AEHS Foundation

34th Annual International Conference on Soil, Water, Energy, and Air

March 17-20, 2025 | San Diego, CA

Workshop 02 – March 17, 2025 - 13:00 PST

Extraction and Injection Methods for Chlorinated and Recalcitrant Compounds

Applications and Enhancements for Groundwater and Soil Remediation

JHA ENVIRONMENTAL

AEHS Foundation

34th Annual International Conference on Soil, Water, Energy, and Air

March 17-20, 2025 | San Diego, CA

Workshop - 02

MODULE-01

Introduction, Remediation Hydraulics

JHA Environmental

13:00-14:25 Introduction

I. Introduction

II. Remediation Hydraulics, Flow through porous media

III. Data collection and analysis

IV. Data visualization-

V. Injection , ISCO, EISB, CAC, ZVI + EVO

14:25-14:35 Short Break Discussions

14:35 – 15:55 Extraction - Recirculation

VI. Soil Vapor Extraction (SVE),

VII. Two-Phase, Multiphase Extraction

VIII. In-Well Stripping and Recirculation

15:55-16:05 Short Break Discussions

16:05-17:00 Case Studies

IX. Case Studies and Lessons Learned

I. Chicago, IL	I. Buena Park, CA
II. Charleston, SC	II. Los Angeles, CA
III. Huntington Beach, CA	III. Rancho Dominguez, CA

X. Discussions and Q & A

Workshop Outline

This is an information sharing presentation, Please do not hesitate to ask question and provide feedback.

Workshop Duration: 4 hours + Discussions

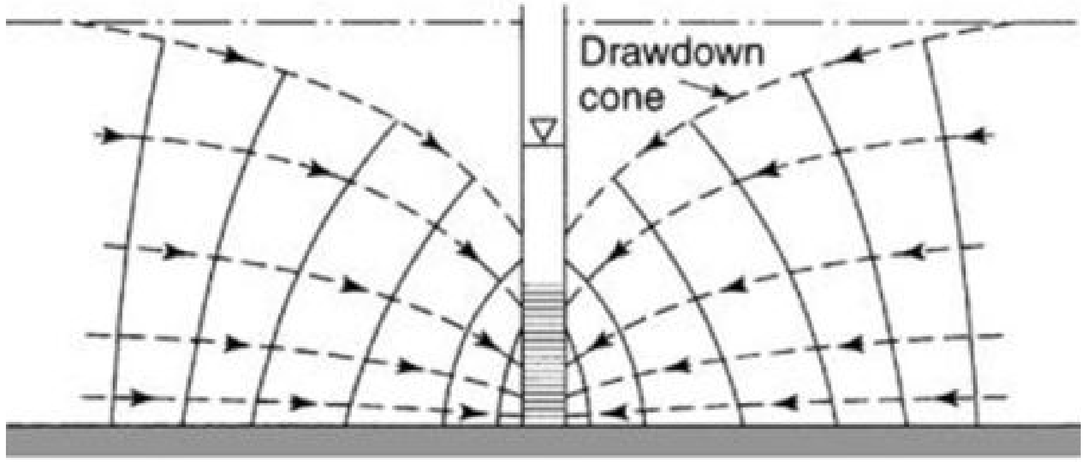
Housekeeping Items

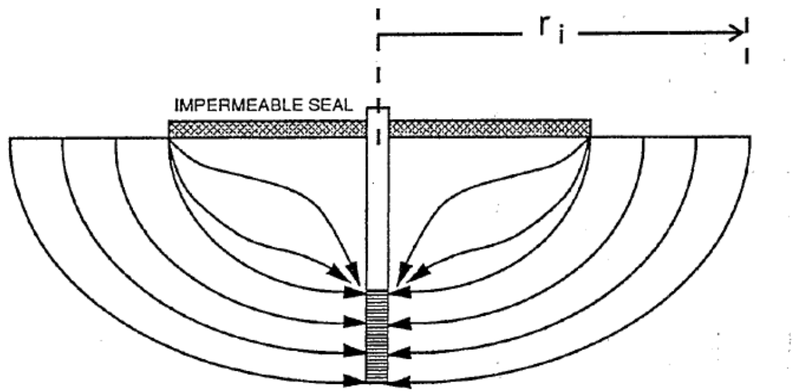
Introductions

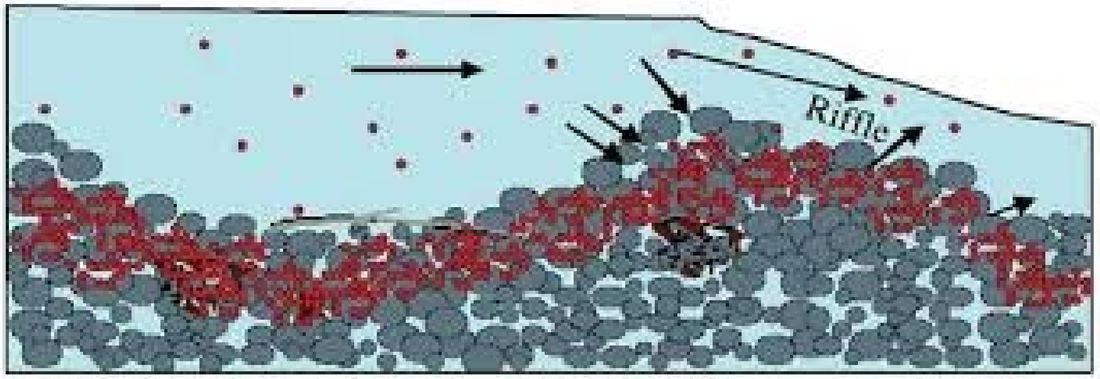
Speakers

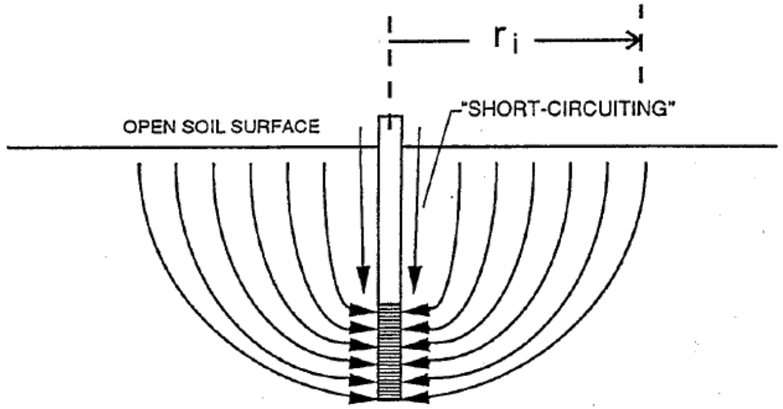
Students

Flow Through Porous Media

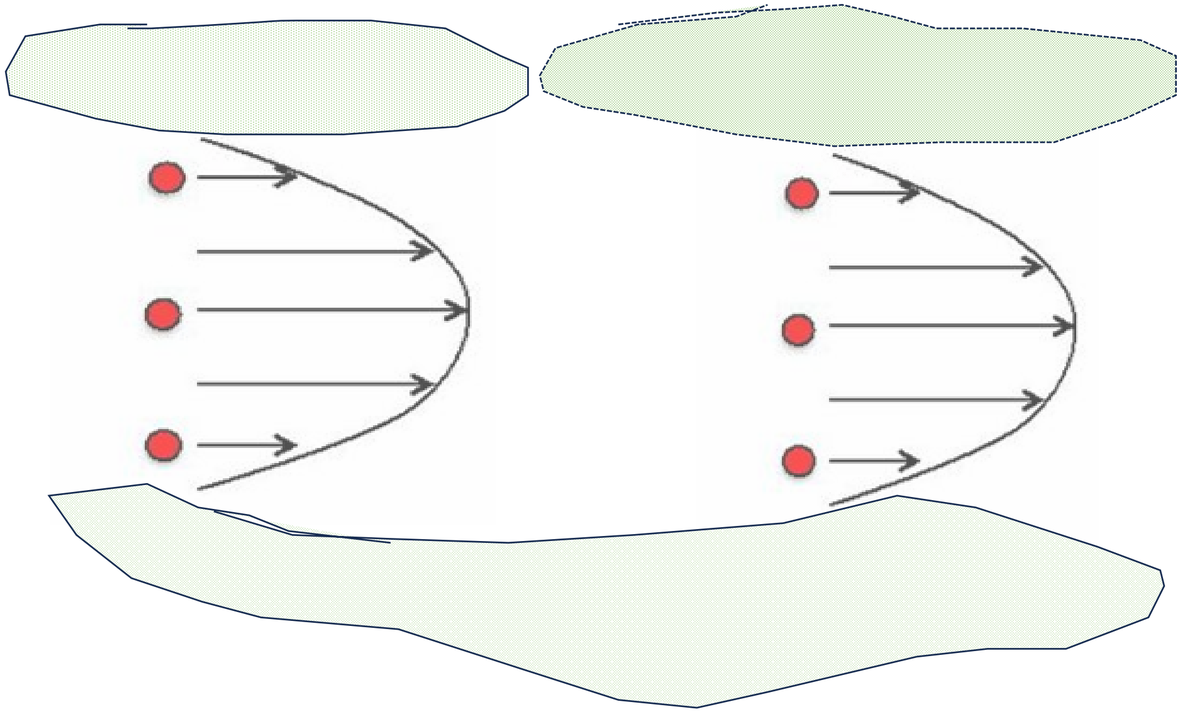


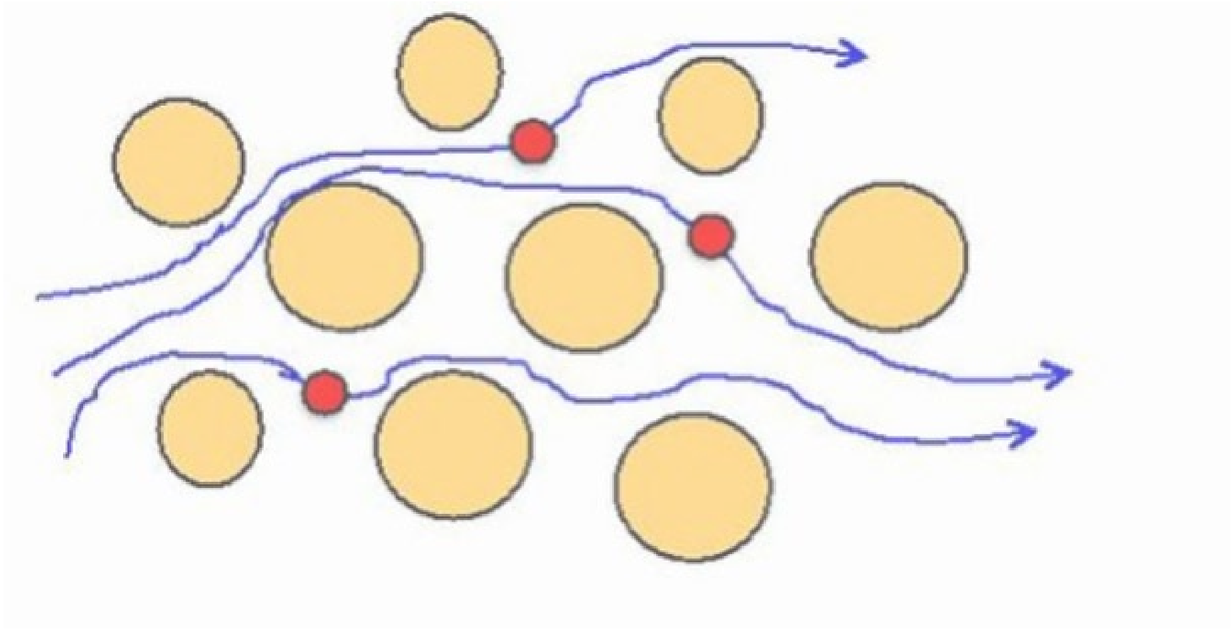






Flow through Porous Media





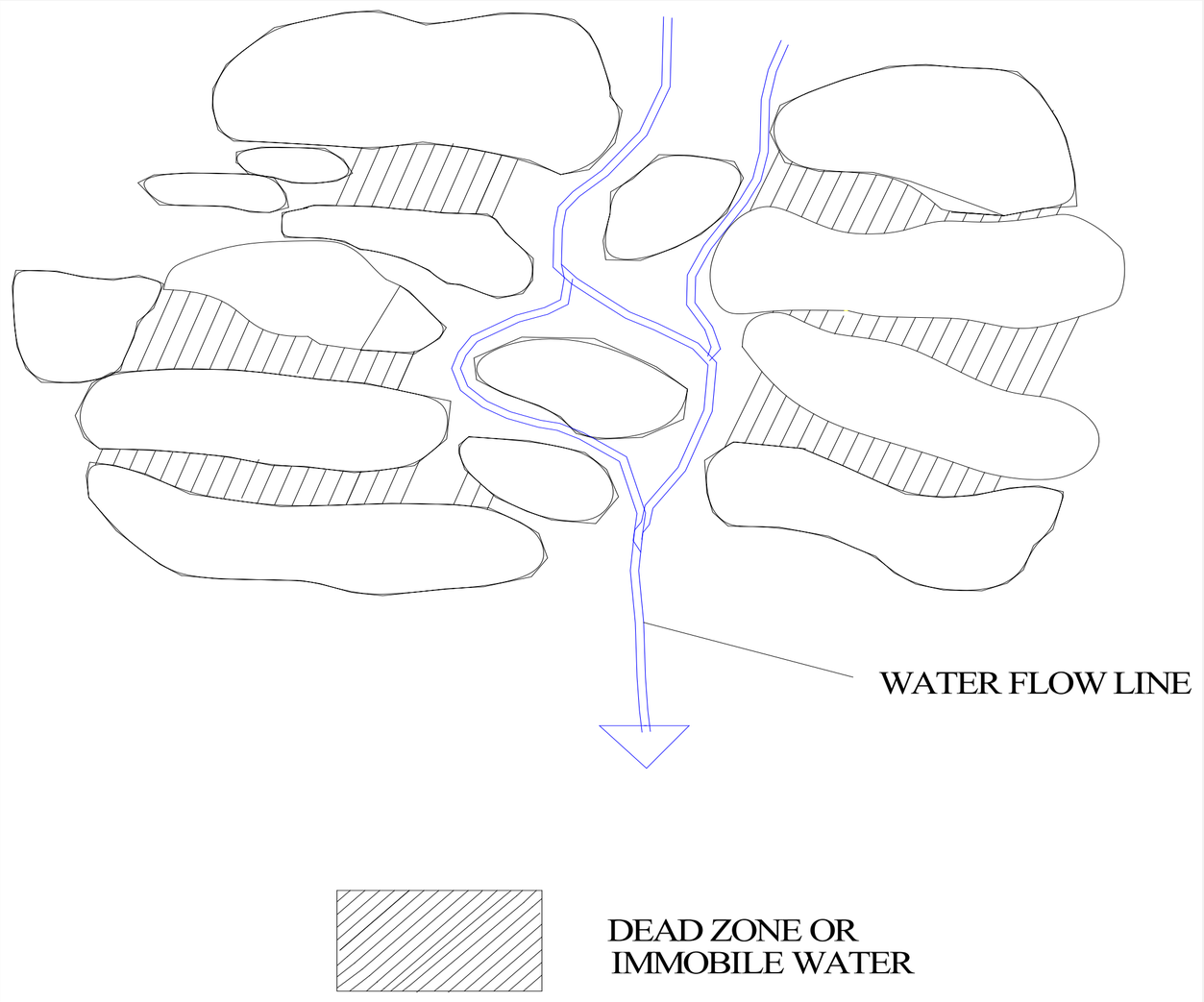
Soil Characteristics

Petro-Physical Testing

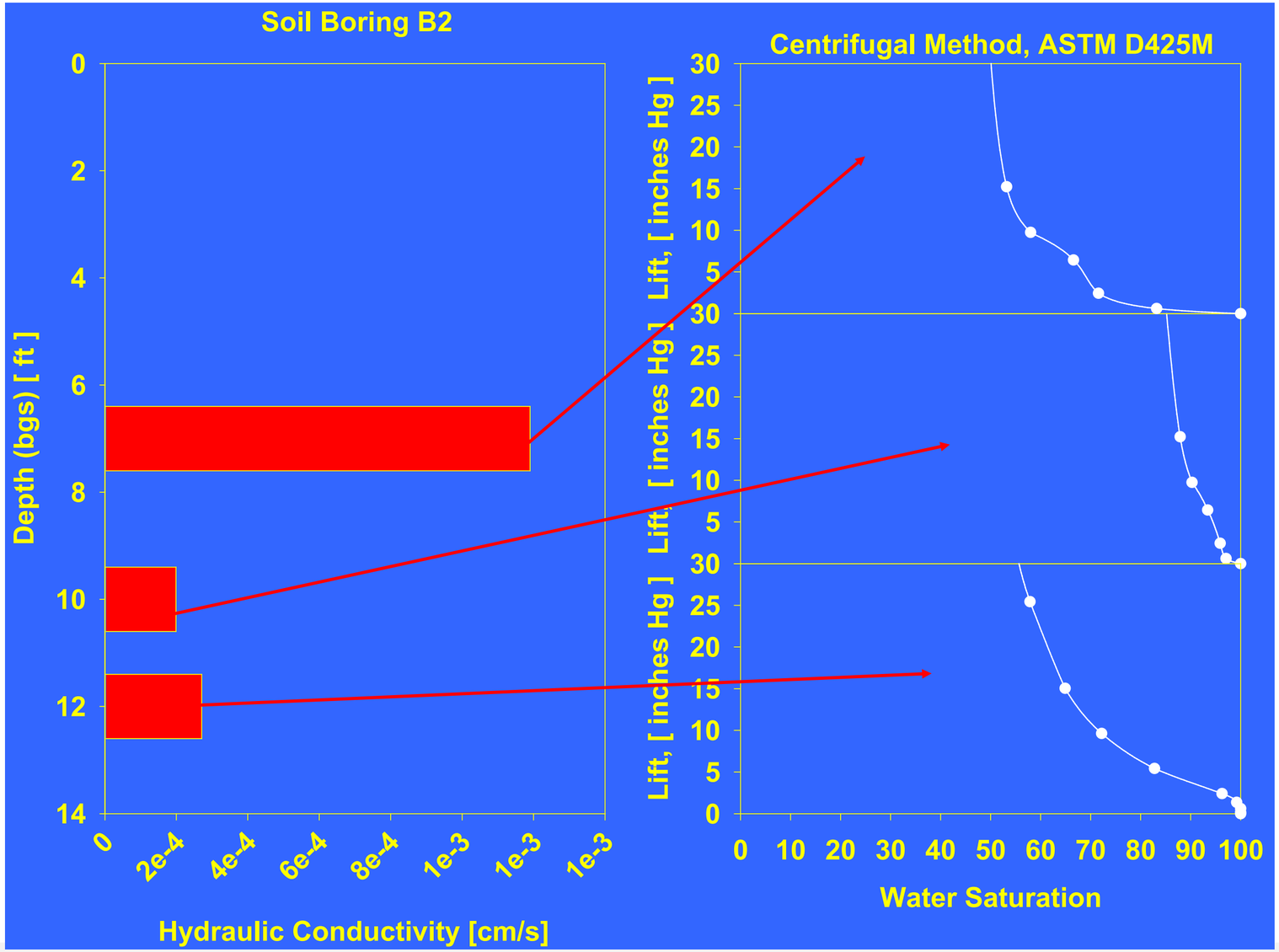
- Grain size distribution
- Porosity- Effective and Bulk
- Permeability
- Capillary Pressure Tests

Advanced Site Characterization Tools

- MIP Investigation
- CPT Investigation
- Wireline logging
- Hydraulic profiling tools



Effective Porosity

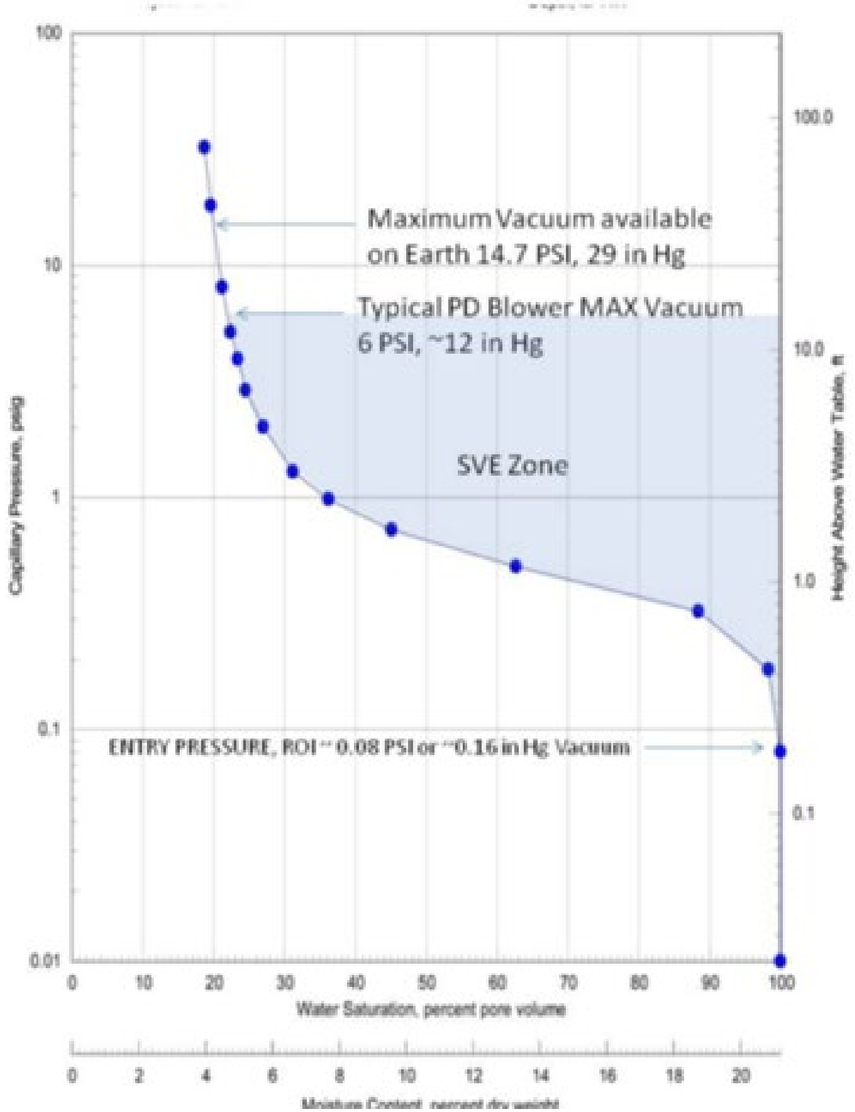


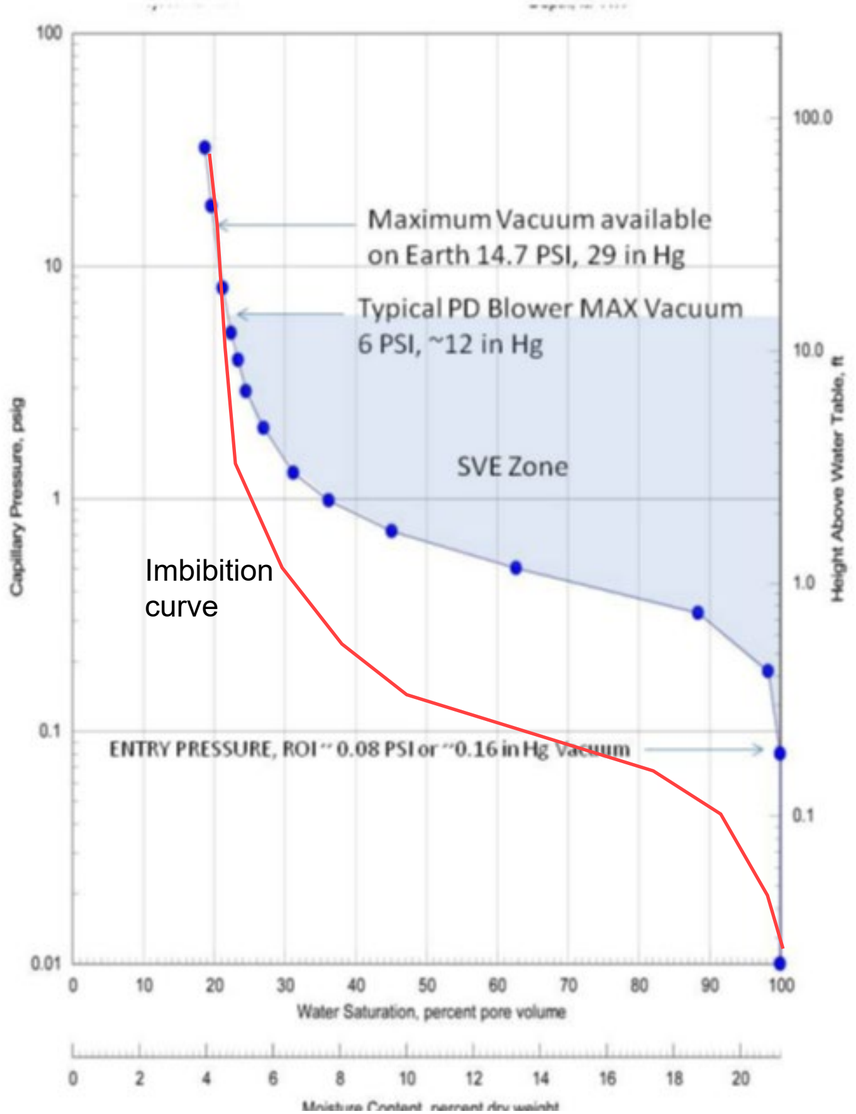
C

A

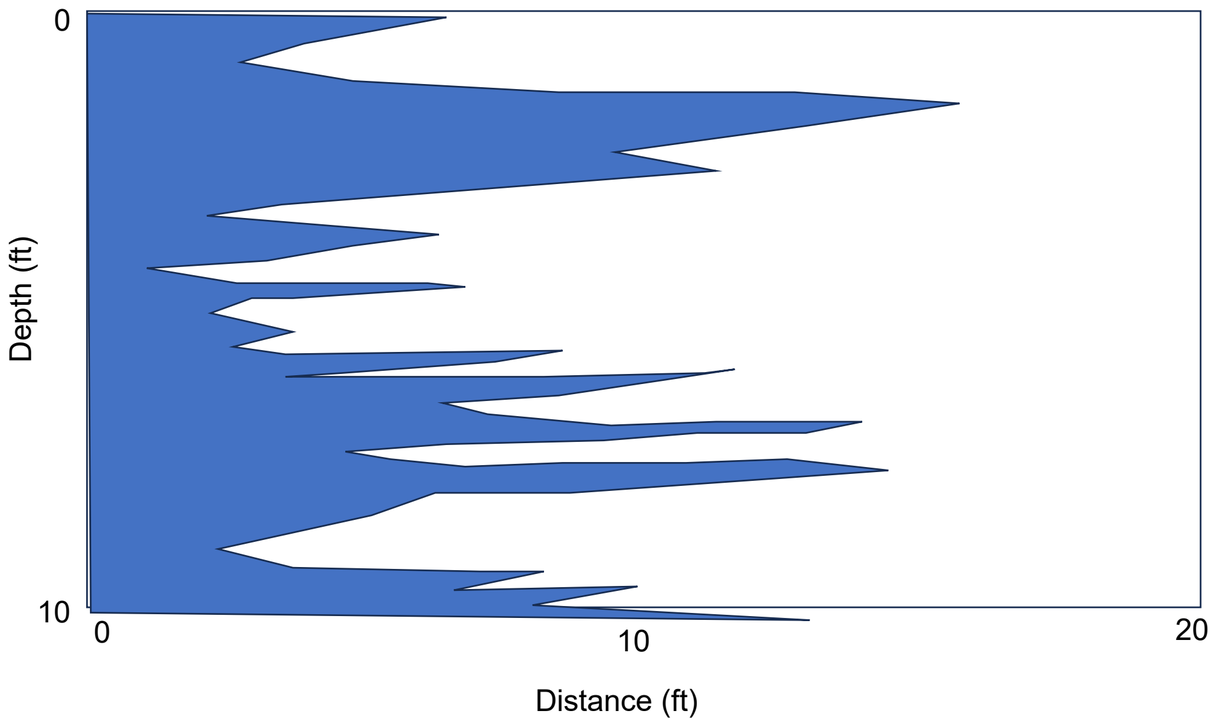
B

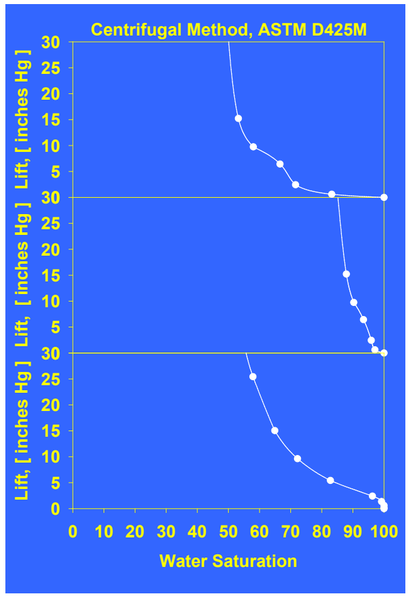
Effective Porosity vs Mobile Porosity?



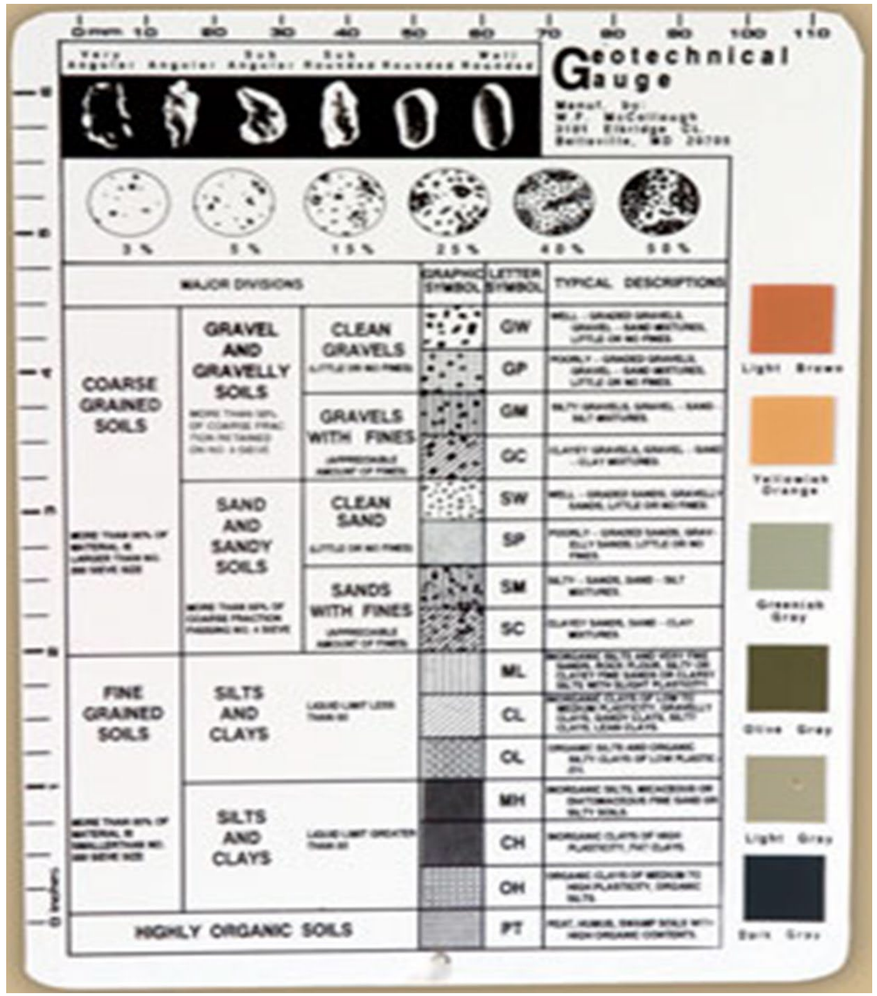


Dispersion, Layered Stratigraphy

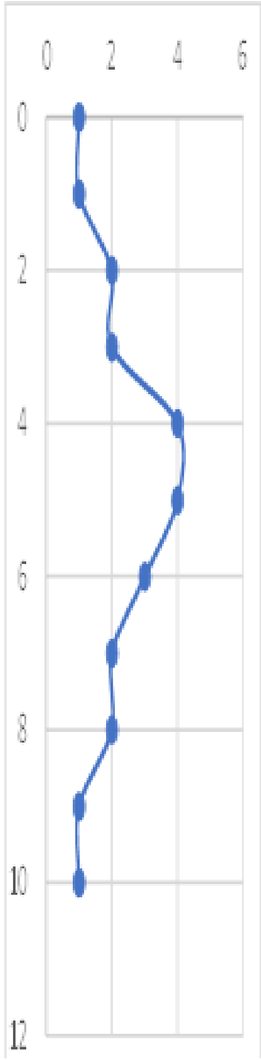




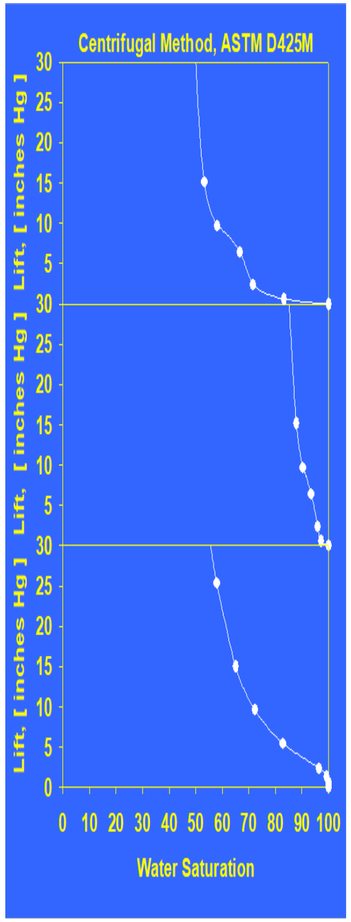
USCS and Sequence Stratigraphy



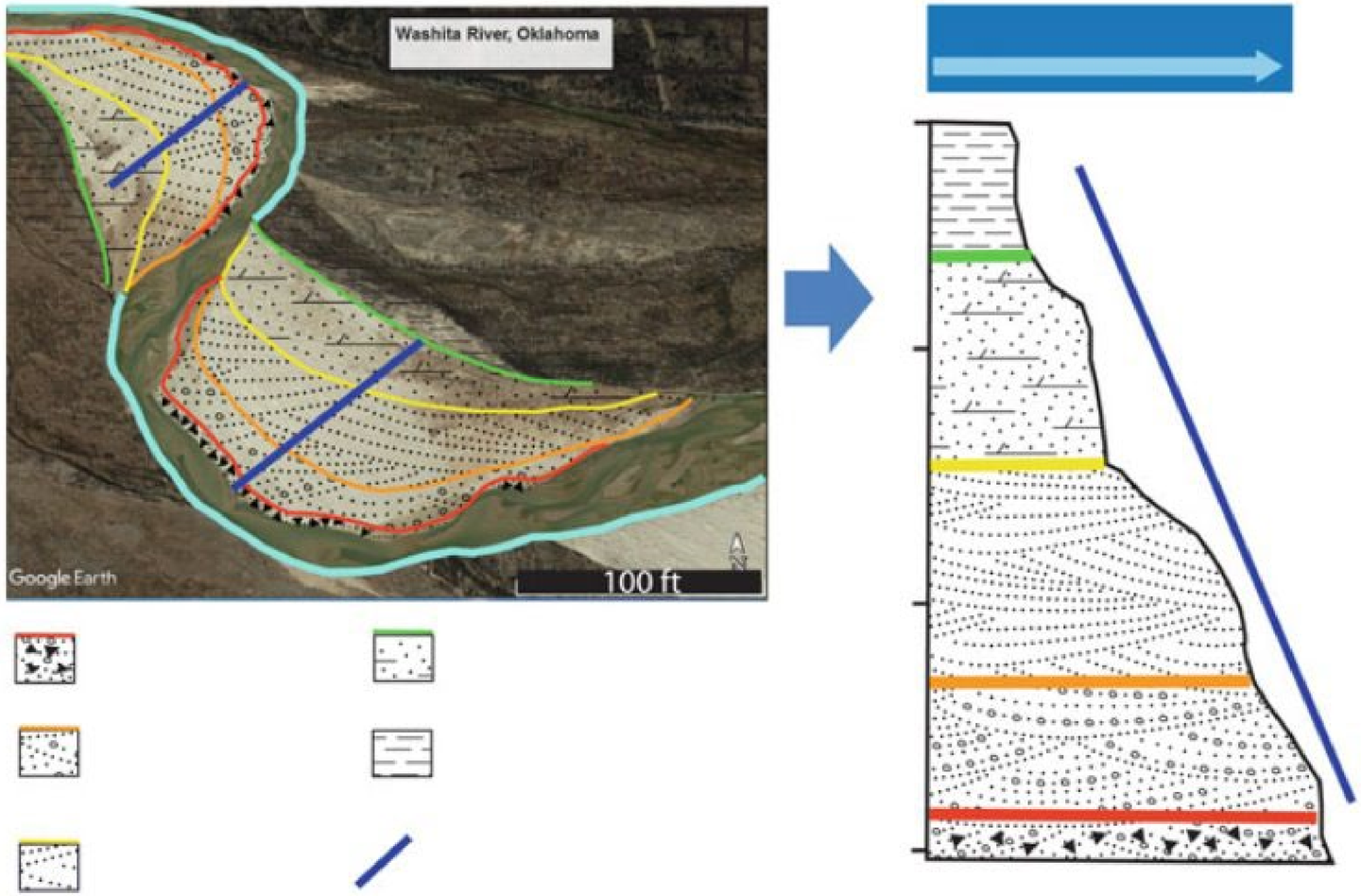
GP
GP/GW
SP
SM
SM/ML
SM/ML
SP
SP
GP/GW
GP



SP
ML
SP/SM

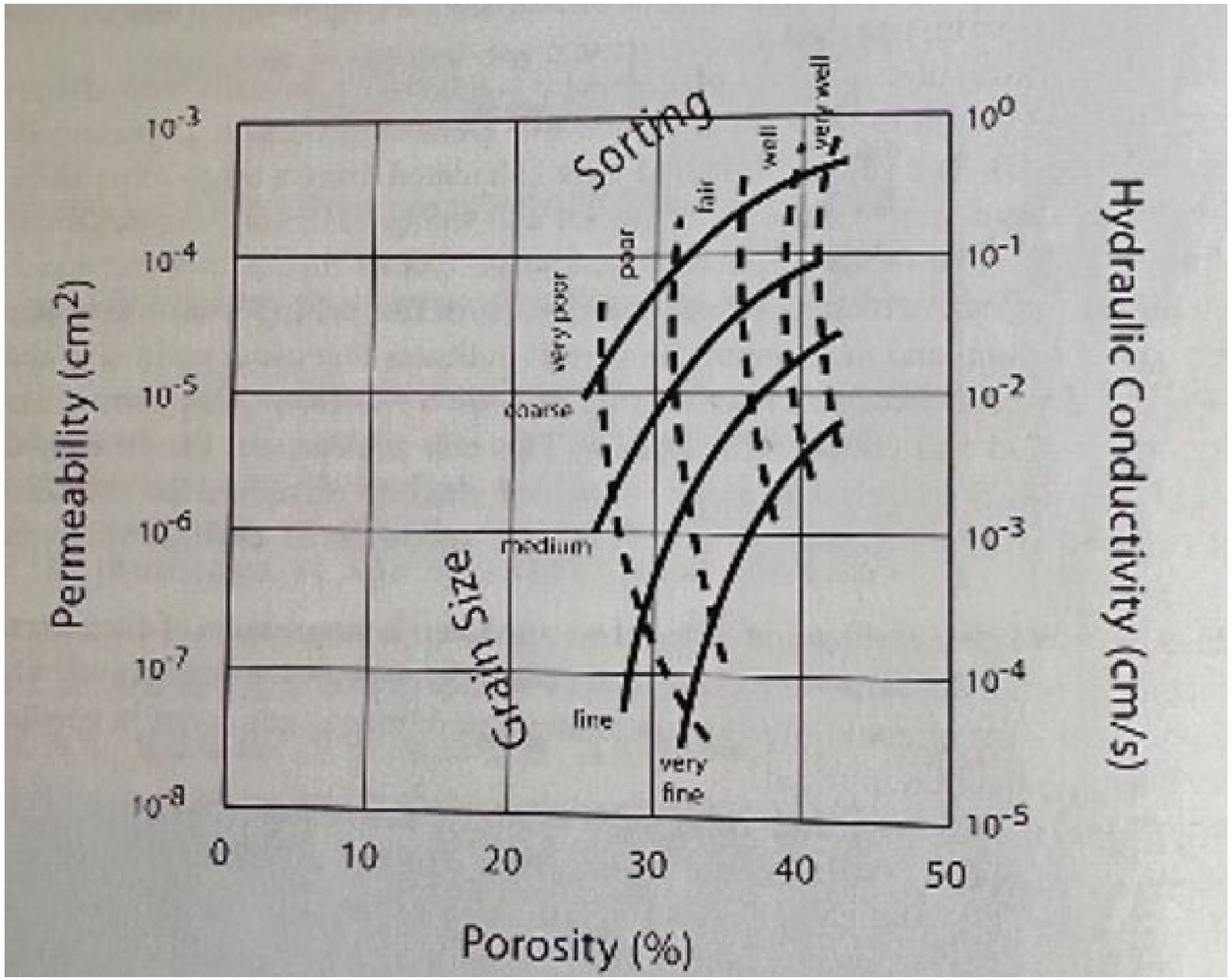


Sequence Stratigraphy Application for Fluvial Sediments



Advances in the Characterization and Remediation of Sites Contaminated with Petroleum Hydrocarbons - Jonás García-Rincón · Evangelos Gatsios · Robert J. Lenhard · Estella A. Atekwana · Ravi Naidu Editors, Springer – Open Access

USCS and Porosity / Permeability



Permeability Conversions

Table 2.2 Range of Values of Hydraulic Conductivity and Permeability

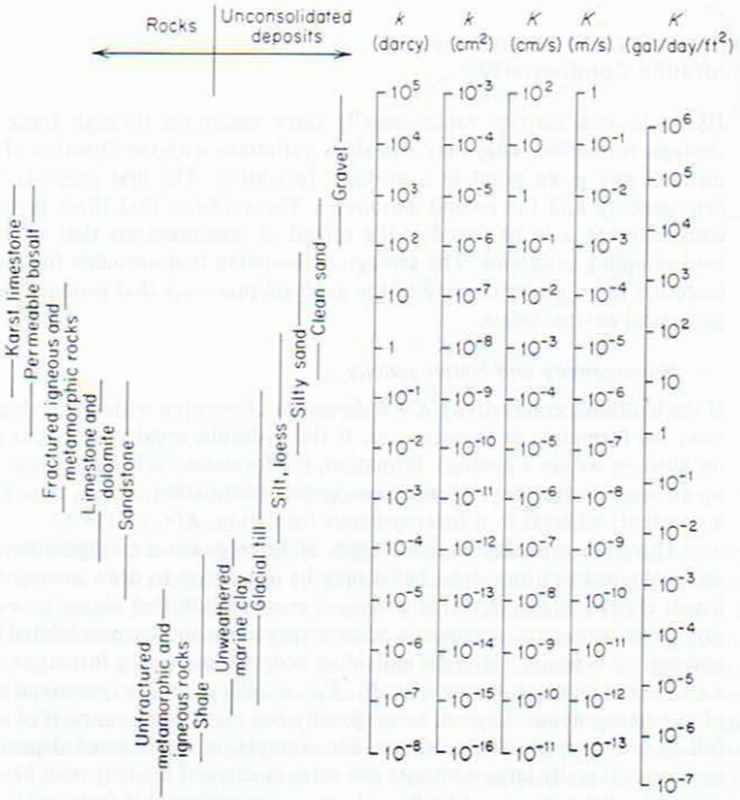


Table 2.3 Conversion Factors for Permeability and Hydraulic Conductivity Units

	Permeability, k*			Hydraulic conductivity, K		
	cm²	ft²	darcy	m/s	ft/s	U.S. gal/day/ft²
cm²	1	1.08×10^{-3}	1.01×10^{8}	9.80×10^{2}	3.22×10^{3}	1.85×10^{9}
ft²	9.29×10^{2}	1	9.42×10^{10}	9.11×10^{5}	2.99×10^{6}	1.71×10^{12}
darcy	9.87×10^{-9}	1.06×10^{-11}	1	9.66×10^{-6}	3.17×10^{-5}	1.82×10^{1}
m/s	1.02×10^{-3}	1.10×10^{-6}	1.04×10^{5}	1	3.28	2.12×10^{6}
ft/s	3.11×10^{-4}	3.35×10^{-7}	3.15×10^{4}	3.05×10^{-1}	1	6.46×10^{5}
U.S. gal/day/ft²	5.42×10^{-10}	5.83×10^{-13}	5.49×10^{-2}	4.72×10^{-7}	1.55×10^{-6}	1

*To obtain k in ft², multiply k in cm² by 1.08×10^{-3}.

29 Physical Properties and Principles / Ch. 2

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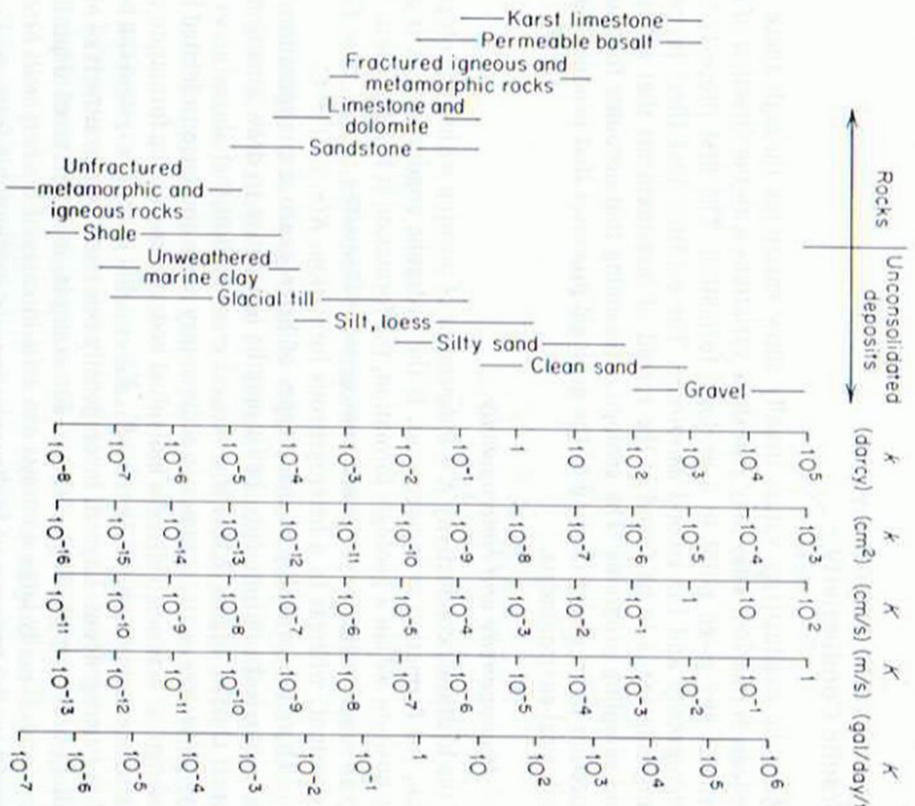

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*To obtain k in ft², multiply k in cm² by 1.08×10^{-3}.

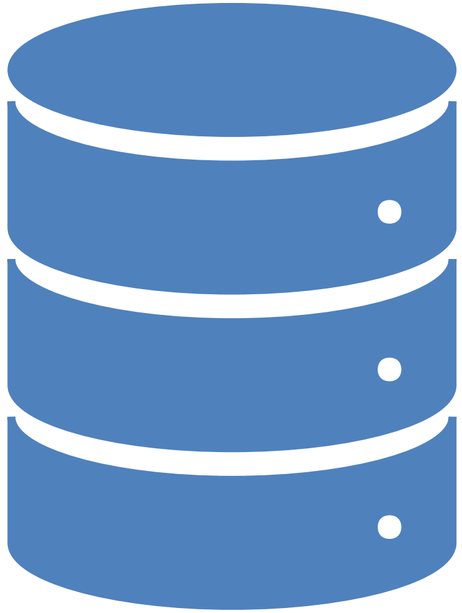
Data Collection Strategy and Analysis starts in the field

- With custom data applications you can make sure your field staff will be able to enter data quickly, accurately and efficiently
- Using electric field forms you can add rules to only allow data to be entered correctly the first time.
- Modern field form applications allow for the collection of data without direct user input. (positional data, photos)
- Field calculations can be programmed into forms to make sure units are converted correctly or complex calculations can be done instantly and used for reference.

Data Collection Structure

- Using data hierarchy, related data can be collected to enhance data reporting and entry.
- A clear structure is required to organize your data in related tables.

Projects	Events	Objects	Field Data
Site information Client Information Billing Information Project specific Compliance	Specific Tasks Specific to one form Event specific parameters	Data collection points Wells, Probes, System Data collection points. Physical Data Stored in these records. Depth, thickness, positional data.	Data collected for Objects Temp, ORP, pH, Depth Photos, Positional data

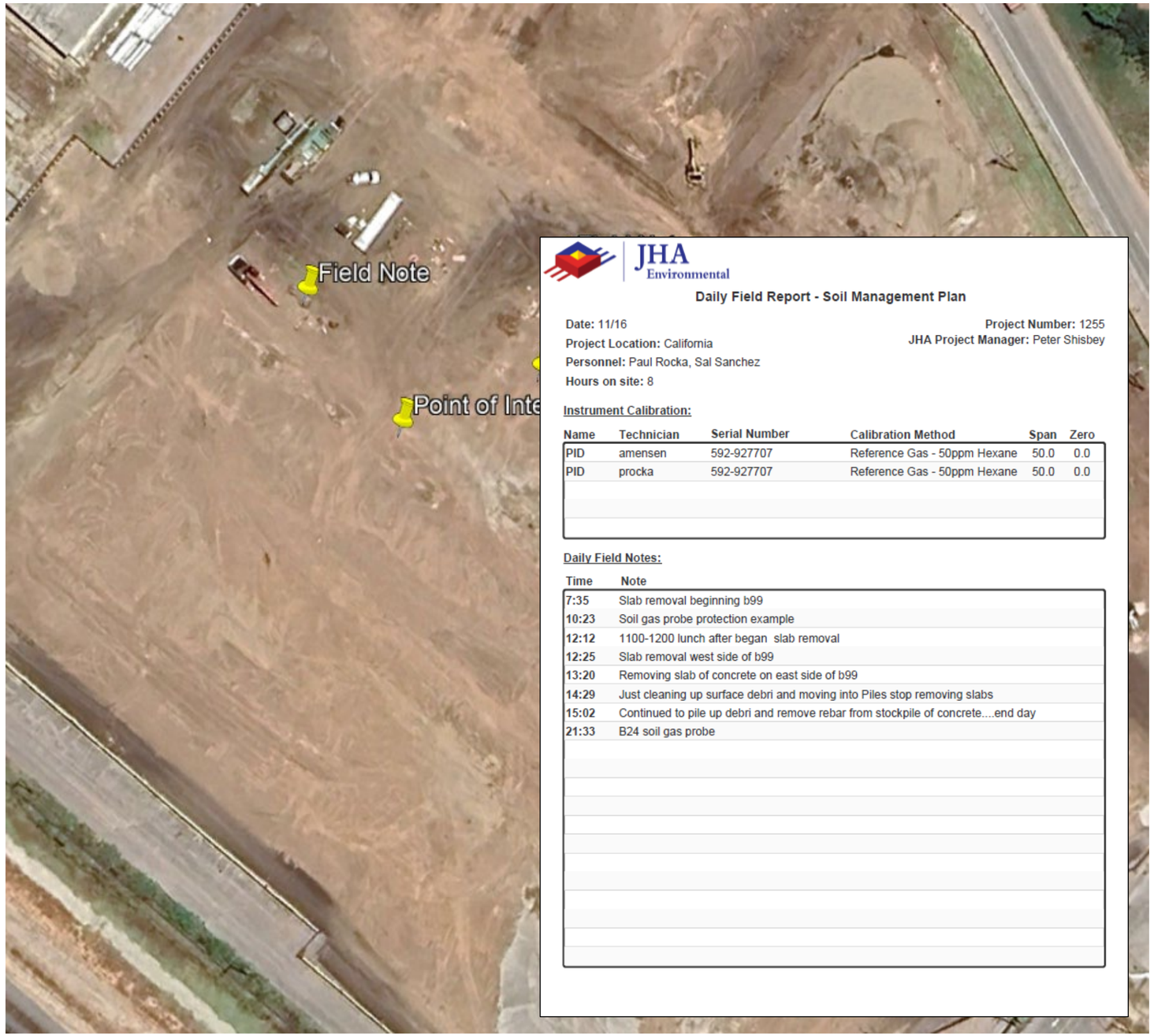


A case study – Site Background

- Large multiuse property with ongoing demolition
- Strict regulatory requirements and multiple instruments running collecting data at once.
- Up to five technicians in the field collecting regulatory data and assessment data.
- All data being collected on paper and then transcribed into excel databases.
- Multiple deliverables due daily from the site

A case study – Digital Transformation

- All field staff equipped with smart phones and or tablets
- Electronic monitoring equipment files incorporated into project database.
- Through electric field forms photo logs and positional data was incorporated into automated daily field reports.
- Custom exports allow for data to still be used in legacy spreadsheets when required.
- Site deliverables completed almost autonomously eliminating hours of reporting time.
- Automated reports sent to stakeholders when milestones were met on the project.



JHA Environmental

Daily Field Report - Soil Management Plan

Date: 11/16
Project Location: California
Personnel: Paul Rocka, Sal Sanchez
Hours on site: 8

Project Number: 1255
JHA Project Manager: Peter Shisbey

Instrument Calibration:

Name	Technician	Serial Number	Calibration Method	Span	Zero
PID	amensen	592-927707	Reference Gas - 50ppm Hexane	50.0	0.0
PID	procka	592-927707	Reference Gas - 50ppm Hexane	50.0	0.0

Daily Field Notes:

Time	Note
7:35	Slab removal beginning b99
10:23	Soil gas probe protection example
12:12	1100-1200 lunch after began slab removal
12:25	Slab removal west side of b99
13:20	Removing slab of concrete on east side of b99
14:29	Just cleaning up surface debri and moving into Piles stop removing slabs
15:02	Continued to pile up debri and remove rebar from stockpile of concrete....end day
21:33	B24 soil gas probe

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Workshop - 02

MODULE-02

Site Characterization, 3D Visualization, Remedial Evaluation and Injection Optimization

JHA Environmental

Part 1: Investigation Tools and Technology

Part 2: Example Deliverables

Part 3: Evaluation of Remedial Options

Part4: Injection Design & Optimization

Part 1: Investigation Tools and Technology

- What are the Drilling Tools?
- Example Boring Logs
- Vendors
- 3D Technology – What's Changed?
- 3D Visualization Software Options
- Automation

Data Collection – What are the Drilling Tools?

Membrane Interface Probe (MIP)

Optical Image Profiler (OIP)

Groundwater Profiling Tool

Hydraulic Profiling Data Typically Collected Simultaneously

Membrane Interface Probe (MIP) or MiHPT

Membrane Interface Probe (MIP)

Description:

As the tool is advanced, a heater block volatilizes contaminants in both soil and groundwater. Contaminants pass through the membrane and are transported to the surface by an inert carrier gas to be analyzed by a series of detectors, typically a PID, FID, and XSD (halogen-specific detector).

Applications:

Chlorinated Solvents (TCE, PCE, Vinyl Chloride)
Hydrocarbons (Gasoline and Diesel)
Most Volatile Contaminants in Soil or Groundwater (500 ppb to 10,000 ppm)

Not For:

PFOA or PFOS
Metals or other Non-Volatile Contaminants
Free Product (with Caution)

Membrane Interface Probe (MIP) – Example Log

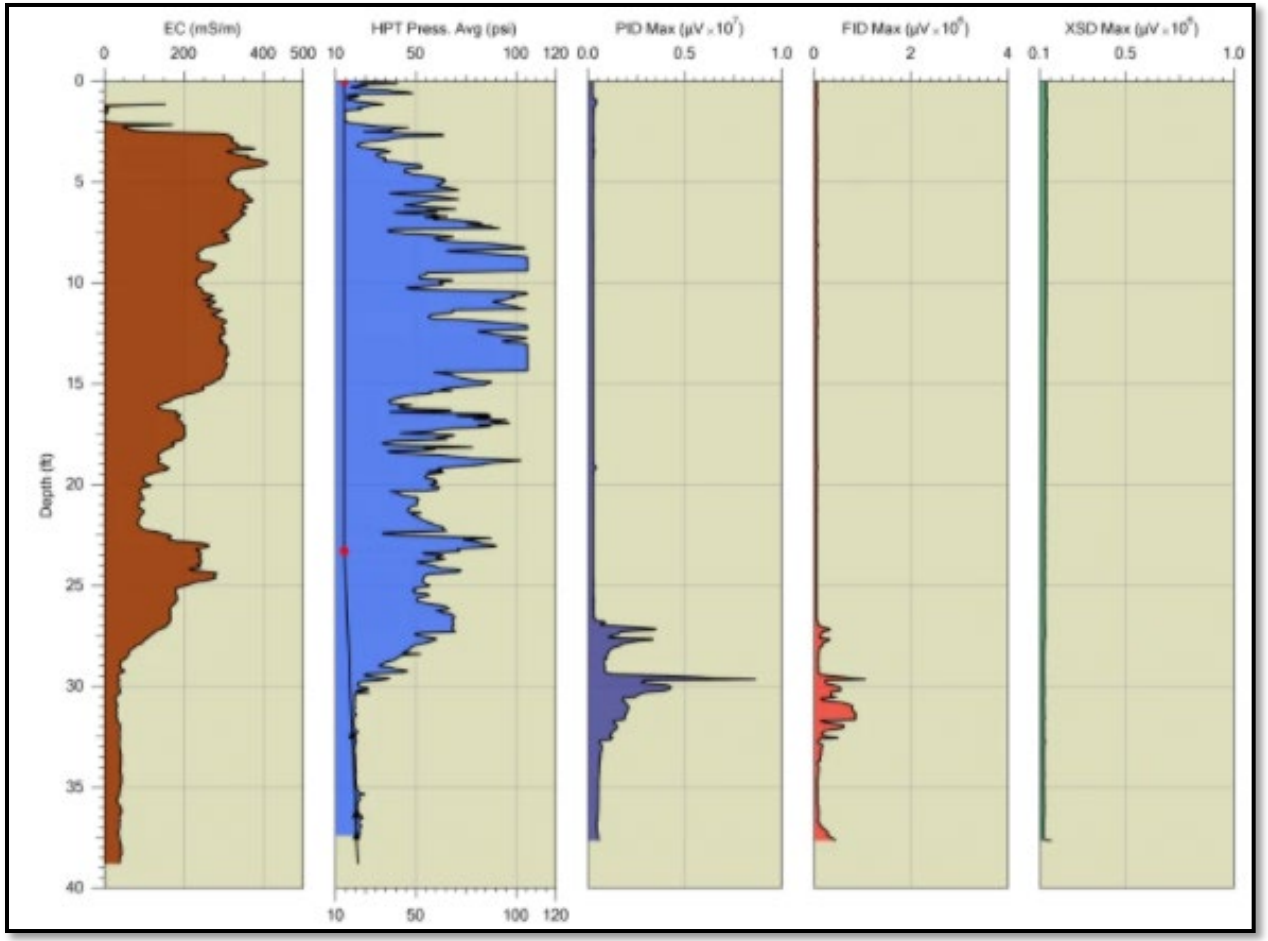
Electrical Conductivity: Electrical conductance of the subsurface soils – generally higher in finer-grained soils

Hydraulic Profiling Tool Pressure: Measured pressure from injected water

Photo Ionization Detector (PID): Commonly used detector, sensitive to Volatile Organic Compounds (VOCs), like petroleum distillates and chlorinated ethenes

Flame Ionization Detector (FID): Less sensitive, responds to many of the same compounds as the PID, also methane.

Halogen Specific Detector (XSD): Only sensitive to chlorinated, fluorinated, and brominated compounds, including chlorinated ethenes and alkanes (PCE, TCE, 1,1,1-TCA, vinyl chloride, etc.)



Optical Image Profiler (OIP) or OIHPT

Optical Image Profiler (OIP)

Description:

As the tool is advanced, an Ultra-Violet (UV) light induces fluorescence of the Polycyclic Aromatic Hydrocarbons (PAHs) found in hydrocarbons. This fluorescence is captured by an onboard camera and recorded in high resolution (every 0.05' of advancement).

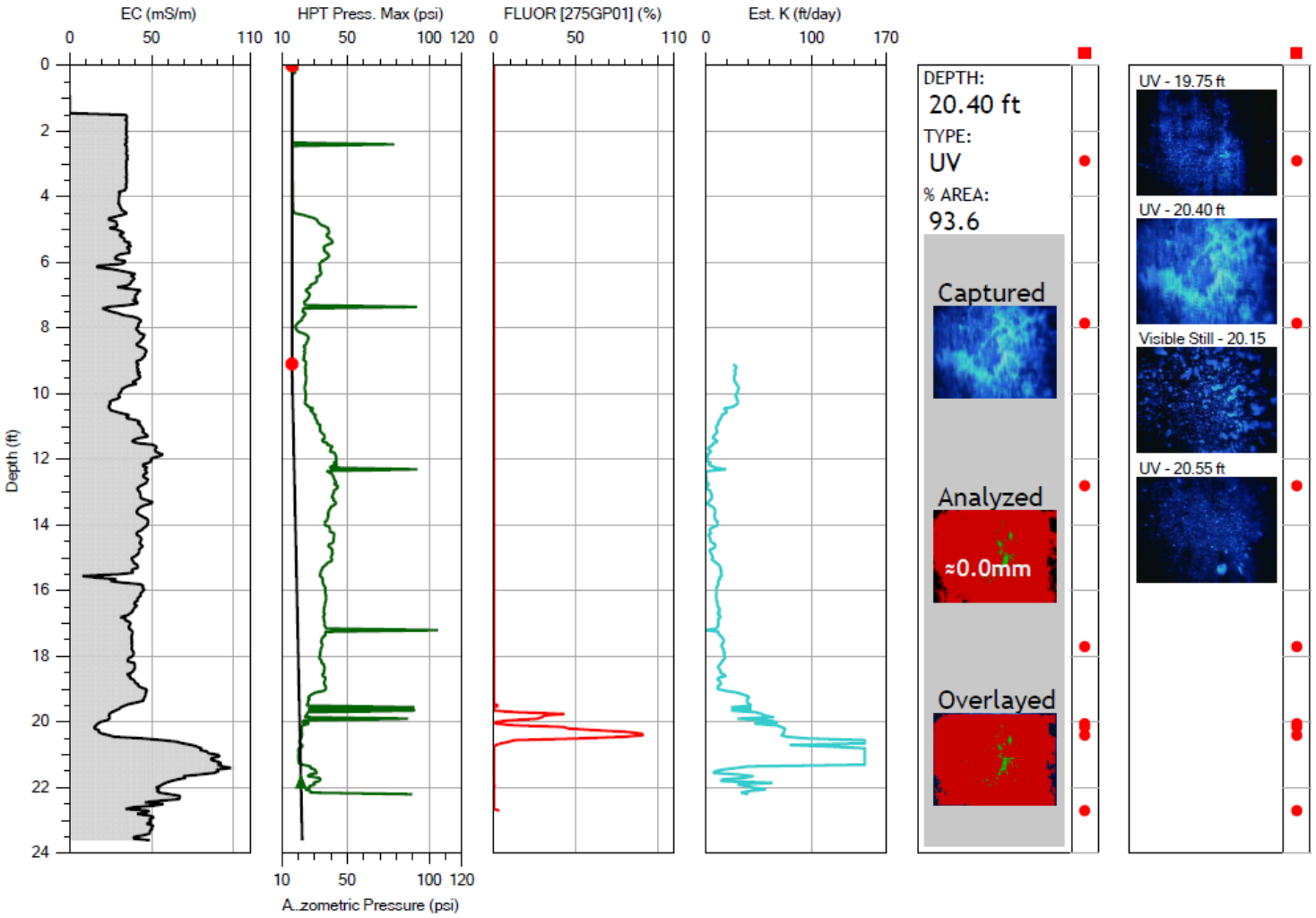
Applications:

Free Product - Light and Mid Range Hydrocarbons
Hydrogeologic Classification (Hydraulic Profiling Tool)

Not For:

Free Product from Heavier Hydrocarbons (OIP-G)
Dissolved or Sorbed Contamination

Optical Image Profiler (OIP) – Example Log



Electrical Conductivity: Electrical conductance of the subsurface soils – generally higher in finer-grained soils

Hydraulic Profiling Tool Pressure: Measured pressure from injected water

FLOUR (%): Fluorescence percentage. Measured as a percentage of fluorescence within the window of the OIP tool

Est. K: The estimated hydraulic conductivity of the subsurface soils. Calculated from the injection pressure and flow rate

Groundwater Profiling Tool

Groundwater Profiling Tool

Description:

As the tool is advanced, a small amount of deionized water is continuously injected into the formation while injection pressure values are continuously recorded. Below the water table, flow can be stopped and groundwater samples can be collected for laboratory analysis.

Applications:

PFOA or PFOS
Metals
Any Contaminant in Groundwater

Not For:

Free Product

Data Collection – **Vendors**

CASCADE

Vista GeoScience

Direct Push Analytical Corp.

GEO IMAGING SYSTEMS LLC

COLUMBIA TECHNOLOGIES

parratt wolff inc

GREGG

DAKOTA TECHNOLOGIES

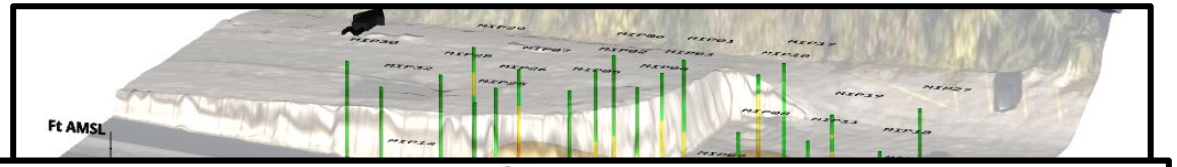
CONETEC

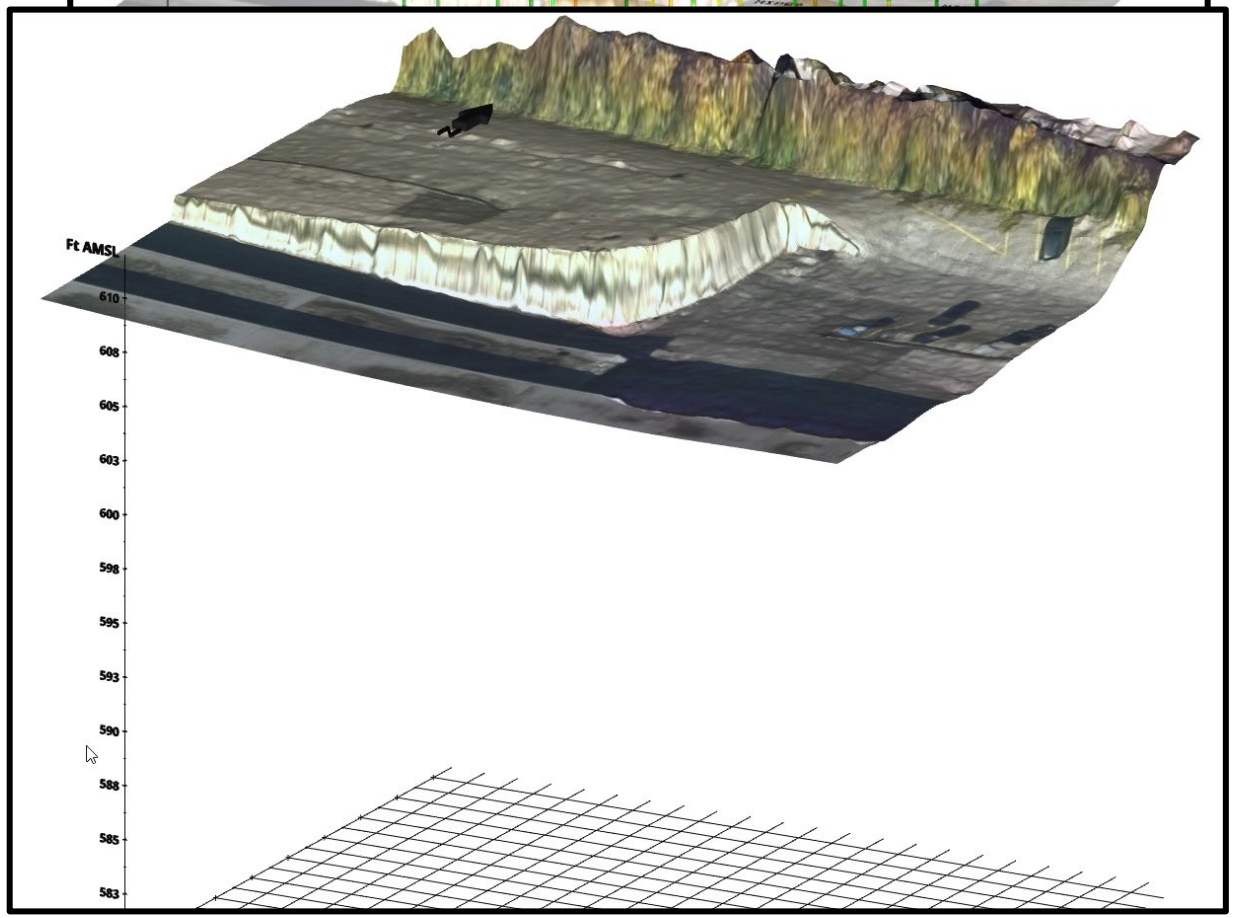
EAGLE SYNERGISTIC

Specializing in HRPC subsurface imaging technologies

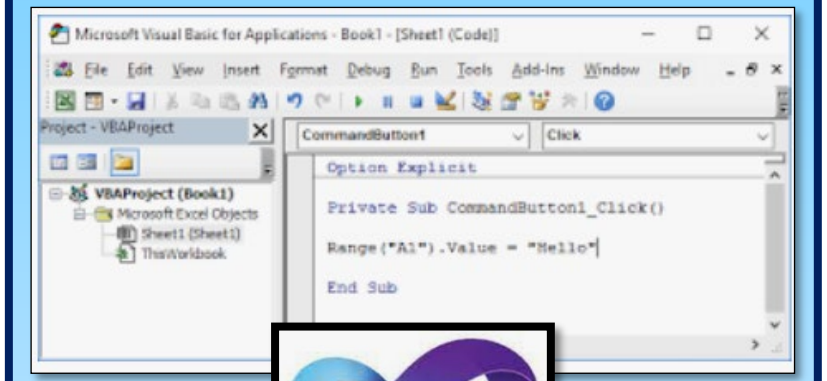
3D Visualization Technology – **What's Changed?**

	Older Technology	Recent Technology
Types of Deliverables	**Static** (Screenshots)	**Interactive** (Animations & Web Scenes)
Number of Data Points	**Tens to Hundreds** (Analytical Data)	**Thousands to Millions** (HRSC & LiDAR)
Modeling Run Times	**Minutes to Hours** (Antiquated Hardware)	**Seconds to Minutes** (Moore's Law)
Data Formatting Times	**Days To Weeks** (Manual)	**Hours** (Automation)





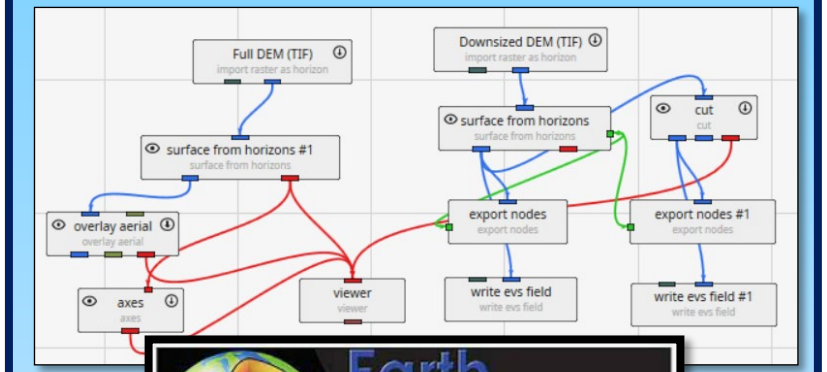
Data Automation – What are the Tools?



