In-Situ Thermal Remediation of TCE DNAPL from Glacially Deposited Clay-Silt Diamicton and Subsequent Remedial Performance Assessment

Great Lakes Environmental Remediation and Redevelopment Conference, Lansing MI.

16 October, 2019

Project Team

- EGLE - RRD State Project Manager
  - Ray Spaulding, David Heywood, Carol Hefferan
- Global Remediation Technologies, Inc.
  - Richard Raetz (Project Manager)
  - Rex Johnson (Investigations Lead)
  - Eric Benson (Construction Engineering Manager)
  - Brad Rizzo (System Operations)
  - McMillan & McGee Corp.,
    - Clayton Campbell, Chemical Engineering
    - David Rountree, Environmental Engineering
    - MK Environmental Inc., Edward Tung, Systems Engineering
- Job Site Services
  - Site Construction, Demolition, Restoration

Presentation Topics

- Site History
- Remedial Investigations
- Interim Response Measures
- Feasibility Studies and Remedial Design
- Bidding Specifications and Construction
- System Start Up and Operations
- Removal Performance Summary
- Post Remedial Monitoring and On Going Operations

Site History

- 100-year old former metal plating & wood working facility
- Purchased in 1997 to redevelop as condos

BELGRAVIA - FACTORY CONDOS, 1999

Site History

- Constructed in the early 1900s
- Releases from plating wastes through 1970's
- Primary contaminant
  - Trichloroethene (TCE), 1,2-dichloroethene (1,2-DCE), and other volatile organic compounds
- Release points
  - Suspect waste handling
  - Drain-field disposal

City Site Reclamation Grant (01-02)

- Test pitting
- Soil borings to 10 feet
- Soil, GW, soil gas sampling
- Building material assessment
- Excavation of old septic tank
- Removed 200 yards Hazardous content/soil

City Site Reclamation Grant (02-04)

- Indoor air sampling - Factory Condo units
  - One sample exceeded exposure criteria
- Performed deeper SBs in plating room
  - Disposed of plating room floor and 4 feet of soil excavated for pool
  - Designed a Response Plan: Installed subfloor SVE system and Liquid Boot ® vapor barrier

Factory Condominiums - 2004

Factory Condominiums - 2004

- Health Club Developed
  - Gymnasium
  - Tennis Courts
  - Pool

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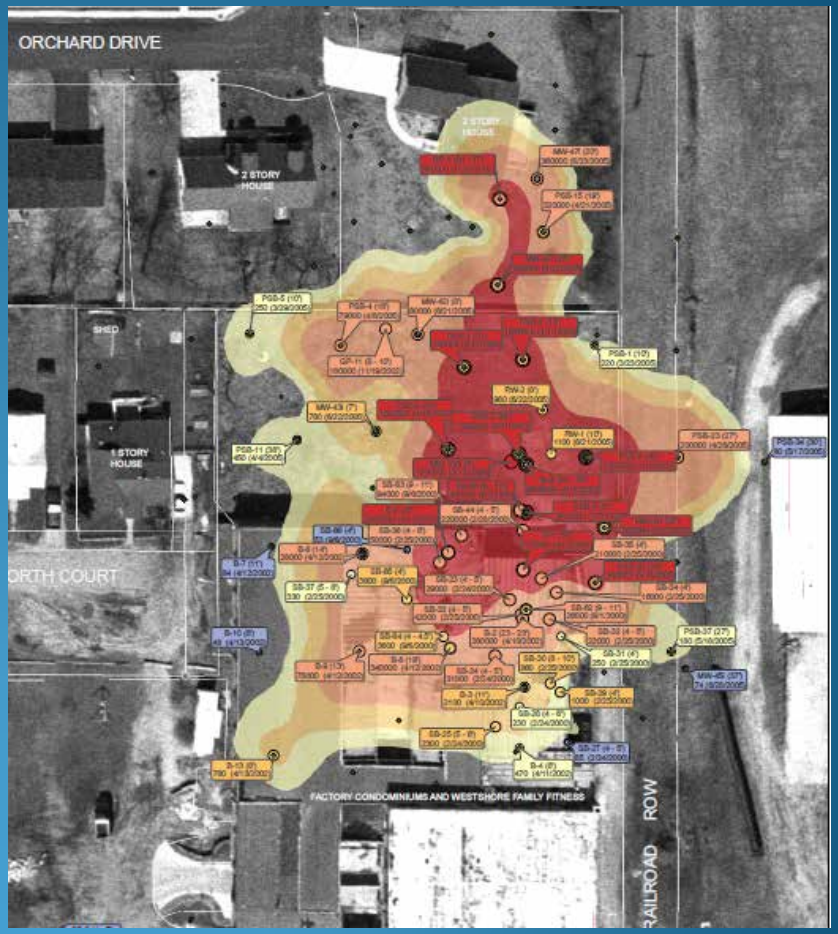
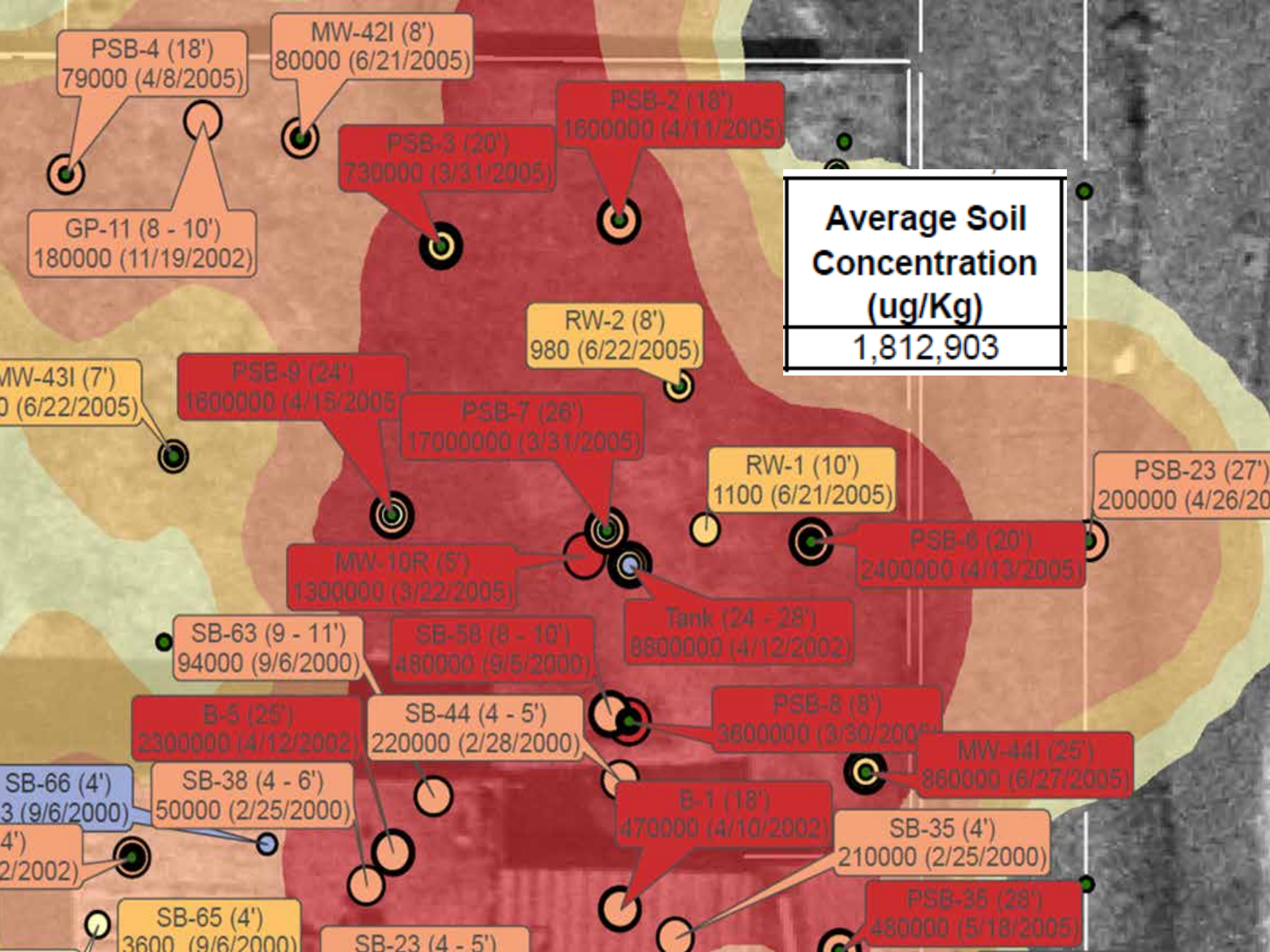
Remedial Investigations 2005-2009

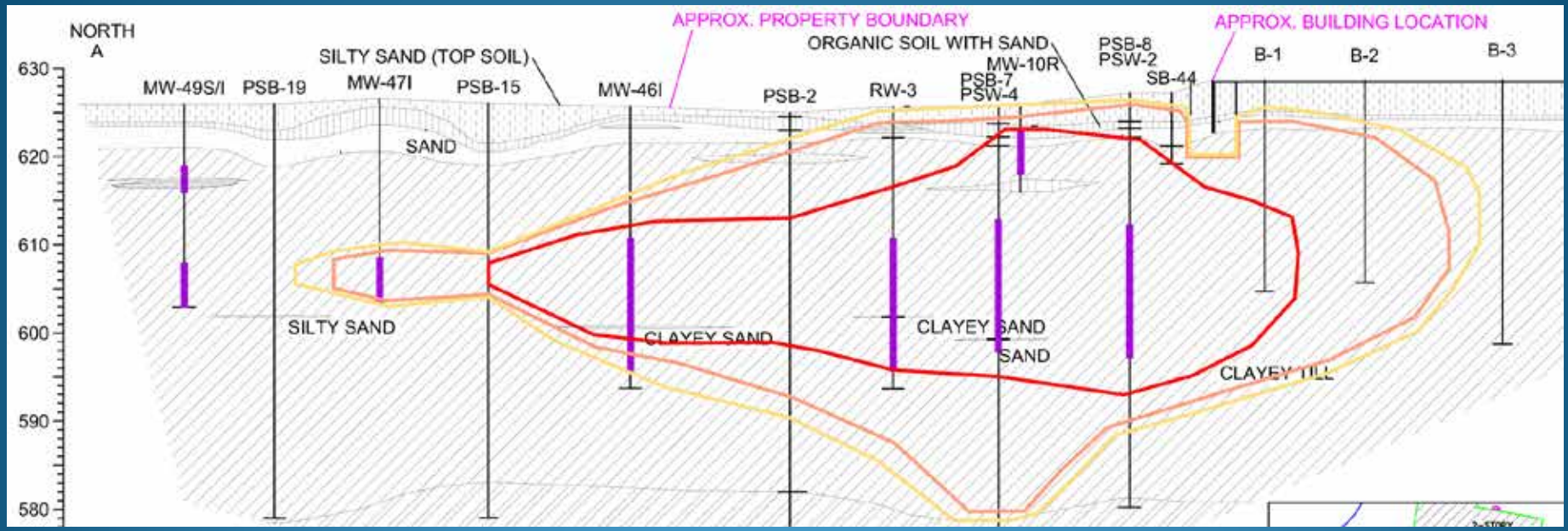
- Investigative Tools
  - § Sonic Drilling, Geoprobe
  - § Soil Gas Sampling
  - § Indoor Air Sampling
  - § Sump Water Sampling
- Factory Condos
- Affected Residences (3)

TCE Impact In Glacial Till Unit

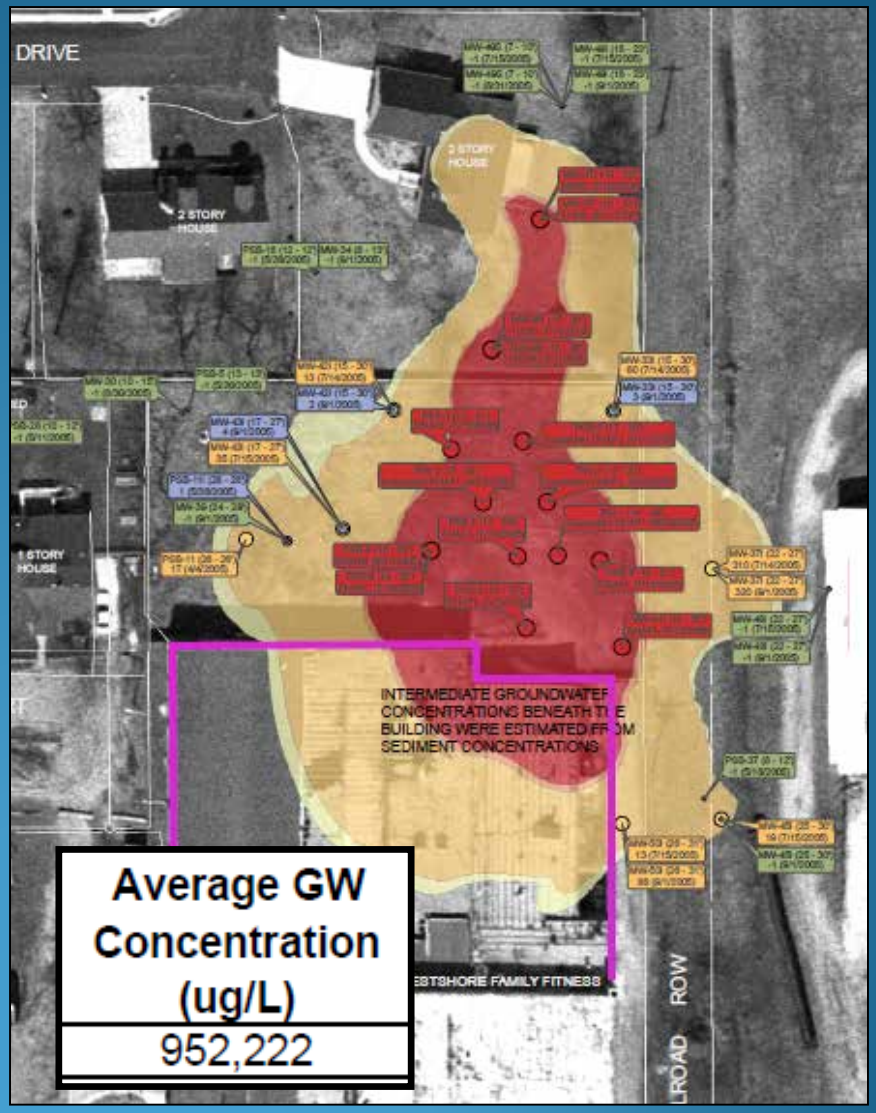



PSB-4 (18')
79000 (4/8/2005)
MW-42I (8')
80000 (6/21/2005)
PSB-2 (18')
1600000 (4/11/2005)
PSB-3 (20')
730000 (3/31/2005)
GP-11 (8 - 10')
180000 (11/19/2002)
Average Soil Concentration (ug/Kg)
1,812,903
RW-2 (8')
980 (6/22/2005)
MW-43I (7')
0 (6/22/2005)
PSB-9 (24')
1600000 (4/15/2005
PSB-7 (26')
17000000 (3/31/2005)
RW-1 (10')
1100 (6/21/2005)
PSB-23 (27')
200000 (4/26/20
PSB-6 (20')
2400000 (4/13/2005)
MW-10R (5')
1300000 (3/22/2005)
Tank (24 - 28')
8800000 (4/12/2002)
SB-63 (9 - 11')
94000 (9/6/2000)
SB-58 (8 - 10')
480000 (9/5/2000)
B-5 (25')
2300000 (4/12/2002)
SB-44 (4 - 5')
220000 (2/28/2000)
PSB-8 (8')
3600000 (3/30/200
MW-44I (25')
860000 (6/27/2005)
SB-66 (4')
3 (9/6/2000)
4')
2/2002)
SB-38 (4 - 6')
50000 (2/25/2000)
B-1 (18')
470000 (4/10/2002)
SB-35 (4')
210000 (2/25/2000)
PSB-35 (28')
480000 (5/18/2005)
SB-65 (4')
3600 (9/6/2000)
SB-23 (4 - 5')

TCE/DNAPL Impact Profile



Dissolved Phase TCE Impact



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VI Studies Condos & Residence

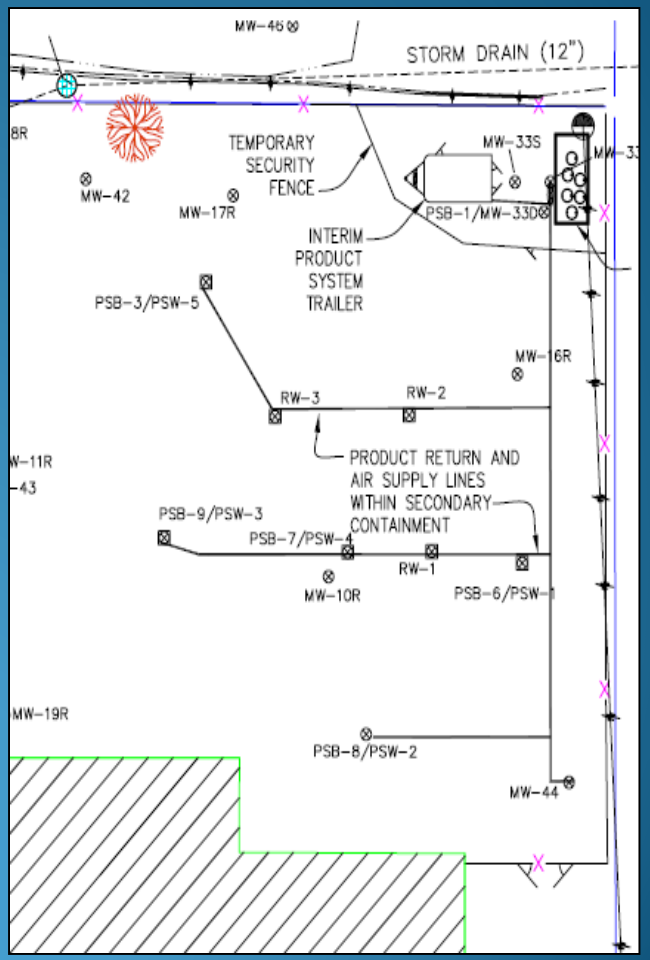
- Indoor Air Sampling
- Soil Gas Sampling
- Vapor Pin Sampling
- Crawl Space Air Sampling

