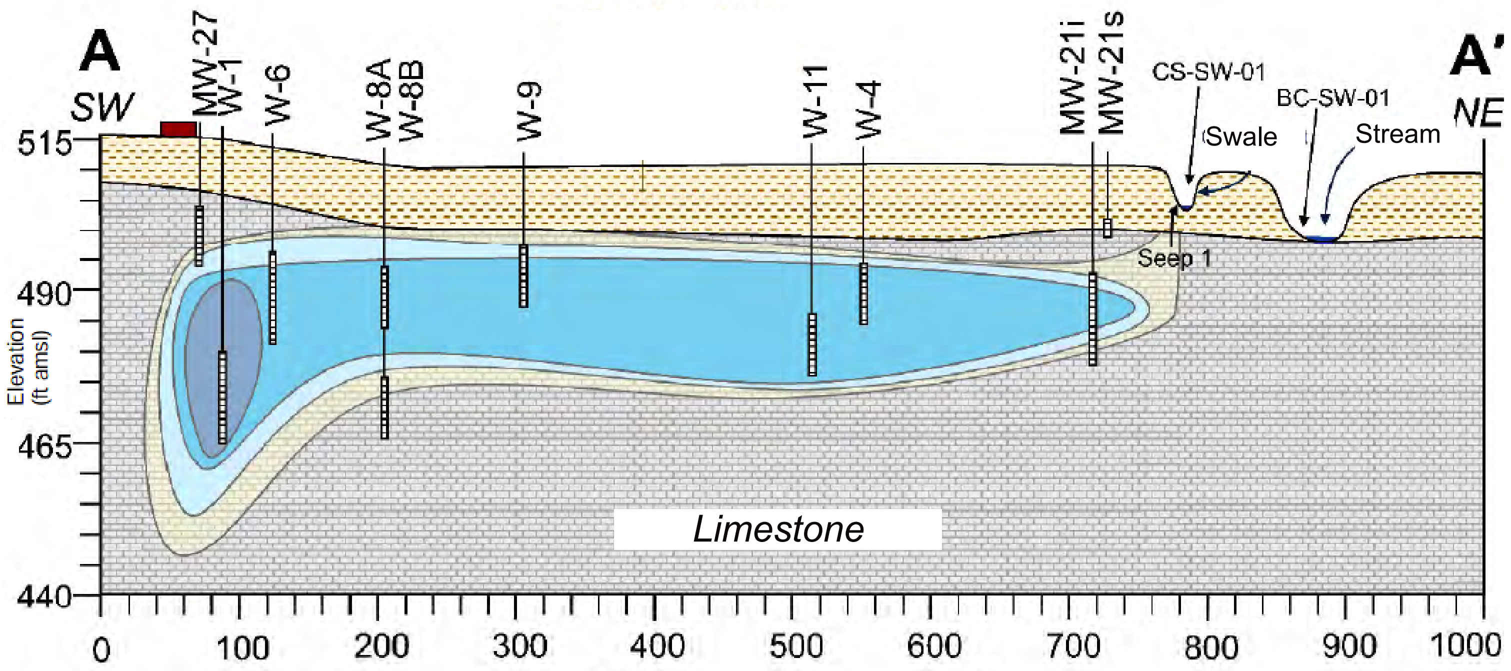


Beth Parker et al.

Achievable Solutions

The challenge of fractured rock remediation can be overcome by:

- Focusing on high concentration source and flux zones
- Setting appropriate risk-based remedial goals based on CSM
- Having an adaptive remedial approach

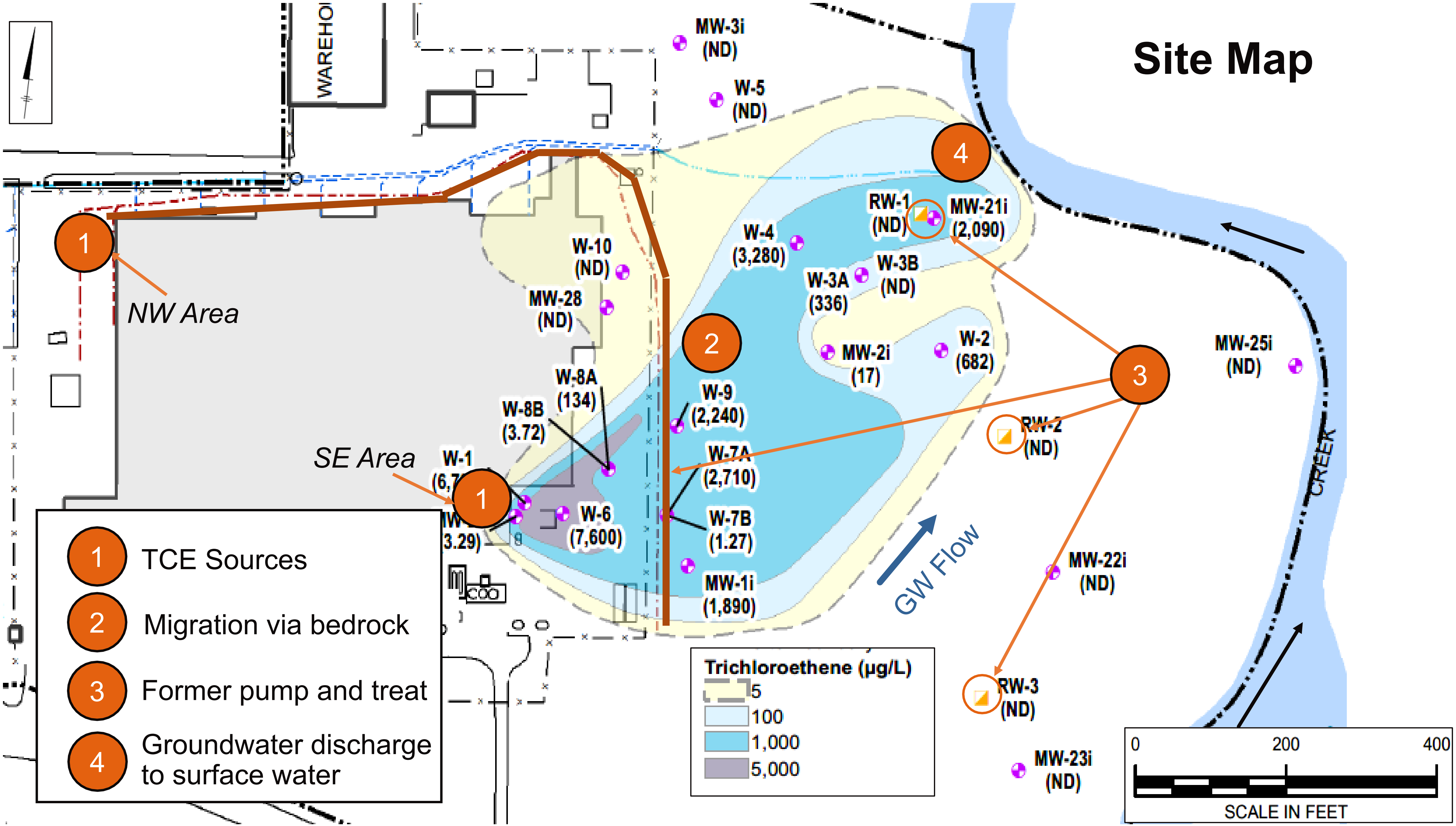


Bedrock In Situ Injection-Based Remediation Case Study

Manufacturing Facility:

- TCE releases from degreasing operations
- Migration via limestone bedrock
- Former groundwater extraction remedy for plume containment
- Groundwater discharge to surface water