Macros in Excel

Compile Data and Build Input Files Efficiently

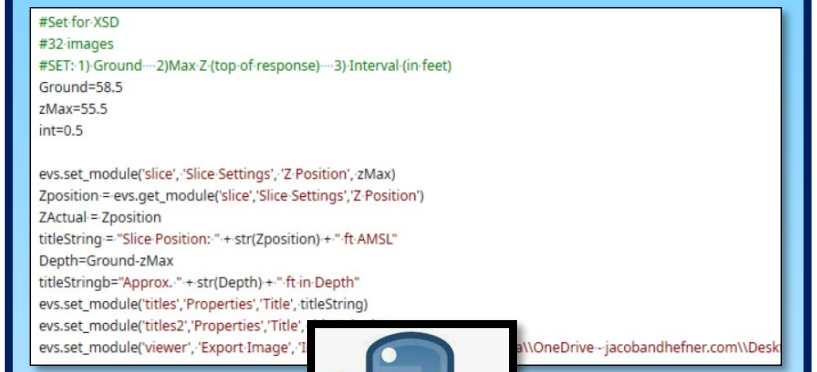
Some Coding Needed



EVS by C-Tech

Process and Visualize Datasets Repeatably

"No Code"

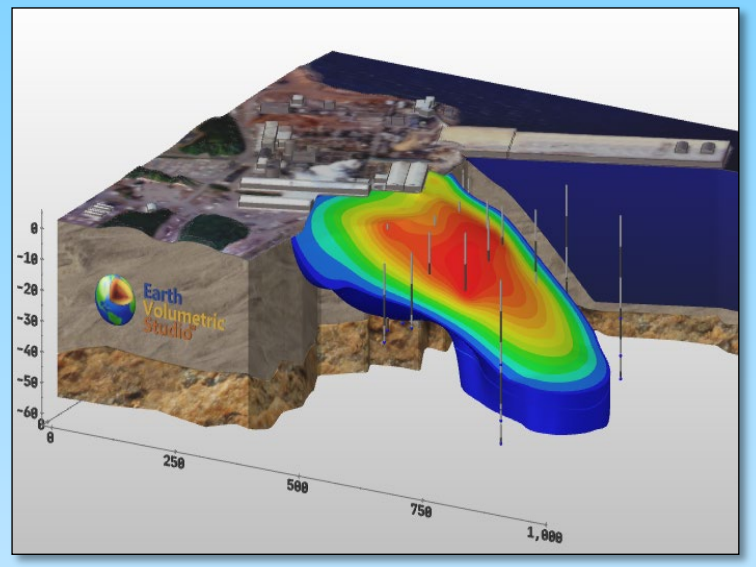


Python Scripting

Create Data Deliverables Automatically

"Low Code"

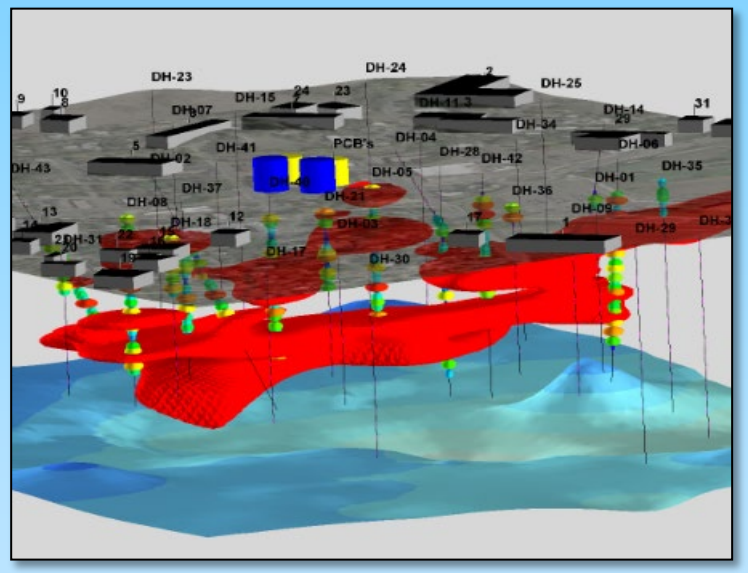
Software Options: 3D Statistical Modeling Programs



Earth Volumetric Studio

by C-Tech

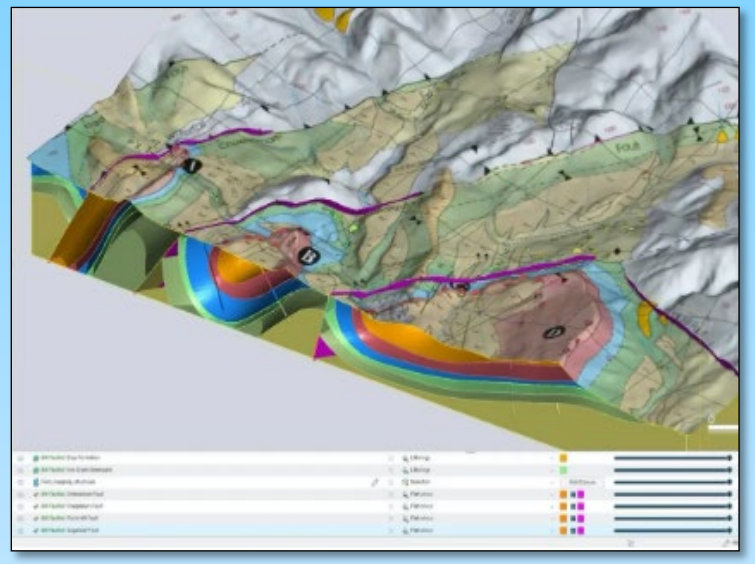
$17,000/License + 3,500/year



Rockworks

By Rockware

$5,000/License



Leapfrog Geo

By Seequent

$2,100/Month

Other Data Resources

USGS
science for a changing world

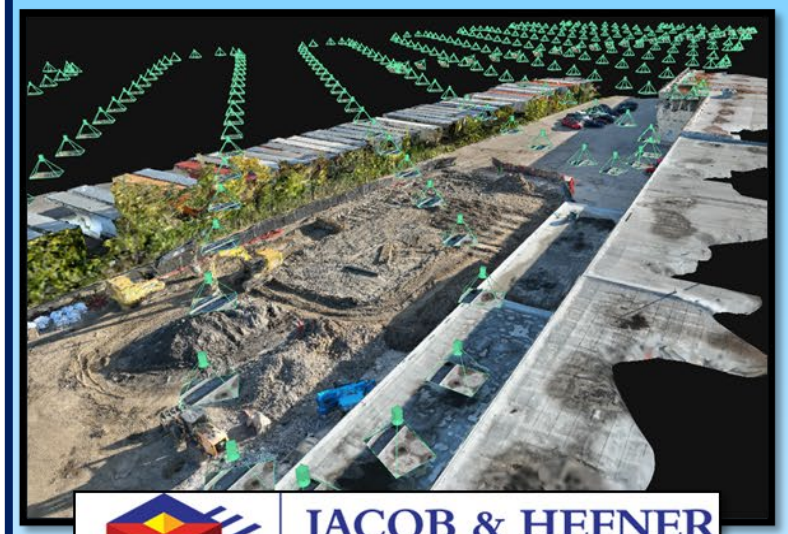
USGS 3D Elevation Program (3DEP)

Free LiDAR Data

nearmap

Near Map

High Resolution Aerial Photos



JACOB & HEFNER ASSOCIATES

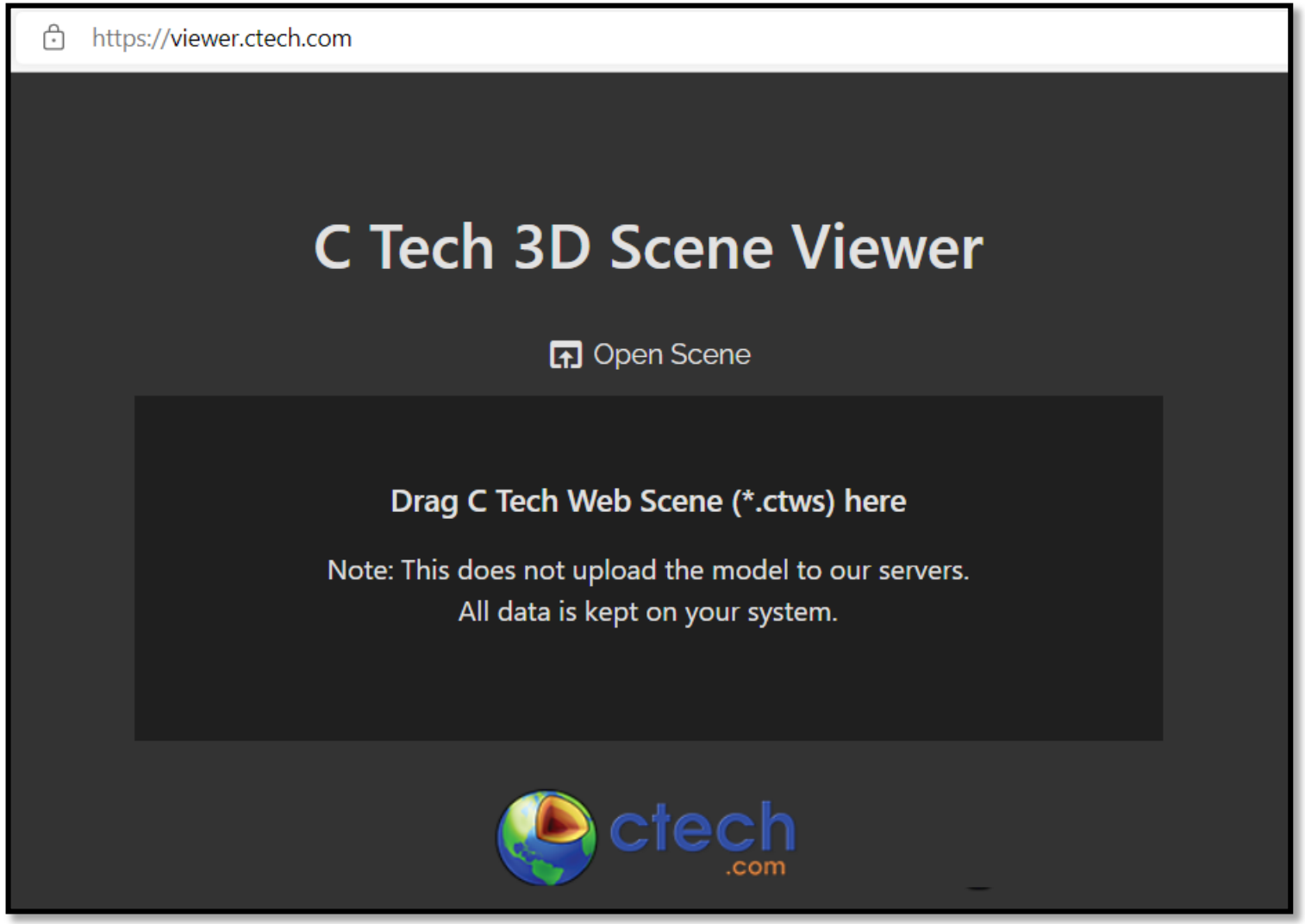
Drone Surveying

High Resolution Aerial Photos and LiDAR Data

Part 2: Example Deliverables

- 3D Web-Based Interactive Deliverable
- Footprint Maps
- Plan View Maps By Elevation
- Cross Sections
- Volume Estimation
- Mass Calculations

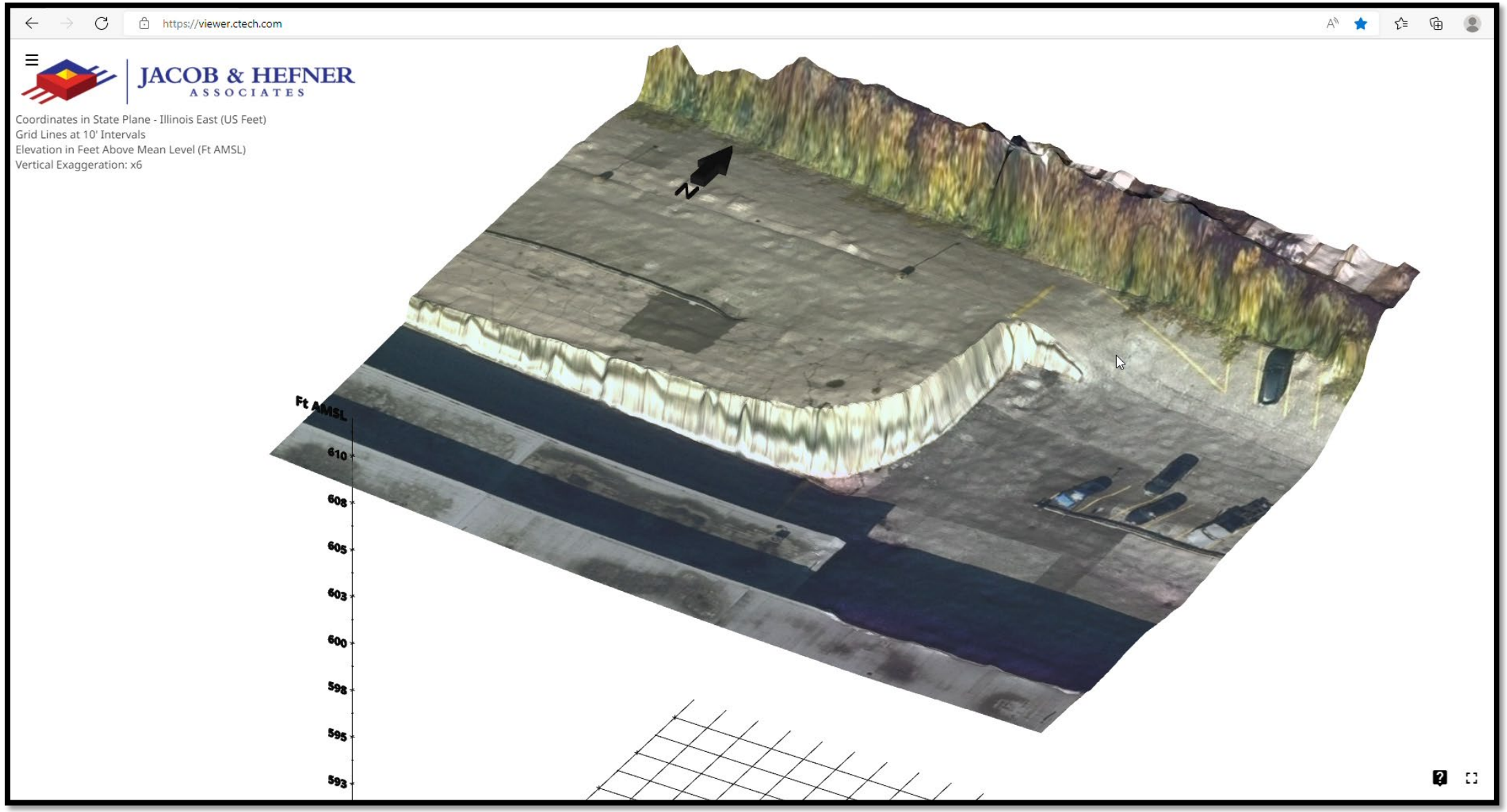
Web Based 3D Deliverable - Accessible and Understandable



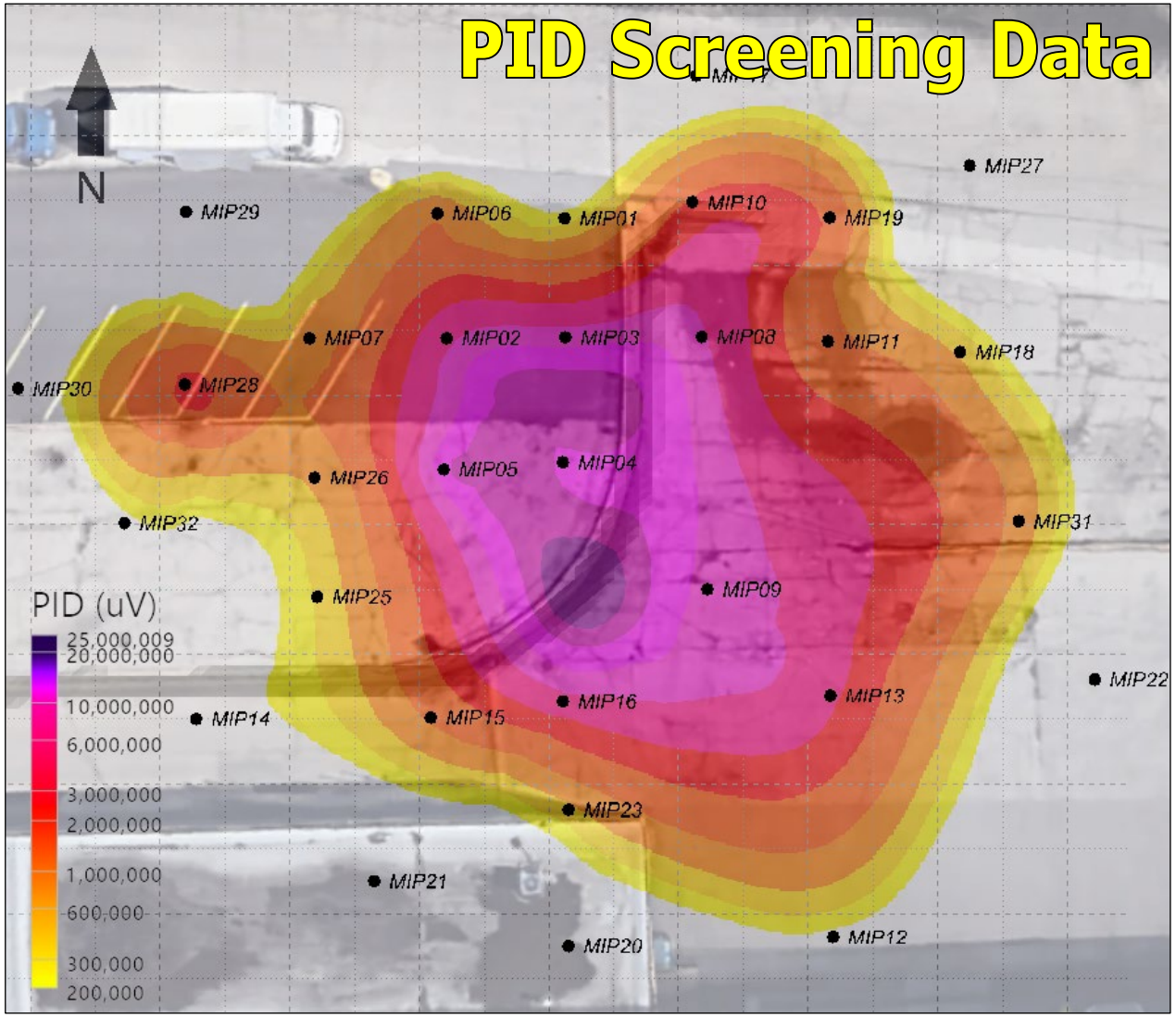
Web Scene.ctws

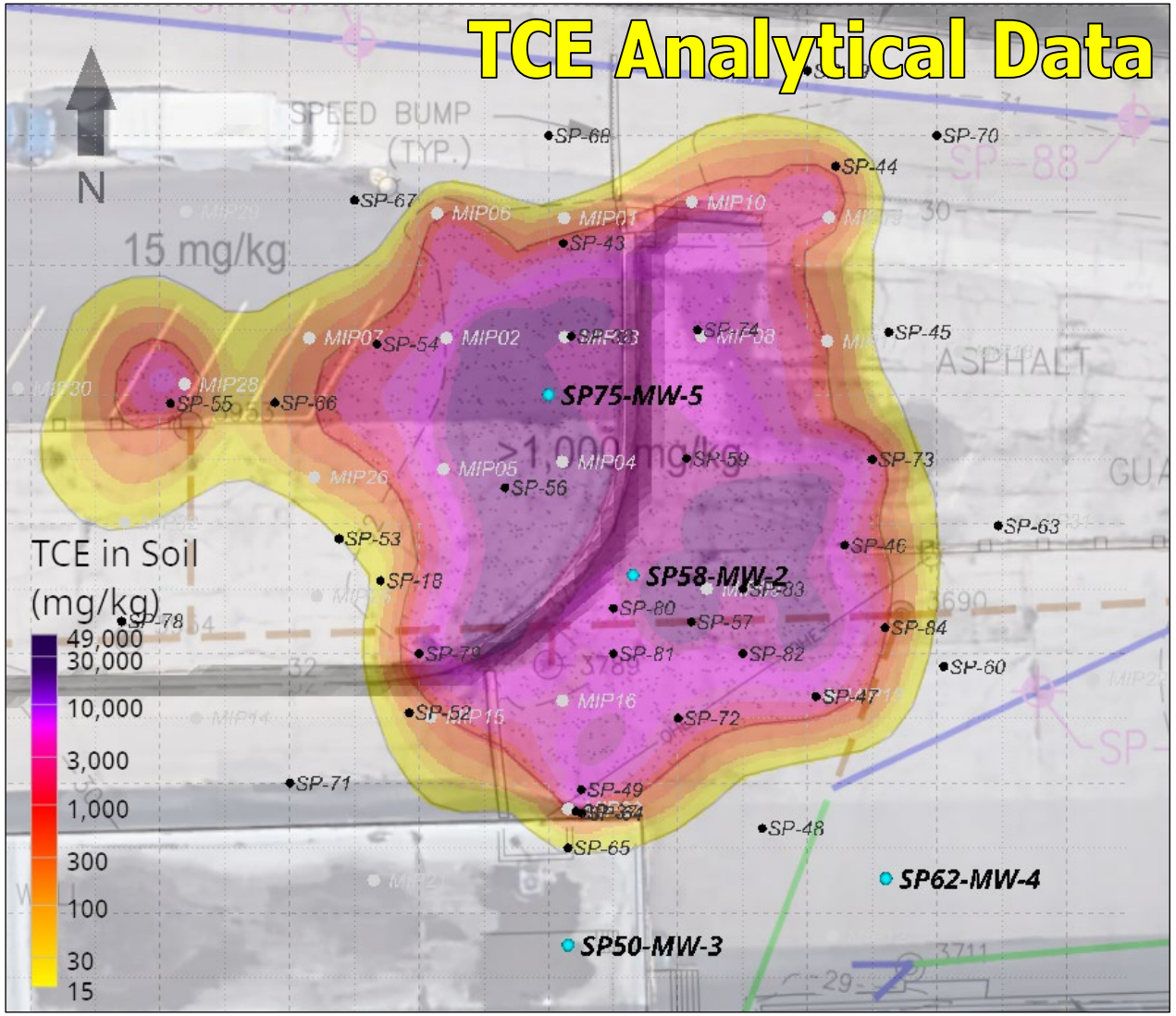
Drag and Drop File
No Software Needed

Example - Web-Based 3D Deliverable

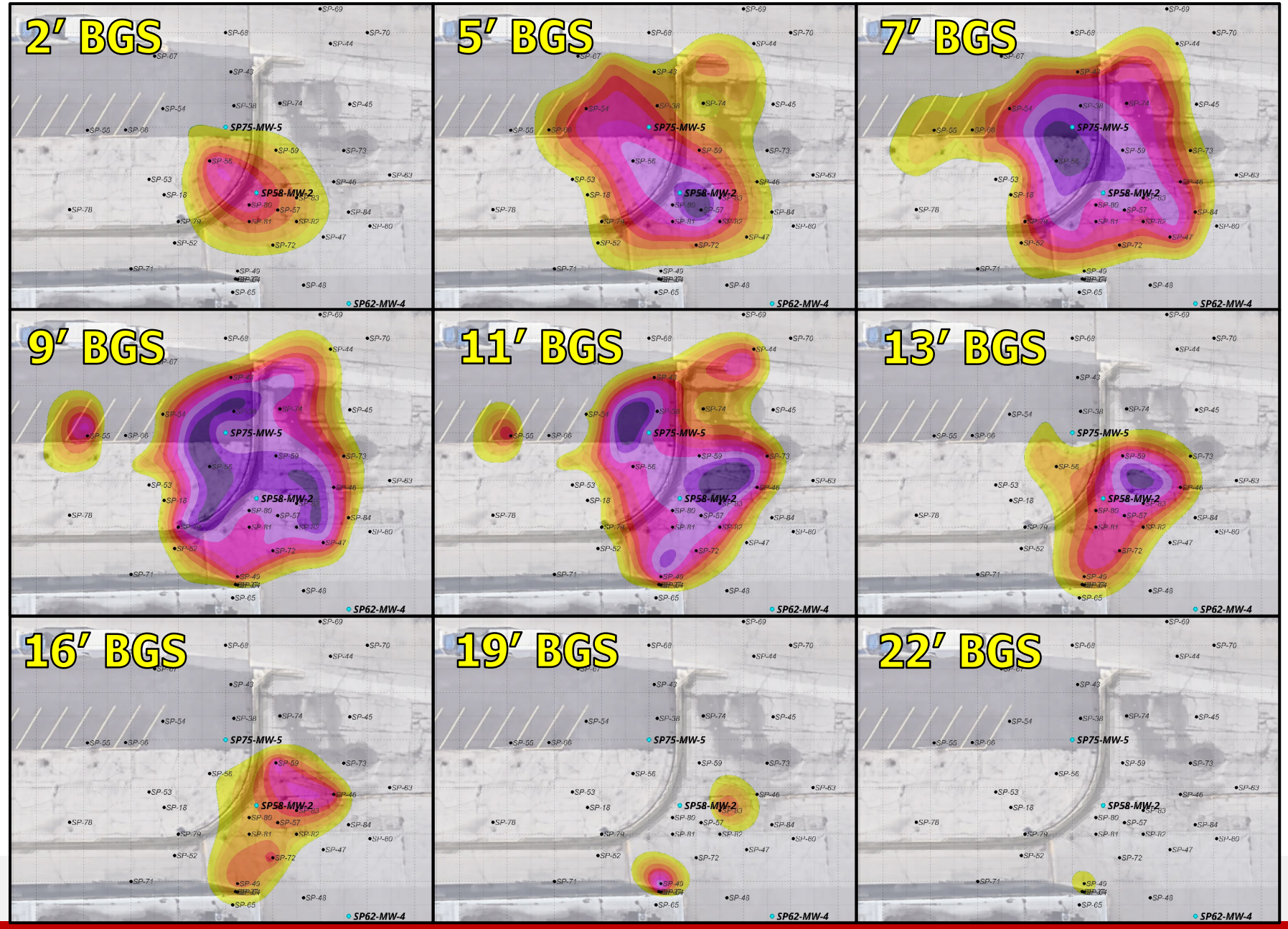


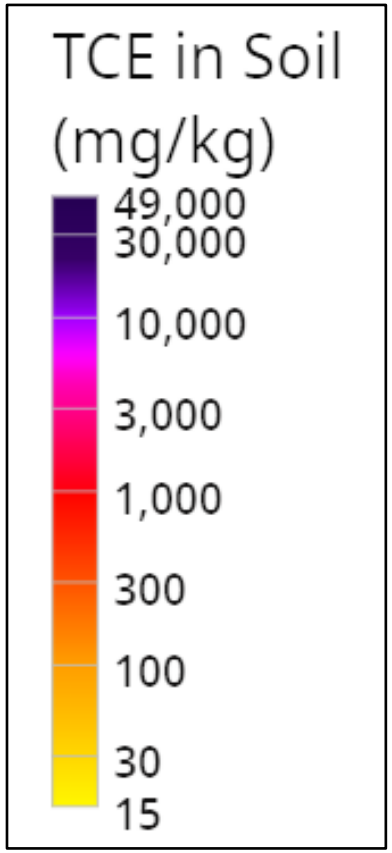
Footprint Maps for Delineation





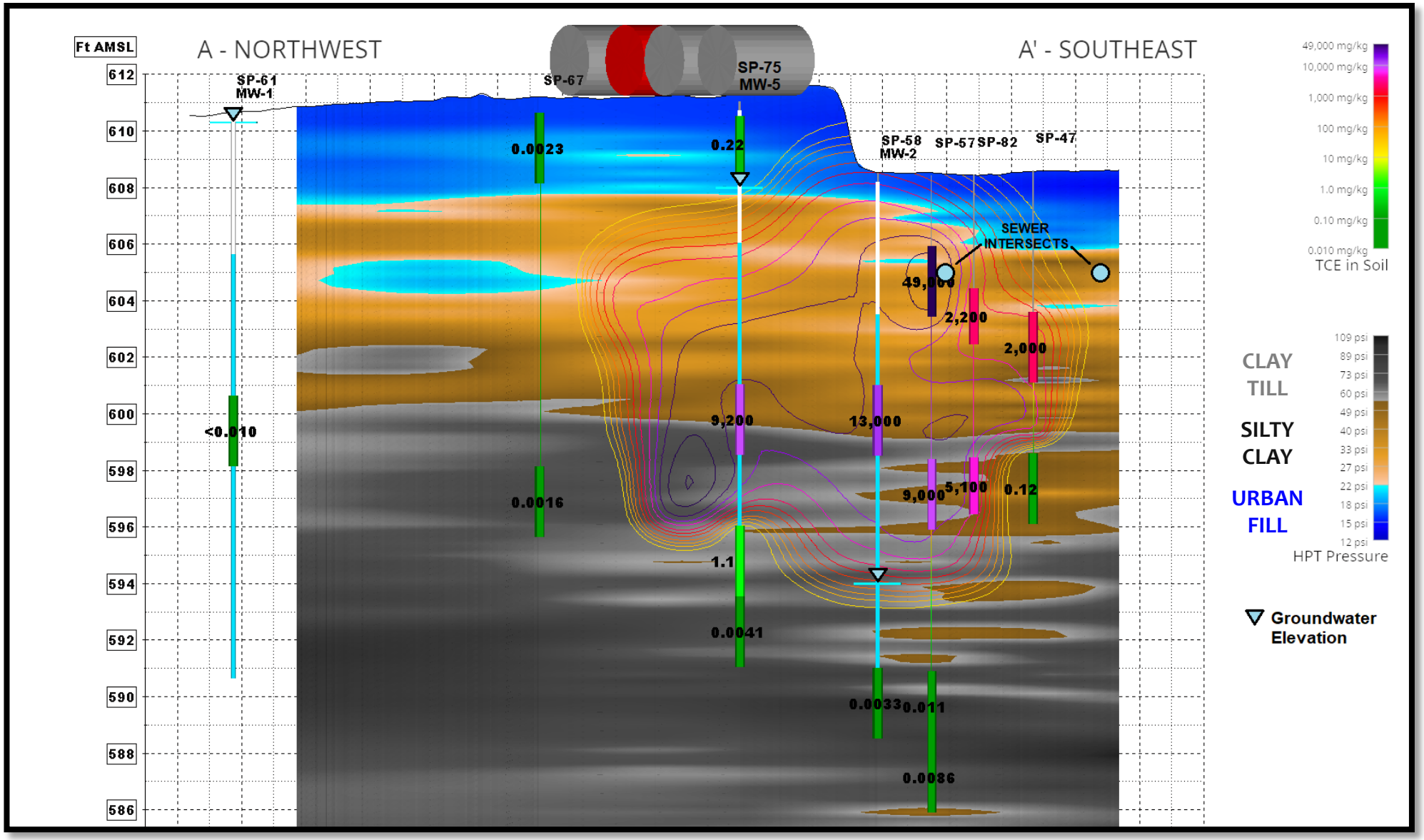
Plan View Maps at **Any** Elevation or Depth



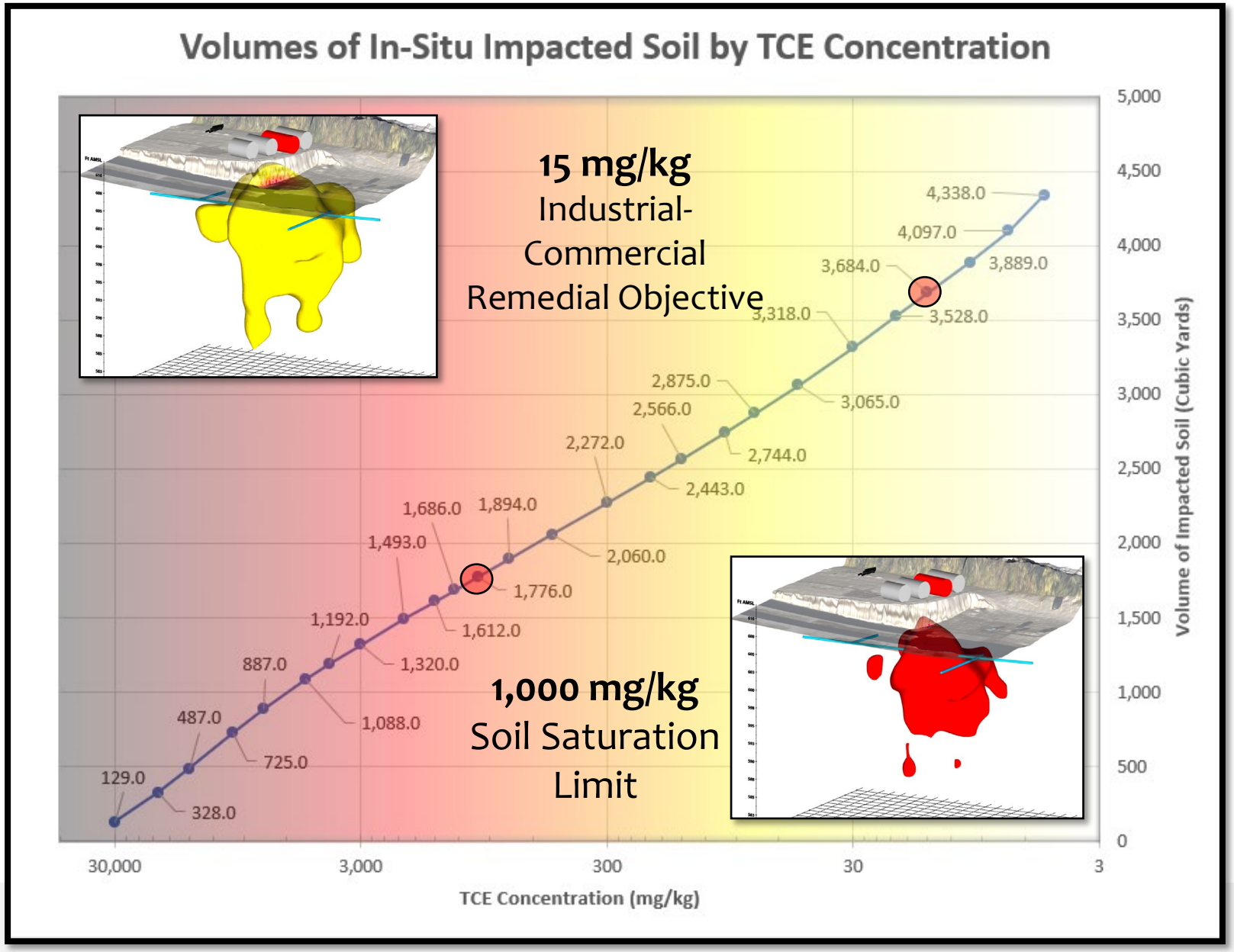


JHA ENVIRONMENTAL

Cross-Sections Through **Any** Transect

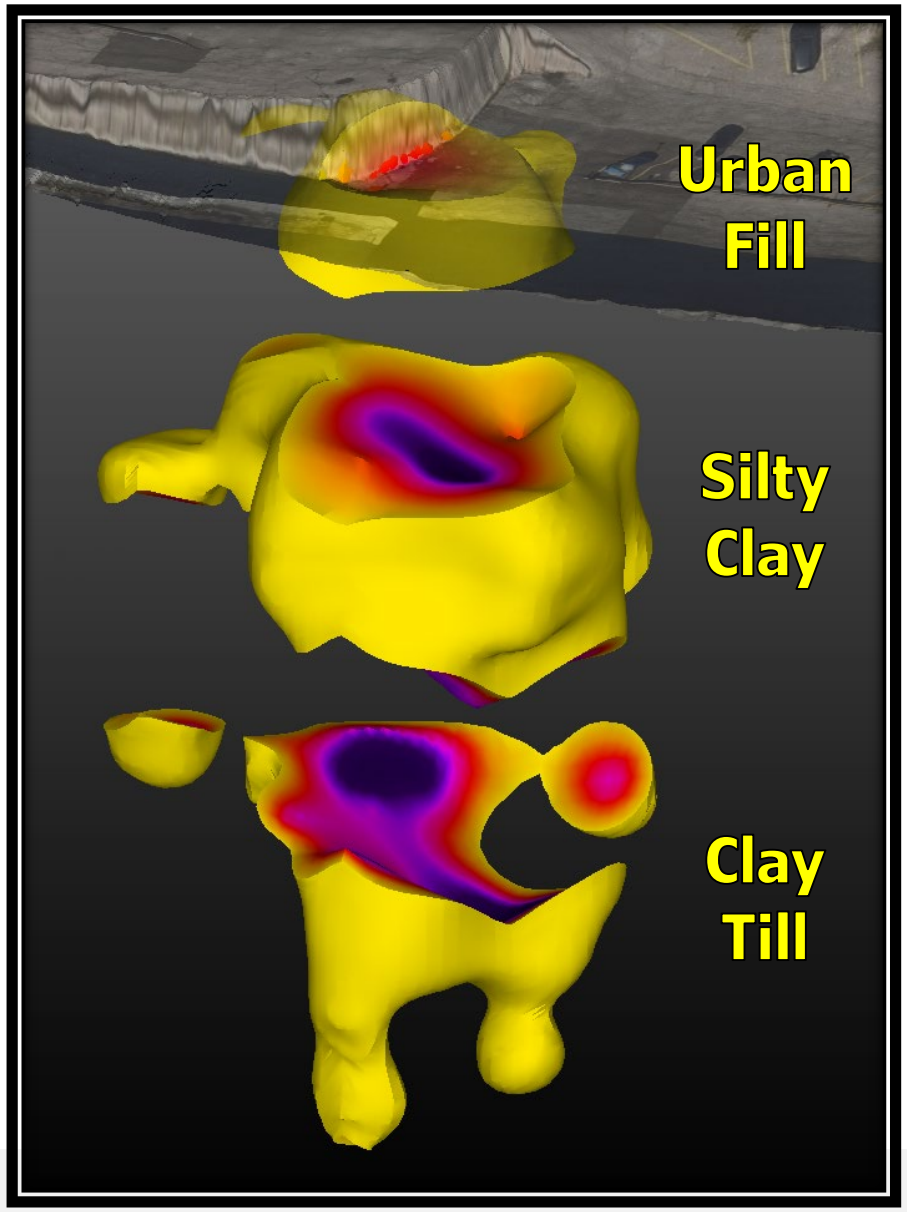


Estimate Volumes of Impacted Soil at **Any** Concentration



TCE Conc. (mg/kg)	Volume of Soil (Cubic Yards)
5	4,338
7	4,097
10	3,889
15	**3,684**
20	3,528
30	3,318
50	3,065
75	2,875
100	2,744
150	2,566
200	2,443
300	2,272
500	2,060
750	1,894
1,000	**1,776**
1,250	1,686
1,500	1,612
2,000	1,493
3,000	1,320
4,000	1,192
5,000	1,088
7,500	887
10,000	725
15,000	487
20,000	328
30,000	129

In-Situ Mass Calculations by Geologic Unit



	Soil Density (g/cc)	TCE Mass (Pounds)
Urban Fill	1.60	1,971
Silty Clay	1.75	51,166
Clay Till	1.90	9,295
Total		**62,432**

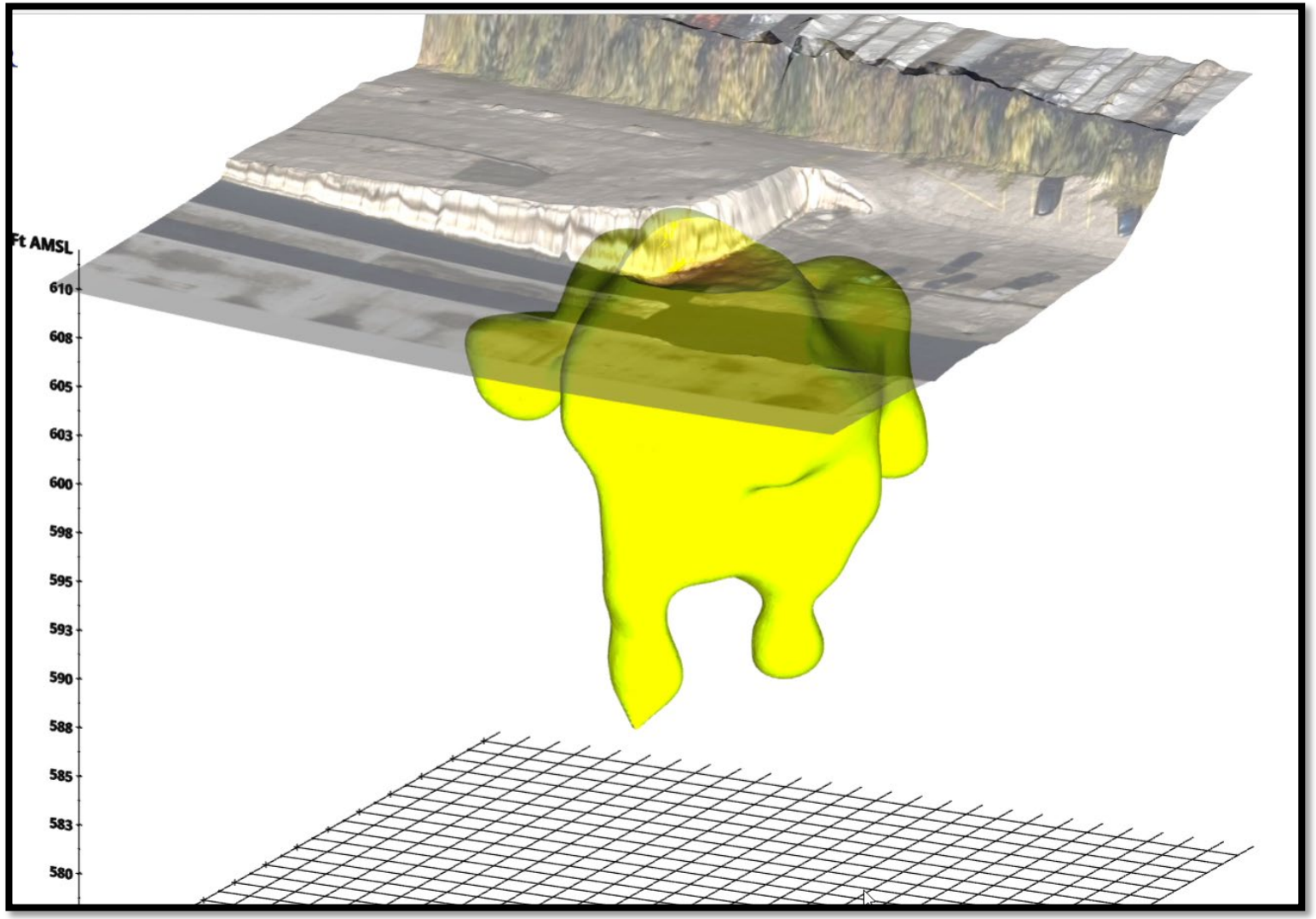
- **3.2%** in the Urban Fill
- **81.9%** in the Silty Clay
- **14.9%** in the Clay Till

Part 3: Evaluation of Remedial Options

- 3D Excavation Planning Tool
- In-Situ Thermal
- Soil Blending
- Injection

Evaluation of Remedial Options

Excavation Tool: Calculation of Overburden Soils



Slope from Horizontal

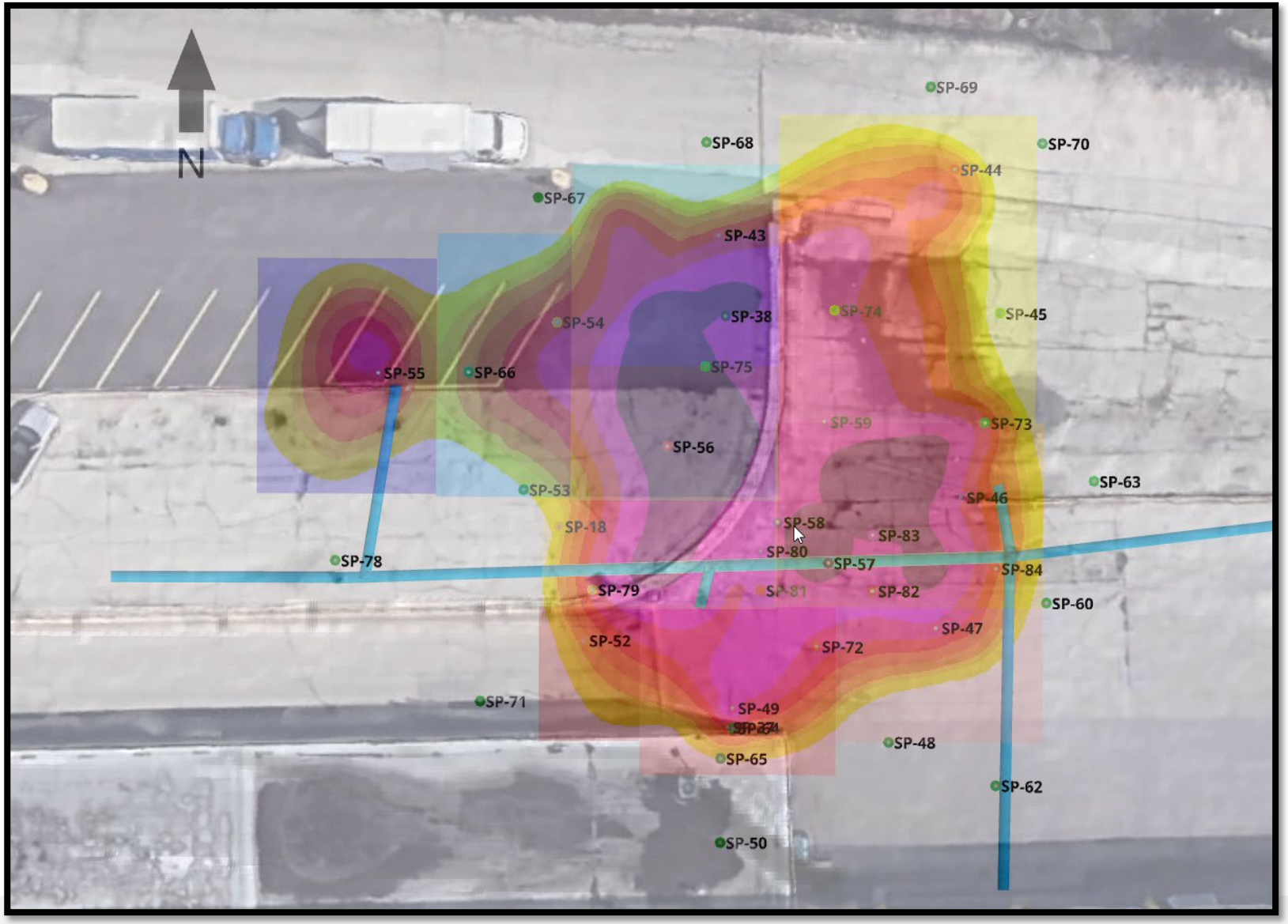
60 Degree: **Green**

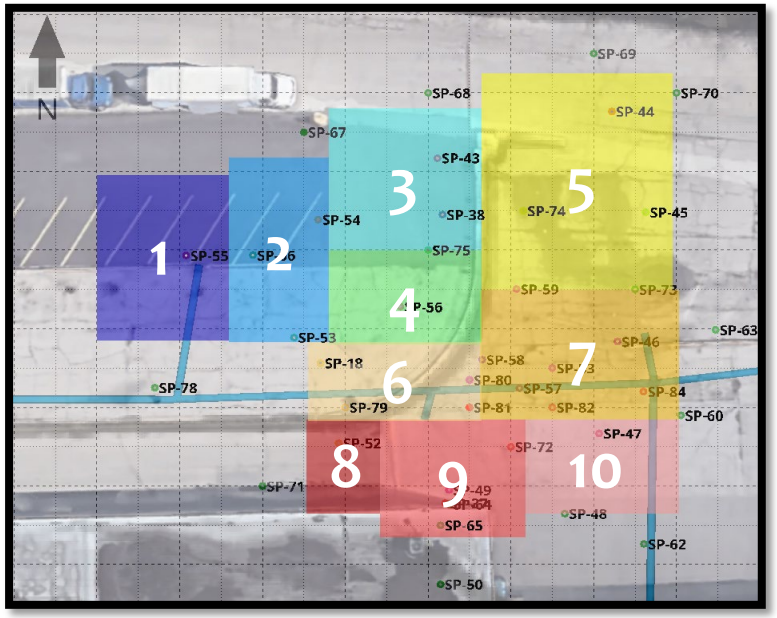
75 Degree: **Light Blue**

90 Degree: **Dark Blue**

	60° Slope	75° Slope	90° Slope
Impacted Soil	3,684 yards³		
Overburden	11,074 yards³	4,234 yards³	1,920 yards³
Total	**14,560 yards³**	**7,918 yards³**	**5,604 yards³**

In-Situ Thermal: Treatment Plan

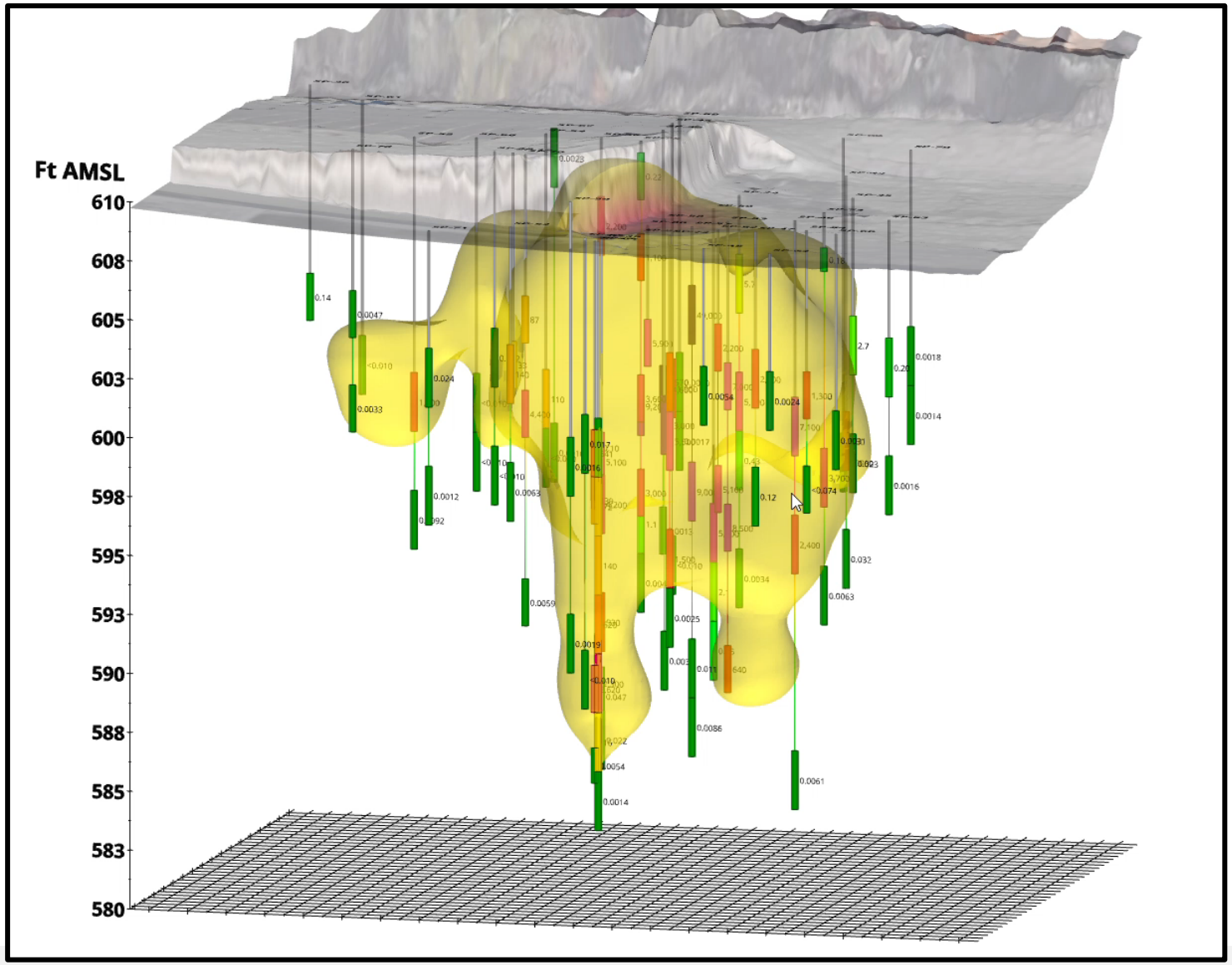


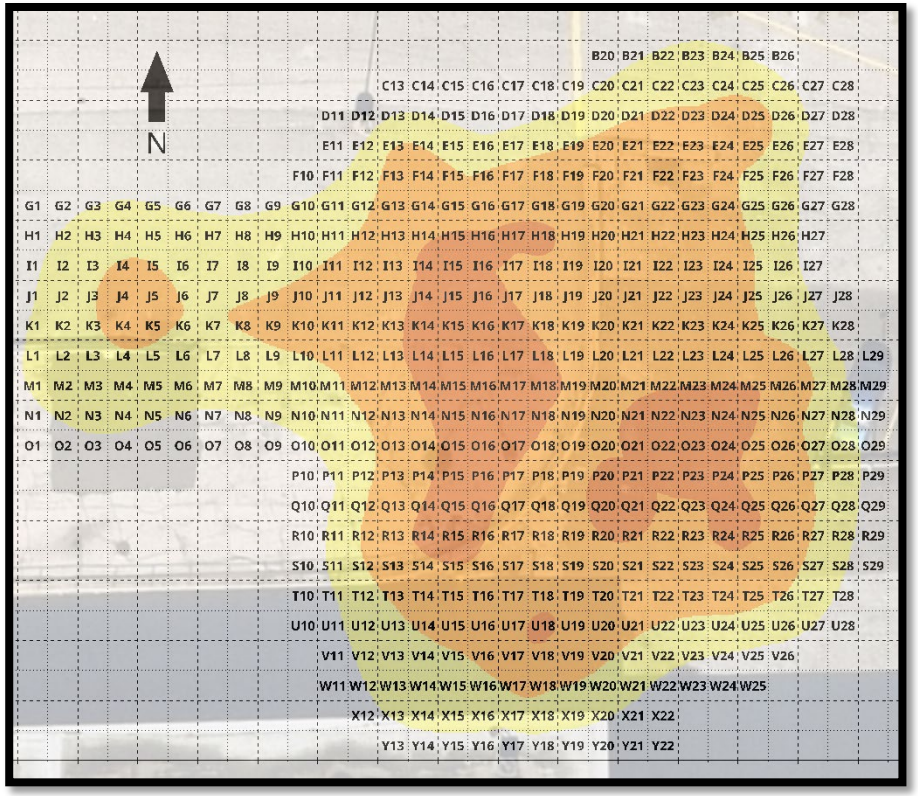


Box #	Color	Depth	Width (Ft)	Length (Ft)	Cu Yards
1	Purple	15	32	42	747
2	Blue	13	24	47	543
3	Lgt Blue	17	37	36	839
4	Green	18	37	24	592
5	Yellow	16	46	55	1499
6	Lgt Orange	18	42	20	560
7	Orange	23	48	33	1349
8	Dark Red	12	18	24	192
9	Red	23	35	30	894
10	Lgt Red	16	37	24	526

Volume of Soil:
7,742 cubic yards

Soil Mixing - In Situ Chemical Reduction (ISCR)

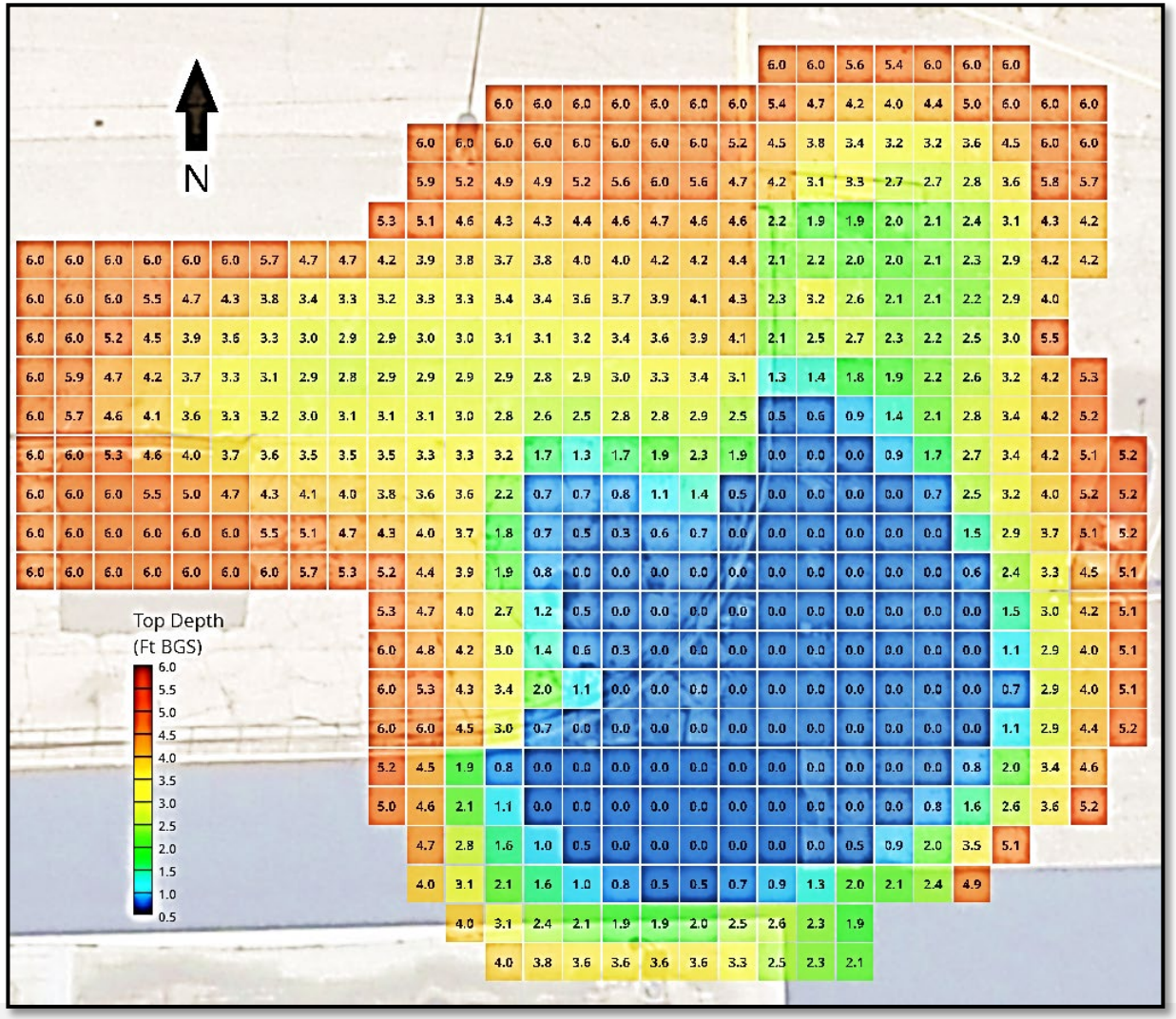




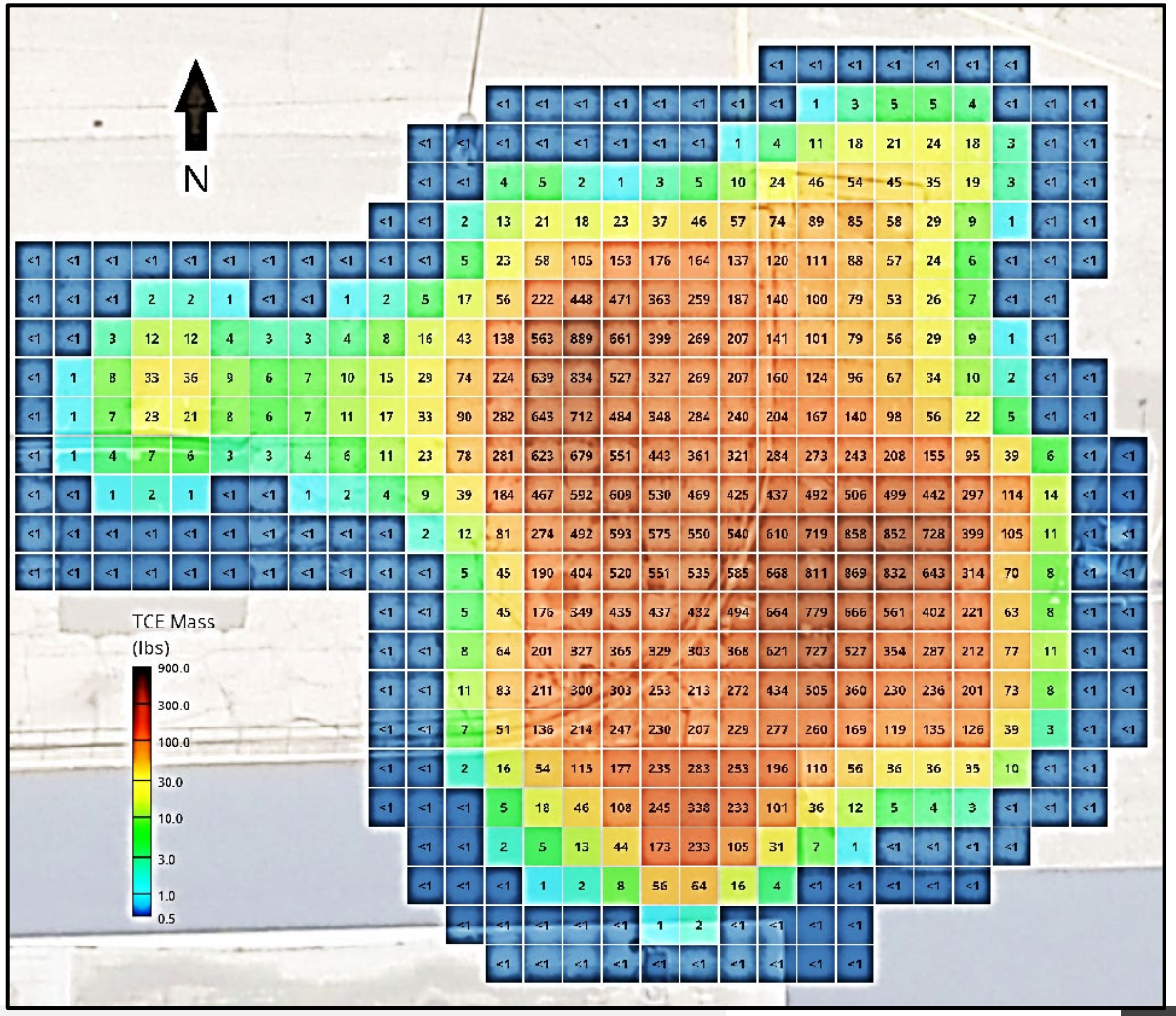
Volume of Soil:
5,127 cubic yards

Understandable Maps for Use in the Field

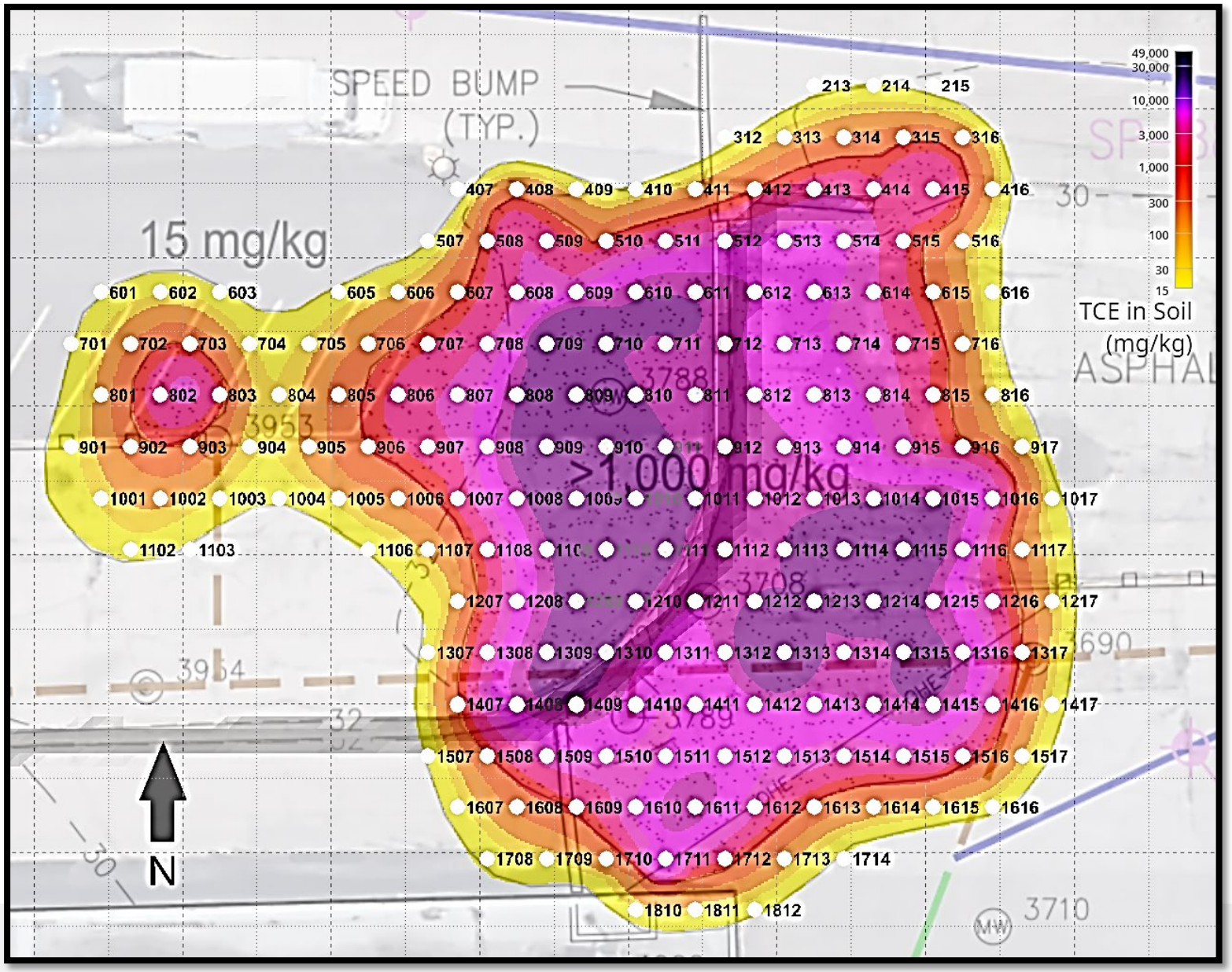
Top of Treatment Depth (Ft BGS)



Estimated TCE Mass (Pounds)



In-Situ Injection Tool: Determine Injection Locations



Injection Plan Specifications

Target: 15 mg/kg (Yellow)

Well Spacing: 8’ Centers

Number of Wells: 187

Part 4: Injection Design & Optimization

- Trends in the Industry
- The Problem and Solution
- Example Targeted Injection Plan
- Injection Overview
  - Where?
  - How?
  - How much?
  - What to inject?

In Situ Treatment – **What's the Trend?**

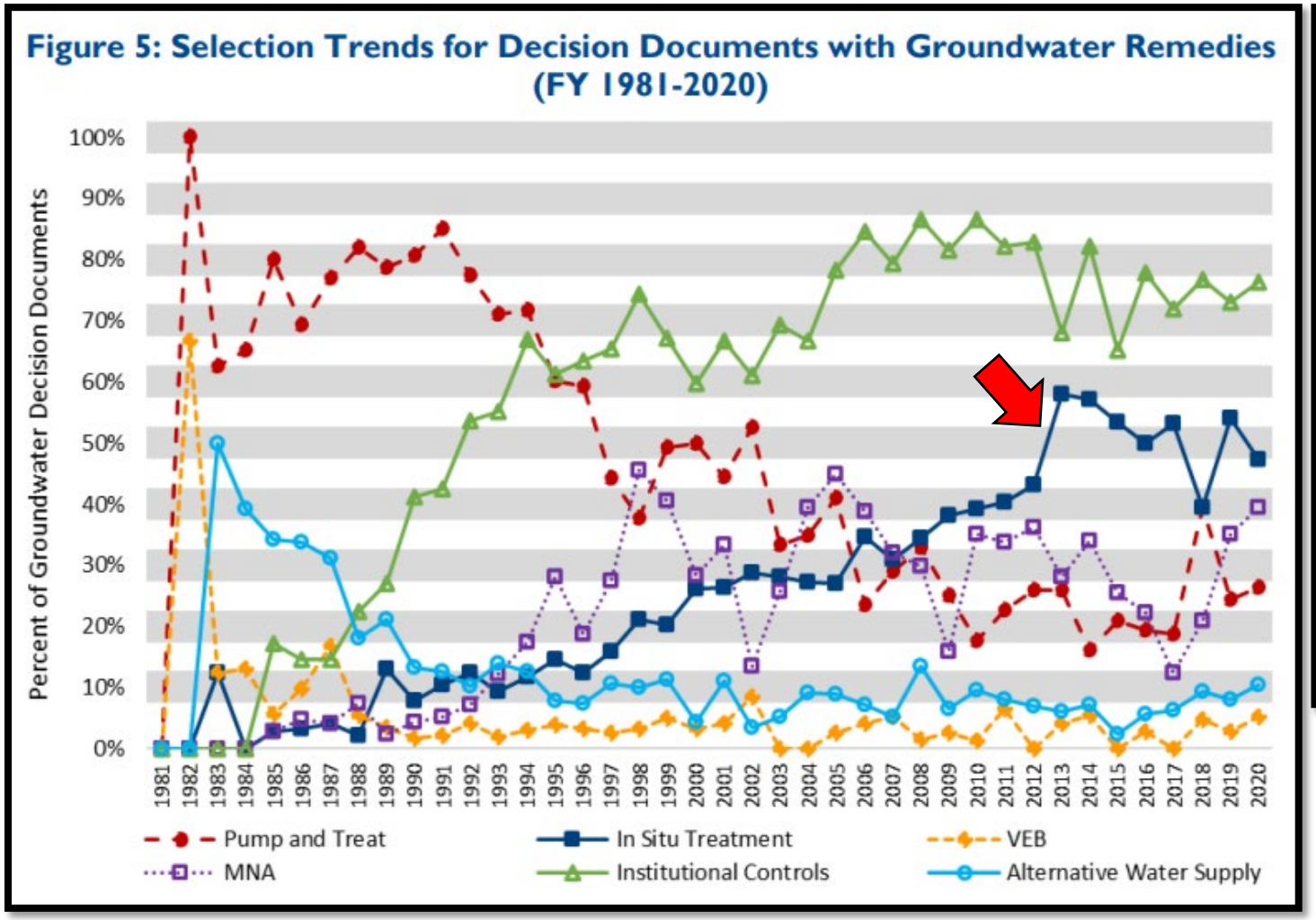


Table 6: Groundwater Remedies Selected Most Frequently in Recent Decision Documents (FY 2018-2020)

Selected Remedy	Number	Percent
Treatment	**79**	**67%**
In Situ Treatment	55	47%
Bioremediation	29	25%
Chemical Treatment	19	16%
Thermal Treatment	11	9%
Air Sparging	5	4%
Permeable Reactive Barrier	3	3%
Multi-phase Extraction	3	3%
Solidification/Stabilization	2	2%
Vapor Extraction	2	2%
Ex Situ Treatment (P&T)	36	31%
Vertical Engineered Barrier	**5**	**4%**
Monitored Natural Attenuation	**37**	**31%**
Institutional Controls	**89**	**75%**
Alternative Water Supply	**11**	**9%**
Other	**6**	**5%**

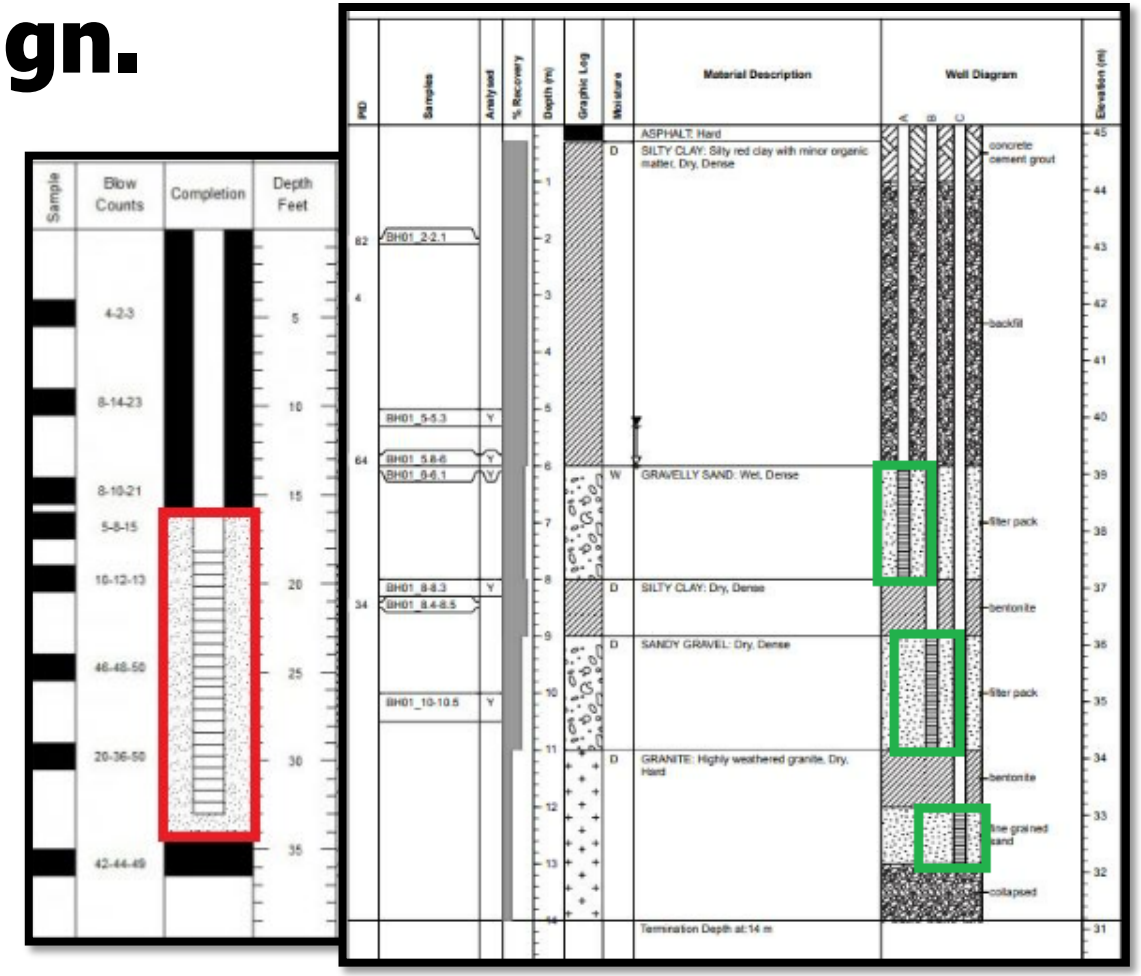
- Percentages based on 118 groundwater decision documents issued in FYs 2018 through 2020.

Source: Superfund Remedy Report, US EPA, January 2023

The PROBLEM

Many injection strategies often rely on monitoring well data for treatment design.

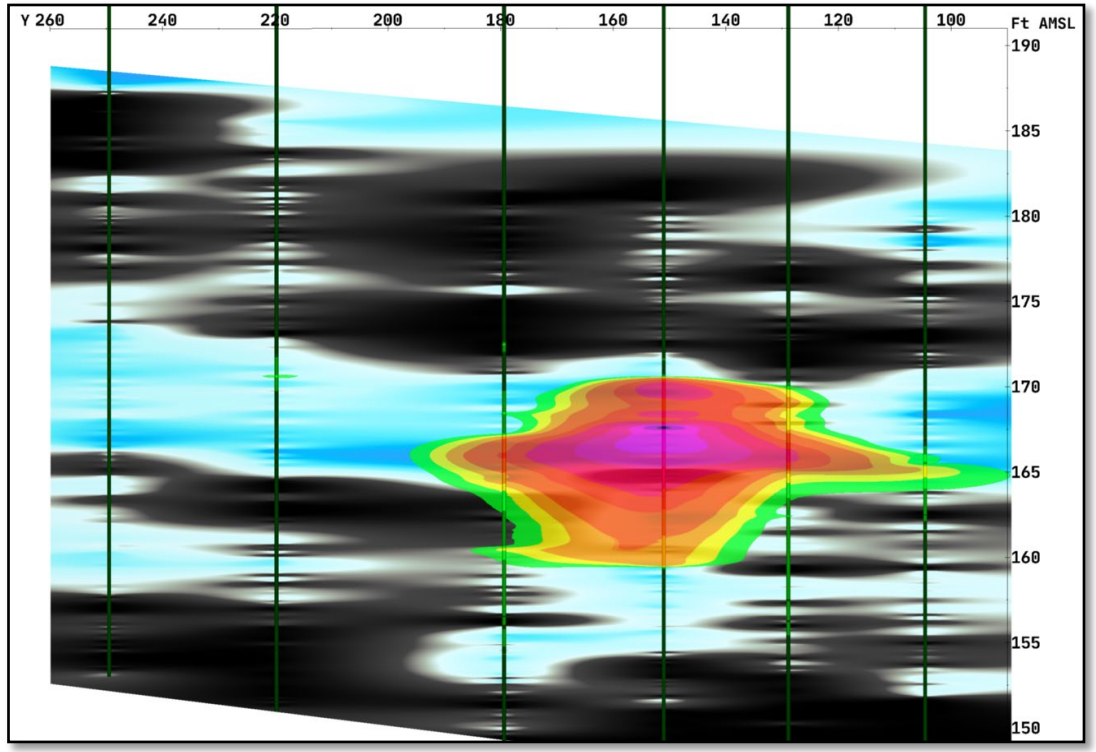
- Typically, limited data
- No verticality to the data
  (unless well nests exist)
- No geologic definition of impacts
- Injections can occur in **suboptimal** locations or at the **incorrect** depths



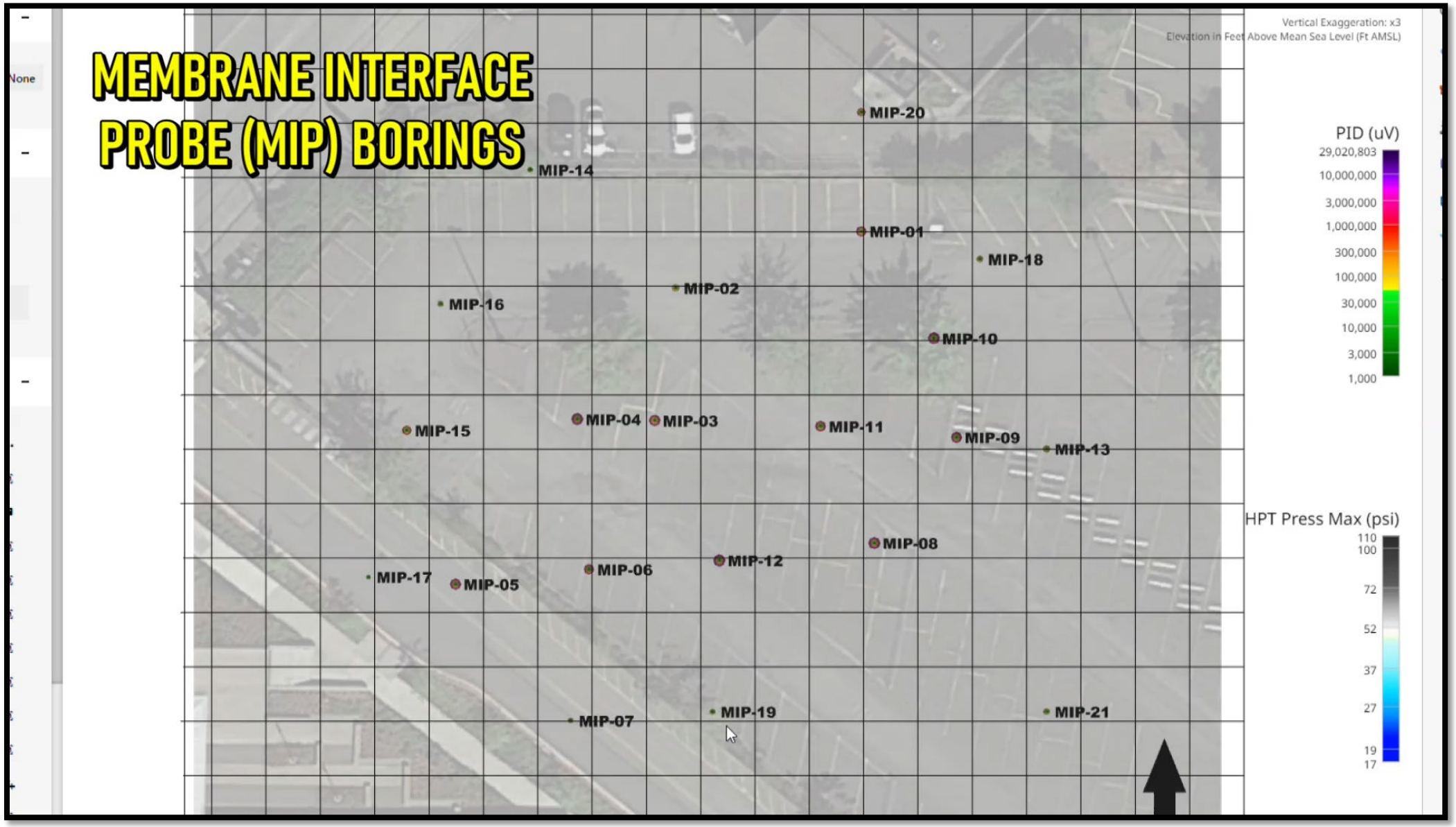
The SOLUTION

Create targeted injection plans by combining high resolution data and 3D statistical modeling

- Tens of thousands of data points
- Excellent vertical data distribution
- Geologic definition of contamination (storage zones vs. transport zones)
- Injection locations, depths, and injection pressures can be **OPTIMIZED**



Targeted Injection Plan - MiHPT Data



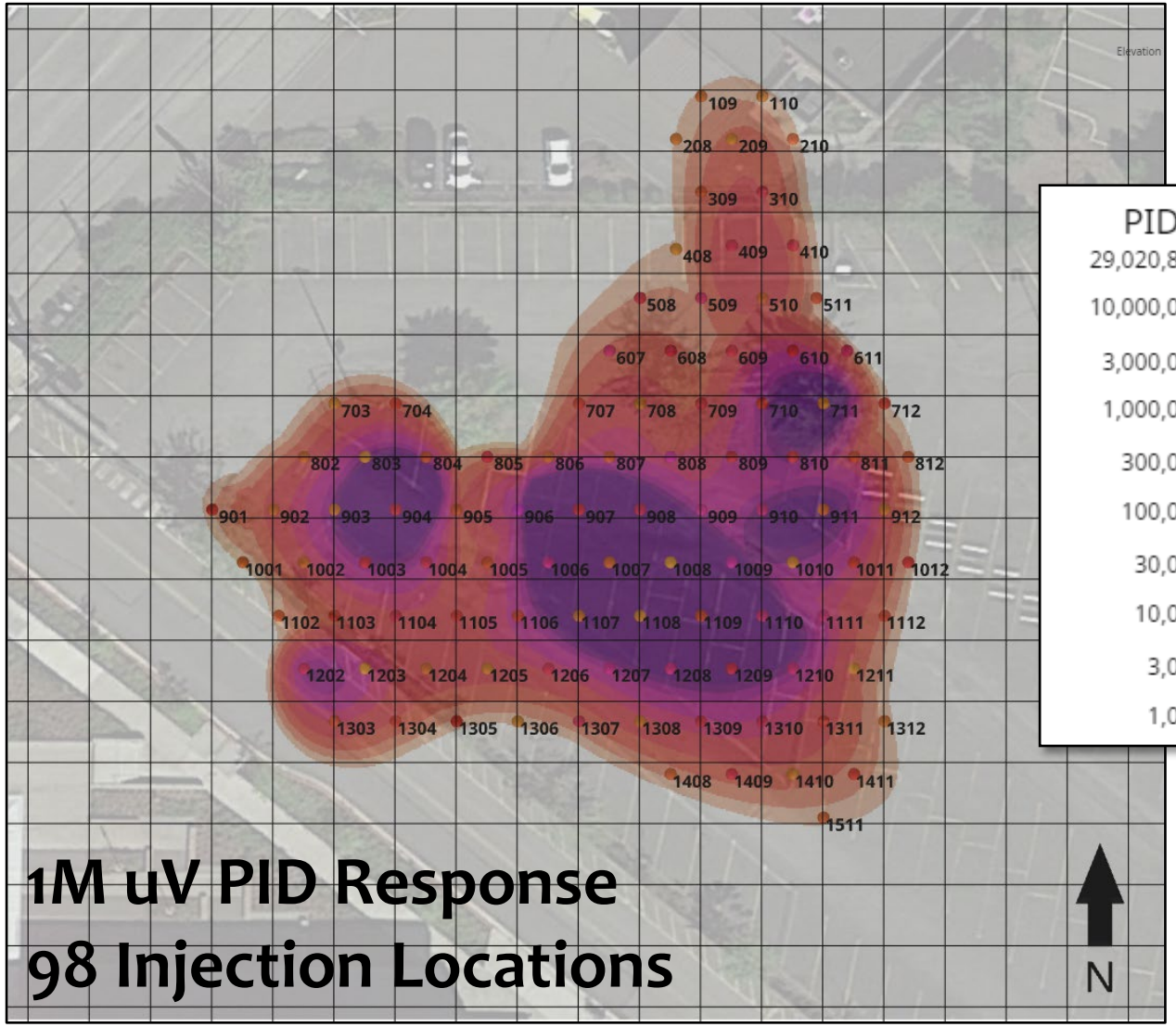
Where to Inject?