Interim Response Measures

- Sealed sumps to extract volatiles at residences
- Retro-coat sealed residential basements

Interim Response Measures

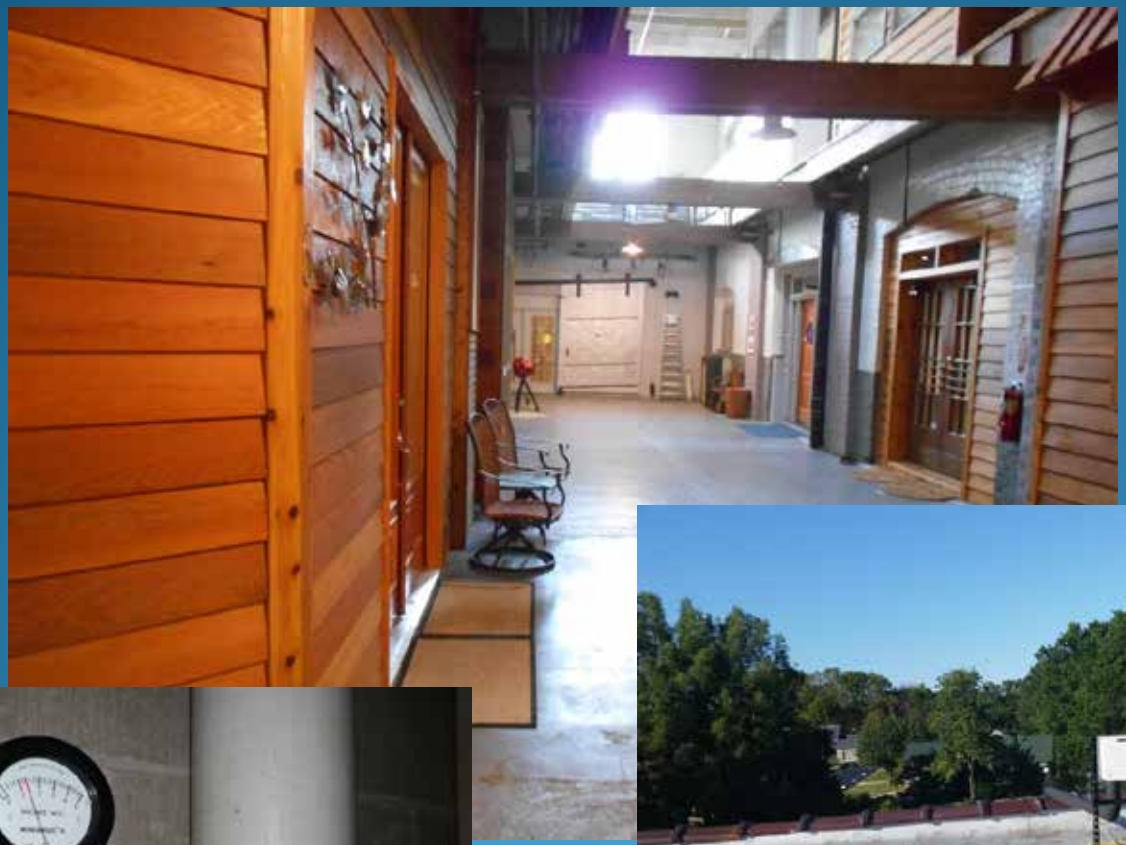
- Initiated DNAPL Recovery
  - § 10 well collection system
  - § Seasonally operated 2005-2010
  - § 100 gal. NAPL removed in 5 Yr



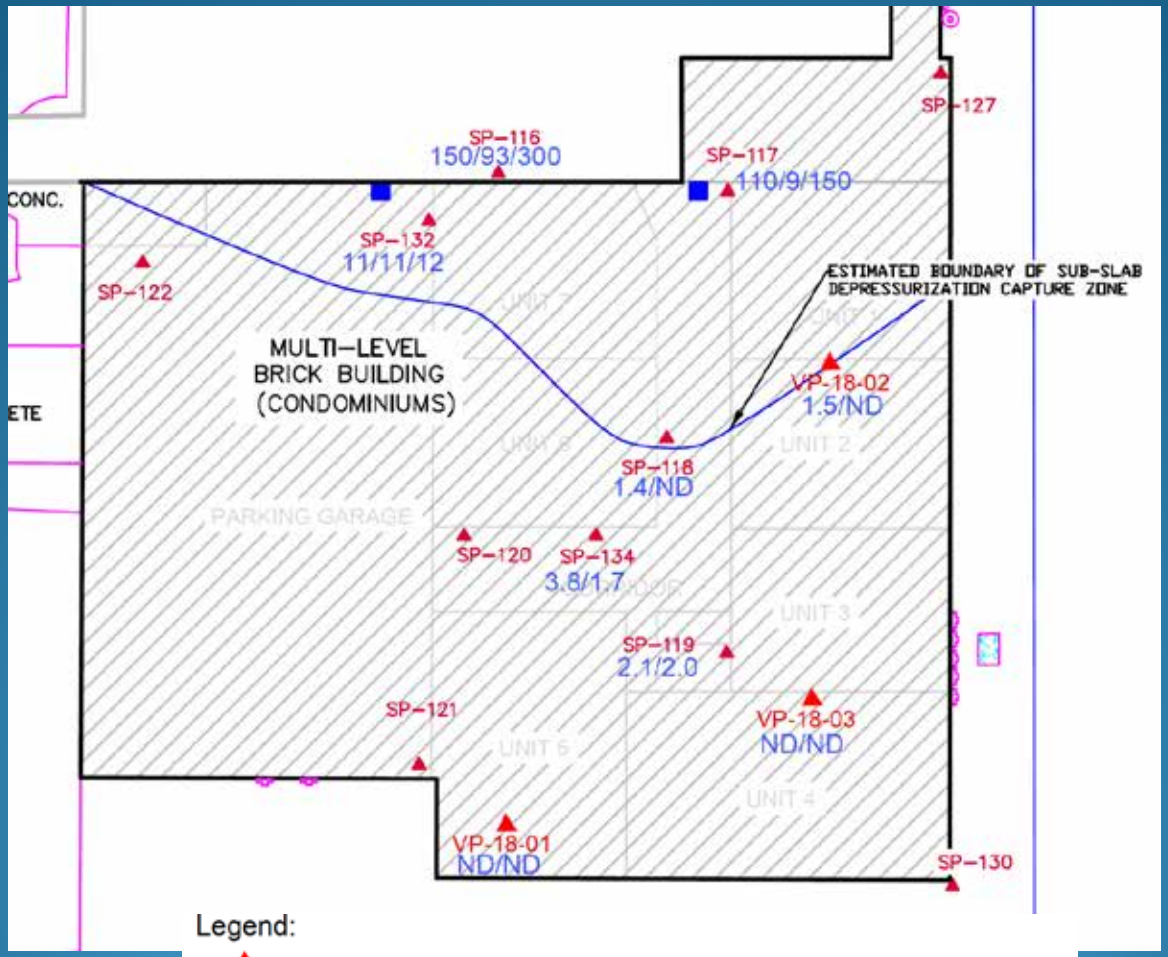
2015 Health Club Demolition

- SVE system removed under health club flooring

2015 - Installed F.C. SSD System



PFE Testing, Soil Gas Sampling



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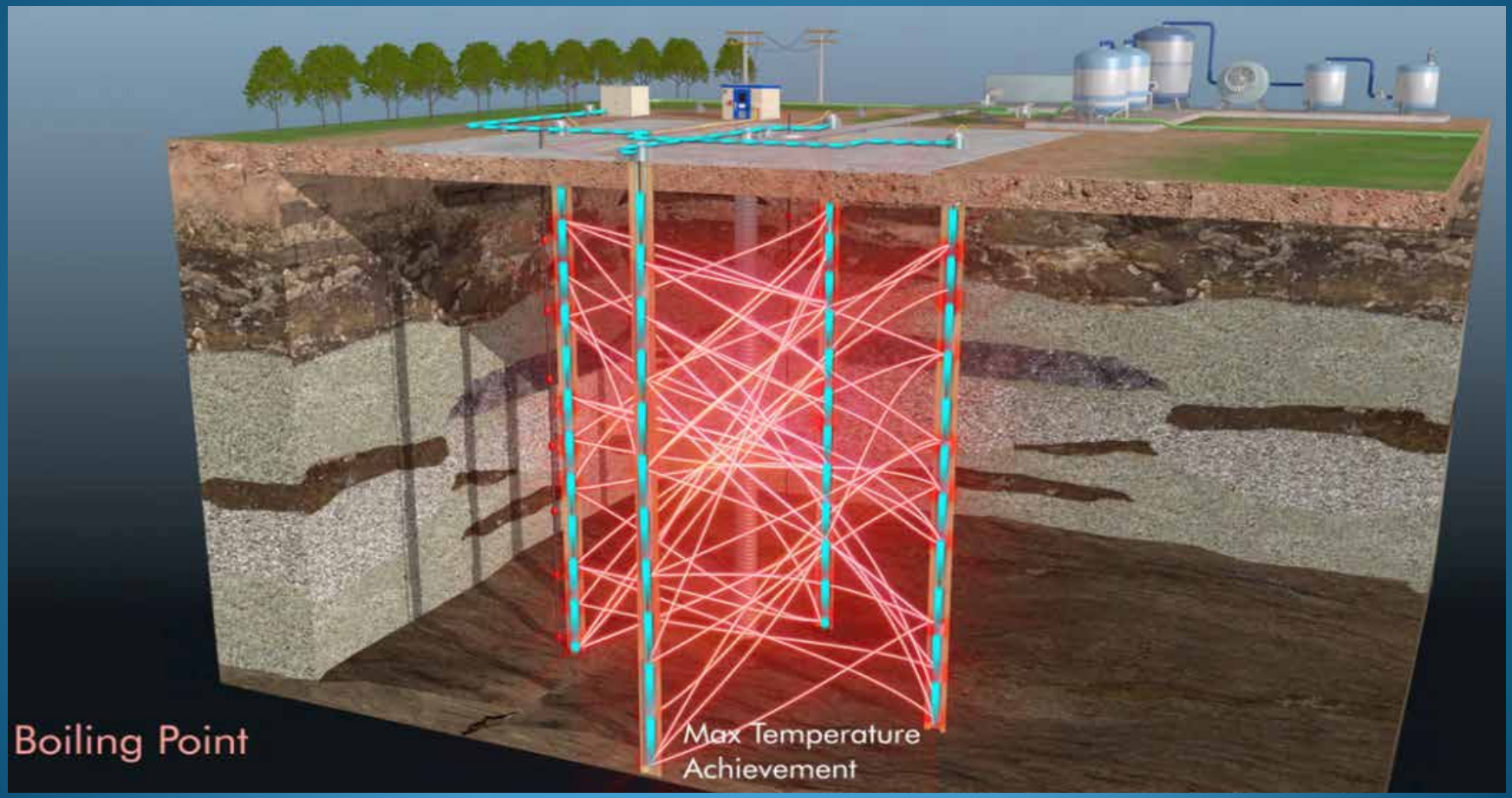
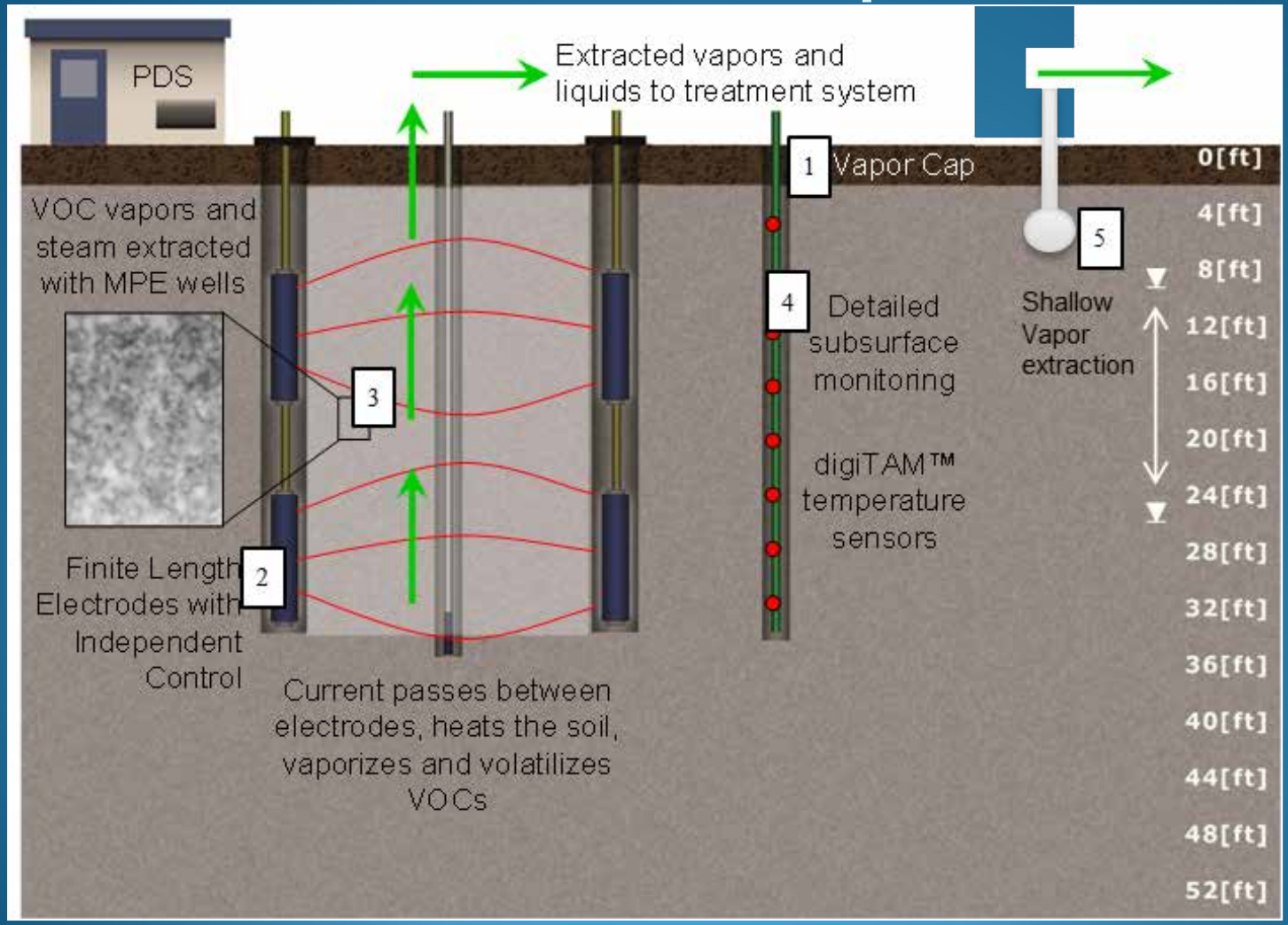
Feasibility Studies (Technologies Assessment and Reassessment)

- Soils Excavation
- ISCO and In Situ Bioremediation
- ISCR Emplaced via Hydraulic Fracturing into Clay Till
- ZVI Mixing, Large Diameter Augers
- Capping and Hydraulic Control
- In Situ Thermal Remediation (ISTR)
  - Electrical Resistance Heating (ERH)

ERH Design: Electro-Thermal Dynamic Stripping Process (ET-DSP™)

