Accelerating Site Closeout, Improving Performance, and Reducing Costs Through Optimization

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Advances in Site Characterization and Investigation Technologies

Methodology For Integrating The Membrane Interface Probe With In-Situ Remediation Injection Design

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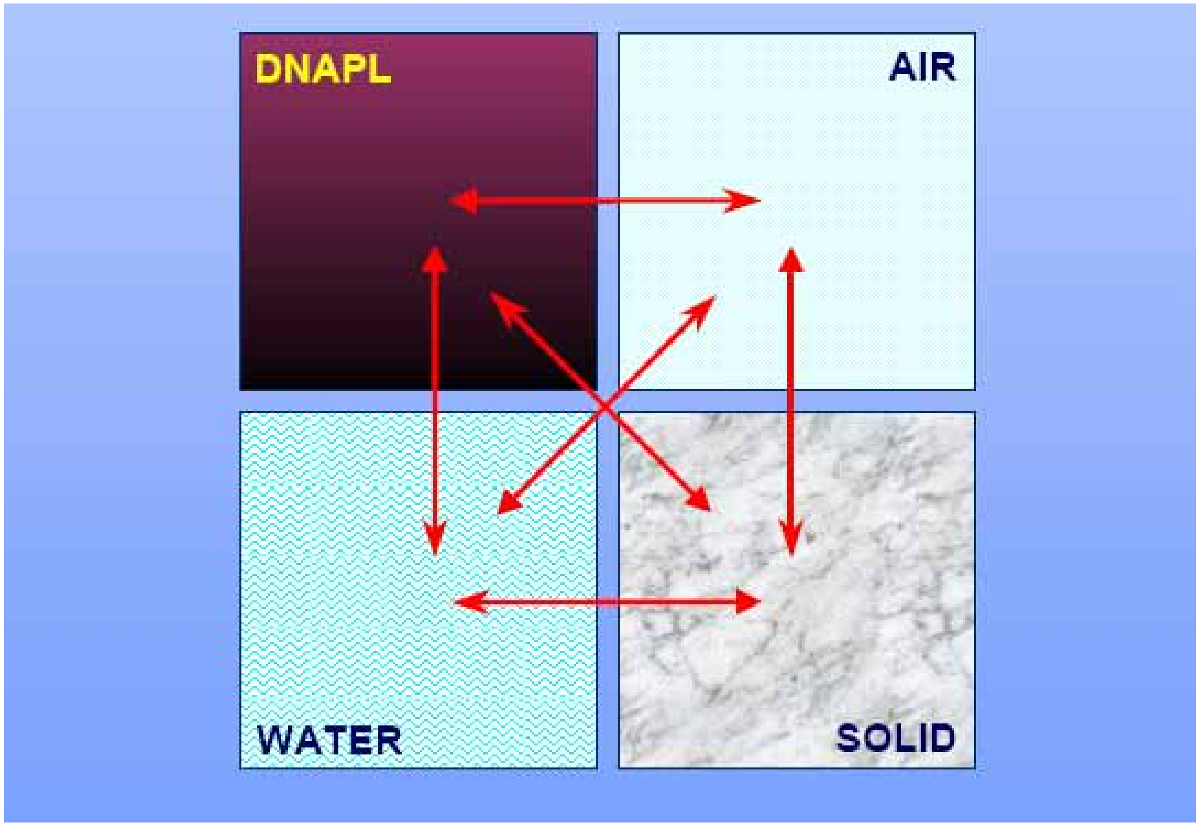
Methodology Overview

- **To identify contaminant mass in relation to lithology through use of the MIP and confirmation sampling.**
- To identify target injection intervals and delivery conduit.
- To determine reagent volumes required to meet treatment objectives.
- To select a pumping system to deliver reagent volumes at the design ROI and injection rate.

Contaminant Mass Distribution



Contaminant mass distribution is based Water-Soil Equilibrium Partition theory….the ability of organic carbon in soil to absorb contamination.

EPA Difficulty To Treat Matrix

Hydrogeology	Mobile Dissolved (Degrades/ Volatilizes)	Mobile Dissolved	Strongly Sorbed, Dissolved	Strongly Sorbed, Dissolved (Degrades/ Volatilizes)	Separate Phase LNAPL	Separate Phase DNAPL
Homogeneous, Single Layer	1	1-2	2	2-3	2-3	3
Homogeneous, Multiple Layers	1	1-2	2	2-3	2-3	3
Heterogeneous, Single Layer	2	2	3	3	3	4
Heterogeneous, Multiple Layers	2	2	3	3	3	4
Fractured Bedrock	3	3	3	3	4	4

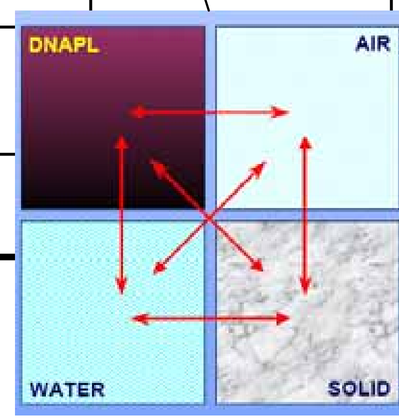
1= Least Difficult   4 = Most Difficult

Nobel Prize

Contaminant Mass In Relation To Lithology

Treatment Zone	Competing Reactions		Contaminant Mass			
Treatment Interval (Ft to Ft bgs)	Bioremediation and Oxidant Scavengers (ppm)	Natural Oxidant Demand (g/kg)	Dissolved (ppm)	Sorbed (ppm)	Residual NAPL (ppm)	Free Phase NAPL (ppm)