- Determine the Extent of Soil to Treat
  - MIP Response Level
  - Soil/Groundwater Concentration

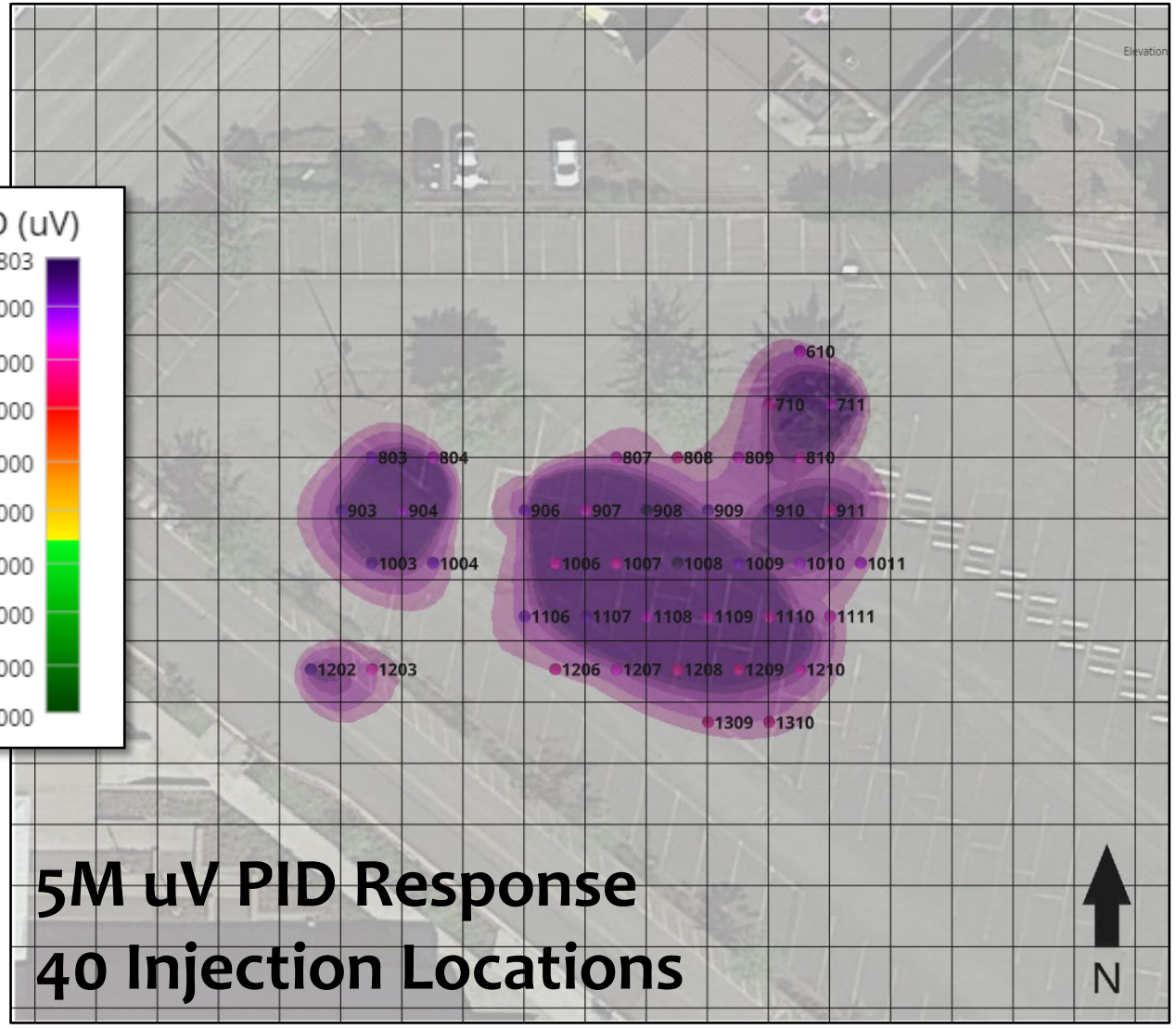
Injection Well Spacing?

- Estimating Radius of Influence
  - 2.5 feet (Tight Clays) - 25 feet (Permeable Saturated Sands) [ITRC 2002]
  - Source Area Treatment or Plume Treatment
  - What Amendment is Being Injected (Kinetics)

Targeted Injection Plans - 10’ Centers (5' ROI)

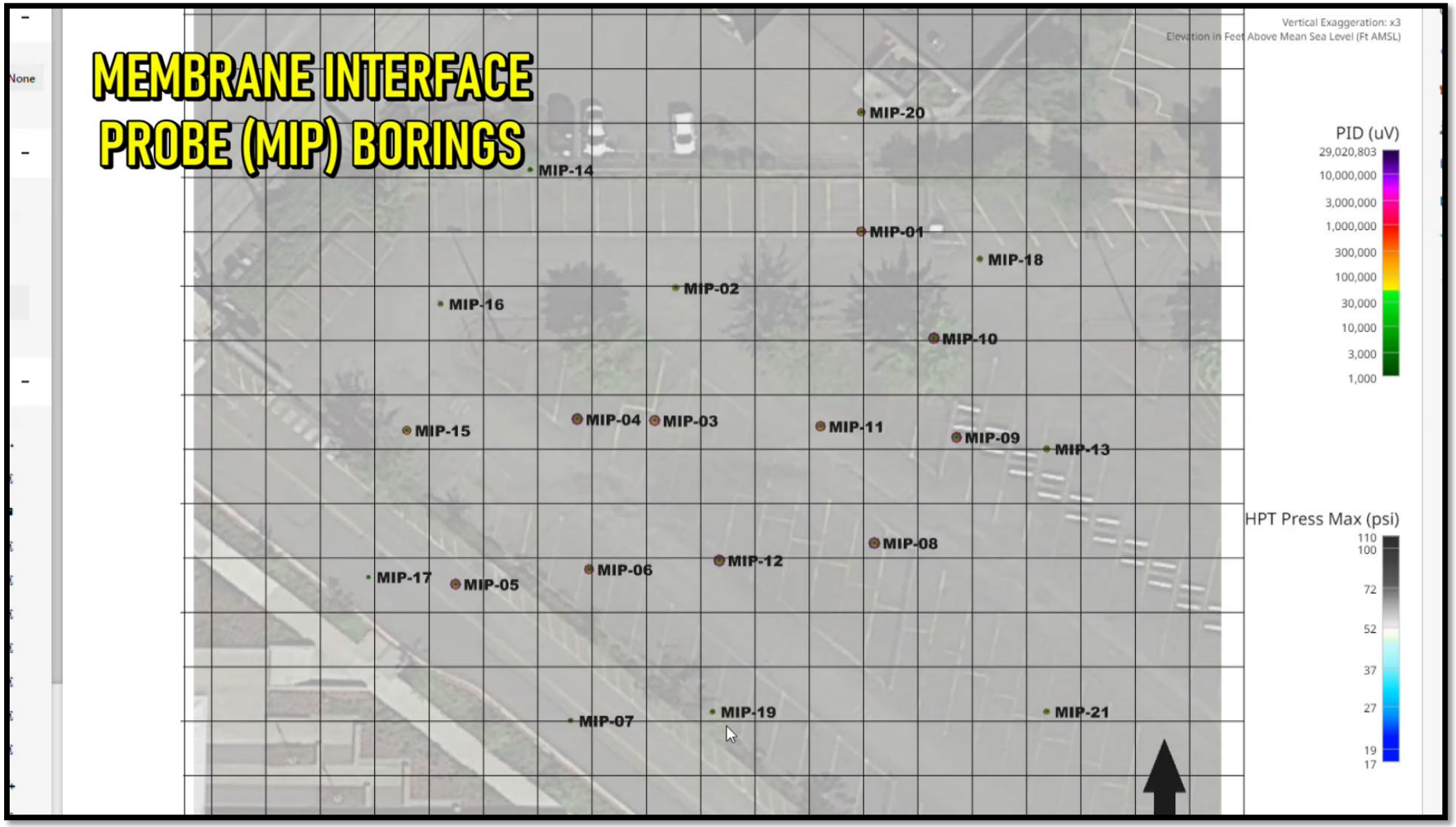


1M uV PID Response
98 Injection Locations



5M uV PID Response
40 Injection Locations

Targeted Injection Plan - MiHPT Data



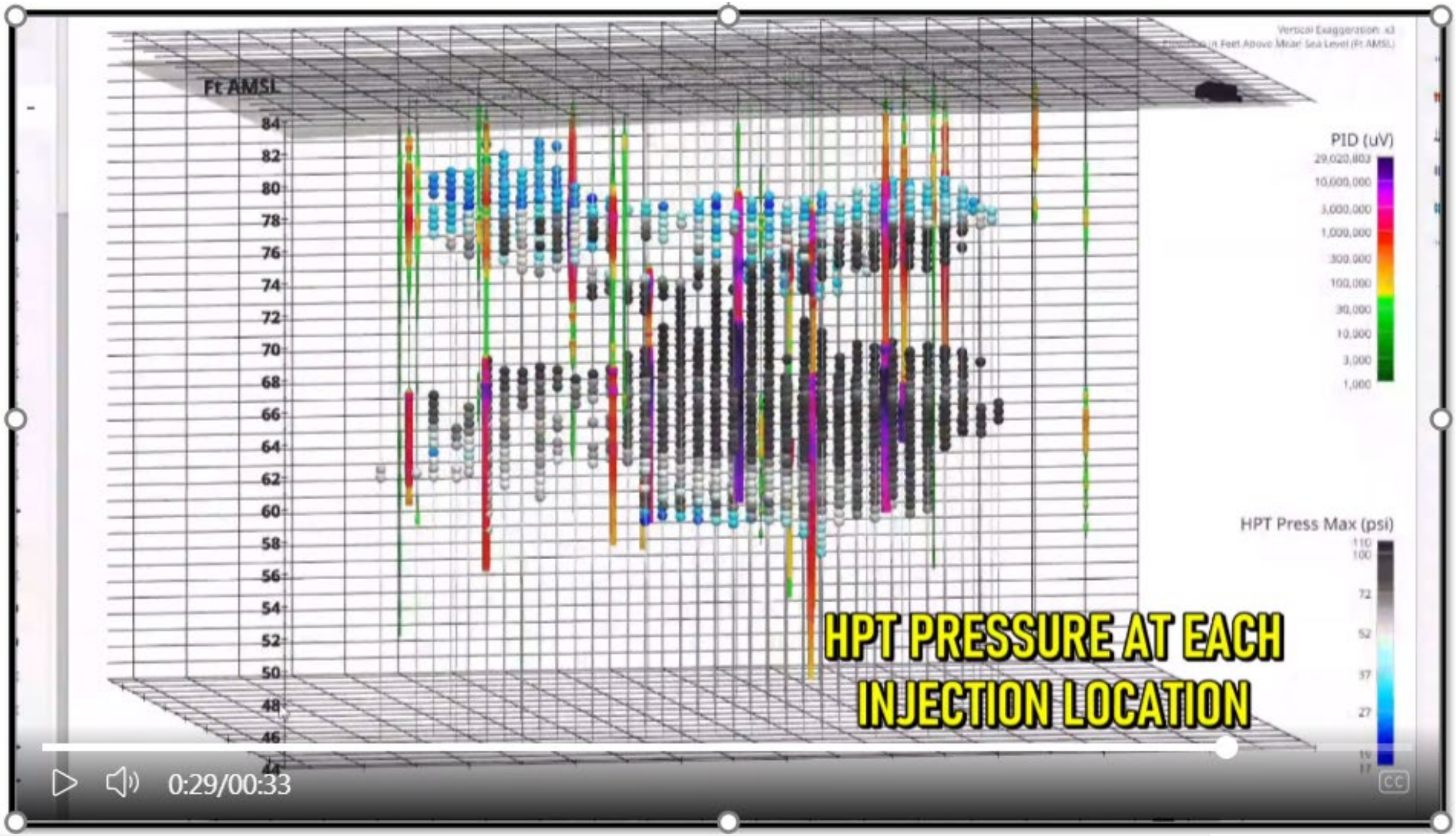
How Much to Inject?

Radius of Influence (feet)	Effective Porosity (%)									
	2%	3%	5%	7%	10%	12%	15%	20%	25%	30%
2.5	3	4	7	10	15	18	22	29	37	44
3	4	6	11	15	21	25	32	42	53	63
4	8	11	19	26	38	45	56	75	94	113
5	12	18	29	41	59	70	88	117	147	176
6	17	25	42	59	85	102	127	169	211	254
7	23	35	58	81	115	138	173	230	288	345
8	30	45	75	105	150	180	226	301	376	451
9	38	57	95	133	190	228	286	381	476	571
10	47	70	117	164	235	282	352	470	587	705
12	68	102	169	237	338	406	508	677	846	1,015
15	106	159	264	370	529	634	793	1,057	1,322	1,586

Gallons Per Linear Foot in One (1) Pore Volume

How to Inject?

- Monitoring Wells or Direct Injection (Push Tools)
  - Monitoring wells allow for multiple events, but will target high flow zones
  - Direct Injection is one time only, but locations and injection pressure can be optimized to target low-flow (storage) zones
- Liquid Amendments or Solid Slurries
  - Liquid amendments for transmissive zones (sands)
  - Solid slurries for storage zones (silts and clays)
- HPT Pressure can be Used as a Guide


Ft AMSL
84
82
80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
PID (uV)
29,020,803
10,000,000
3,000,000
1,000,000
300,000
100,000
30,000
10,000
3,000
1,000
HPT Press Max (psi)
110
100
72
52
37
27
19
17
HPT PRESSURE AT EACH
INJECTION LOCATION
0:29/00:33
CC

Targeted Injection Plan - MiHPT Data

ID	X (Easting)	Y (Northing)	Ground Surface (Ft AMSL)	Depth (Ft BGS)	Elevation (Ft AMSL)	HPT Pressure (PSI)	PID (uV)
INJ-901	1306270.1	369796.4	82.7	23.7	59	54	764,124
INJ-901	1306270.1	369796.4	82.7	23.2	59.5	56	927,280
INJ-1001	1306275.1	369787.8	82.8	23.3	59.5	53	789,599
INJ-902	1306280.1	369796.4	82.9	23.9	59	51	767,800
INJ-902	1306280.1	369796.4	82.9	23.4	59.5	58	1,002,718
INJ-902	1306280.1	369796.4	82.9	22.9	60	51	886,889
INJ-902	1306280.1	369796.4	82.9	22.4	60.5	26	908,341
INJ-902	1306280.1	369796.4	82.9	21.9	61	46	1,161,765
INJ-902	1306280.1	369796.4	82.9	21.4	61.5	47	1,002,301
INJ-902	1306280.1	369796.4	82.9	20.9	62	63	783,220
INJ-902	1306280.1	369796.4	82.9	20.4	62.5	74	770,288
INJ-902	1306280.1	369796.4	82.9	19.9	63	76	818,094
INJ-902	1306280.1	369796.4	82.9	19.4	63.5	79	939,798
INJ-902	1306280.1	369796.4	82.9	18.9	64	87	924,687
INJ-902	1306280.1	369796.4	82.9	8.9	74	42	1,273,307
INJ-902	1306280.1	369796.4	82.9	8.4	74.5	30	2,130,379
INJ-902	1306280.1	369796.4	82.9	7.9	75	33	3,181,142
INJ-902	1306280.1	369796.4	82.9	7.4	75.5	33	1,824,982
INJ-902	1306280.1	369796.4	82.9	6.4	76.5	25	880,995
INJ-902	1306280.1	369796.4	82.9	5.9	77	25	933,080
INJ-902	1306280.1	369796.4	82.9	5.4	77.5	27	764,189
INJ-1102	1306281.0	369779.0	82.9	23.4	59.5	51	750,563
INJ-1102	1306281.0	369779.0	82.9	22.9	60	53	715,831
INJ-1102	1306281.0	369779.0	82.9	21.4	61.5	58	746,526
INJ-1102	1306281.0	369779.0	82.9	20.9	62	66	802,967
INJ-1102	1306281.0	369779.0	82.9	20.4	62.5	69	809,376
INJ-1202	1306285.1	369770.4	83.0	26.5	56.5	41	776,464
INJ-1202	1306285.1	369770.4	83.0	25.5	57.5	47	776,323
INJ-1202	1306285.1	369770.4	83.0	25.0	58	62	821,393
INJ-1202	1306285.1	369770.4	83.0	24.5	58.5	58	984,468
INJ-1202	1306285.1	369770.4	83.0	24.0	59	48	983,048
INJ-1202	1306285.1	369770.4	83.0	23.5	59.5	51	1,147,790
INJ-1202	1306285.1	369770.4	83.0	23.0	60	61	1,285,177
INJ-1202	1306285.1	369770.4	83.0	22.5	60.5	72	1,781,504
INJ-1202	1306285.1	369770.4	83.0	22.0	61	53	1,127,391
INJ-1202	1306285.1	369770.4	83.0	21.5	61.5	68	1,133,235

Injection Point ID

Coordinates (X and Y)

Ground Surface

Inj. Depths

Inj. Elevation

HPT Pressure

PID Reading

FOR EVERY LOCATION

What to Inject?

- Oxidizing Agents (ISCO)
- Zero Valent Iron (ISCR)
- Oxygen Releasing Compounds (Aerobic)
- Hydrogen Releasing Compounds (Anaerobic)
- Active Bacteria
- Activated Carbon
- Trap and Treat Materials

Information - Oxidizers

- Effective on many cVOCs, BTEX, MTBE, carbon tetrachloride, some pesticides and energetics
- Less effective on PNAs, TCA, DCA, and chloroform
- Notable health hazards and safety issues when transporting and applying strong oxidizers
- Know the Natural Oxidant Demand (NOD) of the site soils
  - 0.05 (low) - 20 mg/kg (high)

Information - Zero Valent Iron (ZVI)

- Provides electrons directly to the contaminant to support processes that requires electrons to degrade contaminants (Beta-elimination)
- Effective on many CVOCs, not 1,2-DCA or dichloromethane
- Natural Oxidant Demand (NOD) of the site soils is irrelevant
- A small percentage of degradation products (cis-DCE and vinyl chloride) can be generated

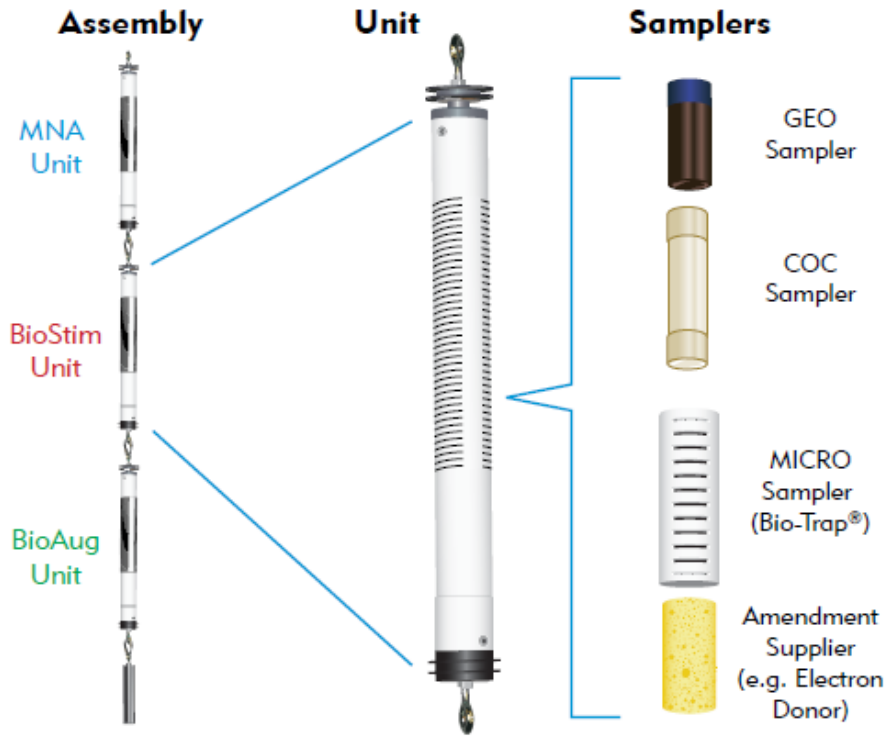
Information – Hydrogen Releasing Compounds

- Enhances the reductive dechlorination of chlorinated compounds by providing a food source for indigenous dechlorinating bacteria
- Typically food grade (safe)
- Degradation products (cis-DCE and vinyl chloride) can be generated
- Microcosm study is needed to determine if bacteria are present, most studies show a lack of nutrients and not a lack of bacteria

microbialinsights
www.microbe.com

BioTrap

Perform a Pilot Study to Evaluate Biodegradation and Screen Remedial Alternatives



Control (MNA Unit)	The Control Unit contains no additional electron donor or amendments and represents MNA or existing site conditions.
Biostimulation (BioStim Unit)	The BioStim Unit contains a specified electron donor (sodium lactate, EOS®, HRC®, molasses, etc), electron acceptor (e.g. oxygen, nitrate, sulfate), or other amendment.
Bioaugmentation (BioAug Unit)	The BioAug Unit is pre-inoculated with a commercial culture (e.g. *Dehalococcoides*) and amended with an electron donor.

QuantArray

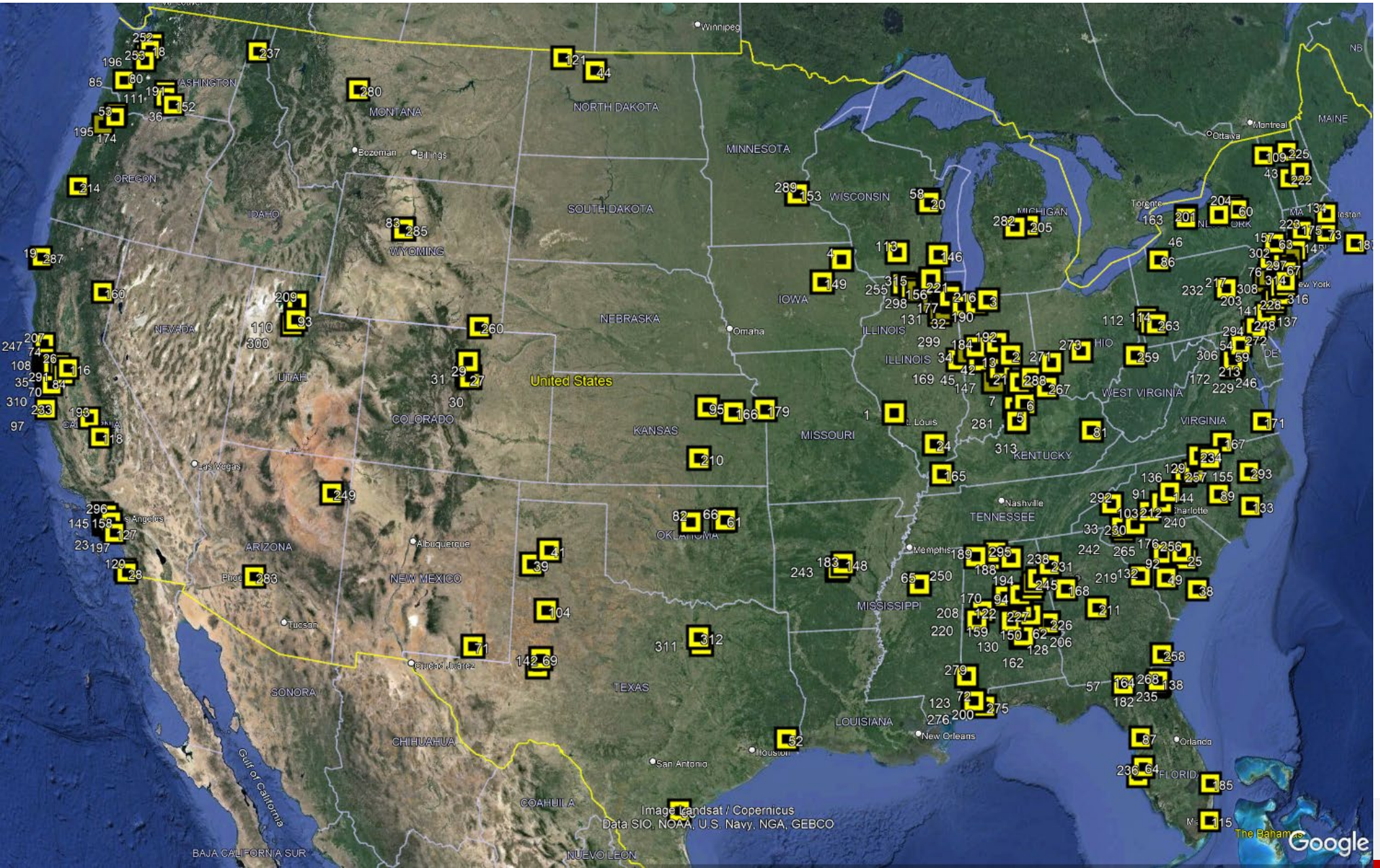
Quantify Bacteria and Functional Genes Involved in Biodegradation

miQuantArray®
MOLECULAR BIOLOGICAL TOOL

Final Thoughts

- Determine the location of utility lines, piping or other possible migration pathways for short circuiting
- Some amendments react quickly (limits ROI), closely spaced, lower volume injection points is usually best
- Some metals can be mobilized by a change in the oxidation state. It is important to know the geochemistry of the soils.
- **MANAGE CLIENT EXPECTATIONS** – Determine remedial goals and how to target storage zones and transmissive zones

3D Deliverable or Remedial Design: 325 Projects



Thank You

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BREAK

AEHS Foundation

34th Annual International Conference on Soil, Water, Energy, and Air

March 17-20, 2025 | San Diego, CA

Workshop - 02

MODULE-03

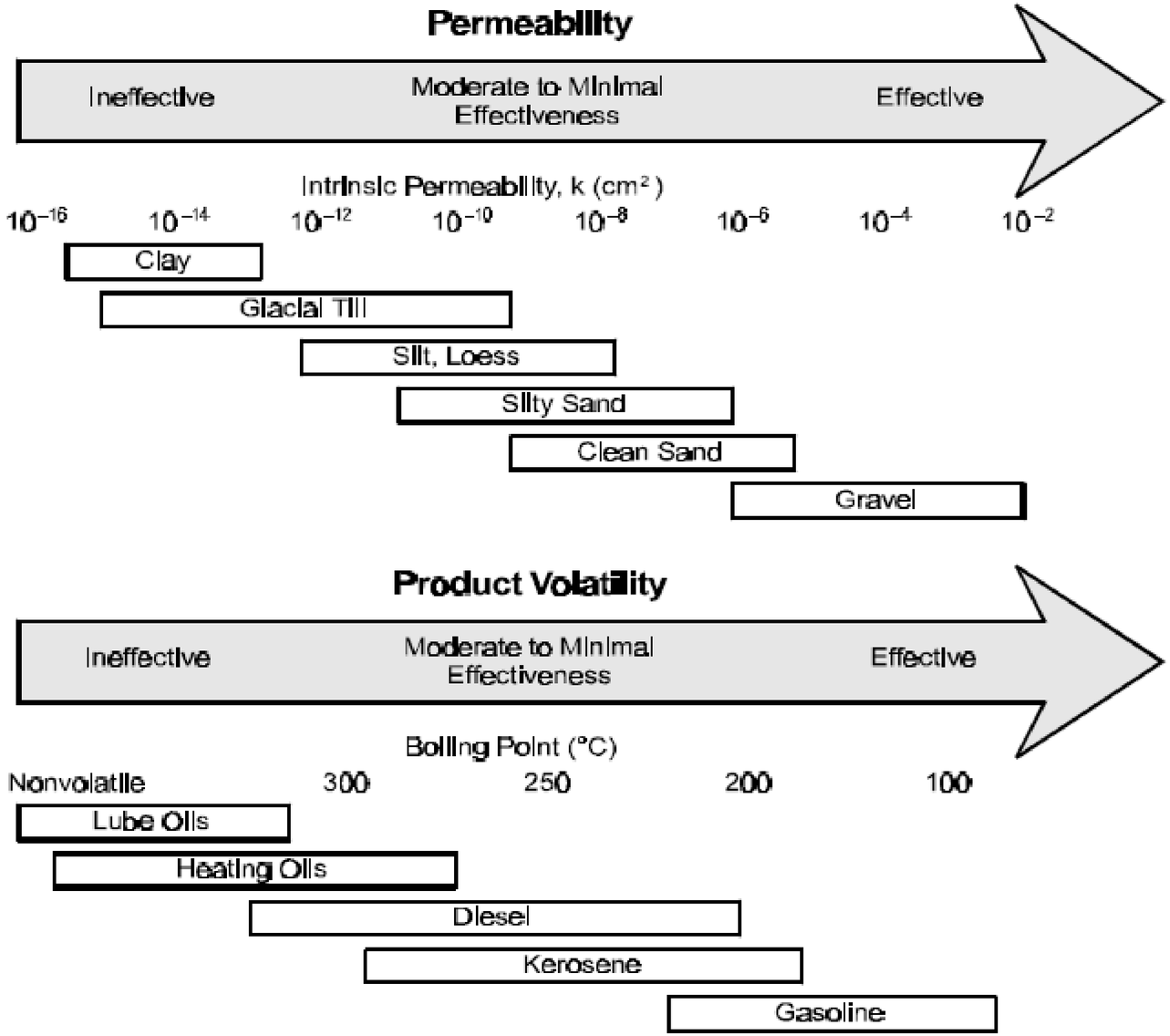
SVE, TPE, Recirculation

JHA Environmental

SOIL VAPOR EXTRACTION (SVE)

- SVE is effective in Soil with Intrinsic Permeabilities are greater than 10^{-8} cm^2
- SVE is effective for volatile compound (vapor pressure greater than 0.5 mm Hg) chemicals with Henry's Law Constant greater than 0.01 $atm \cdot m^3/mol$

SVE EFFECTIVENESS



HC Mass in Place

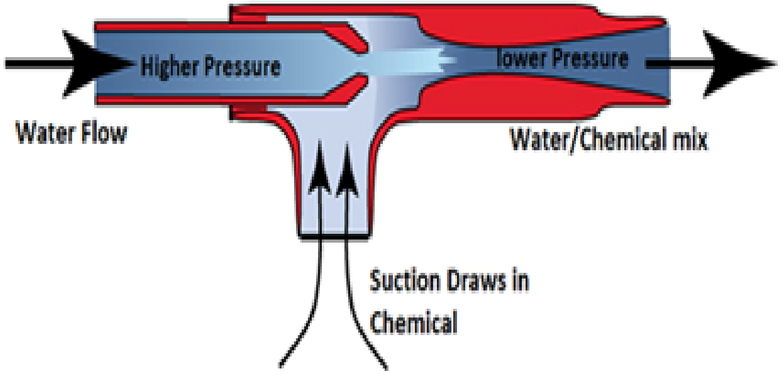
Total Mass	=	Conc. X area X thickness
Recoverable by SVE	=	Total Mass X (effective porosity/ bulk porosity)

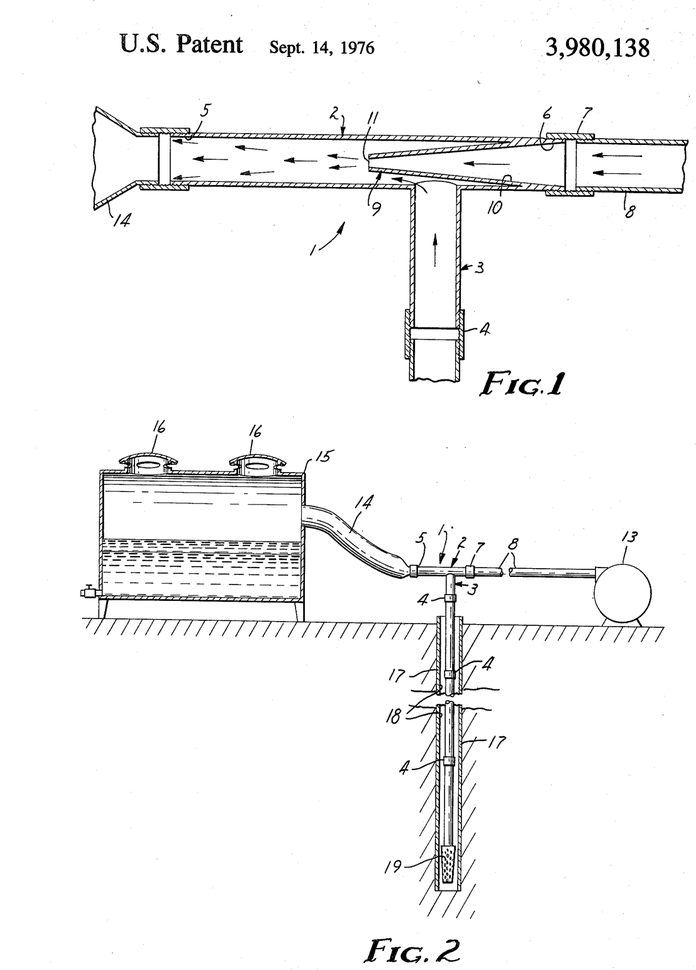
Diffusion and Biodegradation will remove the rest

History of Vapor/Two Phase Extraction

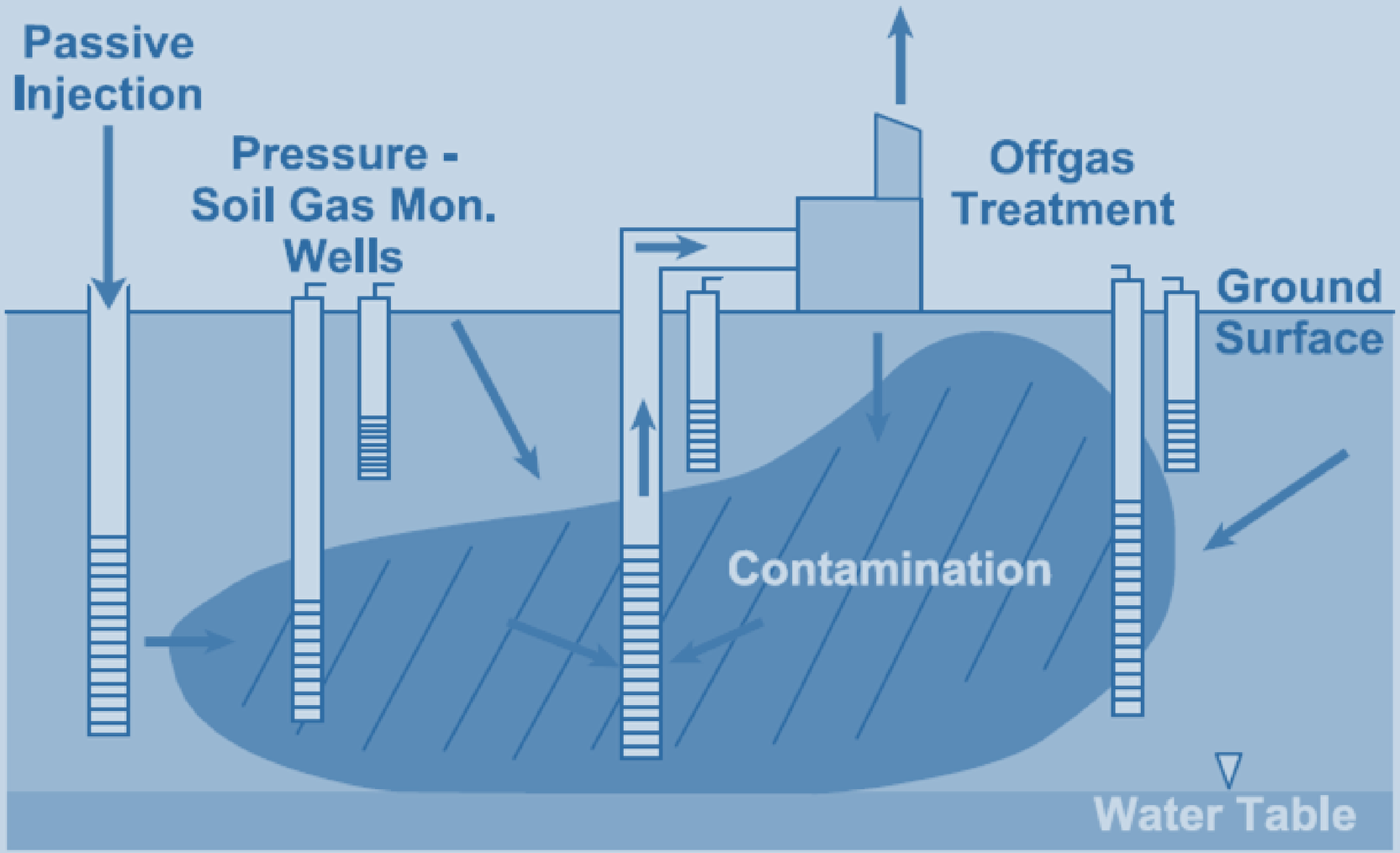
It all started when a gas station owner decided to recover lost product from tank leak and remarket it.

In 1976 - Duane L. Knopik developed a process to recover fuel from ground using a venturi tubing and a common garden hose (Patent No: 3,980,138 and 4,323,122)

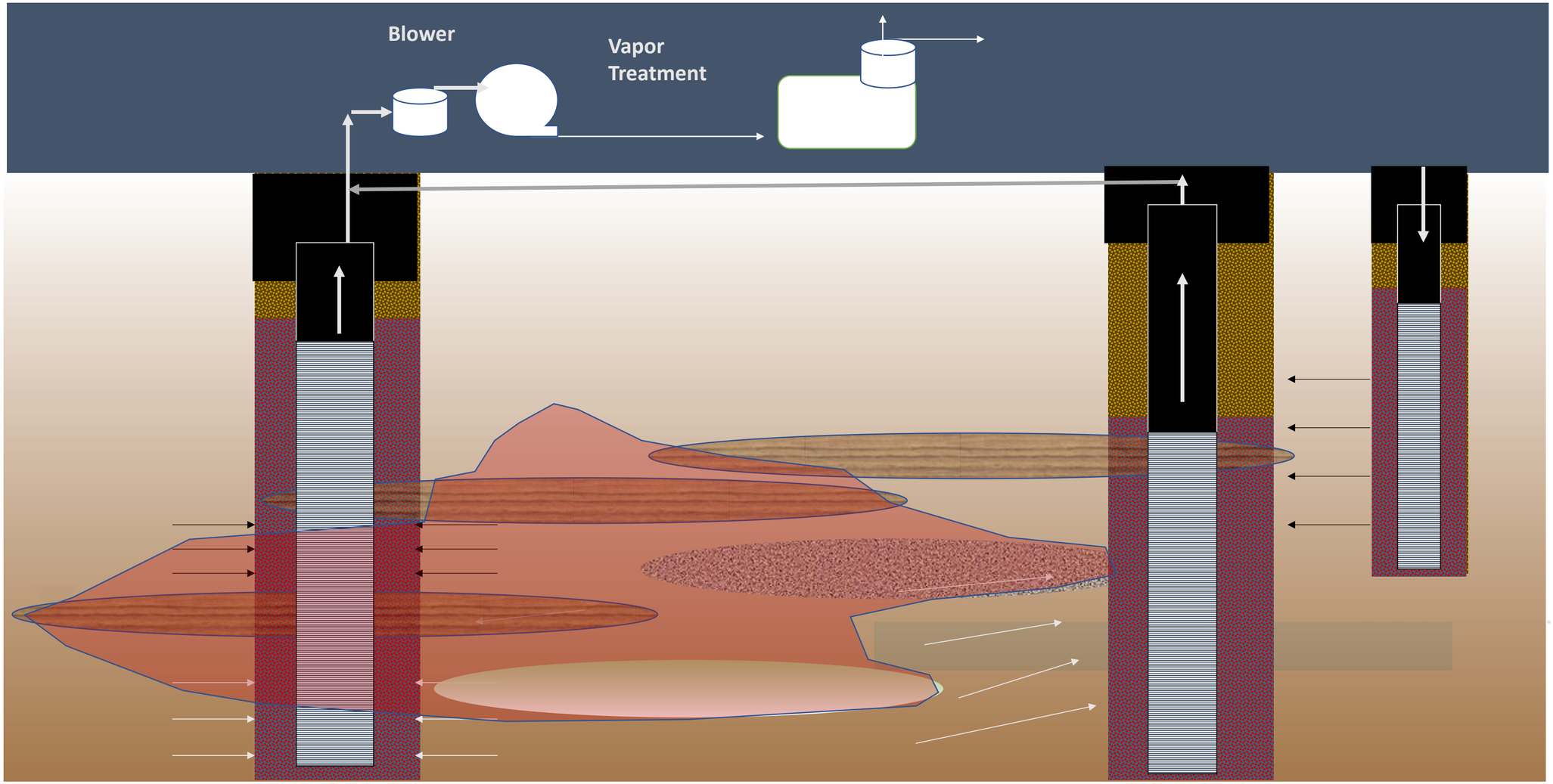




SVE System Layout



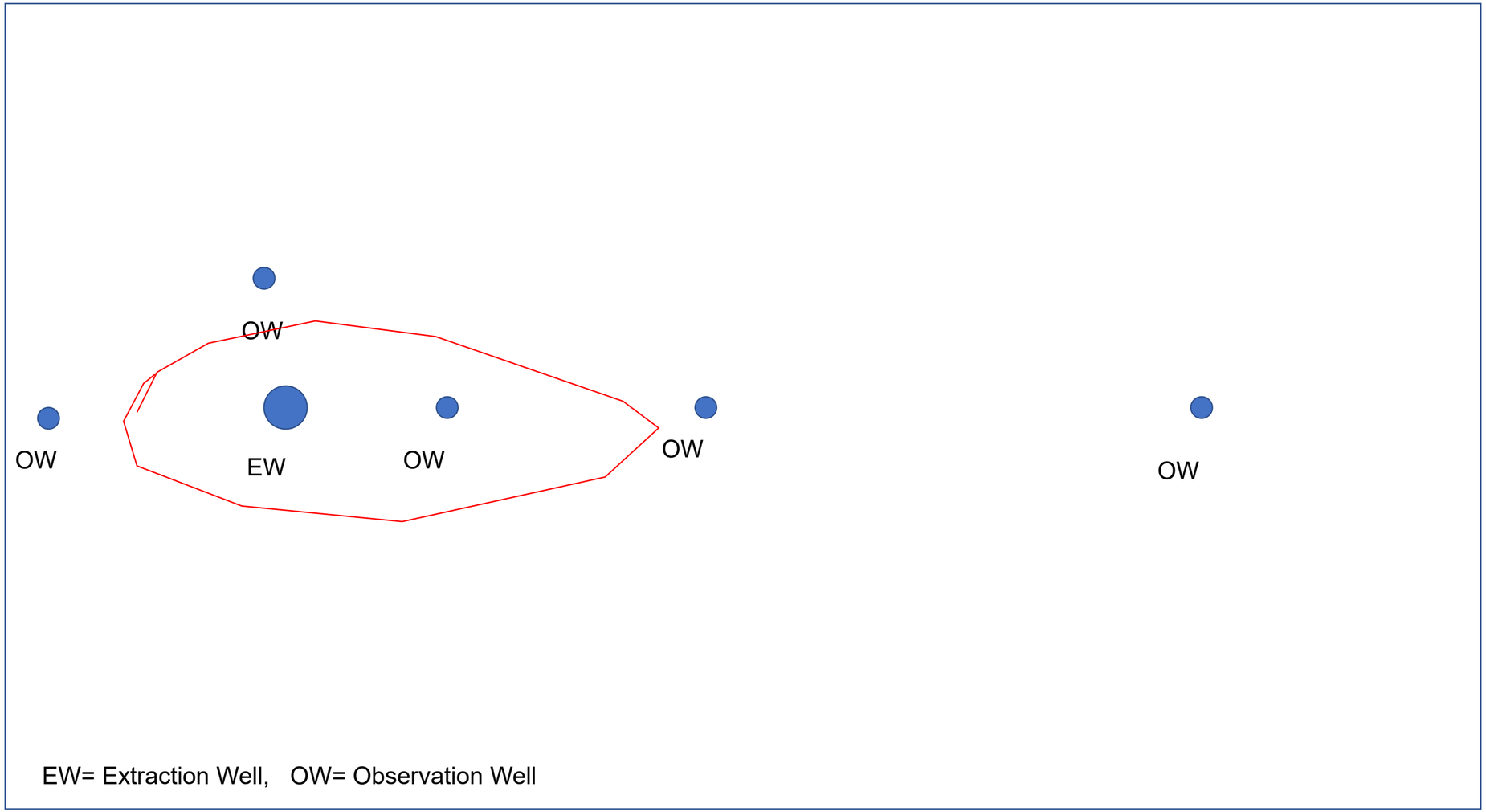
SVE System Schematic



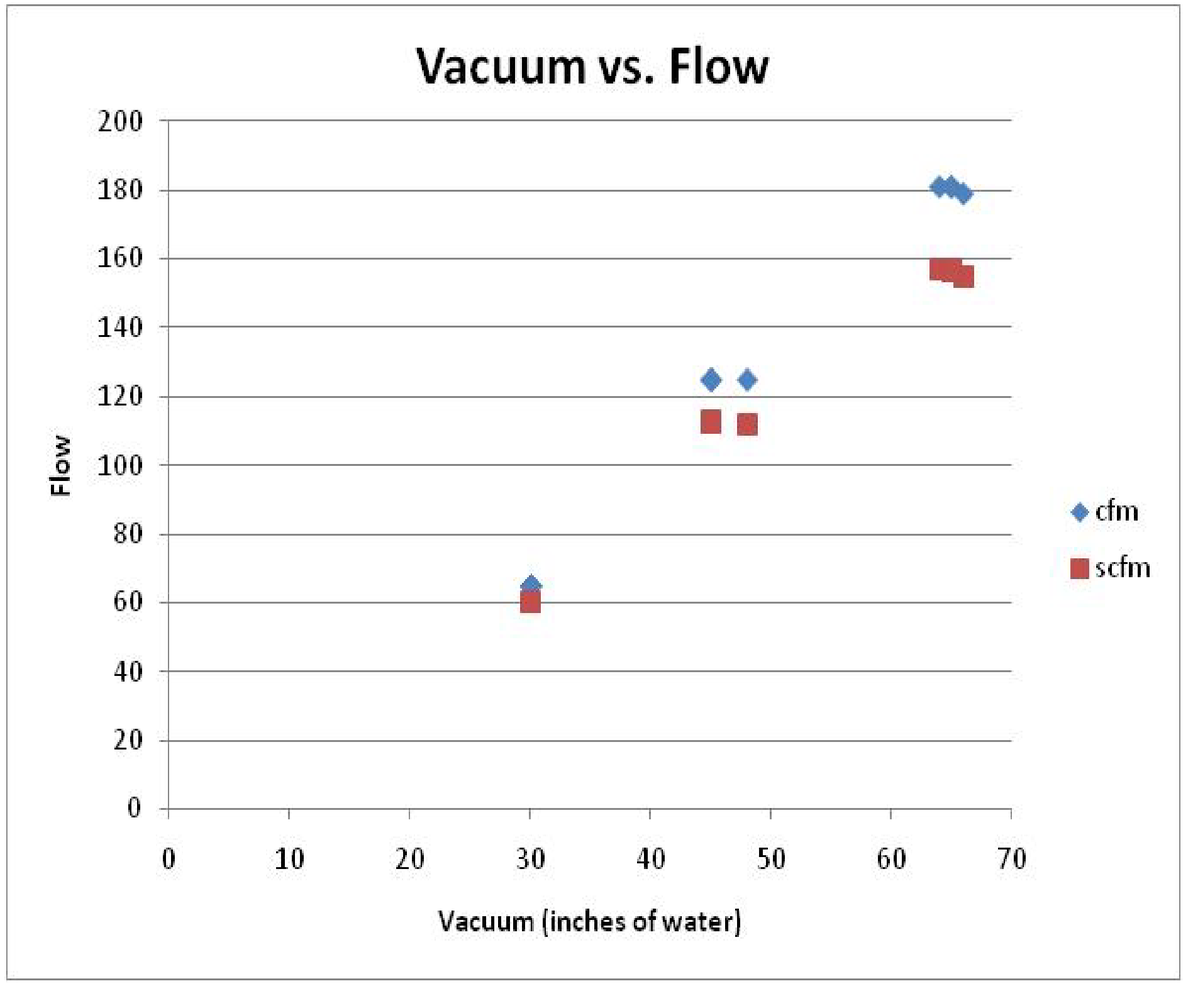
SVE ELEMENTS

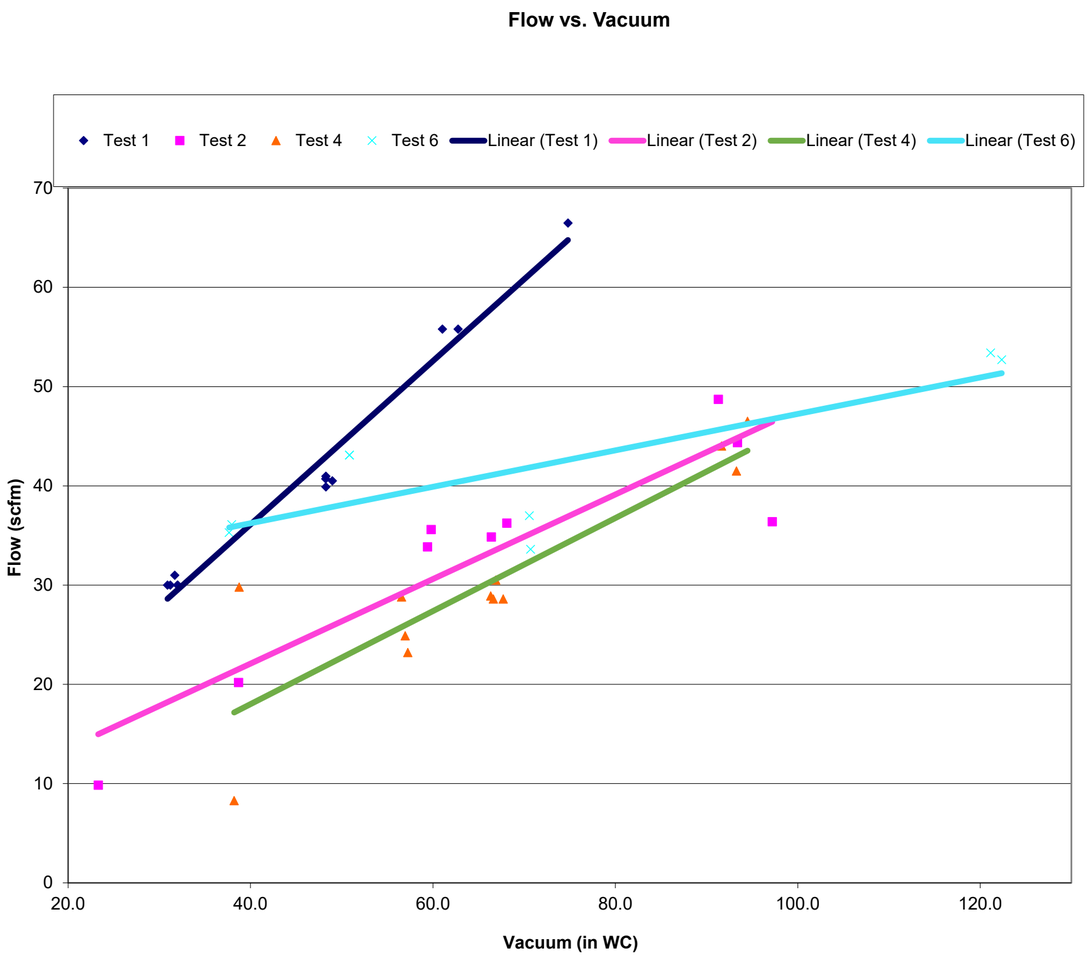
- Pilot Tests
- Extraction/Observation Wells
- Equipment Selection
- Step tests
- Zone of influence
- Permeability Calculations
- Removal rates
- Biodegradation Rates (CO_2)

Pilot Test Well Placement

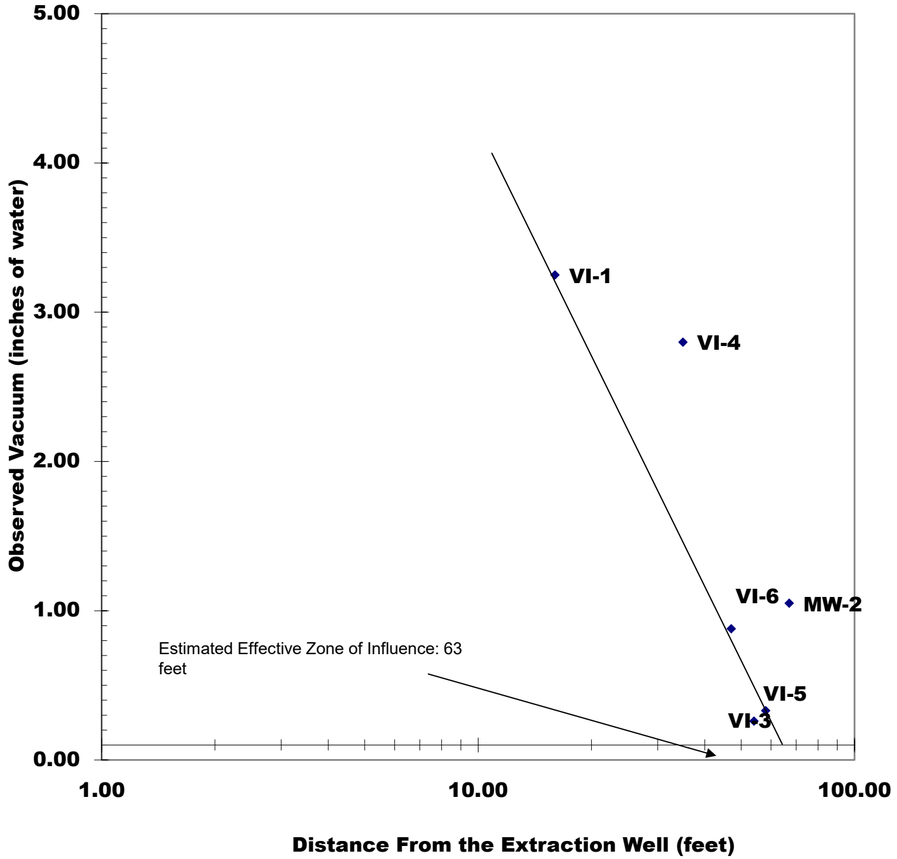


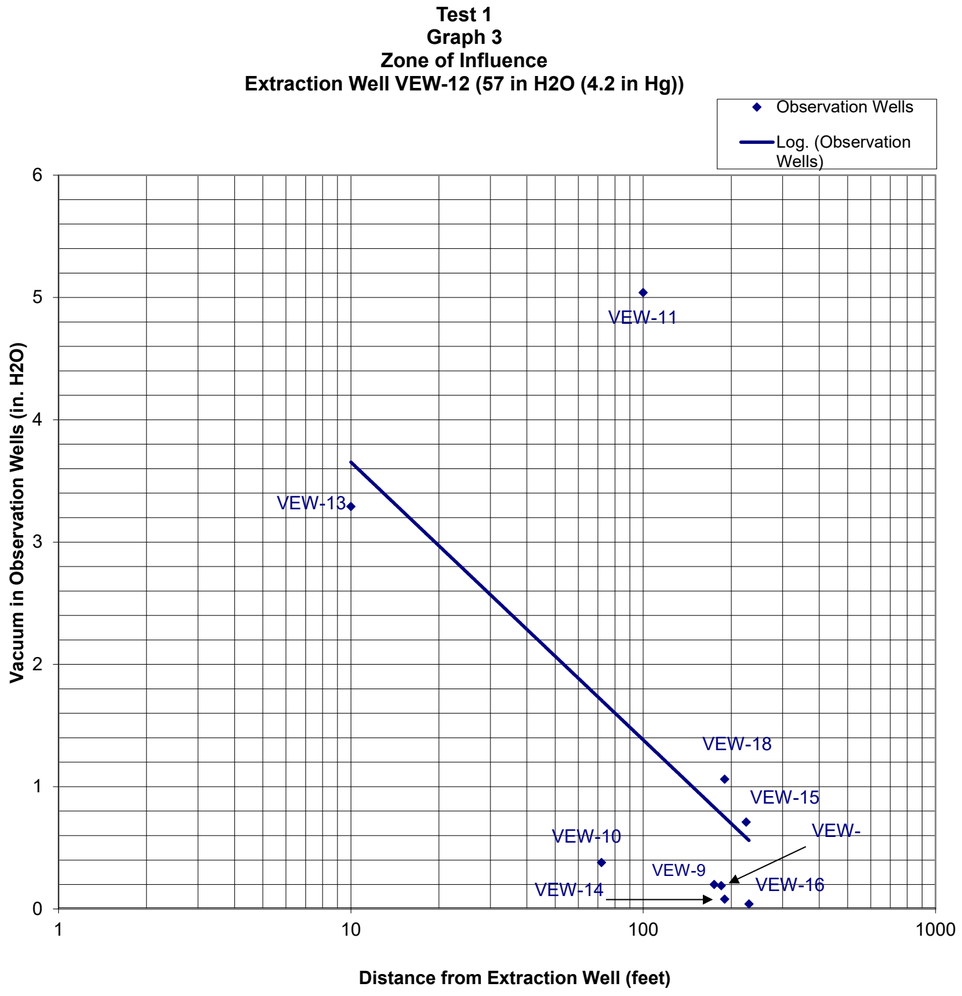
Step Test


Vacuum vs. Flow
Flow
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Vacuum (inches of water)
cfm
scfm


Flow vs. Vacuum
Test 1
Test 2
Test 4
Test 6
Linear (Test 1)
Linear (Test 2)
Linear (Test 4)
Linear (Test 6)
Flow (scfm)
70
60
50
40
30
20
10
0
20.0
40.0
60.0
80.0
100.0
120.0
Vacuum (in WC)

Zone of Influence Based on Vacuum



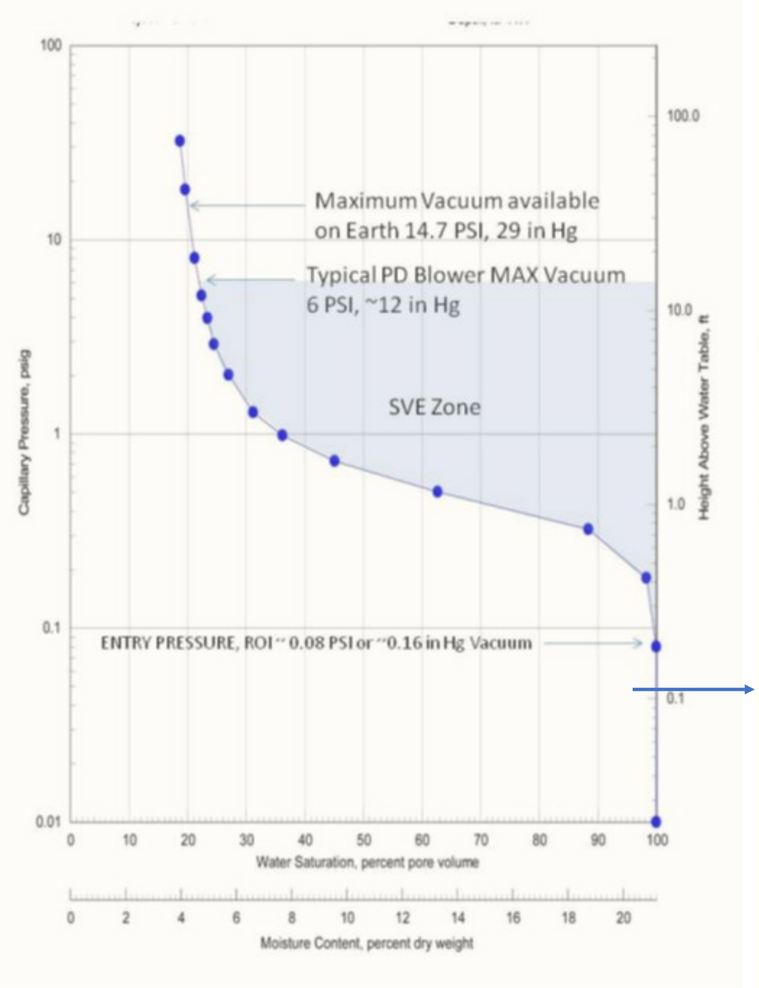


Minimum Entry Pressure (ZOI)

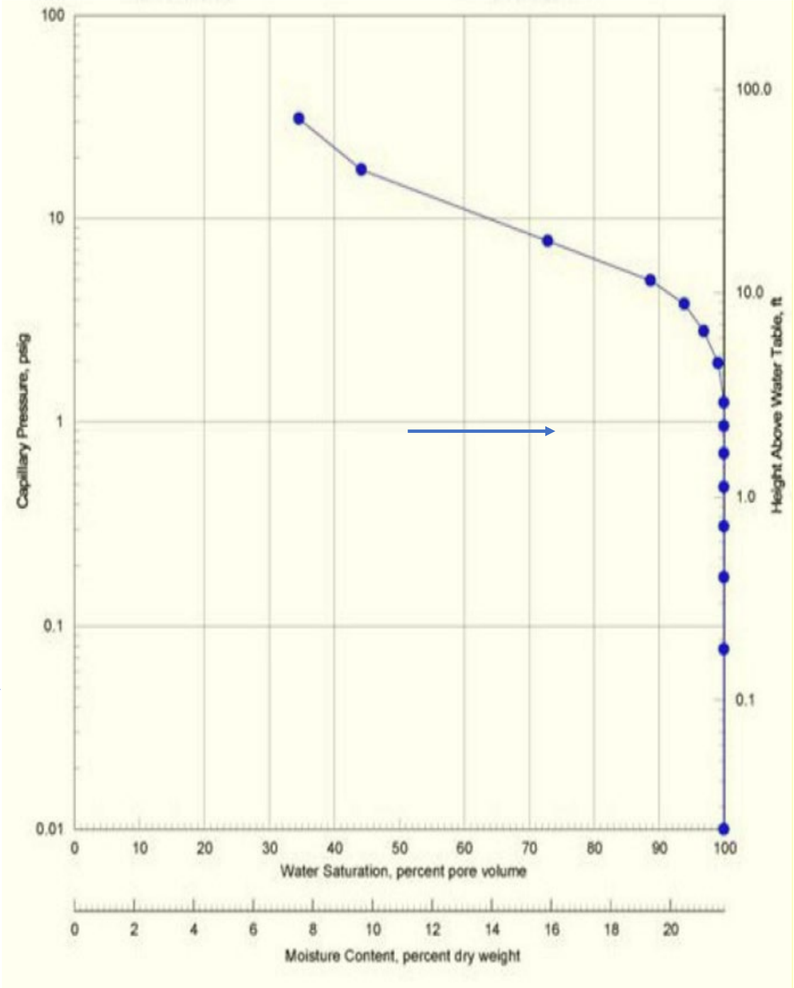
Estimate Zone of Influence at minimum entry pressure / vacuum

Set ZOI at Minimum Entry Pressure/Vacuum

Sand ~0.2 ft WC
Sand

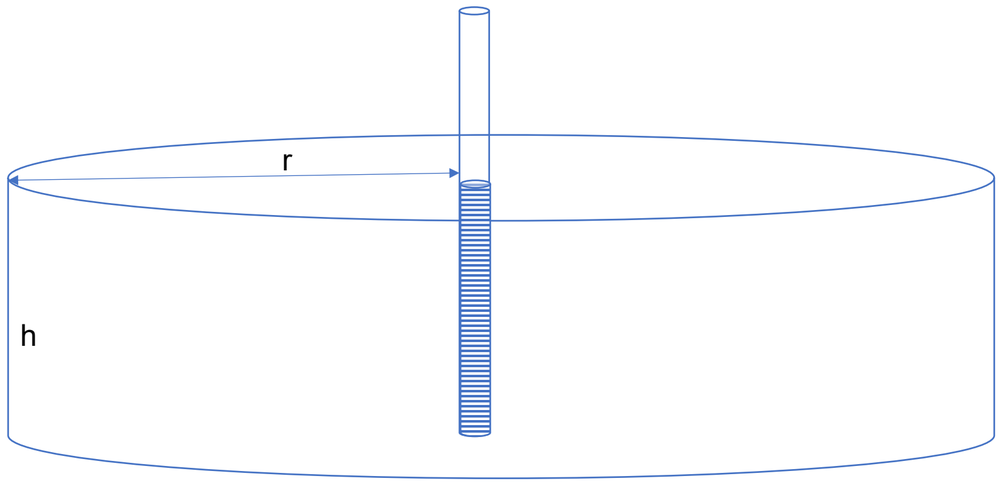


Silt ~ 3.0 ft WC
Silt



Zone of Influence Based on Pore Volume Removal

- Assume 2 pore volume per day is necessary for the SVE to be successful.
- Set up zone of influence (radius of Influence) using effective porosity, area and well flow rate



One pore volume (1PV) = $h \times \pi \times r^2 \times n_e$

Two pore volume per day is expected to be removed from the well.
We will calculate radius of influence (r) using the well flow and screen interval

$h \times \pi \times r^2 \times n_e = CFM*1440/2$

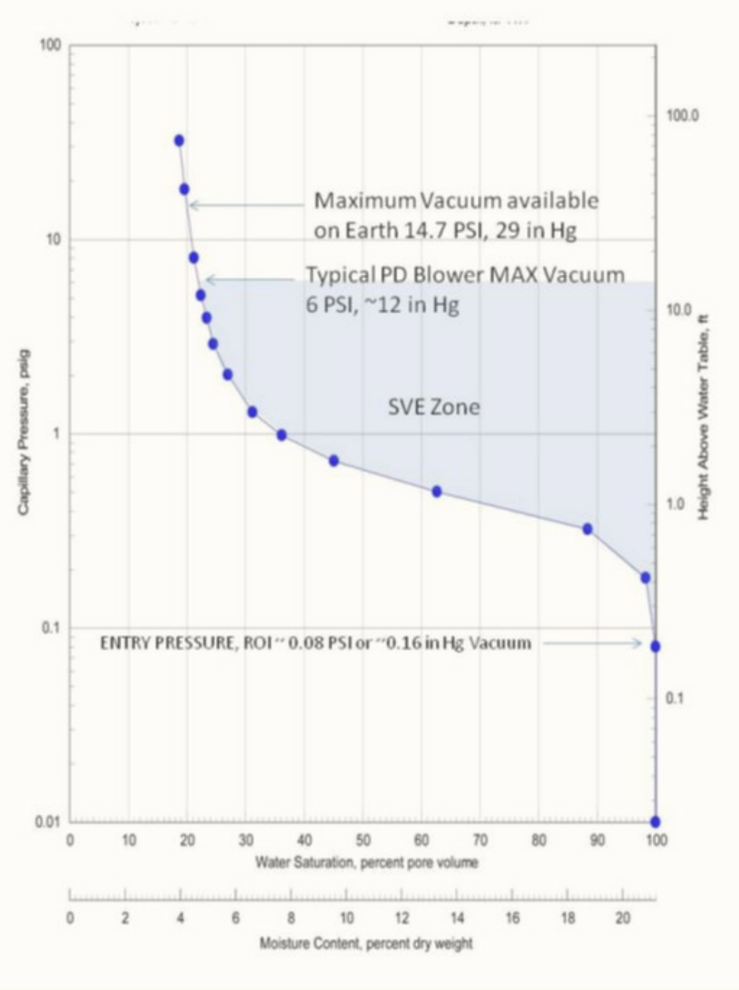
$\cancel{h \times \pi} \times r^2 \times \cancel{n_e} = CFM*720 / (n_e \times h \times \pi)$

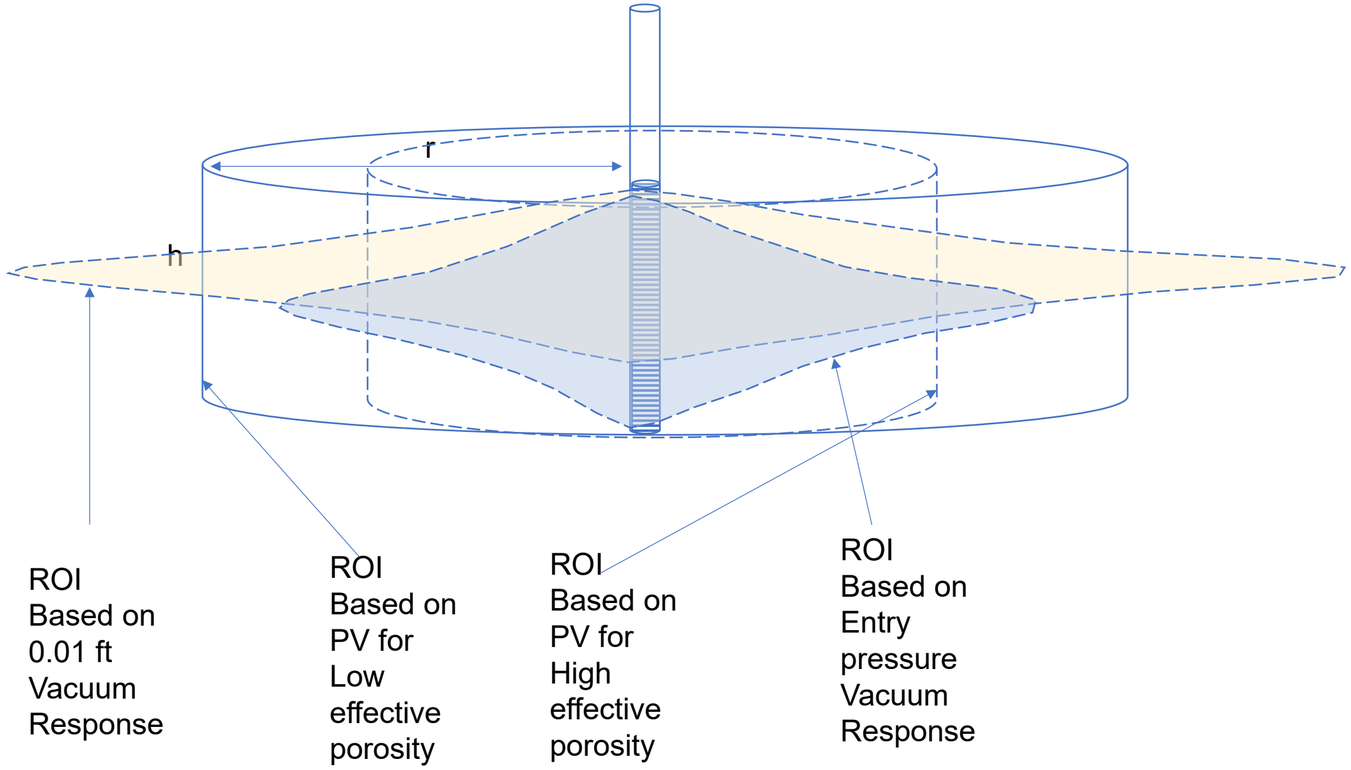
$r^2 = CFM*720 / (n_e \times h \times \pi)$

$r = [(CFM*720)/ (n_e \times h \times \pi)]^{(1/2)}$

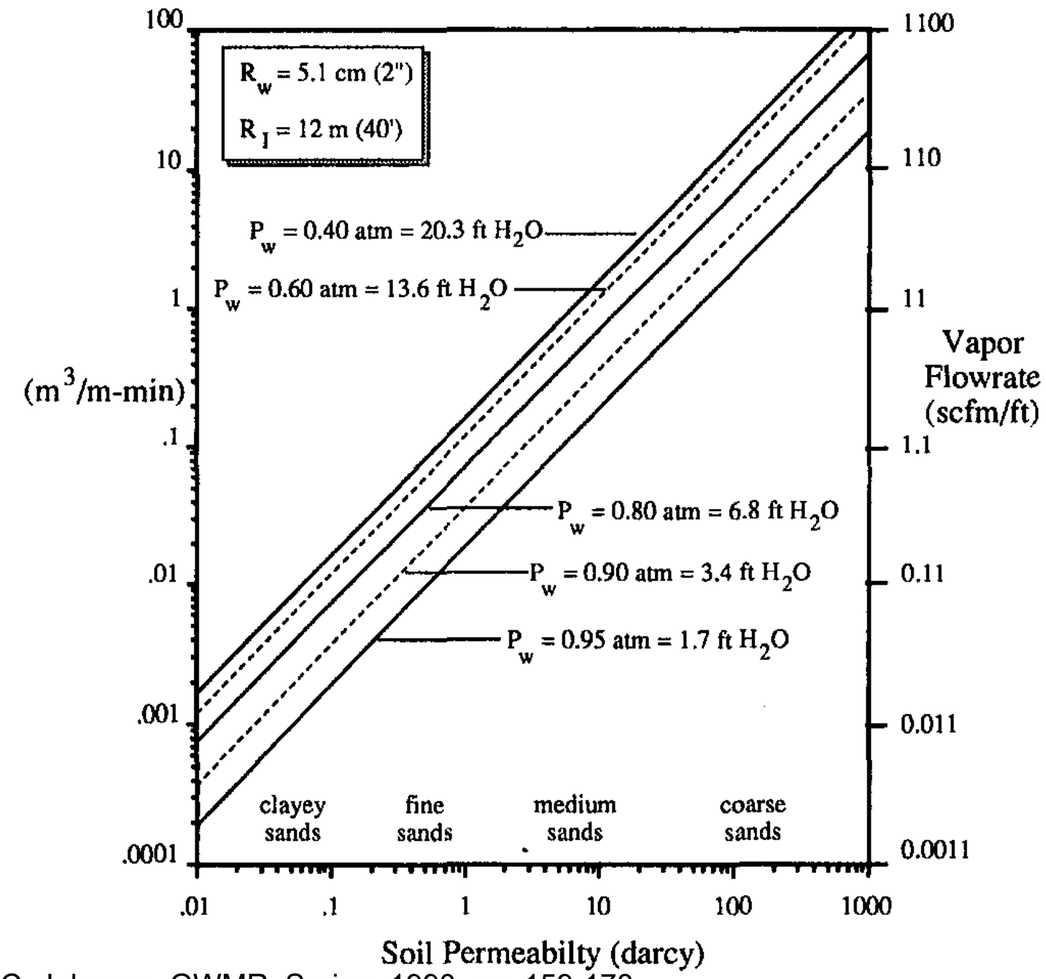
r= SQRT((50x720)/(0.2x20x(22/7))) = 53 ft

ZOI on PV and Capillary Pressure



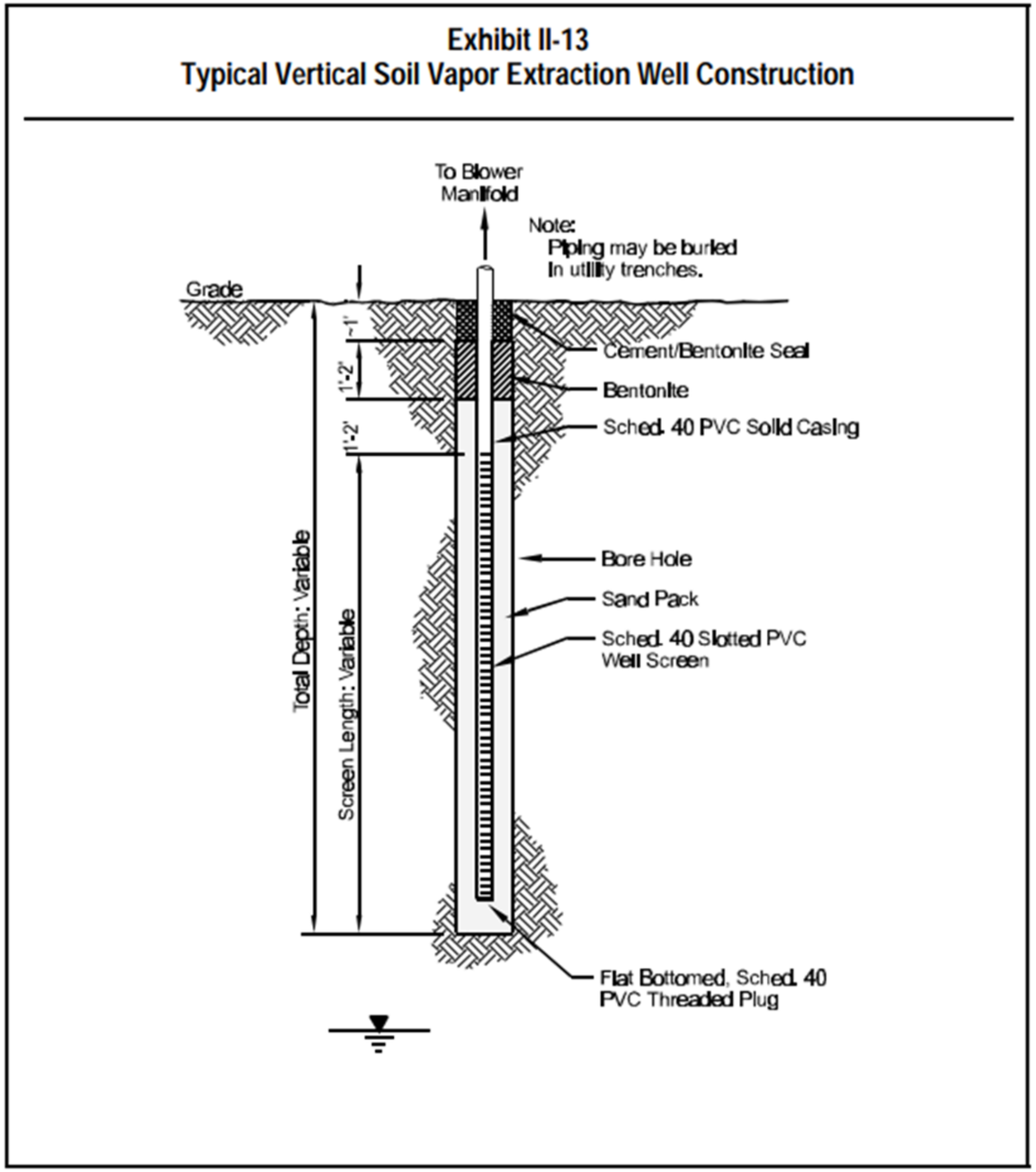


Equipment Selection



P.C. Johnson, GWMR, Spring, 1990, pp: 159-178

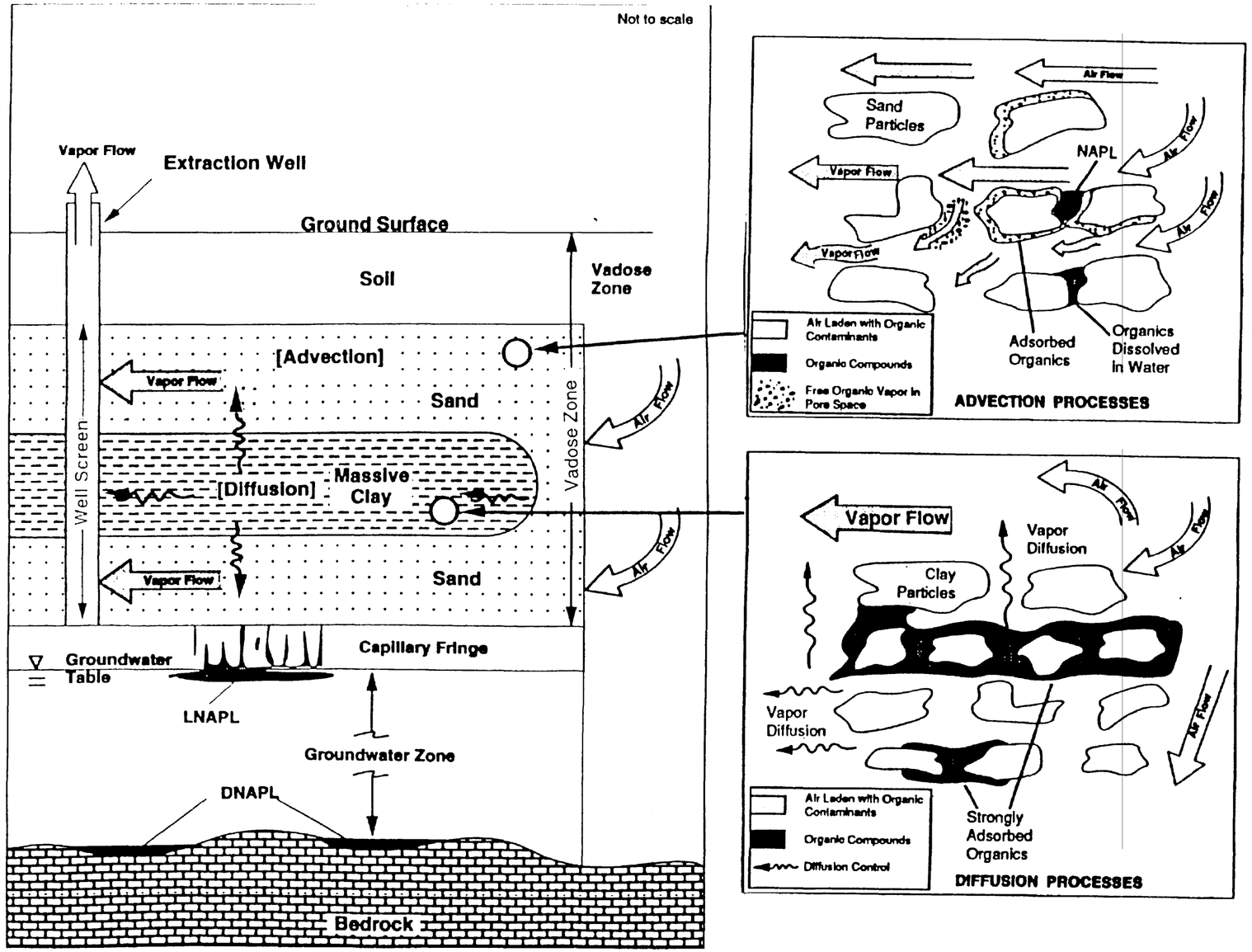
- Well Specifications
- Blower size – Soil Permeability
- Anticipated Vapor Concentrations
- Contaminant of Concern
- Duration of Test
- Environment-local ordinances