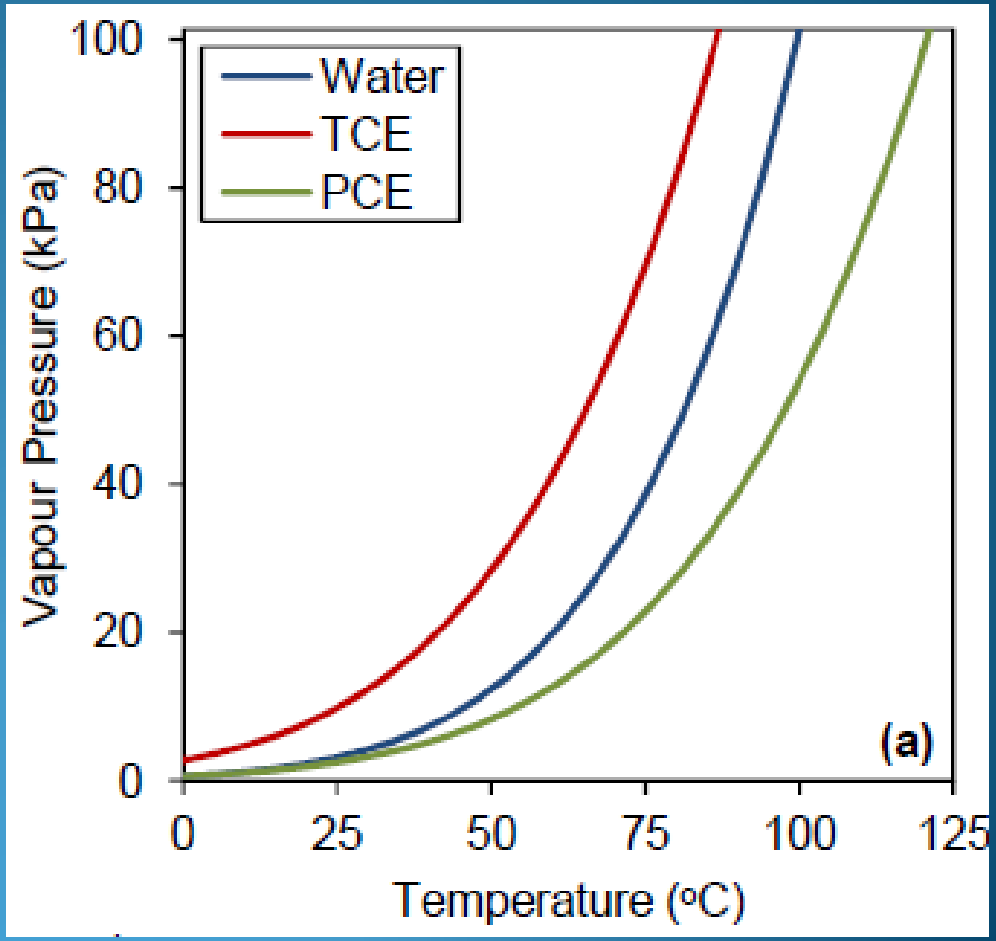


ET-DSP™ - Electrodes, MPE Wells, Horizontal Wells, Temp. Sensors, PDS



ET-DSP™ System Design

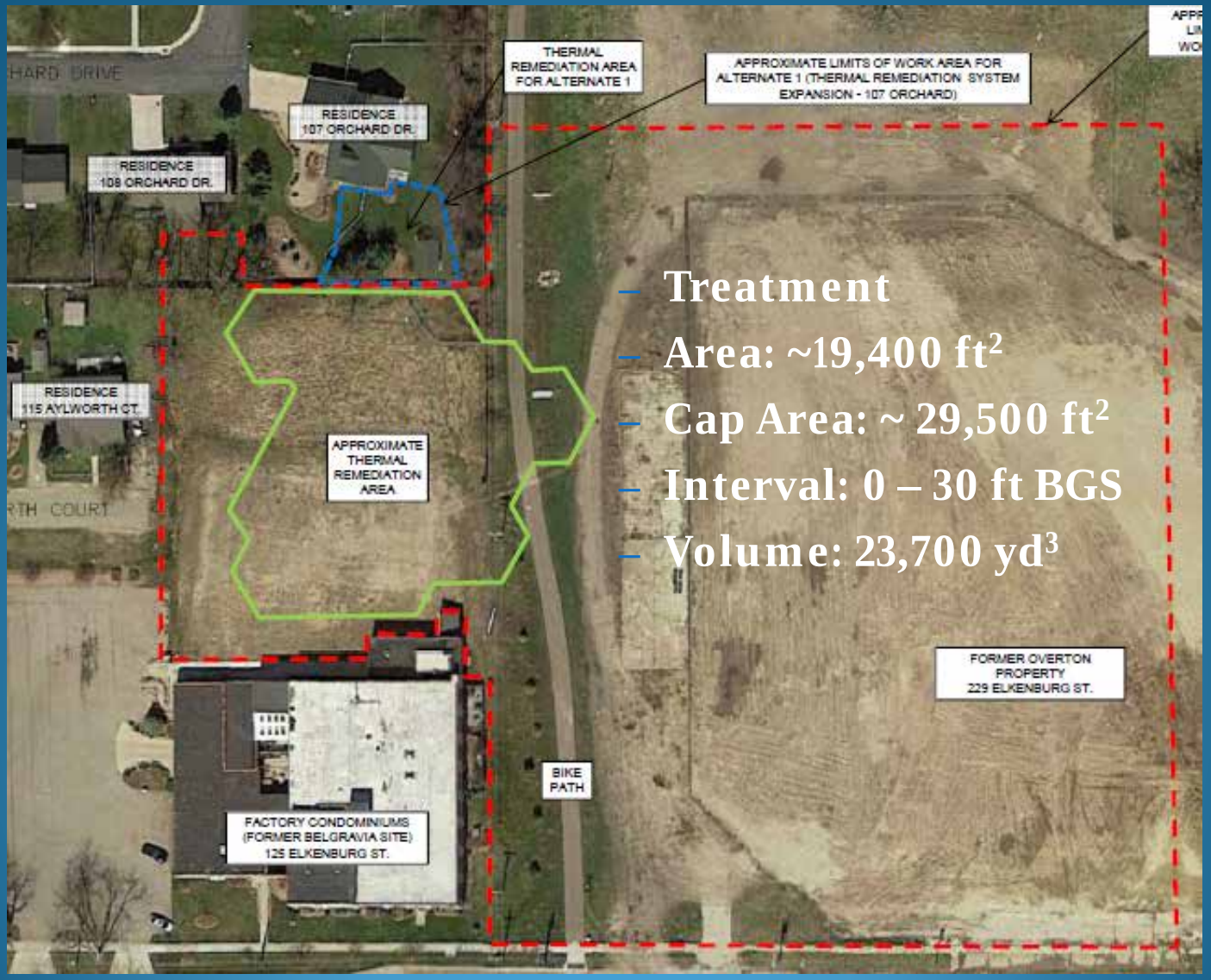
- Remedial Goal
  - Ave TCE 5000 ug/kg
- Target Temperature
  - 70 to 100 Celsius
- Vapor Recovery Rate
  - 500 to 600 cfm
- Liquid Extraction Rate
  - 6 to 8 gpm
- Soil Resistivity
  - 23 - 109 ohm-meters



ET-DSP™ System Design

Parameter	Units	Notes
ET-DSP™ Electrodes	168	8 inch OD x 10 ft long; 2/boring
Power Systems	3 x 1330 kVA	Site computer and Internet control
Temperature Sensors	6 strings	72 Elements, 12 sensors per
Electrode Spacing	20 ft	Electrical, conductive, convective
Vertical Extraction Wells	55	SS304, 6-slot
Shallow Extraction Wells	6	Fiberglass, 10-slot
Input Power	907 kW	Peak power 1360 kW
Energy Input	3,919 MW/hr	Total energy to electrodes over operations period
Duration	180 Days	Baseline

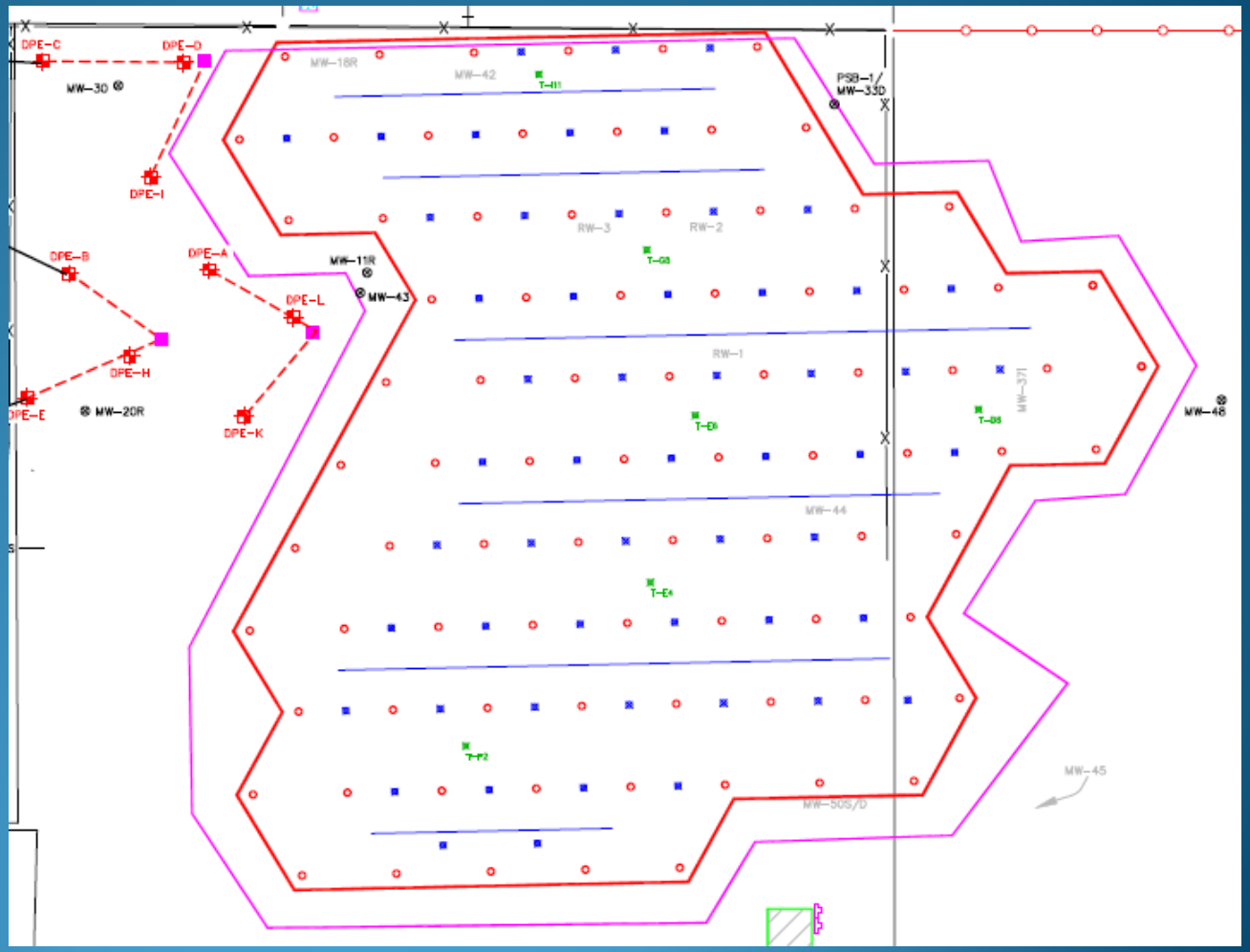
ISTR - Treatment Area(s)



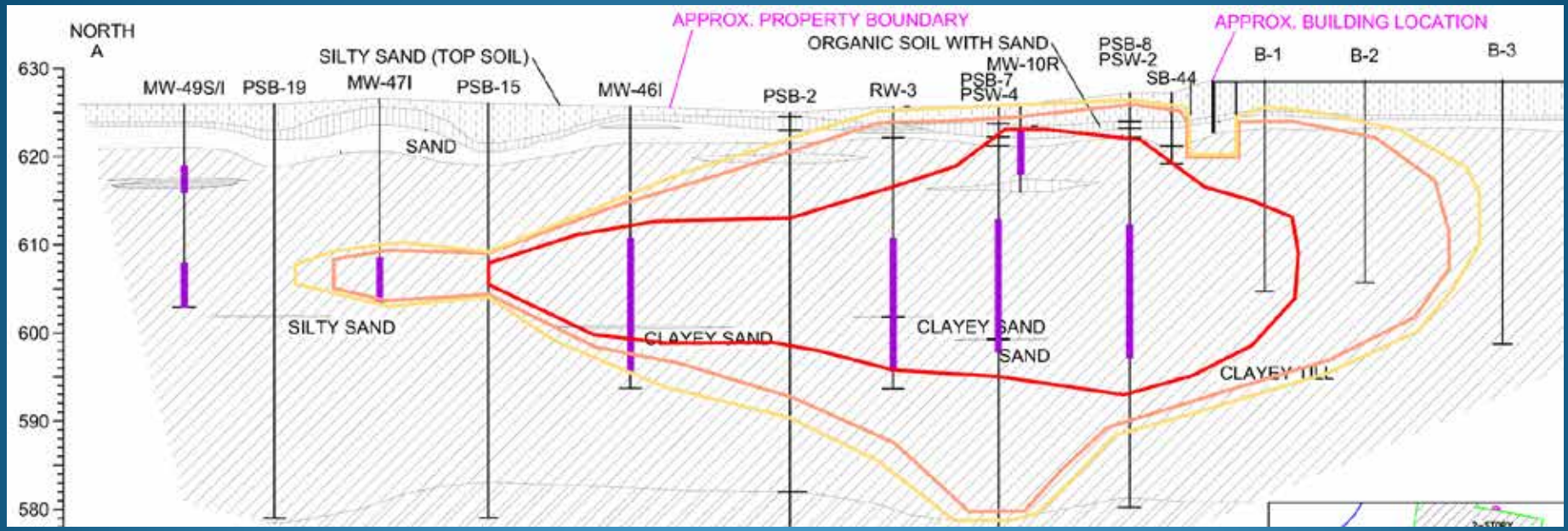
- **Treatment**
- **Area: ~19,400 ft^2**
- **Cap Area: ~ 29,500 ft^2**
- **Interval: 0 – 30 ft BGS**
- **Volume: 23,700 yd^3**

ISTR Thermal Well Field

- 168 Electrodes
- 55 MPE Wells
- 12 DPE Wells
- 6 Temp. Strings
  - 72 Sensors
  - 12 per Profile



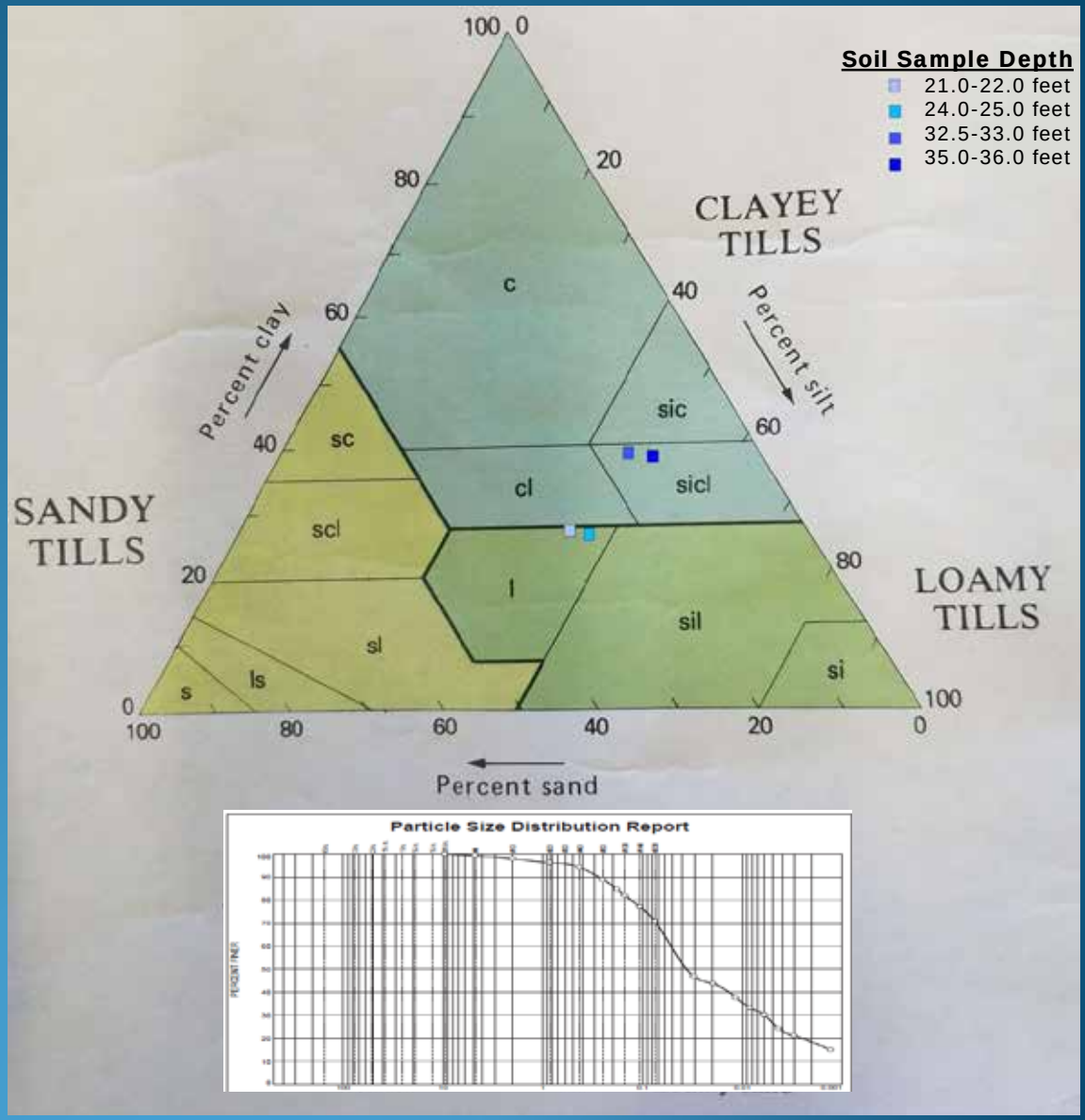
ISTR – Treatment Target Zones



Csat/DC TARGET ZONE	SVII/GVII TARGET ZONE	GSIP/GSI TARGET ZONE

Diamicton - Grain Size Distribution

Grain Size Distribution			
Depth (feet)	% Fine Sand	% Silt	% Clay
21.0-22.0	23.6	43.9	26.8
24.0-25.0	22.5	46.5	26.0
32.5-33.0	12.8	45.6	38.4
35.0-36.0	10.4	49.2	37.4



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Trade Contractor Bidding Specifications