Site Map

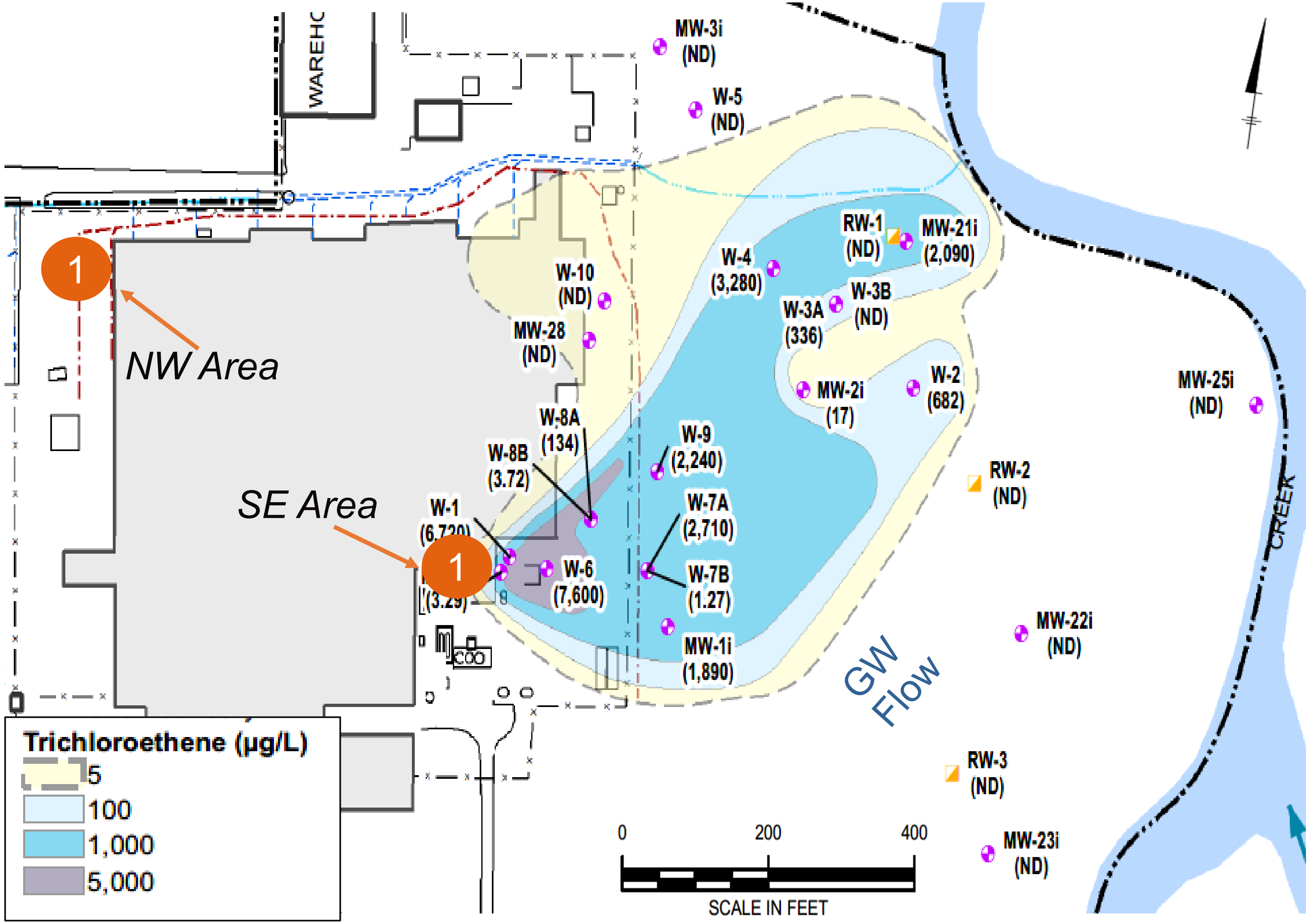

WAREHO
MW-3i
(ND)
W-5
(ND)
4
RW-1
(ND)
MW-21i
(2,090)
W-4
(3,280)
W-3B
(ND)
W-3A
(336)
W-10
(ND)
MW-28
(ND)
1
NW Area
2
MW-2i
(17)
W-2
(682)
3
MW-25i
(ND)
W-8A
(134)
W-8B
(3.72)
W-9
(2,240)
RW-2
(ND)
SE Area
W-1
W-7A
(2,710)
W-6
(7,600)
W-7B
(1.27)
3.29)
MW-1i
(1,890)
GW Flow
MW-22i
(ND)
CREEK
1 TCE Sources
2 Migration via bedrock
3 Former pump and treat
4 Groundwater discharge to surface water
Trichloroethene (µg/L)
5
100
1,000
5,000
RW-3
(ND)
MW-23i
(ND)
0
200
400
SCALE IN FEET

Building the CSM. Addressing the Data Gaps.

Pre-Design Data Gaps:

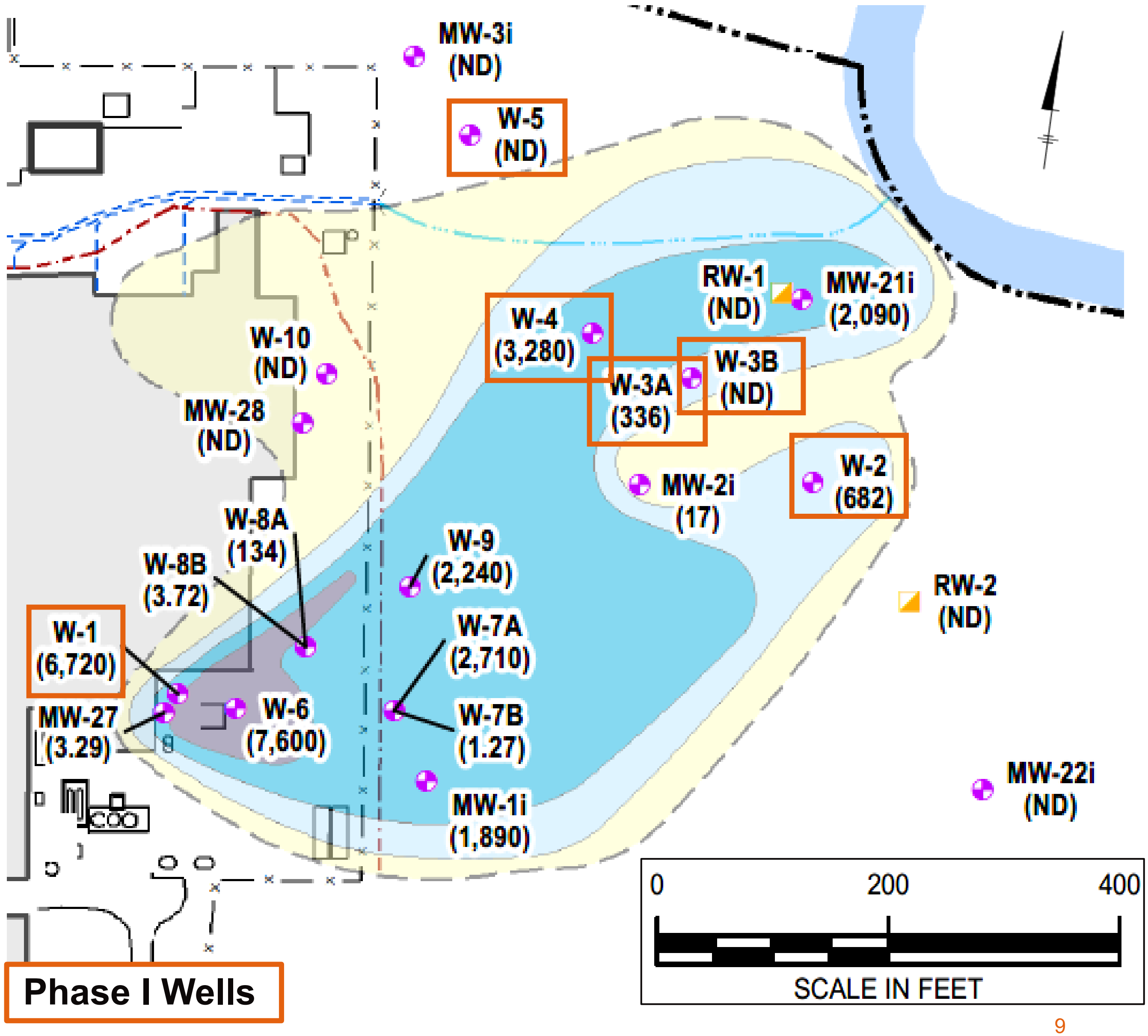
- ❑ Source Area Characterization
- ❑ Mass Flux Pathways

➢ <u>Implemented Two Phase Pre-Design Investigation Program</u>

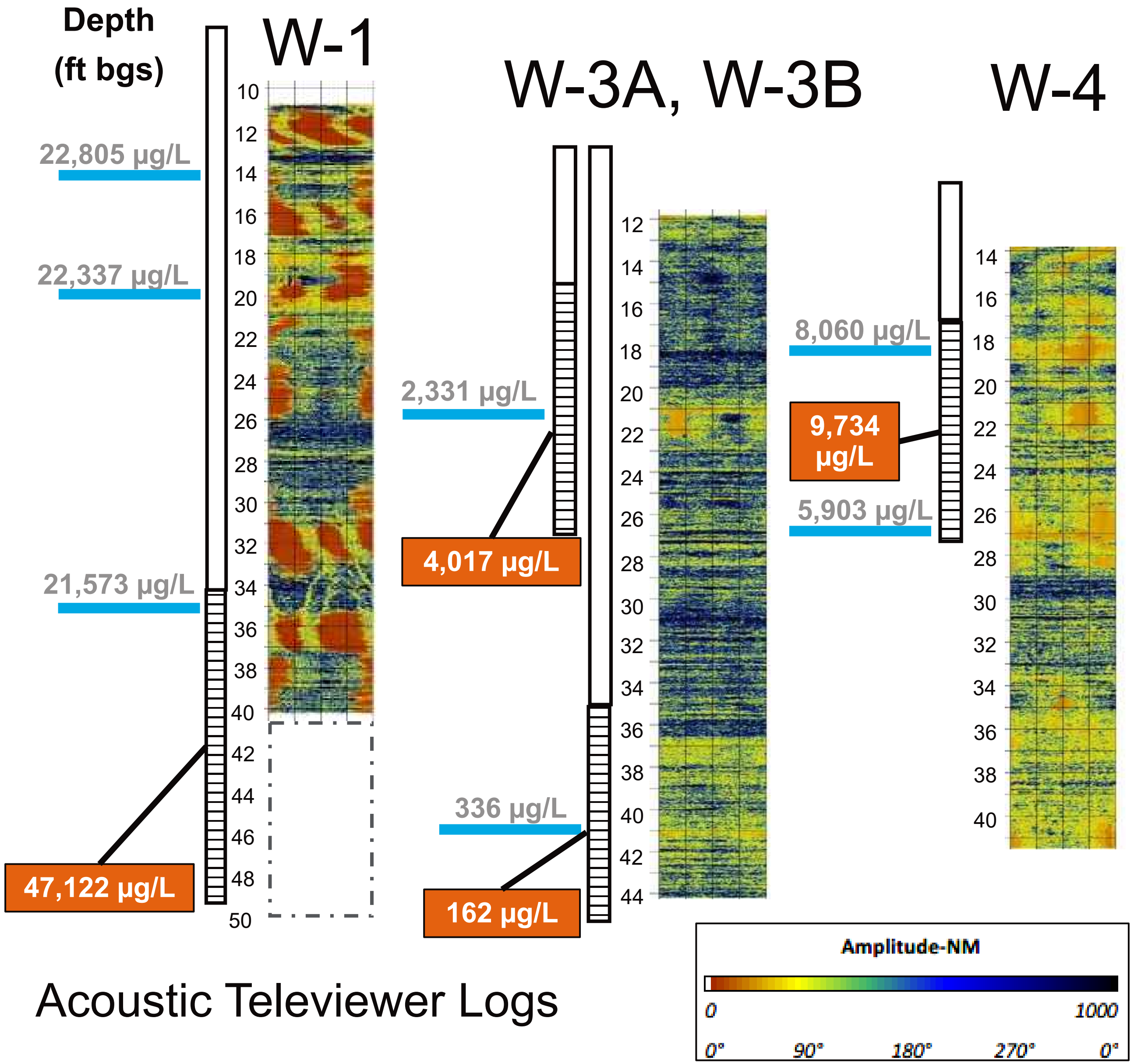


Phase I of II Pre-Design Investigation (Early 2018)