SVE Well Specifications

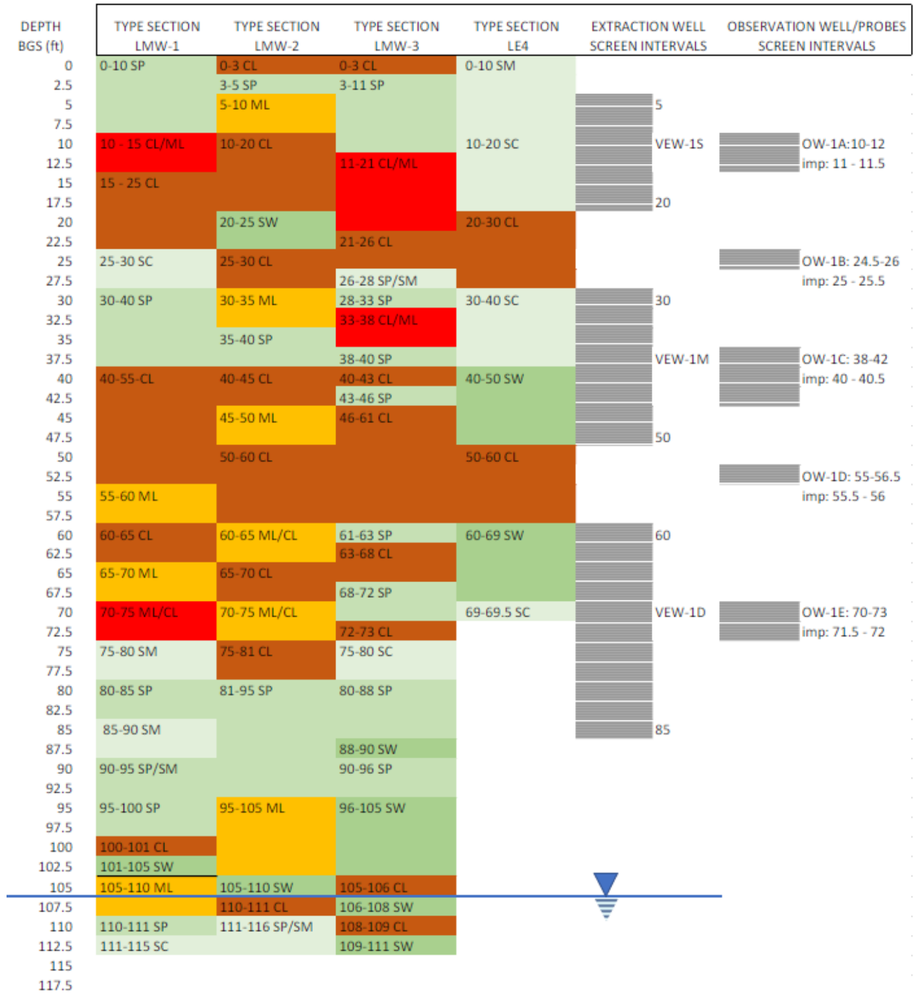
- Well Diameter, Screen size and Length
- 6-inch diam well vs 4-inch or 2-inch
- Screen Interval
- Bottom in Low K
- Vertical vs. Horizontal

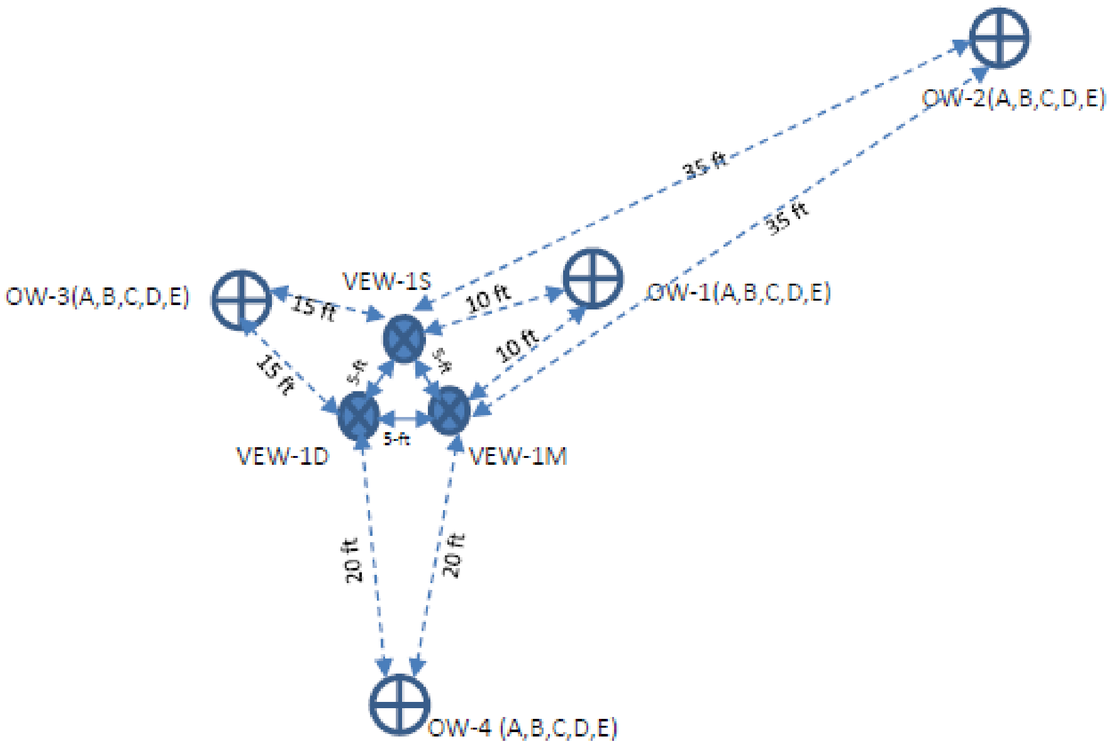
SVE Well Flow



Source: after USEPA 1991c

SVE Well Layout





Air Permeability

Table 8. Summary of Air Permeability (Ka) Estimations

Site: SVE Test Site

Test Date:

Ka=((ma*Q)/(PI*H*Pw))*((LN(Rw/Ri))/(1-(Pi/Pw)^2))

CALCULATIONS					FIELD MEASUREMENTS		
TEST 1	TEST 2	UNITS	SYMBOLS	FACTOR	TEST 1	TEST 2	
VE-1	VE-2				VE-1	VE-2	UNITS
22.81	**31.18**	**darcy**	**Ka**				
85423	87783	cu.cms/sec	**Q**	471.95	181	186	cfm
0.018	0.018	cp	**ma**	1	0.018	0.018	cp
1	1	atm	**Pi**	1	1	1	atm
0.84	0.88	atm	**Pw**	0.002458	65	50	Vw
12.7	12.7	cm	**Rw**	30.48	0.417	0.417	feet
1828.8	1828.8	cm	**Ri**	30.48	60	60	feet
304.8	304.8	cm	**H**	30.48	10	10	feet

EXPLANATIONS

Ka: Average horizontal permeability [L^2] cm^2
Q: Air flow rate [(L^(3))/T]
ma: Viscosity of air[M(T^(-1))(L^(-1))] =1.8*10^(-4) g/cmsec or 0.018 cp
Pi: Absolute gas pressure at a location Ri from the well [ML(T^(-2))]
1.01*10^6 g/cm-s^2 = 1 Atm at radius of influence
Pw: Absolute gas pressure in the well [ML(T^(-2))], (1atm-vacuum in units of atm)
Rw: Effective radius of the well [L]
Ri: Radius of Influence [L]
H: Screened zone in the test well (extraction well) [L]
L: Length
M: Mass
T: Time
^: to the power
LN: logaritm
PI: 3.141592654
atm: atmosphere
Vw: vacuum in inches of water

P.C.Johnson, GWMR, Spring 1990, pp 159-178

Well Flow Estimations

$$Q/H=\pi*(k/\mu)*P_{w*}((1-(P_{Atm}/P_w)^2)/(\ln(R_w/R_i))$$

$$Q=(\pi*(k/\mu)*P_{w*}((1-(P_{Atm}/P_w)^2)/(\ln(R_w/R_i)))*H$$

Excel (Q) =B38*(PI()*(B31/B33)*B35*((1-((B34/B35)^2))/(LN(B36/B37))))

CALCULATIONS					FIELD MEASUREMENTS		
ESTIMATE1	ESTIMATE2	UNITS	SYMBOLS	FACTOR	ESTIMATE1	ESTIMATE2	
VEW-1S	VEW-1D				VEW-1S	VEW-1D	UNITS
232120.9557	445572.9121	cu.cms/sec	Q	0.002118869	491.8337868	944.1104188	cfm--Well Flow
75.72	96.90	darcy	k	0.001	75720	96900	Milidarcy (Lab-Vertical)*
0.018	0.018	cp - Air Viscosity	μ	1	0.018	0.018	cp - Air Viscosity
1	1	atm	P_{Atm}	1	1	1	atm
0.88	0.88	atm	P_w	0.002458	50	50	Vw
12.7	12.7	cm	R_w	30.48	0.417	0.417	feet
1219.2	1219.2	cm	R_i	30.48	40	40	feet
304.8	457.2	cm	H	30.48	10	15	feet

* Permeability testing was performed on vertical section of the cores in the lab. Typically, horizontal permeability values are order of magnitude

EXPLANATIONS

k : Average horizontal permeability $[L^2]$ cm^2 - From lab results

Q : Air flow rate $[(L^3)/T]$ - Per well - Calculated using assumed screen interval and well diameter

μ : Viscosity of air$[M(T^{-1})(L^{-1})]$ $=1.8*10^{-4}$ g/cmsec or 0.018 cp

P_{Atm} : Absolute gas pressure at a location Ri from the well $[ML(T^{-2})]$

$1.01*10^6$ g/cm-s^2 = 1 Atm at radius of influence

P_w : Absolute gas pressure in the well $[ML(T^{-2})]$, (1atm-vacuum in units of atm)

R_w : Effective radius of the well [L] - assumed 4-inch well in 10-inch borehole

R_i : Radius of Influence [L], - Assumed 40-feet as a conservative value

H: Screened zone in the test well (extraction well) [L]

L: Length

M: Mass

T: Time

^: to the power

LN: natural logaritm

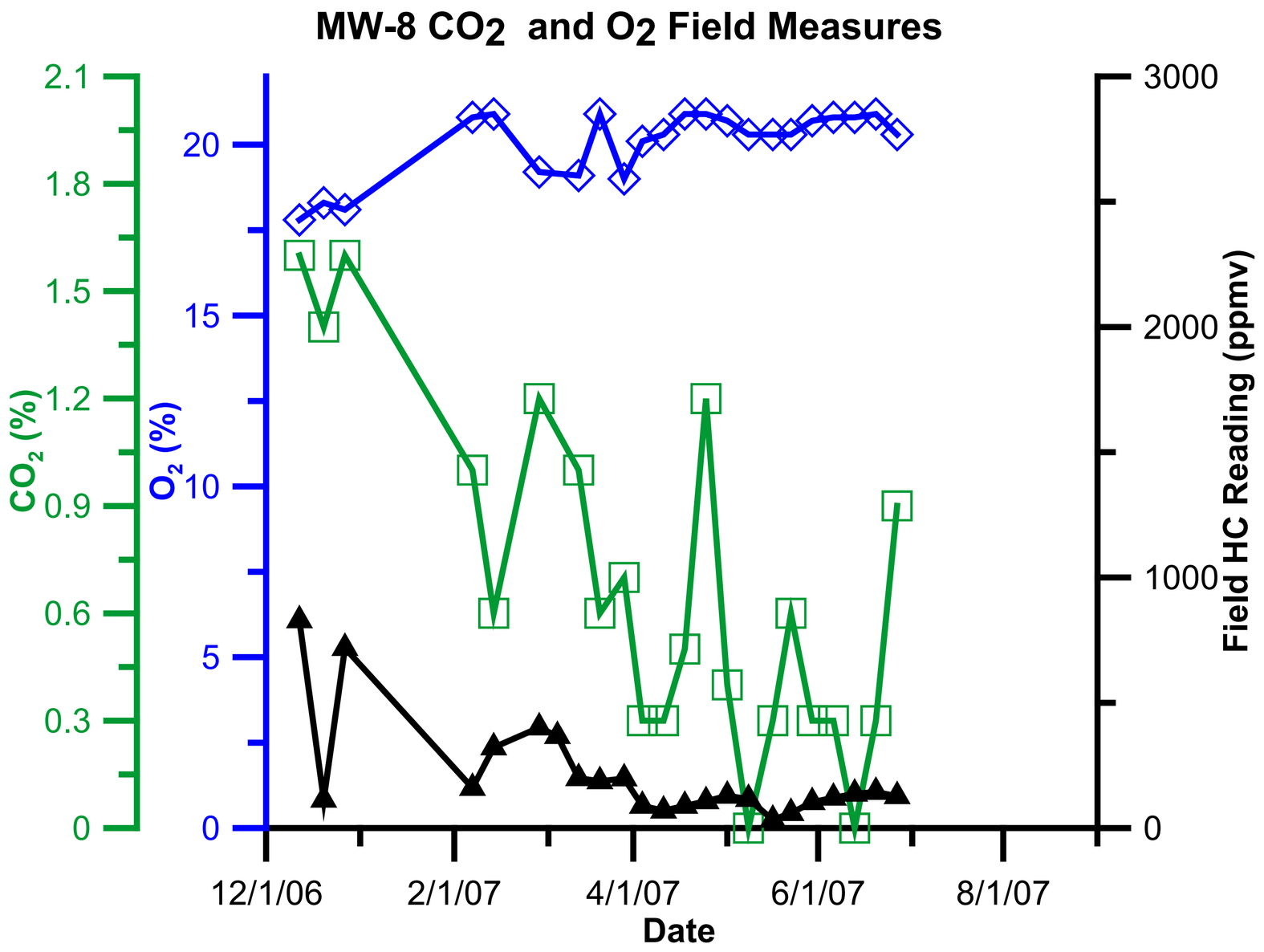
π 3.141592654

atm: atmosphere

Vw: vacuum in inches of water

$$\frac{Q}{H} = \pi \frac{k}{\mu} p_w \frac{[1-(P_{Atm}/P_w)^2]}{\ln(R_w/R_I)}$$

P. Johnson, 1990



CO_2 and O_2 Field Measurements

CO_2 and VFH Conversion

$$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$$

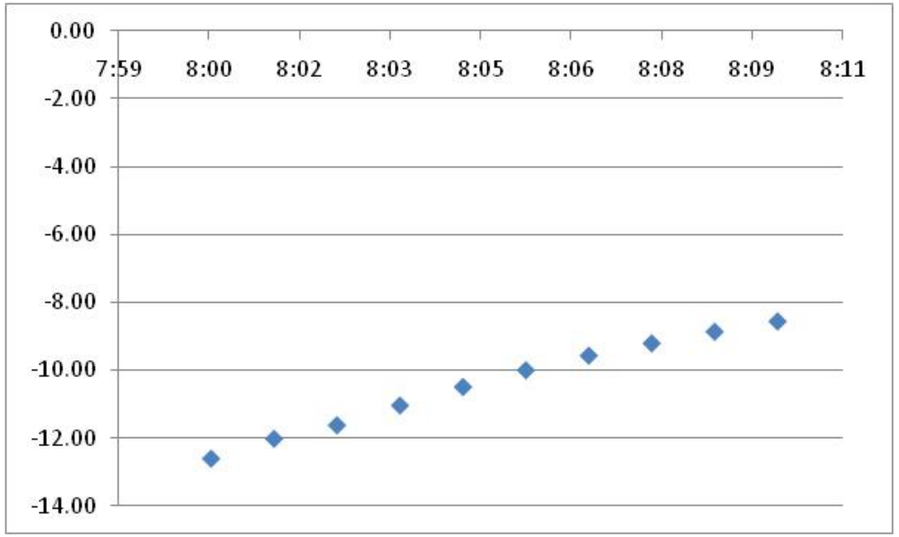
$$(7X12+16)+11X32 \rightarrow (7x12+7x32) + (16+8x16)$$

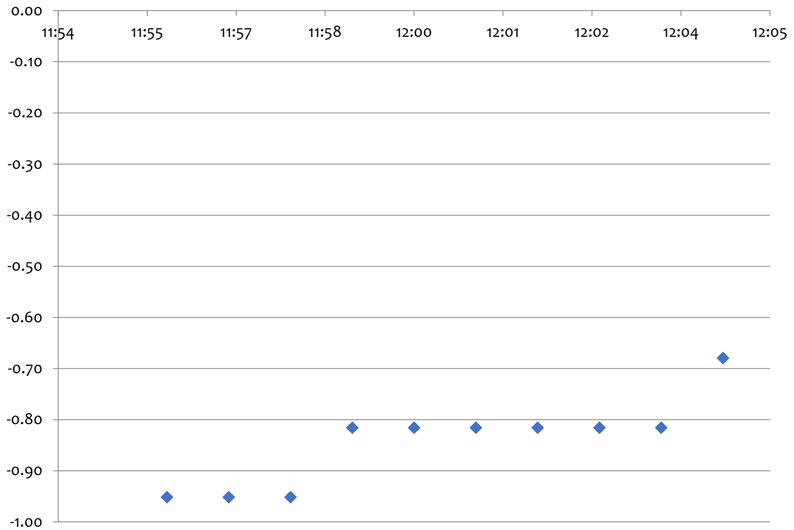
$$100 + 352 \rightarrow 308 + 144$$

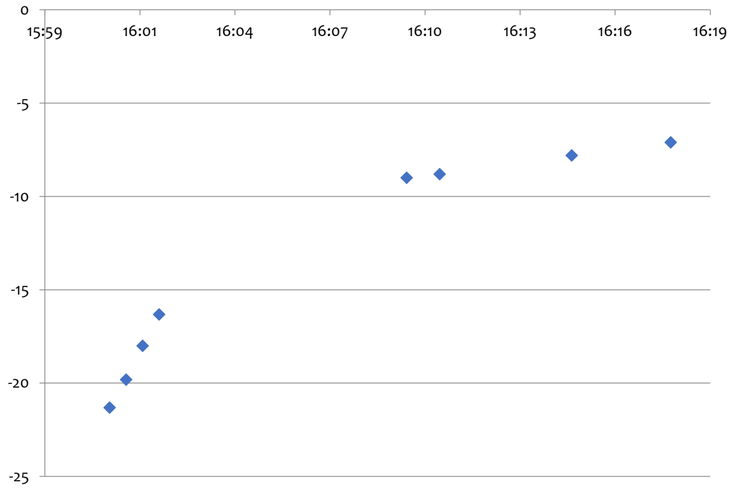
1.0 lb VFH ≈ 3.0 lb CO_2

(**after biodegradation**)

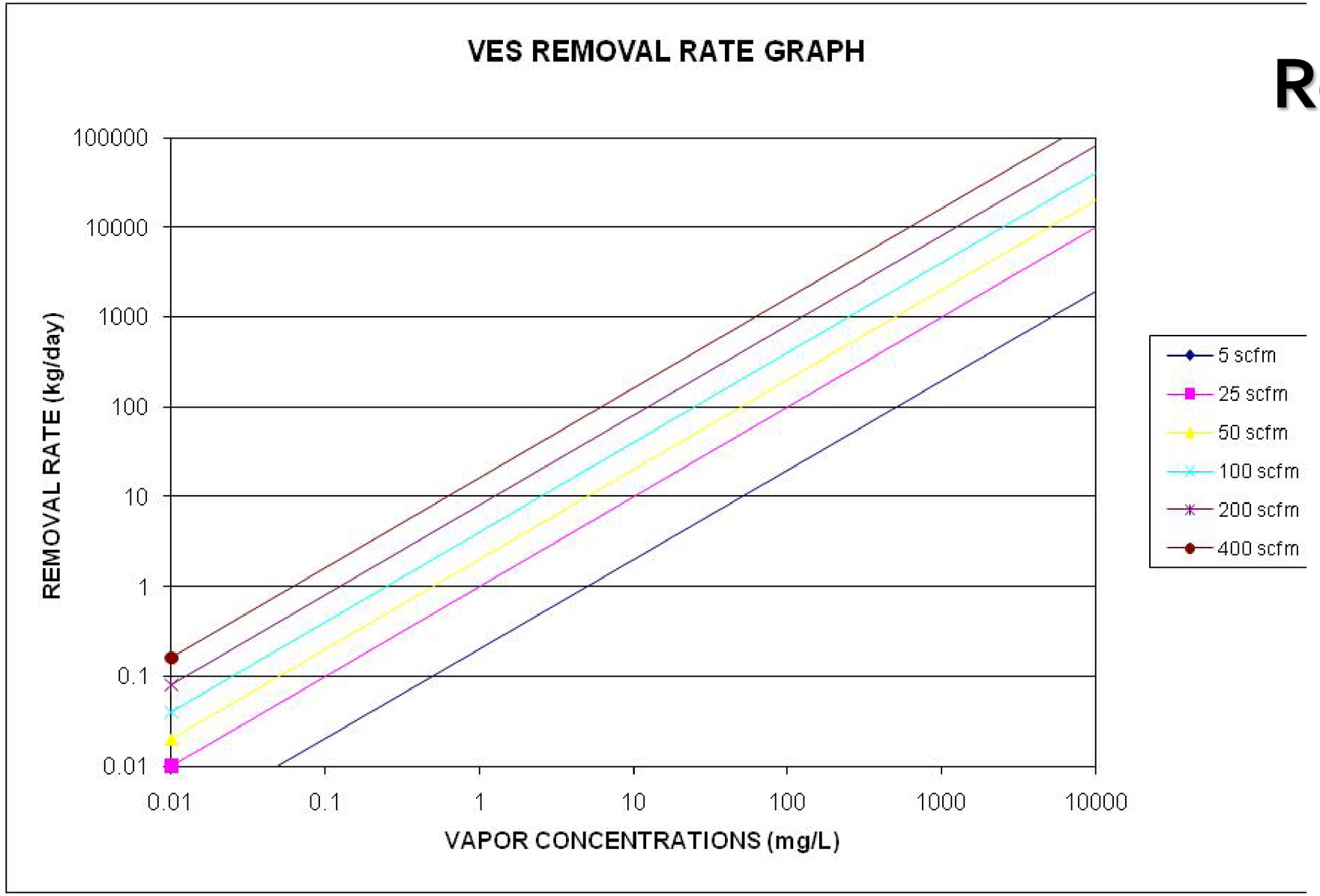
Vacuum Recovery Readings







Removal Rate Graph



Removal Rate

Estimated Removal Rate Calculations

EXTRACTION WELL: VEW-12			PARAMETERS	
3 in Hg	6 in Hg	7.5 in Hg		
			CALCULATIONS	
525.7	**158.9**	**153.1**	**lb/day**	**Calculated HC removal rate**
21.9	**6.6**	**6.4**	**lb/hr**	**Calculated HC removal rate**
0.365	**0.110**	**0.106**	**lb/min**	**Calculated HC removal rate (Field)**
1.9	**1.9**	**1.7**	**lb/min**	**Calculated HC removal rate (Lab)**
			lb/min=	(ppmV*SCFM*Mw)/(1,000,000*379 cu.ft./lb-mole[gas constant])
3,250	1,100	1,160	ppmV =	parts per millions by volume (Field)
17,000	19,000	18,000	ppmV =	parts per millions by volume (Lab)
495	442	404	SCFM =	Flow Rate (standard cubic feet per minute [SCFM])
86	86	86	Mw =	molecular weight (n-hexane = 86.2 g/mole(AQMD uses);gasoline=95g/mole;
				weathered gasoline = 111g/mole; benzene = 78.1 g/mole;toluene = 92 g/mole;
				xylene 106 g/mole, methane 16.05 g/mole ?) Ref: Johnson et al, 1990
31.0	**8.8**	**16.5**	**actual lbs removed (based on field PID)**	
162.3	**152.4**	**255.8**	**actual lbs removed (based on lab concentrations)**	
85	**80**	**155**	**Total operation time (min)**	

Maximum Removal Rate = Flow X Max Conc.

Desired Removal Rate = $\frac{\text{Mass}}{\text{Desired Clean up time}}$

REMOVAL PROGRESS EVALUATION

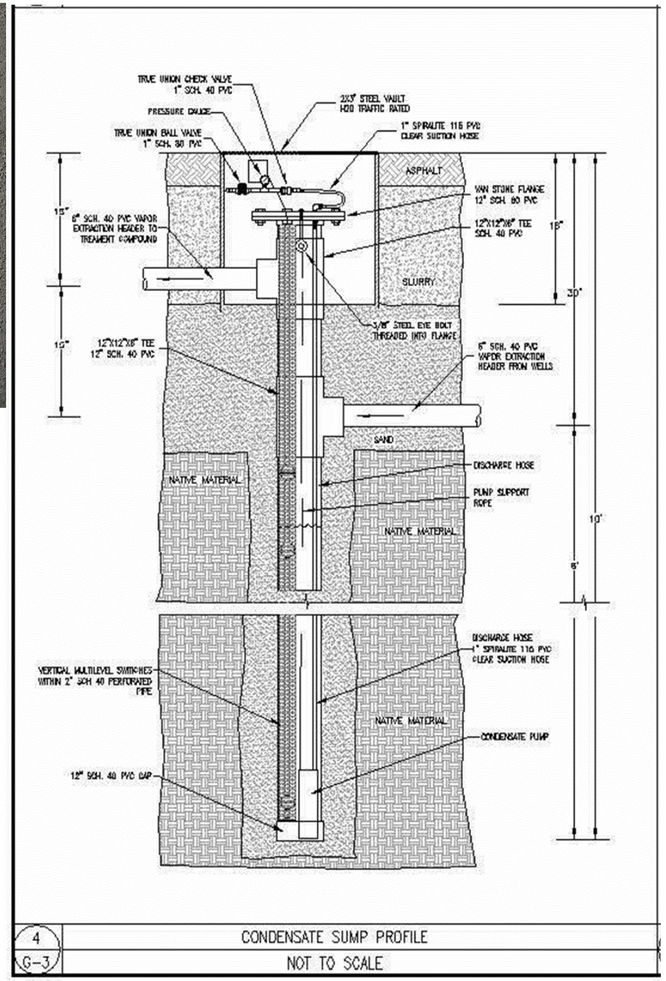
- Pore Volume (PV) = Total Volume of Effective Porosity (EP) within the Effective ROI/ZOI (in cubic ft)
- One PV = ZOI/ROI Area (sqft) X Thickness (ft) X EP (decimal)
- #of PV (S1-S2) = (T1-T2)X(CFM)X(1440)/(One PV)

  - # of pore volume to reach from S1 to S2
  - S1 – Sample 1, S2 – Sample 2
  - T1 - Date and time of S1, T2 – Date and time of S2
  - CFM – System inlet flow (undiluted) in cubic ft per minute

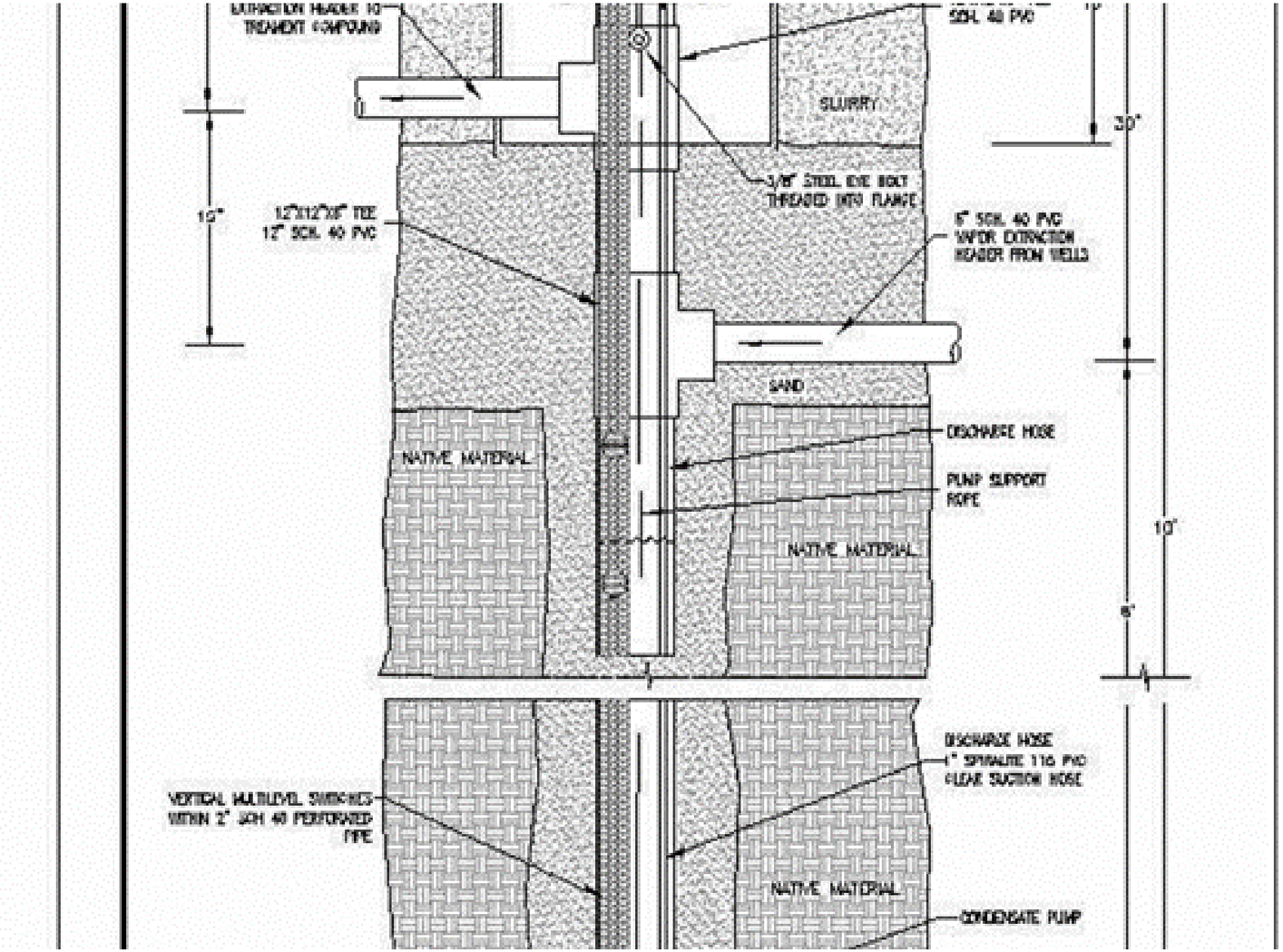
System Optimization

- Operation time (Up time)
- Power supply problems
- Permit Issue (permit limits too low)
- Piping Issues/Manifold
- Well placement/screen issues
- Water Recovery/Cold Temperatures
- Upwelling
- Lower recovery rates than estimated
- Toggling
- Rebounding
- Tracer Studies
- Removal rate revisions
- In-fill areas

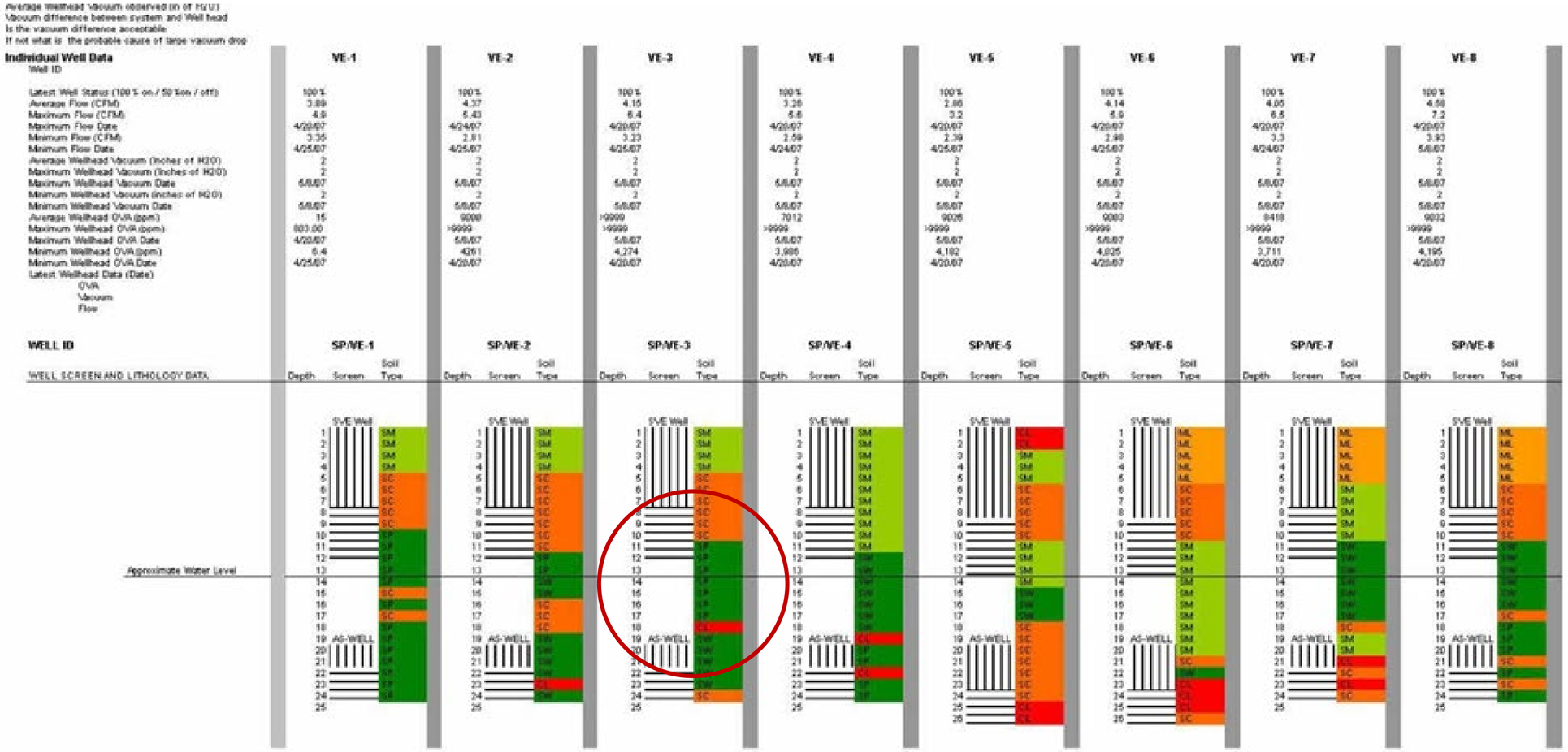
Piping Issues / Manifold



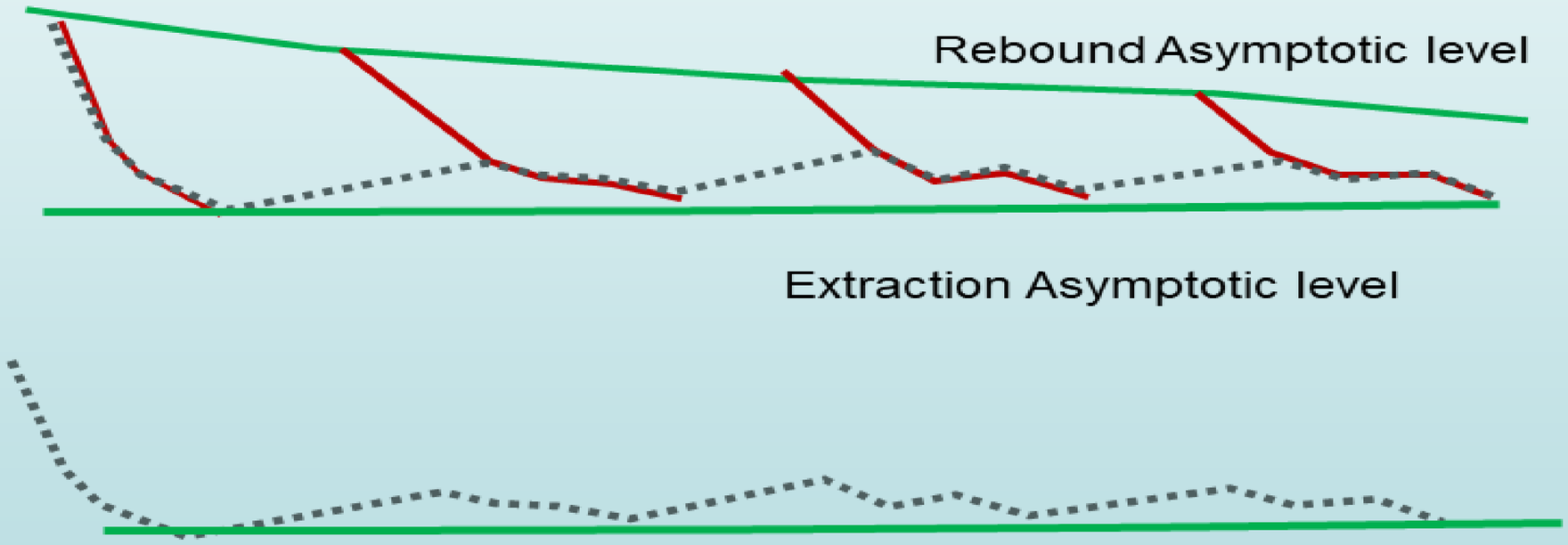
Water Recovery



Well Screening - Upwelling



Asymptotic Levels



Rebound Testing

REBOUND % = (1-TMR/TM) [1]

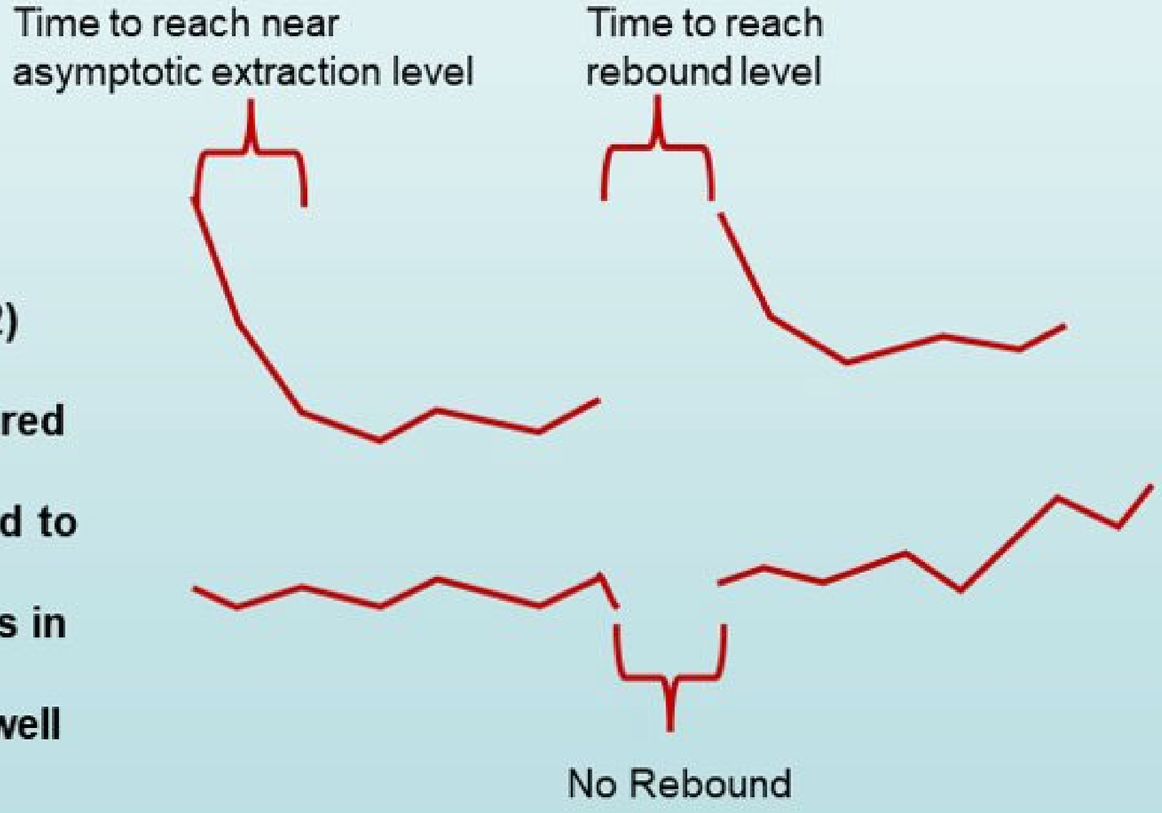
REBOUND TIME may be the time it took to reach initial asymptotic level [2]

TM: TOTAL MASS
TMR: TOTAL MASS REMOVED
%MR: % MASS REMOVED : TMR/TM
IC: INITIAL CONCENTRATION
REBOUND CONC.(%RC) : IC x (%MR) (2)

Hydrocarbon sites: CO_2 must be measured and HC removal by in situ respiration/degradation should be added to total mass removed.

[1] Assume all Initial calculations of mass in place and mass removed are correct.

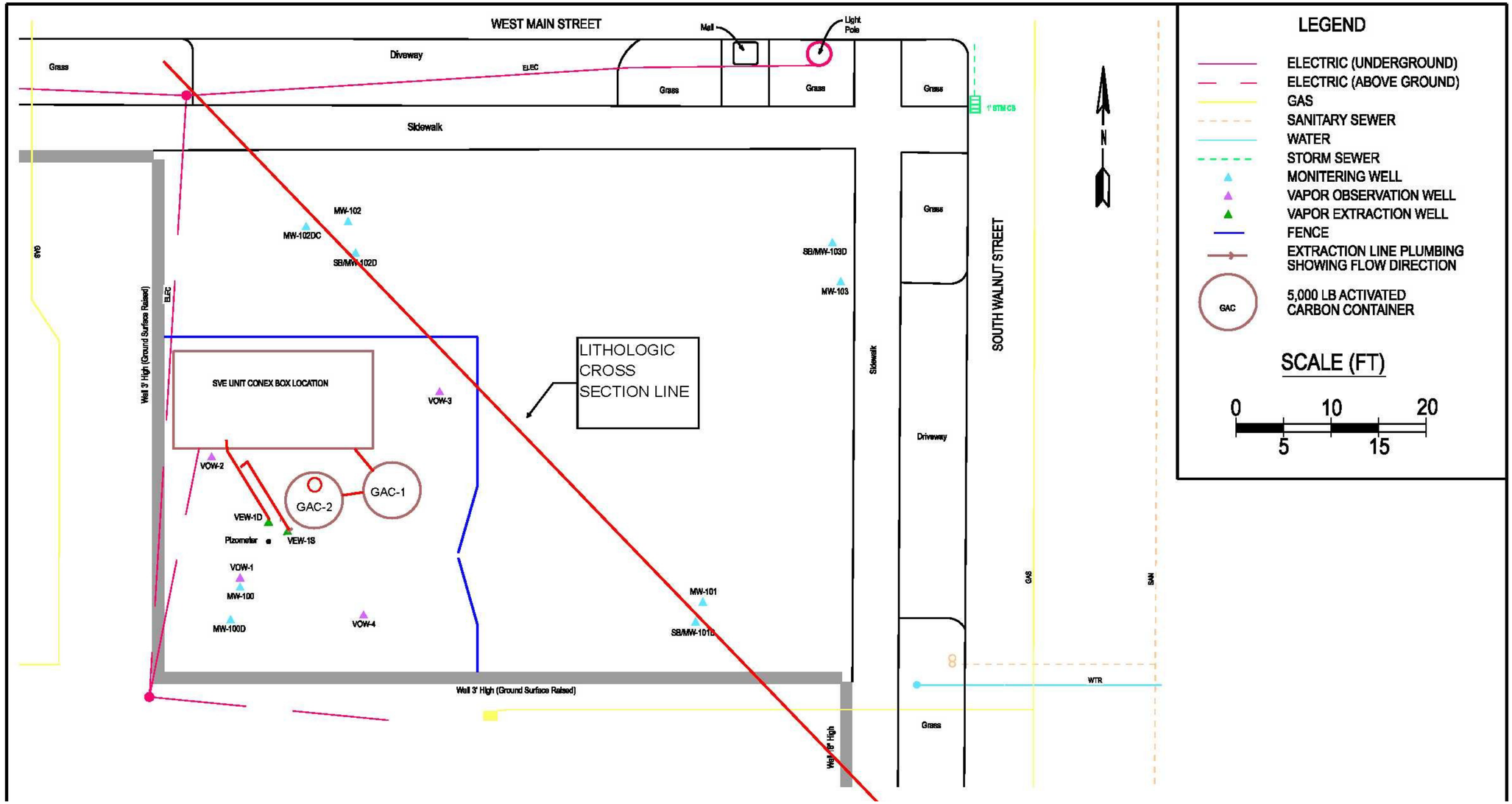
[2] Estimate widely varies based on the well location and plume distribution

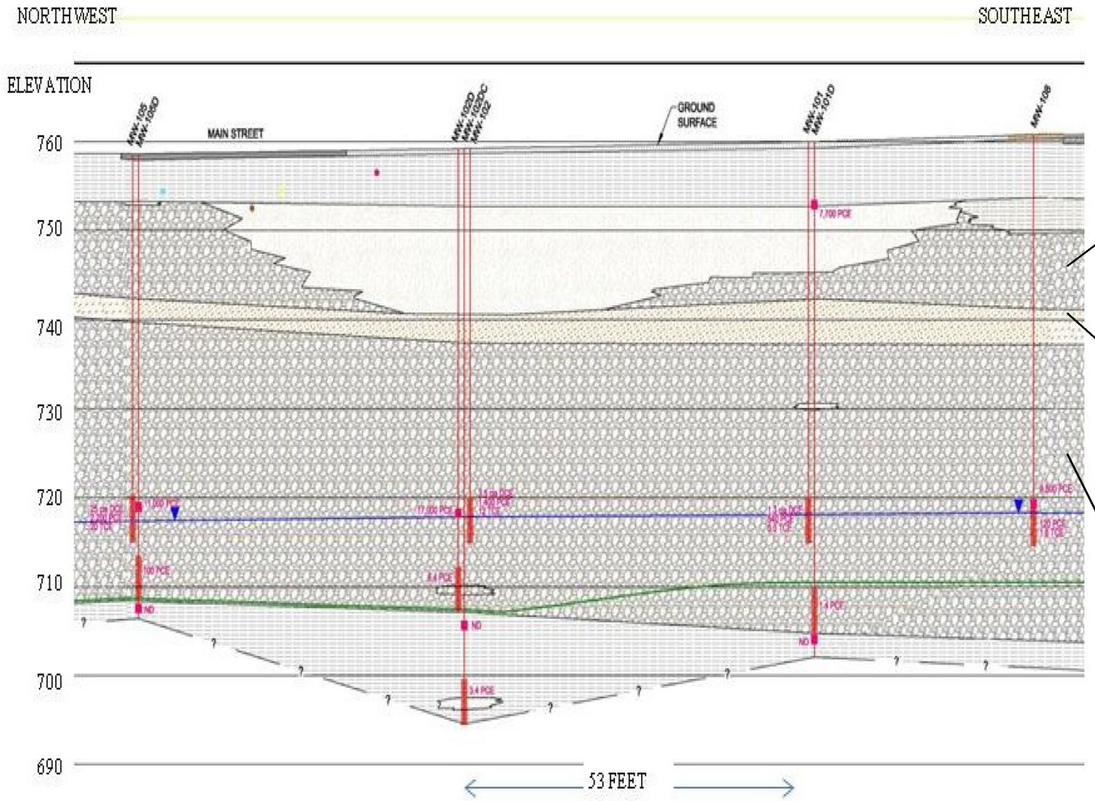


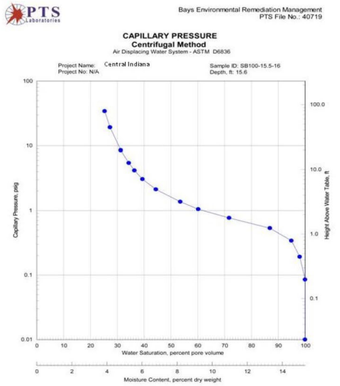
Carbon Footprint

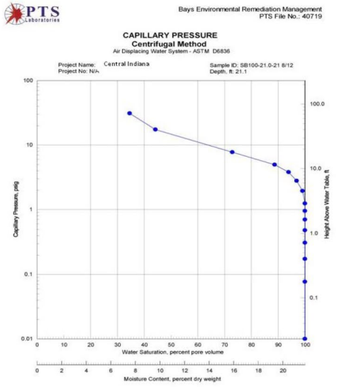
- Electricity Use:
- ~ 1.9 lbs CO_2 per horsepower/hour
- 10 hp motor 19 lbs CO_2 / hr X 24 = 456 lbs of CO_2 /day Technician Driving: 1 lb CO_2 per mile based on 20 MPG Vehicle 20 miles each way total 40 miles per week
- **1.0 lb VFH ≈ 3.0 lb CO_2**

SVE Case Exercise









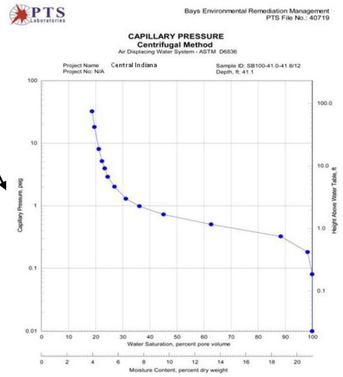


Figure 2 _ Cross-Section with Capillary Pressure Curve Graphs

Well Flow Estimations

$$Q/H=\pi*(k/\mu)*P_{w*}((1-(P_{Atm}/P_w)^2)/(\ln(R_w/R_i))$$

$$Q=(\pi*(k/\mu)*P_{w*}((1-(P_{Atm}/P_w)^2)/(\ln(R_w/R_i)))*H$$

Excel (Q) =B38*(PI()*(B31/B33)*B35*((1-((B34/B35)^2))/(LN(B36/B37))))

CALCULATIONS					FIELD MEASUREMENTS		
ESTIMATE1	ESTIMATE2	UNITS	SYMBOLS	FACTOR	ESTIMATE1	ESTIMATE2	
VEW-1S	VEW-1D				VEW-1S	VEW-1D	UNITS
232120.9557	445572.9121	cu.cms/sec	Q	0.002118869	491.8337868	944.1104188	cfm--Well Flow
75.72	96.90	darcy	k	0.001	75720	96900	Milidarcy (Lab-Vertical)*
0.018	0.018	cp - Air Viscosity	μ	1	0.018	0.018	cp - Air Viscosity
1	1	atm	P_{Atm}	1	1	1	atm
0.88	0.88	atm	P_w	0.002458	50	50	Vw
12.7	12.7	cm	R_w	30.48	0.417	0.417	feet
1219.2	1219.2	cm	R_i	30.48	40	40	feet
304.8	457.2	cm	H	30.48	10	15	feet

* Permeability testing was performed on vertical section of the cores in the lab. Typically, horizontal permeability values are order of magnitude

EXPLANATIONS

k : Average horizontal permeability $[L^2]$ cm^2 - From lab results

Q : Air flow rate $[(L^3)/T]$ - Per well - Calculated using assumed screen interval and well diameter

μ : Viscosity of air$[M(T^{-1})(L^{-1})]$ $=1.8*10^{-4}$ g/cmsec or 0.018 cp

P_{Atm} : Absolute gas pressure at a location Ri from the well $[ML(T^{-2})]$

$1.01*10^6$ g/cm-s^2 = 1 Atm at radius of influence

P_w : Absolute gas pressure in the well $[ML(T^{-2})]$, (1atm-vacuum in units of atm)

R_w : Effective radius of the well [L] - assumed 4-inch well in 10-inch borehole

R_i : Radius of Influence [L], - Assumed 40-feet as a conservative value

H: Screened zone in the test well (extraction well) [L]

L: Length

M: Mass

T: Time

^: to the power

LN: natural logaritm

π 3.141592654

atm: atmosphere

Vw: vacuum in inches of water

$$\frac{Q}{H} = \pi \frac{k}{\mu} p_w \frac{[1-(P_{Atm}/P_w)^2]}{\ln(R_w/R_I)}$$

P. Johnson, 1990

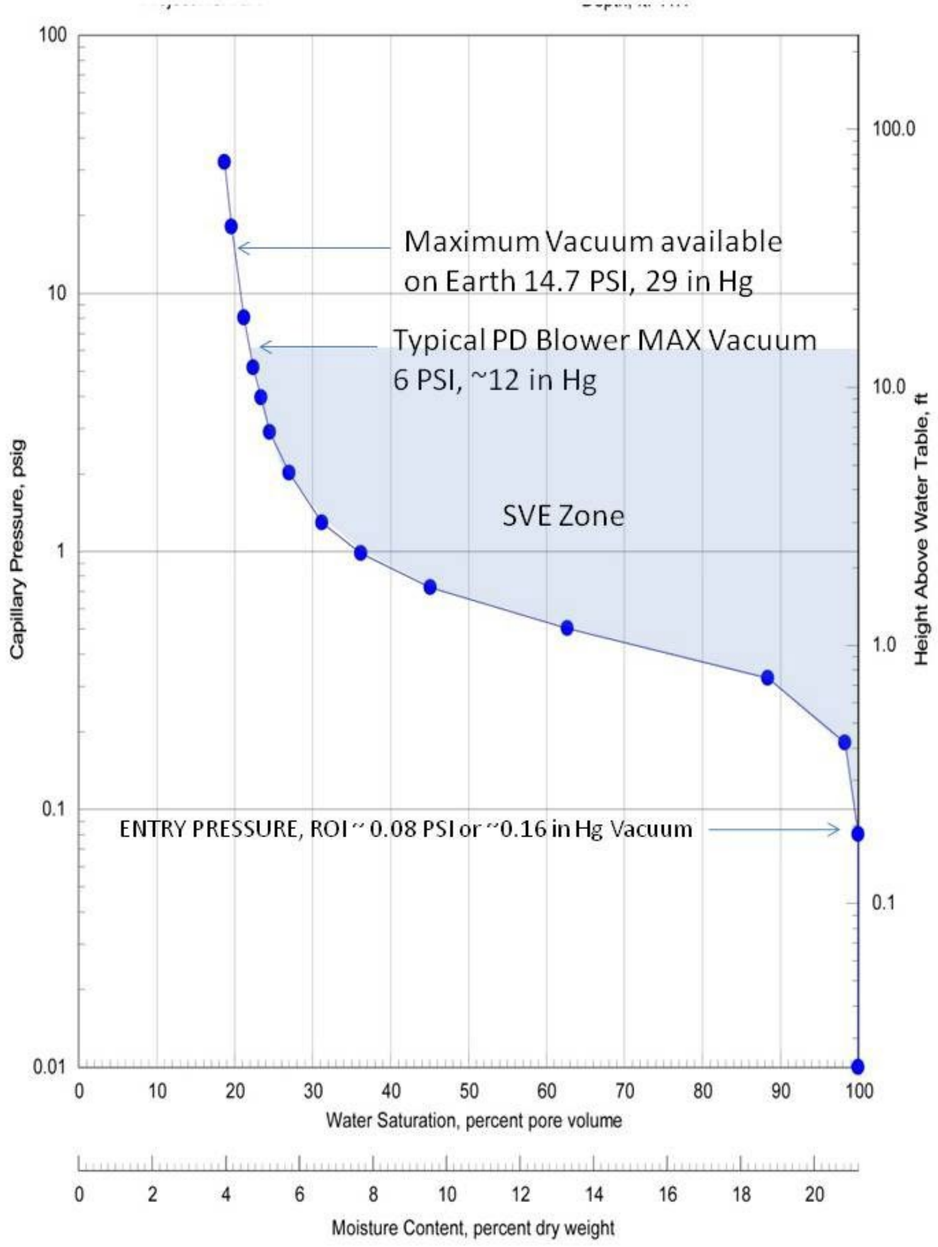
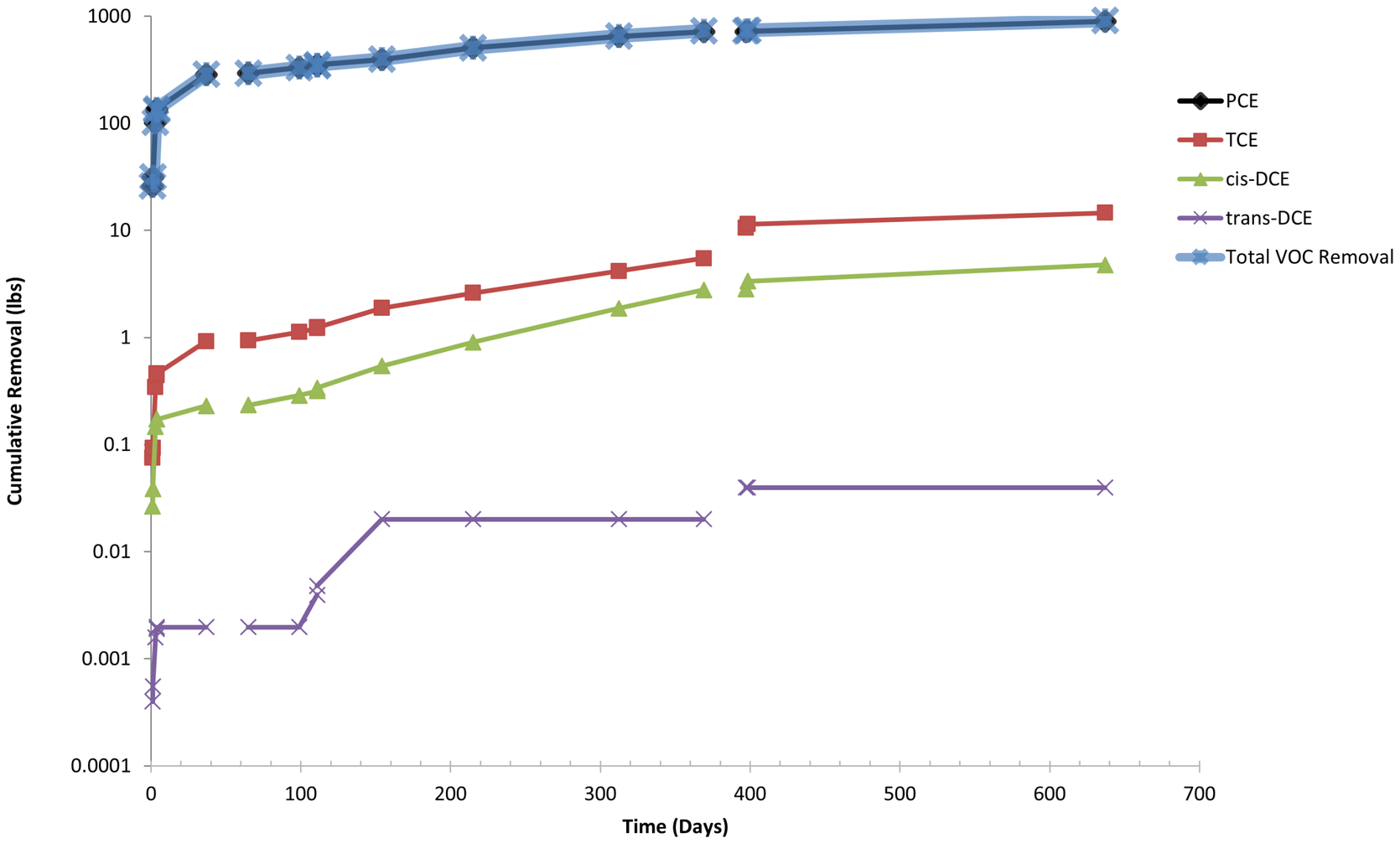
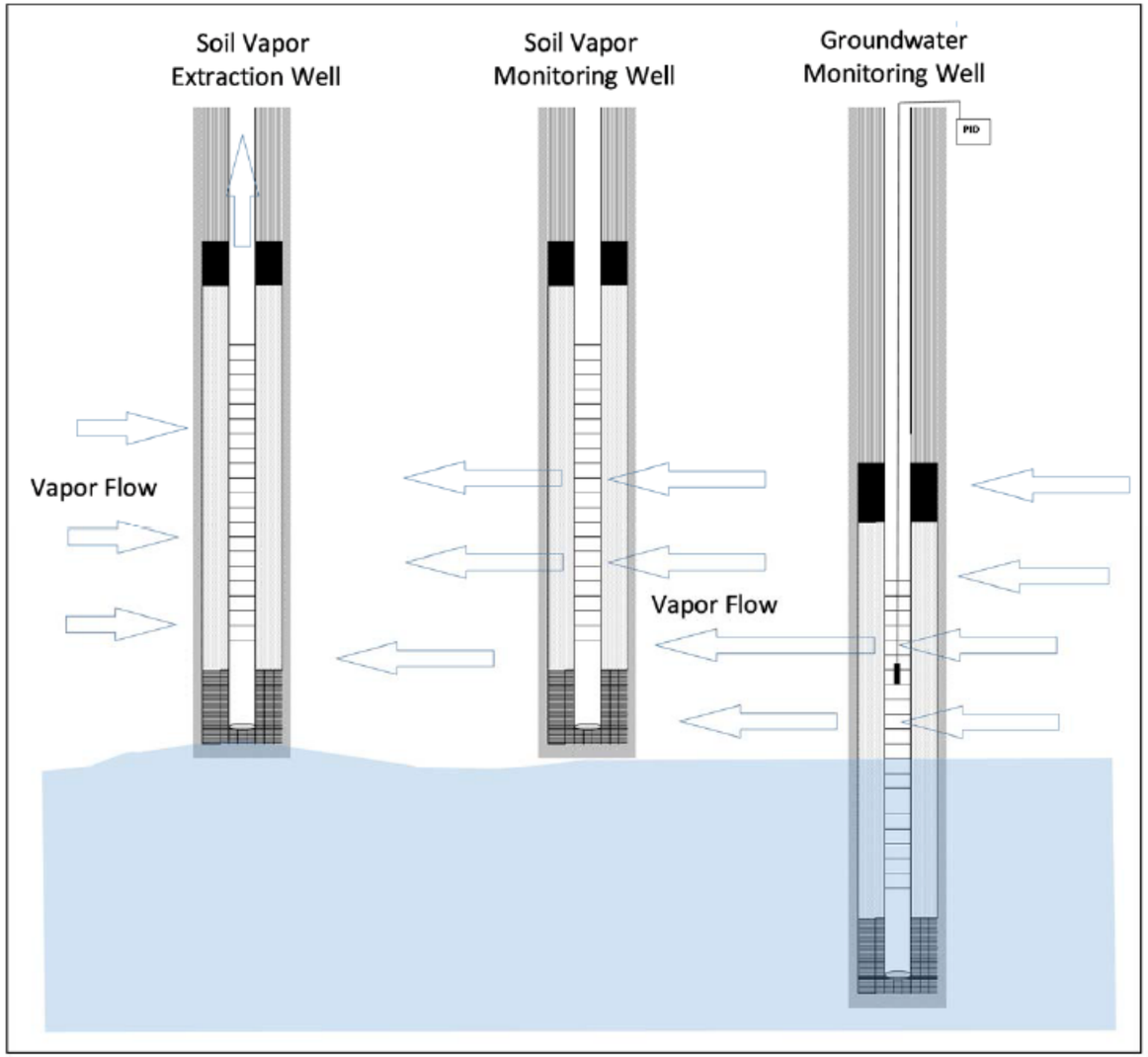

Maximum Vacuum available on Earth 14.7 PSI, 29 in Hg
Typical PD Blower MAX Vacuum 6 PSI, ~12 in Hg
SVE Zone
ENTRY PRESSURE, ROI ~ 0.08 PSI or ~0.16 in Hg Vacuum
Capillary Pressure, psig
100
10
1
0.1
0.01
Height Above Water Table, ft
100.0
10.0
1.0
0.1
0 10 20 30 40 50 60 70 80 90 100
Water Saturation, percent pore volume
0 2 4 6 8 10 12 14 16 18 20
Moisture Content, percent dry weight

Figure 4 _ SVE System: A 1000 CFM PD blower enclosed in a Cargo container and two 8000 lbs (filled 5000) Granular Activated Carbon (GAC) Vessels

Graph 3 - VOC Removal Rates, Carbon Inlet (IG-1)

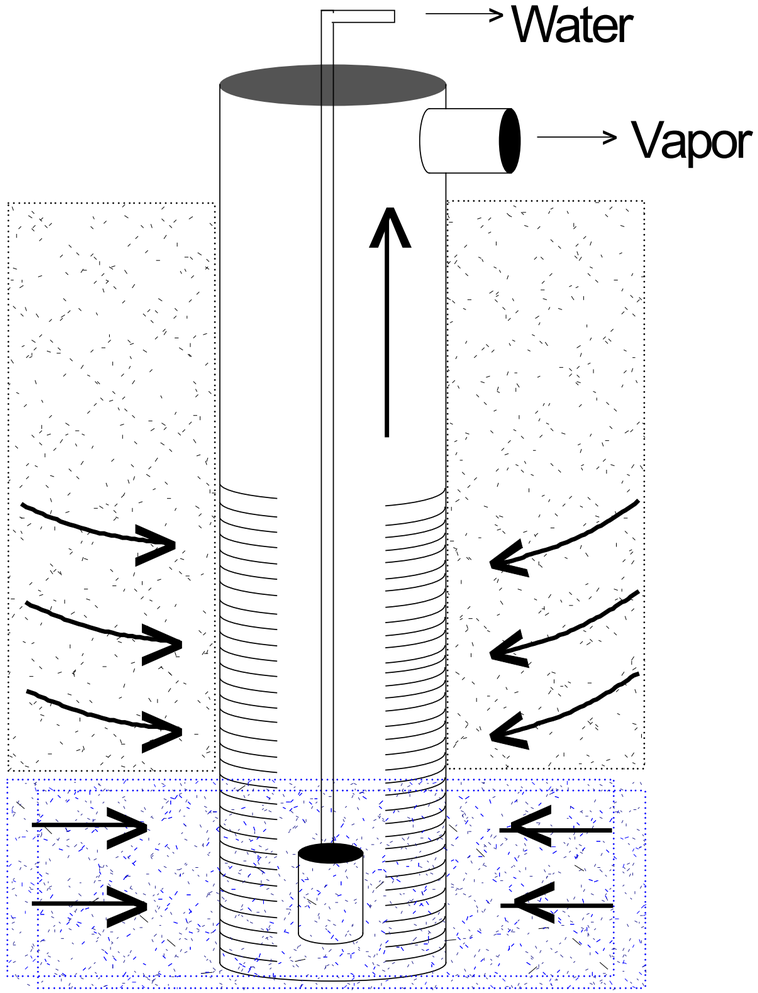


Using GW Monitoring Wells for SVE Observation Readings



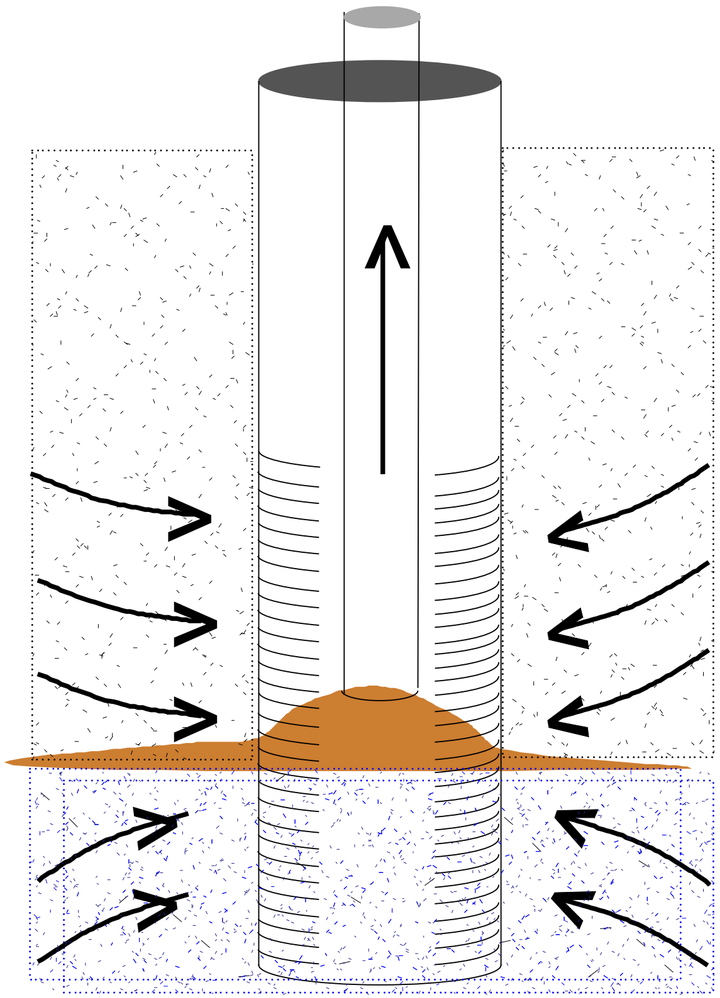

PID Readings in the Wellhead and Screen Zone
PID Readings (ppm)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
MW101S
MW103S
MW102S
MW-104S
MW-118
MW-112
MW-126
MW-111
MW-108
MW-125
PID (ppm) (Wellhead)
PID (ppm) (Screen)

Single Phase / Dual Phase Extraction



Single Phase and Dual Phase Extraction (DPE): Extraction of vapor and water using separate flow streams or mechanism (down hole pump and vapor extraction).

Multiphase and Two-phase Extraction



Multiphase Extraction (MPE) and Two-Phase Extraction (TPE):
Extraction of two or more phases (free floating hydrocarbons, water and vapor) in a combined flow stream using a vacuum source and a drop tube.

Two-phase Flow

K. W. MCQUILLAN and P. B. WHALLEY

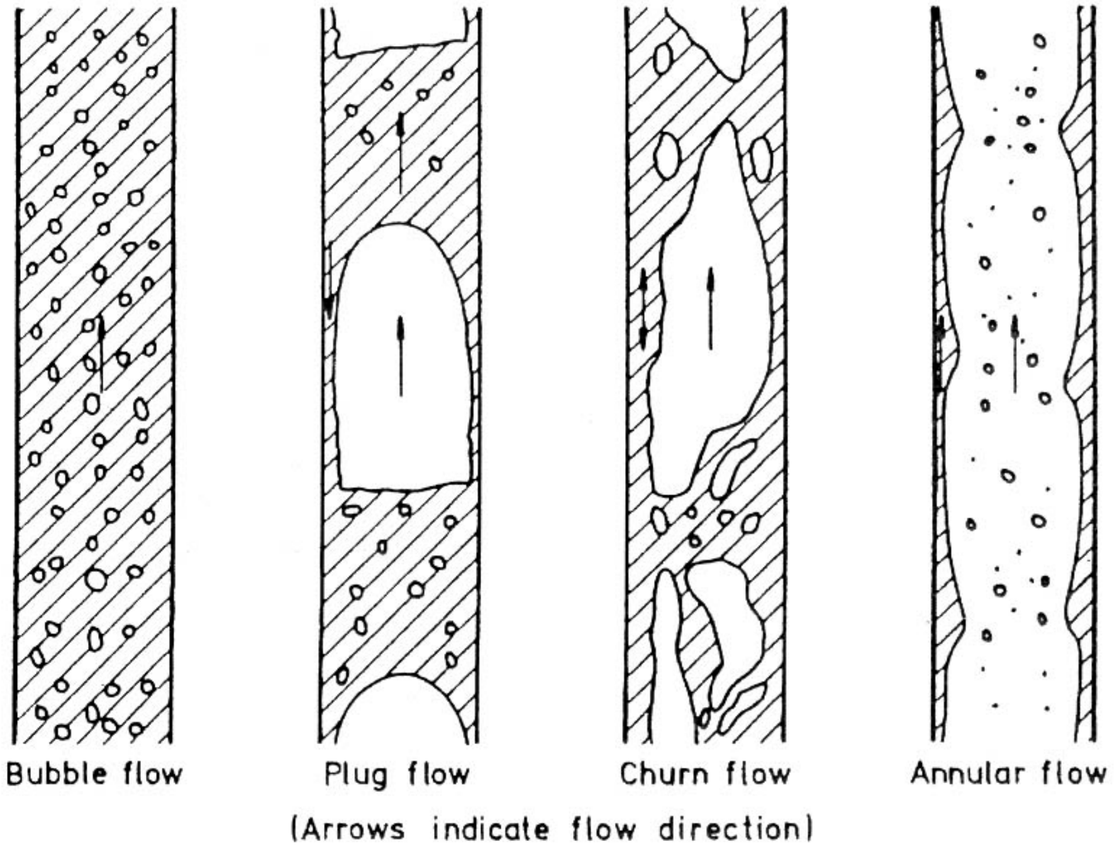
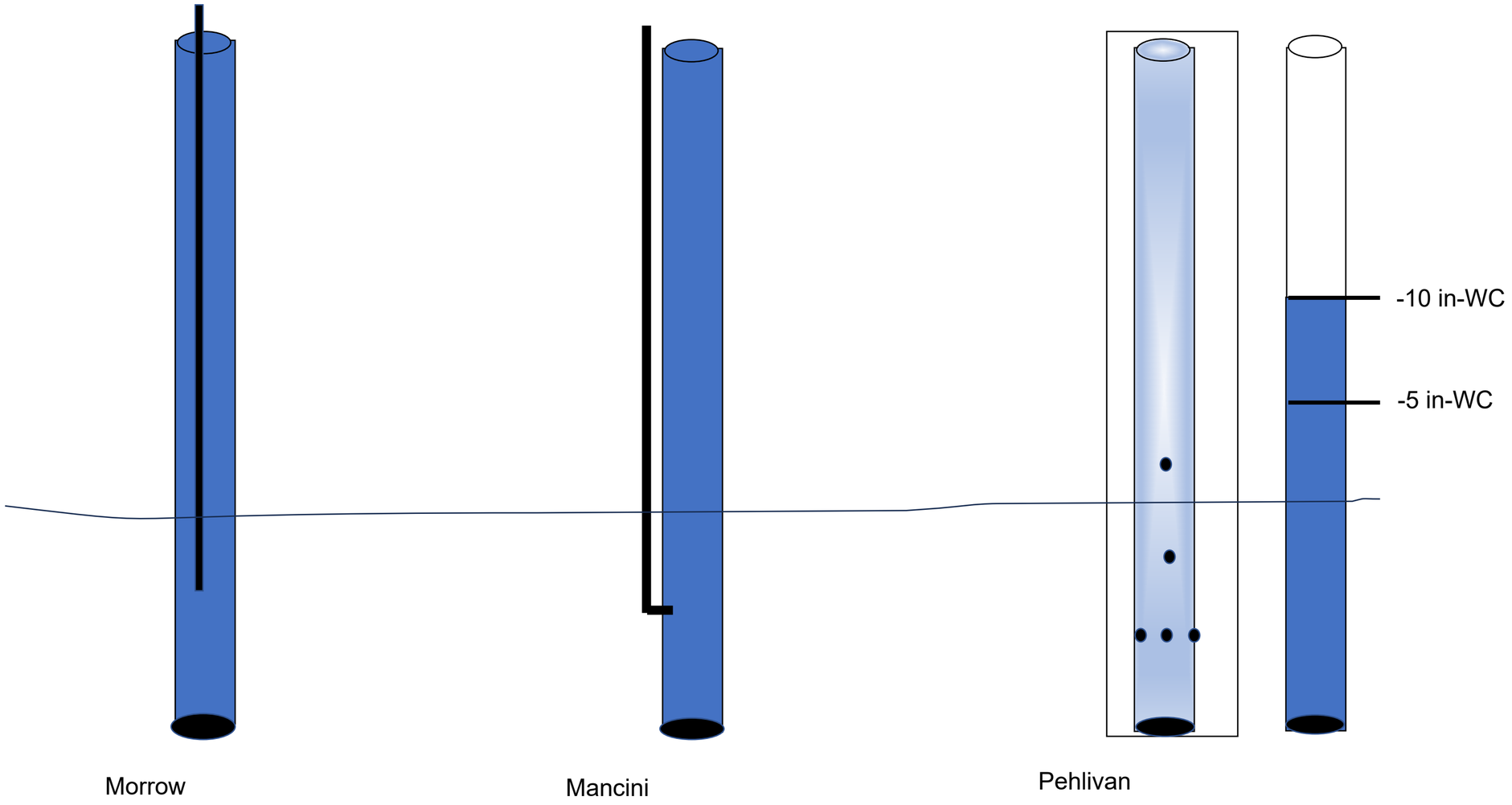


Figure 1. Flow regimes in upwards two-phase flow in vertical tubes.