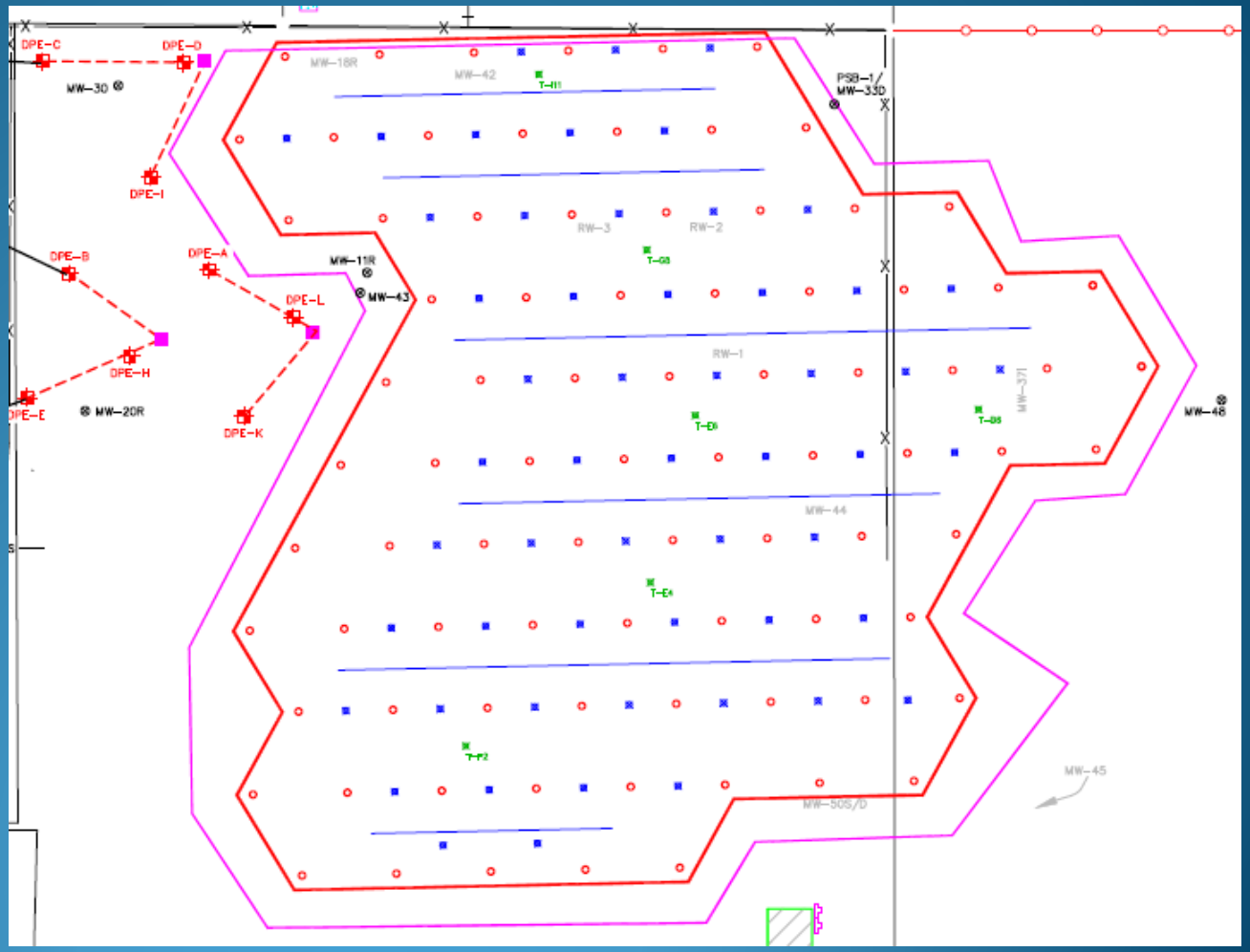
Item No.	Description	Quantity	Units
PHASE 1			
1A	Submittals and Site Service	1	Lump Sum
1B	Mobilization	1	Lump Sum
1C	Construction Field Office - Period Between Phase 1 and Phase 2	8	Month
1D	Site Security Guard	12	Month
2A	Temporary Bike Path	1	Lump Sum
2B	Gravel Access Driveways/Parking Areas and Stone Track-Out Pad	1	Lump Sum
2C	Remove Disused Extraction System Piping, Fencing and Tanks/Containment, and Disused Storm Drain Piping	1	Lump Sum
2D	Abandon Existing Monitoring Wells	1	Lump Sum
2E	Replace Storm Drain Piping	1	Lump Sum
2F	Remove Disused Water Line	1	Lump Sum
3A	Water Service for Thermal Remediation System	1	Lump Sum
3B	Sanitary Sewer Service for Thermal Remediation System	1	Lump Sum
3C	Power Service and Transformer for Thermal Remediation System	1	Lump Sum
4A	Electrode Wells	84	Each
4B	Vertical Multi-Phase Extraction Wells	54	Each
4C	Temperature Sensor Wells	6	Each
4D	Horizontal Vapor Extraction Wells	1	Lump Sum
4E	Concrete Vapor Cap	1	Lump Sum
4F	Cold Weather Installation of the Concrete Vapor Cap	1	Lump Sum
5A	Shallow Dual-Phase Extraction Wells	12	Each
5B	Shallow Dual-Phase Extraction System Piping, Valves, Valve Boxes	1	Lump Sum
6A	Containment, Characterization, Transport & Disposal of Non- Hazardous Solid Waste	1200	Tons
6B	Containment, Characterization, Transport & Disposal of Hazardous Solid Waste	200	Tons
6C	Containment, Characterization, Transport & Disposal of Non- Hazardous Liquid Waste	950	Gallons
6D	Containment, Characterization, Transport & Disposal of Hazardous Liquid Waste	2000	Gallons
7	Demobilization	1	Lump Sum

Construction & Operations Schedule

- Drilling & Concrete Cap Installation
  - March, April, and May 2018
- Surface Component Installations
  - June and July 2018
- System Operations
  - August 2018 to July 2019
- Performance Testing
  - January-, May-, October-, December 2019
- Site Restoration Activities
  - September – October 2019

Drilling and Concrete Cap Installation

- 168 Electrodes
- 55 MPE Wells
- 12 DPE Wells
- 6 Temp. Strings
  - 72 Sensors
  - 12 per Profile



Installation

MPE Well w/Sump

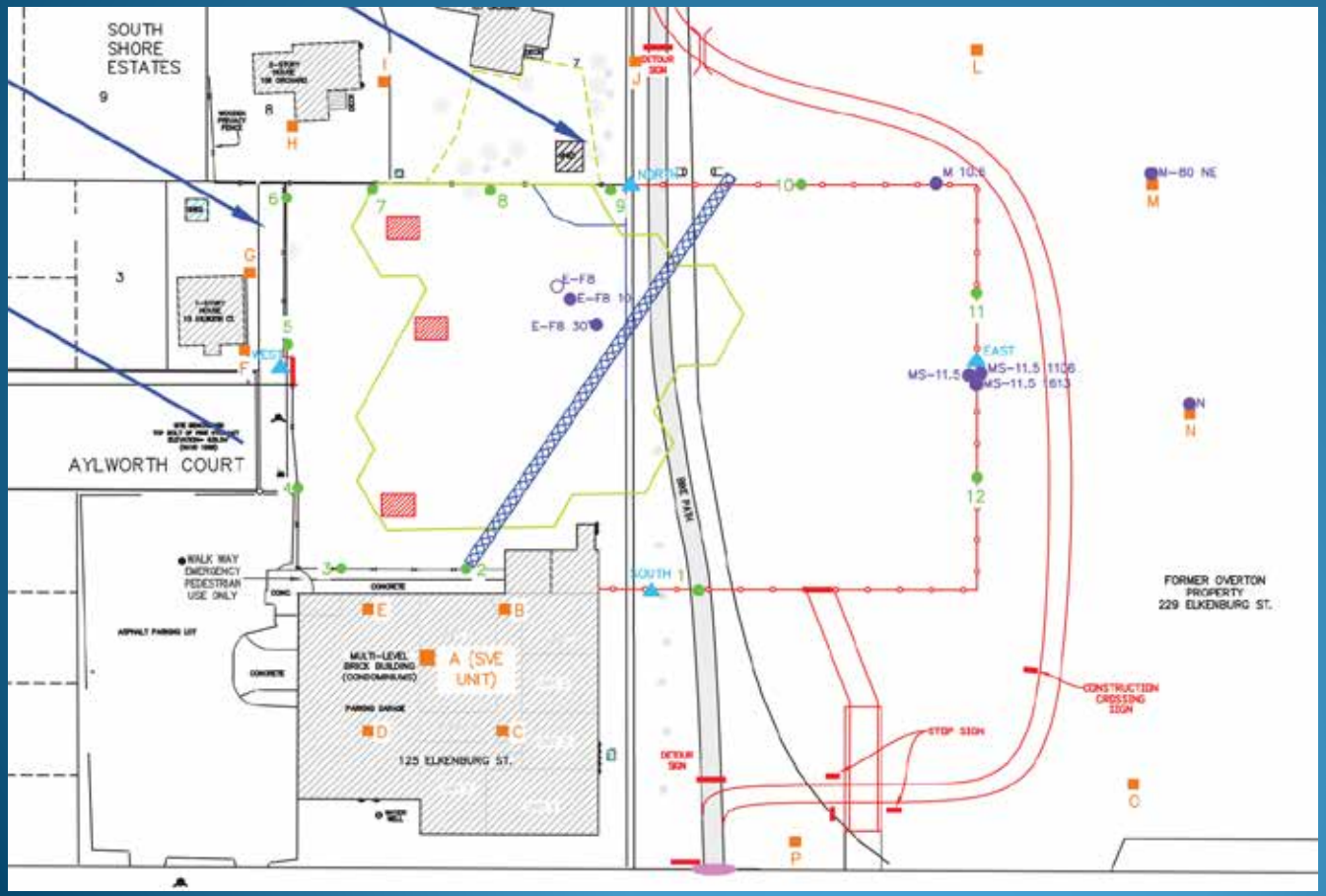
Electrode Stack

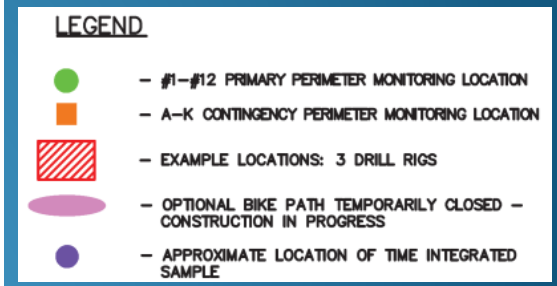
Installation

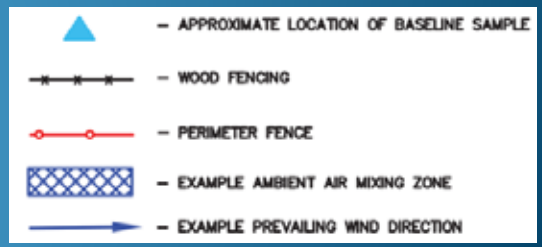
- Bagging Soils - Reduce Volatile Loss

Perimeter Air Monitoring

PID values collected from 12 monitoring stations in the “breathing zone”.
If necessary, reading were collected from 2ndary monitoring stations A-K.







Perimeter Air Monitoring

Objective: Protect residence and general public from volatiles associated with system construction.

- PID TCE correction factor = 0.54 @ 65% TCE
- 1.0 ppb PID reading equivalent to 0.35 ppb TCE.
- Real-time 24-hour average action level of **1.0 ppb** above background across prevailing wind direction was selected as a trigger action level for VOC emissions at the site perimeter.
- A background average PID value of **32 ppb** was established from 3 drill rigs running idly in center of site prior to drilling.
- Gaussian dispersion calculations assessed ambient air mixing in the breathing zone.
  - Calculations indicated a 98 fold reduction in concentration 30 meters from the source at wind a velocity of 8 mph. Reductions doubled with distance.

Perimeter Air Monitoring

Perimeter air monitoring preformed hourly for the first week . A minimum of 3 times daily for the remainder of well construction.

		Perimeter Air Monitoring Station Readings (1-minute averages)[1]													
Date	Hour	MS-1	MS-2	MS-3	MS-4	MS-5	MS-6	MS-7	MS-8	MS-9	MS-10	MS-11	MS-12	Weather Conditions (Temperature, Prevailing Wind)	Activities
8-Mar-18	0700	0	0	0	0	0	0	0	0	0	0	0	0	28 °F, NW @ 13 mph	1 rig operating at E-G2, 2 rigs warming up at E-F7 and X-G4
	0800	5	1	0	1	0	0	0	0	0	0	0	0	28 °F, NW @ 15 mph	3 rigs operating at E-F7, E-G2 and X-G4;
	0900	17	11	8	7	7	0	0	0	0	0	0	4	27 °F, NW @ 12 mph	3 rigs operating at E-F7, E-G2 and X-G4;
	1000	12	5	5	7	9	0	0	0	0	0	1	11	28 °F, NW @ 10 mph	3 rigs operating at E-F7, E-F2 and X-H5
	1100	10	14	8	9	11	0	0	1	9	2	3	10	28 °F, NW @ 8 mph	3 rigs operating at E-F8, E-F2 and X-H5;
	1200	0	0	0	0	0	0	0	0	0	0	5	4	30 °F, NW @ 9 mph	No rigs operating
	1300	16	23	16	16	18	9	9	10	10	12	28	23	30 °F, NW @ 12 mph	3 rigs operating at E-F8, E-E2 and X-H5;
	1400	0	0	0	0	0	0	0	0	0	0	0	4	30 °F, NNW @ 16 mph	3 rigs operating at E-F8, E-E2 and X-E3
	1500	0	0	0	0	0	0	0	0	0	0	0	3	30 °F, W @ 15 mph	3 rigs operating at X-E3, E-E2 and E-F9
	1600	15	0	0	0	0	3	0	0	0	0	3	9	31 °F, W @ 13 mph	2 rigs operating at E-F9 and E-D2;
	1700	1	0	0	0	0	0	0	0	0	0	0	0	31 °F, W @ 13 mph	1 rig idling at E-F9, 2 rigs shut down;

Wells – Electrodes - Cap Installation

Well Field Surface Build-Out

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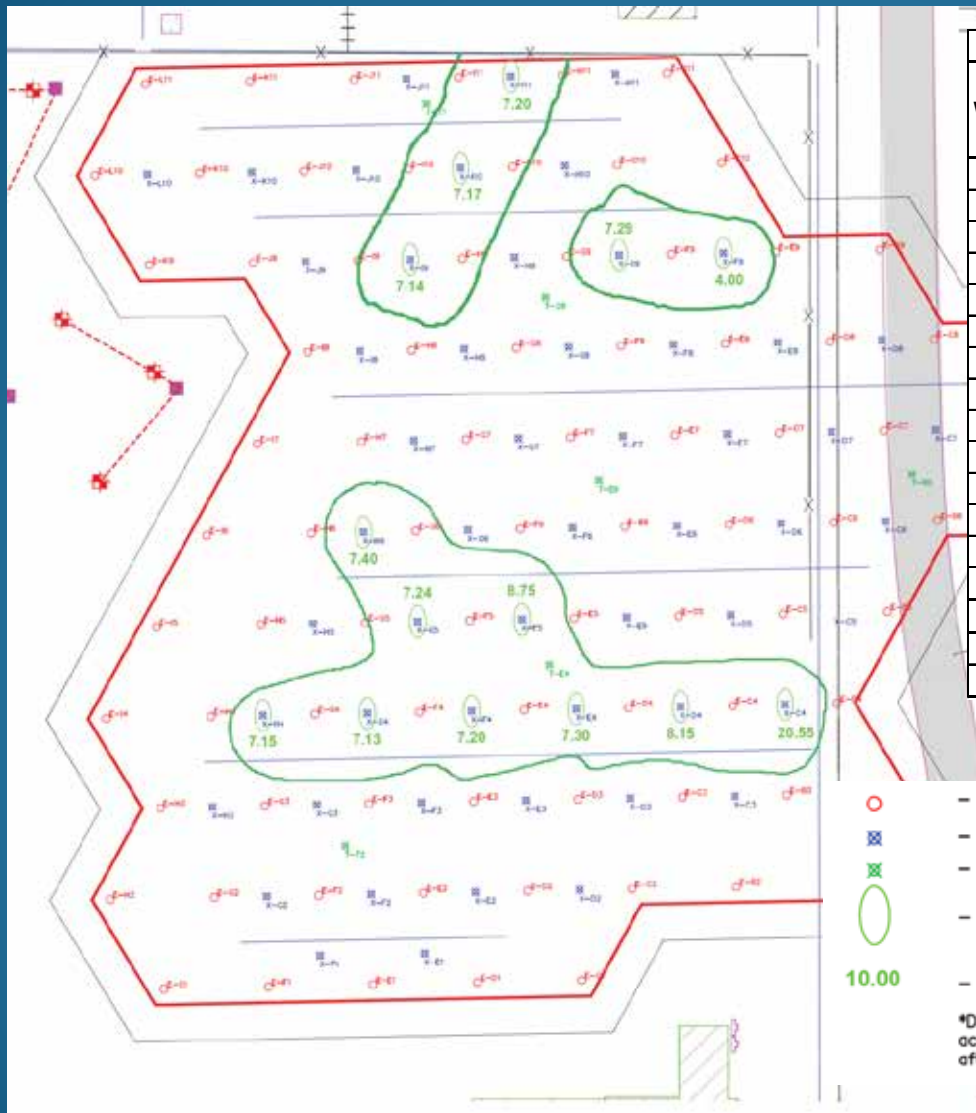
Construction Complete July 2018