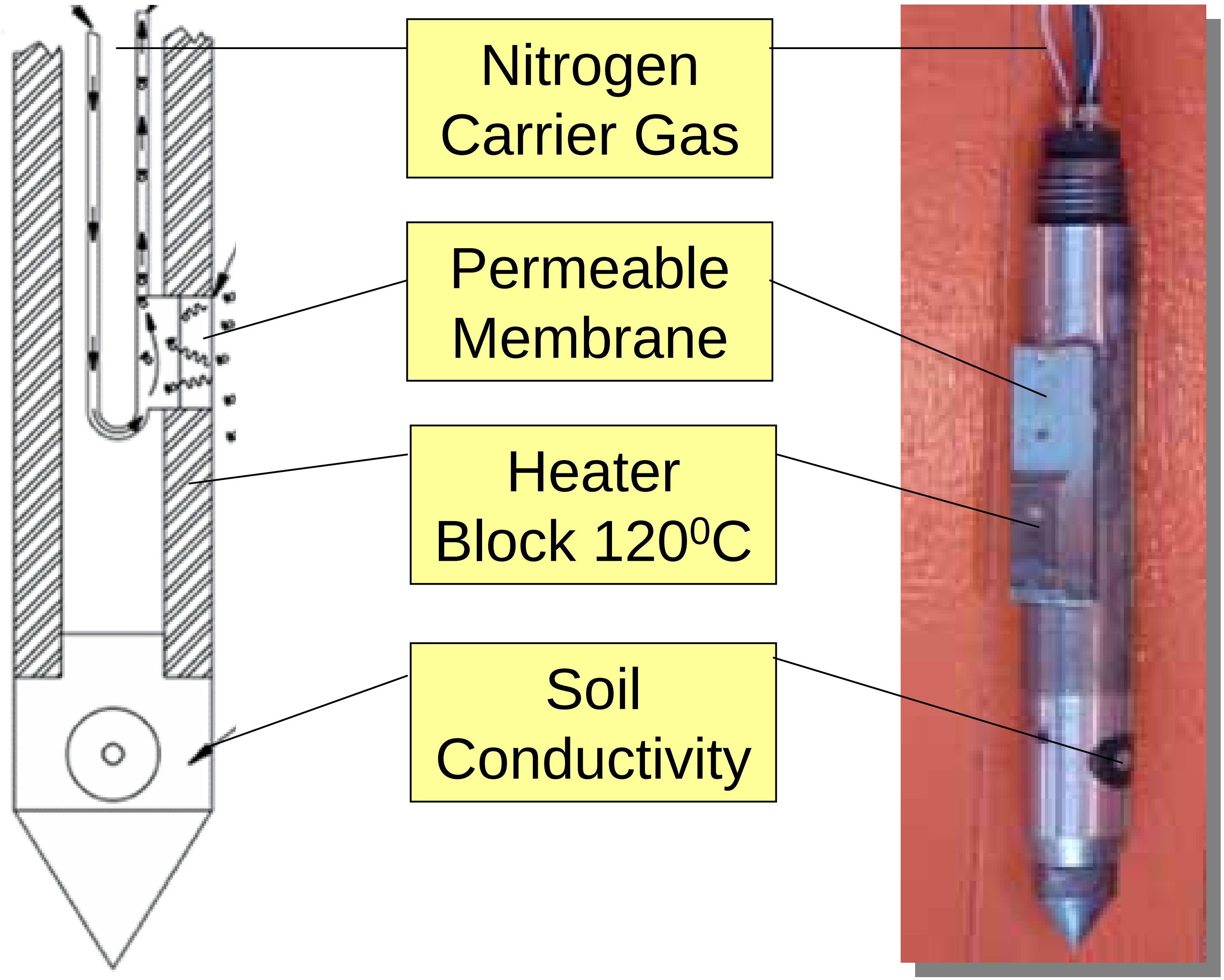
Treatment Interval



Scavengers – e.g. carbonate ions for peroxide

Natural Occurring Demand is the consumption of an oxidant in reactions that are unrelated to degradation of the contaminant of concern

Membrane Interface Probe



Detectors

	Contaminants	Detection Ranges
PID Photo Ionization	Double-Bonded Compounds (gasoline, BTEX, High level PCE & TCE)	1 - 20,000 ppm Qualitative
FID Flame Ionization	Hydrocarbons (gasoline, BTEX methane, butane, landfill gases)	1 - 100,000 ppm Qualitative
ECD Electron Capture	Halogenated Compounds (Low-Level TCE, PCE, VC)	0.25 – 10 ppm Qualitative
Field Portable GC-MS	Speciated VOCs including MTBE	100 x PID/ECD sensitivity 100% ID of unknowns Quantitative