Two-Phase Extraction (TPE):
Extraction of both vapor and water in a combined flow stream using a vacuum source and a drop tube.

Two-phase Extraction

Overcoming Vacuum Limitations



Two-Phase Extraction

Knopik 1982 patent

U.S. Patent Apr. 6, 1982 4,323,122

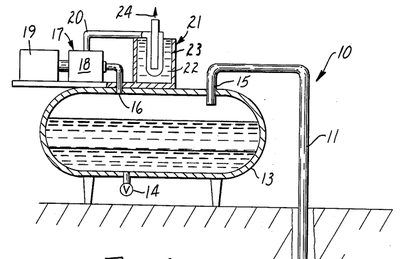


FIG. 1

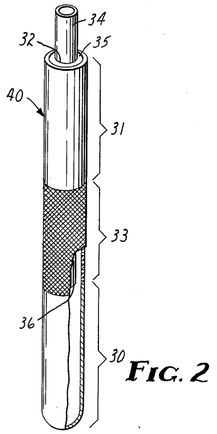
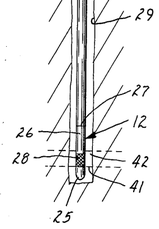


FIG. 2



Morrow 1991

United States Patent [19]
Morrow

[11] **Patent Number: 5,076,360**
[45] **Date of Patent: Dec. 31, 1991**

[54] **PRIMING METHODS FOR VACUUM EXTRACTION WELLS**

[75] Inventor: **Steven R. Morrow**, Hatboro, Pa.

[73] Assignee: **Dames & Moore**, Los Angeles, Calif.

[21] Appl. No.: **504,240**

[22] Filed: **Apr. 4, 1990**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 413,273, Sep. 27, 1989.

[51] **Int. Cl.**[5] **E21B 43/20**

[52] **U.S. Cl.** **166/267**; 166/370; 166/372

[58] **Field of Search** 166/267, 369, 370, 372, 166/68

[56] **References Cited**

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4,660,639	4/1987	Visser et al.	166/267
4,730,672	3/1988	Payne	166/266
4,886,119	12/1989	Bernhardt et al.	166/267
4,890,673	1/1990	Payne	166/266
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4,945,988	8/1990	Payne et al.	166/370 X

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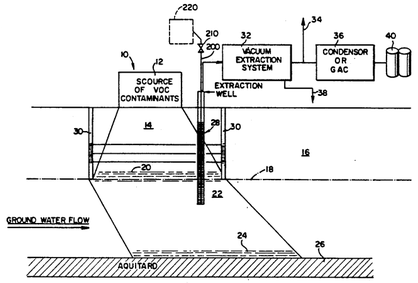
Stinson, "EPA Site Demonstration of the Terra-Vac In Situ Vacuum Extraction Process in Groveland, Massachusetts" (1989).

Primary Examiner—Hoang C. Dang
Attorney, Agent, or Firm—Woodcock Washburn Kurtz Mackiewicz & Norris

[57] **ABSTRACT**

Methods and apparatus for vacuum extraction of contaminants from the ground which, in a preferred embodiment, involves vacuum withdrawal of liquid and gaseous phases as a common stream, separation of the liquid and gaseous phases, and subsequent treatment of the separated liquid and gases to produce clean effluent. A primed vacuum extraction employs a single vacuum generating device to remove contaminants in both the liquid stream and soil gases through a single well casing utilizing a priming tube which introduces air or other gas to the liquid collected at the bottom of a well. The present invention permits vacuum extraction of both liquids and gases from the subsurface by way of wells having a liquid layer which is more than thirty feet below the soil surface or in which a screened interval of the extraction pipe is entirely below the liquid surface.

5 Claims, 3 Drawing Sheets



Mancini et. Al. 1994

United States Patent [19]
Mancini et al.

[11] **Patent Number: 5,358,357**
[45] **Date of Patent: Oct. 25, 1994**

[54] **PROCESS AND APPARATUS FOR HIGH VACUUM GROUNDWATER EXTRACTION**

[75] Inventors: **Alfonso R. Mancini**, Penfield; **Ronald E. Hess**, Webster; **Richard A. Williams**, Sodus Point; **Douglas J. Montgomery**, Ontario; **Heinrich J. Jurzysta**, Rochester, all of N.Y.

[73] Assignee: **Xerox Corporation**, Stamford, Conn.

[21] Appl. No.: **56,349**

[22] Filed: **Apr. 30, 1993**

[51] **Int. Cl.**[5] **E03B 3/12**; E21B 43/00

[52] **U.S. Cl.** **405/128**; 166/268; 166/372

[58] **Field of Search** 166/268, 275, 372; 405/128, 129

[56] **References Cited**

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4,593,760	6/1986	Visser et al.	166/267
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4,660,639	4/1987	Visser et al.	166/267
4,730,672	3/1988	Payne	166/266
4,886,119	12/1989	Bernhardt et al.	166/267
4,890,673	1/1990	Payne	166/266
4,892,664	1/1990	Miller	210/747
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Forced Venting to Remove Gasoline Vapor from a Large-Scale Model Aquifer, API Publication 4431 (1984).

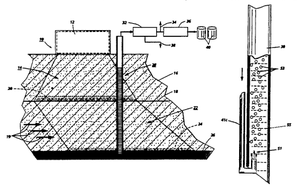
Venting for the Removal of Hydrocarbon Vapors from Gasoline Contaminated Soil, J. Environ. Sci. Health, A17(1), pp. 31–44 (1982).

Primary Examiner—Randolph A. Reese
Assistant Examiner—John A. Ricci
Attorney, Agent, or Firm—Judith L. Byorick

[57] **ABSTRACT**

Disclosed is a process and apparatus in which vacuum extraction is used to remove soil contaminants in both the saturated and vadose zones. One embodiment of the present invention is directed to a process for removing contaminants from a contaminated area of the ground having a vadose zone and a water table, which comprises providing a borehole in the contaminated area to a depth below the water table; placing in the borehole to a depth below the water table a perforated riser pipe inside of which is situated a vacuum extraction pipe with a bottom opening situated within the perforated riser pipe, said vacuum extraction pipe containing groundwater prior to application of a vacuum thereto, said vacuum extraction pipe having at least one gas inlet situated below the groundwater level in the vacuum extraction pipe; while introducing a gas into the riser pipe, applying a vacuum to the vacuum extraction pipe to draw gases and liquid from the soil into the perforated riser pipe and from the riser pipe into the vacuum extraction pipe and transport both the gases and the liquid to the surface as a two-phase common stream; introducing a gas into the vacuum extraction pipe at a level below the groundwater level in the vacuum extraction pipe to initiate two-phase flow within the vacuum extraction pipe; forming from the common stream a stream which is primarily liquid and a stream which is primarily gaseous; and separately treating the separated liquid and gas streams. Also disclosed is an apparatus for carrying out the process.

18 Claims, 8 Drawing Sheets



Pehlivan et. Al. 1999

US005906241A

United States Patent [19]
Pehlivan et al.

[11] **Patent Number: 5,906,241**
[45] **Date of Patent: May 25, 1999**

[54] **METHOD FOR BUBBLING EXTRACTION OF GROUNDWATER**

[75] Inventors: **Mehmet Pehlivan**, Mission Viejo; **James R. Miller**, Palos Verdes Est., both of Calif.

[73] Assignee: **Tait Environmental Management, Inc.**, Calif.

[21] Appl. No.: **08/897,201**

[22] Filed: **Jul. 21, 1997**

[51] **Int. Cl.**[6] **E21B 43/00**; E21B 43/12

[52] **U.S. Cl.** **166/372**; 166/370; 405/128; 210/170; 210/747

[58] **Field of Search** 405/52, 128; 166/67, 166/68.5, 370, 372; 210/170, 747

[56] **References Cited**

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5,050,676	9/1991	Hess et al.	166/370 X
5,076,360	12/1991	Morrow	166/370 X
5,262,065	11/1993	Hansen	210/747
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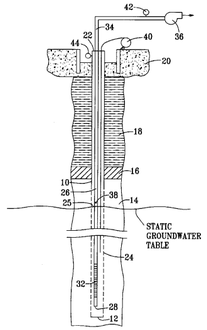
Primary Examiner—David J. Bagnell
Assistant Examiner—Jong-Suk Lee
Attorney, Agent, or Firm—Klein & Szekeres, LLP

[57] **ABSTRACT**

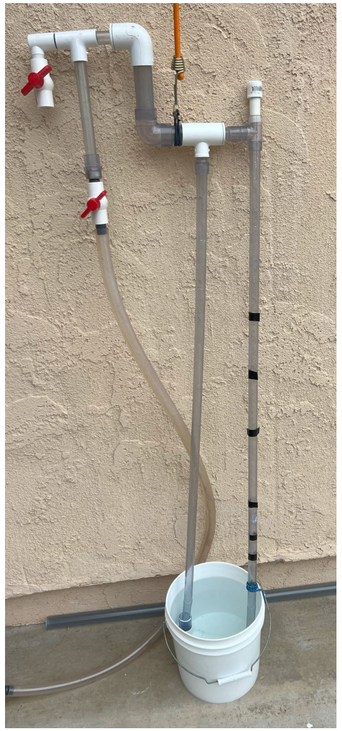
An apparatus for extracting groundwater from a well extending below the static groundwater table includes an extraction pipe having a distal end located a predetermined distance below the static groundwater table, and a proximal end adapted for communication with a source of subatmospheric pressure. The extraction pipe includes a "bubbling hole" a short distance above a static water column established in the well to introduce air bubbles into the extraction pipe to augment the vacuum in lifting the water through the extraction pipe. A method of extracting groundwater employing this apparatus includes the steps of (1) measuring the height of the static water column in the well; (2) providing an extraction pipe having a proximal end, a distal end, and a hole located axially along the length of the extraction pipe at a specified distance from the distal end thereof; (3) extending the extraction pipe into the well so that the distal end of the extraction pipe is located at a first predetermined distance below the static groundwater table, and the hole is located a second predetermined distance above the static water column in the well; and (4) applying a subatmospheric pressure to the proximal end of the extraction pipe, the magnitude of the subatmospheric pressure being sufficient to lift the groundwater through the proximal end of the extraction pipe with the assistance of air bubbles introduced into the extraction pipe from the well through the hole.

8 Claims, 5 Drawing Sheets



Two-phase Extraction

Controlling Flow with Applied Vacuum



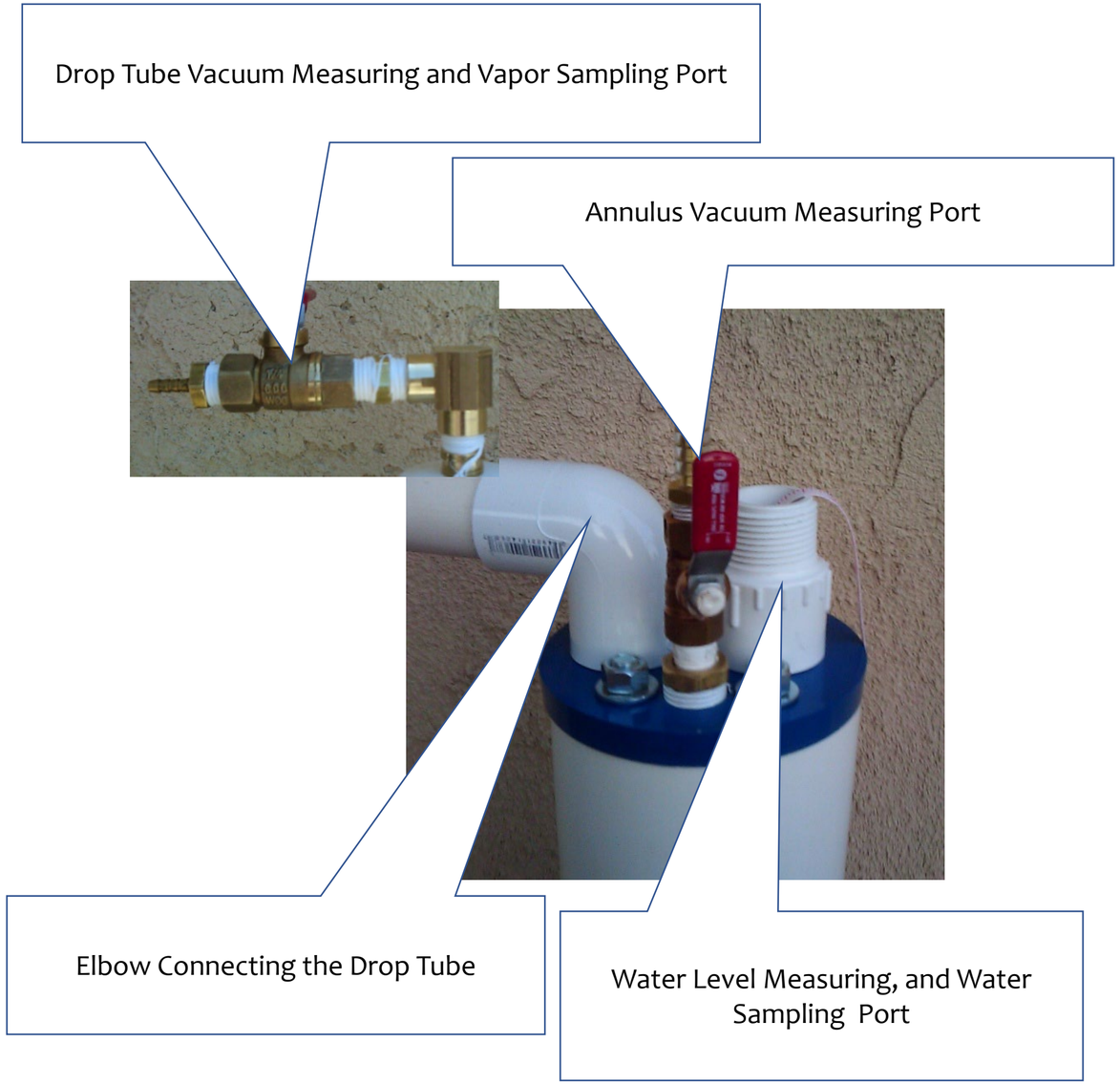
[redacted]

Morrow

[redacted]

Pehlivan

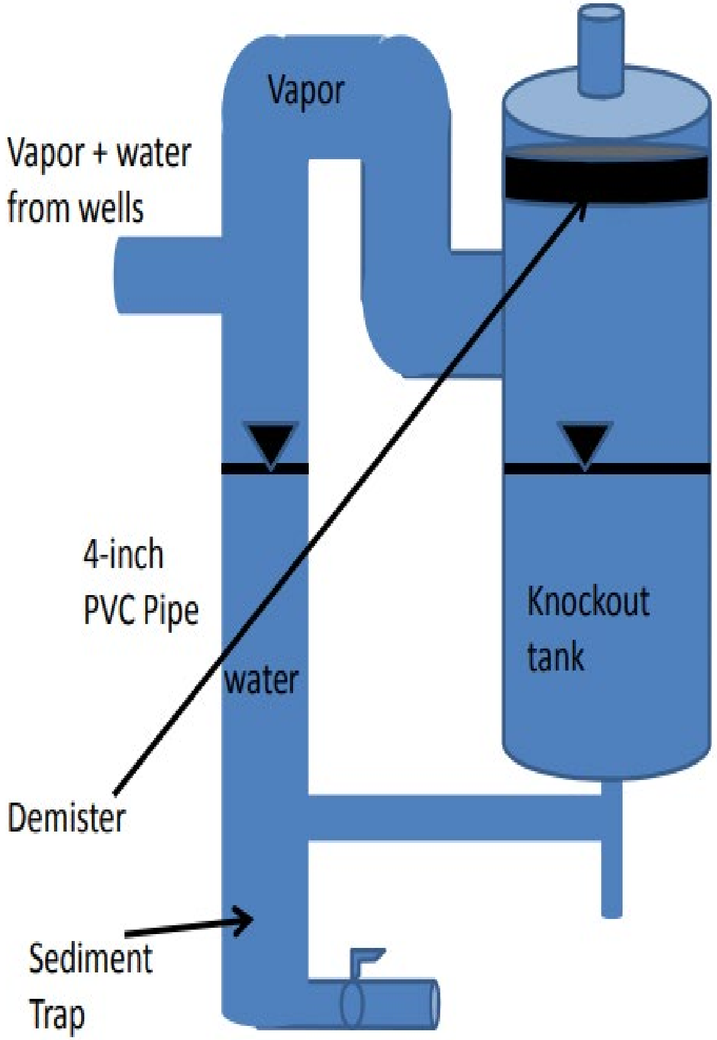
Wellhead Measurements



- Allows annulus and stinger vacuum measurements
- Allows water level measurements during extraction
- Allows water sample collection using ½-inch bailer from the extraction well
- Allows installation of two 1-inch drop tubes for high yielding formations

Water & Vapor Flow

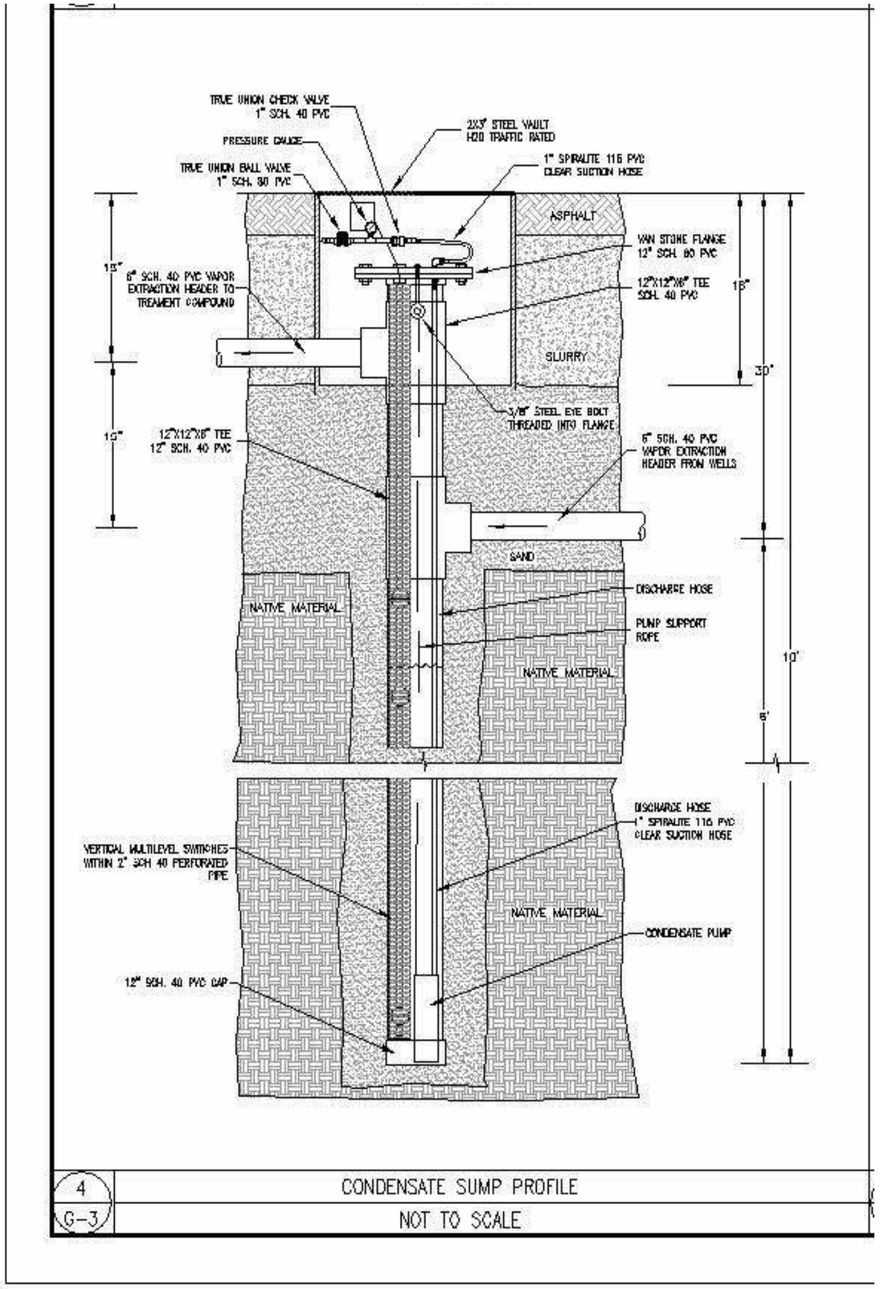
Reduce Friction Loss – First Generation



Removing Silt without Vacuum Loss

Reduce Friction Loss

The Third Generation



Reduce Friction Loss

The Fourth Generation –Silt Trap as well

FLOW SPLITTER - 1

Flow Splitter

- Allows measurements of both vapor and water flow separately at the extraction well head.
- Provides visual observation for the extracted material

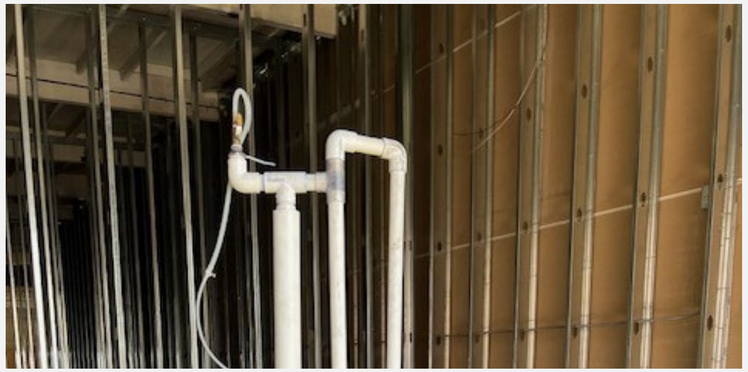
FLOW SPLITTER – 2

Reduce Friction Loss – Second Generation

VOC Stripping

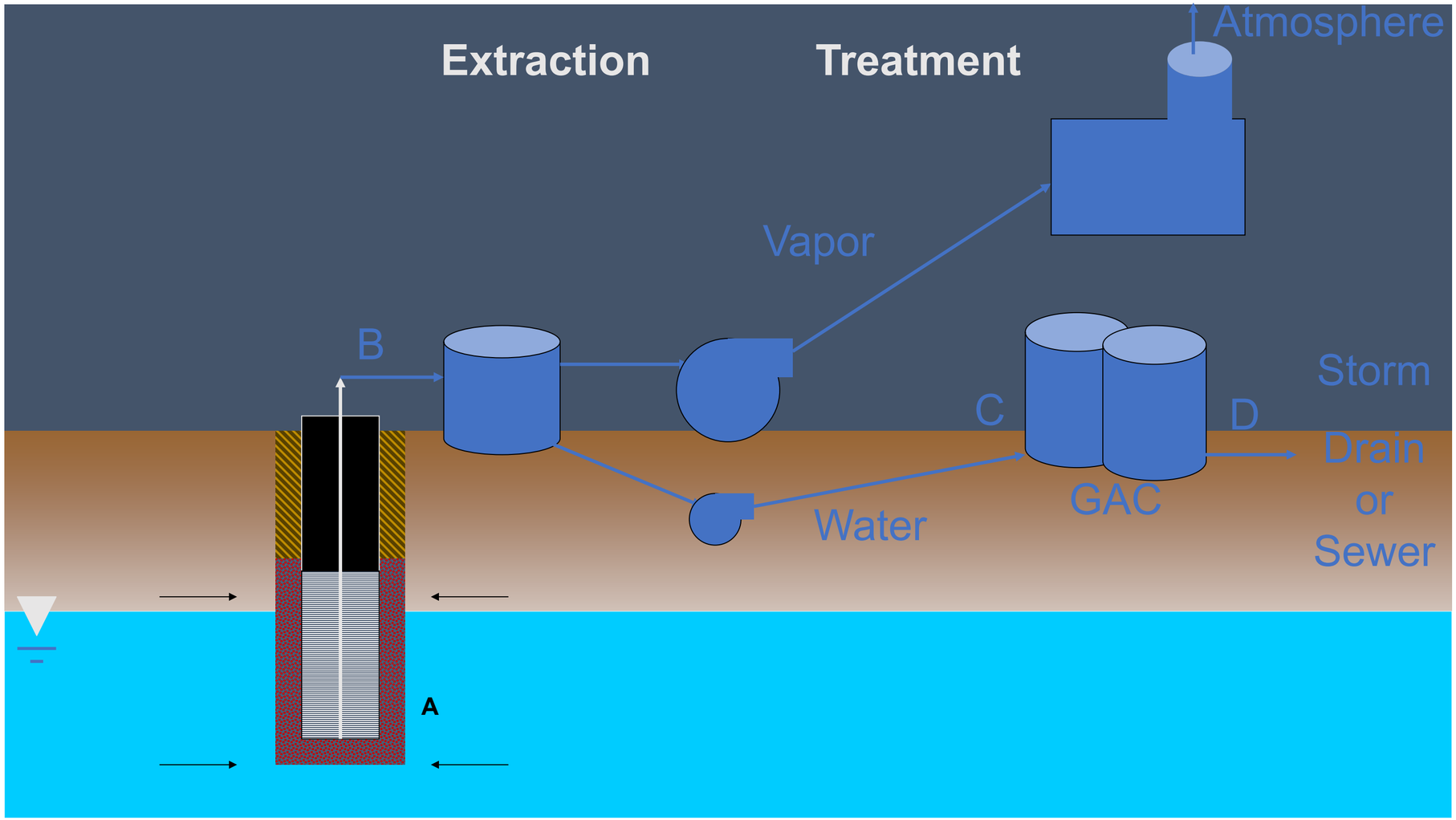
	TEST 1 Los Angeles	TEST 2 Lawndale	TEST 3 Los Angeles	TEST 4 Yorba Linda	TEST 5 Antioch
Depth (ft) to Groundwater	38	15	43	34	37
Extraction Vacuum (inches of W.C.)	108	210	80	80	110
Vapor Flow (CFM)	190	87	~50	~50	140
Water Flow (gpm)	<1.0	6	<1.0	1.3	0.5
Average MTBE Stripping Ratio in the well	92%	47%	80%	74%	98%
Average BTEX Stripping Ratio in the well	98%	90%	>99%	40%	>99%

VOC Stripping



PCE in the Well 6500 ug/l, PCE end of the green hose 30 ug/l, PCE from the tank water 3.9 ug/l J flagged

Two-Phase Extraction Typical System Layout

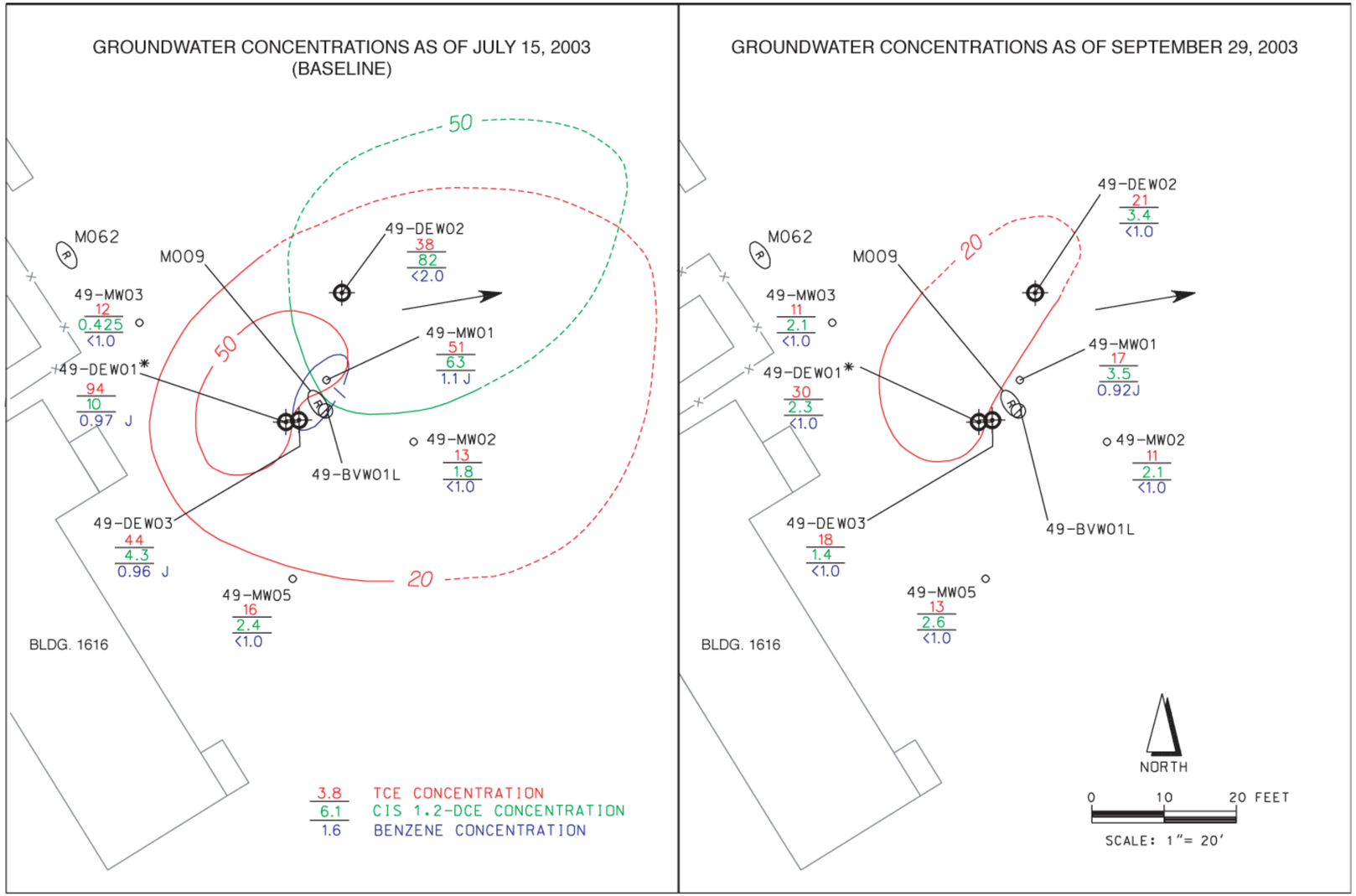


Pilot Test #1

- Test Site 1 is in Lancaster, California
- Previous TPE was not successful removing VOC below the action level and unmanned operation.
- The objective is to reduce low level VOC (TCE) concentrations below action level in the area.
- The test was performed for six weeks.
- Started with 4 wells added two more when determined availability of the excess system capacity.
- Used a system with separate vapor and water entry knockout tank.

Pilot Test # 1 Test Layout

Pilot Test # 1 Site Map



PILOT TEST # 1 (cont.)

TCE concentrations (µg/L) in groundwater

Date	DEW01	DEW02	DEW03	MW01
04/22/03	70	7.7	44	42
07/14/03 Beginning of test	94	38	-	51
08/04/03	550	-	-	-
08/18/03	100	-	-	-
09/03/03 End of Test	17	17	14	-
9/29/03	30	21	18	17

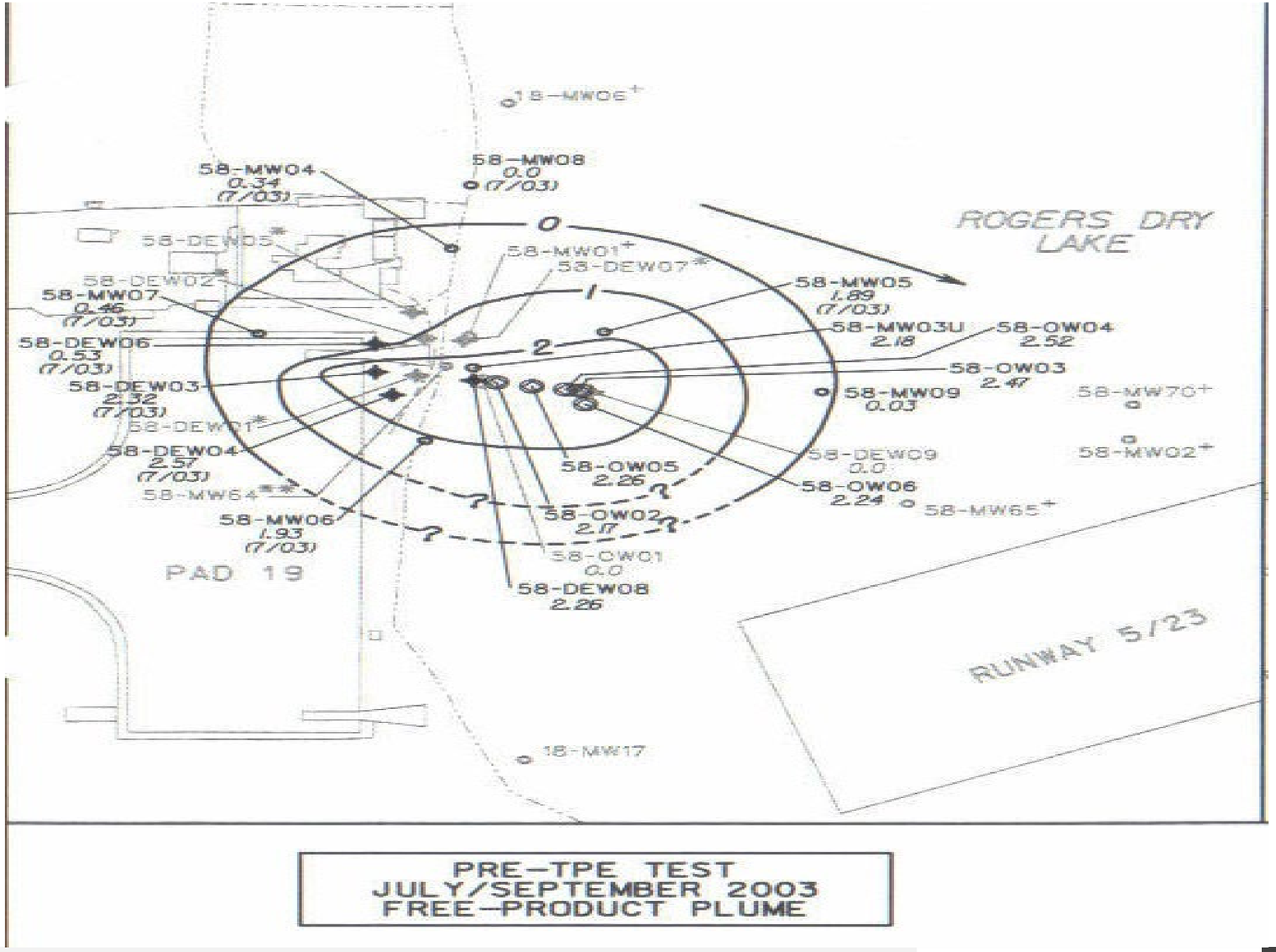
PILOT TEST # 1 - RESULTS

- The ZOI of the water drawdown over 150 feet.
- The TCE concentration in GW was 550 µg/L in DEW01.
- At the end of the TPE test, the TCE concentrations in well DEW01 were reduced to 17 µg/L. Up to 95 % of VOC were removed in two weeks.
- Following TPE, TCE in were all below 30 µg/L in Well 49-DEW01 only.
- No cis-1,2-DCE or benzene were reported.
- The TCE concentrations were reduced by more than 50% in most wells with initial concentrations exceeding 30 ug/L

PILOT TEST # 2

- Test Site 2 is in Lancaster, California.
- Up to 2.5 feet of measurable LNAPL in wells.
- The lateral extent of LNAPL 500 to 600 feet.
- Assess if TPE is an effective method removing LNAPL in Fractured Bedrock formation.
- Two EW and six OWs were used for the test.
- The observations wells installed at 8, 20 and 50 feet distance from the extraction wells to calculate zone of influence for LNAPL thickness change, water drawdown and vacuum response.

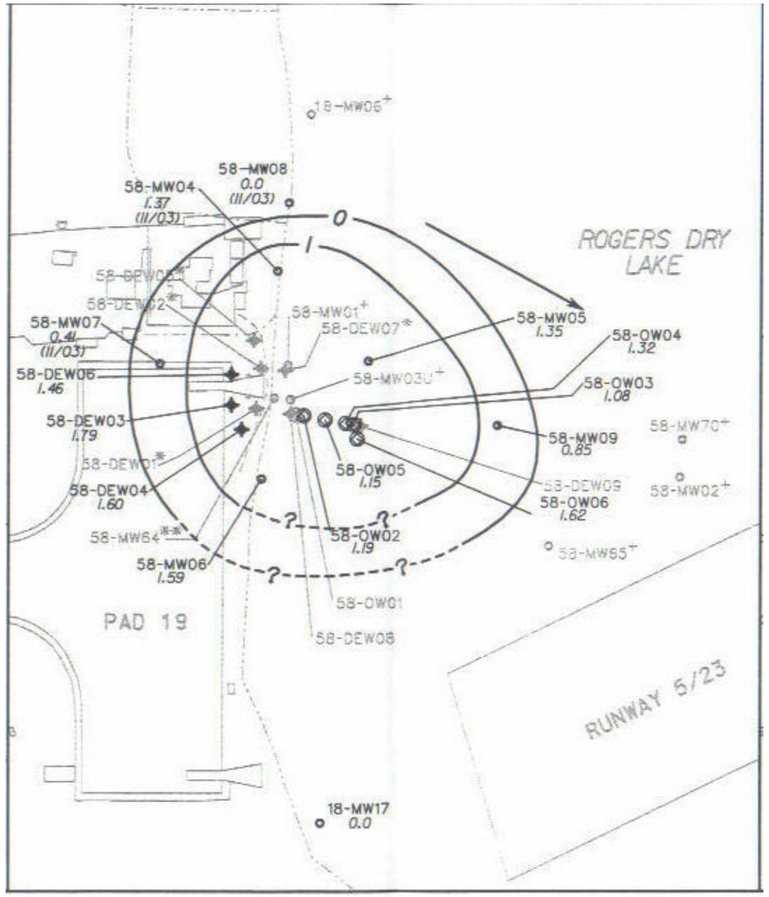
PILOT TEST # 2 SITE MAP



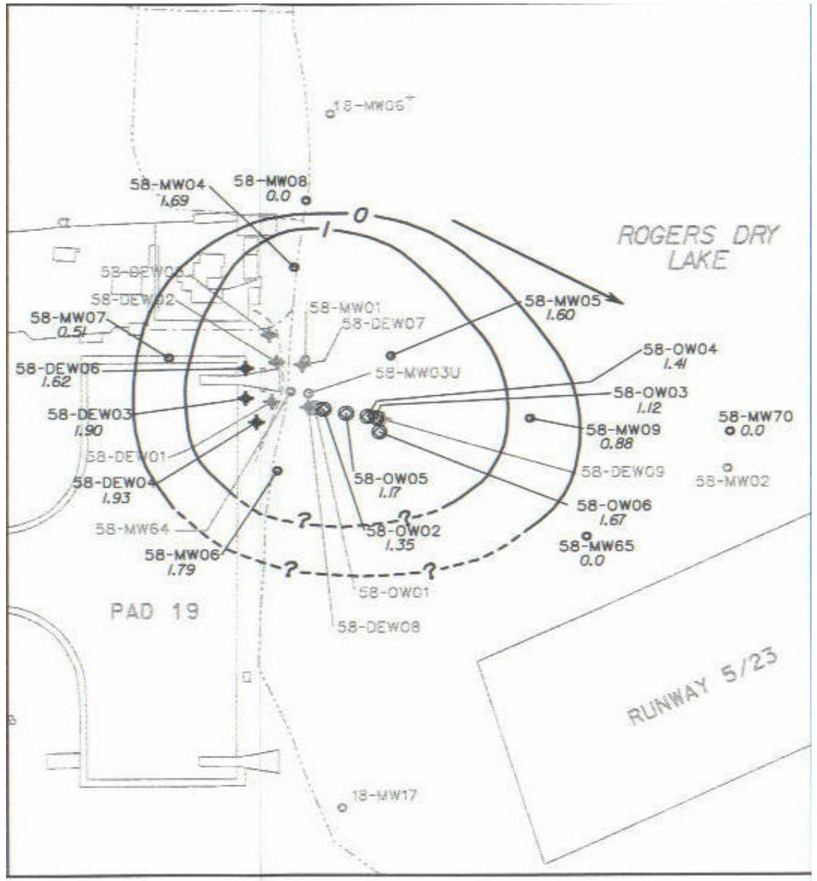
PILOT TEST # 2 RESULTS

- 240,000 gal of GW extracted with up to 4 ft DD.
- No emulsification was observed
- Up to one foot of reduction in LNAPL thickness after 45 days of extraction in OWs within the 20 foot radius.

PILOT TEST # 2 RESULTS

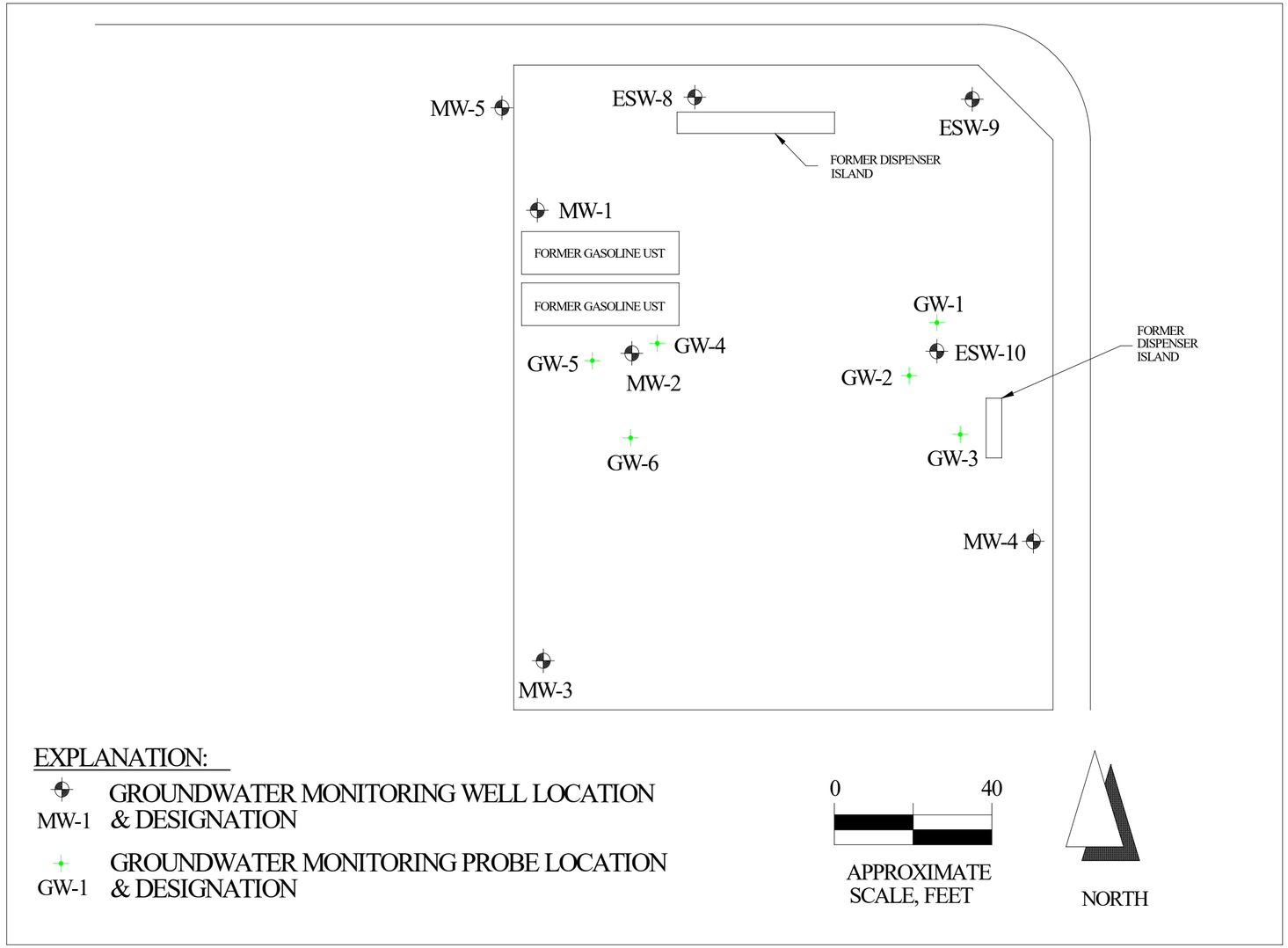


POST-TPE TEST (2 WEEKS)
OCTOBER 2003
FREE-PRODUCT PLUME



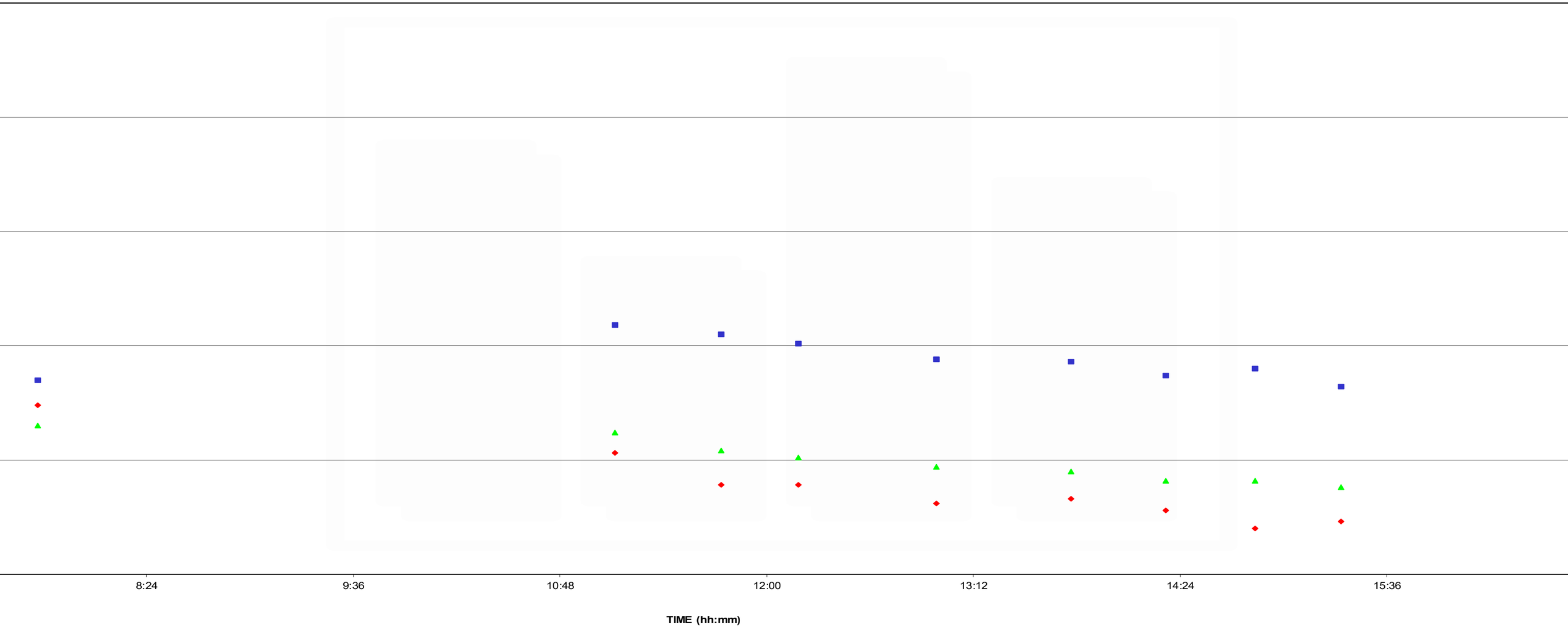
POST-TPE TEST (7 WEEKS)
DECEMBER 2003
FREE-PRODUCT PLUME

PILOT TEST # 3

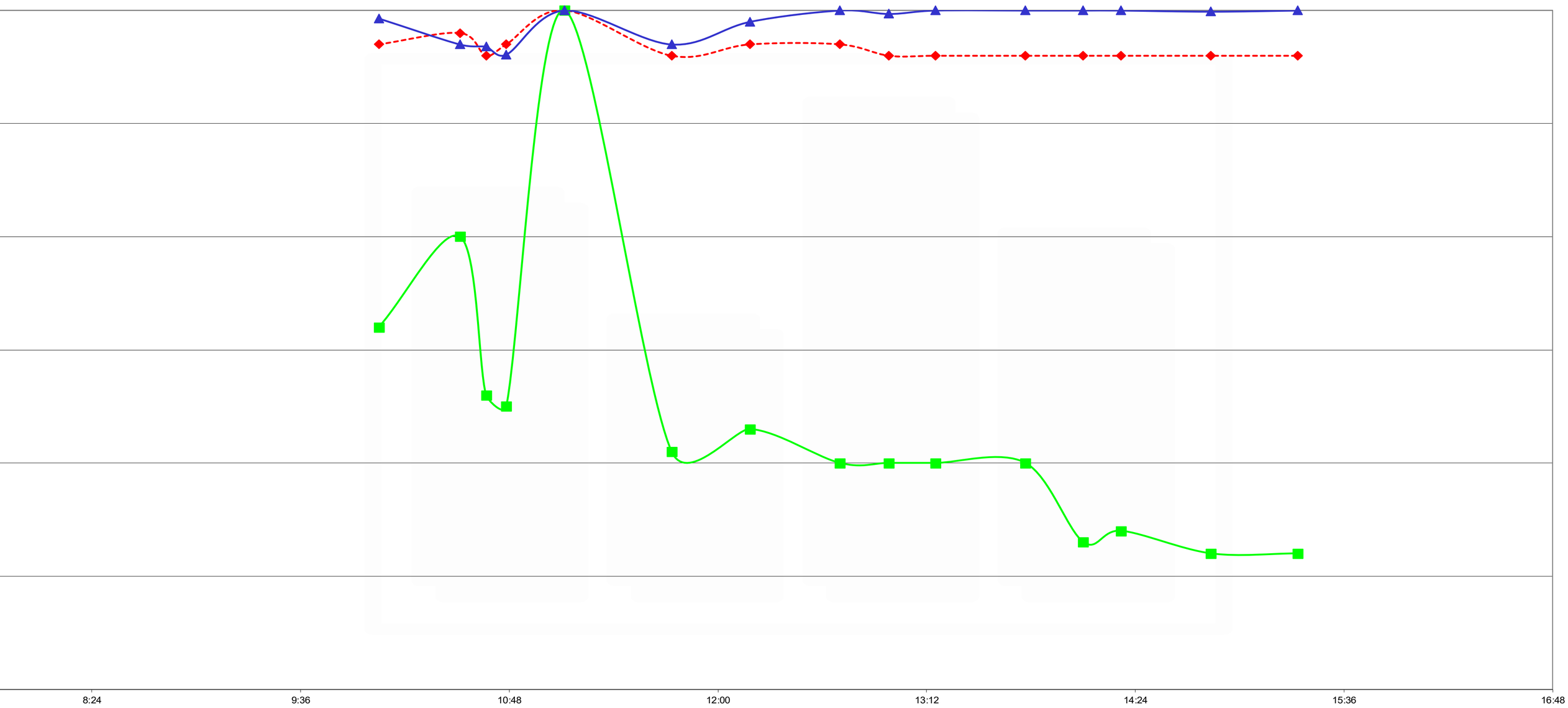


- A former service station in Whittier.
- Used two wells for extraction.
- Installed observation wells near extraction wells to obtain vacuum and water drawdown data.
- One extraction well was near the source of contamination (ESW-10).
- One extraction well was at the perimeter of the plume.

PILOT TEST # 3 (Drawdown)

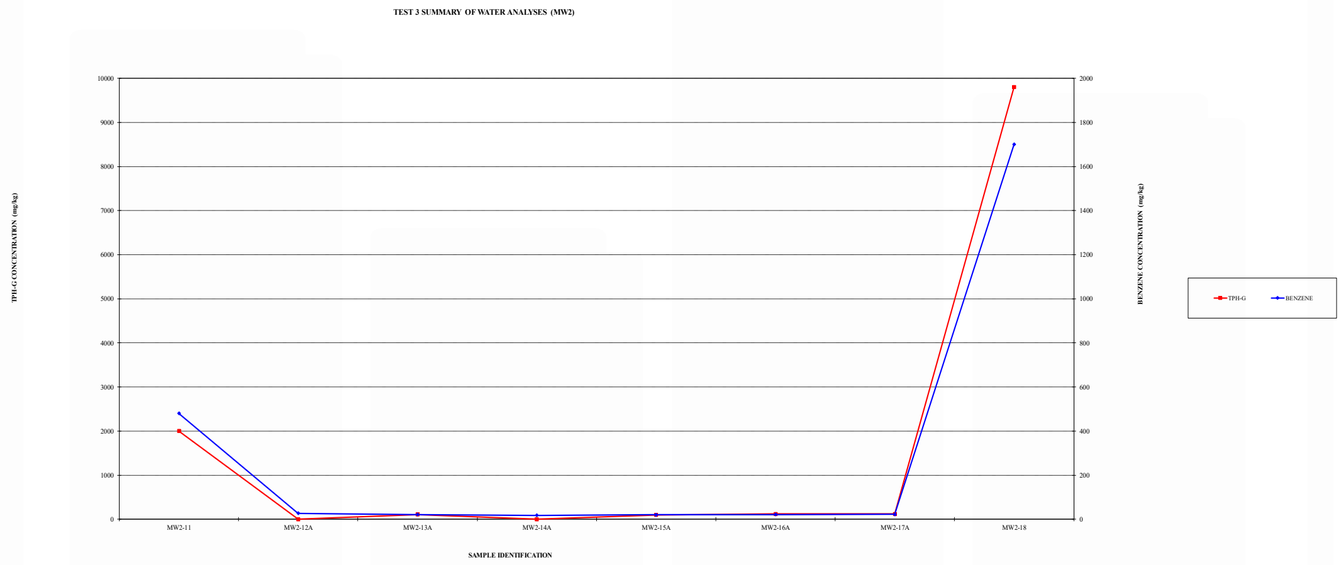


PILOT TEST # 2 (Vacuum)



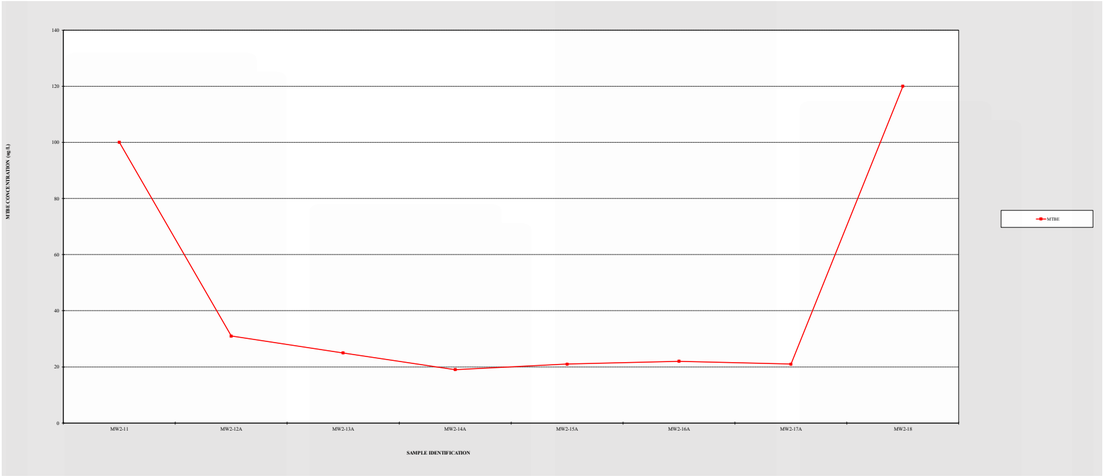
PILOT TEST # 3 (TPH-Benzene)

Concentrations in Extracted Water (MW2)



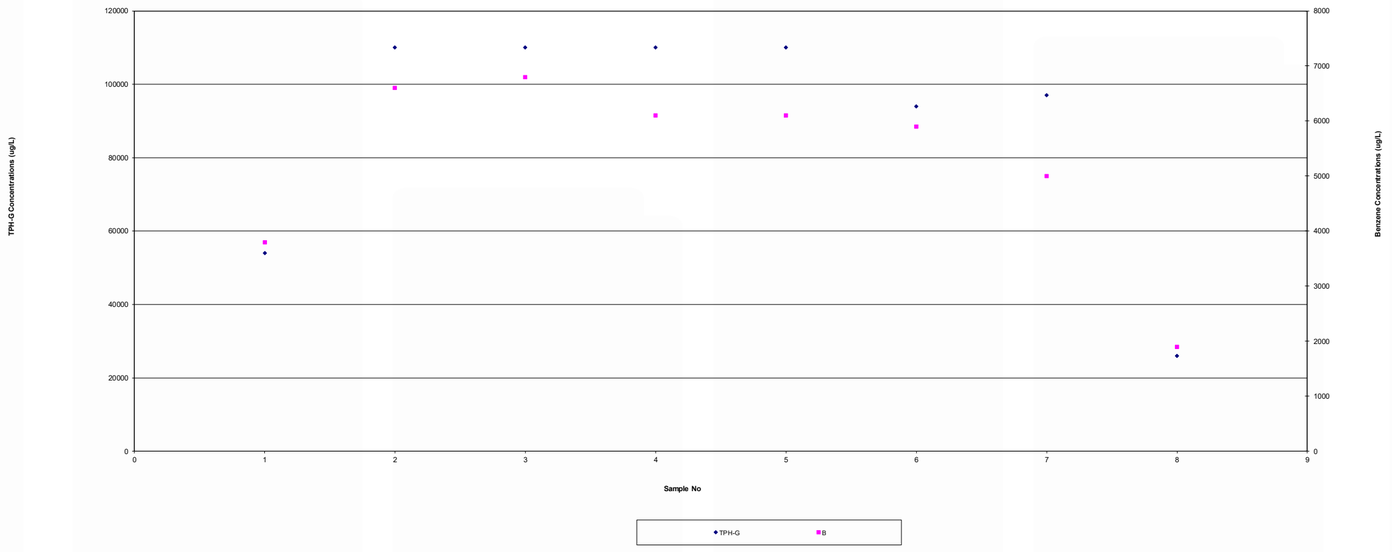
PILOT TEST # 3 (MTBE)

MTBE Concentrations in Extracted Water (MW2)



The concentrations of MTBE in the groundwater was increased between pre-test (MW2-11) and post test (MW2-18) samples. MTBE concentrations in the extracted water samples (MW2-12A through MW2-17A) show up to 90% stripping during extraction.

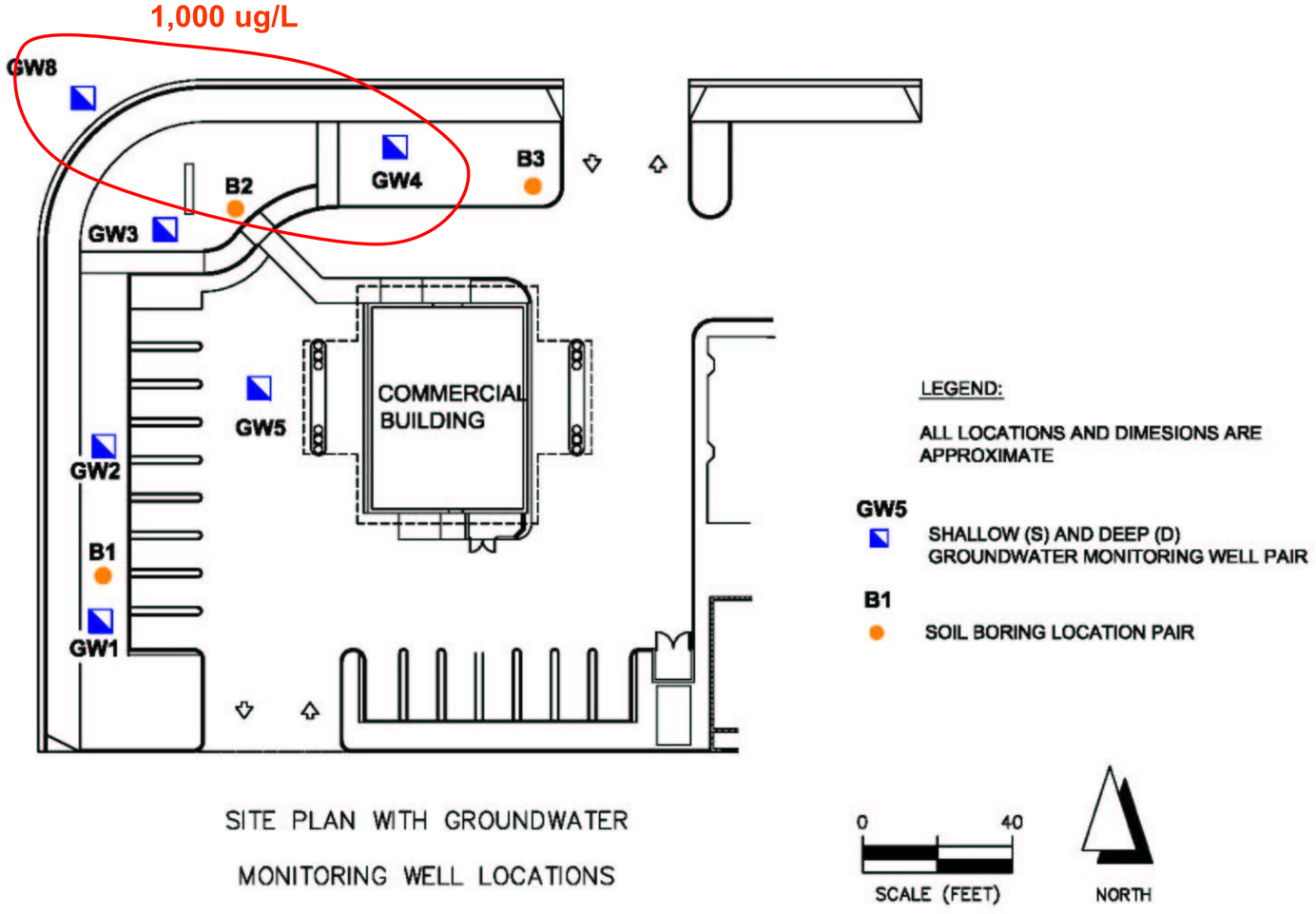
PILOT TEST # 3 (TPH-Benzene in ESW10)



Case Study : Former Gas Station – *Huntington Beach, California*

Stimulated in situ Bioremediation of MTBE In a Tight Soil Formation using Two Phase Extraction

- **Former Gas Station (BTEX, MTBE)**
- **Depth to groundwater: ~ 8 ft**
- **Gradient: 0.005 ft/ft**
- **Mostly silty clays (perm. 0.02 - 5 Darcy)**



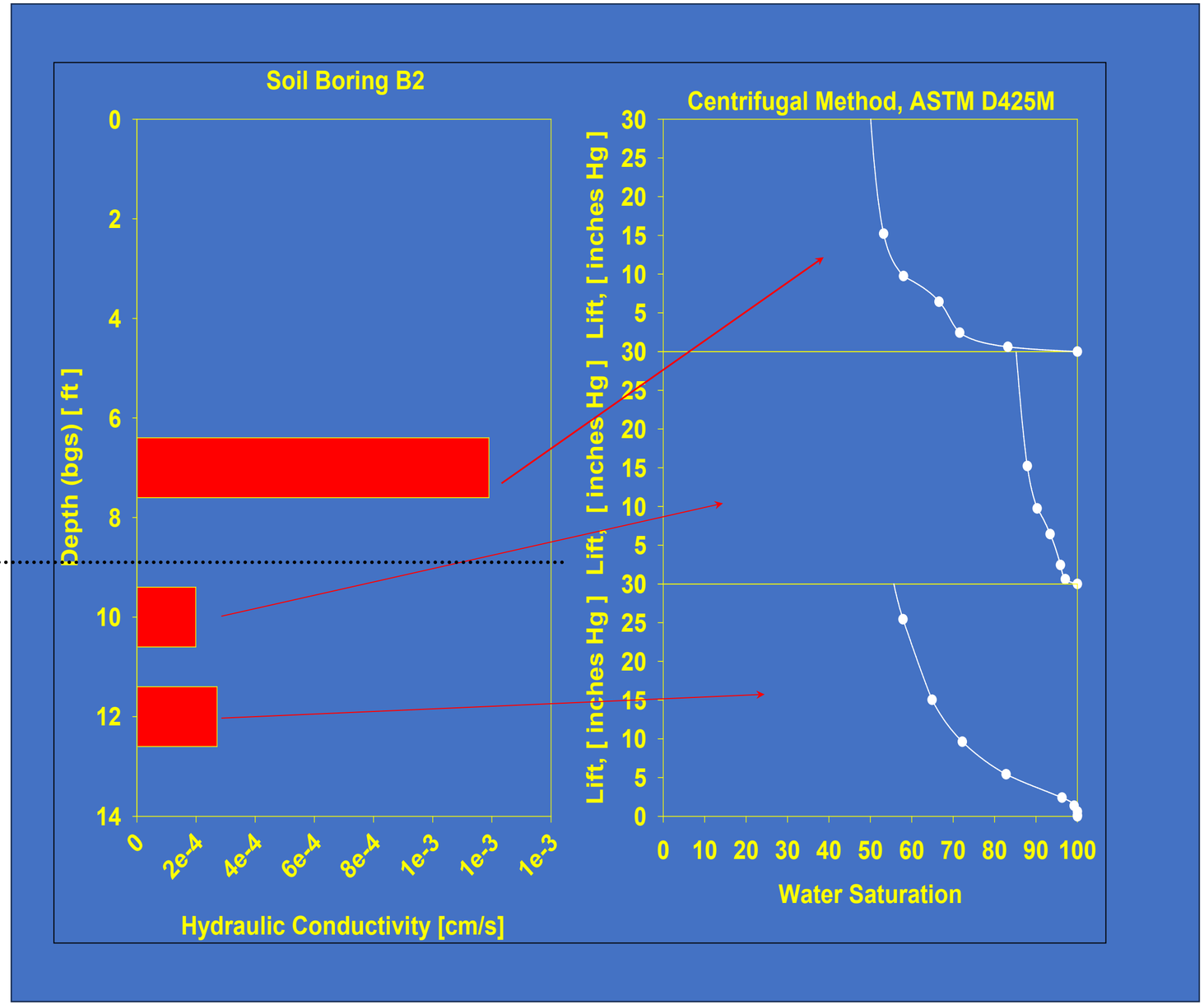
SITE PLAN WITH GROUNDWATER MONITORING WELL LOCATIONS

Site Characteristics

Majority of contamination resides in a clayey silt formation, 9 - 10 ft bgs, in the saturated zone

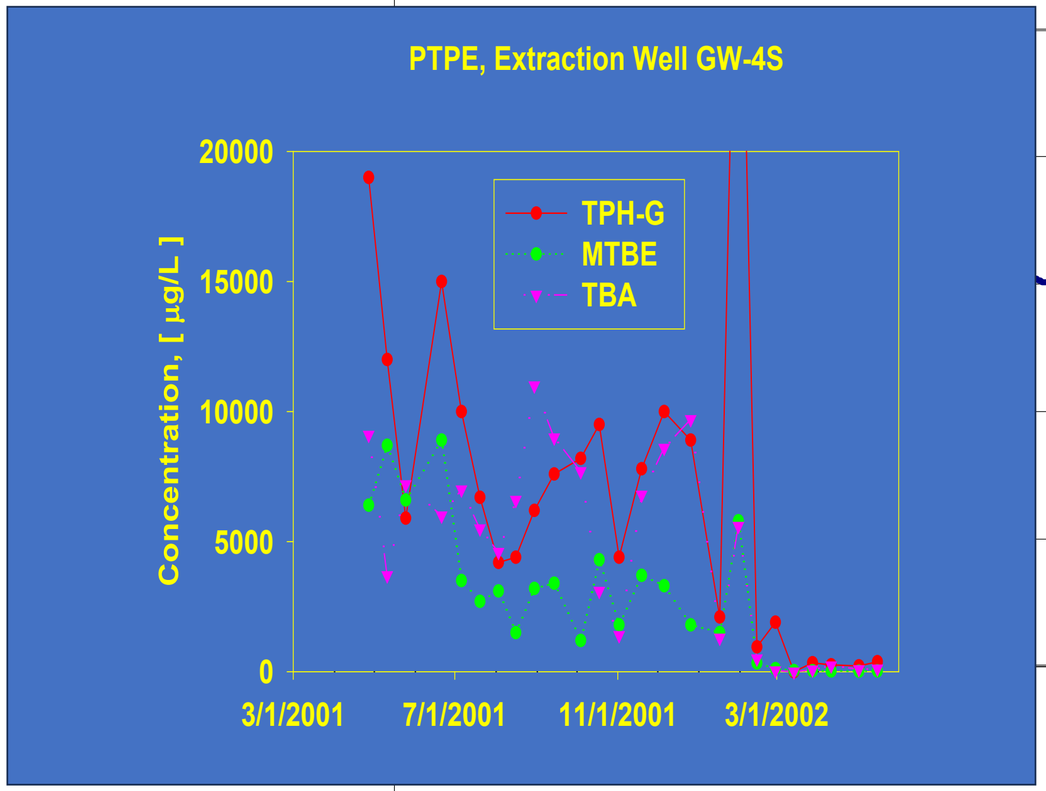
Max. TPH-G level was 35,000 μg/L

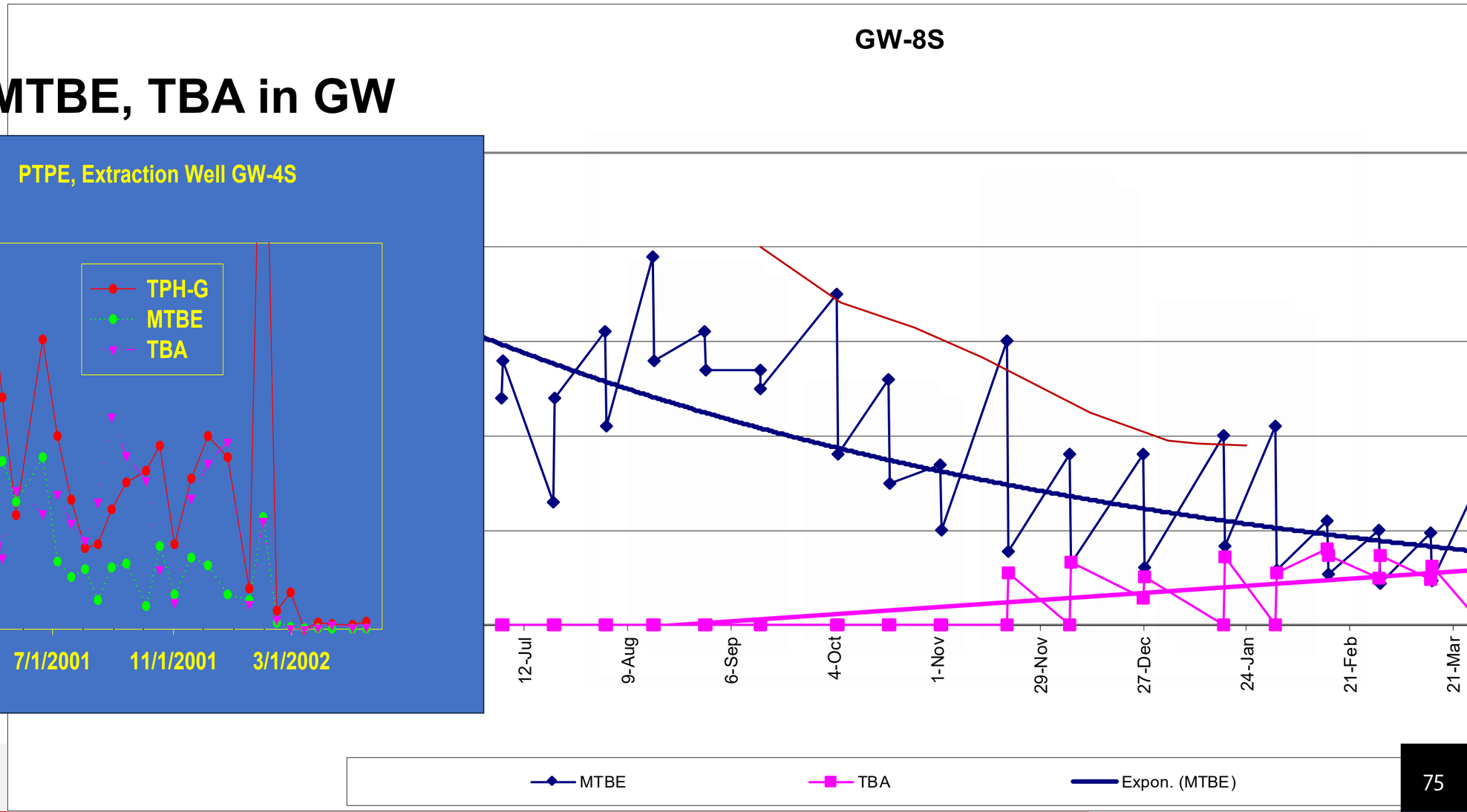
Limited access due to present business activities



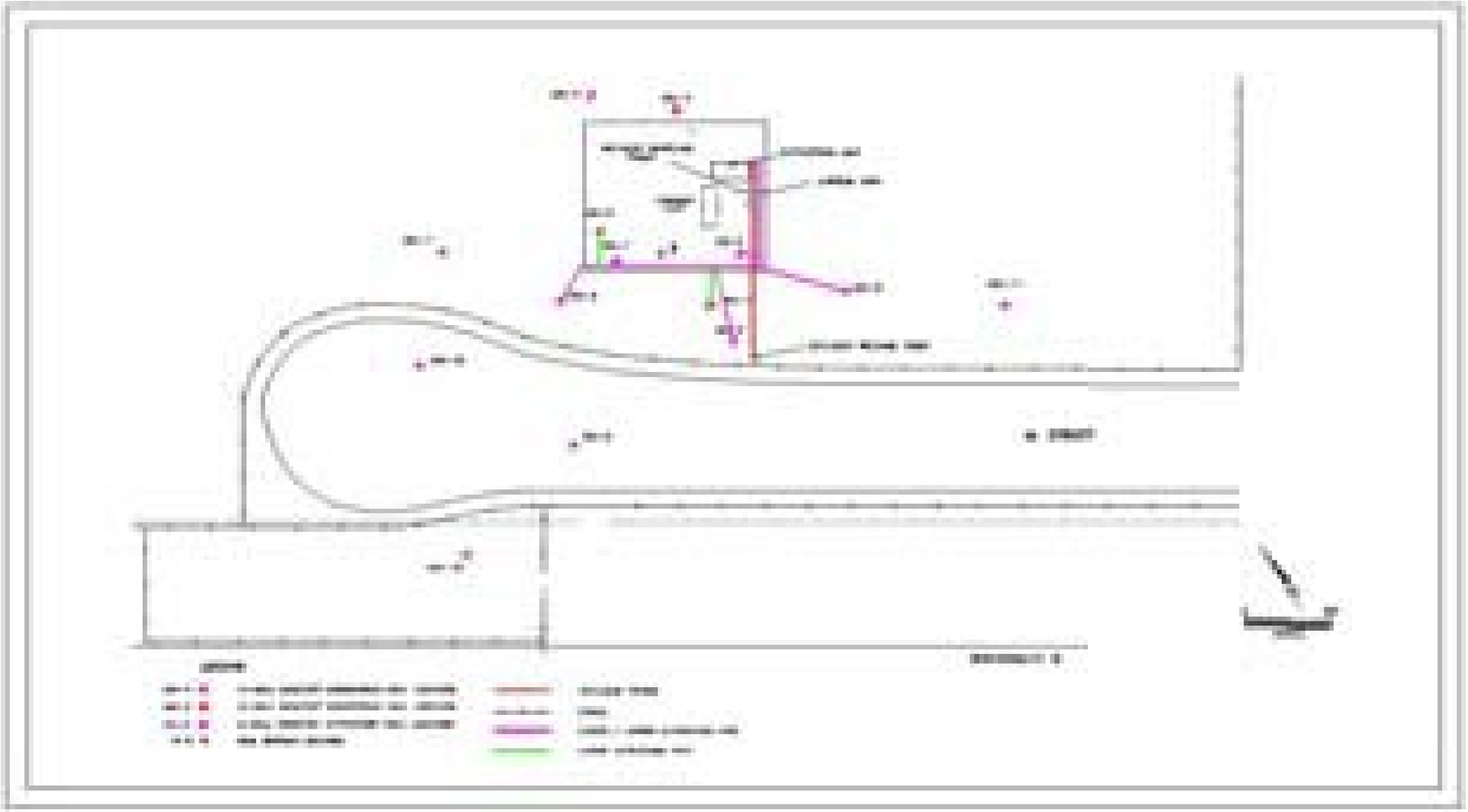
Results

TPH-G, MTBE, TBA in GW



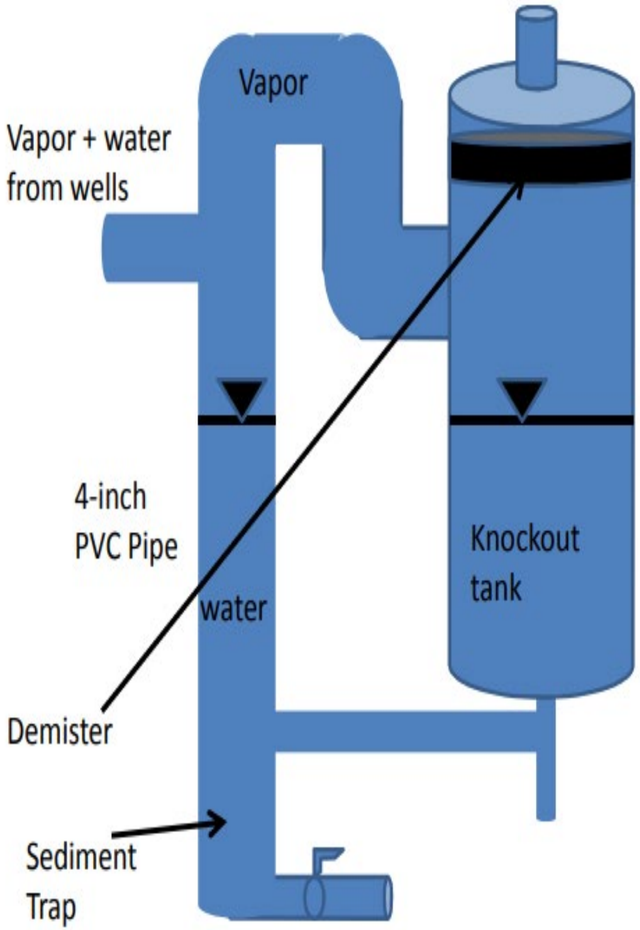


Case Study: Former Car Dealership– *Buena Park, California*



- 1000 gallons UST leaked
- Free product in tank Cavity
- UST Cleanup fund case
- Property was to be redeveloped and purchased from owner
- 2-million dollar held in escrow to be dispersed after case closure

BUENA PARK SITE
Dealing With the Friction Loss



- Lifting water to Knockout tank level after extracting from the well provided challenge.
- Water was slushing back and forth in the elbow where water and vapor flow to be lifted to the knockout inlet.