DNAPL Pumping - MPE Wells

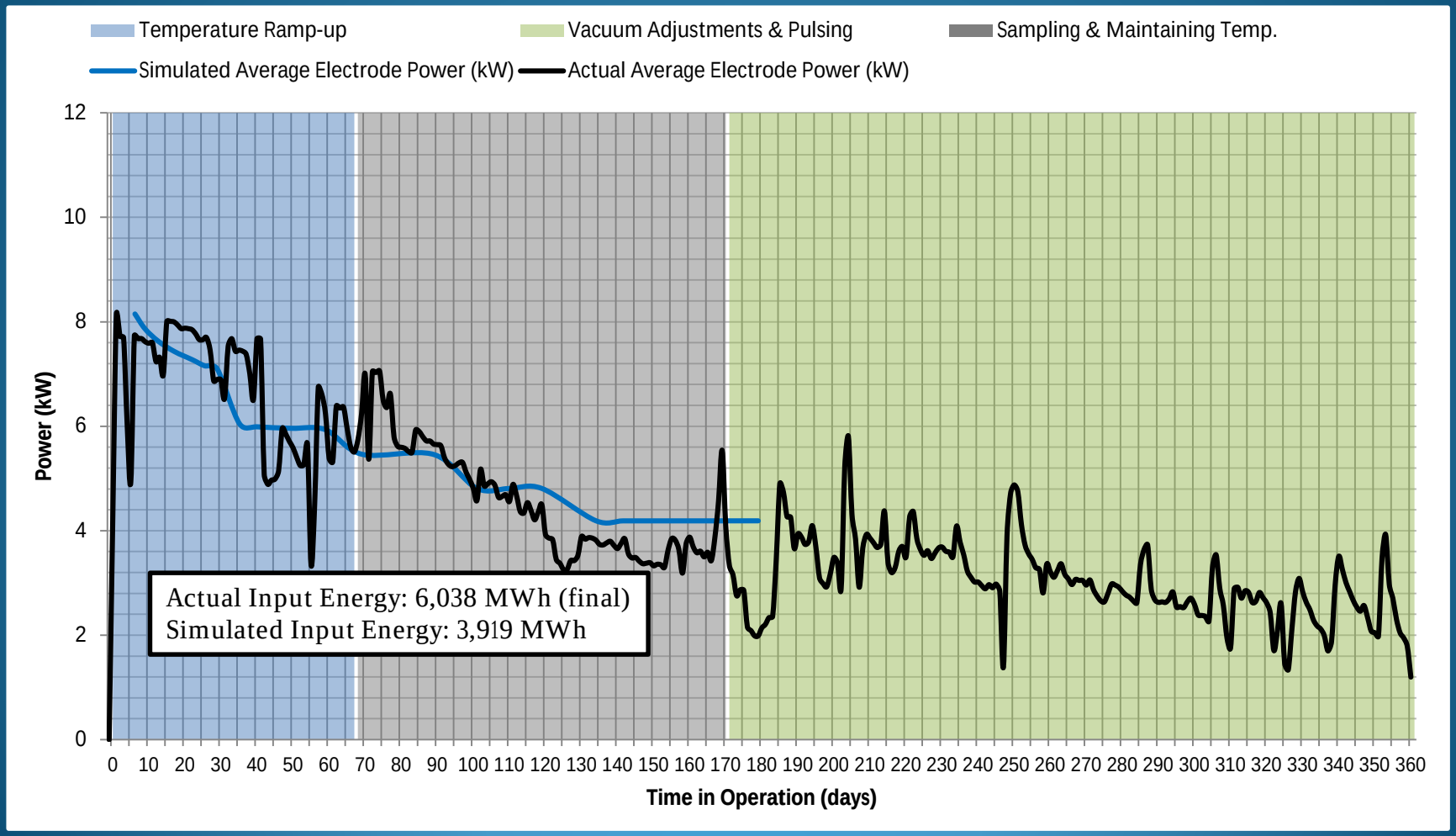


Estimated DNAPL Purge Volume		
Well Location	**Date**	**Product Volume (gal)**
X-C4	4/5/18	**25.3**
X-D4	4/5/18	**10.0**
X-E4	4/5/18	**9.0**
X-F4	4/5/18	**8.9**
X-G4	4/5/18	**8.8**
X-H4	4/5/18	**8.8**
X-F9	4/6/18	**4.9**
X-G5	4/5/18	**8.9**
X-F5	4/5/18	**10.8**
X-H6	4/5/18	**9.1**
X-G9	4/5/18	**9.0**
X-I9	4/5/18	**8.8**
X-I10	4/5/18	**8.8**
X-I11	4/5/18	**8.9**
		139.8
# wells checked:		24
# wells w/DNAPL:		14