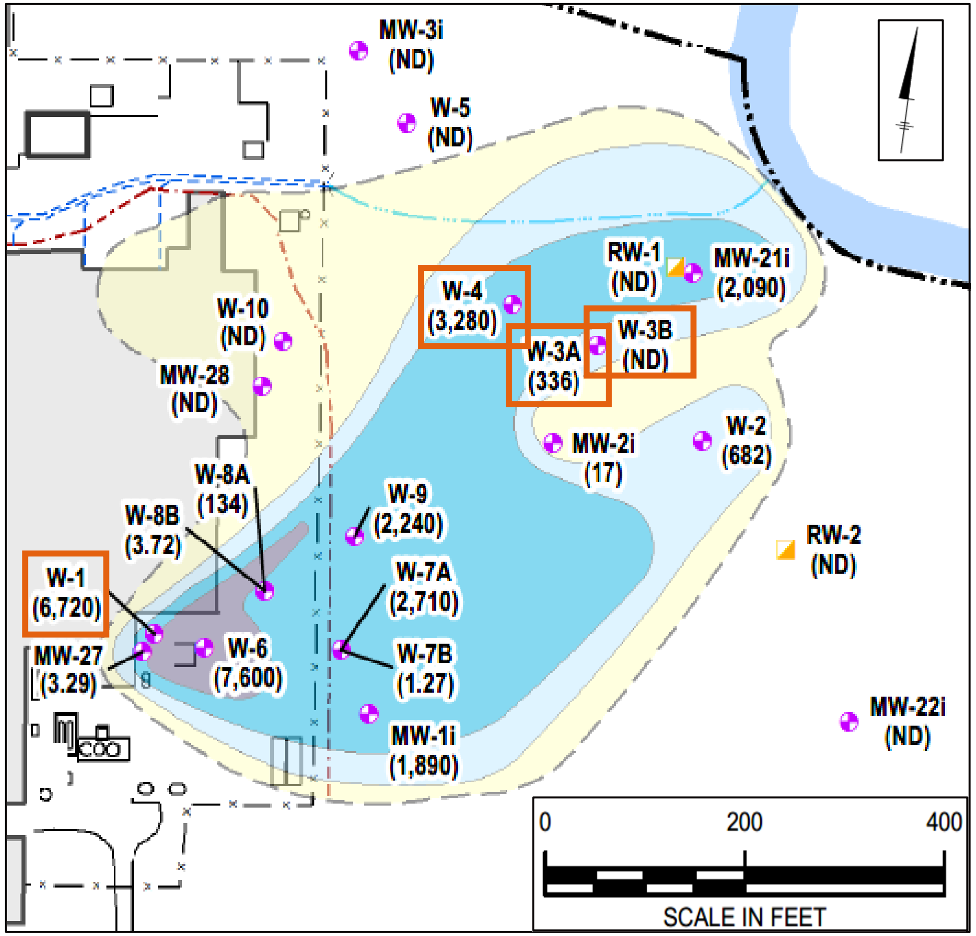
- **Objectives:**
  - Understand source strength and depth in bedrock: W-1
  - Downgradient flux pathways: W-2 to W-5
- **Activities**
  - Downhole Geophysics
  - Grab Groundwater Sampling
  - Hydraulic Testing
    - Enhanced Well Development
    - Transducer Logging
    - Short-duration Injection Testing at W-1
  - Baseline sampling of new wells



Defining Transport in Fractures



Acoustic Televiewer Logs



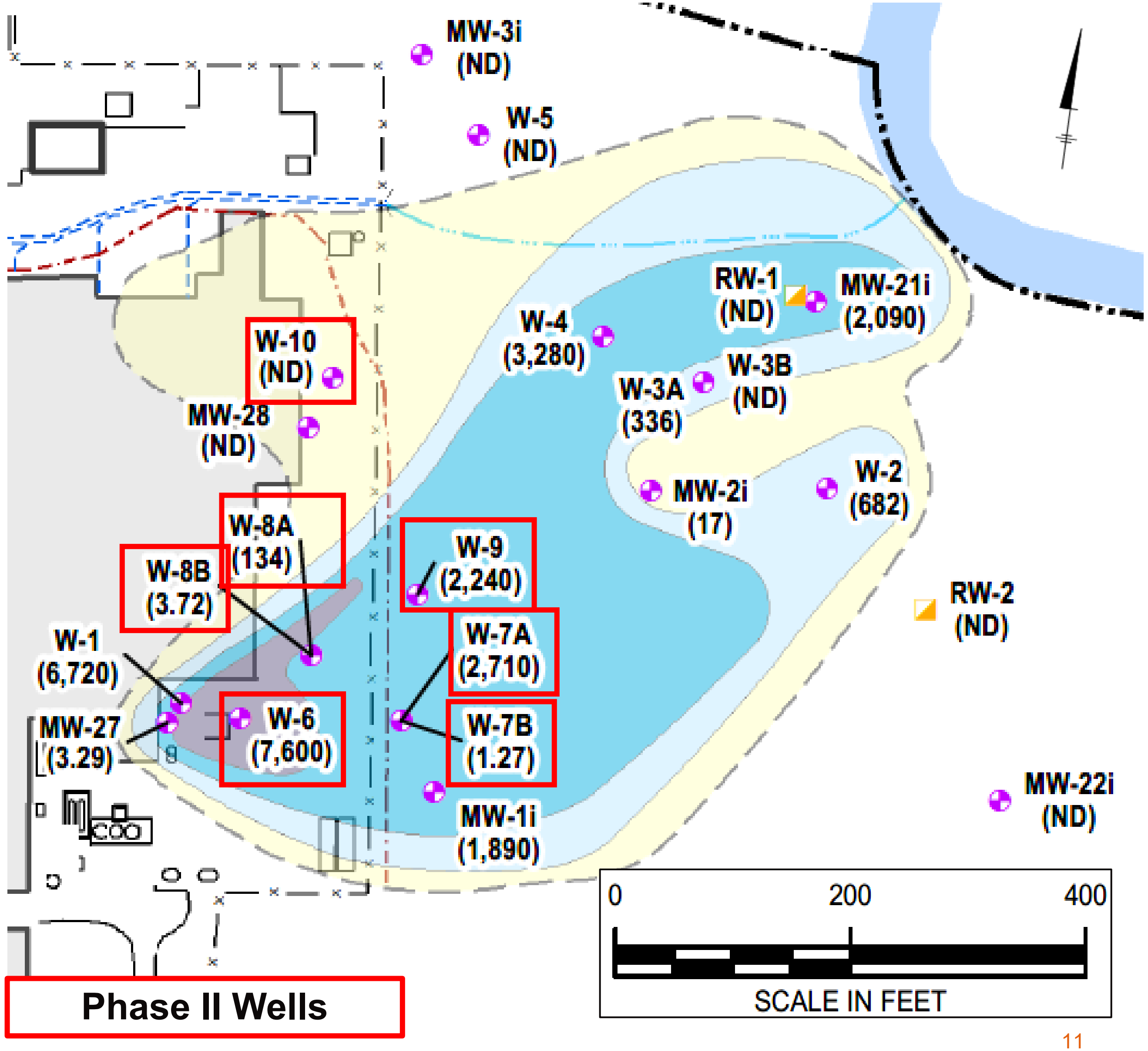
1,637 µg/L Total VOCs (grab sampling)

Approximate Borehole Fracture Location

79 µg/L Total VOCs (low-flow sampling)

Phase II of II Pre-Design Investigation (Early 2018 - Late 2019)

- **Objectives:**
  - Fracture connectivity and mass flux pathways from source area to downgradient plume
  - Build network that can be adapted for remedy implementation
- **Activities**
  - Surface and Downhole Geophysics – ERI
  - Hydraulic Testing
    - Enhanced Well Development
    - Transducer Logging
    - Pumping Tests
    - Slug Test
  - Baseline low-flow sampling of new wells