Site Closure- Soil Confirmation

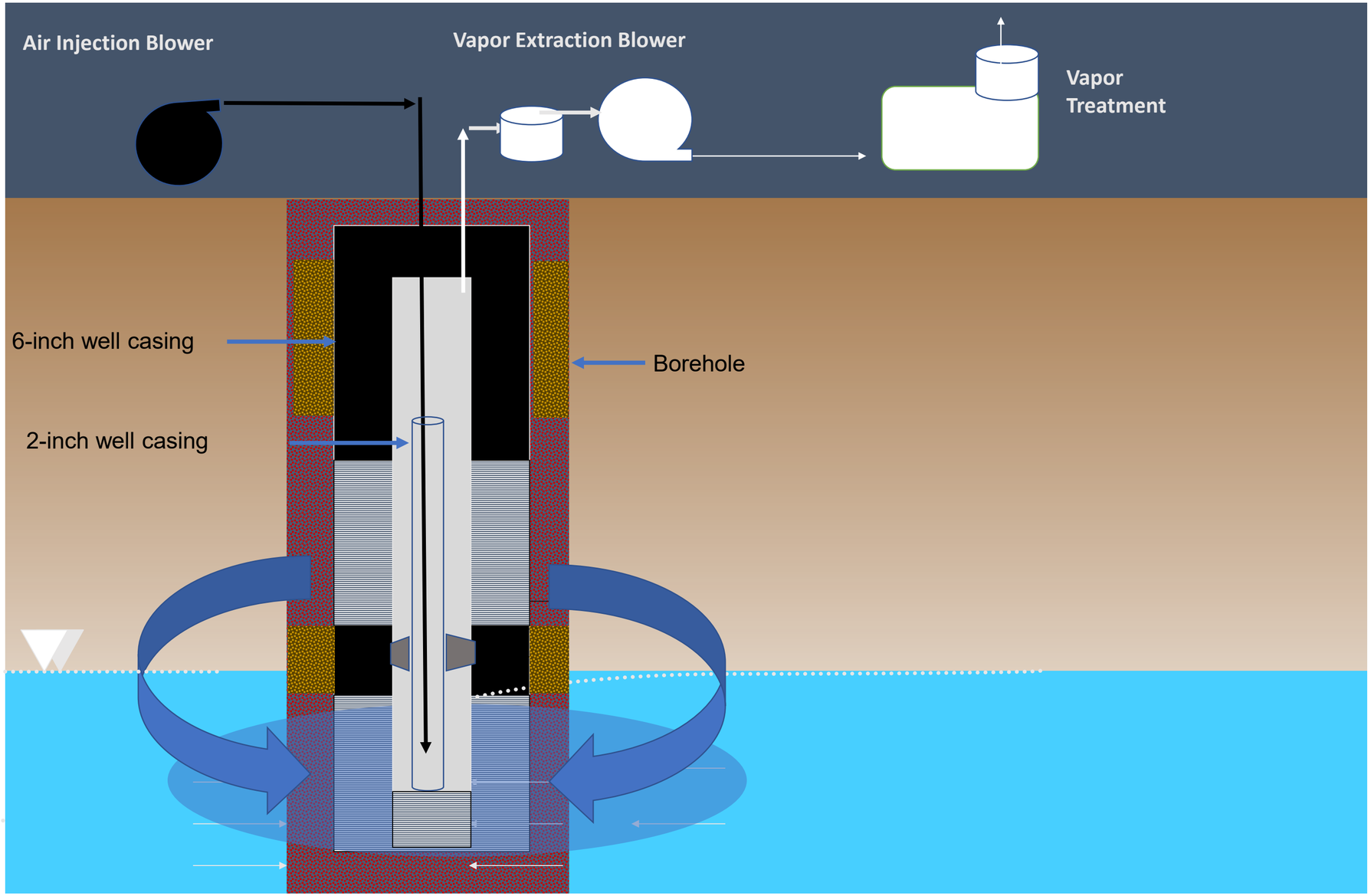
Six confirmation borings were advanced to a depth of 21.5 feet in the areas of worst contamination on March 5, 2002. Only trace concentrations of MVF contamination were detected in soil samples. MTBE, benzene and toluene were not detected in any of the 24 soil samples taken; ethylbenzene was detected in only one sample (31 ppb) and xylene was detected in only two samples (5 ppb, 17 ppb).

- First Case of Pilot Test to Site Closure
- Single blower SVE system operated as TPE
- PD Blower
- Complete Remediation in 7 Months - ~250,000 gallons of water ~ 30M cuft Vapor were extracted-
- Confirmation soil samples are all ND or very low level of TPH-G
- Case Closure – Client received 2M held in escrow after the closure.

In-Well Stripping and Recirculation

In-well stripping methods use wells to strip VOCs from groundwater which incorporates water recirculation, air injection, vapor extraction and a vapor treatment unit.

Typical In-Well Stripping and Recirculation System



In-Well Stripping/Recirculation Methods

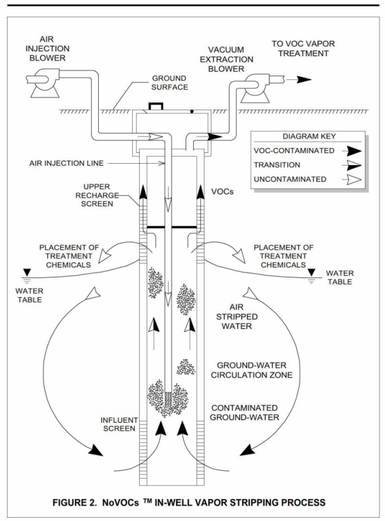


FIGURE 2. NoVOCs ™ IN-WELL VAPOR STRIPPING PROCESS

GWRTAC 6 O Series: TO-97-01 In-well Vapor Stripping

NoVOC System was developed by Stanford University and Purchased by EG&G Environmental in 1994.

NoVOC System uses dual screened well, air sparging and vapor extraction in the same well.

Unterdruck-Verdampfer-Brunnen (UVB) Method uses dual screened well that upper and lower screen portions are divided by a packer

Above the packer a diffusion plate is installed at the lower section of the upper screen interval

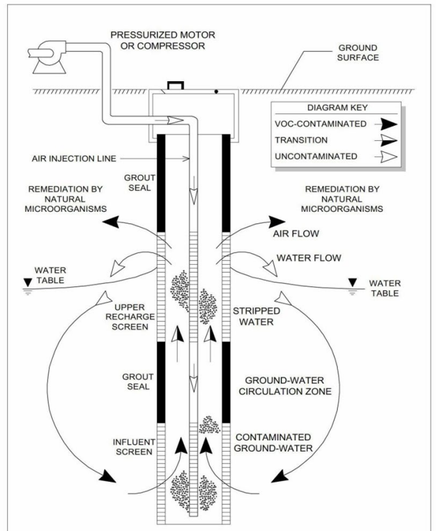


FIGURE 4. DDC IN-WELL VAPOR STRIPPING PROCESS

GWRTAC 9 O Series: TO-97-01 In-well Vapor Stripping

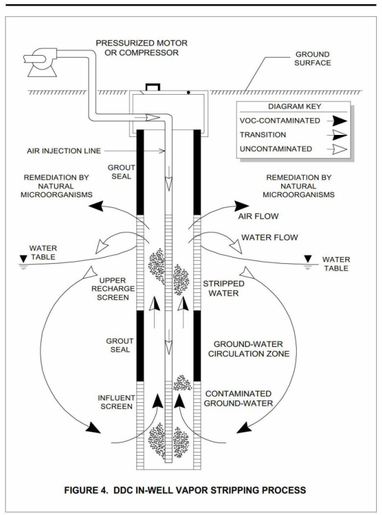


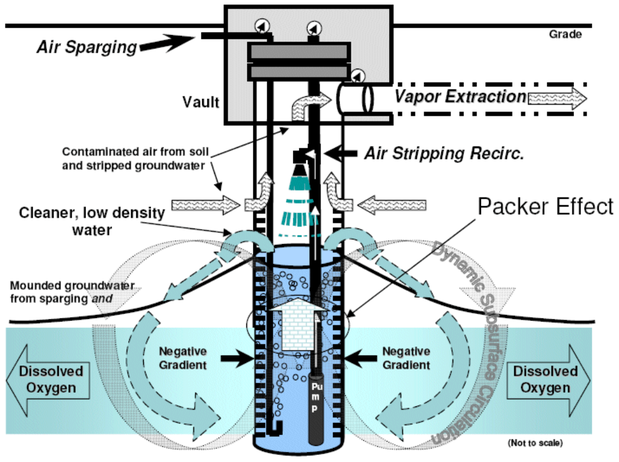
FIGURE 4. DDC IN-WELL VAPOR STRIPPING PROCESS

GWRTAC 9 O Series: TO-97-01 In-well Vapor Stripping

Density Driven Convection (DDC) system, developed and patented by Wasatch Environmental, Inc.

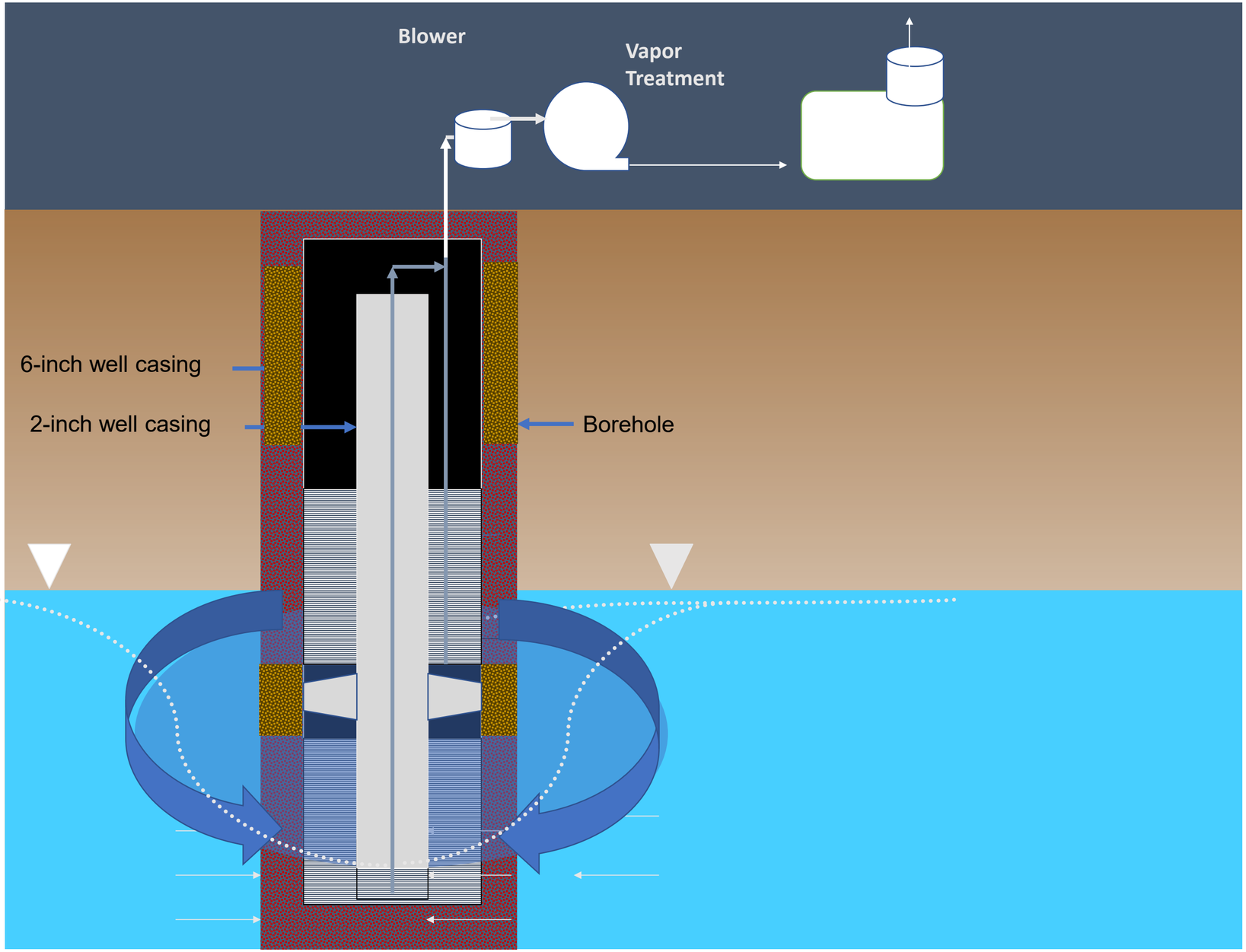
DCC Method uses dual screened well. Air Sparged into the water from the nearly bottom of the well. Air is allowed to escape into the vadose zone after stripping VOCs from the water.

Accelerated Remediation Technologies, Inc. (ART), was patented “ART In-Well Technology” in 1996. Technology uses unique groundwater circulation well to airstrip VOCs, extract vapor and recirculate groundwater in the well.



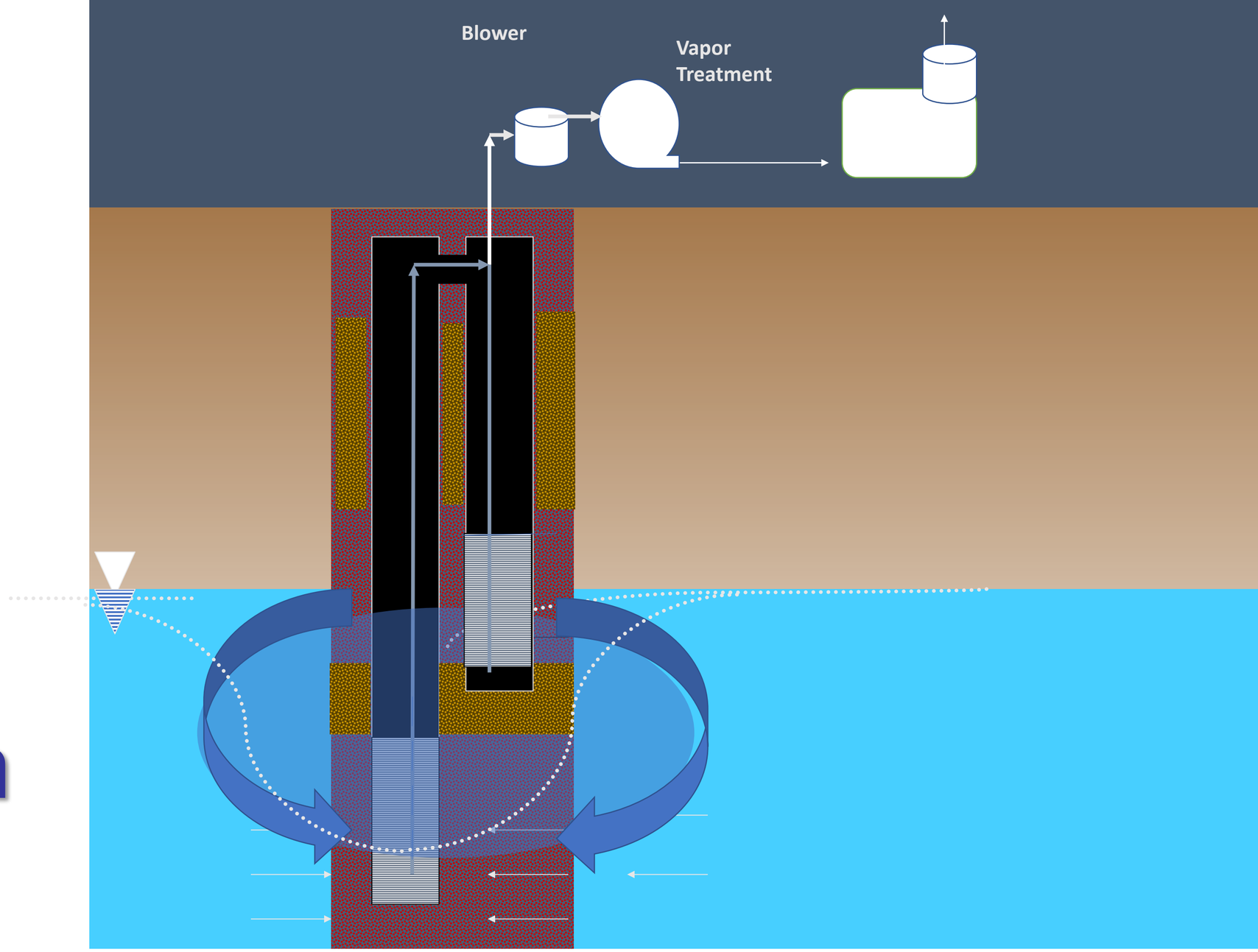
Vacuum Driven In-Well Stripping & Recirculation System

Vacuum Driven In-Well Stripping and Recirculation System



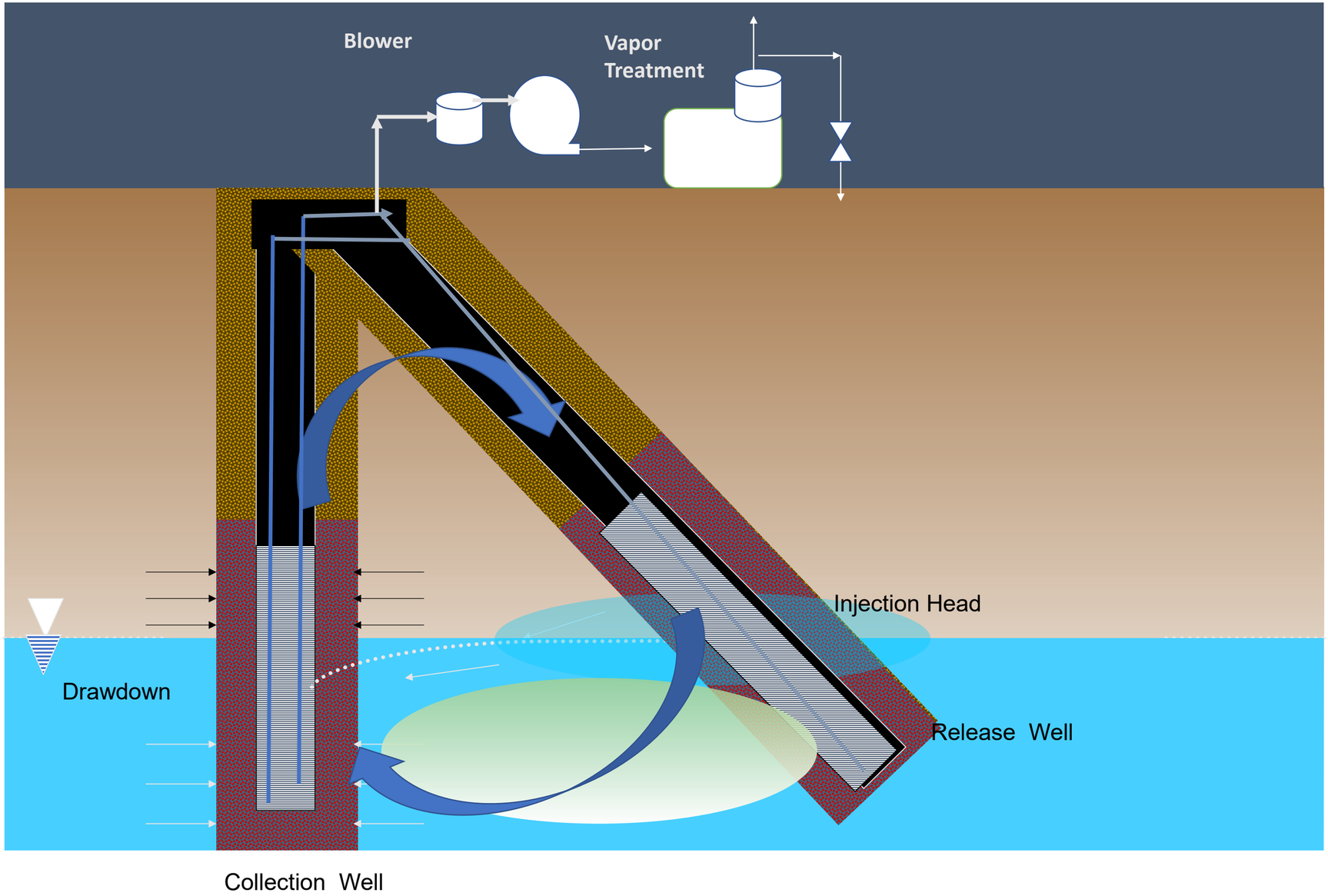
Recirculation Well

Single Borehole Dual Well Recirculation

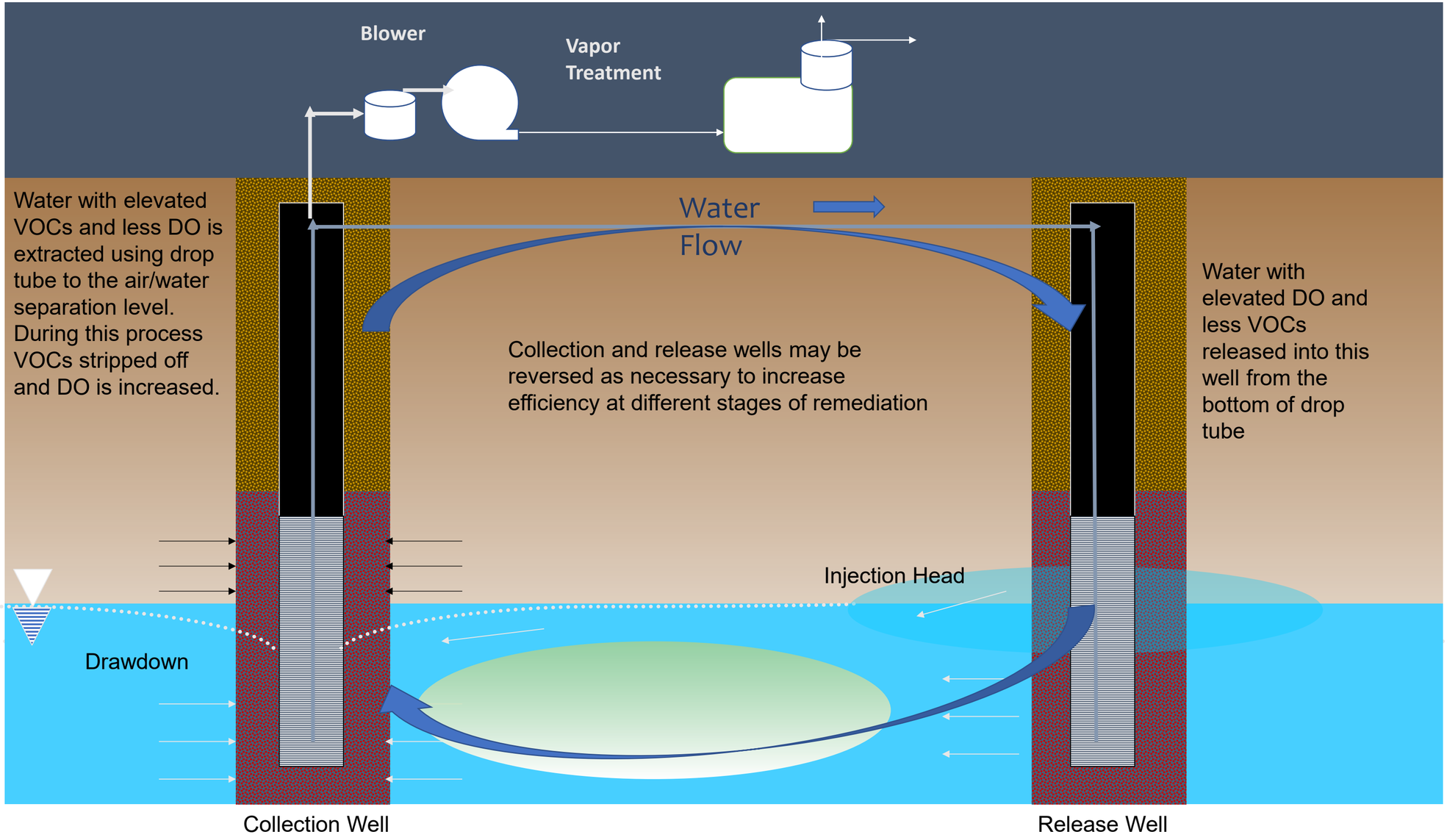


Recirculation Well Pairs

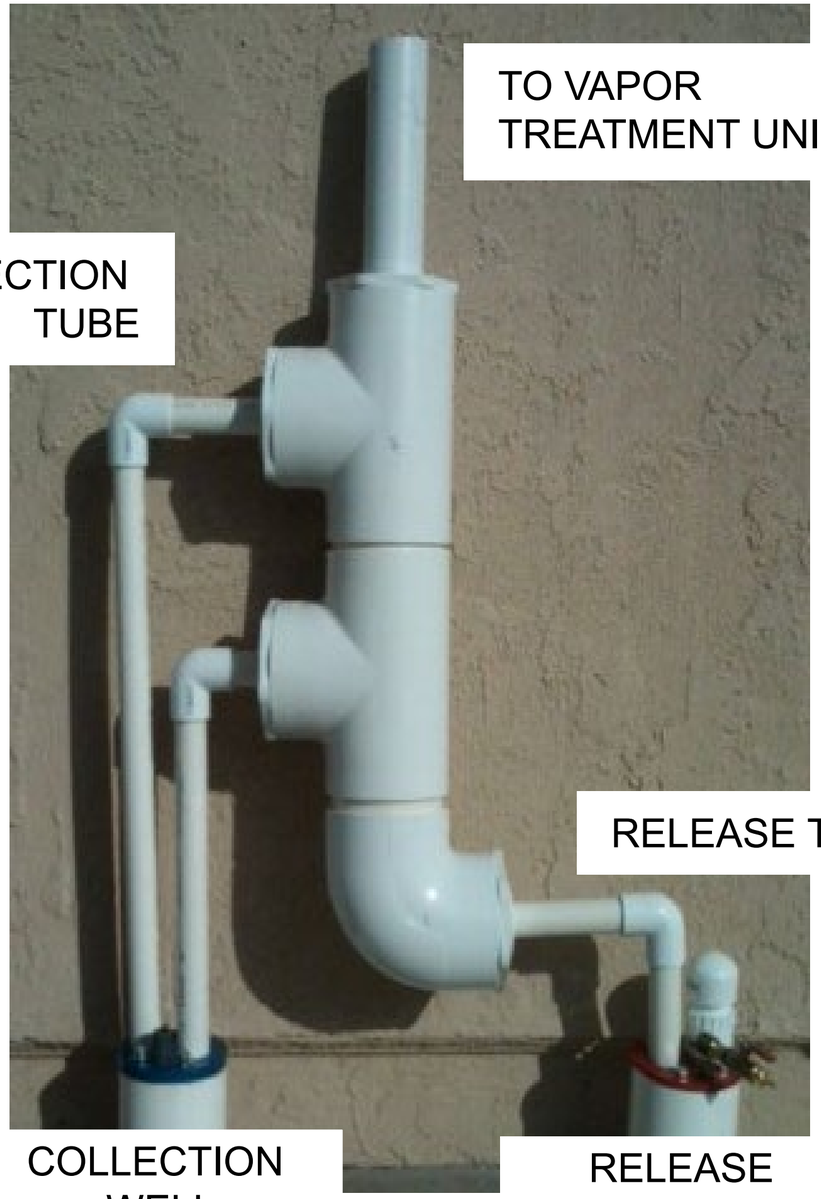
Slant Well Pair



Dual-Well Pair

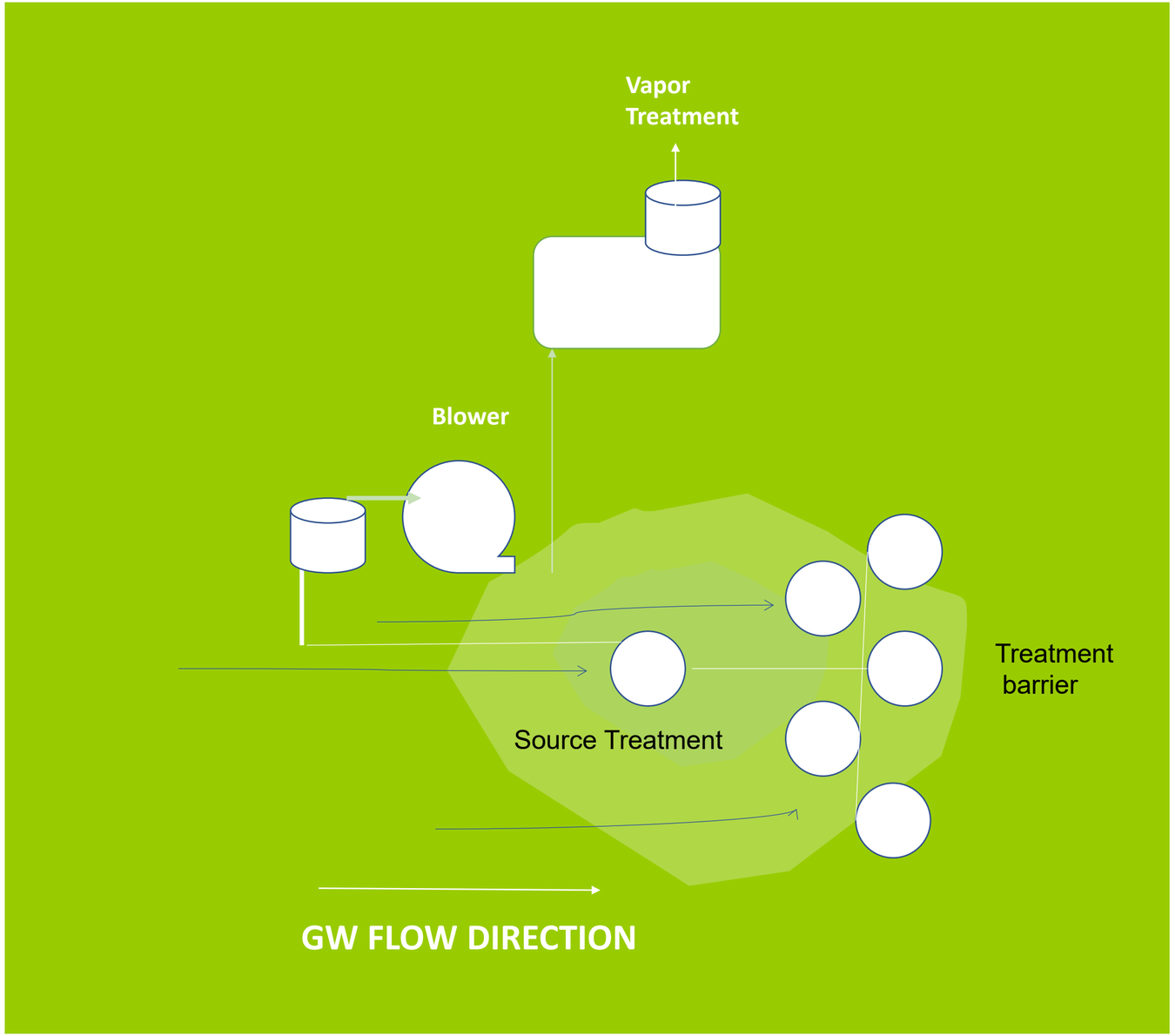


Air/Water Separation



WELLHEAD DETAIL

Typical System Layout

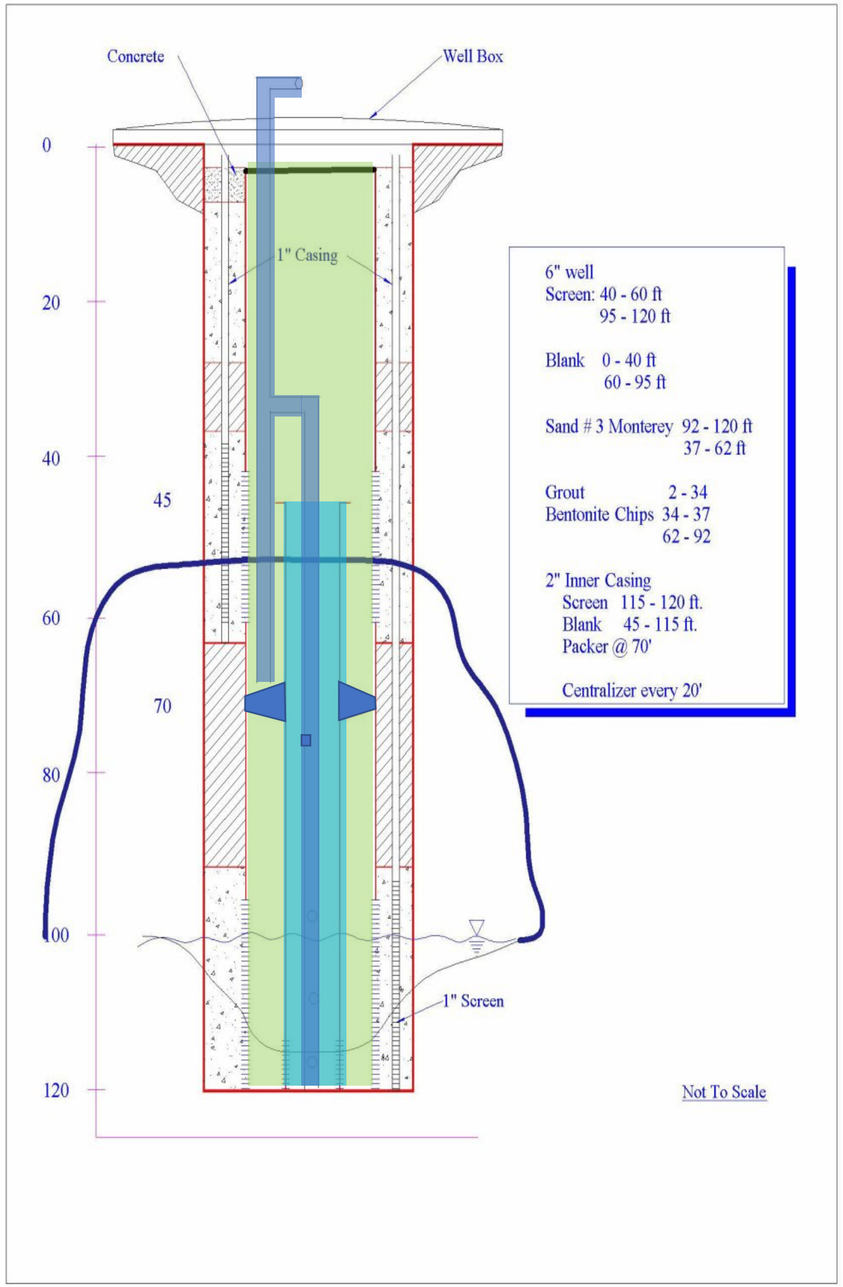


VOC

Removal by

Recirculation

Single Well Pilot Test-1



A pilot test was performed using two-phase in-well stripping method.

The method involved extracting water from the water table using two-phase extraction and re-injecting at the vadose zone using a dual screen/dual well system.

Water levels were measured using two piezometers installed in the well annulus.

Water samples were collected from these two piezometers to assess effectiveness of in-well stripping and chemical composition of extracted and injected water

Single Well Pilot Test-1

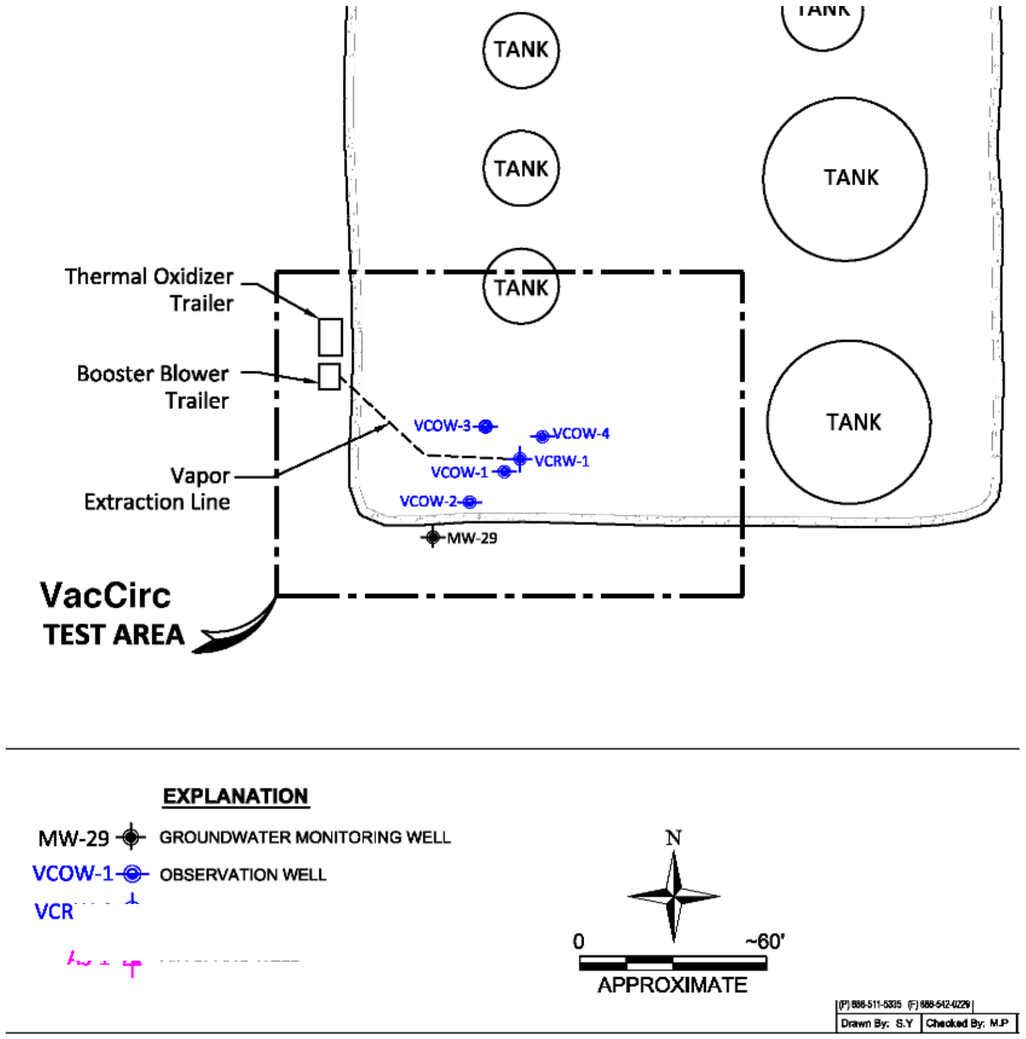
A TYPICAL IN-WELL STRIPPING DATA OBSERVED DURING TWO-PHASE RE-CIRCULATION

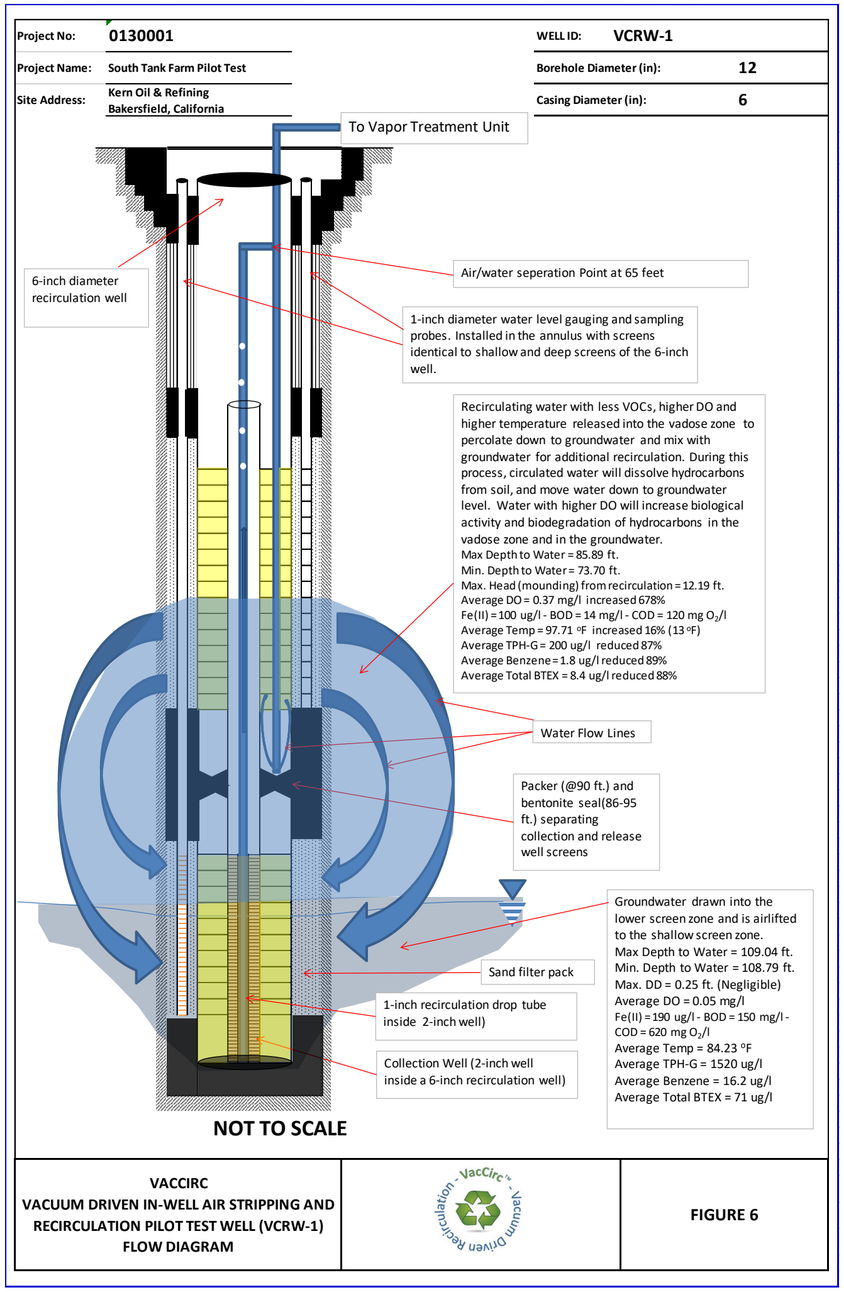
SAMPLE LOCATION	TPH-G (ug/l)	Benzene (ug/l)	Toluene (ug/l)	Ethyl benzene (ug/l)	Xylene (ug/l)	MTBE (ug/l)	TBA (ug/l)
WATER SAMPLE AT THE RETURN SCREEN (post stripping)	**900**	**22**	**79**	**6.6**	**169**	**94**	**ND<10**
WATER SAMPLE FROM DEEP SCREEN (pre-stripping)	**29000**	**2400**	**7600**	**860**	**5700**	**200**	**ND<10**
% IN-WELL STRIPPING	97%	99%	99%	99%	97%	53%	NA

The test was performed using a single borehole dual completion well. Water was removed from 100 feet deep screen zone and released into the vadose zone at 60 feet deep.

Single Well Pilot Test-2

- One In-well stripping and recirculation Well and four Observation Wells were Installed
- Water from the deep saturated zone is air lifted (using the drop tube) up to the unsaturated shallow screen interval in the recirculation well.
- Water is then percolated down through the surrounding soil from shallow screen interval to the saturated zone.





Single Well Pilot Test-2 (Findings)

During Recirculation:

- DO increased
- TPH-g decreased
- BTEX decreased
- BOD/COD/Fe(II) decreased
- Temperature increased

Single Well Pilot Test-2 In-Well Stripping

SAMPLE ID	SAMPLE DESCRIPTION	DATE & TIME	TPH-G (ug/L)	B (ug/L)	T (ug/L)	E (ug/L)	X (ug/L)	MTBE (ug/L)	NOTES
VCRW-1D	Water in the deep screen prior to air lifting to shallow zone	3/1/2017 15:30	2,100.0	20.0	4.9	45.0	24.0	0.52	
VCRW-1S	Water in shallow zone after being air lifted from the deep zone	3/1/2017 16:45	270.0	3.1	0.4	3.7	5.9	<0.50	Reporting limit was used for calculation when ND (<0.50)
VOC Removal/Stripping Ratio (% reduction)		=1-(VCRW-1S)/(VCRW-1D)	87%	85%	92%	92%	76%	NA	
VCRW-1D	Water in the deep screen prior to air lifting to shallow zone	3/3/2017 11:20	1,700.0	4.7	1.1	9.9	4.8	<0.50	
VCRW-1S	Water in shallow zone after being air lifted from the deep zone	3/3/2017 11:40	280.0	<0.50	<0.50	<0.50	<1.0	<0.50	Reporting limit was used for calculation when ND (<0.50)
VOC Removal/Stripping Ratio (% reduction)		=1-(VCRW-1S)/(VCRW-1D)	84%	89%	55%	95%	79%	NA	

DO and Temperature Readings

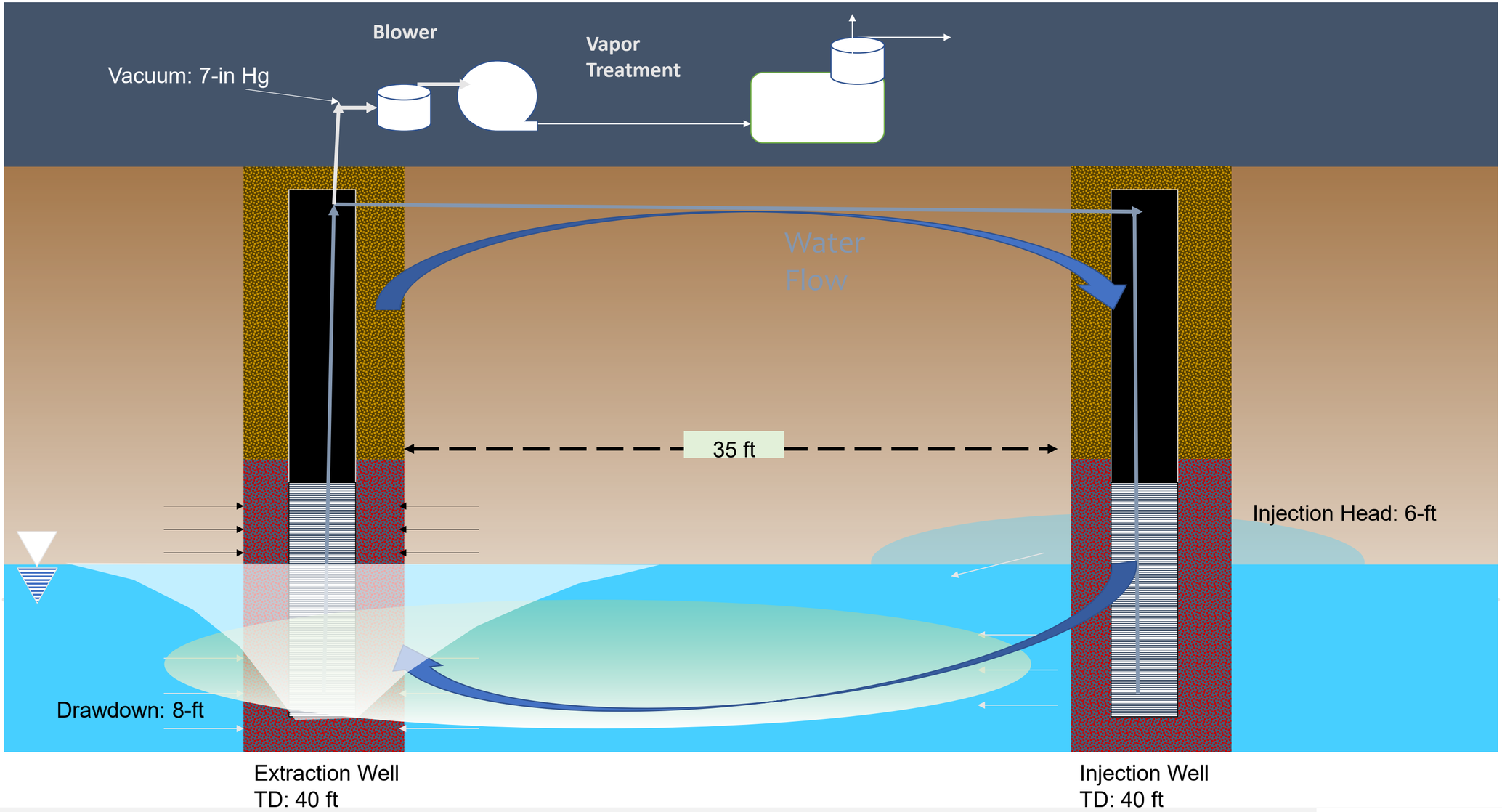
SAMPLE ID	DATE	DO (mg/l)	Temp (F°)	DTW (ft btoc)
VCRW-1D	03/03/17	0.02	85.1	108.79
VCRW-1S	03/03/17	0.09	91.4	73.7
	% Change	350%	7.4%	NA
VCRW-1D	03/10/17	0.04	85.3	108.97
VCRW-1S	03/10/17	0.22	98.2	80.24
	% Change	450%	15%	NA
VCRW-1D	03/15/17	0.08	85.3	108.86
VCRW-1S	03/15/17	0.08	102	83.04
	% Change	0%	19.5%	NA
VCRW-1D	03/24/17	0.05	83.1	108.98
VCRW-1S	03/24/17	0.08	100.4	79.83
	% Change	60%	20.8%	NA

TPH-G/D, BOD, COD, Fe(II) LABORATORY RESULTS

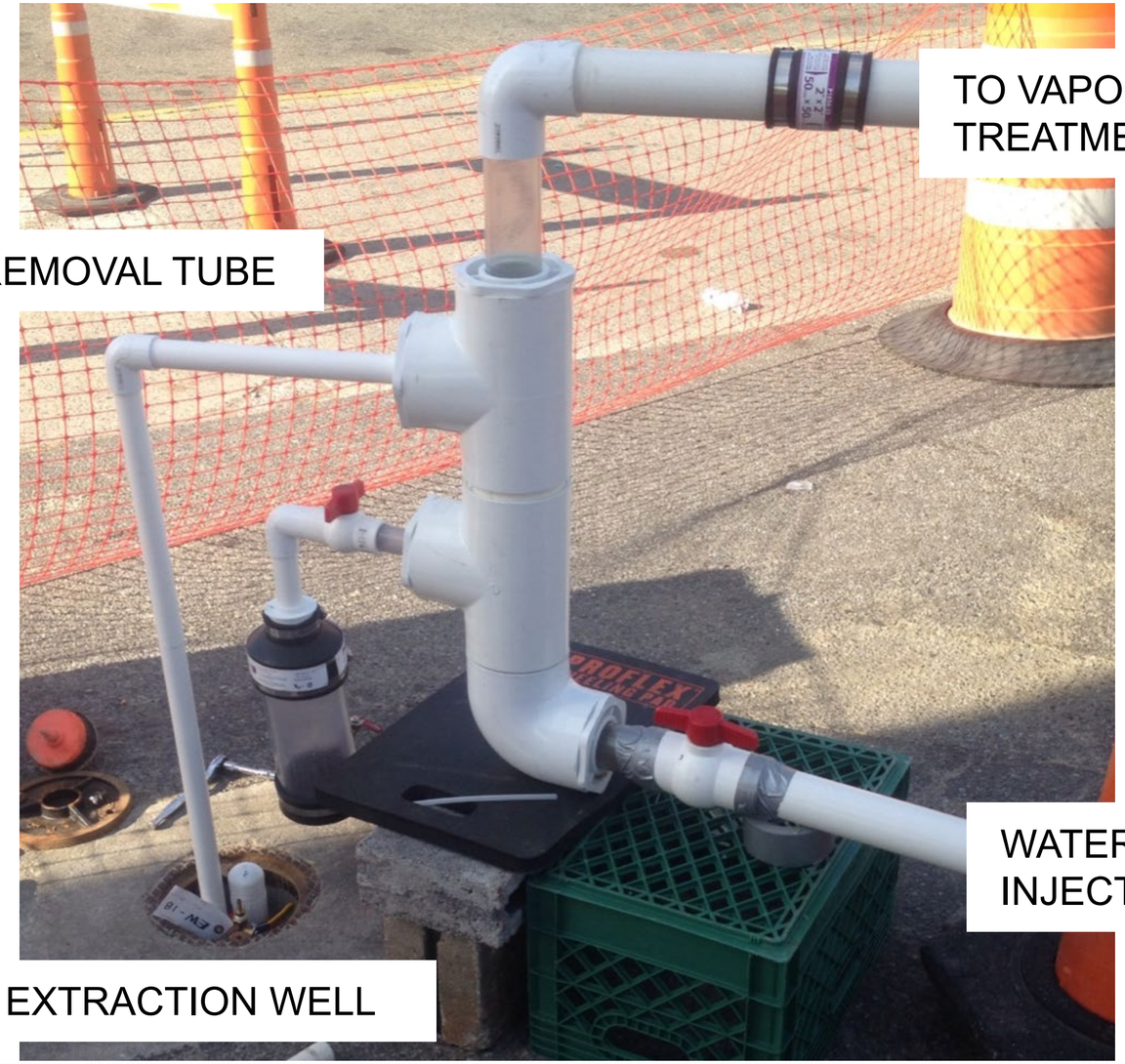
SAMPLE ID	DATE & TIME	TPH-D (C12-C24)	TPH-G (C6-C12)	BOD	COD	Fe(II)
		(ug/L)	(ug/L)	(mg/L)	(mg O2/L)	(ug/L)
VCRW-1S	3/9/2017 12:00	2700	100	24	180	
	3/24/2017 10:45	1800	150	14	120	100
VCOW-1D	3/9/2017 10:15	11000	6,800	150	710	
	3/24/2017 9:30	7400	2,000	150	620	190

JHA ENVIRONMENTAL

Dual-Well Pilot Test Schematic



Dual Well Pilot Test



A gas station site in New York

Separate Extraction Well (EW) and Injection Well (IW) were used

Depth to water ~32 ft

Total depth of EW and IW is 40 ft.

Distance between EW and IW is 35 ft.

Applied Vacuum at the Extraction well drop tube is 7-inches of Hg

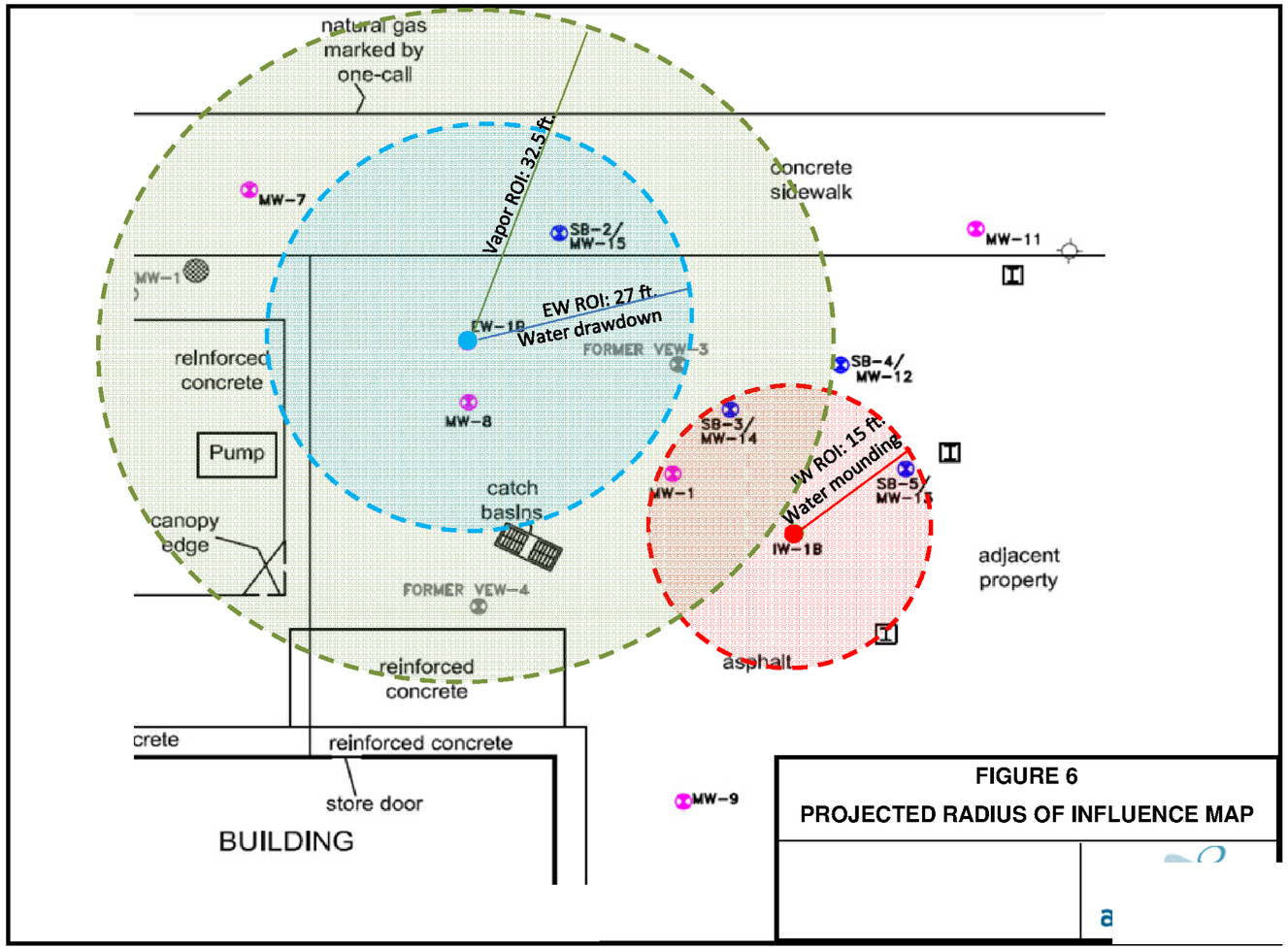
Dual Well Pilot Test, EW Wellhead

Extraction well head and air/water separation column. Clear 4-inch container was used to measure water flow.

Dual Well Pilot Test Information

- 1 Day Test
- Over 32 ft ROI for vacuum Response
- Over 27 ft of ROI for Water Drawdown
- Extraction Well had over 8 ft. Drawdown
- Injection Well had over 6 ft. of head

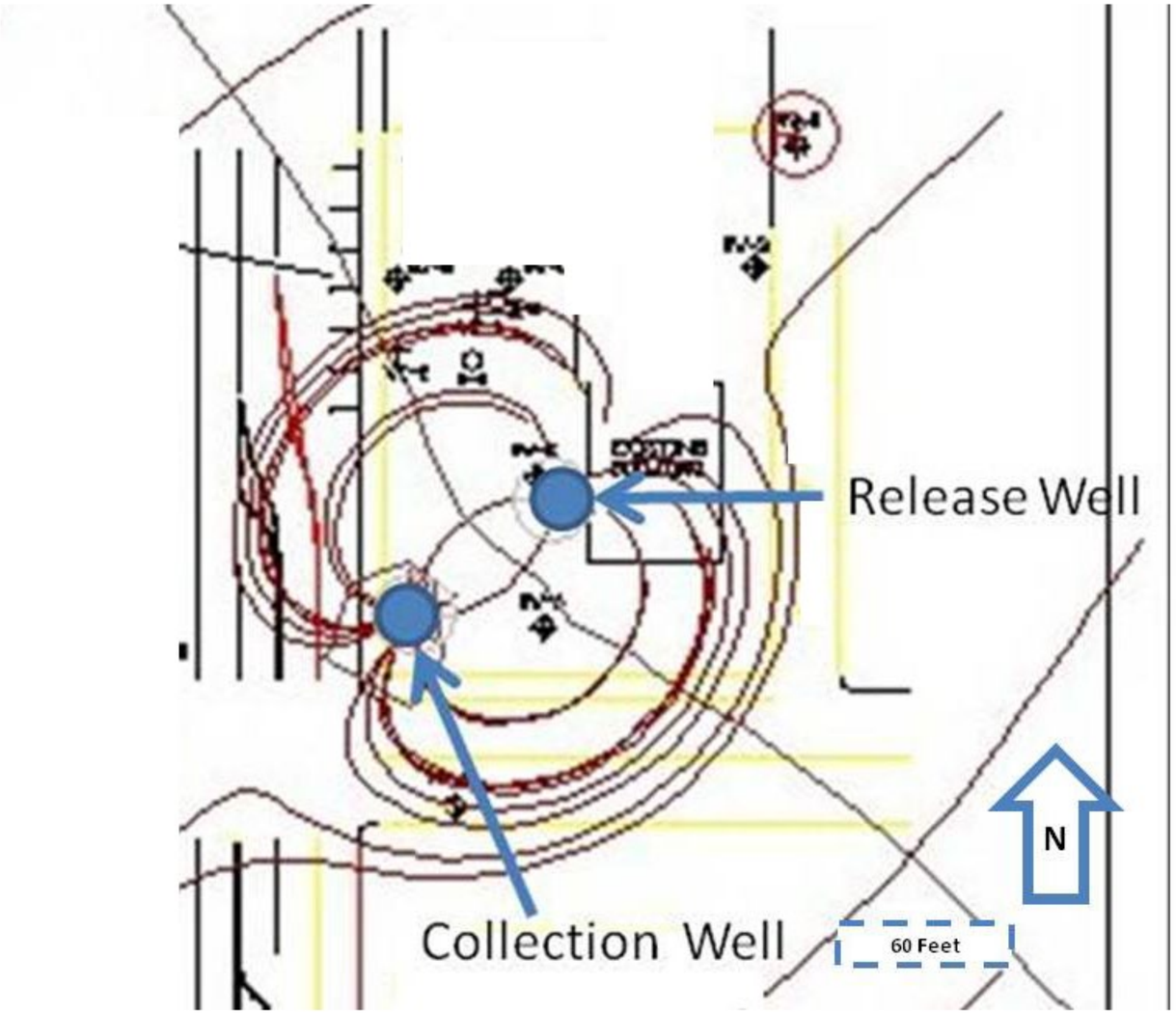
Calculated Zone of Influence



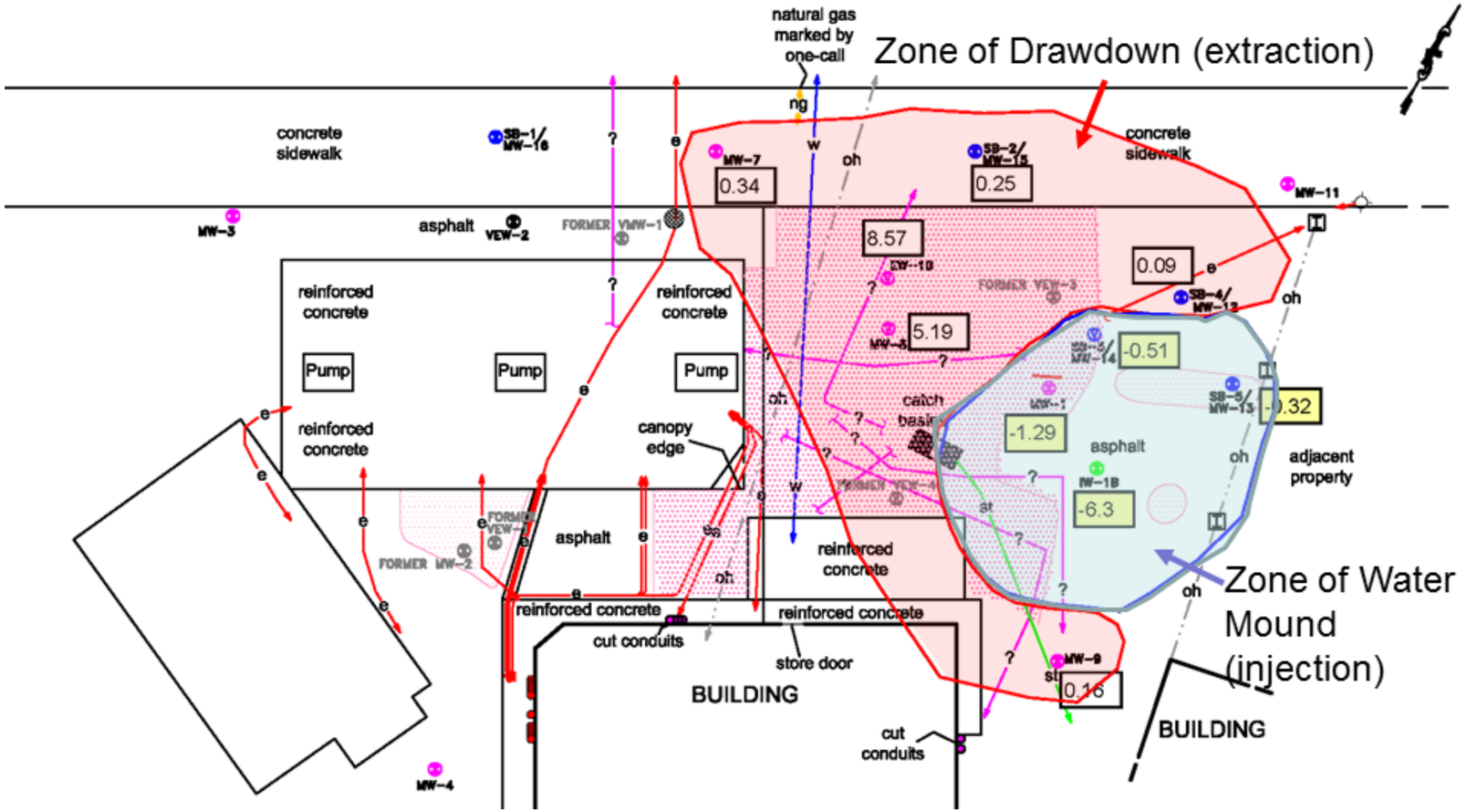
Calculated zone of influence based on distance drawdown and distance head graphs. Considering water flow from High elevation to lower elevation when there is a 6 feet of head in one well and 8 feet of drawdown in the other it is almost imperative that extraction well to capture over 90 % of the injected water.

A two-dimensional analytical model was prepared to evaluate steady state condition of the recirculation cell. Model show that 100% of the injected (release) water is recaptured by the extraction (collection) well. This will make a closed loop treatment cell.

Modeled Zone of Influence



Field Zone of Influence



Zone of influence of drawdown and water mound based on water level drawdown data collected during the pilot test.

Dual Well Pilot Test
VOC Stripping

Sample Location	Benzene	Ethylbenzene	MTBE	Toluene	Xylene (Total)
Extraction Well	670	2,000	49	310	4,700
Injection Well	9	24	4	30	81
% VOC Stripping	**99%**	**99%**	**92%**	**90%**	**98%**

Dual Well Pilot Test Results

With ~7-inches Hg Vacuum and ~55 CFM vapor flow lift water from 40 feet bgs.

EW 8 feet of drawdown in 5 minutes and sustained.

IW had a 6 feet water mound and sustained that.

Can recirculate groundwater 3 – 4 times in a year within 35 feet ZOI

40 feet ZOI for vacuum with directional response.

Over 90% to 98% VOC stripping.

Elevated CO_2 and CH_4 and DO

BREAK

AEHS Foundation

34th Annual International Conference on Soil, Water, Energy, and Air

March 17-20, 2025 | San Diego, CA

Workshop - 02

MODULE-04

Remediation Case Studies

JHA Environmental

Case Studies

Chicago, IL

Charleston, SC

PFAS in Real Estate Transactions

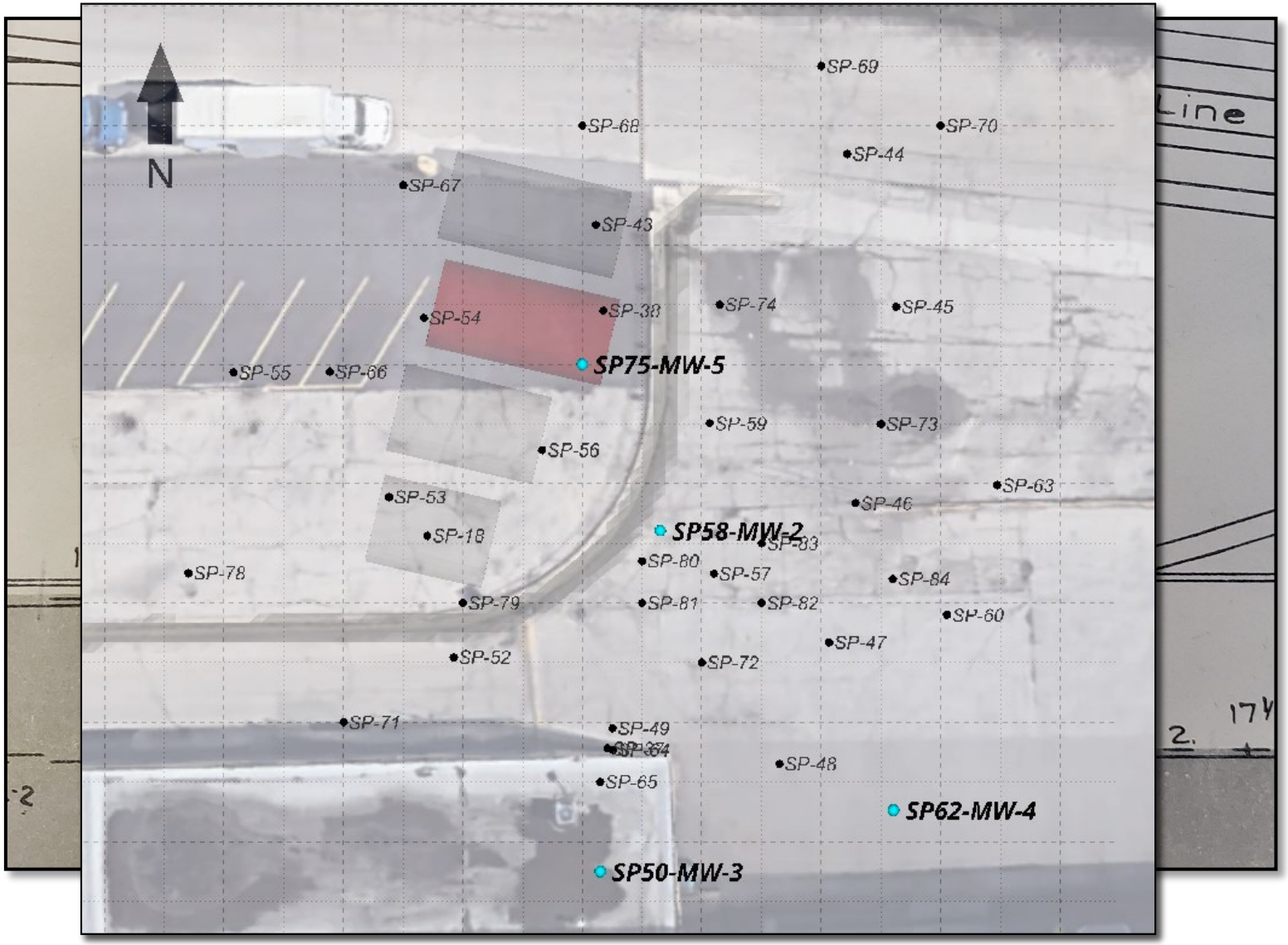
Two Case Studies from Illinois

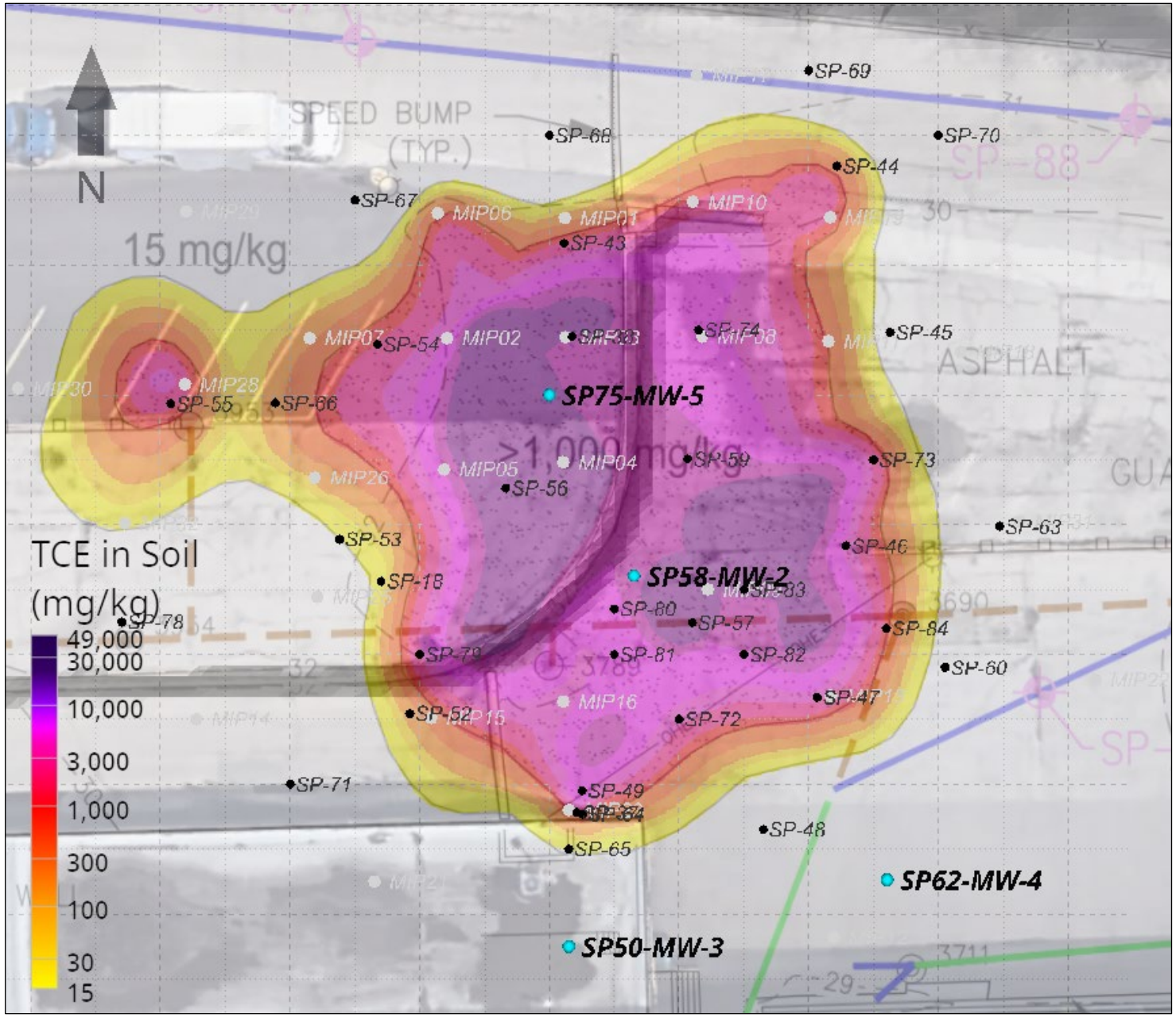
Case Study I : Manufacturing Operation (1940s to 1980s) – *Chicago, Illinois*

Geology:
0-3’ Urban Fill
3-11’ Silty Clay *(Lacustrine)*
11-25’ Dense Clay Till *(Glacial)*

Hydrogeology:
Groundwater at 8’ BGS
Flow to the South-Southeast

Investigations:
1) Limited Phase II **(9 Borings)**
2) MiHPT Investigation **(32 Borings)**
3) Soil Investigation **(41 Borings)**





Area of Impacted Soil (>15 mg/kg):
12,000 Square Feet

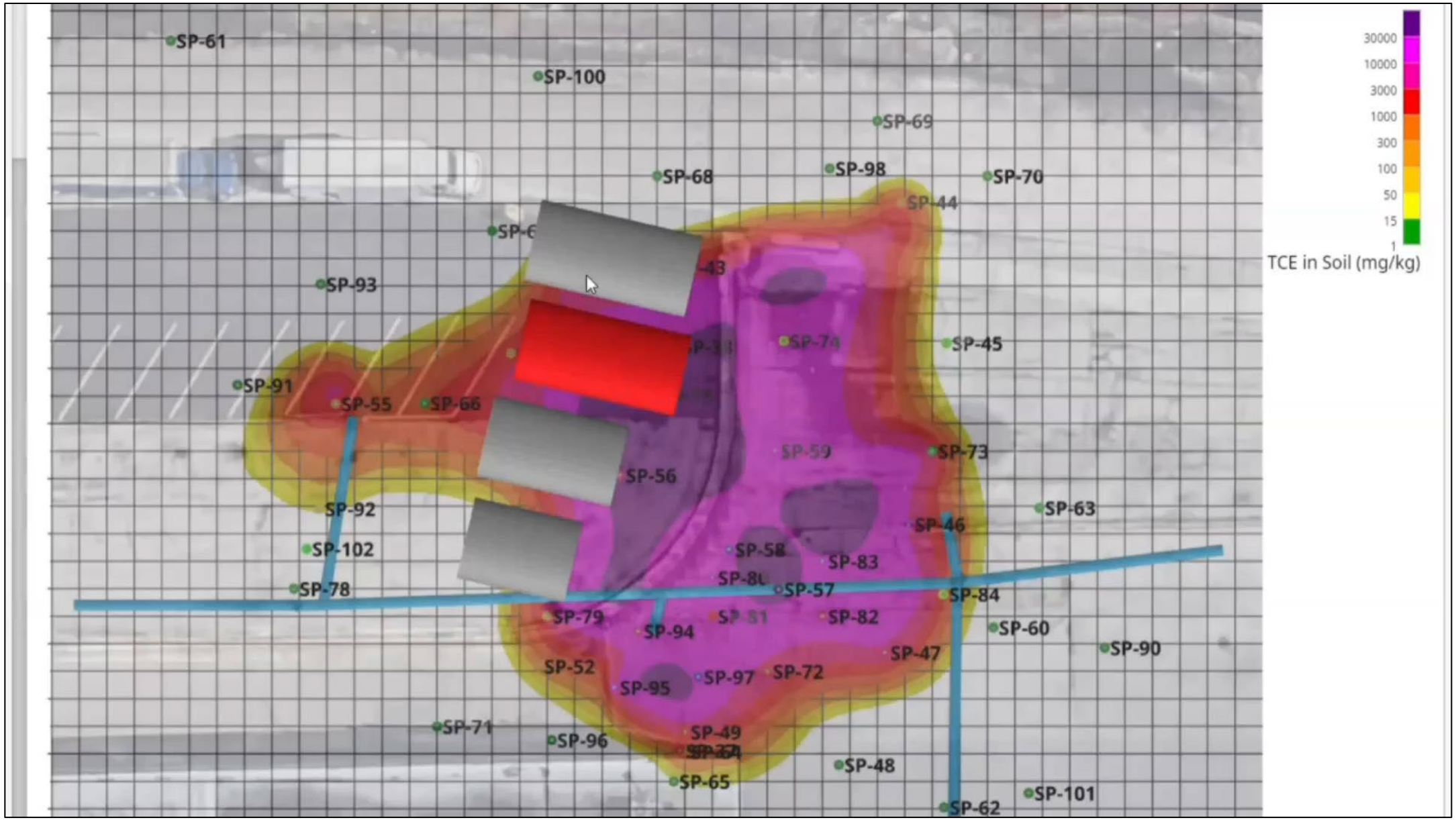
Volume of Impacted Soil (>15 mg/kg):
3,700 Cubic yards