Operations Aug. 2018 – July 2019

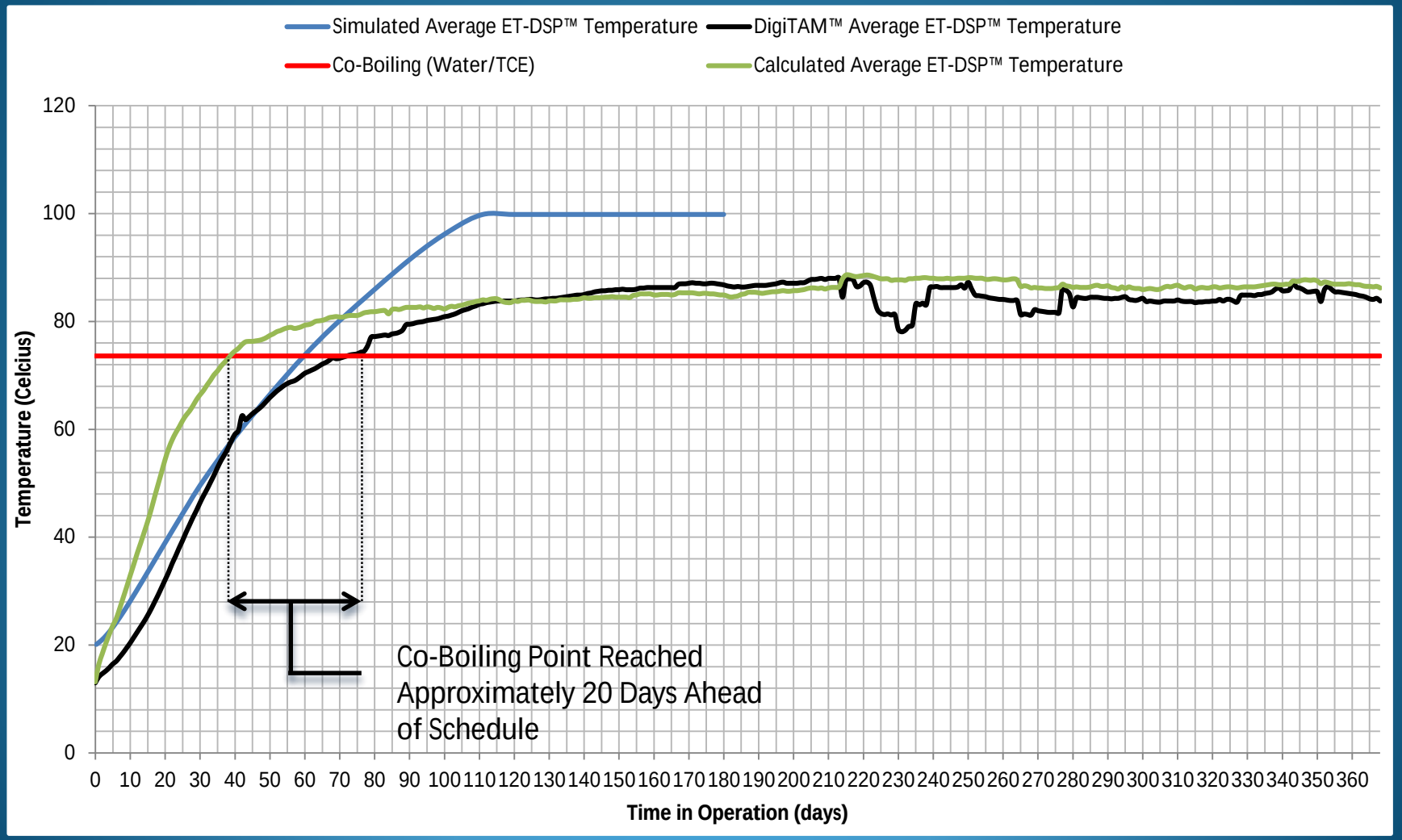
Thermal Operations

Input Power – ET-DSP™

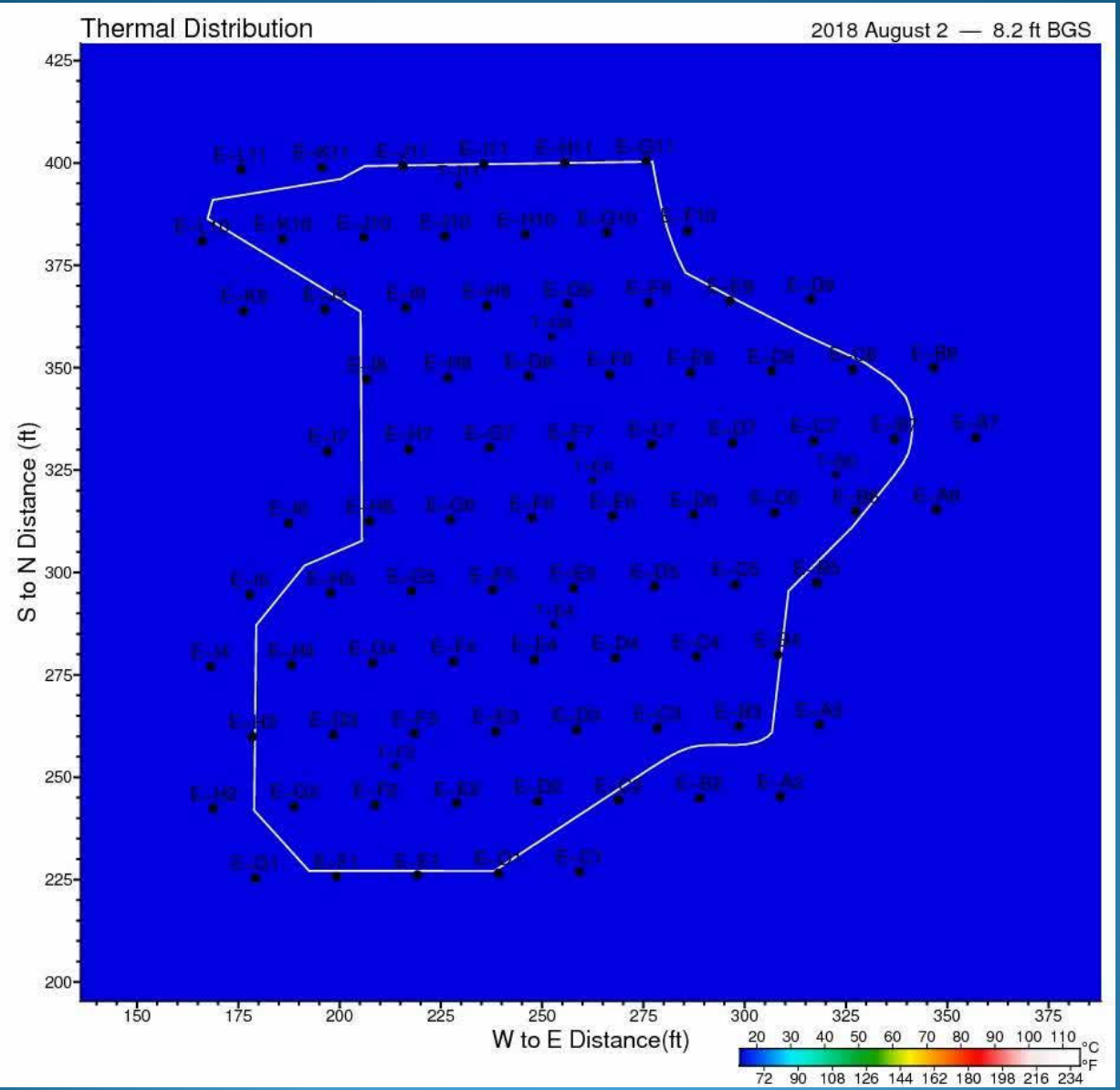


Thermal Operations

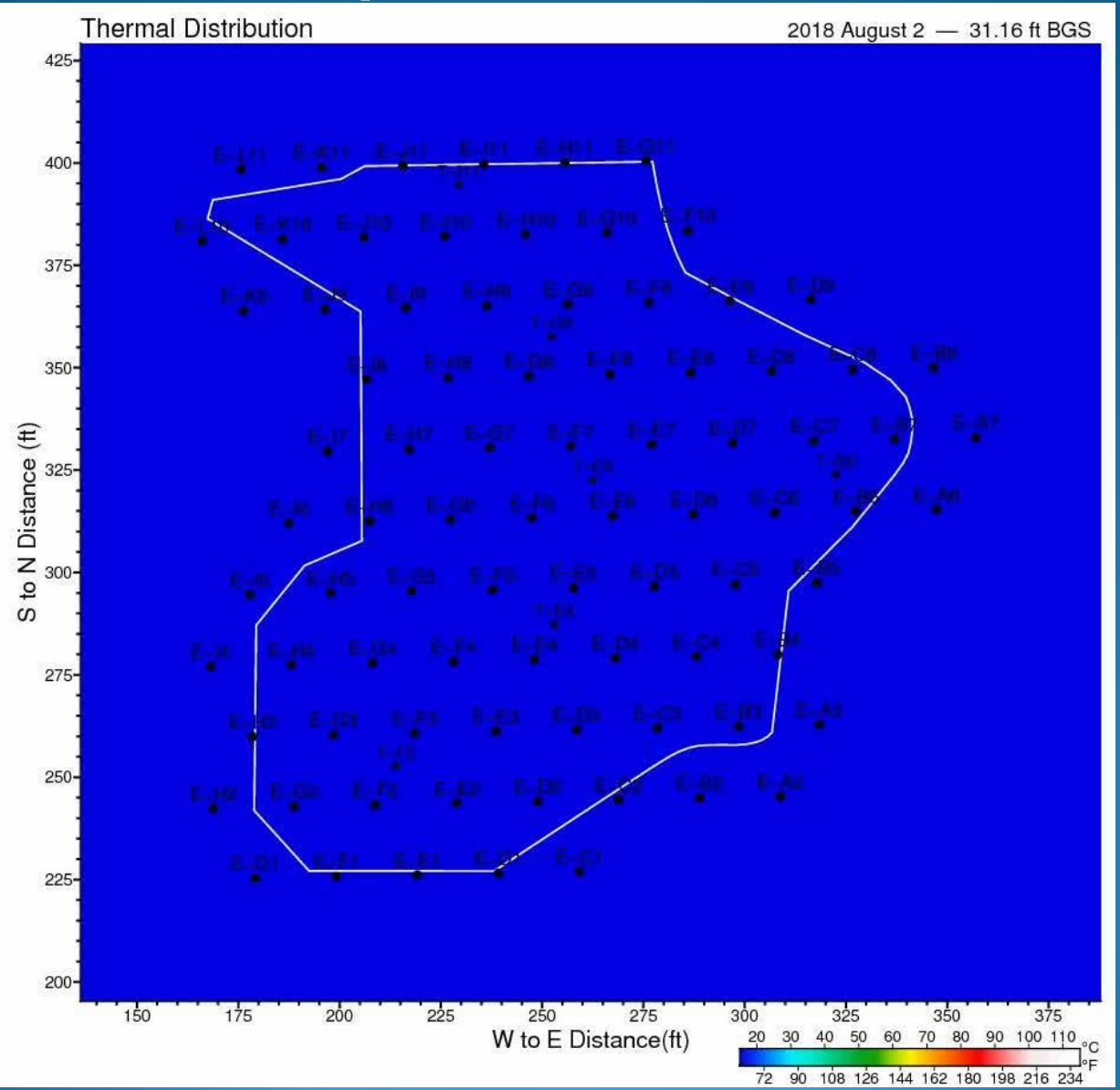
Temperature Distribution – ET-DSP™



Thermal Operations



Thermal Operations



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  - VSR Progress Evaluations
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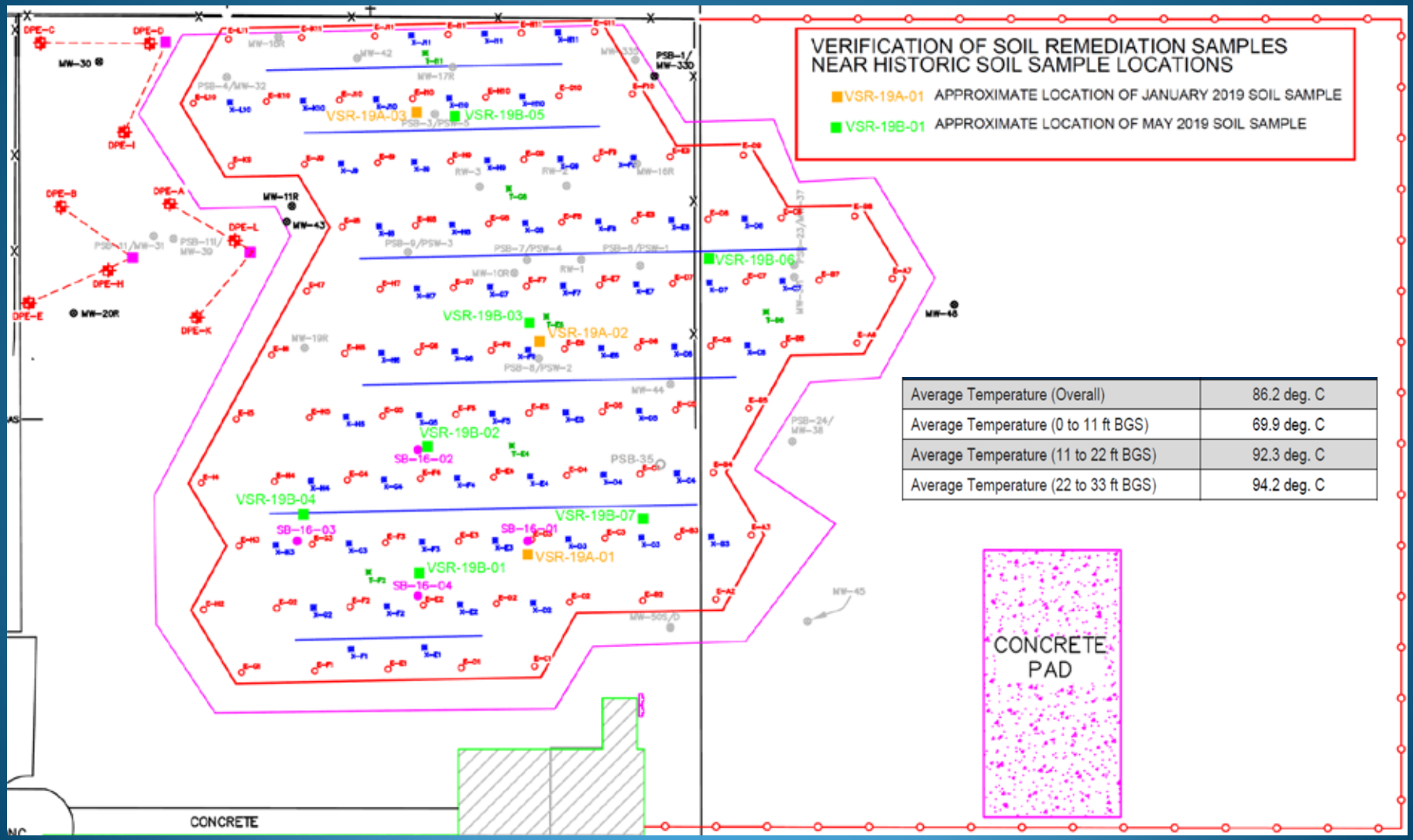
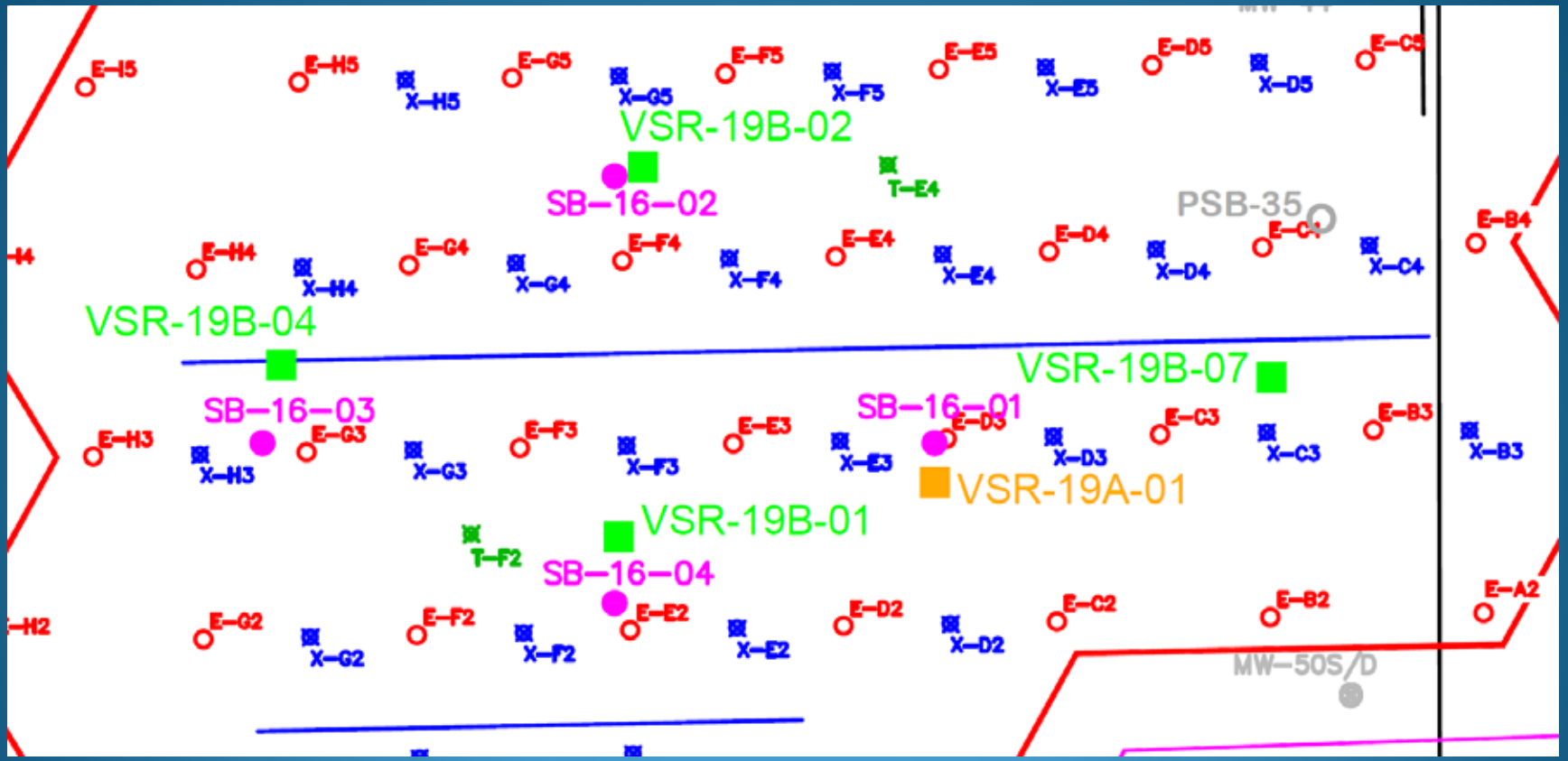
VSR Progress Evaluation



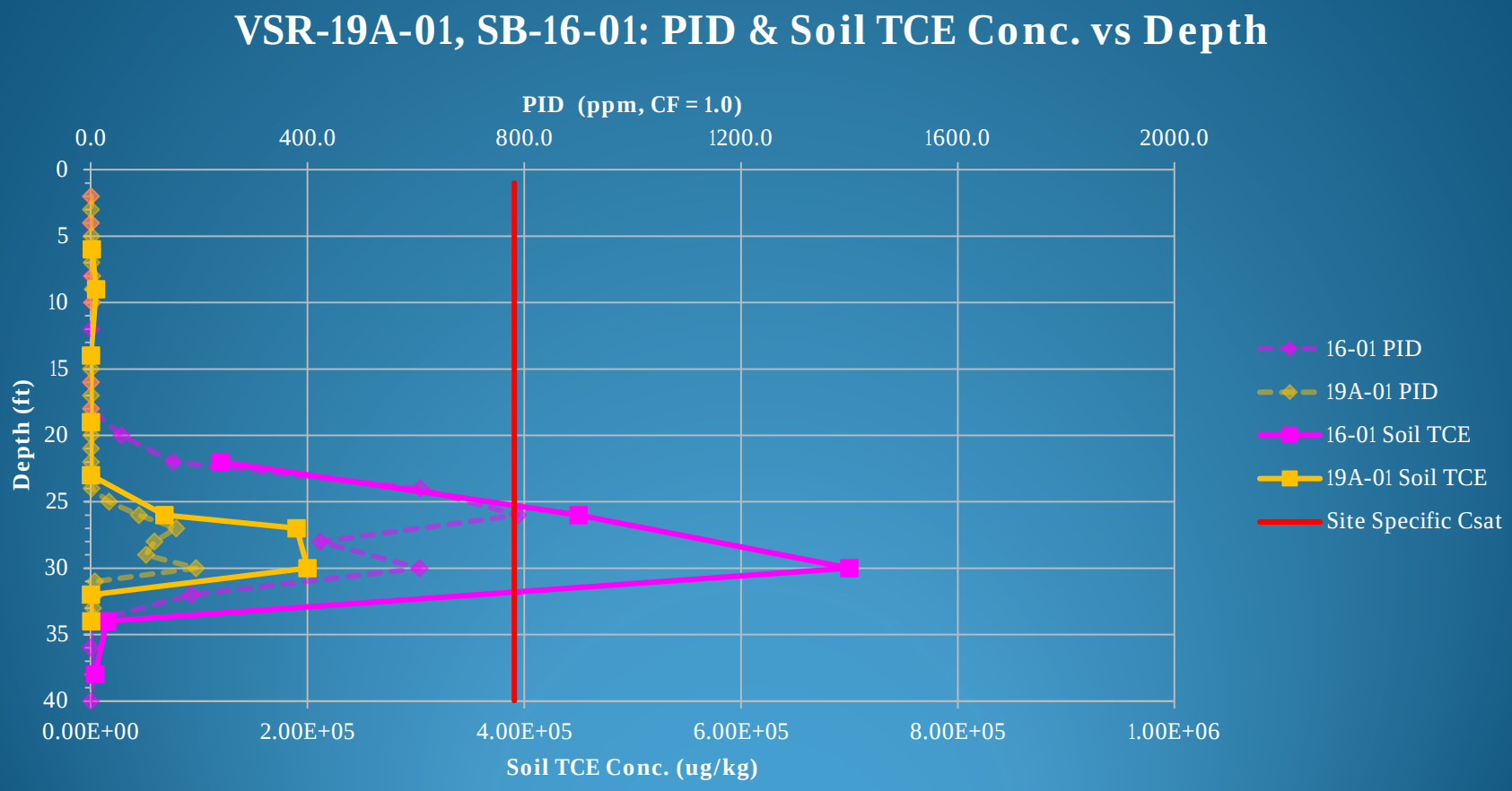
Performance Soil Sampling (after 5 and 9 months of active ISTR)

HOT Soil Sampling

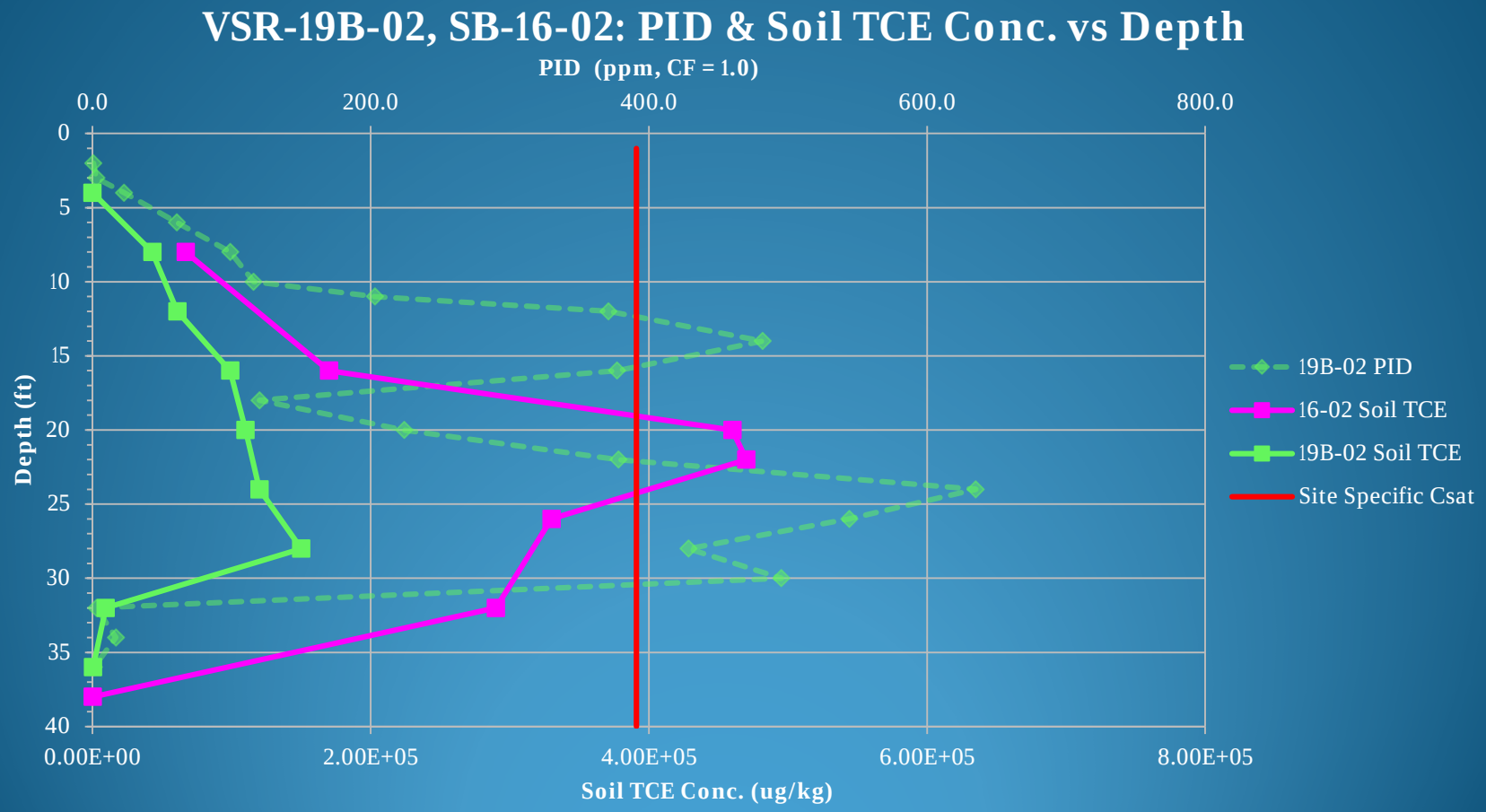
Southern Mass Reduction Trends



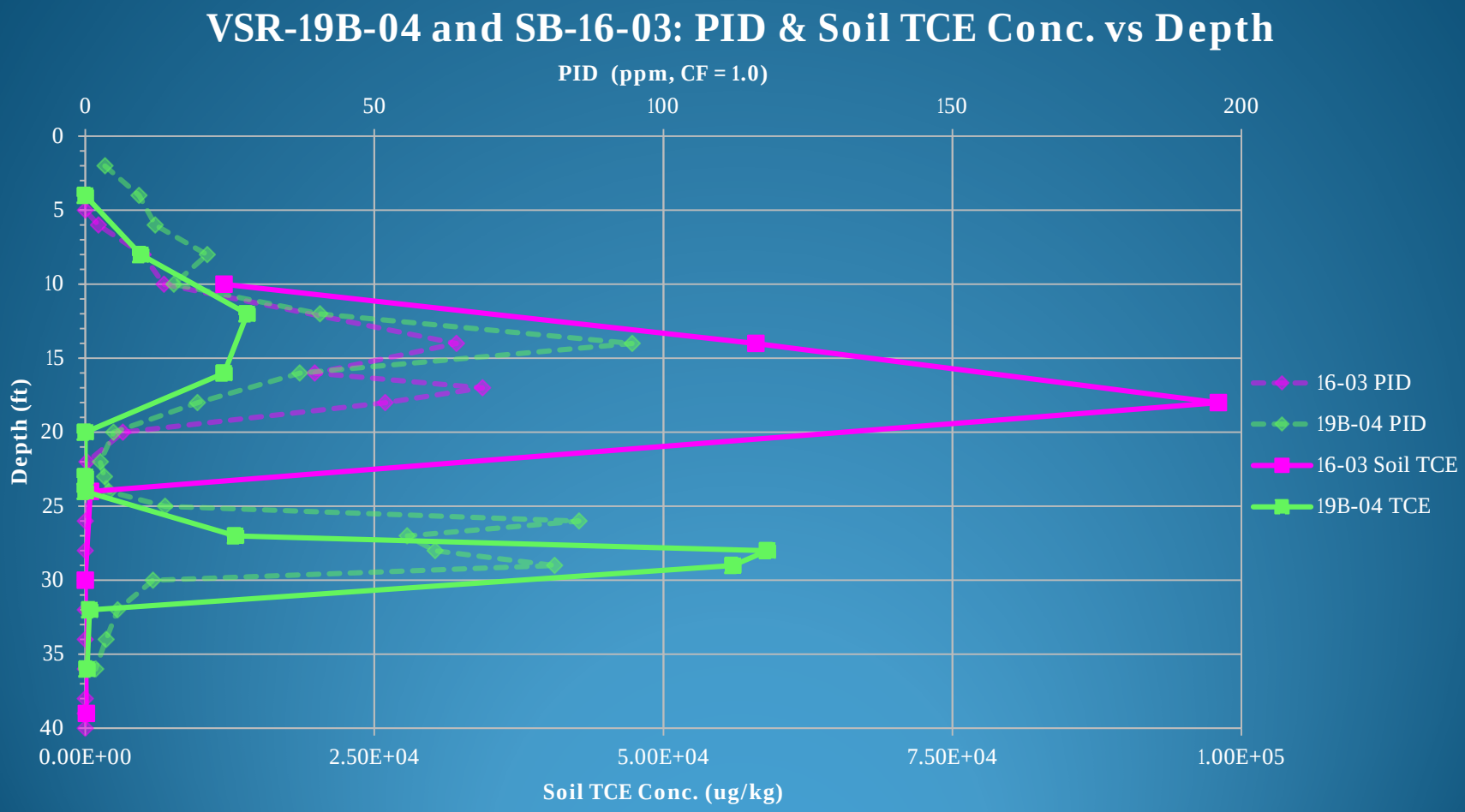
S. Mass Reduction Trends (5 Mo ISTR)