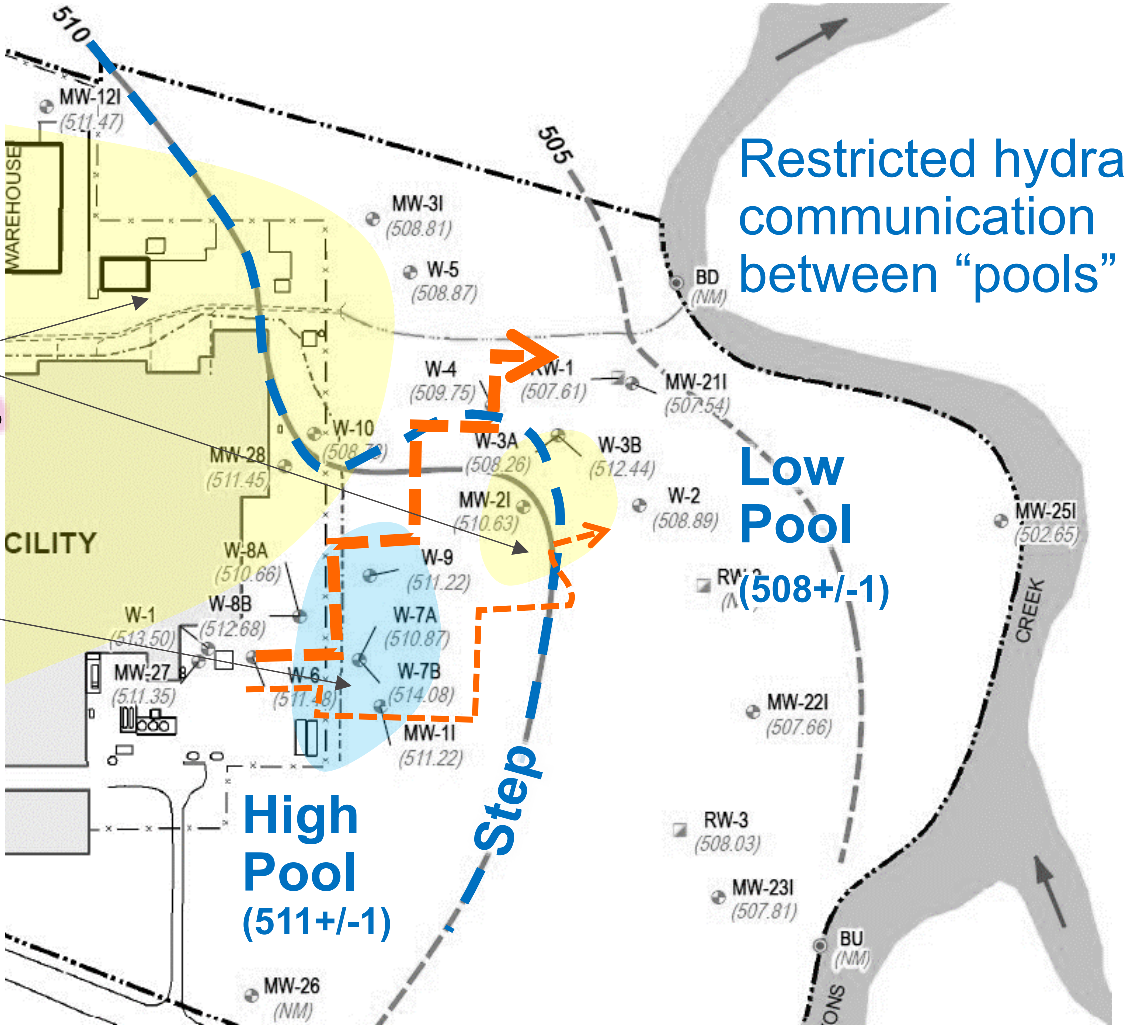


Refining the CSM to Define Primary Transport Pathways

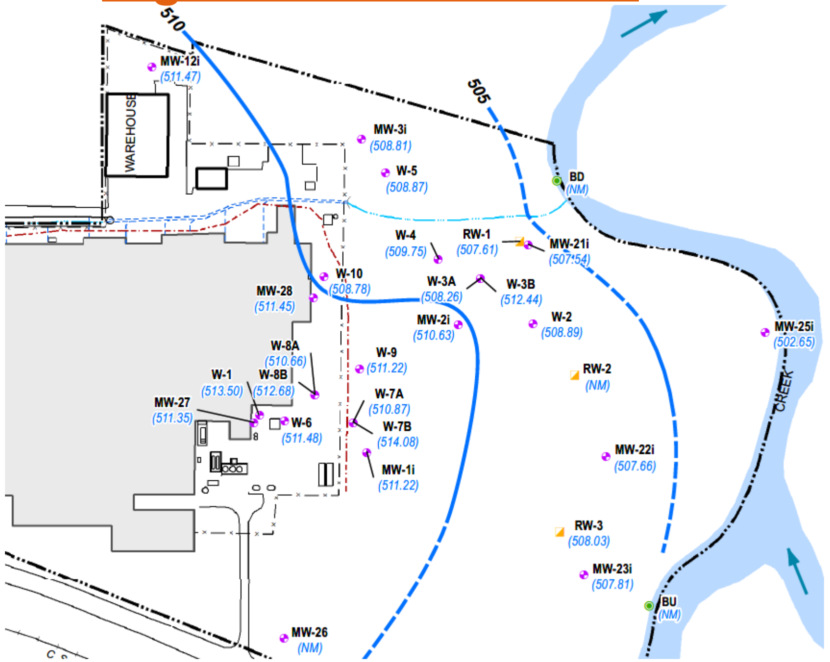
Areas of less-fractured rock restrict pathways

Highly fractured compartment

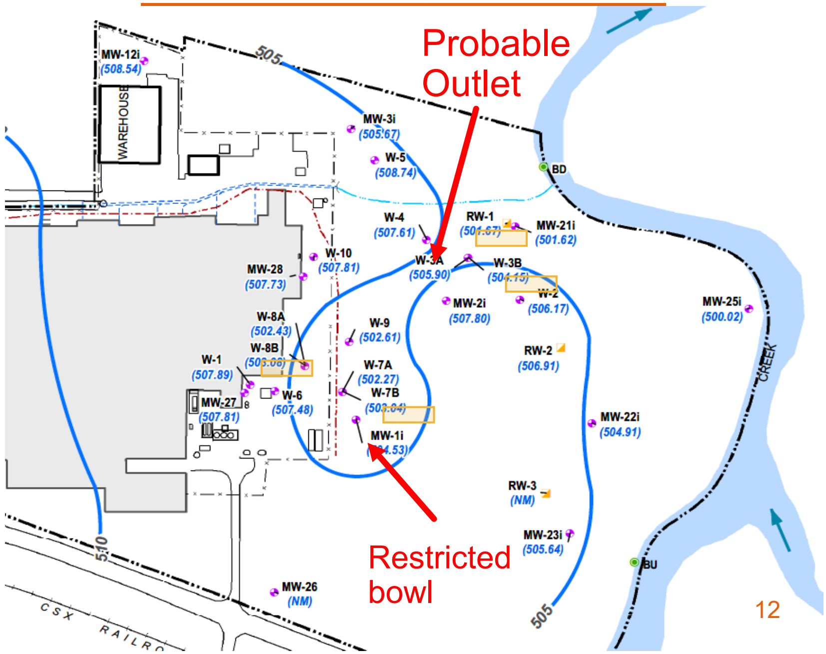
Flow restrictions drive distribution along multiple pathways



High-Water Conditions



Low-Water Conditions



Updated CSM

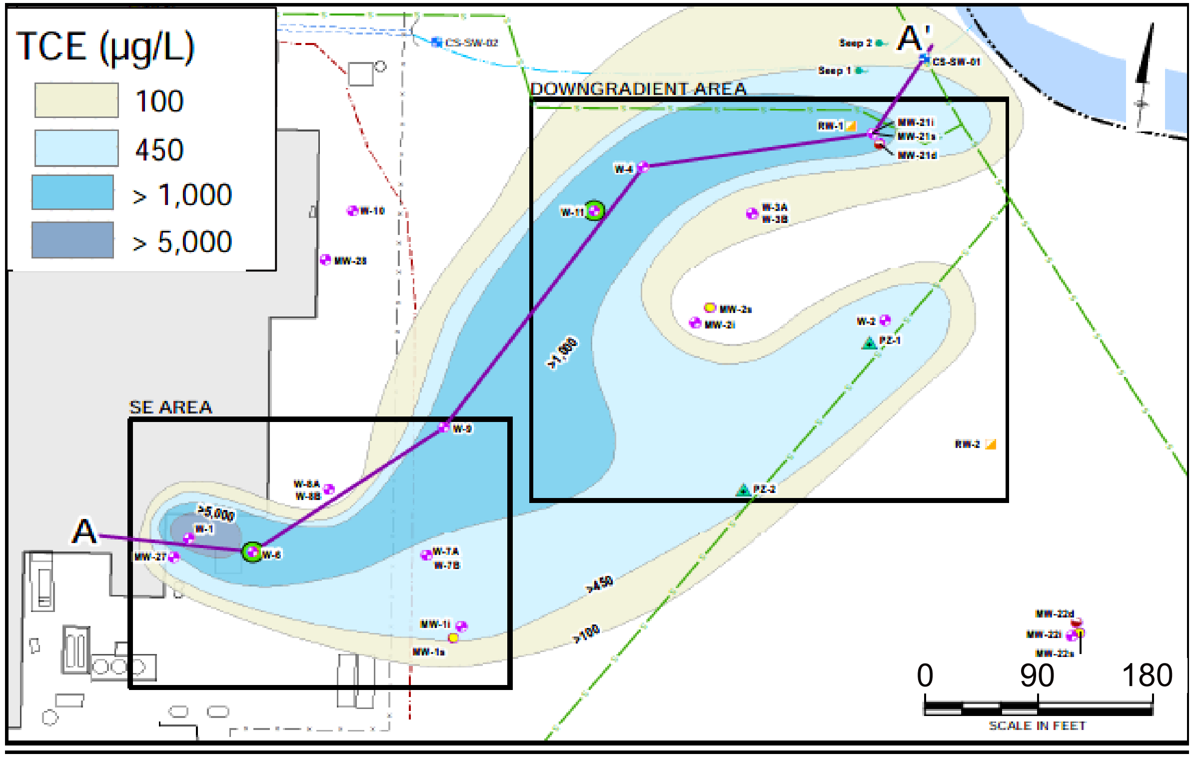
Source Area Characterization

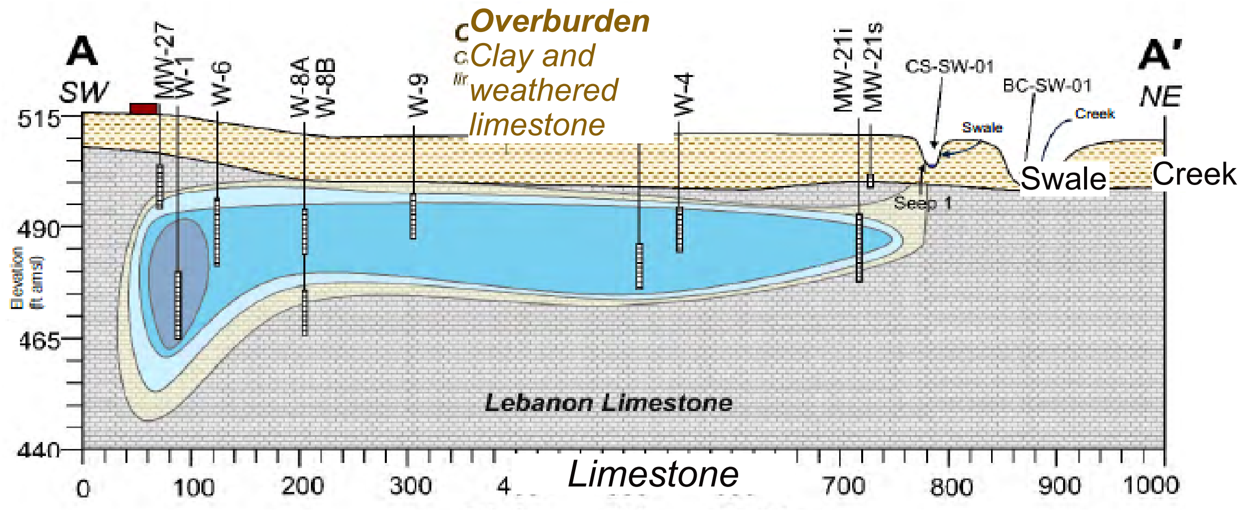
- SE Area is primary source to downgradient plume
- Significant natural dechlorination of TCE

Mass Flux Pathways

- Primary mass flux pathway to downgradient plume defined
- Areas of more massive bedrock represent slower pathways
- Upward vertical migration in distal plume with discharge to surface water

Selected Remedy:
- **Enhanced Reduction Dechlorination**
- **Sub-Slab Depressurization**