HAPSITE - March, 2004

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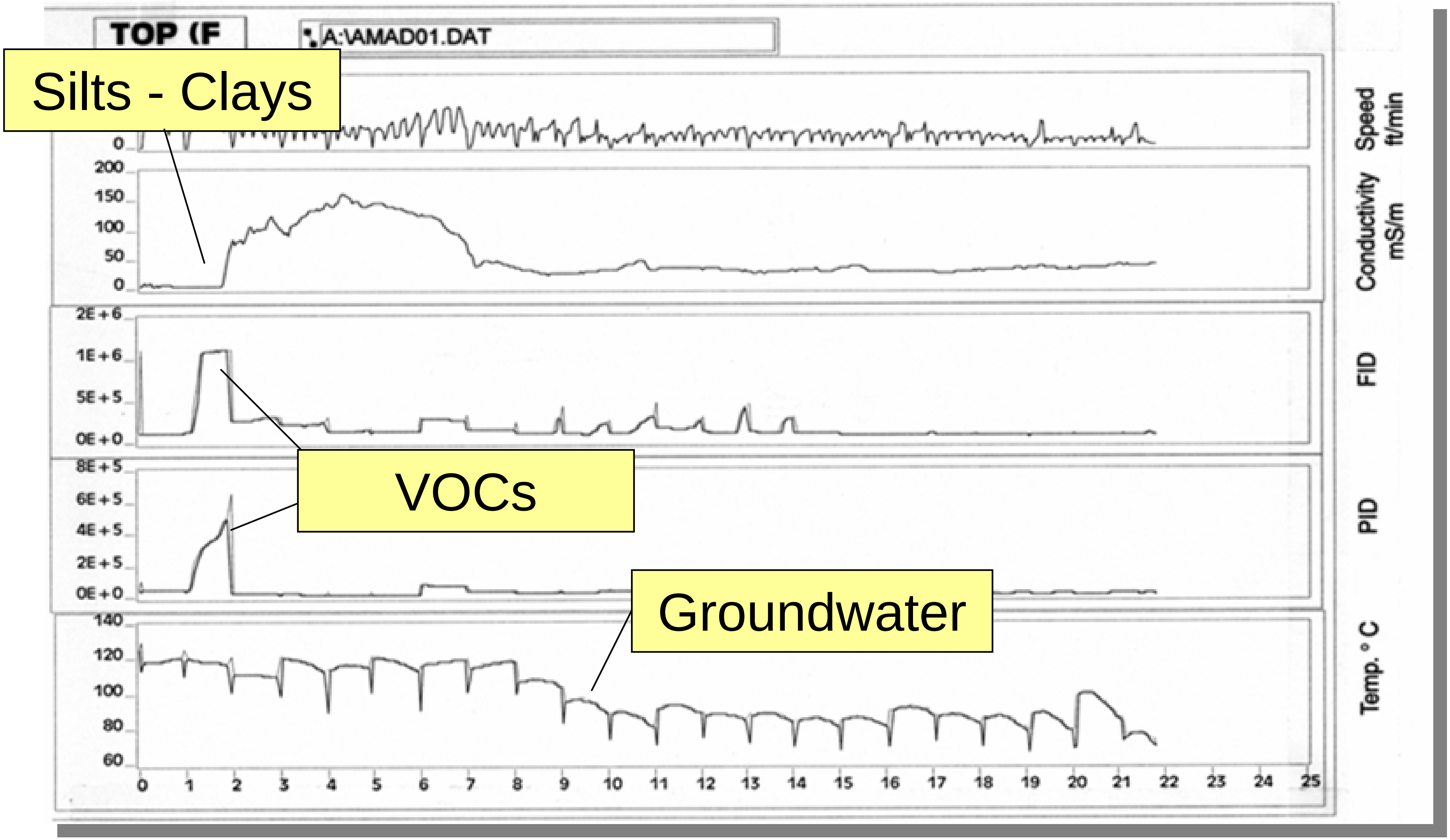
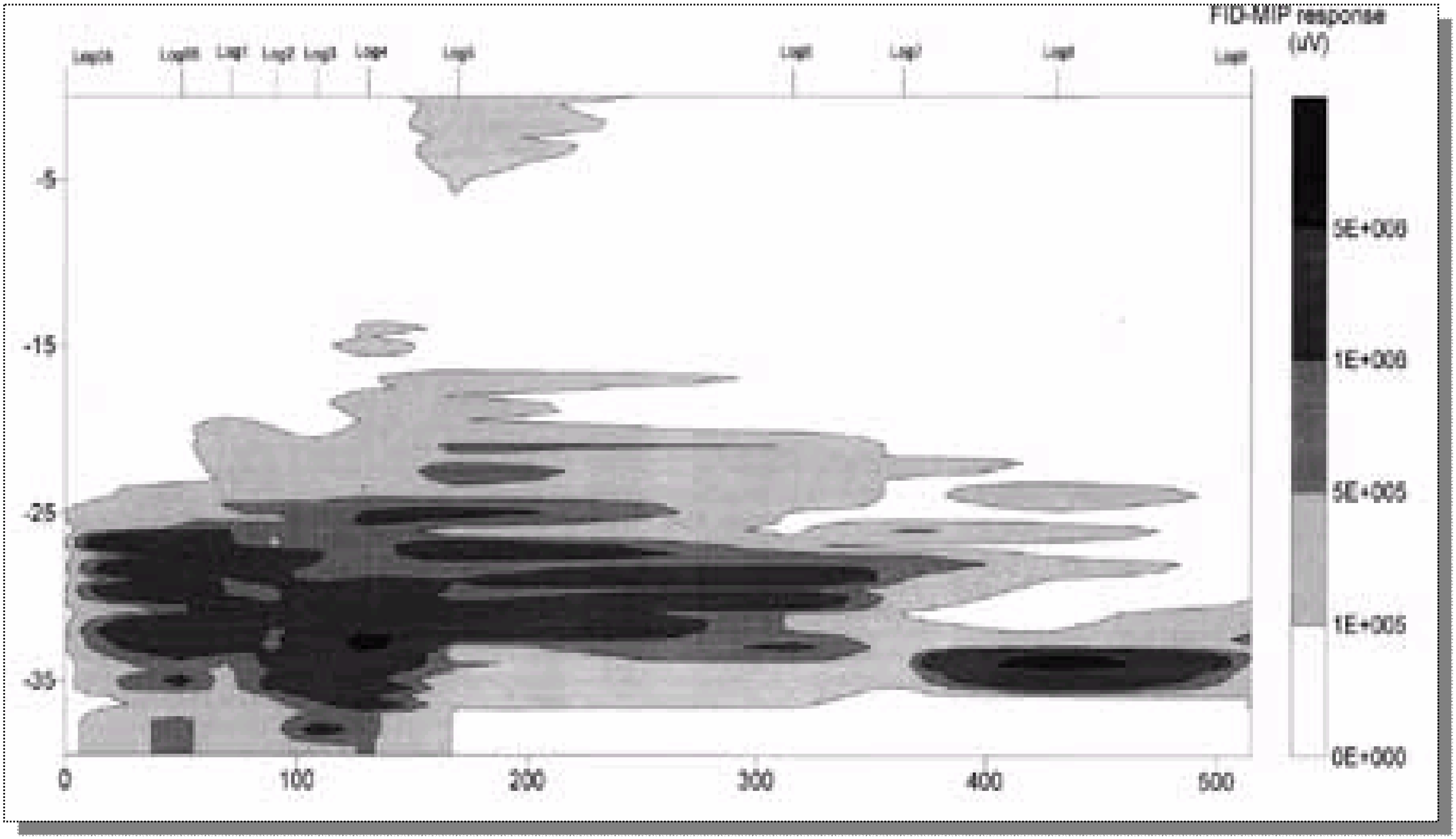
MIP Equipment