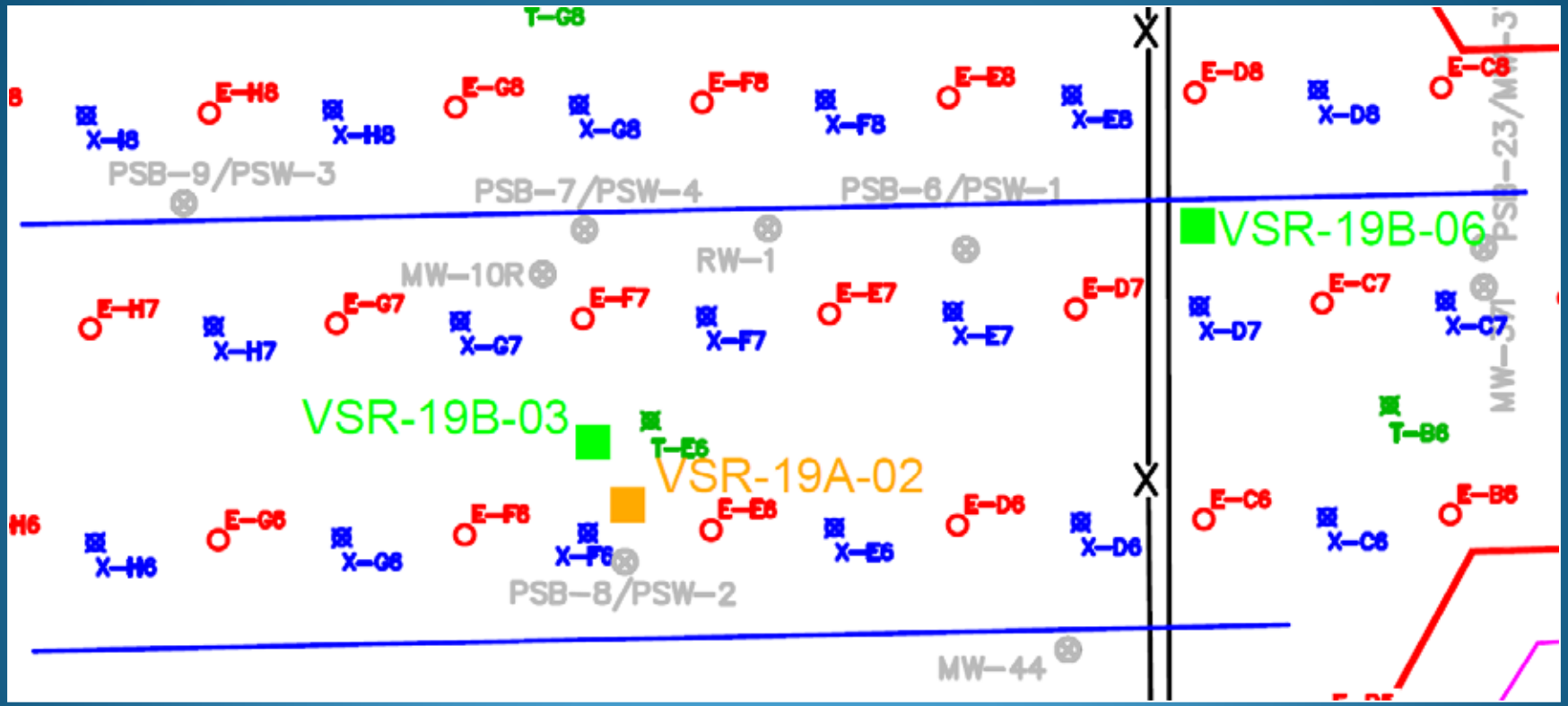
S. Mass Reduction Trends (9 Mo ISTR)



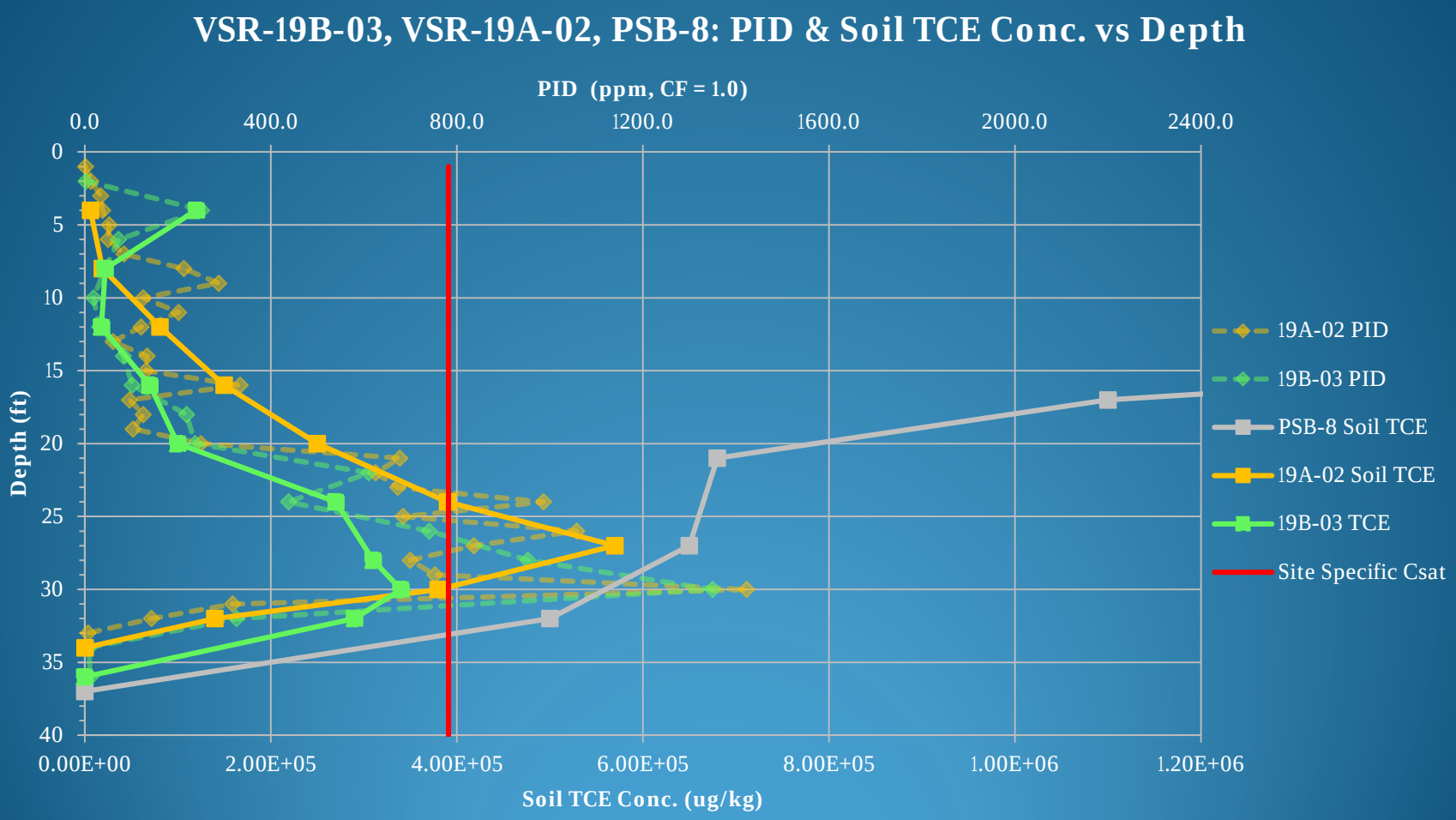
S. Mass Reduction Trends (9 Mo ISTR)



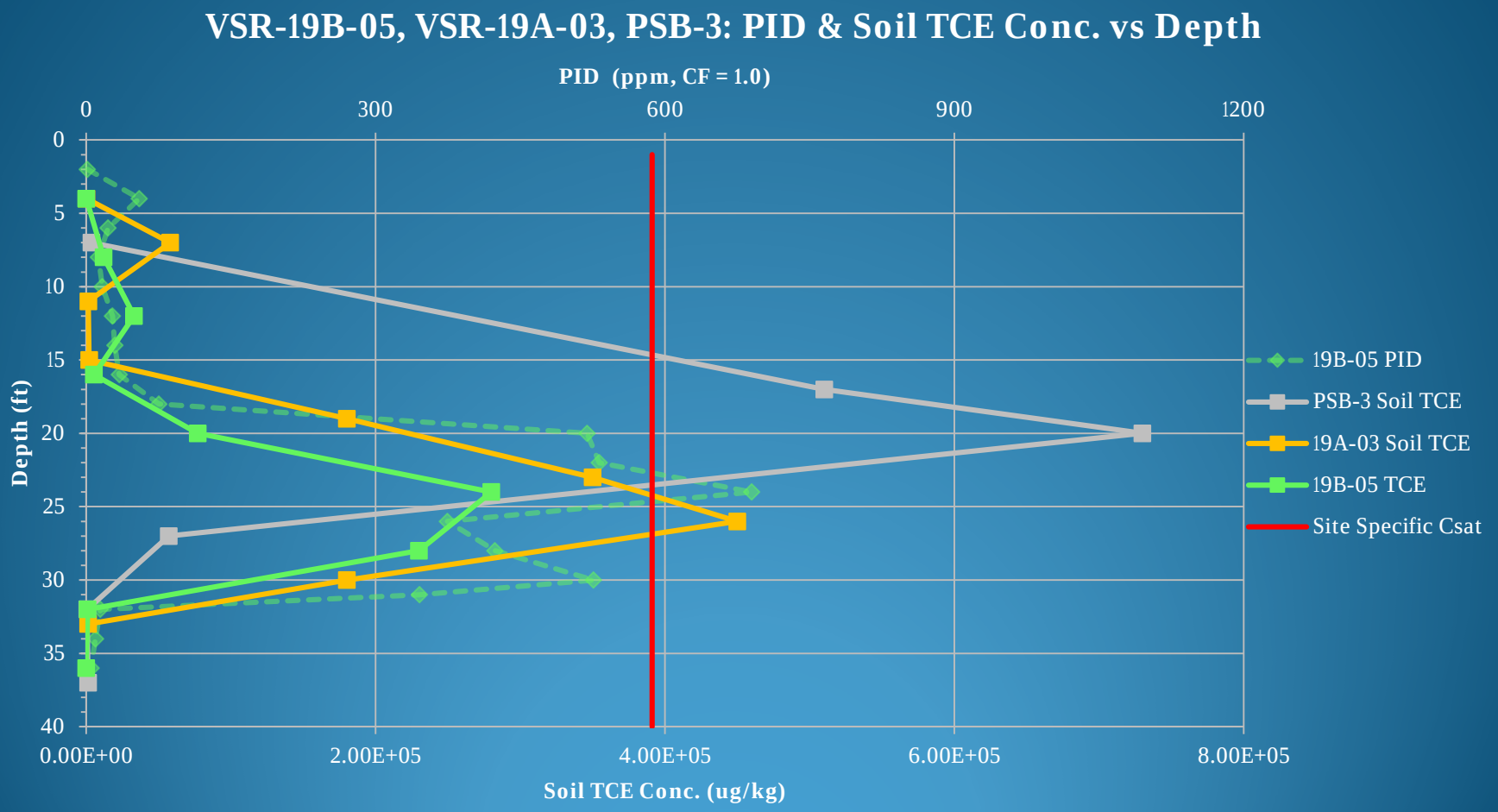
Central Mass Reduction Trends



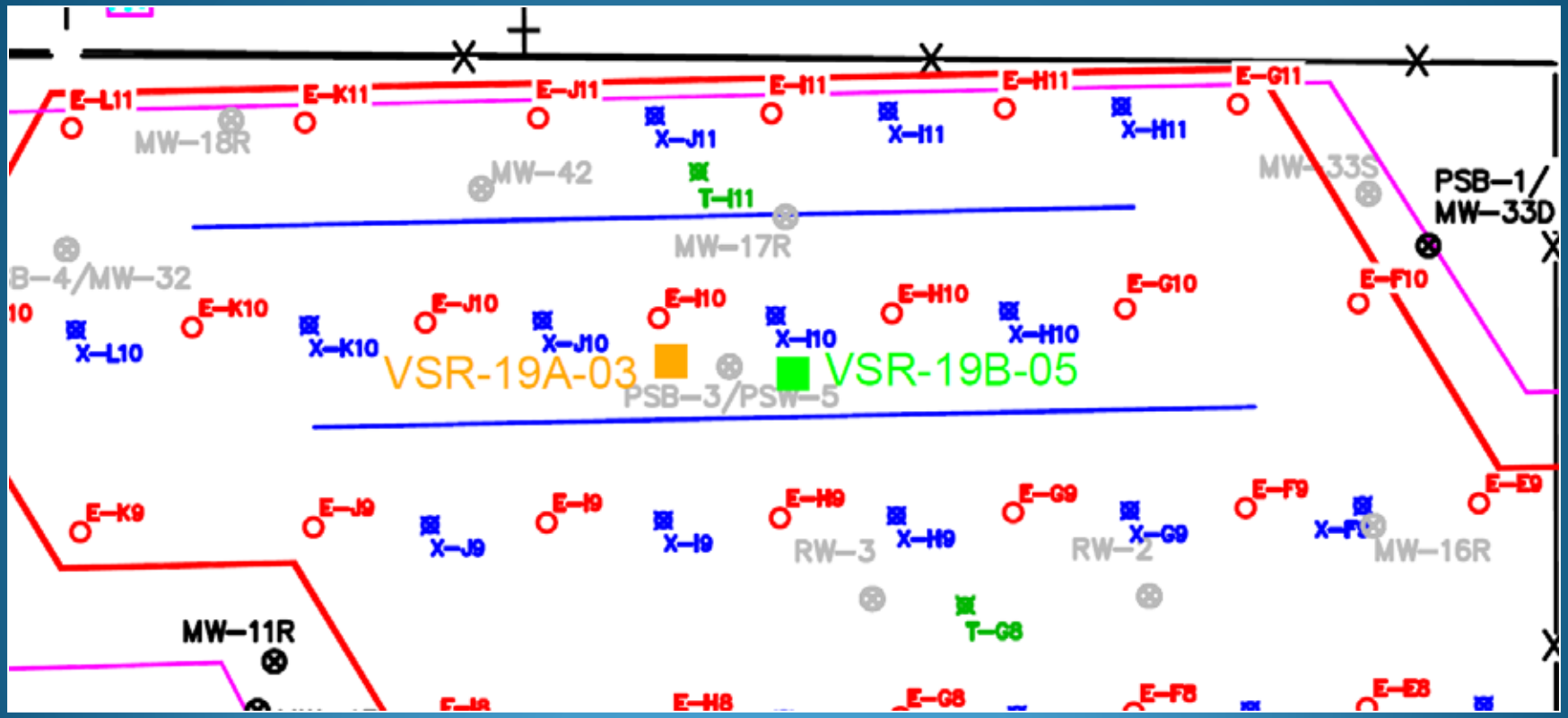
C. Mass Reduction (5 & 9 Mo ISTR)



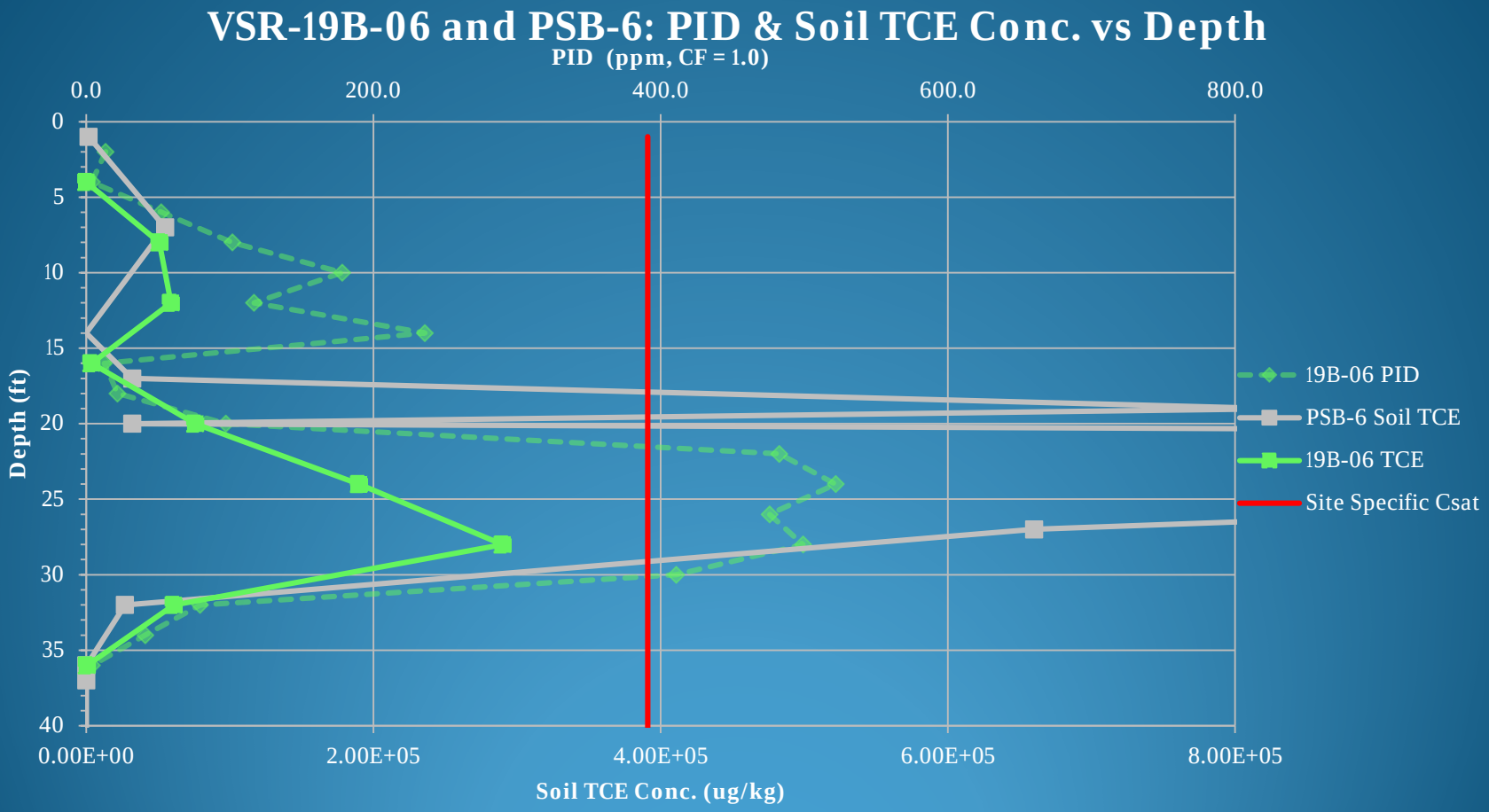
C. Mass Reduction (5 & 9 Mo ISTR)