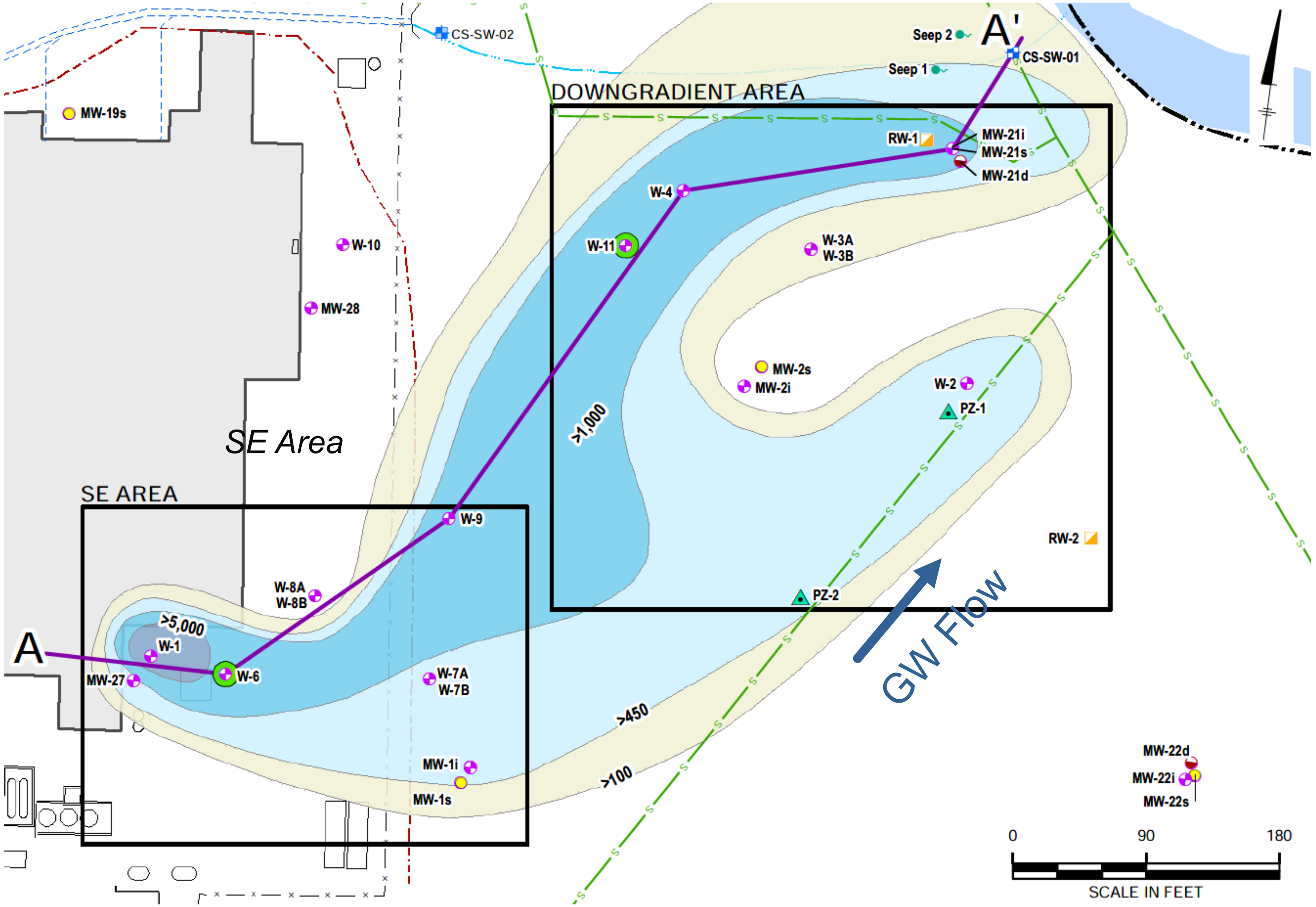




Setting site-specific achievable Remedial goals that reduce risks

Health-Based Remedial Goals

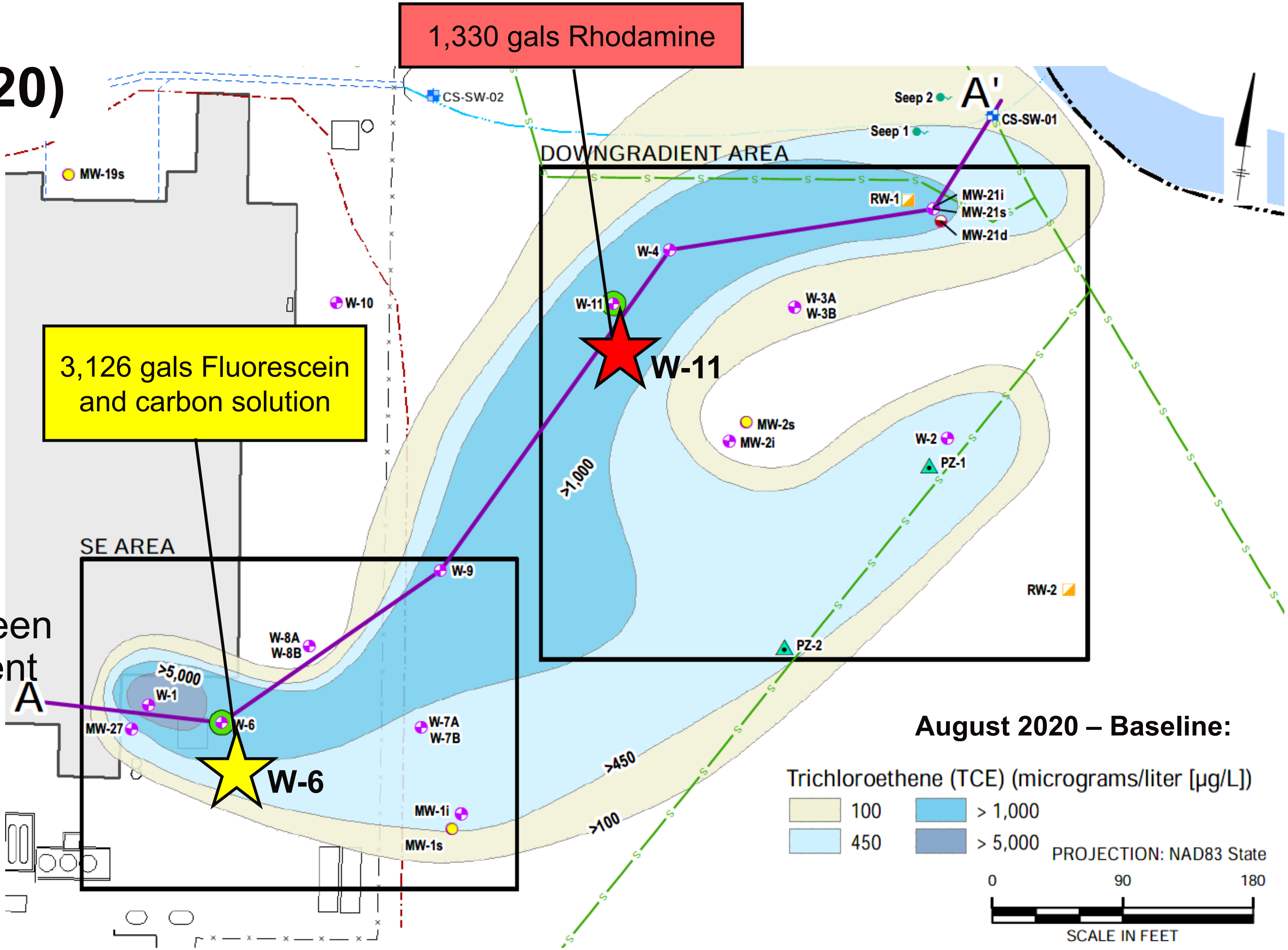
COC	Remedial Goal
1,1-Dichloroethene	11,000 µg/L
cis-1,2-Dichloroethene	41,000 µg/L
trans-1,2-Dichloroethene	170,000 µg/L
Tetrachloroethene	3,400 µg/L
Trichloroethene	450 µg/L
Vinyl chloride	2,700 µg/L



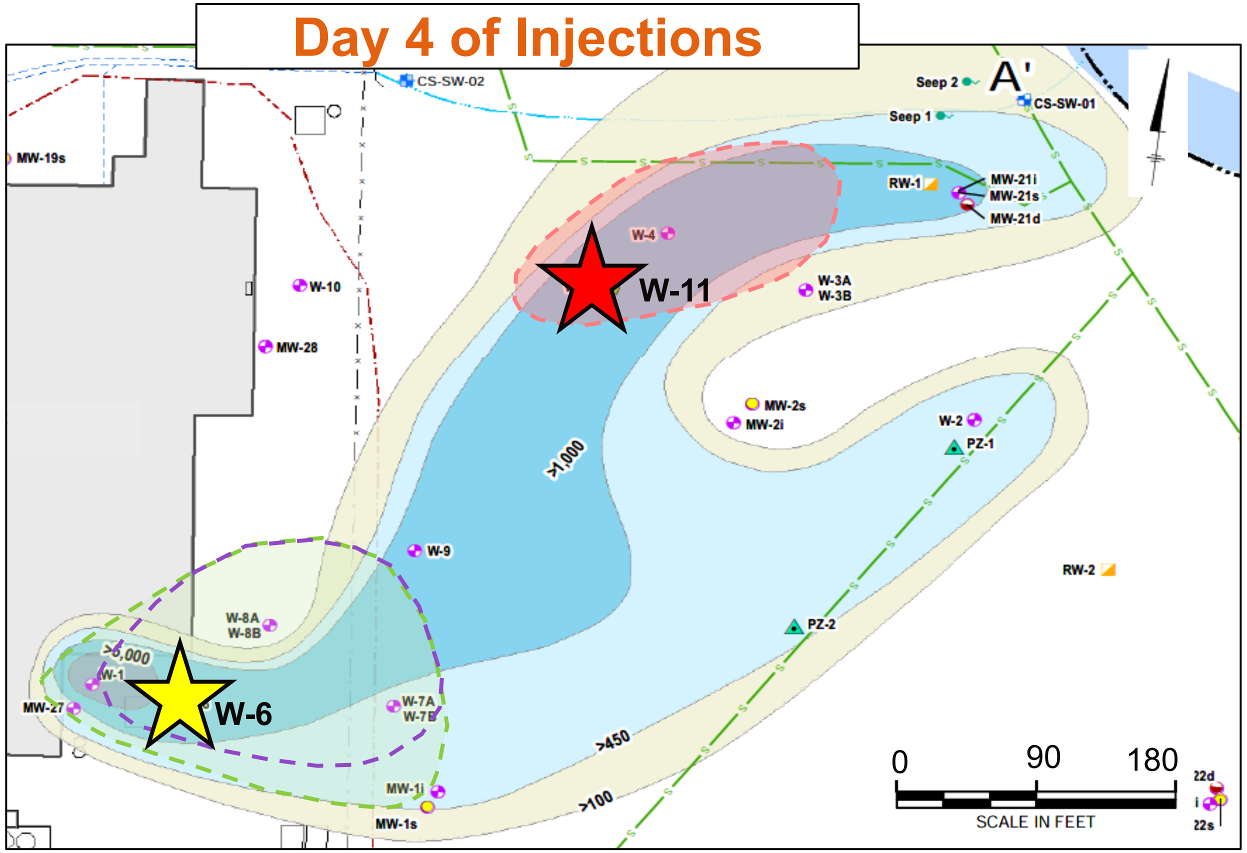
ERD Pilot Study (2020)