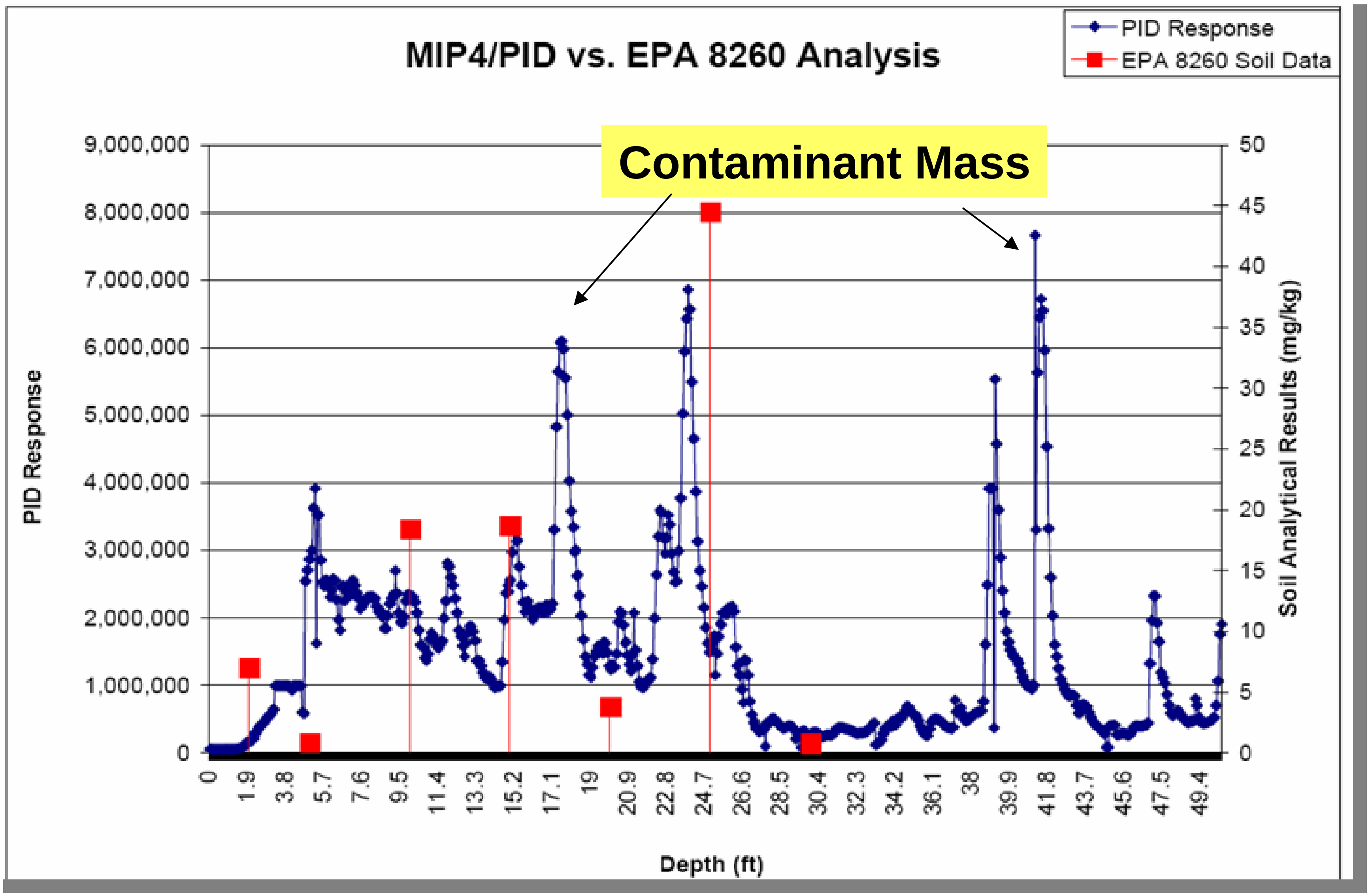
MIP Real Time Data Display



Contaminant Mass Identification – FID Qualitative



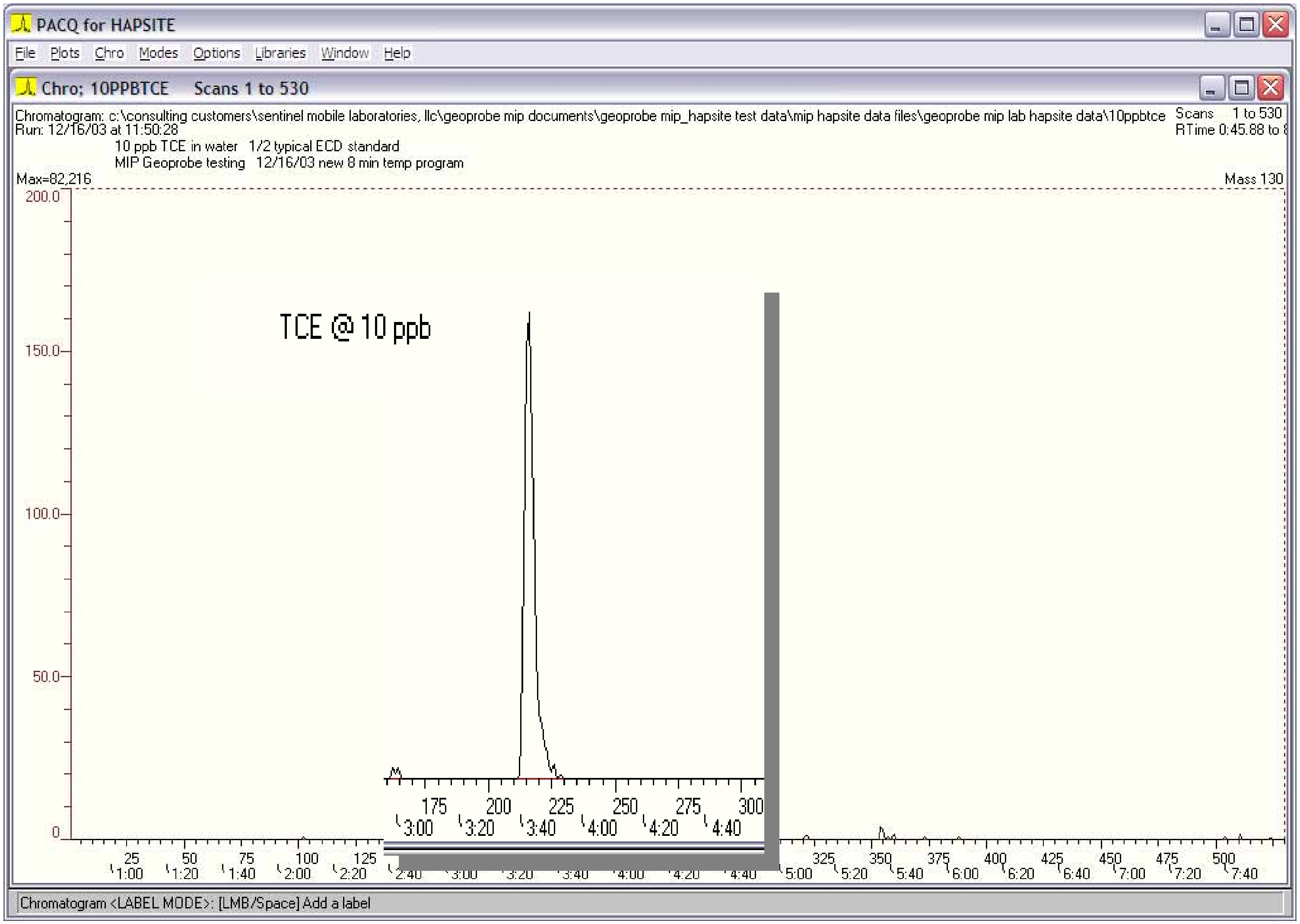
PID Soil Confirmation Samples – Vadose Zone