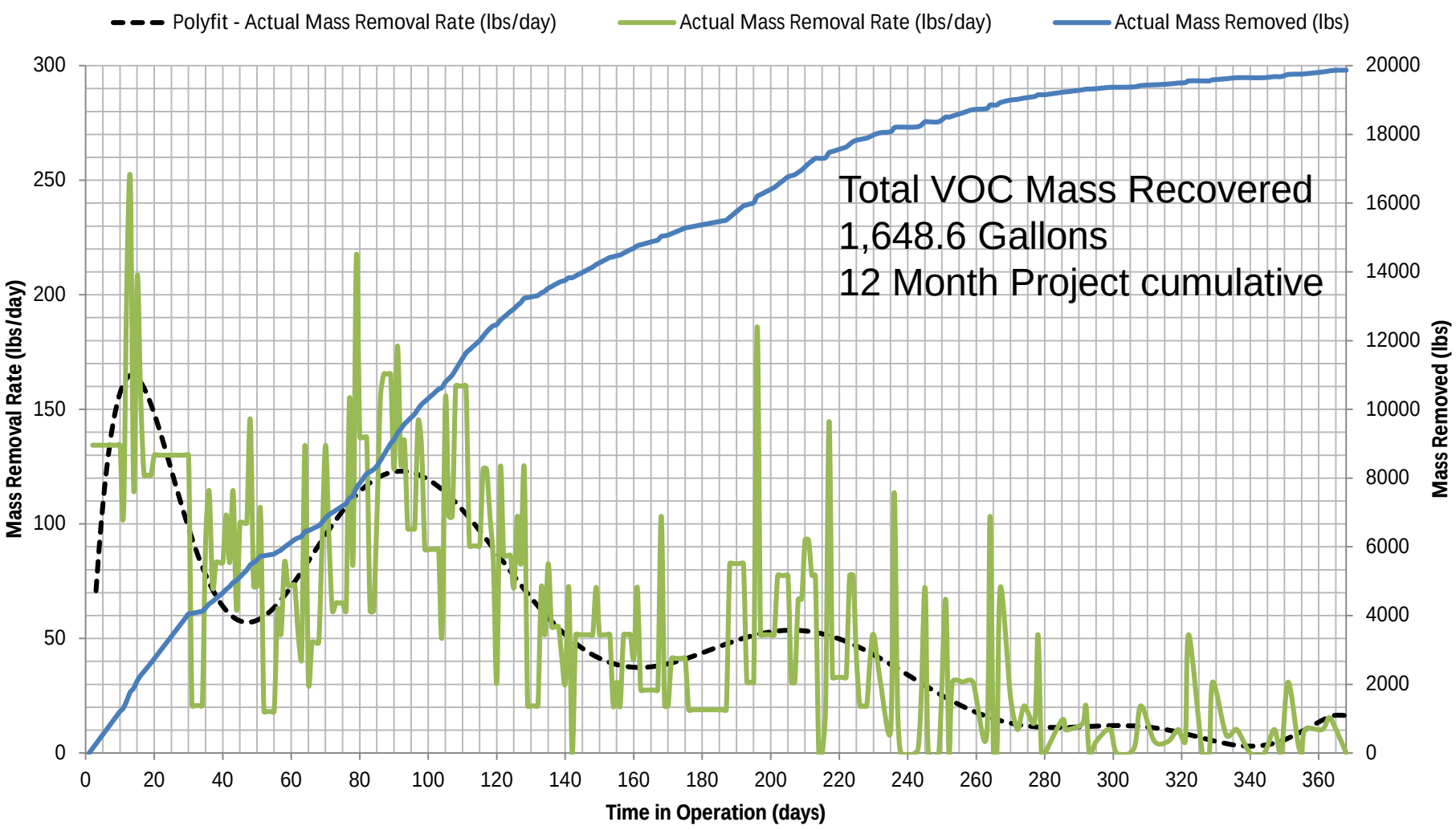
Northern Mass Reduction Trends



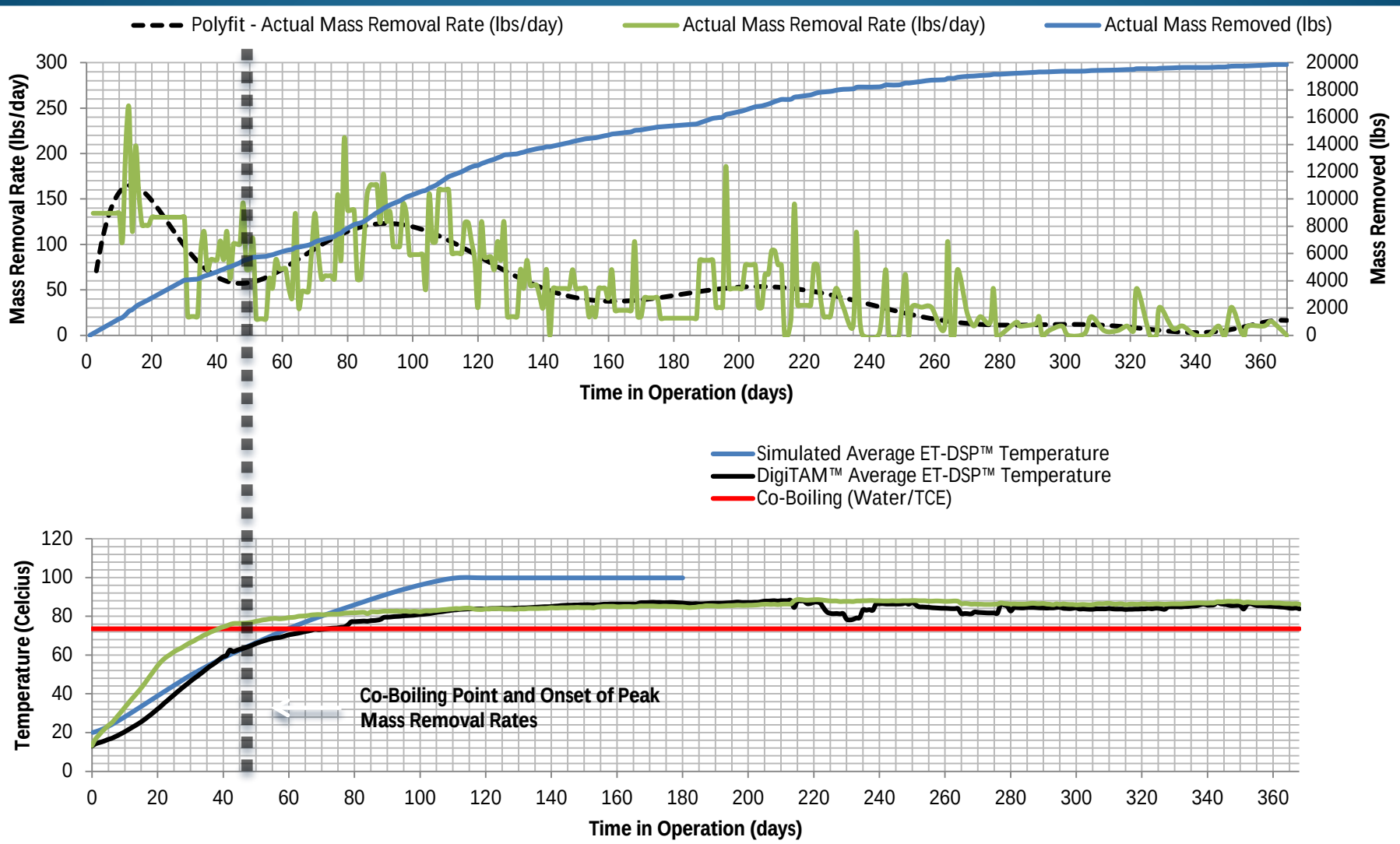
N. Mass Reduction (9 Mo ISTR)



Mass Removal – ET-DSP™



Mass Removal – ET-DSP™



System Shutdown - Post 12 Mo ISTR

- Diminished mass removal no longer justified cost to operate the system
- Electrodes shutdown July 31, 2019
- Vapor extraction and treatment continued until field monitoring indicated minimal VOCs

	8/1/2019	Week of 8/5/19		
	Thurs PM	Mon AM	Wed AM	Thurs AM
Horizontal Extraction:				
HX-1	9.5	2.6	0/0.4	0.0
HX-2	11.2	2.5	0/1.0	0.0
HX-3	4.3	2.5	0.1/0.6	0.0
HX-4	9	3.1	0.1/0.6	0.0
HX-5	7	3.1	0/1.5	0.0
HX-6	3	4.3	0/0.9	0.0
Combined Influent	44.5	28	8	10.2

Grouting Clay Conduit to Surface

- 55 MPE Wells
- 84 Shallow Electrodes
- Temperature Sensors

Presentation Topics

- Site History
- Remedial Investigations 2005 Forward
- Interim Response Measures
- Feasibility Studies and Remedial Design
- Bidding Specifications and Construction
- System Start Up and Operations
- Removal Performance Summary
- Post Remedial Monitoring and On Going Operations

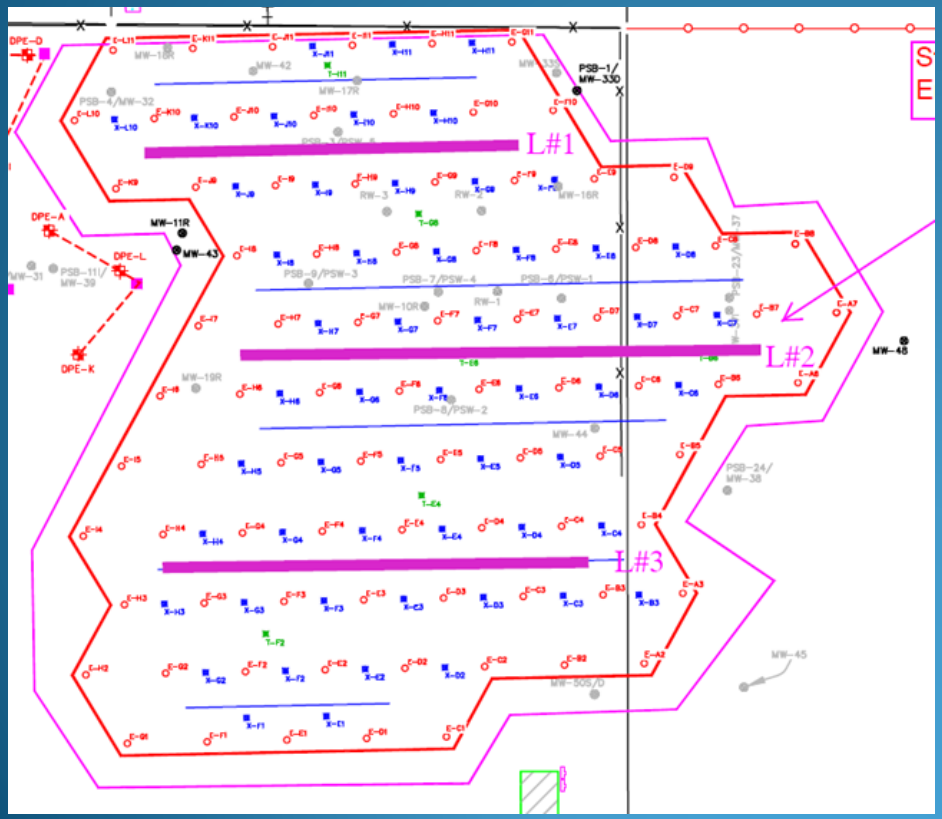
Post Treatment Monitoring

- **Deep high temperatures**
  - **> 150°F – 1 month electrode shutdown**

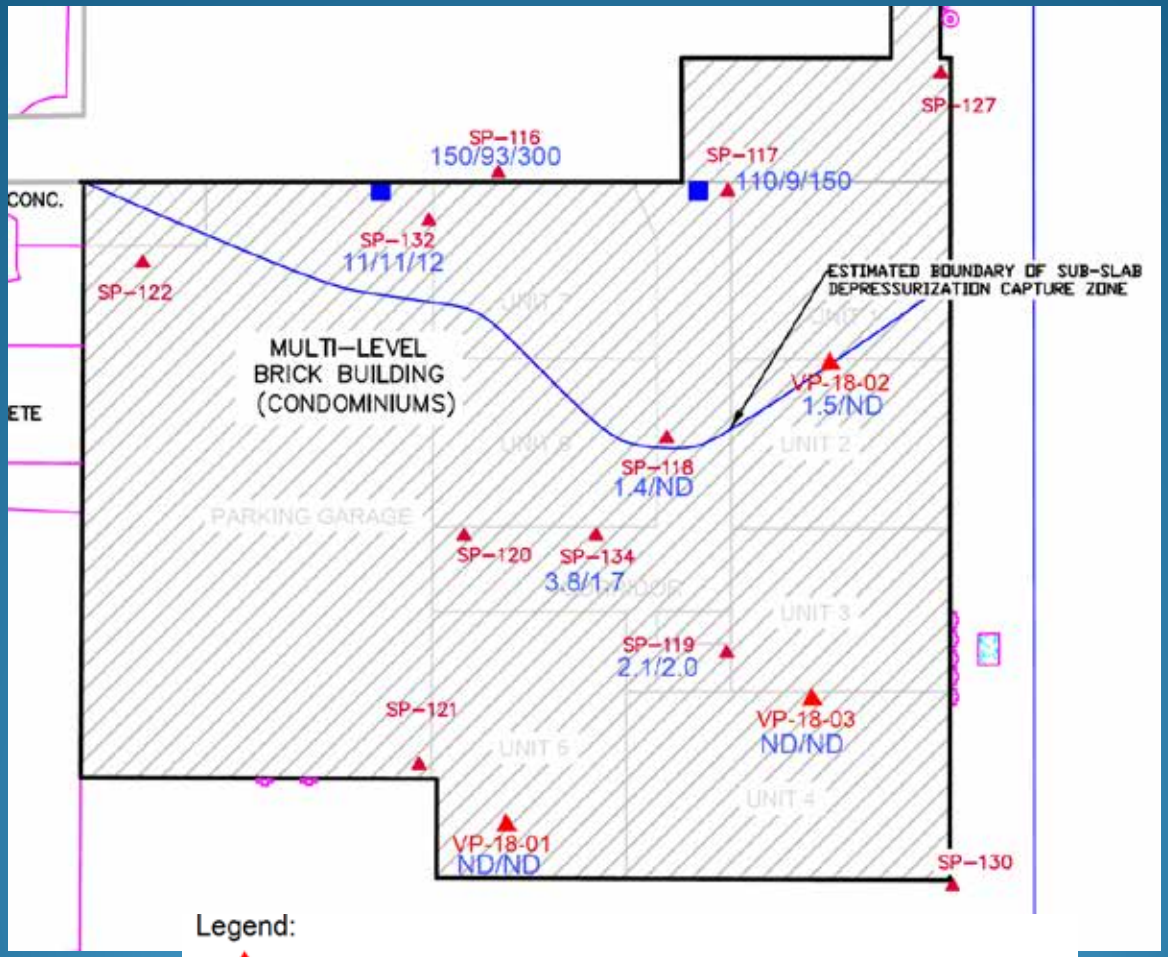
- Post-remediation soil and groundwater sampling above glacial till is ongoing July30-31, October 15-16

- Once temperatures normalize treatment verification sampling of the deep glacial till will be conducted.
  December 2019?

Vadose Zone Soil – GW Sampling In Process (October 15 – 16, 2019)



Pressure Field Extension/S.G. Results



Site Restoration September & October

YTD Removal Evaluation (ISTR)

- Subsurface NAPL Mass (Calculated Estimate)
  - 1750 – 1950 Gallons
- NAPL Mass Removed over 12 Months via ISTR
  - 1648 Gallons
- NAPL Removal Estimate 84% - 94%
- Limiting Factors:
  - Pore entry pressure adds to atmospheric pressure and hydrostatic pressure, thereby raising the temperature that must be achieved before TCE/water vapor mixture can move through available throats o the soil pore space.
  - The only remaining TCE migration mechanism is BY molecular diffusion.

Post ISTR Polishing Step - ISCR

- Zero valent iron (ZVI) injection via emplaced fractures
  - Hydraulic fracturing on 1 meter spacing was assessed was requiring that contact with chemical reductant between fracture intervals is molecular diffusion driven
- Based on the nature of the diamicton, we calculated ½ meter molecular diffusion transport time estimates
- Assumptions:
  - Representative $1m^3$ Diamicton Volume
  - Estimated time for TCE impacted GW to travel from center of this diamicton volume to injectate contact surface ½ meter away
  - Estimated concentration remaining in groundwater is 5.0 g TCE/m^3

Post ISTR Polishing Step Evaluation

Fick's law:

Mass Flux Rate = $-\Delta dc/dx$

Where:

- $\Delta = 5 \times 10^{-12}$ m^2/s [diffusion coefficient, representative of adsorptive constituents in clay soil]
- dc/dx = (change in concentration)/(change in distance) [estimate, assumed constant] =

$$\frac{\left(5.0\frac{g}{m^3} - 0\frac{g}{m^3}\right)}{0.5\text{m}} = 10.0\frac{\text{g}}{\text{m}^4}$$

Average flux rate= $5x10^{-12}\frac{m^2}{s}x\ 10.0\frac{g}{m^4} = 5\ x\ 10^{-11}\frac{g}{m^2 s}$

Mass loss rate [e.g. representative of 1 m^3 soil] = flux rate x flux area:

$$5\ x\ 10^{-11}\frac{g}{m^2 s}\ \text{x}\ 2\ \text{m}^2\ \text{x}\ 86{,}400\frac{\text{seconds}}{\text{day}} = 8.64\ \text{x}\ 10^{-6}\frac{\text{g}}{\text{d}}$$

Molecular Diffusion Time Period $= \frac{target\ mass\ removal}{mass\ loss\ rate} = \frac{1.0\ g - 0.0g}{8.64\ x\ 10^{-6}\frac{g}{d}} = 115{,}740\ days =$

317 years

THANK YOU & QUESTIONS

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