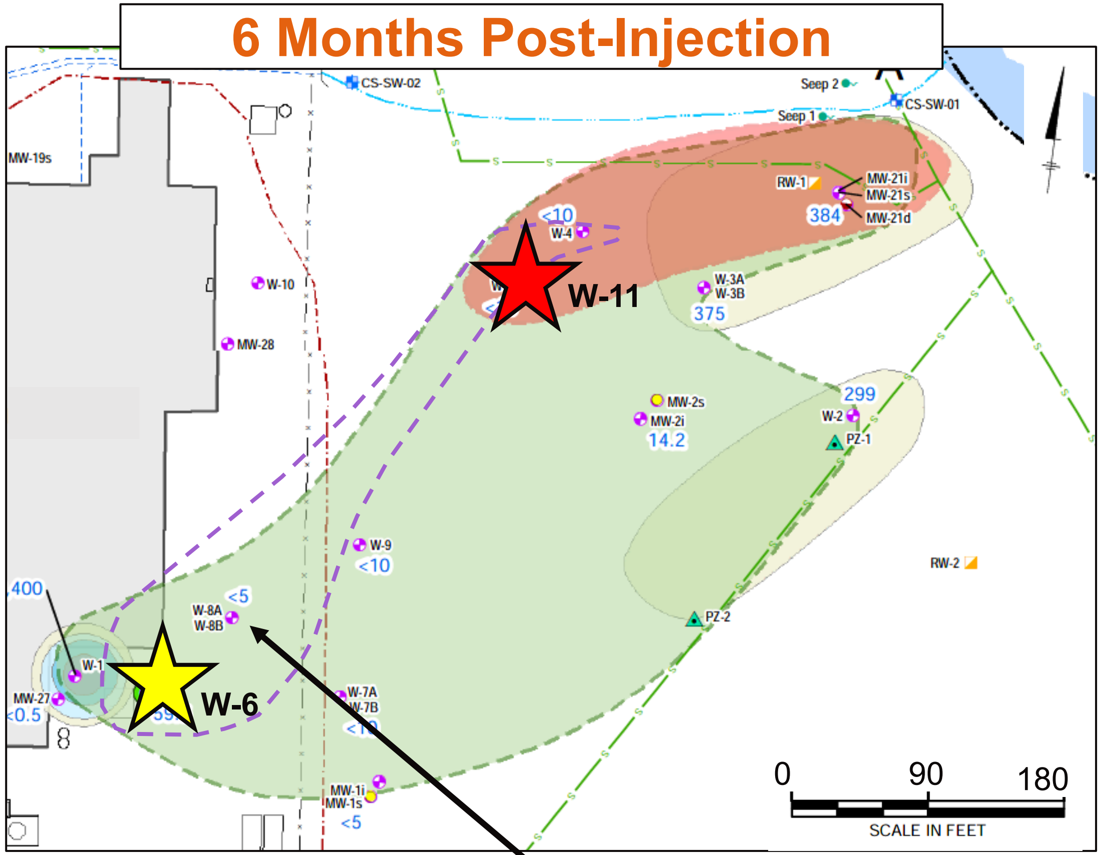
Collect data for Design of Full-scale ERD remedy:

- Injection rates
- Volume-ROI
- Fracture connectivity within injection areas
- Groundwater flow rate between source area and downgradient area



Pilot Study Results – Tracer Distribution and Migration





TCE (µg/L)

100
450
> 1,000
> 5,000

>0.1 µ/L Fluorescein

>5 µ/L Rhodamine

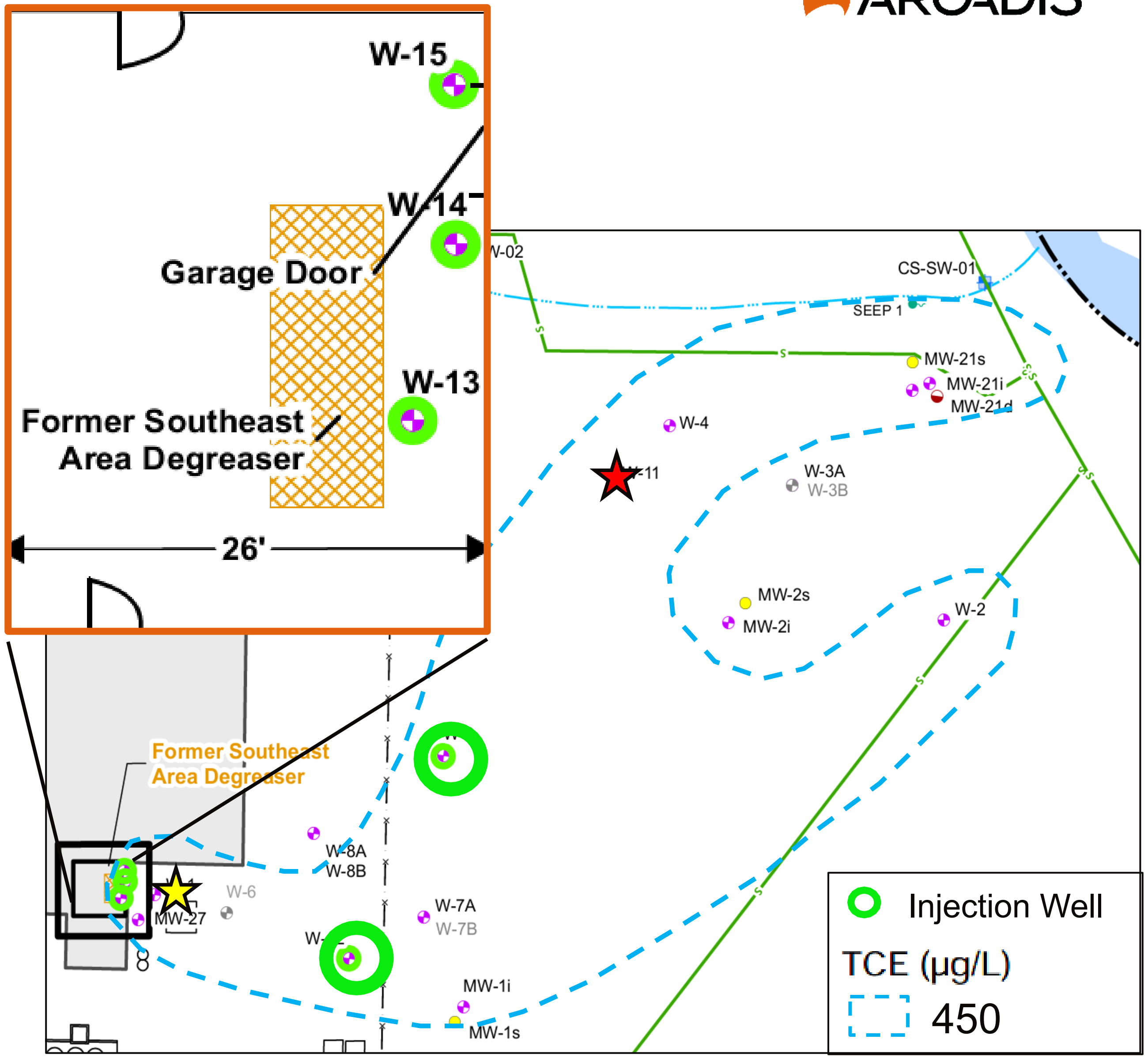
>5 µ/L TOC

W-8A

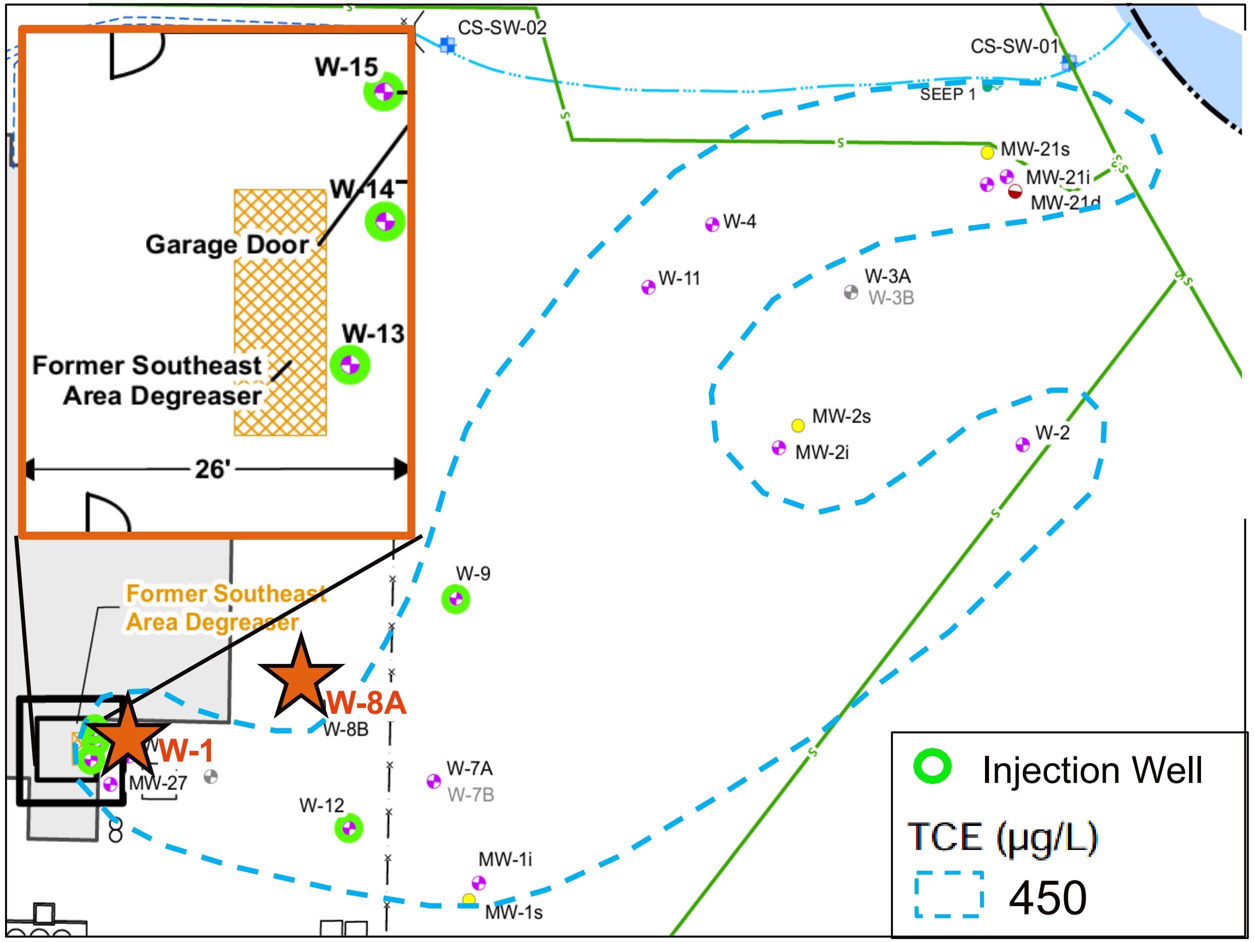
Robust and Complete Dechlorination with 5,000 µg/L of ethene generation