Depth of Impacts:
5-15 Ft BGS (Majority)
21' Ft BGS (Maximum)

Estimated TCE Mass:
62,000 Pounds

Groundwater:
MW-2 and MW-5: Impacted
MW-3 and MW-4: Below ROs

Remedial Option:
Soil Blending with In-Situ Chemical Reduction - Zero-Valent Iron (ZVI)


SP-61
SP-100
SP-69
SP-68
SP-98
SP-70
SP-44
SP-93
SP-74
SP-45
SP-91
SP-55
SP-66
SP-59
SP-73
SP-56
SP-63
SP-92
SP-46
SP-102
SP-58
SP-83
SP-78
SP-57
SP-84
SP-79
SP-82
SP-60
SP-94
SP-90
SP-47
SP-52
SP-97
SP-72
SP-95
SP-71
SP-96
SP-49
SP-48
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SP-101
SP-62
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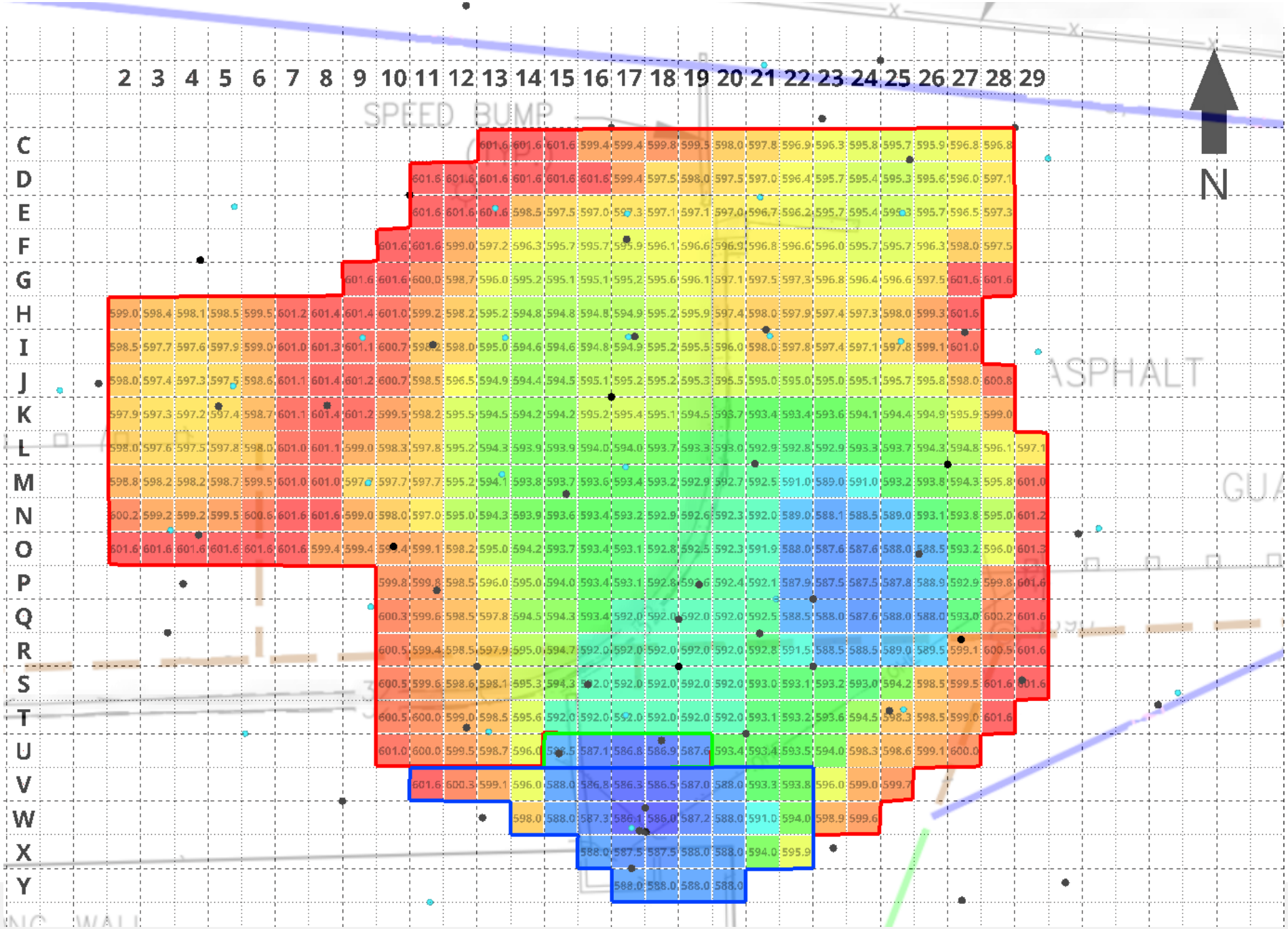
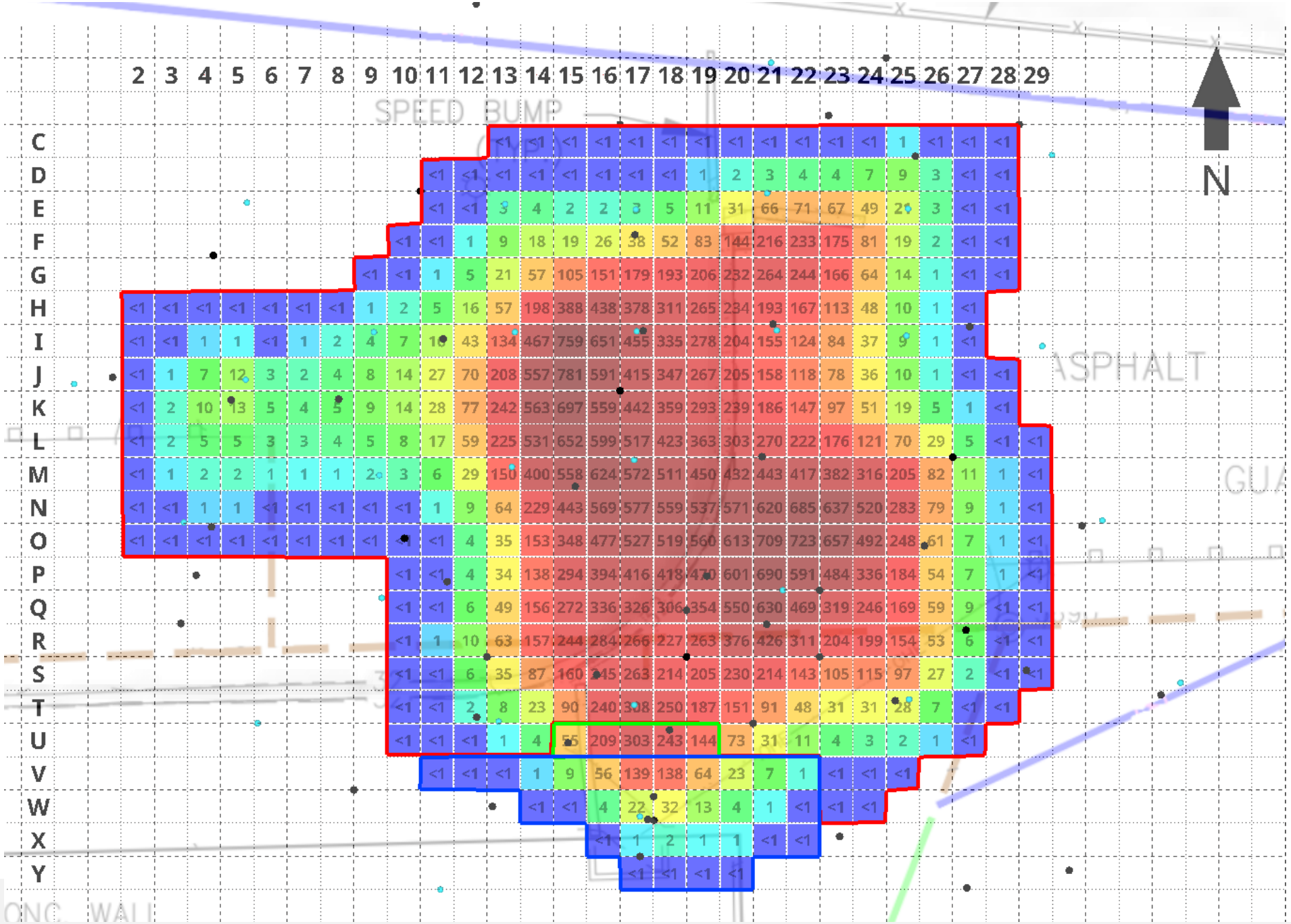
300
100
50
15
1
TCE in Soil (mg/kg)



5x5’ Grid

Bottom Elevation Of Treatment Area (Ft AMSL)



5x5' Grid

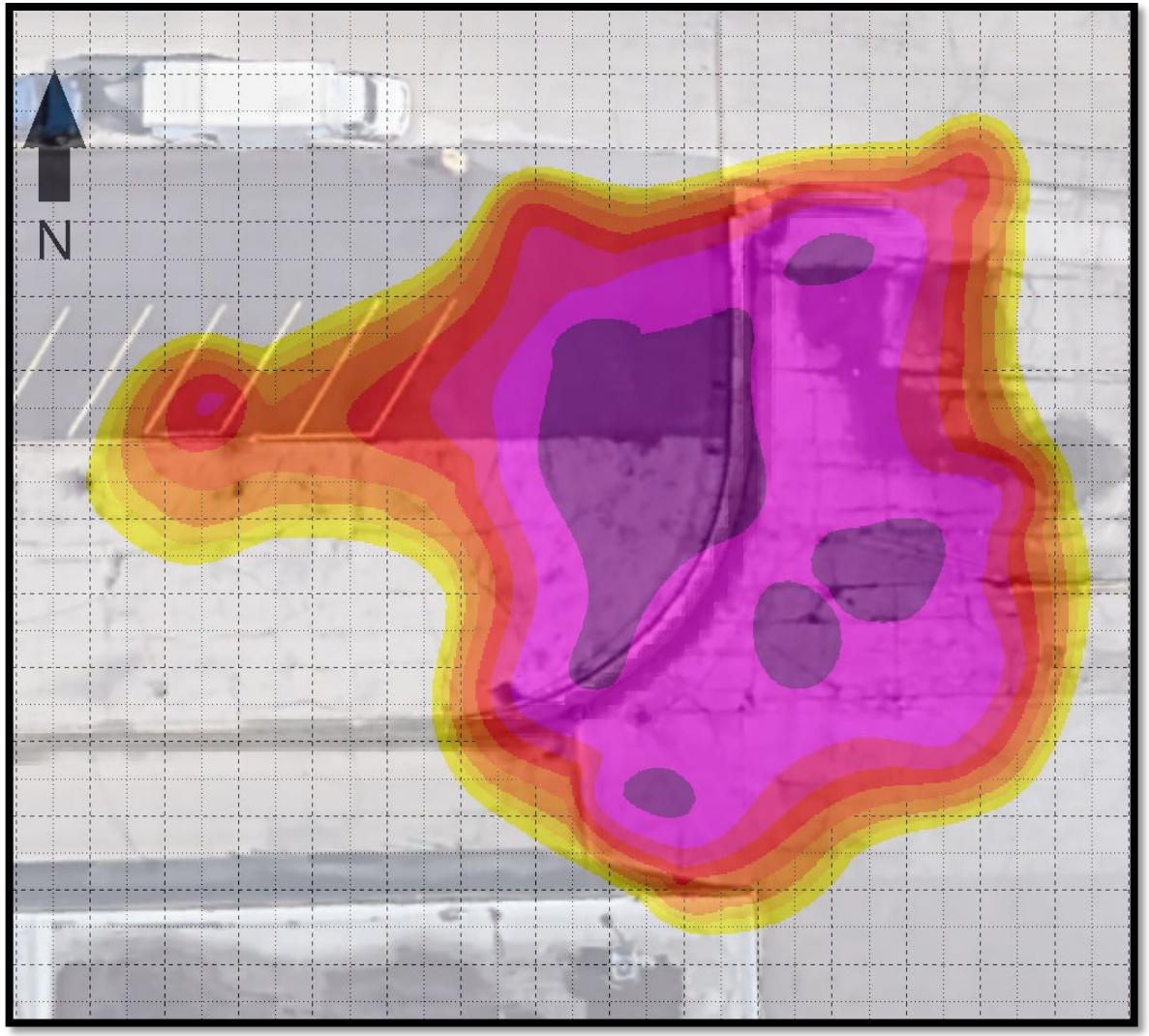
Estimated TCE Mass (Pounds)

475 Tons of Zero Valent Iron (ZVI)

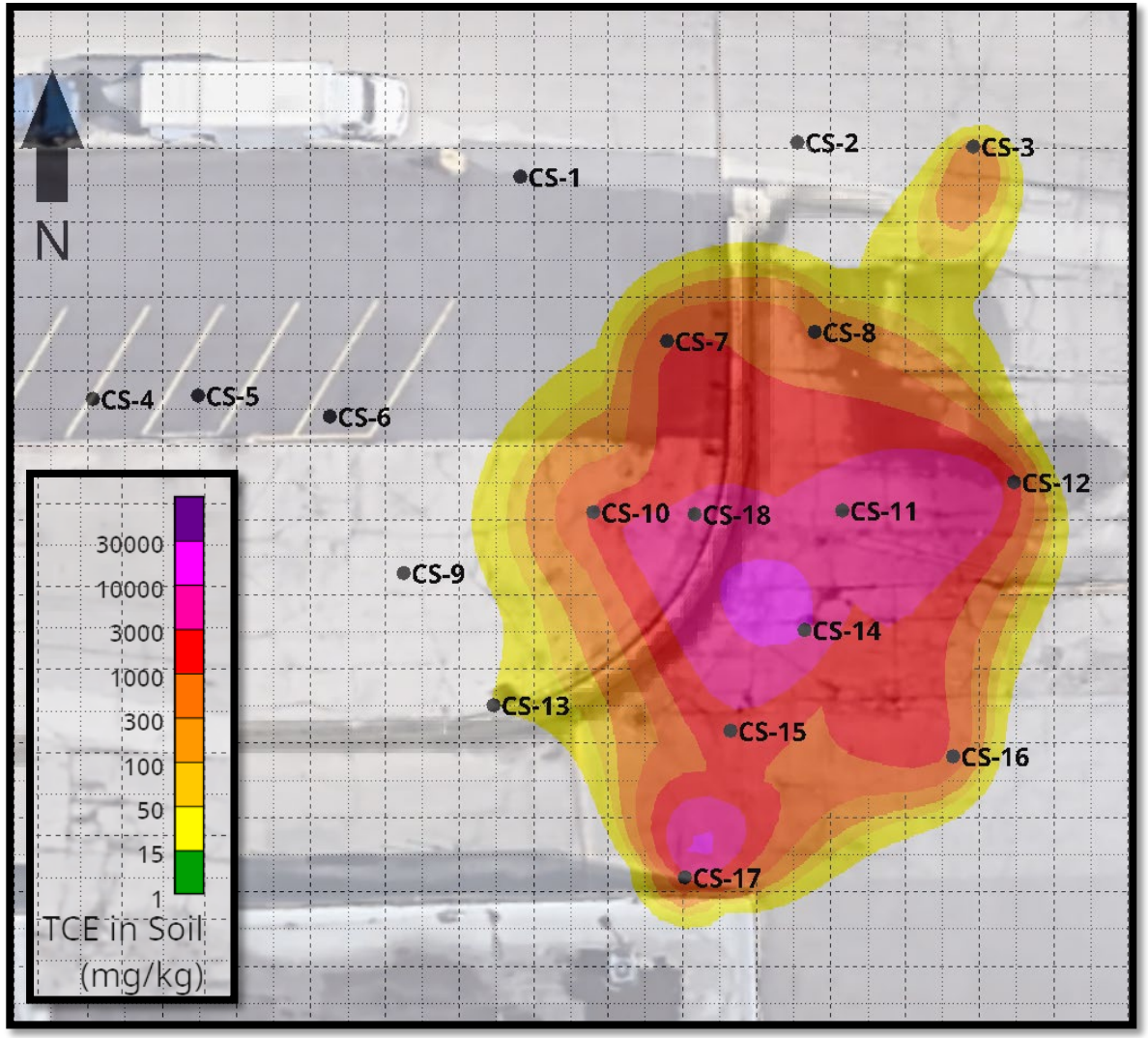
GPS Readout in Cab

Soil Blending Equipment


REDOX TECH, LLC



Initial



Six Months After Treatment

80% Reduction in TCE Mass

Next Steps:

1) Targeted Injections in Recalcitrant Areas

2) Resampling of 12 (of 18) Confirmation Sampling (CS) Locations

3) Reinject (if Needed) – Three Events were Budgeted

4) Resampling of CS Locations not Meeting 15 mg/kg

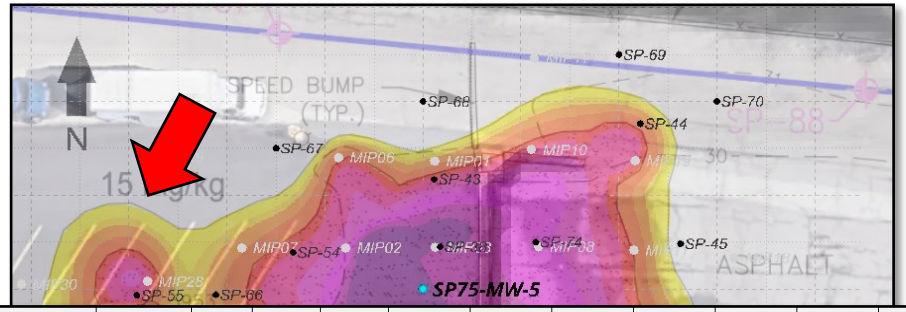
Note: Remediation goal of 15 mg/kg for TCE was guaranteed by contractor

Lessons Learned:

1) Utilize HRSC Tools & Investigate Thoroughly
   - Located an Additional Source Area
   - SICR & RAP Approved by Agency

2) Use 3D Statistical Modeling
   - Mass Estimation
   - Remedial Design & Implementation

3) Perform a Bench Test

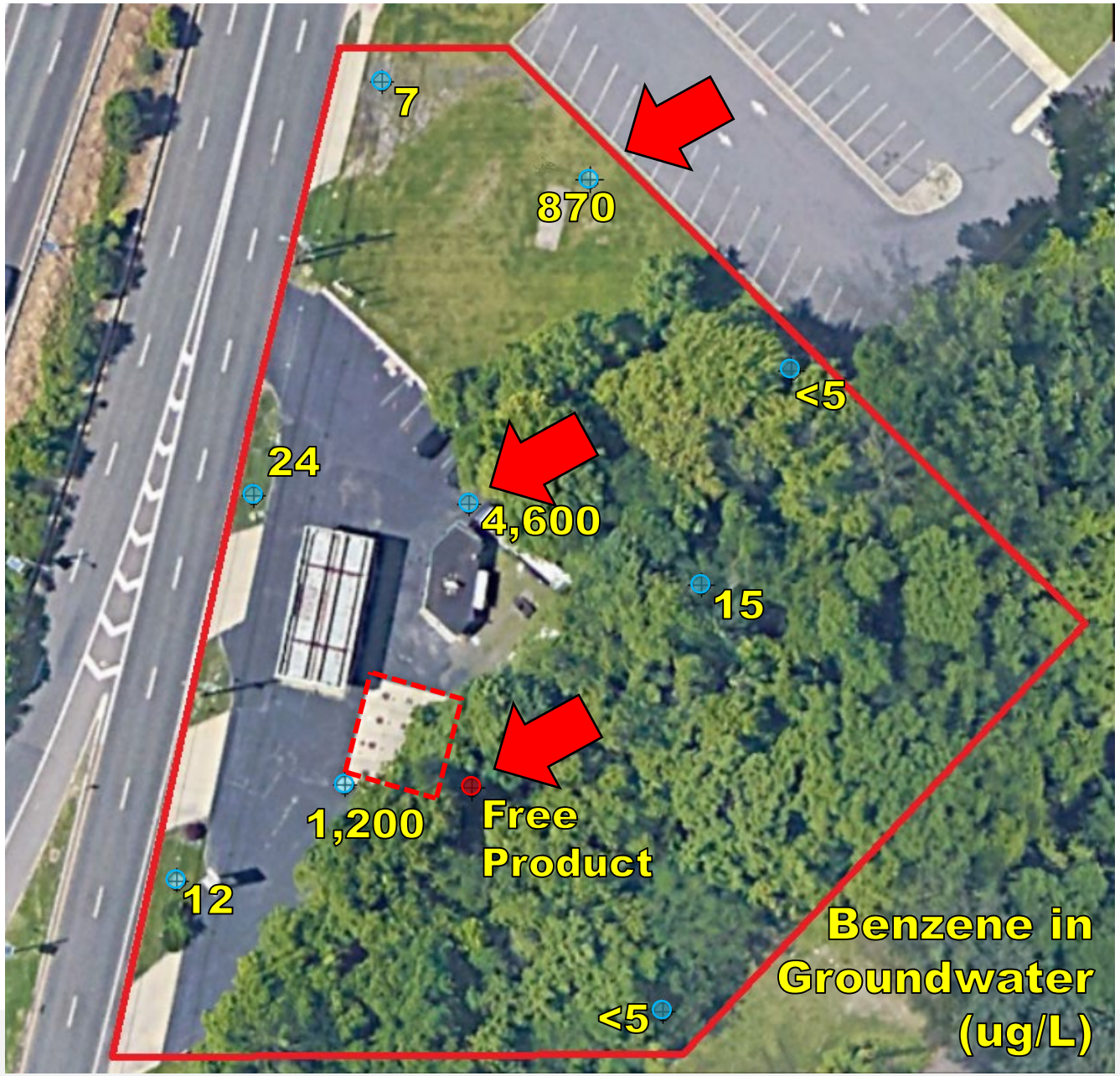


Cell ID	Associated 5ft by 5ft Block from JHA Figure 4	Dimensions (ft x ft)	Area (ft^2)	Depth (ft bgs)	Volume (cy)	Est. Average Mass TCE (lbs)	Est. Low Mass TCE (lbs)	Est. High Mass TCE (lbs)	Target Weight Percent ZVI	Exact Weight Percent ZVI	ZVI Required (lbs)	Super Sacks
1	D11/12, E11/12, F10/11	Figure	150	5-10	27.78	<1	<1	<1	1	2.49	2,205	1
2	C13/14, D13/14, E13/14	10 x 15	150	5-10	27.78	<8	<6	<8	2	2.49	2,205	1
3	C15-18, D15-18, E15-18	20 x 15	300	5-14.5	105.56	<13	<10	<14	2	1.98	6,615	3
4	C19-22, D19-22, E19-22	20 x 15	300	3-14	122.22	189	158	214	4	4.44	17,640	8
5	C23-26, D23-26, E23-26	20 x 15	300	2.5-14.5	133.33	164	140	190	4	4.09	17,640	8
6	C27/28, D27/28	10 x 10	100	6-13.5	27.78	<1	<1	<1	1	2.49	2,205	1
7	G9-11, H9-11, I9-11	15 x 15	225	3-13	83.33	36	30	42	2	2.49	6,615	3
8	F12-14, G12-14, H12-14, I12-14	15 x 20	300	3-17	155.56	1026	841	1214	7	7.20	37,485	17
9	F15-17, G15-17, H15-17, I15-17	15 x 20	300	3-17	155.56	3587	2935	4239	8	8.37	44,100	20
10	F18/19, G18/19, H18/19, I18/19	10 x 20	200	4-16.5	92.59	1723	1391	2058	8	8.43	26,460	12
11	F20-23, G20-23, H20-23, I20-23	20 x 20	400	2-13.5	170.37	2948	2390	3500	8	8.40	48,510	22
12	F24-26, G24-26, H24-26, I24-26	15 x 20	300	2-13.5	127.78	287	234	342	5	5.26	22,050	10
13	E27/28, F27/28	10 x 10	100	4-13	33.33	<1	<1	<1	1	2.09	2,205	1
14	G27/28, H27, I27	Figure	100	4-8	14.81	<1	<1	<1	1	4.58	2,205	1
15	H2-4, I2-4, J2-4, K2-4	15 x 20	300	4-14	111.11	21	18	24	2	2.49	8,820	4
16	H5/6, I5/6, J5/6, K5-6	10 x 20	200	3.5-13.5	74.07	34	30	38	2	2.80	6,615	3
17	H7/8, I7/8, J7-9, K7-9	Figure	250	2.5-10	69.44	35	32	41	2	2.00	4,410	2
								1164	7	6.97	37,485	17
								10772	8	8.08	72,765	33
								6432	8	7.90	74,970	34
								1400	7	7.05	41,895	19
								156	3	3.23	15,435	7
								19	2	1.98	4,410	2
								2	2	2.67	4,410	2
								23	2	2.23	11,025	5

Table 2. Permanganate TOD (48 hour) Results.

Sample	Dosage g/kg	TOD g/kg
TS-1 (1'-10')	34.74	21.0
TS-1 (10'-15')	10.47	9.29
TS-2 (0'-10')	34.83	24.8
TS-2 (10'-15')	34.71	27.6

Case Study II : Former Gas Station – *Charleston, South Carolina*



10 Monitoring Wells

Free Product Present Near USTs

Benzene at **4,600 ug/L** 100' North of USTs

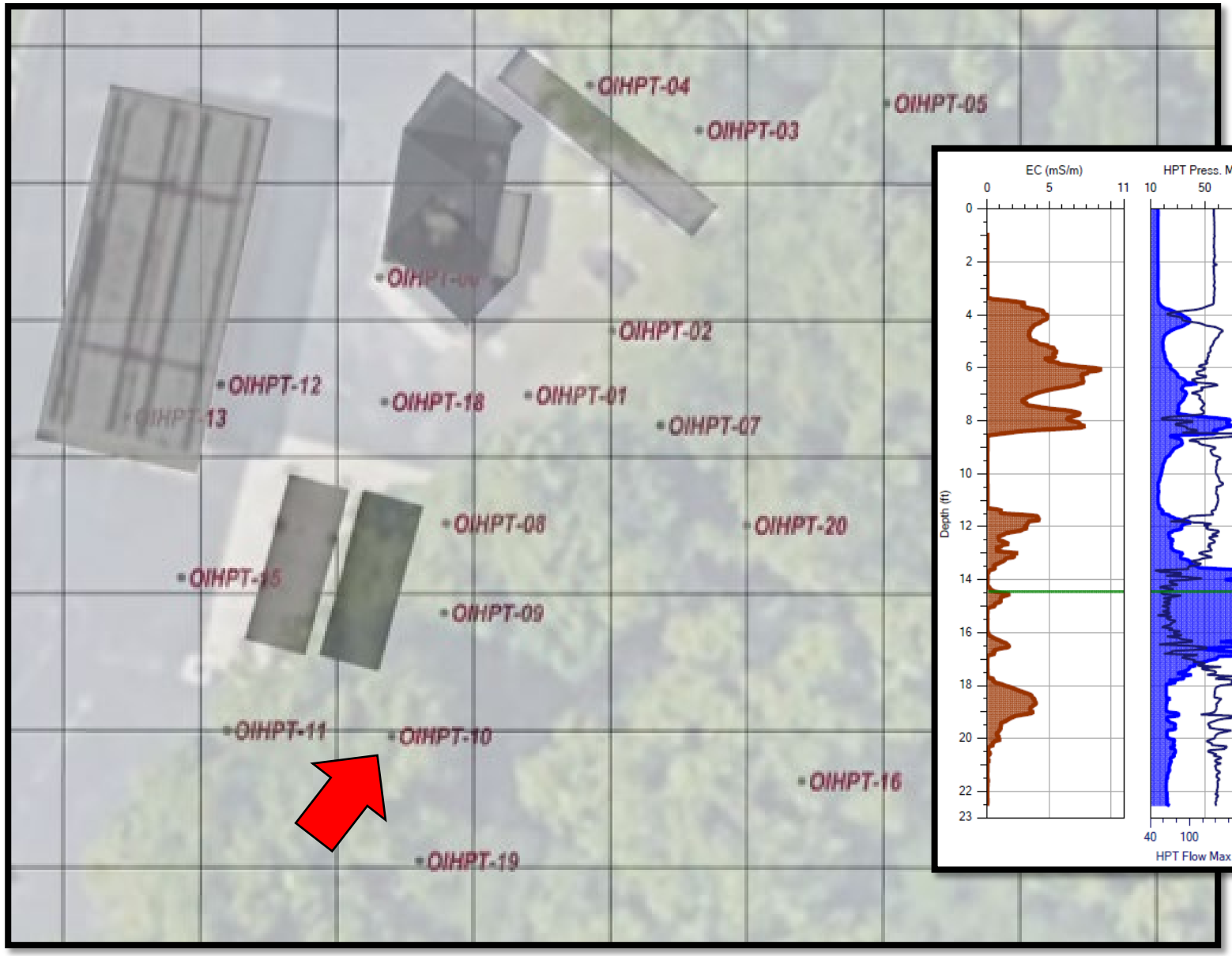
Benzene at **870 ug/L** Near Northern Property Boundary

Steps:

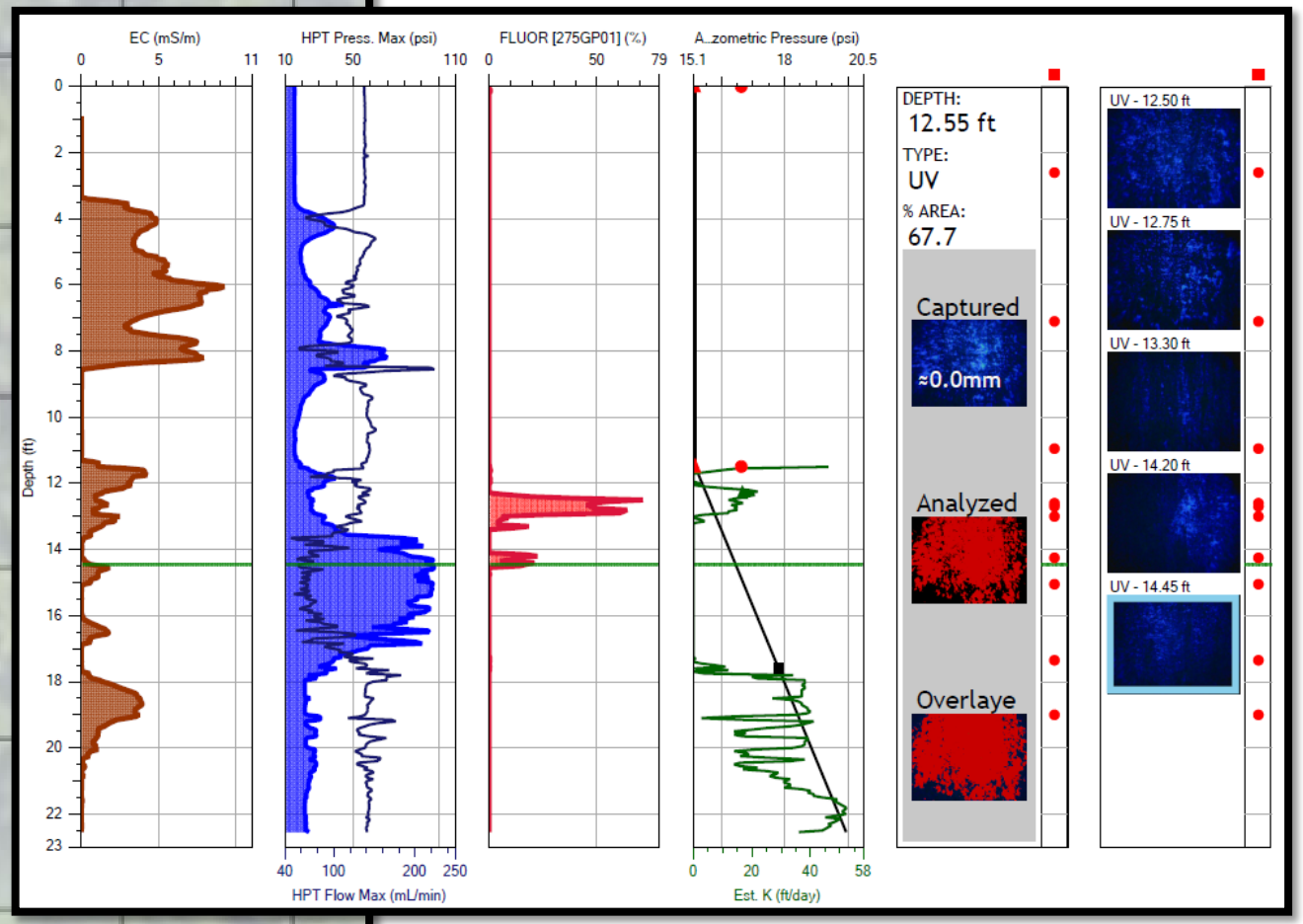
1) Delineate the LNAPL using the Optical Image Profiler / Hydraulic Profiling Tool (OIHPT)

2) Identify the subsurface plume in groundwater using the combined Membrane Interface Probe / Hydraulic Profiling Tool (MiHPT)

3) Evaluate and propose remedial options

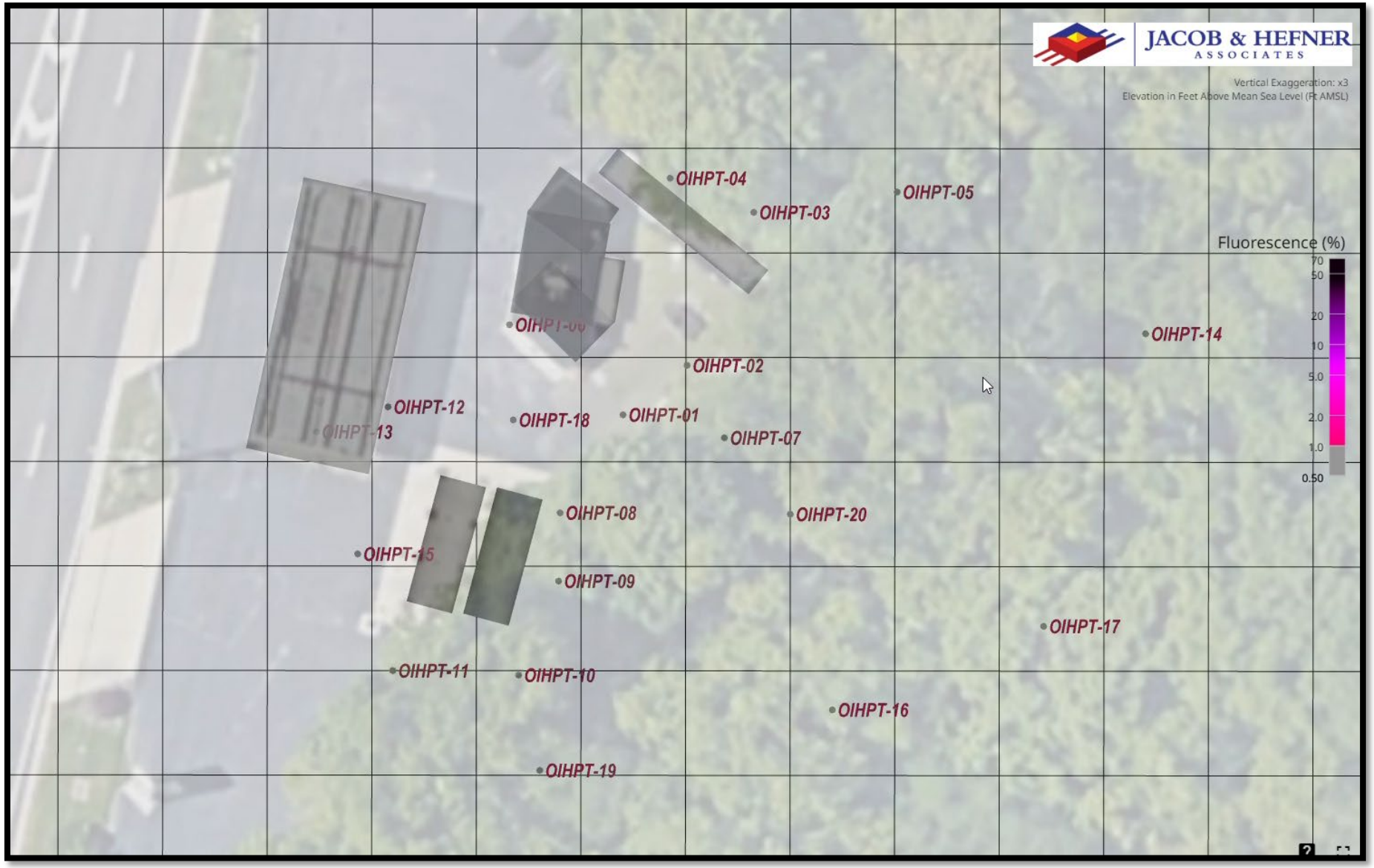


OIP Boring Location Map

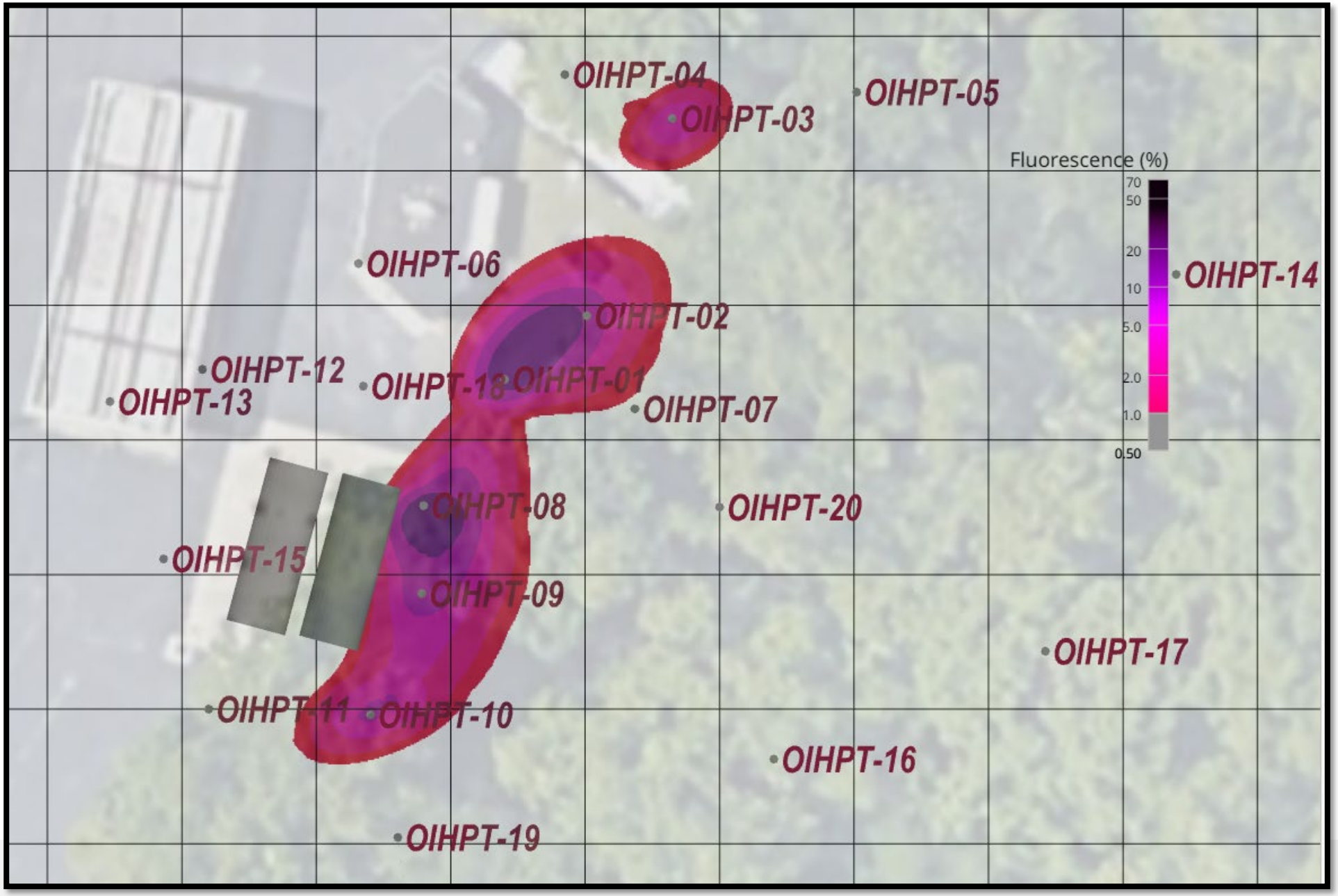


Example Log – OIHPT-10

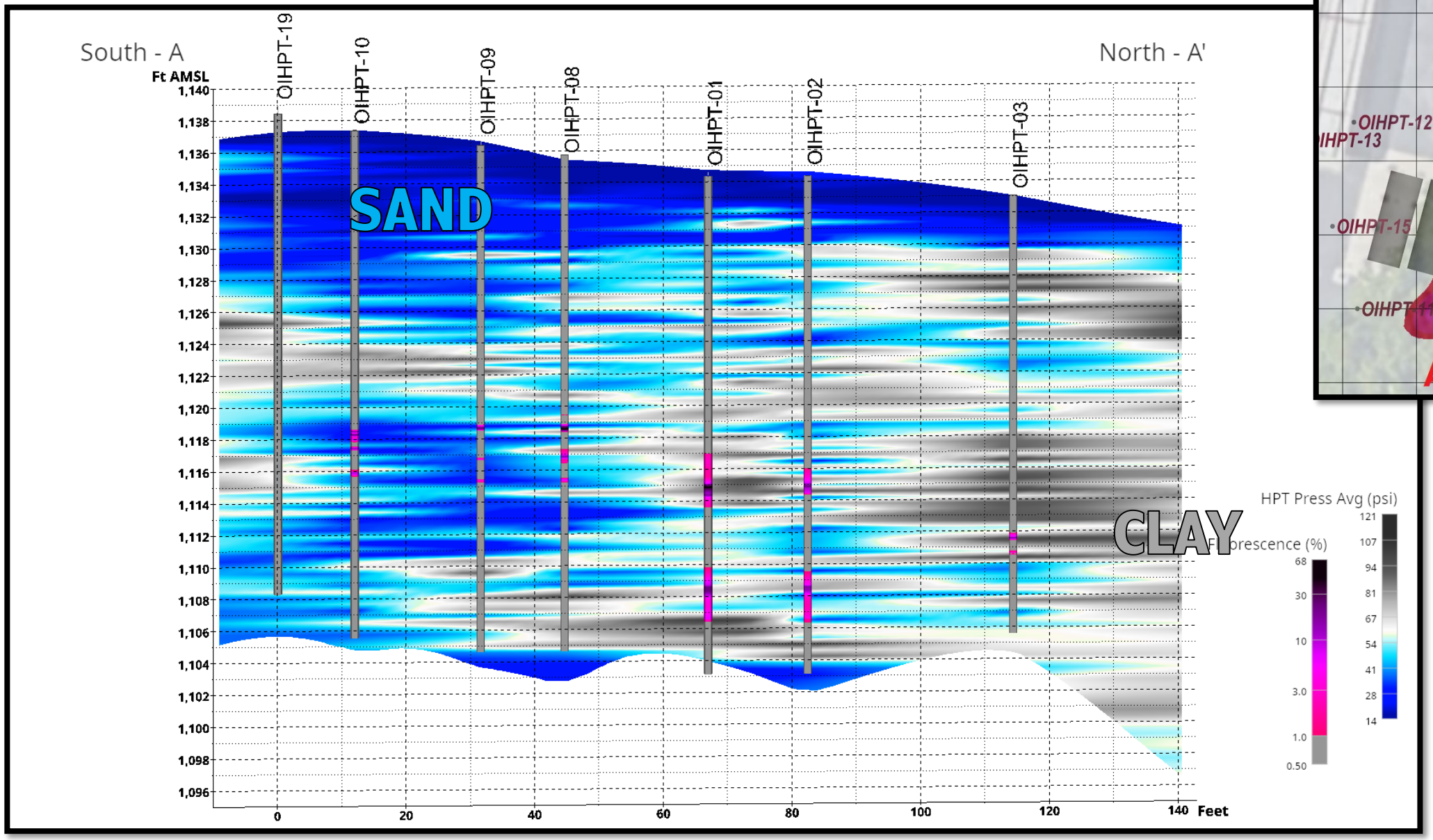
Optical Image Profiler (OIP) Investigation

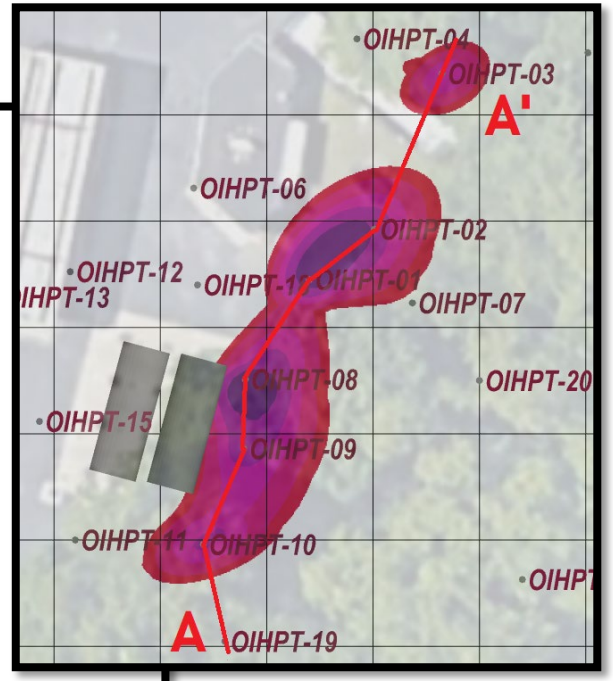


Optical Image Profiler (OIP) – Map of the LNAPL

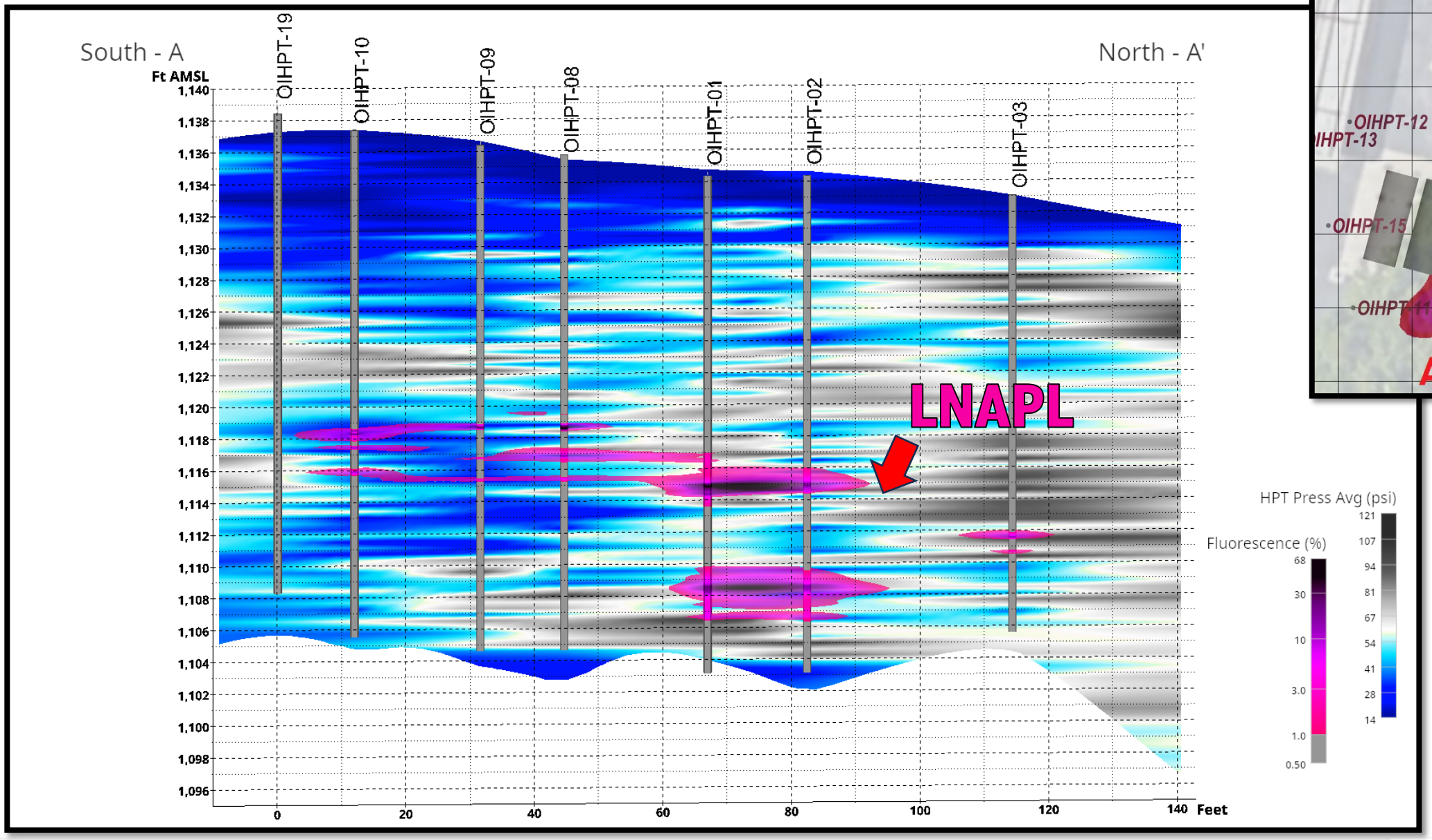


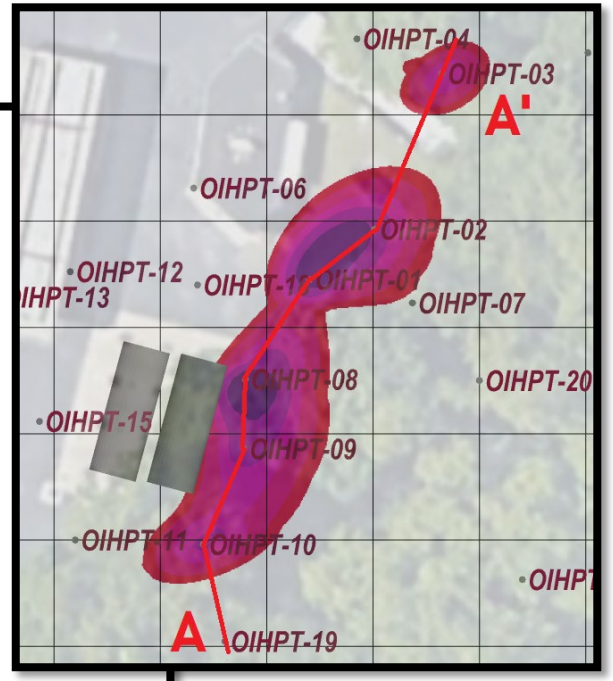
Optical Image Profiler (OIP) – Cross Section





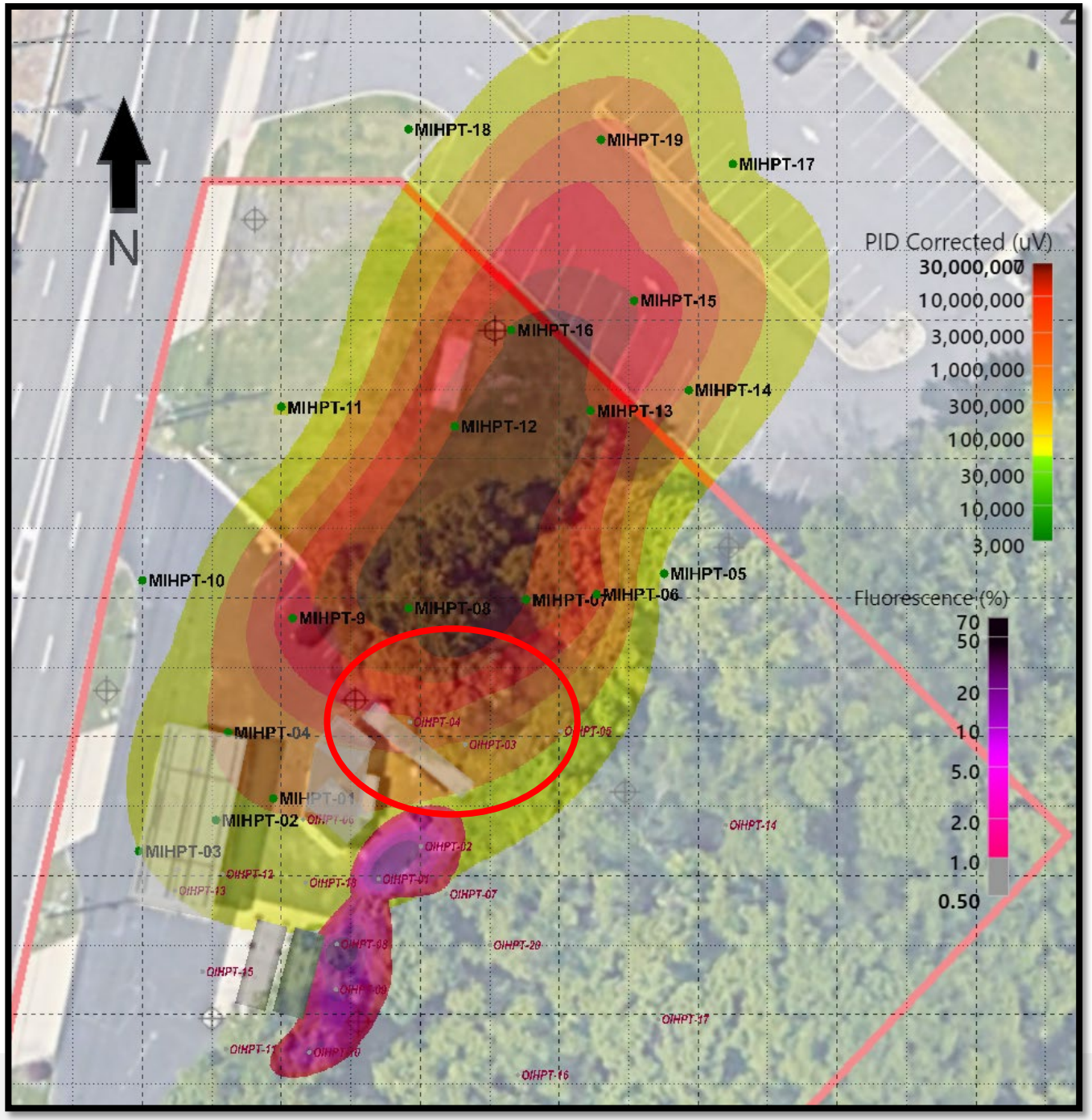
Optical Image Profiler (OIP) – Cross Section





Membrane Interface Probe (MIP) Investigation

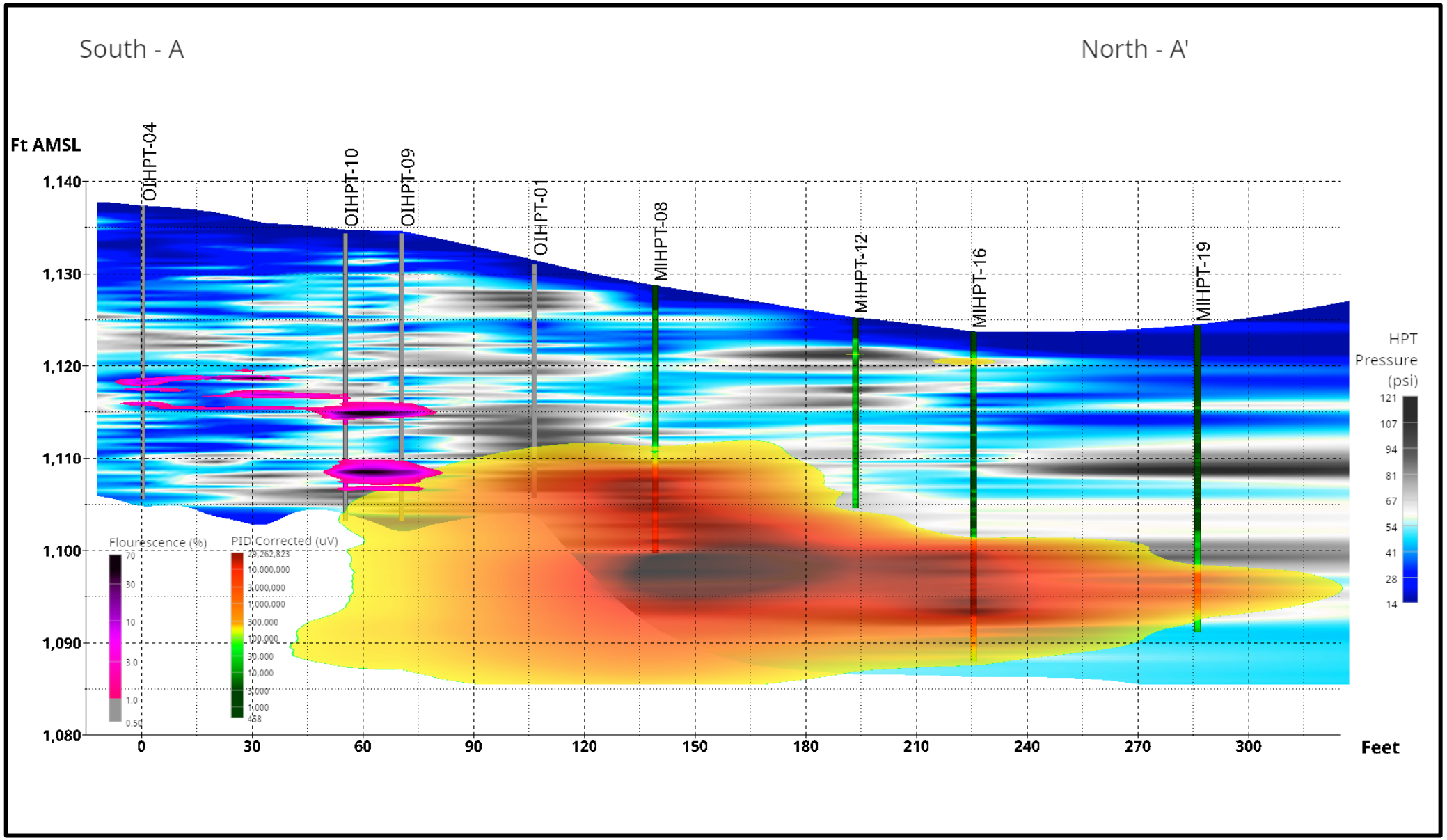
Map of the Dissolved and Sorbed Impacts



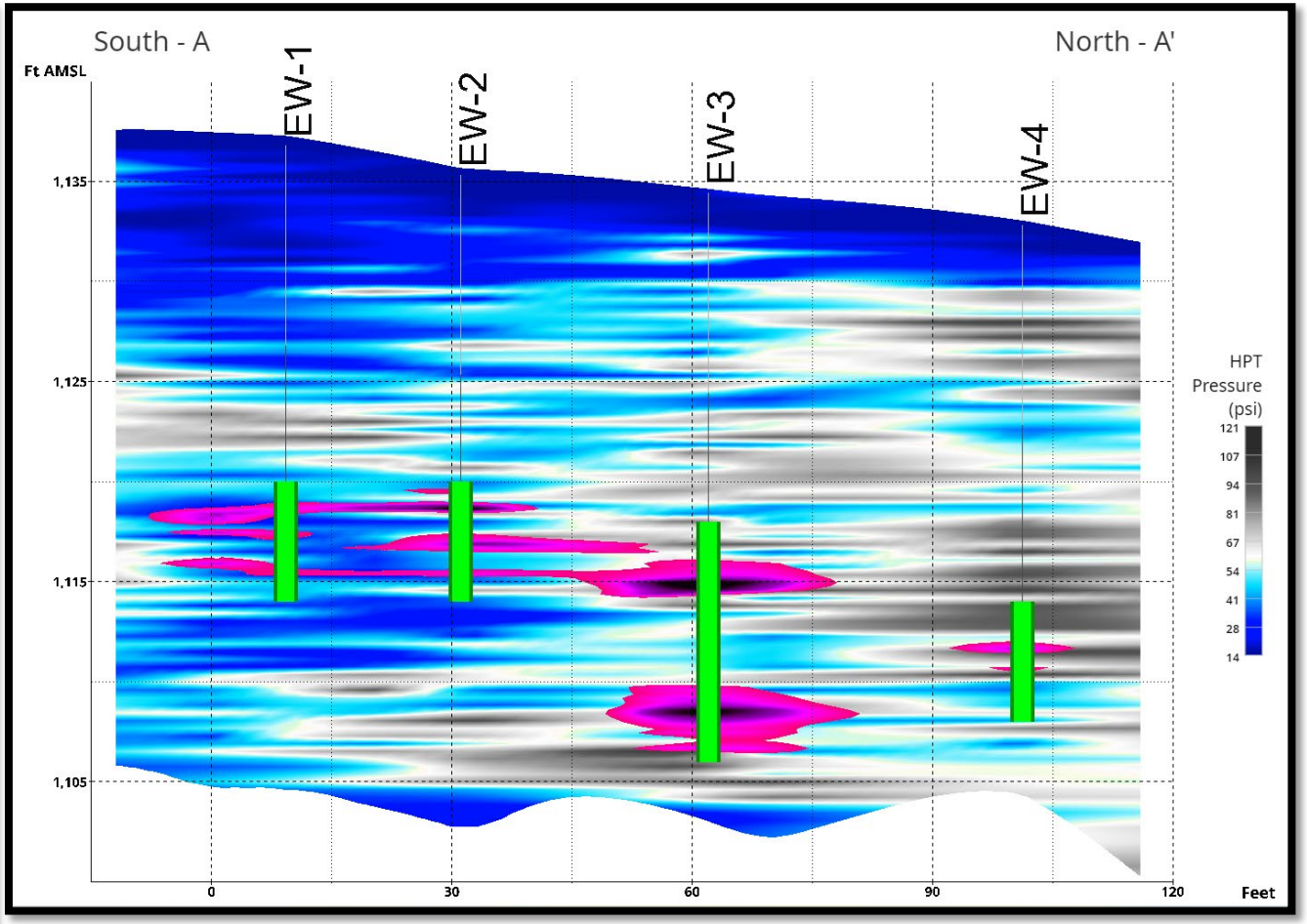
Note:

MiHPT Borings Not Performed Here Due to Strong Likelihood of High Impacts

Combined Cross Section



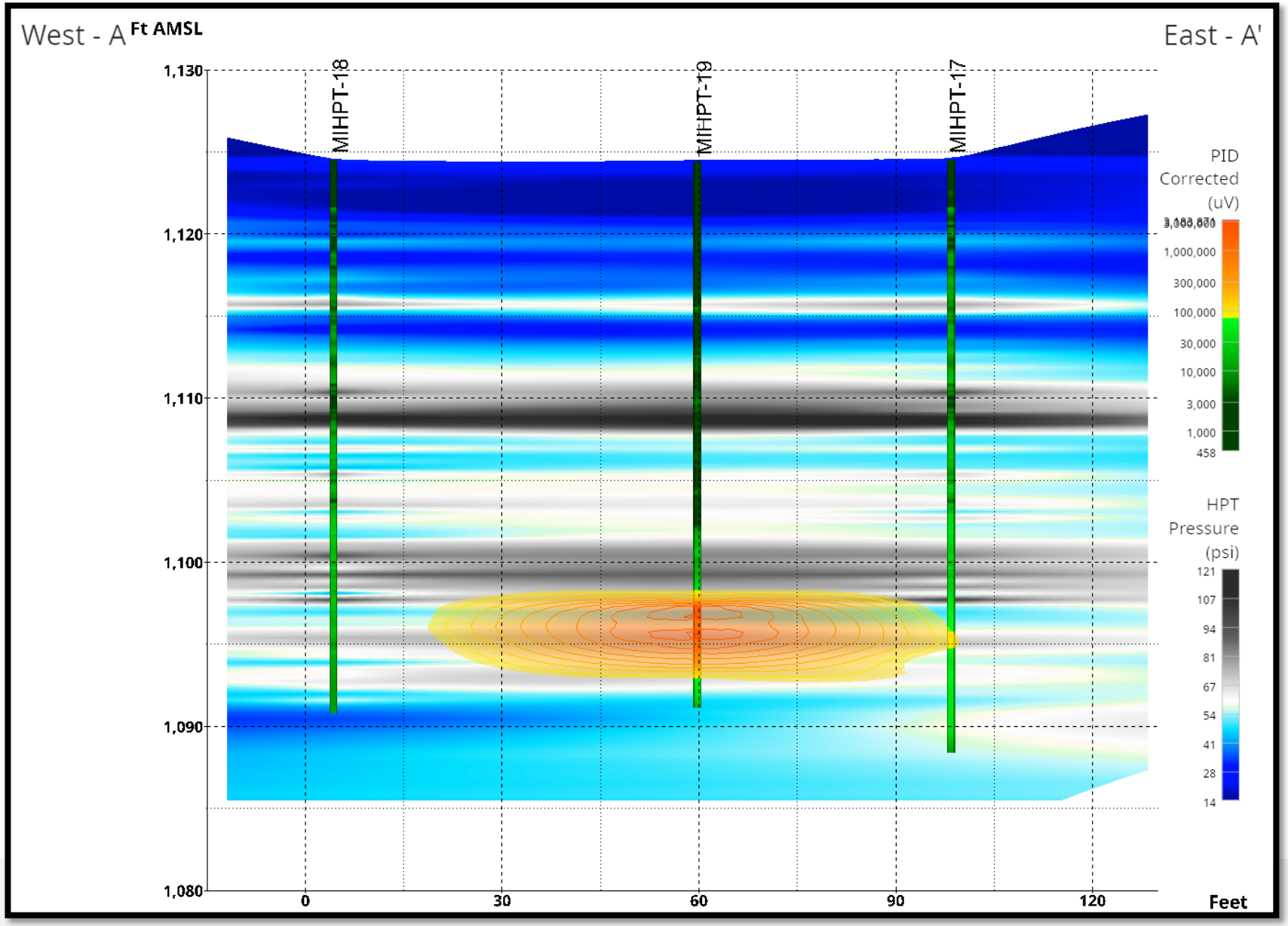
Source Area: Optimize the Placement of Extraction/Injection Wells or ORC Socks

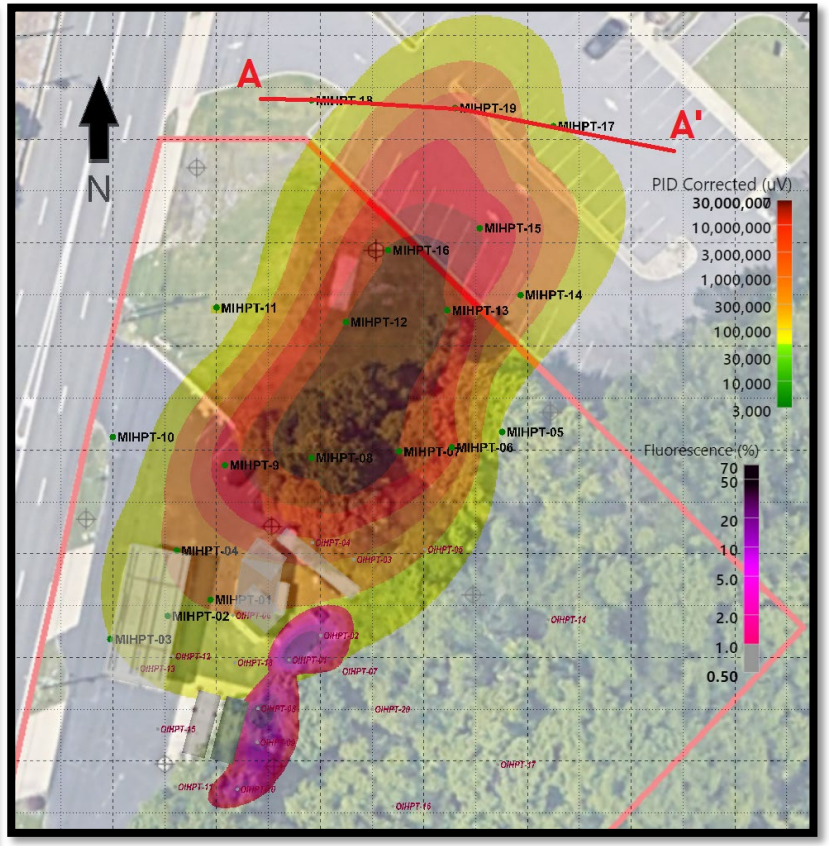


CROSS SECTION VIEW

PLAN VIEW

Downgradient Plume in Groundwater

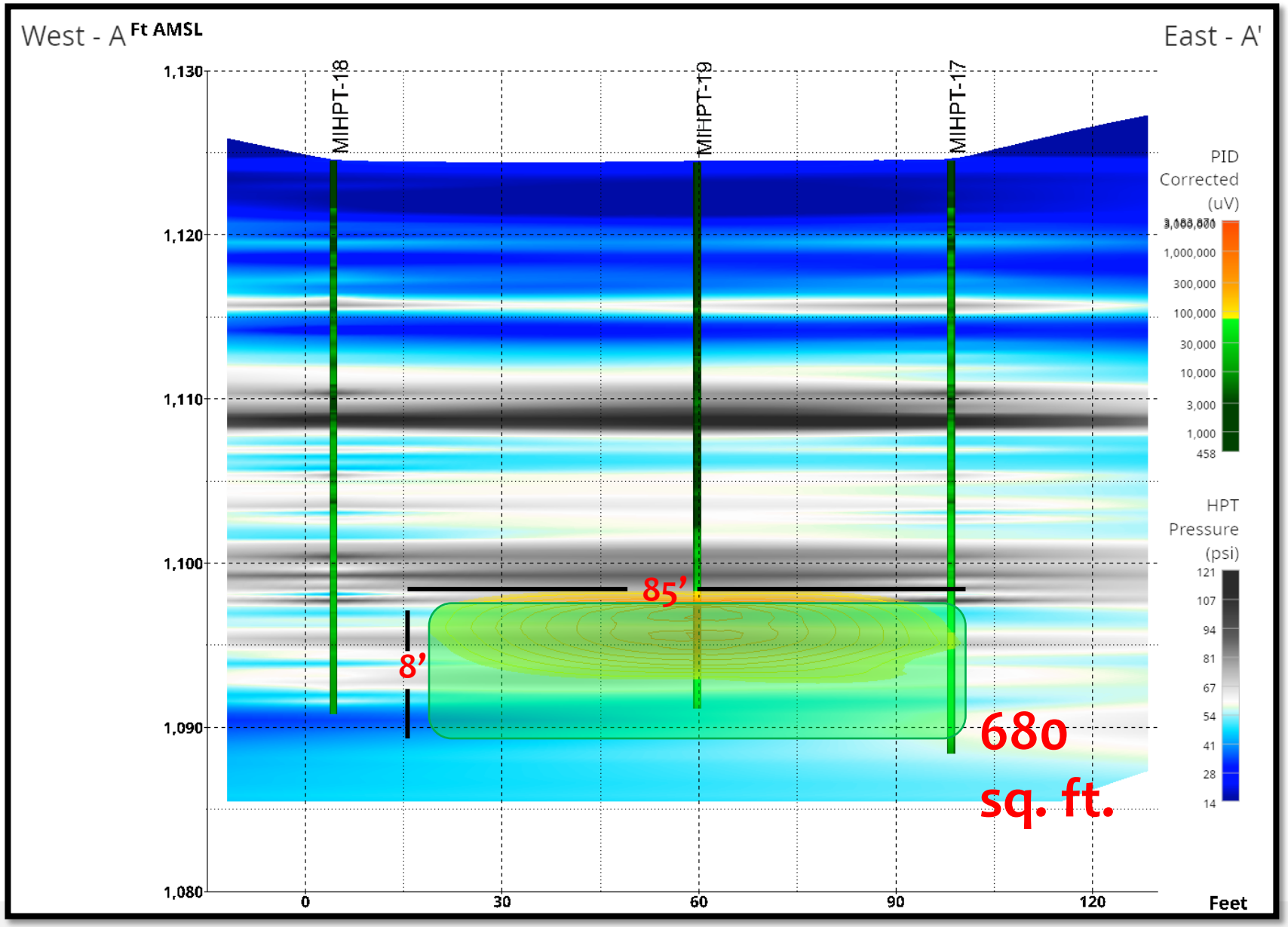


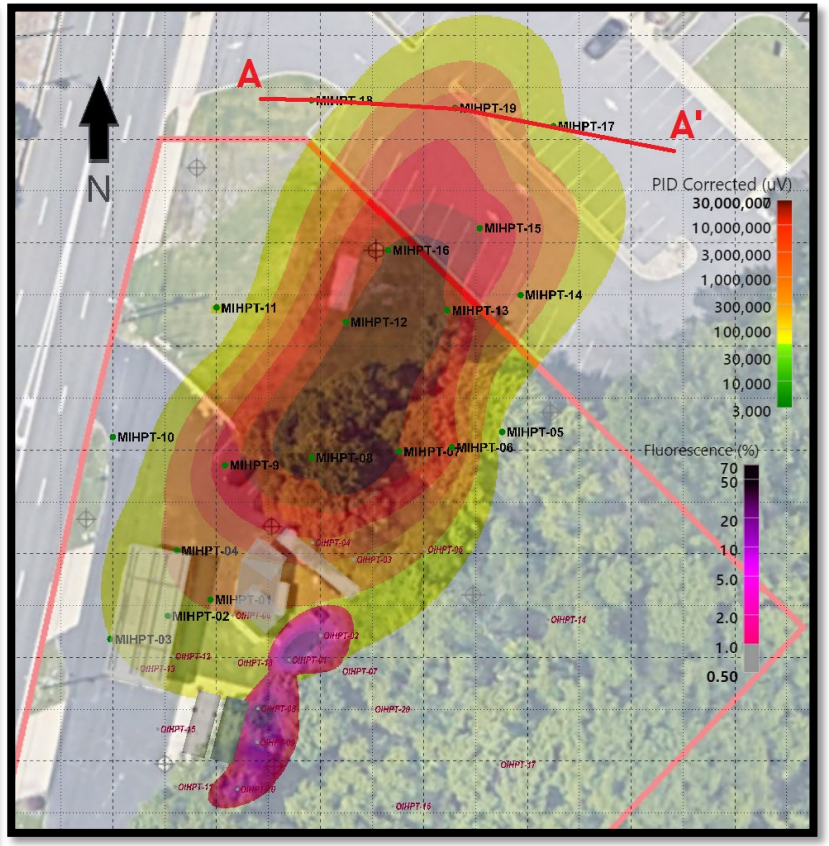


PLAN VIEW

CROSS SECTION VIEW

Permeable Reactive Barrier (PRB) the Treat Downgradient Plume in Groundwater





PLAN VIEW

CROSS SECTION VIEW

Lessons Learned

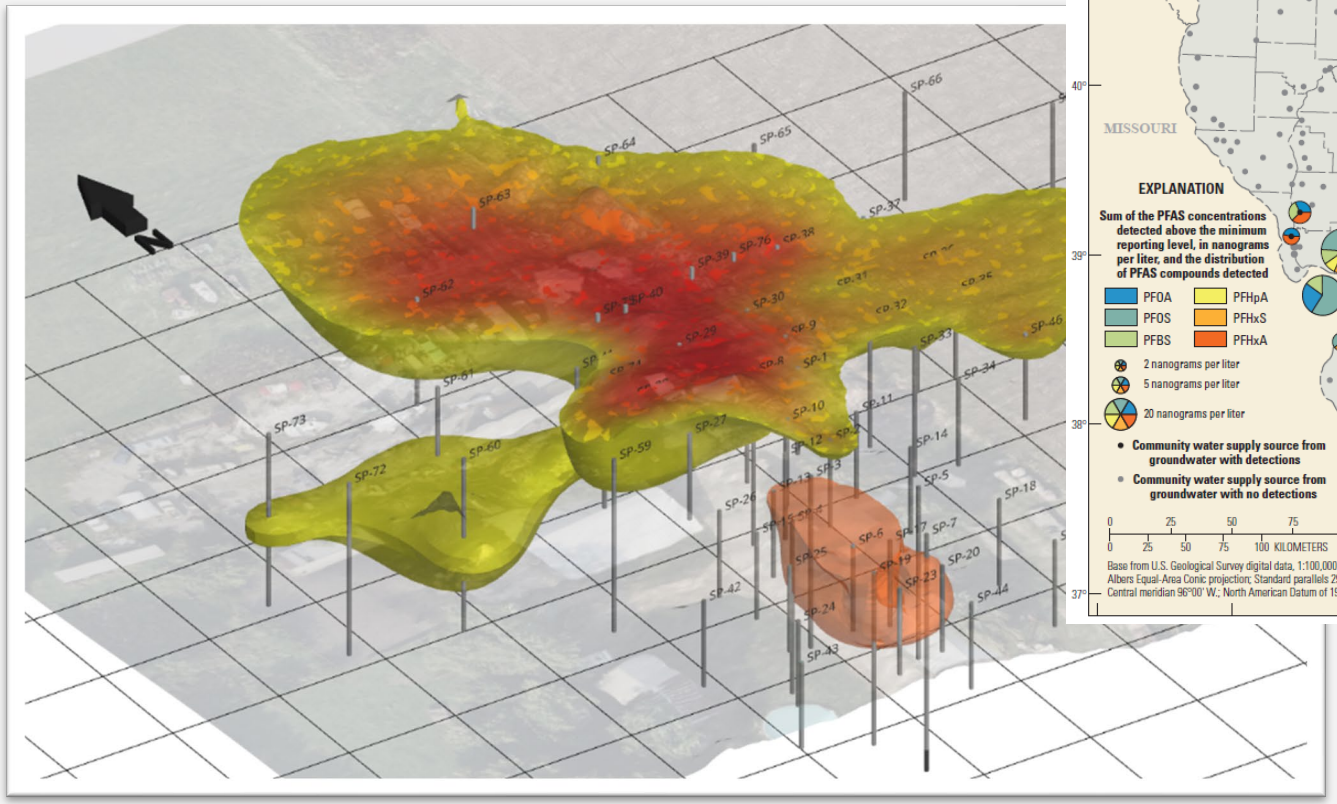
1) Utilize HRSC Tools
   - OIP for LNAPL
   - MIP for Sorbed and Dissolved Phase