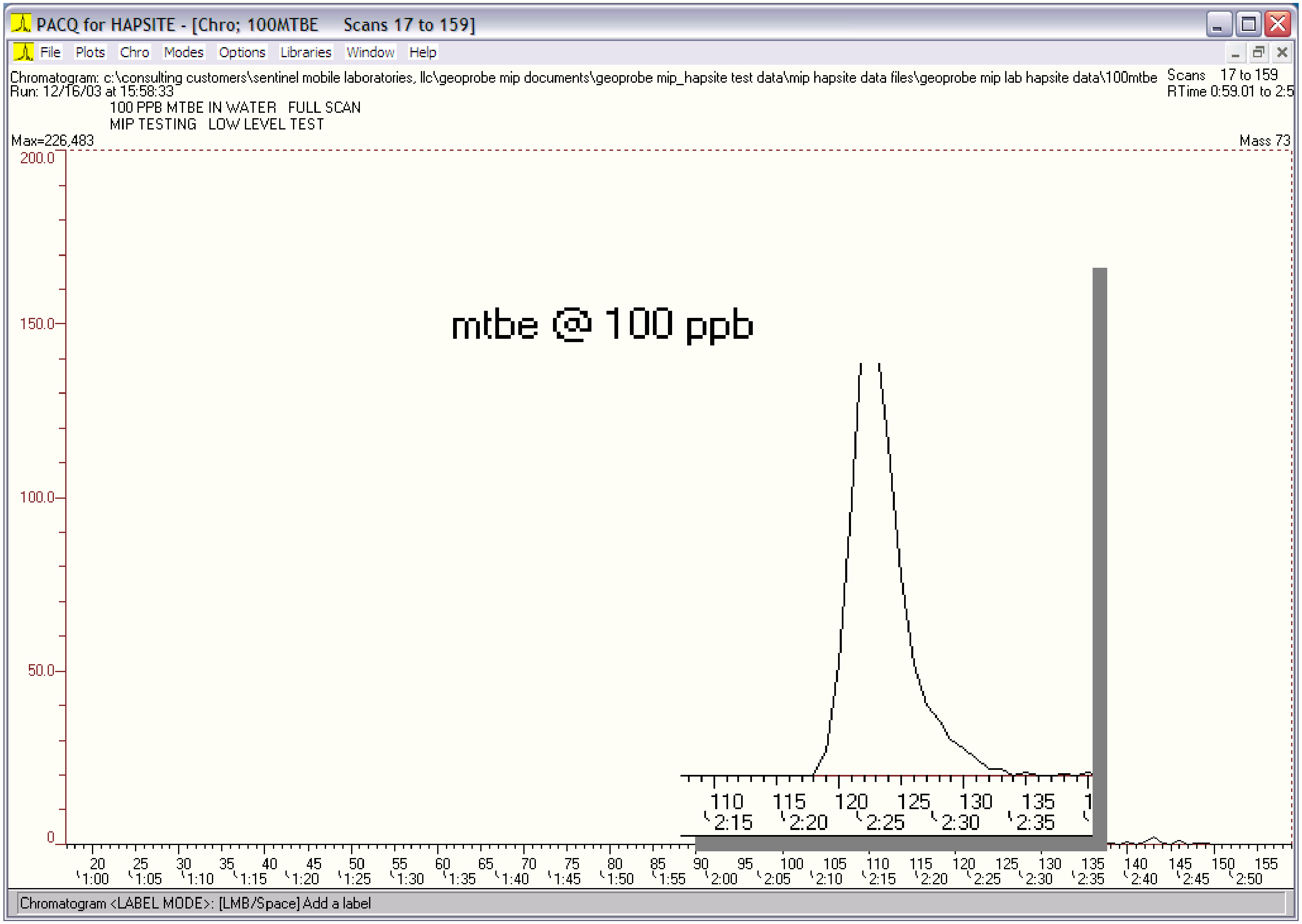
HAPSITE Portable GC-MS & Headspace Sampling System

Membrane Interface Probe

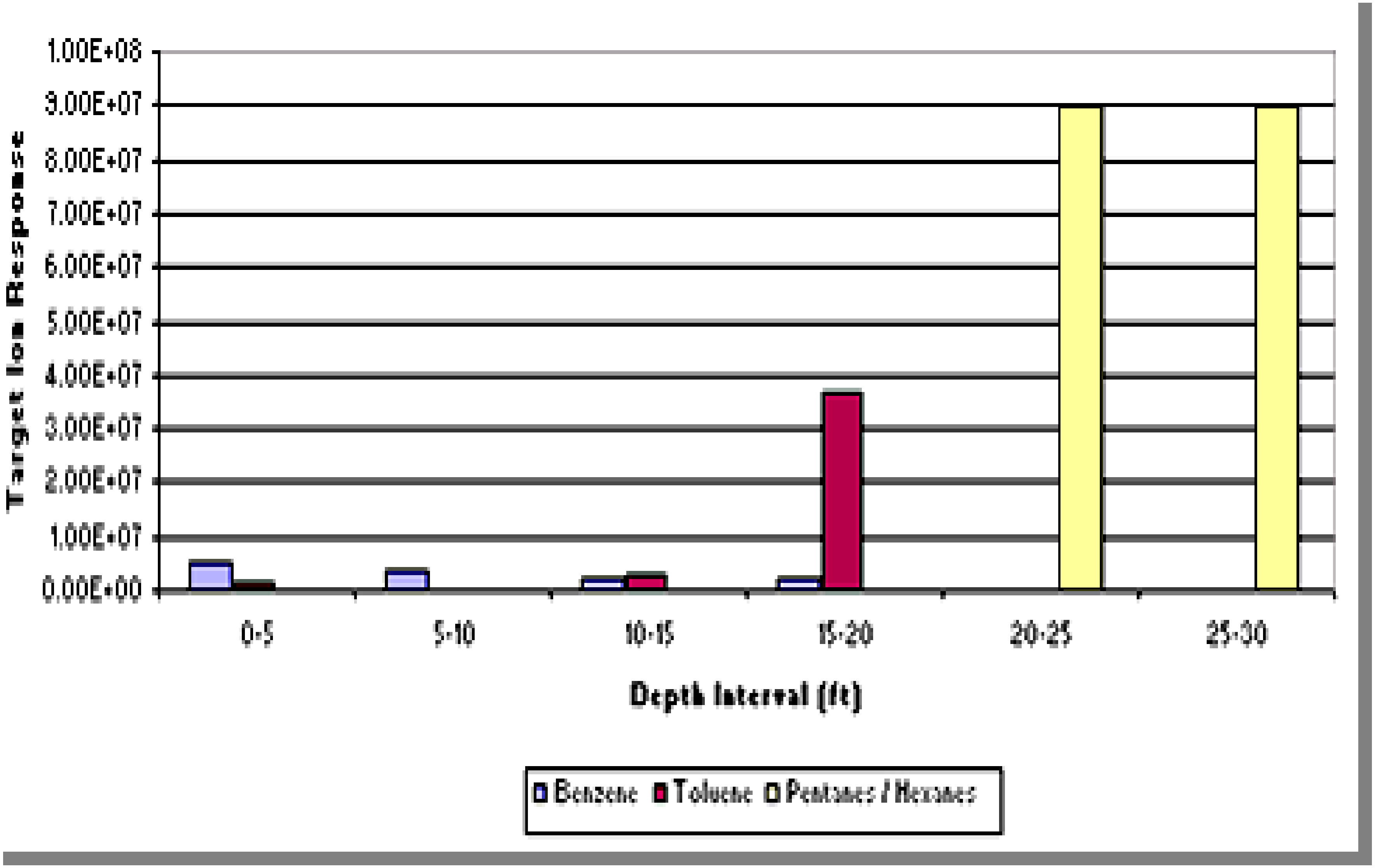
X 100 Increase in Sensitivity with HAPSITE Integrated MIP System