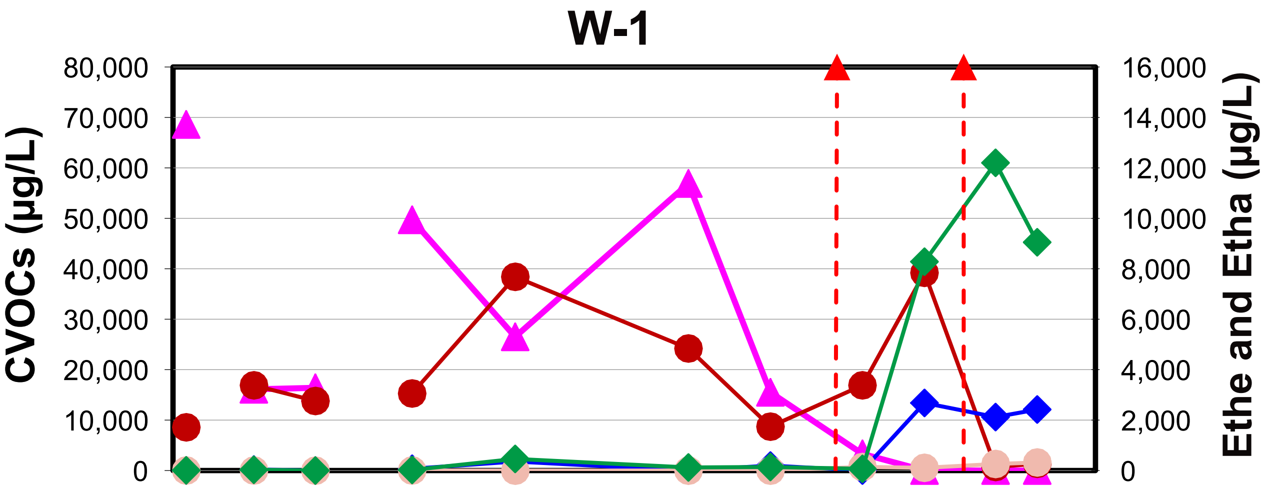
Transition to Adaptive Full-Scale ERD Remedy

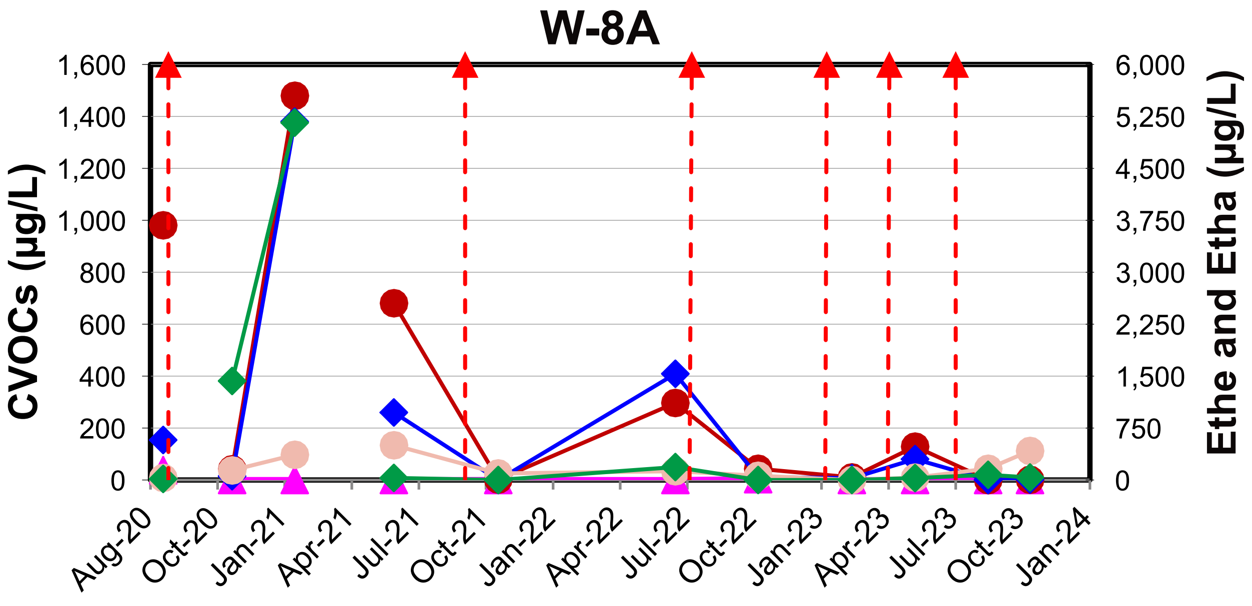
- Expand injection outside source area to cut off flux to downgradient plume – 2 injection wells
- Add injection within source area to directly address source mass – 3 injection wells inside building
- Monitoring-only in downgradient plume