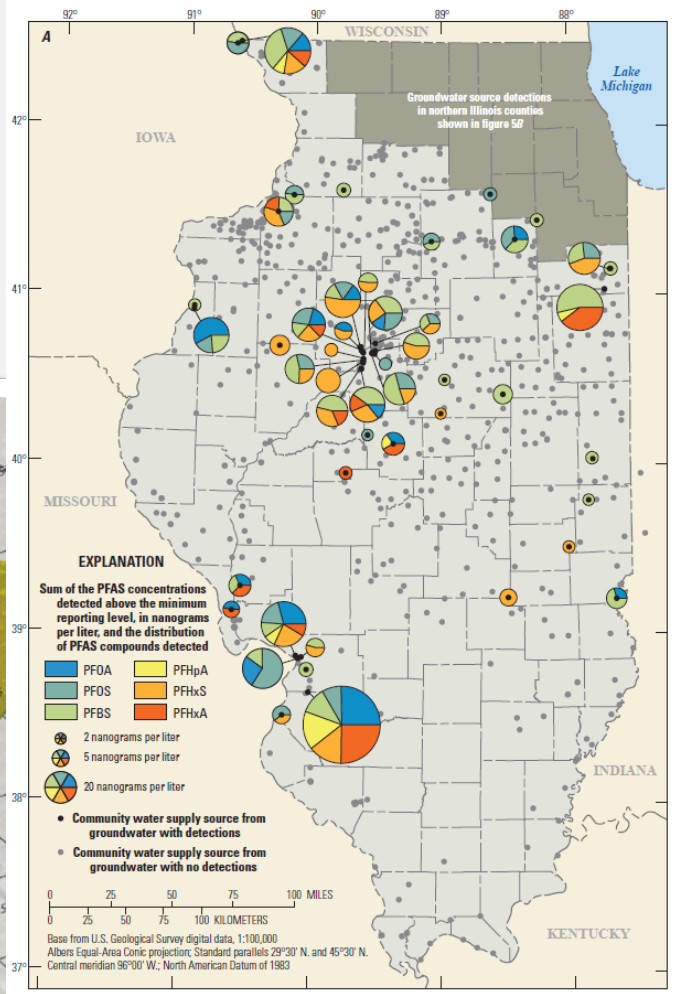
2) Use 3D Statistical Modeling
   - Delineation of Impacts
   - Optimize Remedial Design

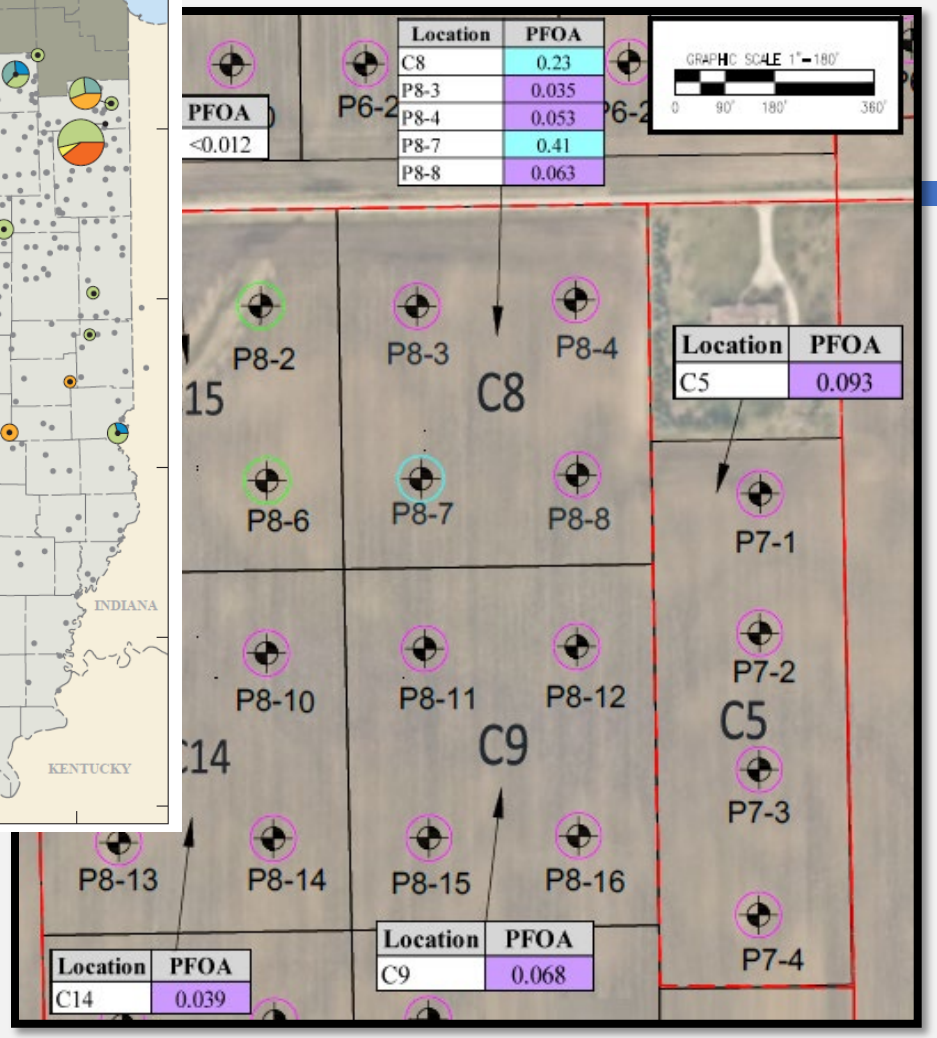
3) Leverage Biodegradation to Reduce Remedial Costs

PFAS IN REAL ESTATE TRANSACTIONS

Two Case Studies from Illinois







Location	PFOA
C8	0.23
P8-3	0.035
P8-4	0.053
P8-7	0.41
P8-8	0.063

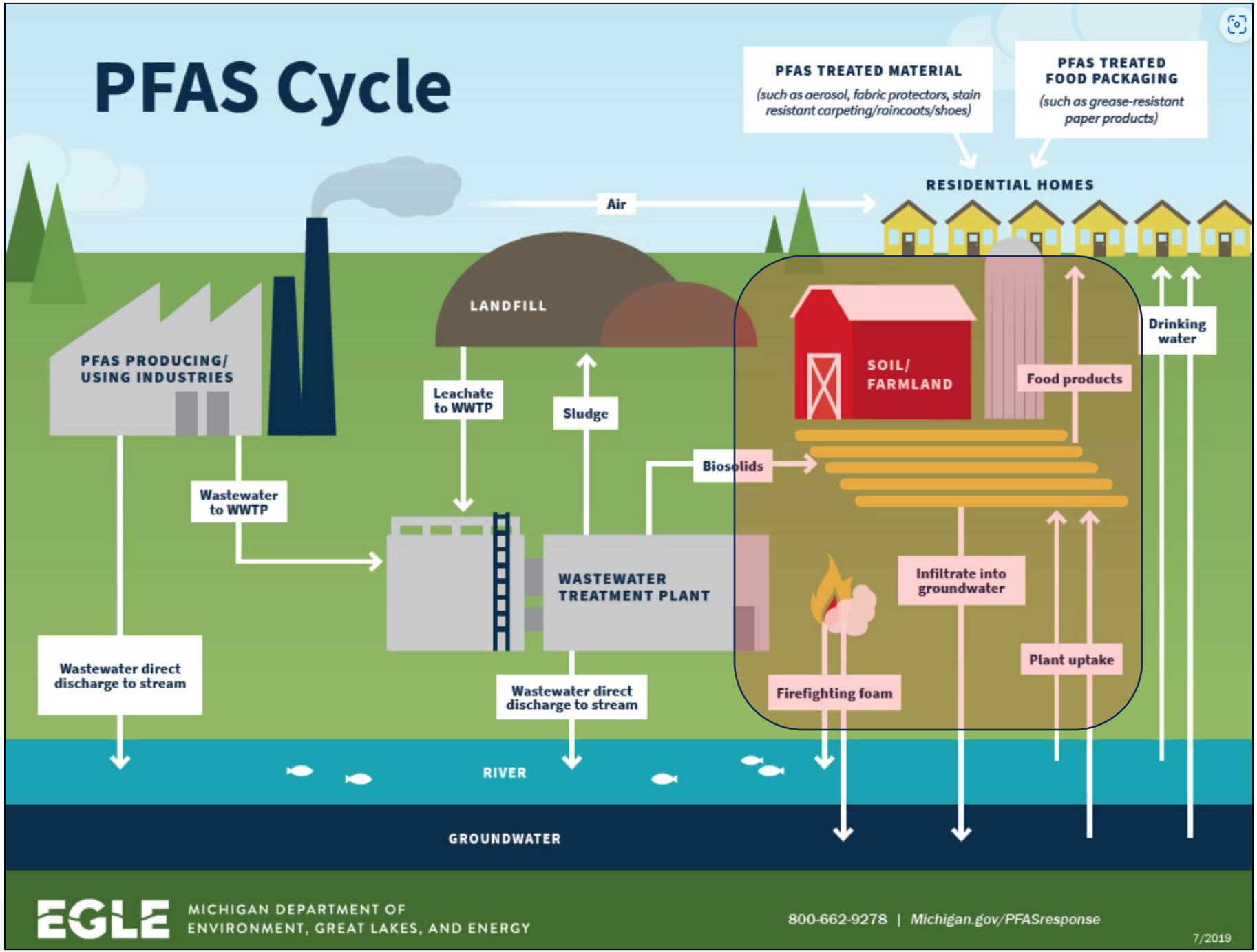
Location	PFOA
C5	0.093

Location	PFOA
C9	0.068

Location	PFOA
C14	0.039

OVERVIEW

- PFAS in the Environment
- Recent Regulatory Highlights
  - US EPA
  - Illinois EPA
- Due-Diligence Challenges for EPs
- Case Studies
- Questions



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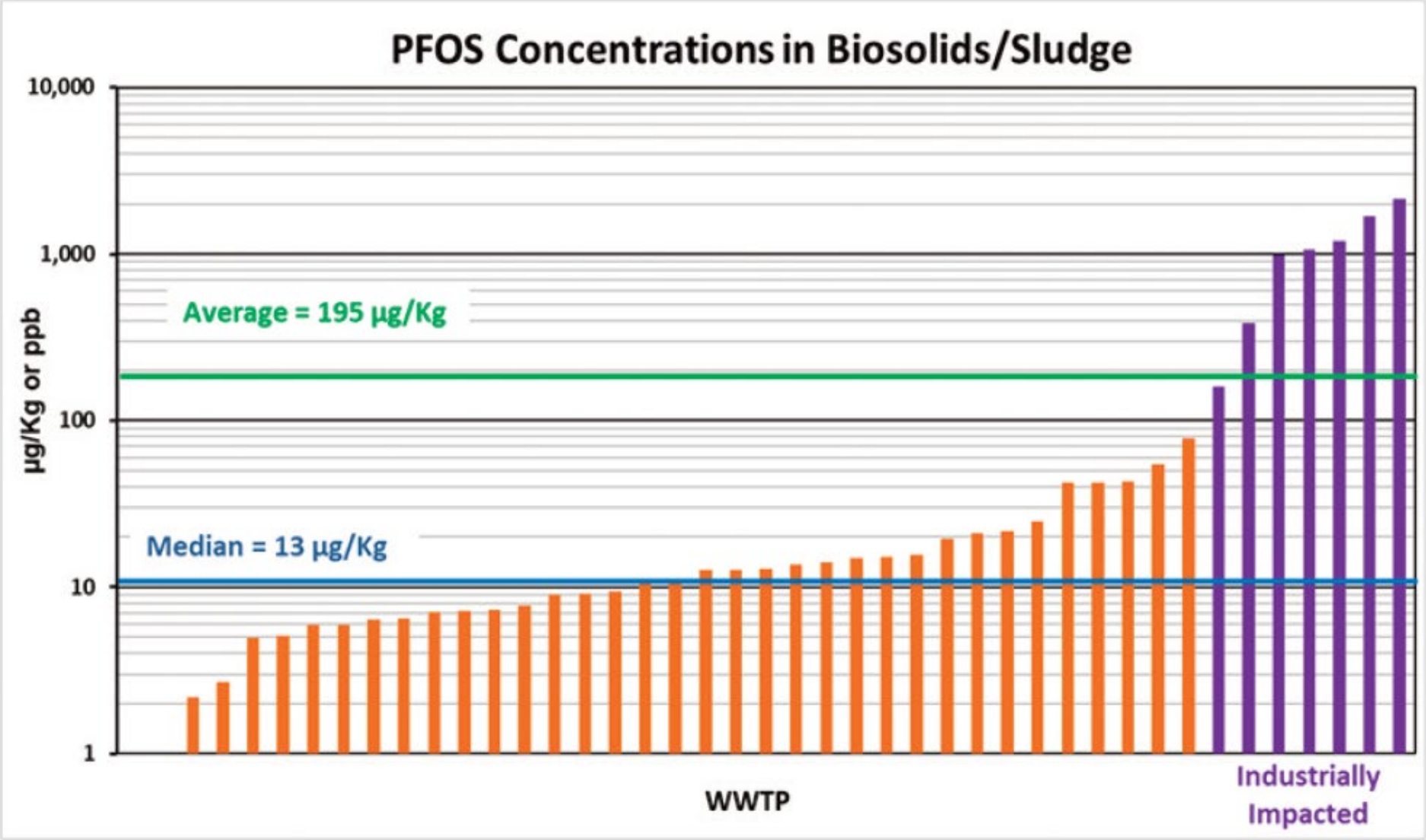
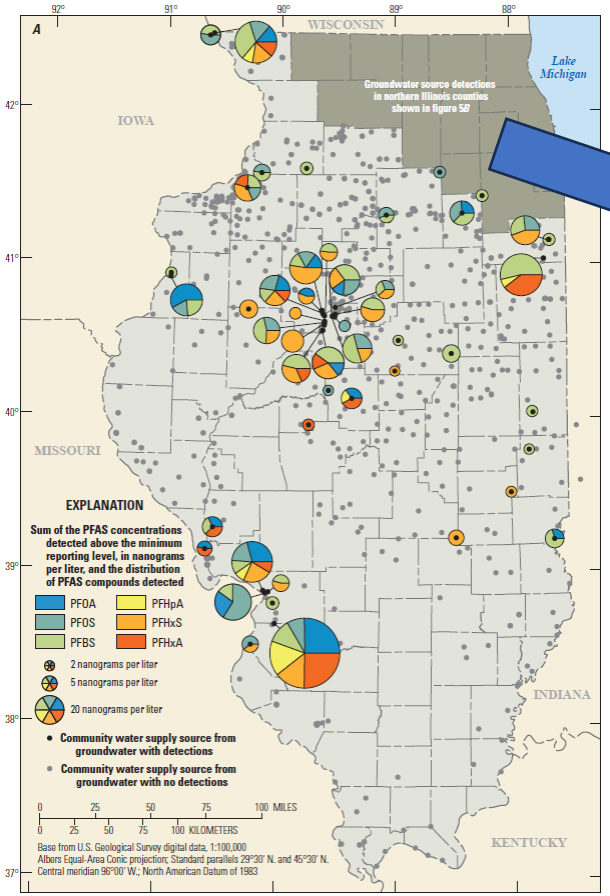
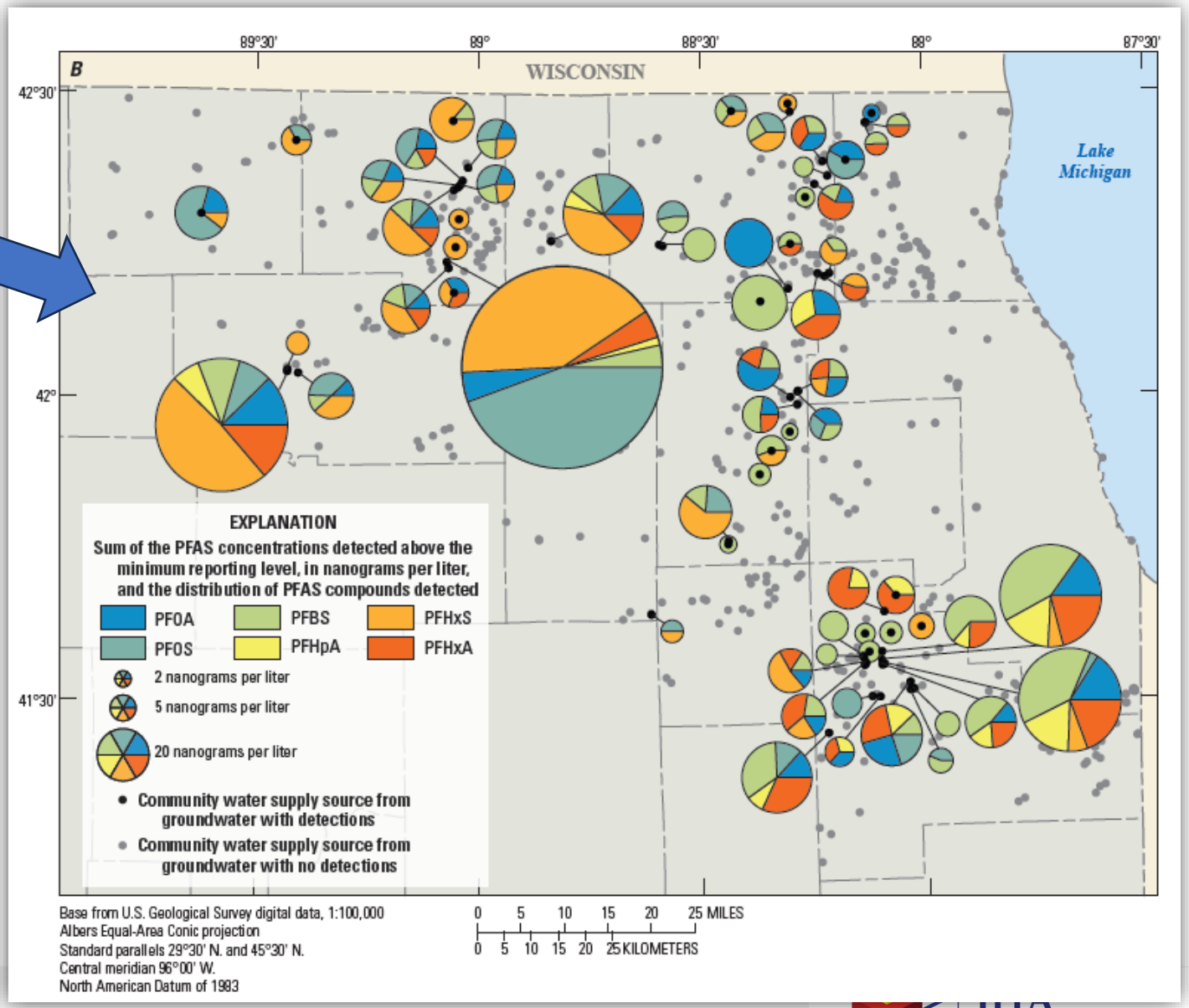
BIOSOLIDS/SLUDGE PFAS SOURCES



Source: pfas-initiatives-wastewater-sludge.pdf (michigan.gov).

PFAS in Community Supply Well Sources





- Illinois EPA PFAS Sampling Network (2020-2021)

PFAS REGULATORY HIGHLIGHTS

- US EPA
  - Designation of PFOA and PFOS as CERCLA Hazardous Substances – May 9, 2024 (effective July 8, 2024)
  - PFAS Enforcement Discretion and Settlement Policy Under CERCLA - April 2024
    - Guidance on how the US EPA will exercise enforcement discretion regarding PFAS
    - Certain protections to "Parties" from PFAS response actions or costs under CERCLA - NOT protected from civil lawsuit
- Illinois EPA
  - Updates to Part 620 GW Standards – 6 PFAS compounds, approval pending
  - Part 742 (TACO) to be updated with PFAS – Date TBD???
  - In the interim, non-TACO screening levels developed (May 2024)

Due-Diligence Challenges for EPs

JACOB & HEFNER ASSOCIATES

- How should an EP evaluate known or potential PFAS releases?
  - Prior to ASTM E1527-21
    - Not evaluated
  - After ASTM E1527-21
    - Considered as emerging contaminants under "Non-Scope Considerations"
    - Depending on User's risk tolerance, possibly considered Business Environmental Risk (BER)
  - After Recent 2024 PFOS and PFOA Haz. Designation
    - Recognized Environmental Condition (REC)
    - Are releases of other PFAS compounds considered BERs?

Case Study #1 – Suspected PFAS During Due-Diligence

- Phase I ESA - Fall 2023
- Farmstead property surrounded by soybean and corn crops
- Res. development to south, owners on shallow bedrock wells

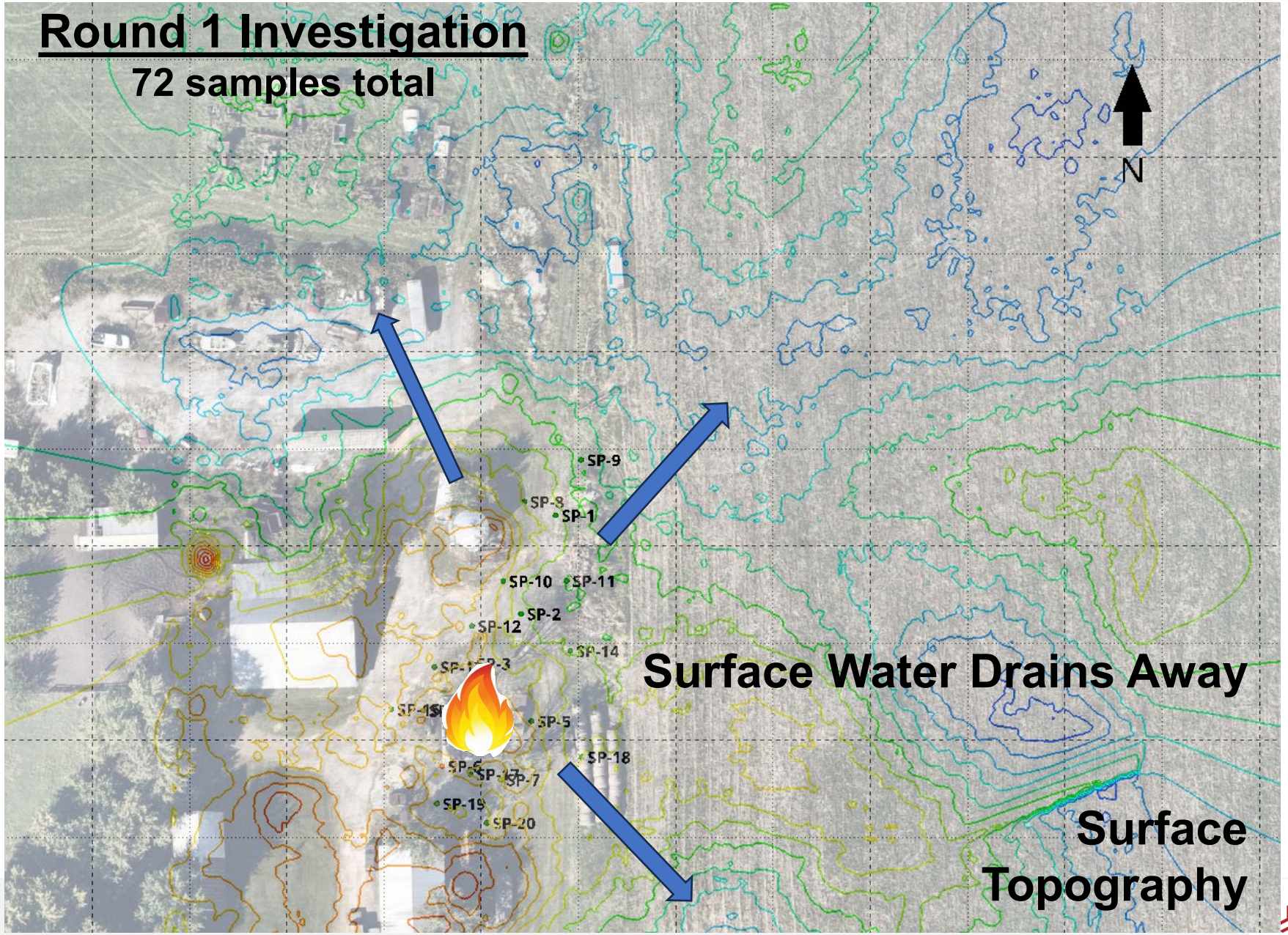
- Corn crib fire - Spring 2021
- AFFF used by FDs to mitigate fire and protect livestock
- Release identified in environmental database

JHA ENVIRONMENTAL

JACOB & HEFNER ASSOCIATES

Round 1 Investigation

72 samples total



JHA ENVIRONMENTAL

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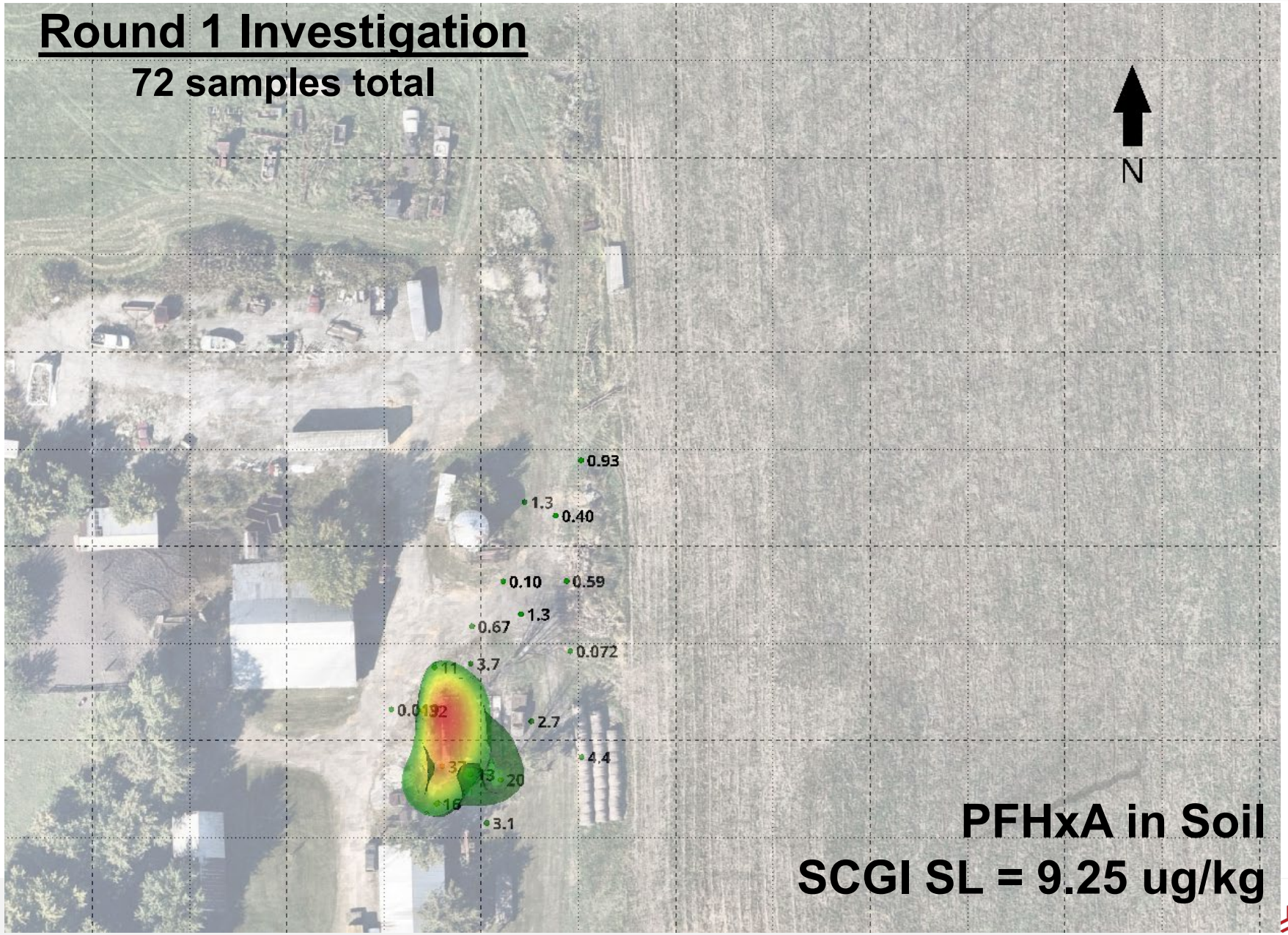
Round 1 Investigation

72 samples total



PFHxA in Soil

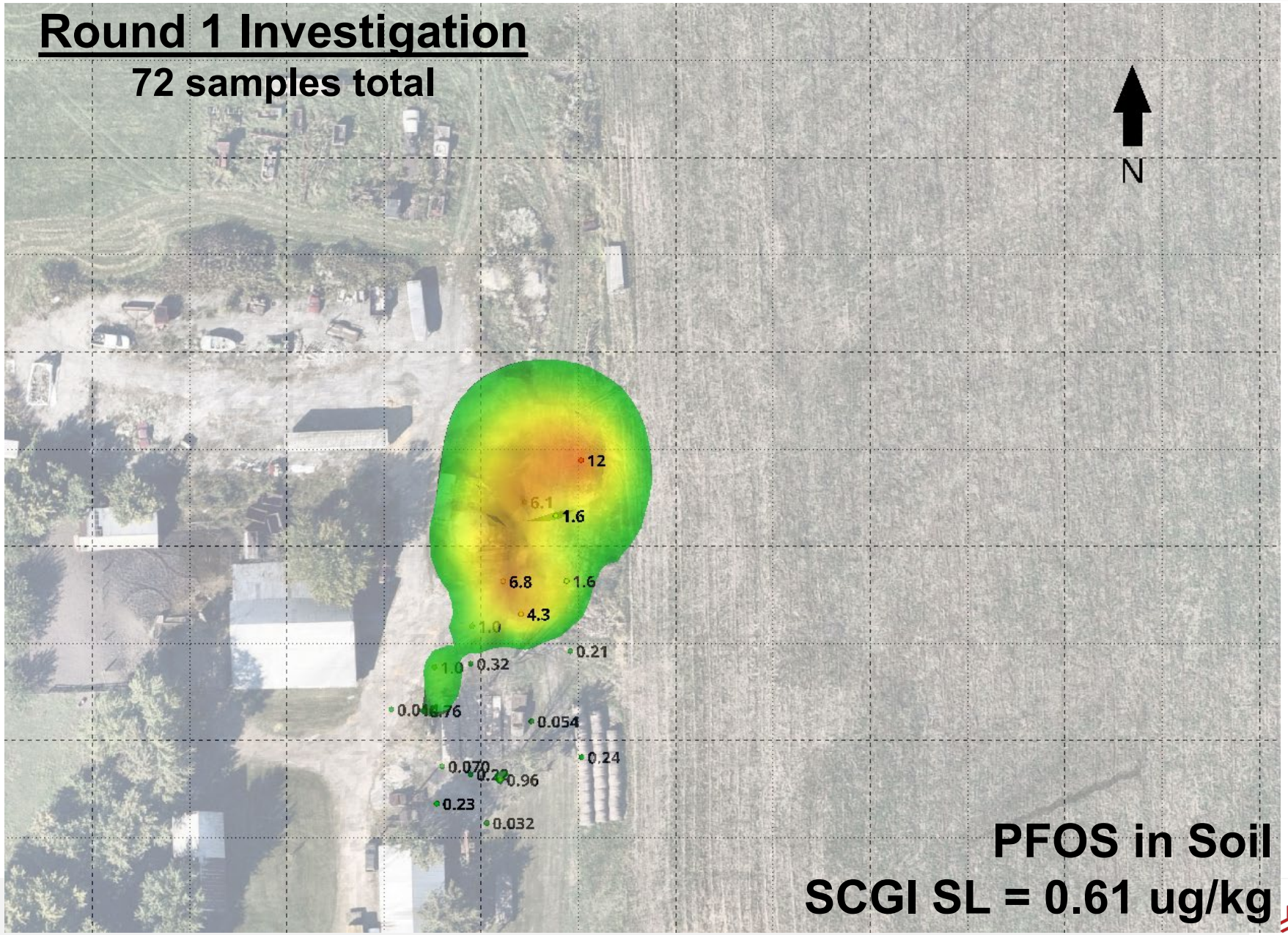
SCGI SL = 9.25 ug/kg

JHA ENVIRONMENTAL

JACOB & HEFNER ASSOCIATES

Round 1 Investigation

72 samples total



PFOS in Soil

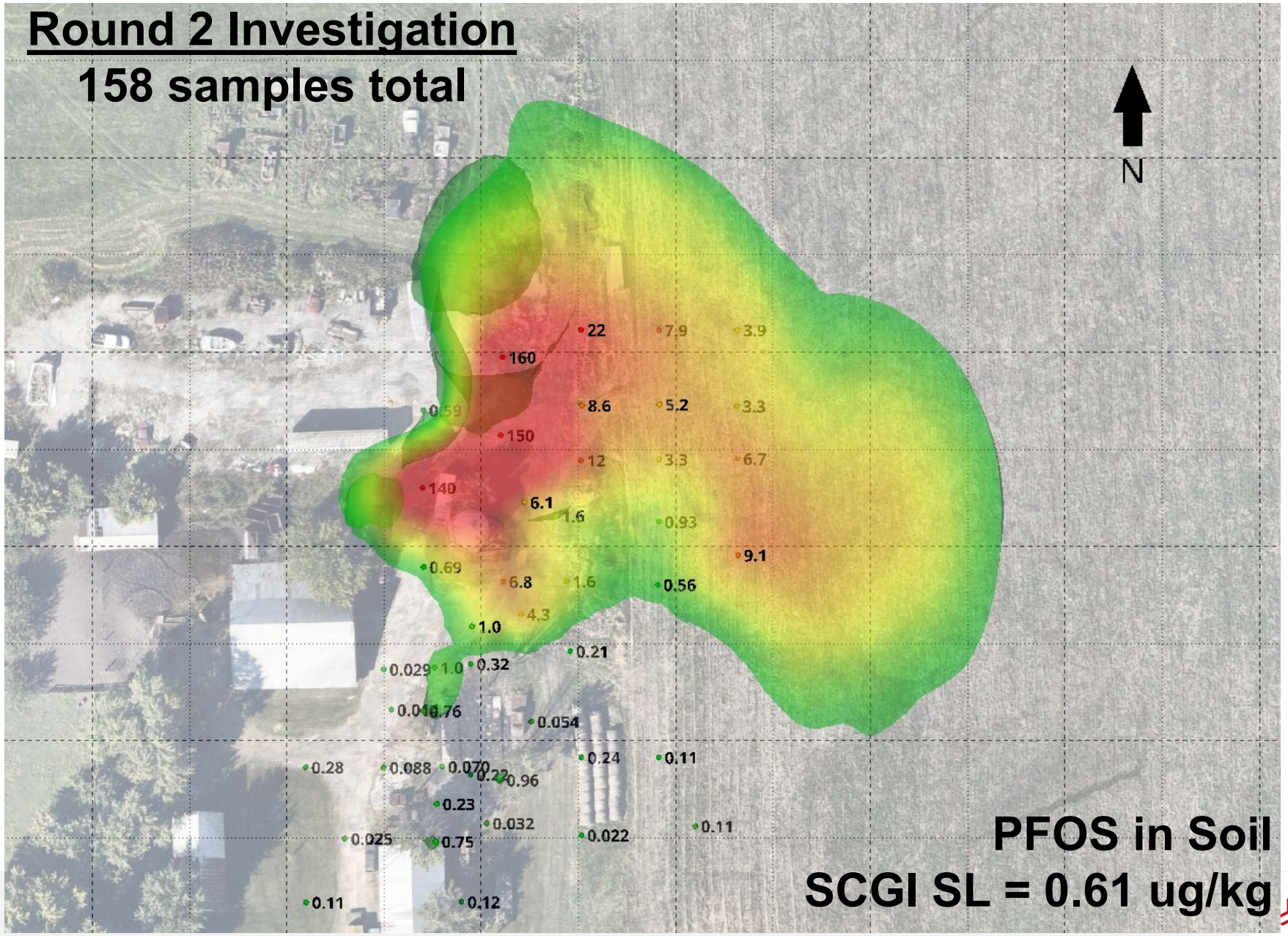
SCGI SL = 0.61 ug/kg

JHA ENVIRONMENTAL

JACOB & HEFNER ASSOCIATES

Round 2 Investigation

158 samples total



PFOS in Soil

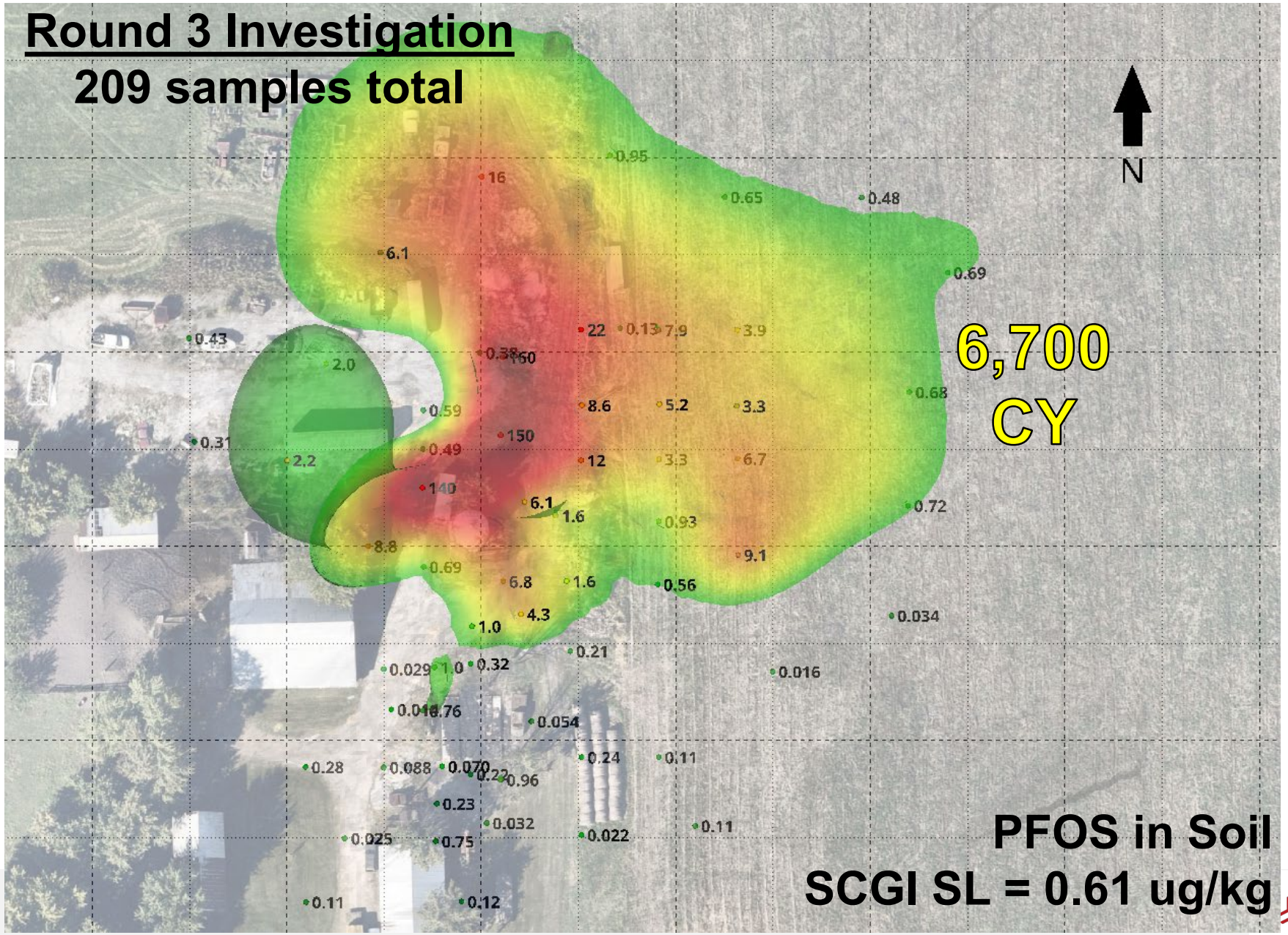
SCGI SL = 0.61 ug/kg

JHA ENVIRONMENTAL

JACOB & HEFNER ASSOCIATES

Round 3 Investigation

209 samples total



PFOS in Soil

SCGI SL = 0.61 ug/kg

JHA ENVIRONMENTAL

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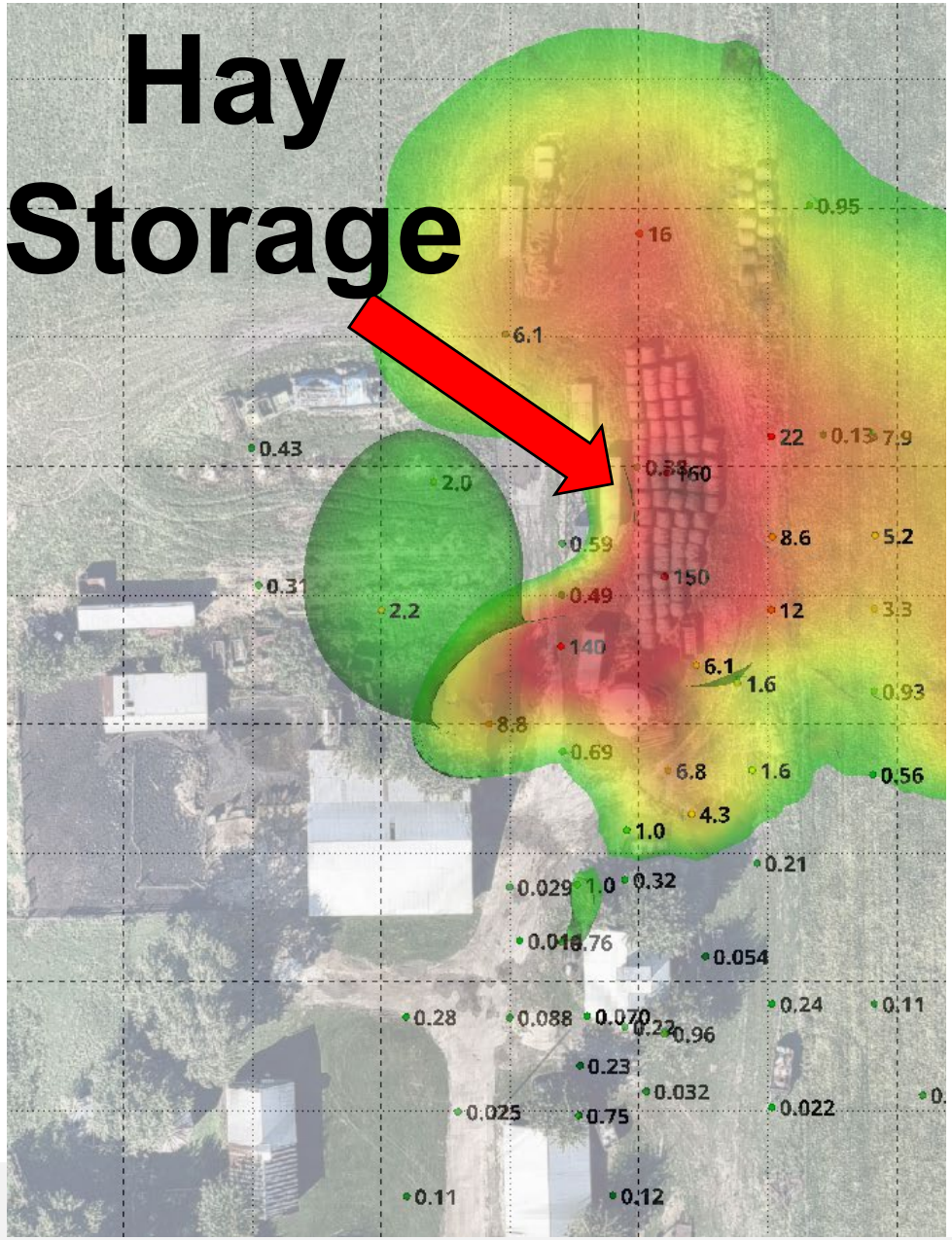
Hay Storage



Recommendations to Farmers Managing PFAS Risks: HAY

Hay can become contaminated from PFAS in soil. To assess potential contamination and the risk for exposure to livestock, it's important to understand current action levels applicable to milk and beef, soil screening levels, and the importance of characterizing your fields and tracking your hay lots. Please contact Pfas.dacf@maine.gov to learn more.

Beef and milk are currently regulated for PFOS contamination in Maine. Beef and milk have action levels above which the products cannot be sold. The action level for beef is 3.4 parts per billion (ppb) PFOS. The action level for cow milk is 210 parts per trillion (ppt) PFOS. Notice the difference in units for milk. **Please be advised that these action levels may be lowered in the future and may include additional PFAS compounds.**

Soil screening levels are under development. If soils are "ND" or non-detect for PFOS, plants and animals should not take up detectable concentrations from consuming feed grown on these soils. If soil concentrations are at or below 6.8 ppb for PFOS, these soils are currently considered adequate for producing forage to feed to beef animals and growing vegetables. However, special consideration must be taken if these soils are intended to grow feed for dairy animals.

For milk to be safely below the current action level, DACF encourages feeding hay that is non-detect (ND) for PFOS. Hay and pasture grown in soil with PFOS concentration of less than 6.8 ppb are still likely to contain detectable amounts of PFOS. As a result, feeding forages from these fields to lactating dairy animals should be avoided.

Corn and small grains take up less PFOS than grass and legumes. This is becoming a viable crop option for fields with higher levels of PFOS. Instead of a hay crop, farmers are growing corn silage, snaplage, or grain for cattle feed.

PFOS concentrations in livestock can be lowered by managing what is fed and when. For example, a farmer can greatly reduce the level of PFOS in beef cattle over a few months with clean feed. It is, therefore, possible for hay that contains low levels of PFOS to be used as feed during certain times of the year or for specific life stages of livestock. Please speak with a PFAS Agricultural Compliance Officer to discuss the details of a potential feeding plan for your farm.

Label your hay lots. Field soils vary in their levels of PFAS contamination, which means that the PFAS contamination in the hay harvested will vary by field. Therefore, storing your baled or wrapped hay in labeled lots is very important. If you use a bunker silo, segregate by fields if you can. Certain lots may be more appropriate for specific purposes than others.

Inform your customers. Let your customers know about the presence of PFAS compounds in your farm's soil so that they can make an informed decision about how to use your hay or silage. If they have specific questions, they can contact Maine DACF at Pfas.dacf@maine.gov

Financial support. DACF has programs available to assist producers impacted by PFAS. Please visit https://www.maine.gov/dacf/ag/pfas/index.shtml#funding to learn more.

March 2023

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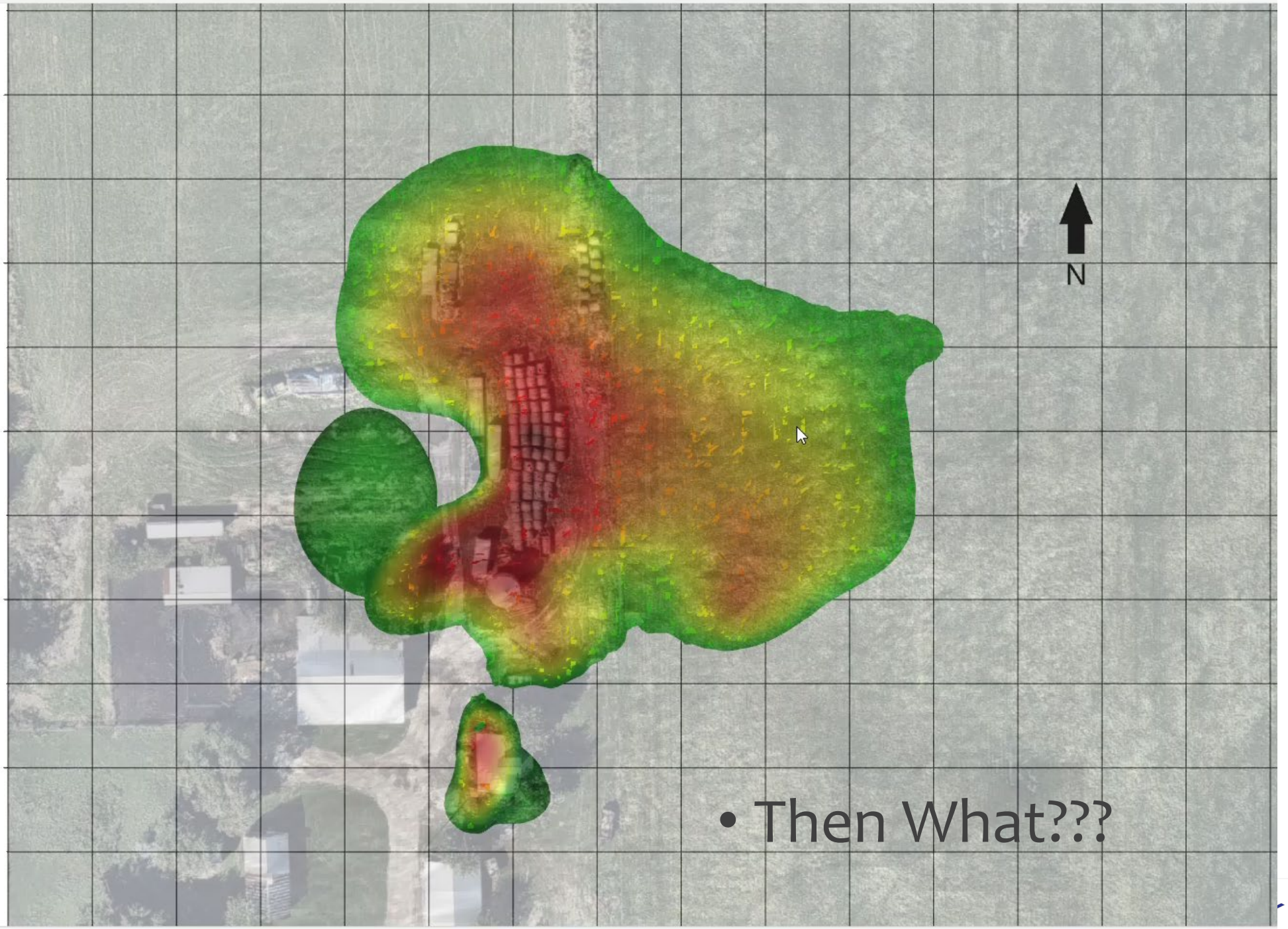

- Then What???

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What Happened?

- Further "What If" IEPA Discussion
  - Non-TACO screening levels used to evaluate data
  - Path forward to Focused NFR in SRP - same process as other COCs
  - Deeper groundwater evaluation required despite geotechnical borings showing thick clay sequence to 25 ft bgs
- Attorneys got involved and data shared with owner
- Buyer/investor's risk profile requires off-site disposal of soils exceeding non-TACO SCGI screening levels

What Happened?

- Profile approved as non-hazardous special waste at sub-title D landfill
- Estimated cost for off-site soil disposal ($85-90/ton)
  - AFFF Impacted Soils – $50,000-55,000
  - Hay Impacted Soils (extent not final) – At least $1MM
- Who pays for cleanup?
- Buyer ultimately walked from deal

Takeaways & Lessons Learned – Phase 1

- Look for hay storage or processing on OR adjacent to a property
- Evaluate historical aerials - ERIS/EDR/, Nearmap, Google Earth
- Bio-sludge applied on the hay source soils?
- Before initiating Phase II ESA, if possible, collect and analyze a sample of hay for PFAS

Takeaways & Lessons Learned - Phase 2

- Source of PFAS impacts can dictate design of sampling
  - AFFF source = denser sampling
  - Bio source = more contingency/step-out sampling

- Rather than monitoring wells, use groundwater profile sample tooling to collect discrete GW samples and identify flow zones using HPT

Takeaways & Lessons Learned - Phase 2

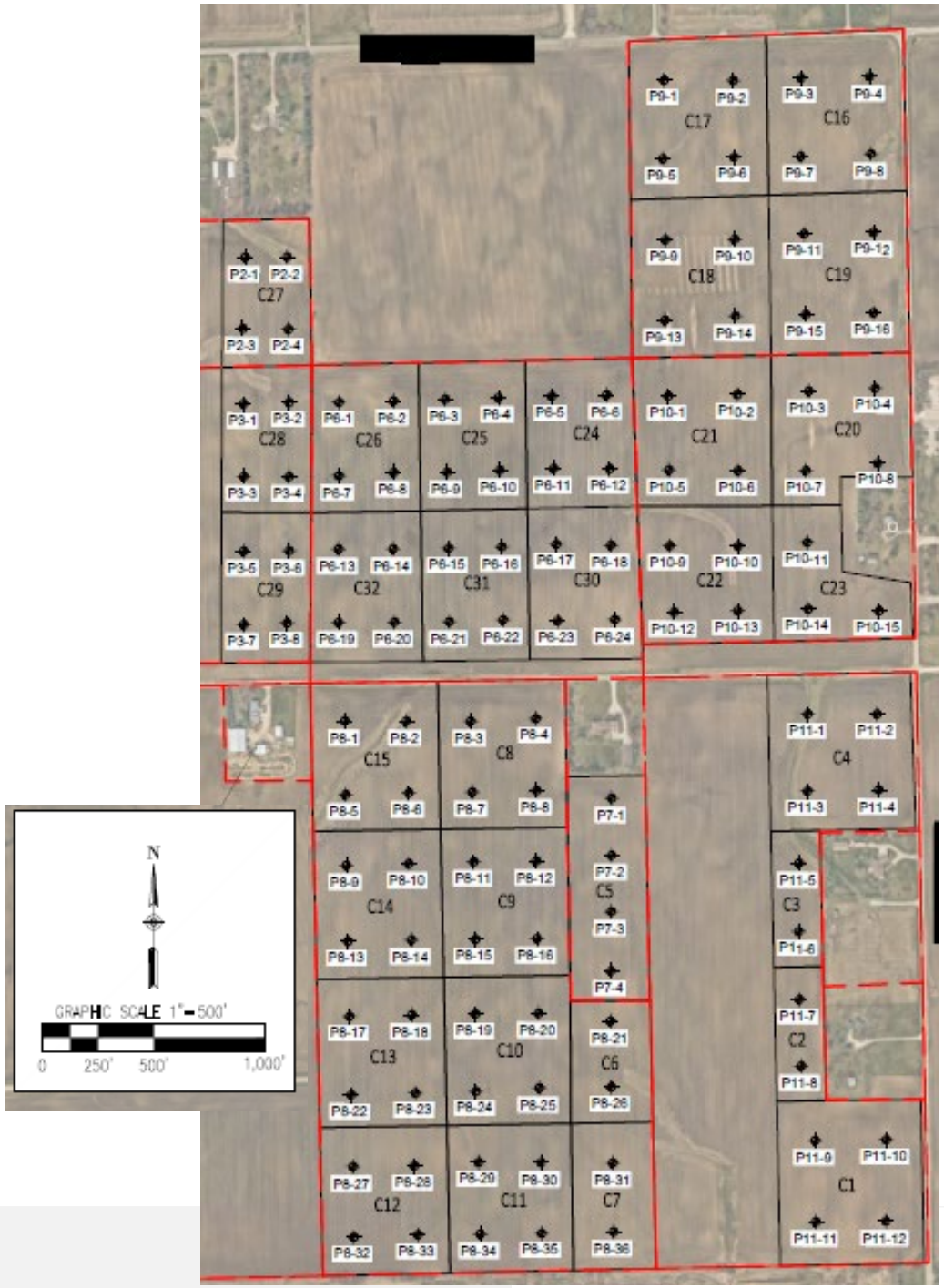
- What lab method is acceptable?
  - **ASTM D8421/8327** - faster TAT and lower price, IEPA had approved for project)
  - **Method 1633** (approved by US EPA in January 2024 for all matrices)
- Are there soil standards established to screen against data?
- Consider running leach testing (SPLP) for marginal exceedances in soil for SCGI pathway

Takeaways & Lessons Learned - Phase 2

- Field Considerations
  - Use driller that has sampled for PFAS before
    - Uses "PFAS-free" equipment and materials
    - Provides data for their water source
  - Develop internal SOPs for sampling, project QAPP (if possible)
  - Ensure materials used by field staff for sampling, PPE, etc. are "PFAS-free"
  - QA/QC sampling is important – collect blanks (equipment, field, trip)
  - If using method ASTM D8421/8327, collect splits for Method 1633

Case Study #2 – Possible PFAS During Due-Diligence Investigation

- 700 Acre Farm Field
- Known Application of Biosolids
- Sampling Area Divided into 32 Composite Cells
  - 119 Total Samples
  - 2-4 Grab Samples per Cell
  - One Composite Sample Per Cell (32)

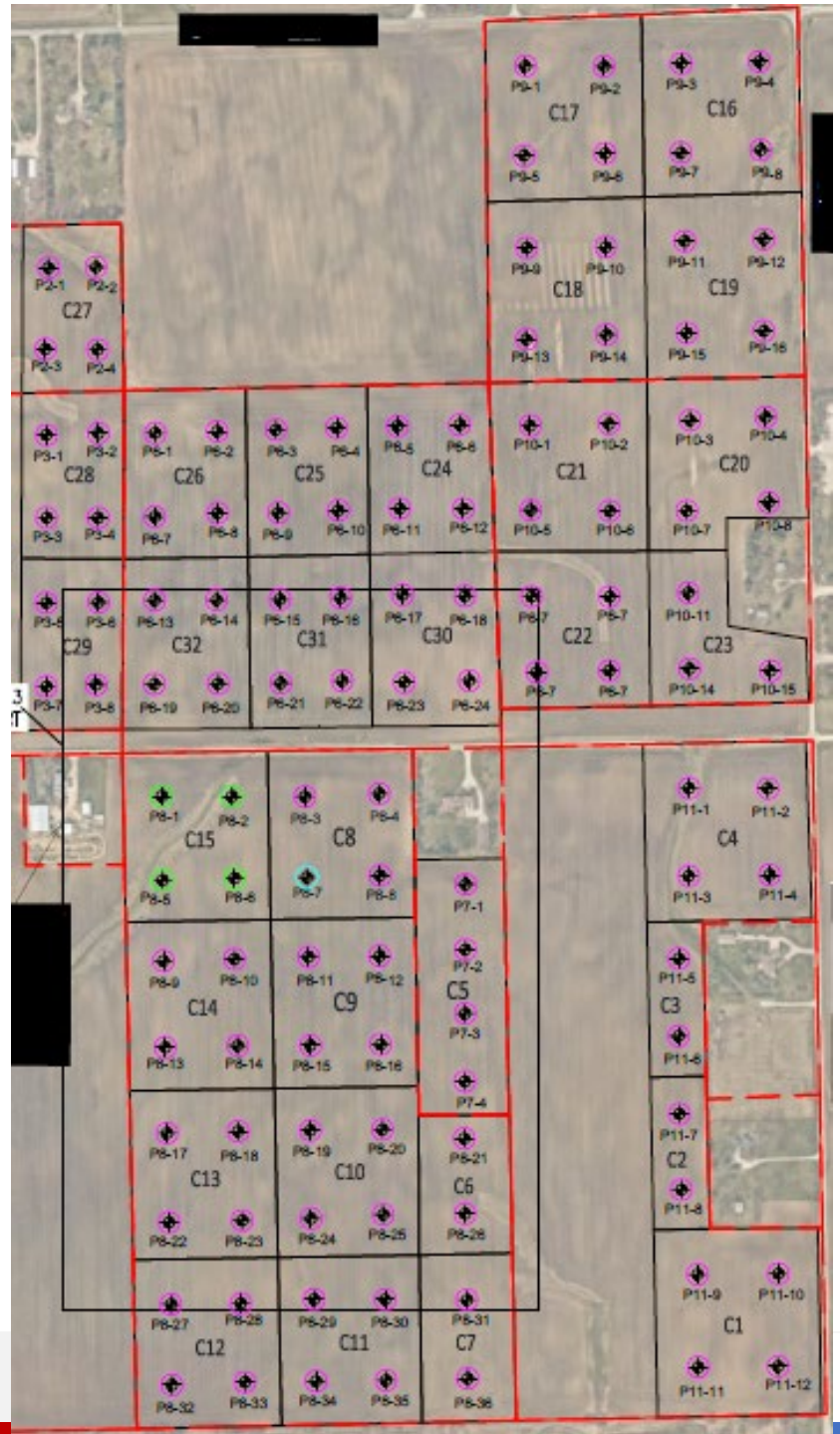


Case Study #2 – PFAS Discovered

CAS Number	Compound	Acronym	Results Units	IEPA Part 742 Provided (Non-TACO)								C1		C2		C3		C4		C5		C6		C7	
				Soil RO (TR 1.0E-06 and THQ 1.0)						Soil Migration to GW (Part 620 Current Method GW) DF 20		10/9/2024		10/9/2024		10/9/2024		10/9/2024		10/9/2024		10/9/2024		10/9/2024	
				CW Inh (Surface Soil CSat)	CW Ing	I/C Inh (Surface Soil CSat)	I/C Ing	Res Inh (Surface Soil CSat)	Res Ing	Class I	Class II	Result	Flag	Result	Flag	Result	Flag	Result	Flag	Result	Flag	Result	Flag	Result	Flag
Perfluoroalkyl Carboxylic Acids																									
375-22-4	Perfluorobutanoic acid (PFBA)	PFBA	ug/kg	2560000*	1,220,000 nc*	2560000*	2,040,000 nc*	2560000*	78,200 nc*	49.3*	49.3*	**0.14**	J	**0.11**	J	**0.1**	J	**0.19**	J	**0.2**	J	**0.11**	J	**0.32**	J
2706-90-3	Perfluoropentanoic acid (PFPeA)	PFPeA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.62		<0.60		<0.58		<0.59		**0.23**	J	**0.14**	J	**0.31**	J
307-24-4	Perfluorohexanoic acid (PFHxA)	PFHxA	ug/kg	55600000*	102,000 nc*	55600000*	1,020,000 nc*	55600000*	39,100 nc*	16.9*	16.9*	**0.06**	J	**0.054**	J	<0.12		**0.049**	J	**0.18**		**0.15**		**0.3**	
375-85-9	Perfluoroheptanoic acid (PFHpA)	PFHpA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	**0.034**	J	**0.022**	J	<0.12		**0.041**	J	**0.042**	J	**0.023**	J	**0.075**	J
335-67-1	Perfluorooctanoic acid (PFOA)	PFOA	ug/kg	NV	4.24 ca*	NV	0.195 ca*	NV	0.0219 ca*	1.22*	1.22*	**0.072**	J	**0.056**	J	**0.12**	J	**0.071**	J	**0.093**	J	**0.075**	J	**0.17**	
375-95-1	Perfluorononanoic acid (PFNA)	PFNA	ug/kg	NV	612 nc*	NV	6,130 nc*	NV	235 nc*	0.84*	0.84*	**0.027**	J	**0.025**	J	<0.12		**0.032**	J	**0.028**	J	<0.12		**0.034**	J
335-76-2	Perfluorodecanoic acid (PFDA)	PFDA	ug/kg	NV	0.408 nc*	NV	4.09 nc*	NV	0.156 nc*	0.113*	0.567*	<0.12		**0.028**	J	<0.12		<0.12		<0.12		<0.12		**0.042**	J
2058-94-8	Perfluoroundecanoic acid (PFUnA)	PFUnA (PFUnDA)	ug/kg	NV	61,200 nc*	NV	613,000 nc*	NV	23,500 nc*	313*	1570*	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
307-55-1	Perfluorododecanoic acid (PFDoA)	PFDoDA (PFDoA)	ug/kg	NV	10,200 nc*	NV	102,000 nc*	NV	3,910 nc*	1190*	5960*	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
72629-94-8	Perfluorotridecanoic acid (PFTrDA)	PFTrDA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
376-06-7	Perfluorotetradecanoic acid (PFTeDA)	PFTeDA (PFTA)	ug/kg	NV	204,000 nc*	NV	2,040,000 nc*	NV	78,200 nc*	65500*	328000*	<0.62		<0.60		<0.58		<0.59		<0.61		<0.61		<0.62	
Perfluoroalkyl Sulfonic Acids																									
375-73-5	Perfluorobutanesulfonic acid (PFBS)	PFBS	ug/kg	103000000*	184,000 nc*	103000000*	613,000 nc*	103000000*	23,500 nc*	21*	21*	**0.067**	J	**0.14**		<0.12		**0.019**	J	**0.18**		**0.14**		**0.53**	
2706-91-4	Perfluoropentanesulfonic acid (PFPeS)	PFPeS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
355-46-4	Perfluorohexanesulfonic acid (PFHxS)	PFHxS	ug/kg	NV	4,080 nc*	NV	40,900 nc*	NV	1,560 nc*	0.0848*	0.0848*	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
375-92-8	Perfluoroheptanesulfonic acid (PFHpS)	PFHpS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
1763-23-1	Perfluorooctanesulfonic acid (PFOS)	PFOS	ug/kg	NV	20.4 nc*	NV	145 ca*	NV	7.82 nc*	0.61*	0.61*	**0.06**	J	**0.068**	J	**0.032**	J	**0.074**	J	**0.073**	J	**0.071**	J	**0.14**	
68259-12-1	Perfluorononanesulfonic acid (PFNS)	PFNS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
335-77-3	Perfluorodecanesulfonic acid (PFDS)	PFDS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
79780-39-5	Perfluorododecanesulfonic acid (PFDoS)	PFDoS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.62		<0.60		<0.58		<0.59		<0.61		<0.61		<0.62	
Fluorotelomer Sulfonic Acids																									
757124-72-4	1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2FTS)	4:2FTS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
27619-97-2	1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2FTS)	6:2FTS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.25		**0.094**	J	<0.23		<0.24		<0.24		**0.8**		**0.62**	
39108-34-4	1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2FTS)	8:2FTS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
Perfluorooctane Sulfonamides																									
754-91-6	Perfluorooctanesulfonamide (PFOSA)	PFOSA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
31506-32-8	N-methyl perfluorooctanesulfonamide (NMeFOSA)	NMeFOSA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
4151-50-2	N-ethyl perfluorooctanesulfonamide (NEtFOSA)	NEtFOSA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
Perfluorooctane Sulfonamidoacetic Acids																									
2355-31-9	N-methyl perfluorooctanesulfonamidoacetic acid (NMeFOSAA)	NMeFOSAA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
2991-50-6	N-ethyl perfluorooctanesulfonamidoacetic acid (NEtFOSAA)	NEtFOSAA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
Perfluorooctane Sulfonamide Ethanols																									
24448-09-7	N-methyl perfluorooctanesulfonamidoethanol (NMeFOSE)	NMeFOSE	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
1691-99-2	N-ethyl perfluorooctanesulfonamidoethanol (NEtFOSE)	NEtFOSE	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
Per- and Polyfluoroether Carboxylic Acids																									
13252-13-6	Hexafluoropropylene oxide dimer acid (HFPO-DA)	HFPO-DA	ug/kg	1920000000*	6,120 nc*	1920000000*	6,130 nc*	1920000000*	235 nc*	0.203*	0.203*	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
919005-14-4	4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	ADONA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
377-73-1	Perfluoro-3-methoxypropanoic acid (PFMPA)	PFMPA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
863090-89-5	Perfluoro-4-methoxybutanoic acid (PFMBA)	PFMBA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
151772-58-6	Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	NFDHA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
Ether Sulfonic Acids																									
756426-58-1	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	9Cl-PF3ONS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
763051-92-9	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS	11Cl-PF3OUdS	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	
113507-82-7	Perfluoro(2-ethoxyethane)sulfonic acid (PFEESA)	PFEESA	ug/kg	NV	NV	NV	NV	NV	NV	NV	NV	<0.12		<0.12		<0.12		<0.12		<0.12		<0.12		<0.12	

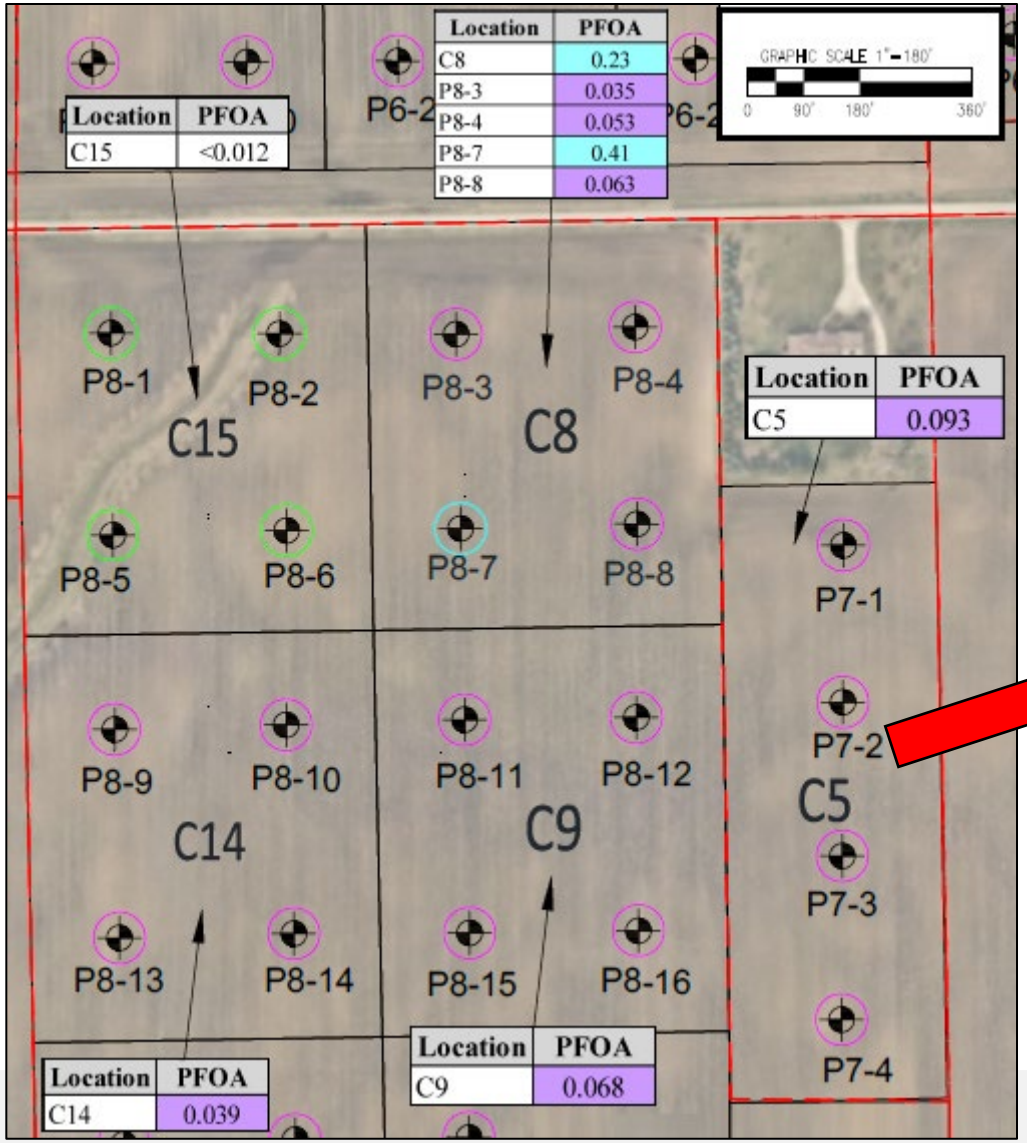
Case Study #2 – Map of PFAS Impacts

- 31 out of 32 Composite Samples Exceeded the Residential Ingestion Objective for PFOA (Purple)
- C15 Did Not Exceed Any Objective for any PFAS Compound (Green)
- C8 Exceeded the Industrial/Commercial Ingestion Objective for PFOA (Blue)
- The 4 Individual Samples in Composite C8 were Analyzed



Case Study #2 – Grab Samples Analyzed From Composite C8

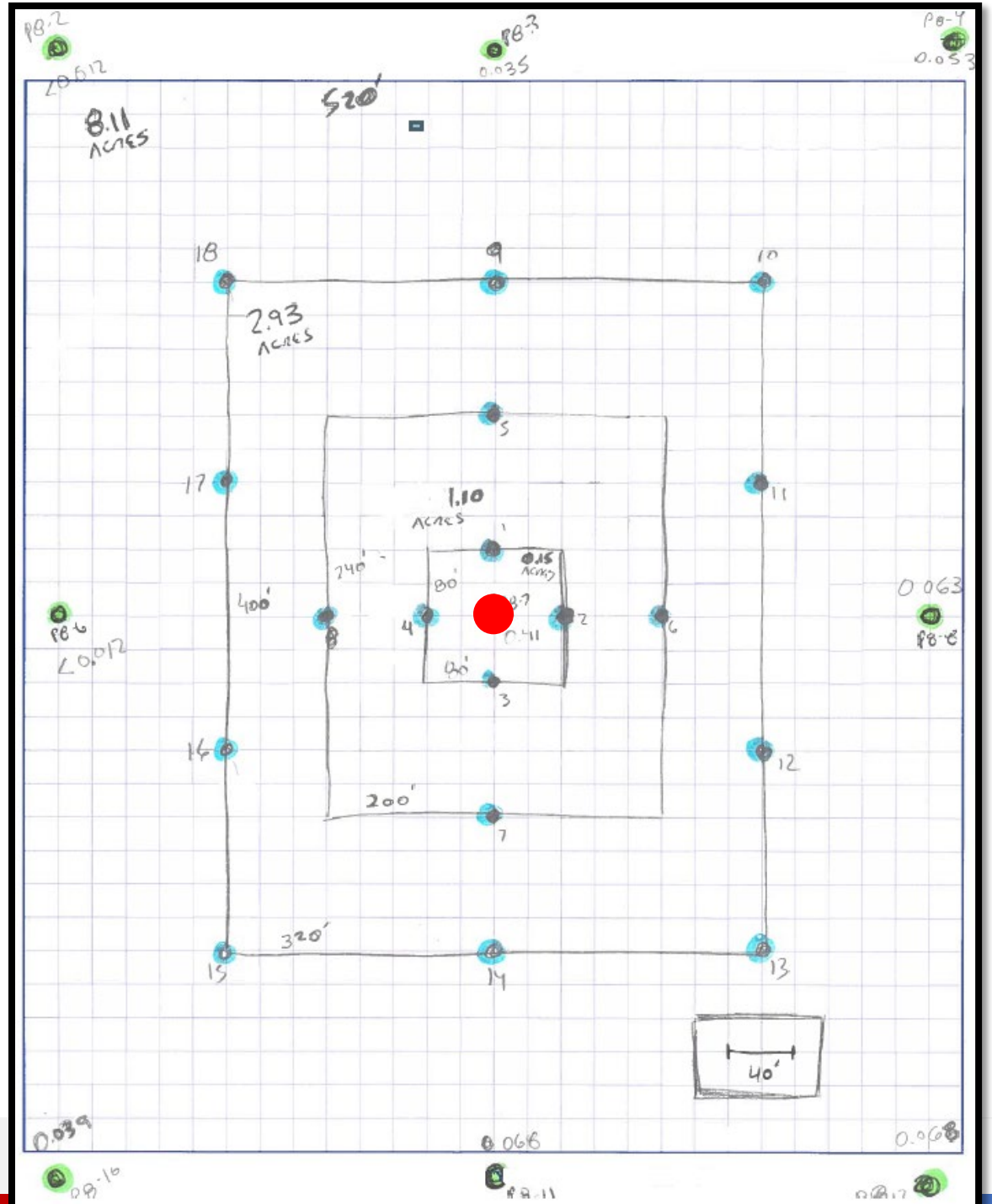
Only P8-7 Exceeded the Industrial Commercial Objective (0.195 mg/kg)



Zoom In

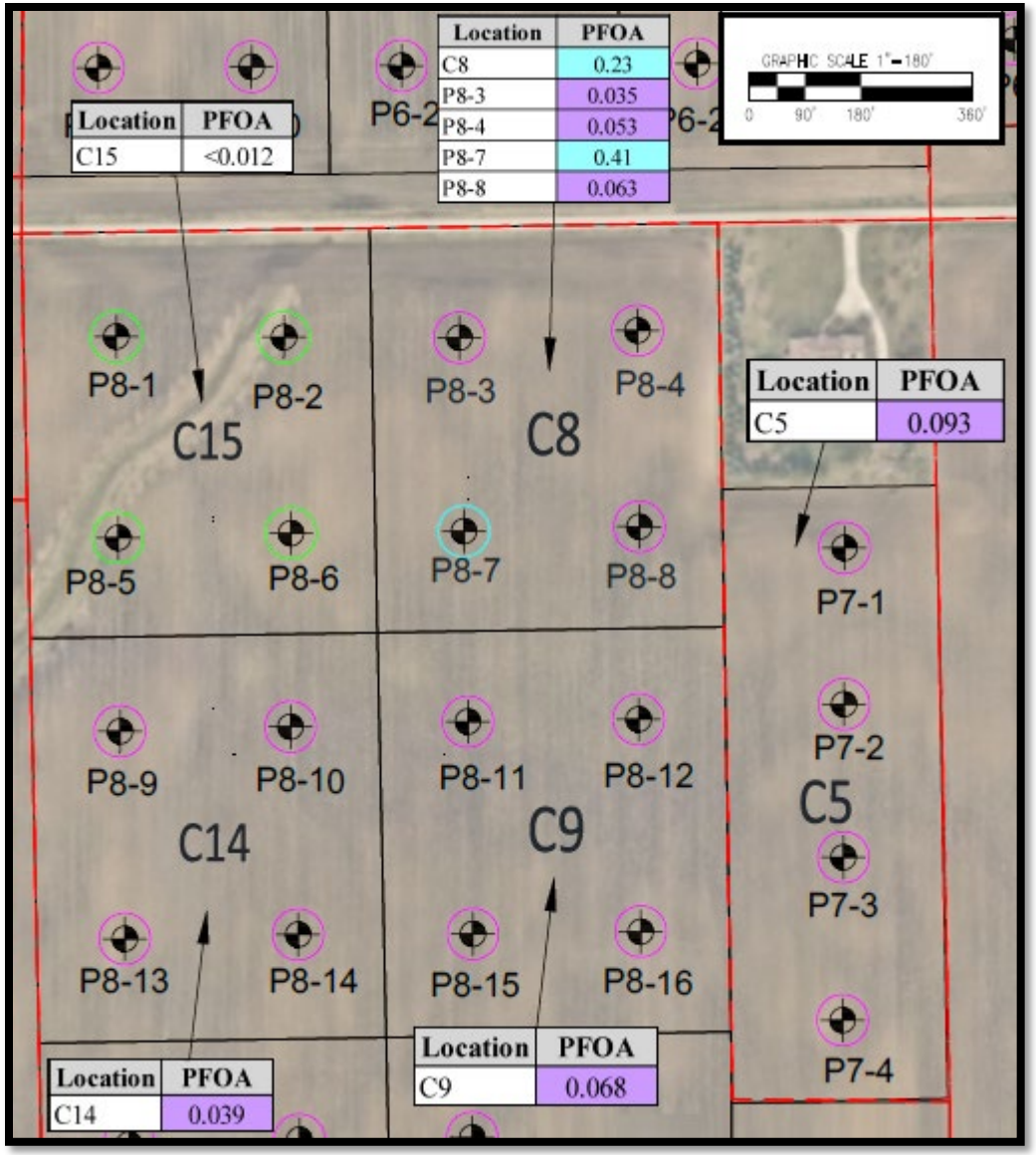
Case Study #2 – Future PFAS Delineation

- Exceedance (P8-7) in Red
- Impacted Area (To Clean Samples)
  - 8.11 Acres (520’ x 680’)
  - **26,000 CY** (Assuming 2’ feet thick)
- Goal: Reduce the Footprint and Volume of Impacted Soil with Additional Sampling (18 Samples)



Case Study #2 – Solutions

- Excavate and Dispose of the Impacted Soil Once Delineated
- Cover the Exceedance with Three Feet of Clean Soil (Meets Residential Objectives)
- Soils from Cell C15 Meet the Criteria of Clean Soil



Discussions

THANK YOU

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