Ability to Detect MTBE



MIP HAPSITE - Quantitative



Confirmation Sampling and Modeling (NAPLANAL)

Sample Name Identification:	LC34B10-15
Model used:	Liquid saturated & porosity known
Porosity (Volume Frac.):	0.3
Fraction organic carbon (f_{oc}):	0.001

NAPLANAL ANALYSIS RESULTS:

Name	Total Mass (mg/kg)*	Mass in Water (mg/kg)*	Mass in Soil (mg/kg)*	Mass in NAPL (mg/kg)*	Conc. in Water (mg/L)	Sorbed in Soil (mg/kg)^	Conc. in NAPL (kg/L)	Mole Fraction in NAPL
c-DCE	4.89	0.4335	0.245	4.2115	3.3227	0.2858	0.0005	0.0005
PCE	0.28	0.0006	0.0014	0.2781	0.0043	0.0016	0	0.0000
TCE	12345	180.571	149.561	12014.9	1384.2	174.41	1.4594	0.9995
t-DCE	0.1	0.0059	0.0023	0.0918	0.0454	0.0027	0	0.0000

(mg/kg)* = mg per kg of soil sample (wet soil)

(mg/kg)^ = mg per kg of solid (dry soil)

Water Volume Frac. (L/L)	0.28219	Bulk Density (kg/L)	2.1632
NAPL Volume Frac. (L/L)	0.01781	NAPL Density (kg/L)	1.4599
Soil Volume Frac. (L/L)	0.7		
Porosity (Volume Frac.)	0.3	NAPL Saturation (%)	5.9364

Mariner, Jin & Jackson, An algorithm for the estimation of NAPL saturation and composition from typical soil chemical analyses. Ground Water Monitoring & Remediation Spring 1997, pp. 122-129.

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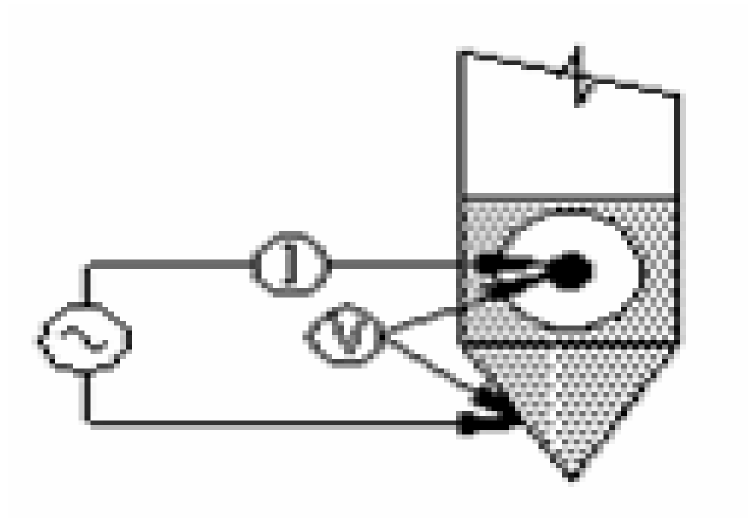
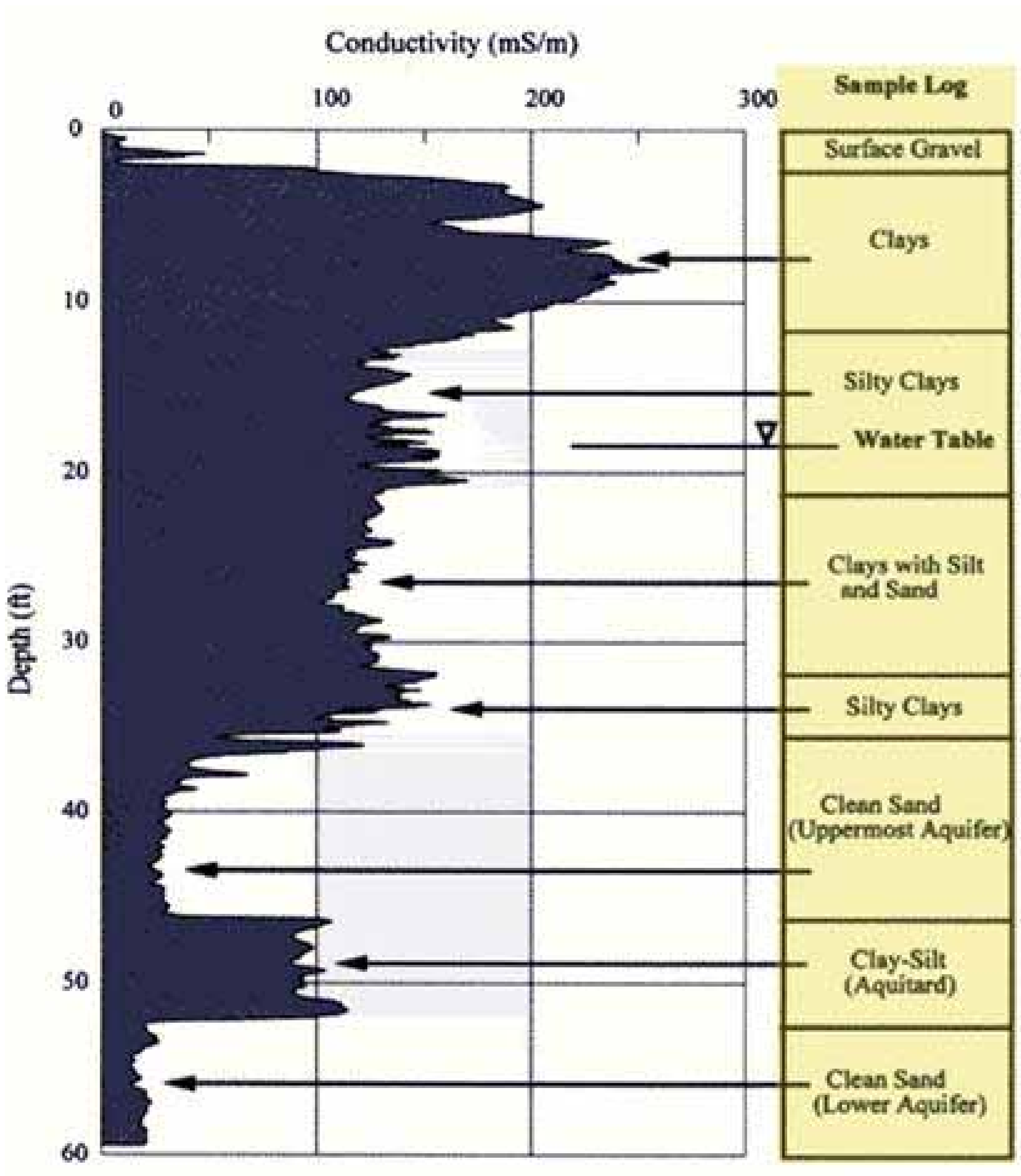
Soil Conductivity