Full-Scale Results: Source Area



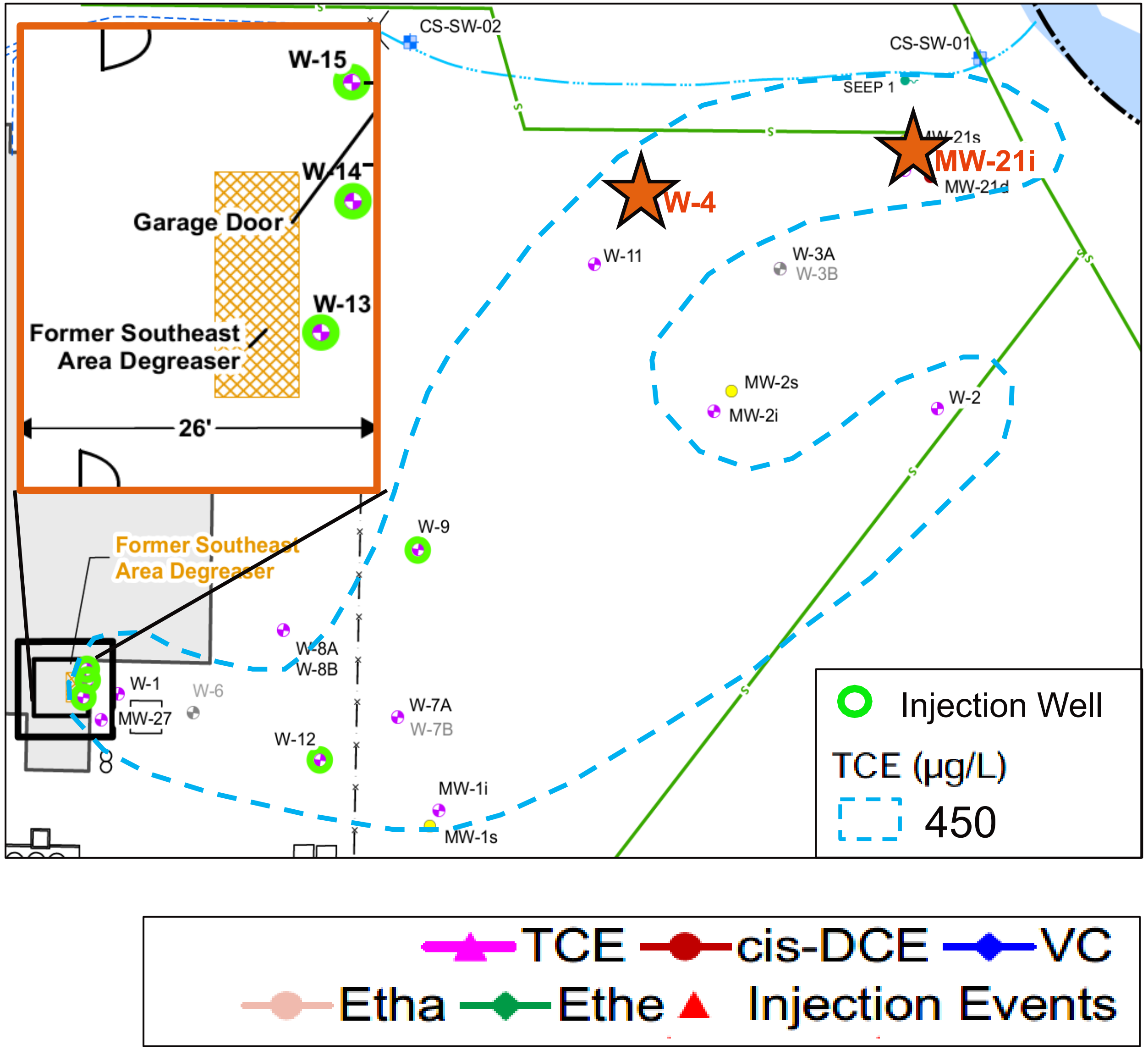


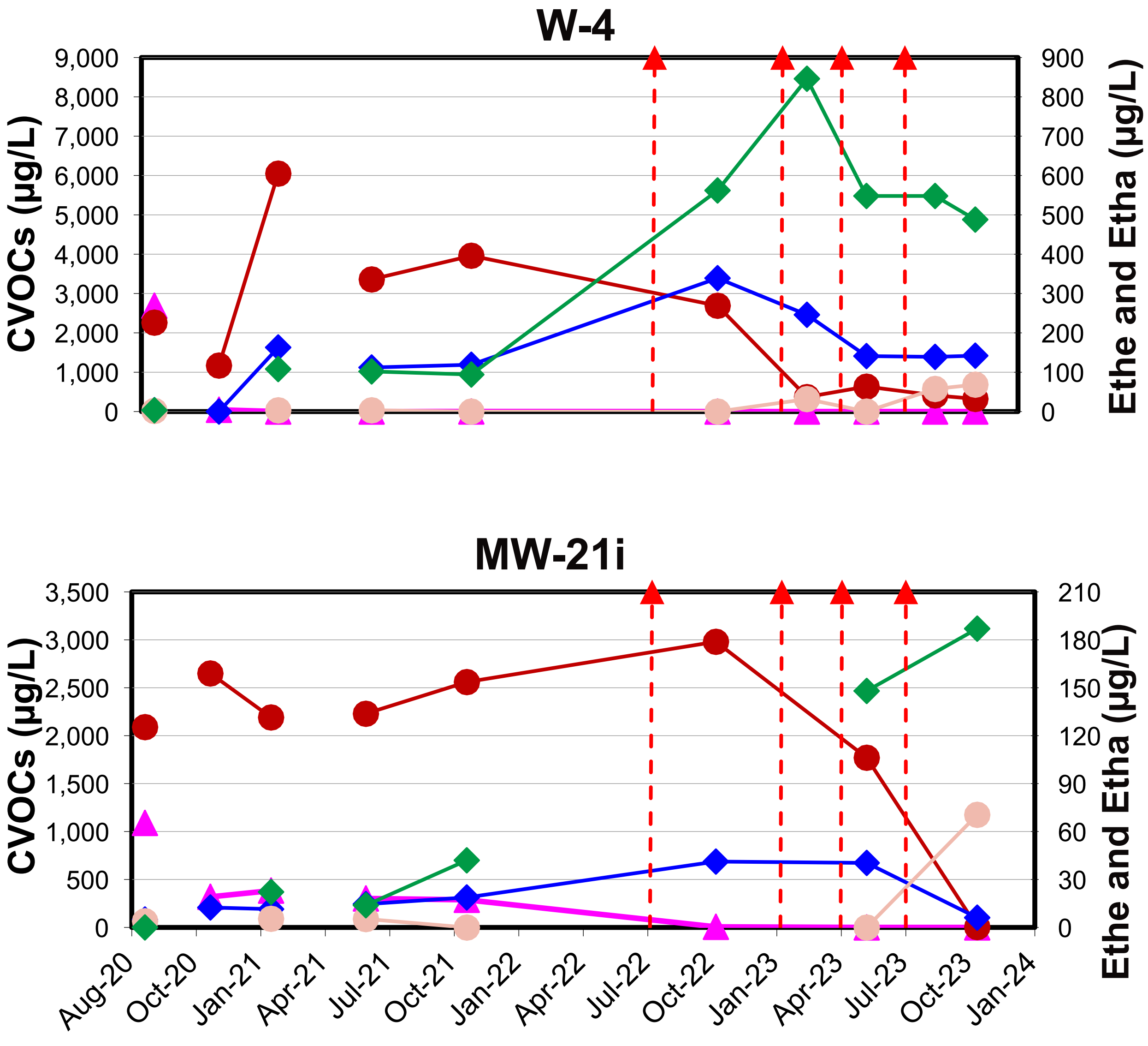


TCE cis-DCE VC

Etha Ethe Injection Events

Full-Scale Results: Downgradient





Conclusions

The challenge of fractured rock remediation can be overcome by:

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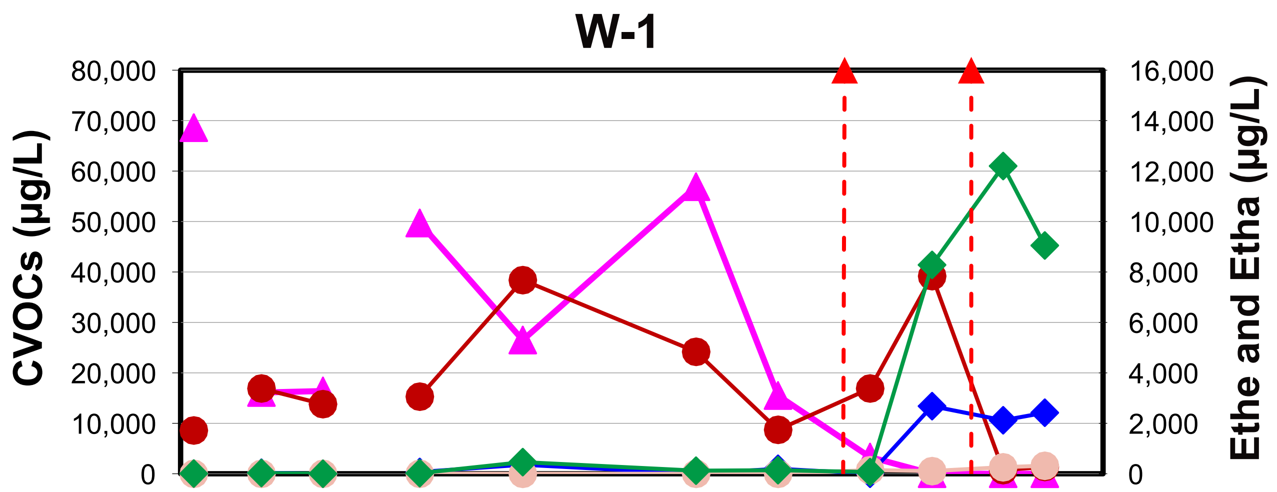

Thank you!

Urvi Tulsiani
Project Environmental Engineer
Urvi.Tulsiani@arcadis.com

Acknowledgments

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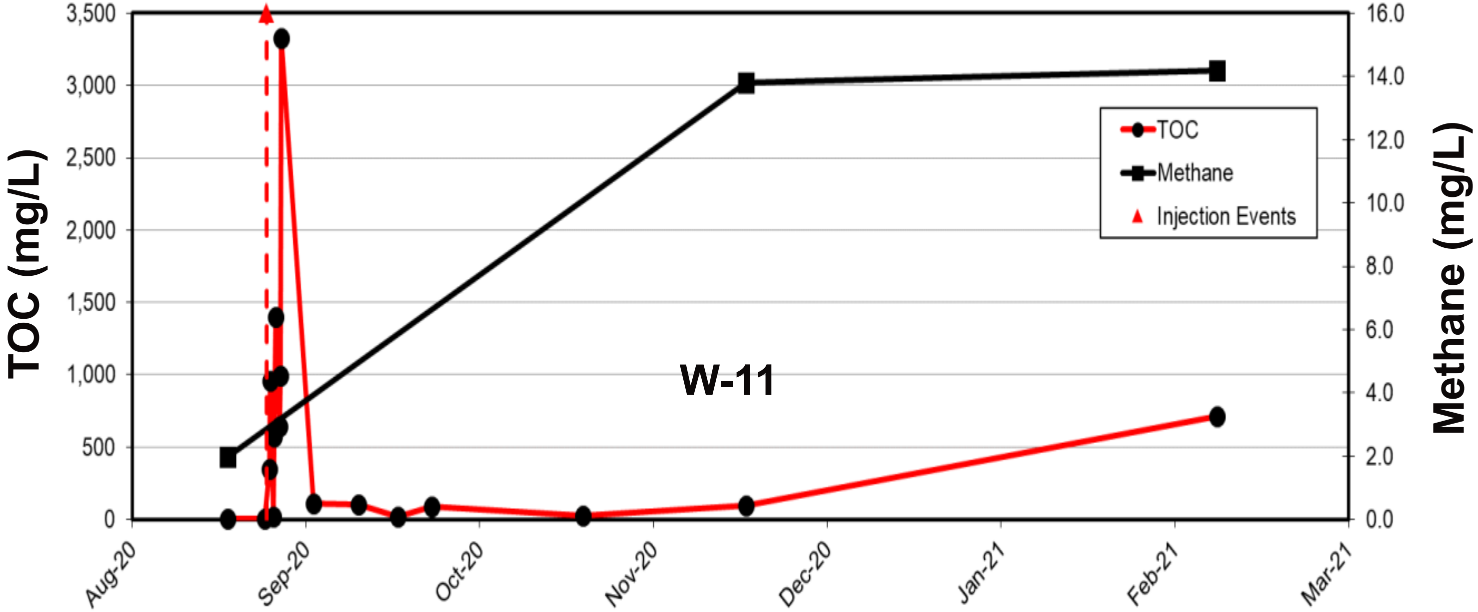
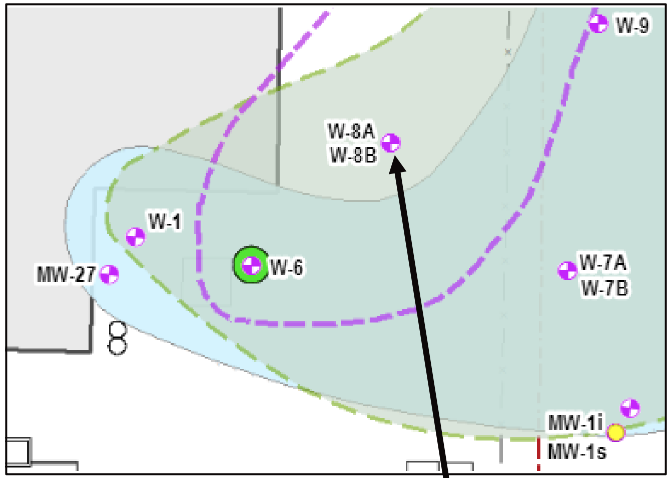
Extra Slides

Pilot Study Results – Geochemistry and Dechlorination

- TOC/dye arrival observed during injection
- Elevated TOC persists 6+ months
- Methanogenic conditions established within injection area
- Robust and complete dechlorination to ethene





W-8A
75 ft from W-6