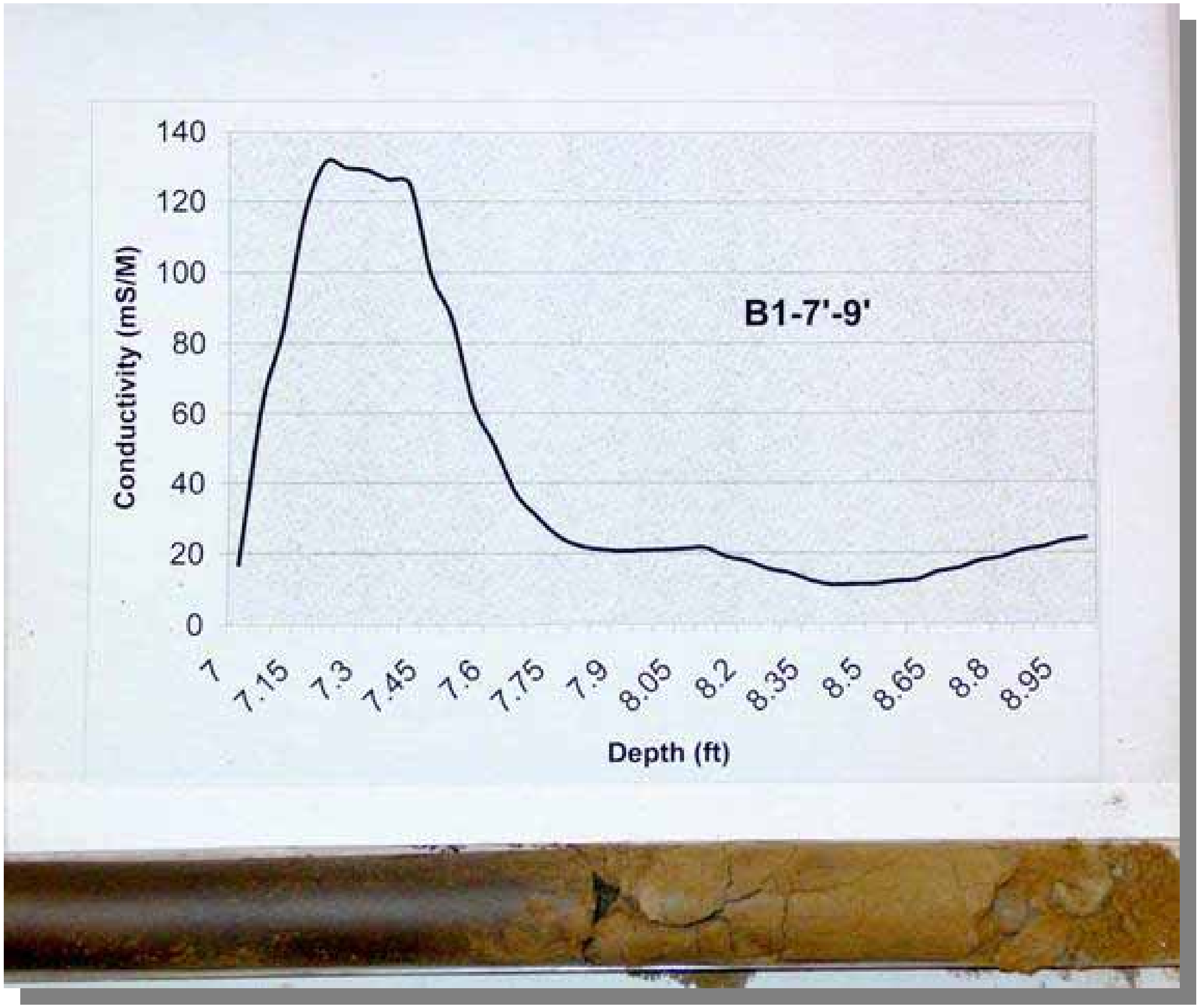
- The soil Ec uses a dipole measurement arrangement
- Alternating current is passed from the center of the probe to the probe body
- The voltage response of the soil to current is measured across the same two points
- Lower conductivities indicate sands, while higher conductivities indicate silts and clay



Soil Ec Log Explanation



Soil Conductivity Confirmation

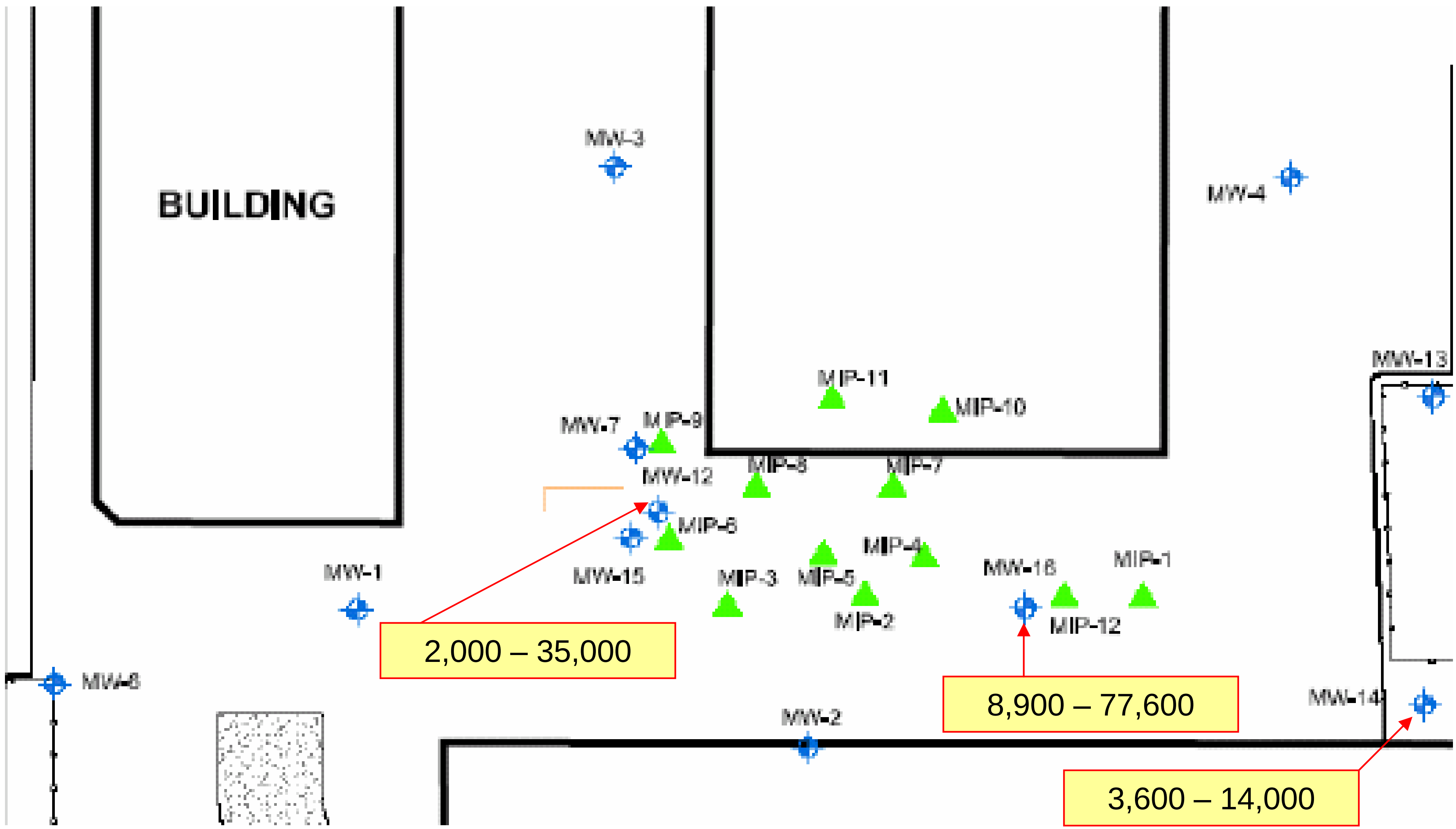


MIP Case Study - Background

- Southern California industrial site where high TCE concentrations were indicated an upgradient unidentified DNAPL source zone
- Target saturated zone 14’ to 33’ bgs
- Primarily silts and clays
- Overriding concern was not to puncture aquitard at 33’ bgs

Groundwater Monitoring Well and MIP Locations

Membrane Interface Probe



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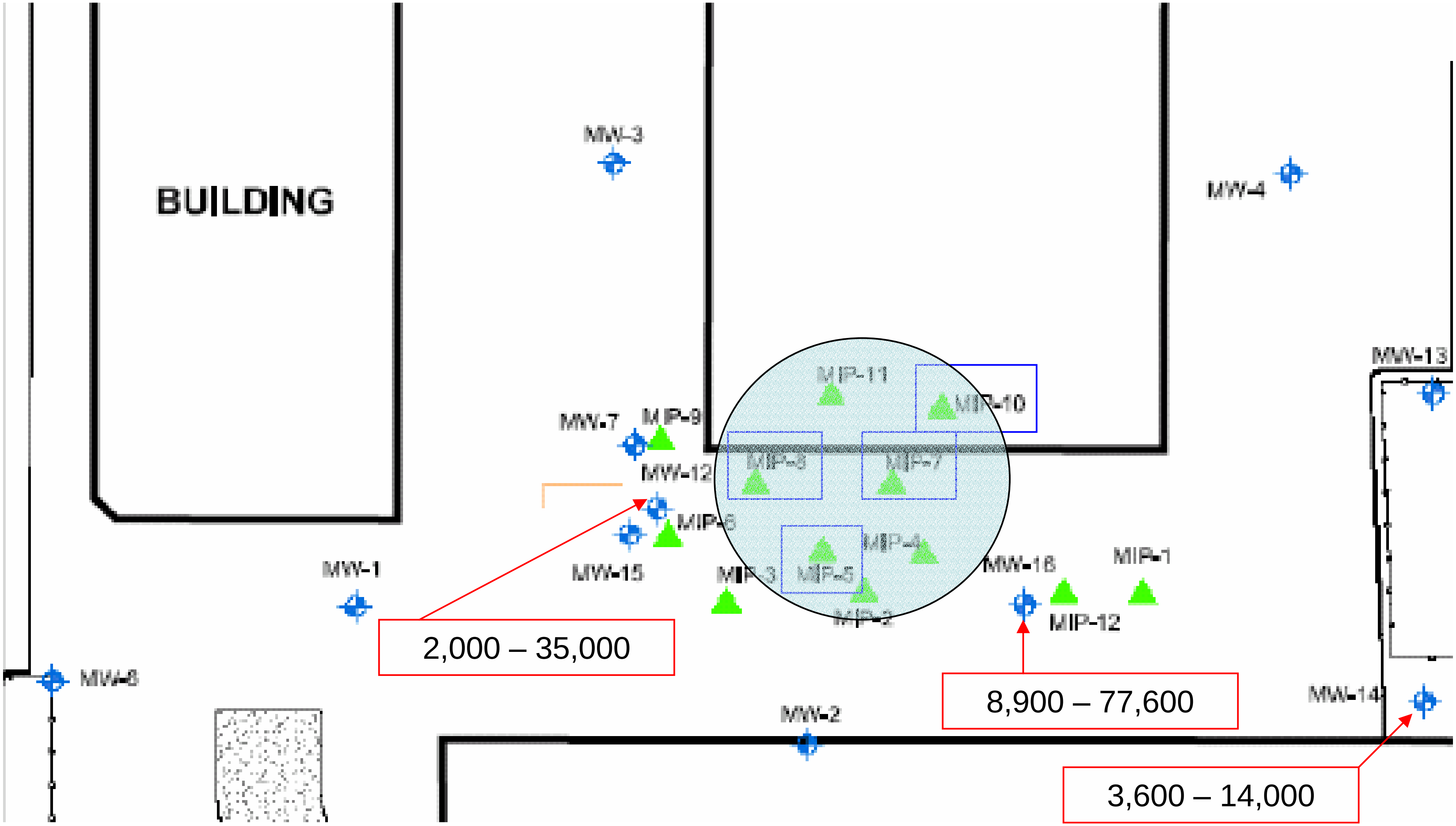
MIP PID and SC Results Summary

MIP Boring	Max PID Response X 10^6	Maximum PID Response Ft-bgs	Response Interval Ft-Ft	Soil Conductivity Max Response*
1	1	31.5	22 - 31	250
2	0.25	24	19-32	150
3	0.1	26	23-30	200
4	0.8	30	23-31	250
5	2	28	23-31	275
6	0.5	33	25-33	200
7	7.8	23	20-28	400
8	4	26	21-29	200
9	0.25	27	25-29	100
10	3.2	23	21-26	150
11	0.65	20	19-24	150
12	0.12	23	20-32	200

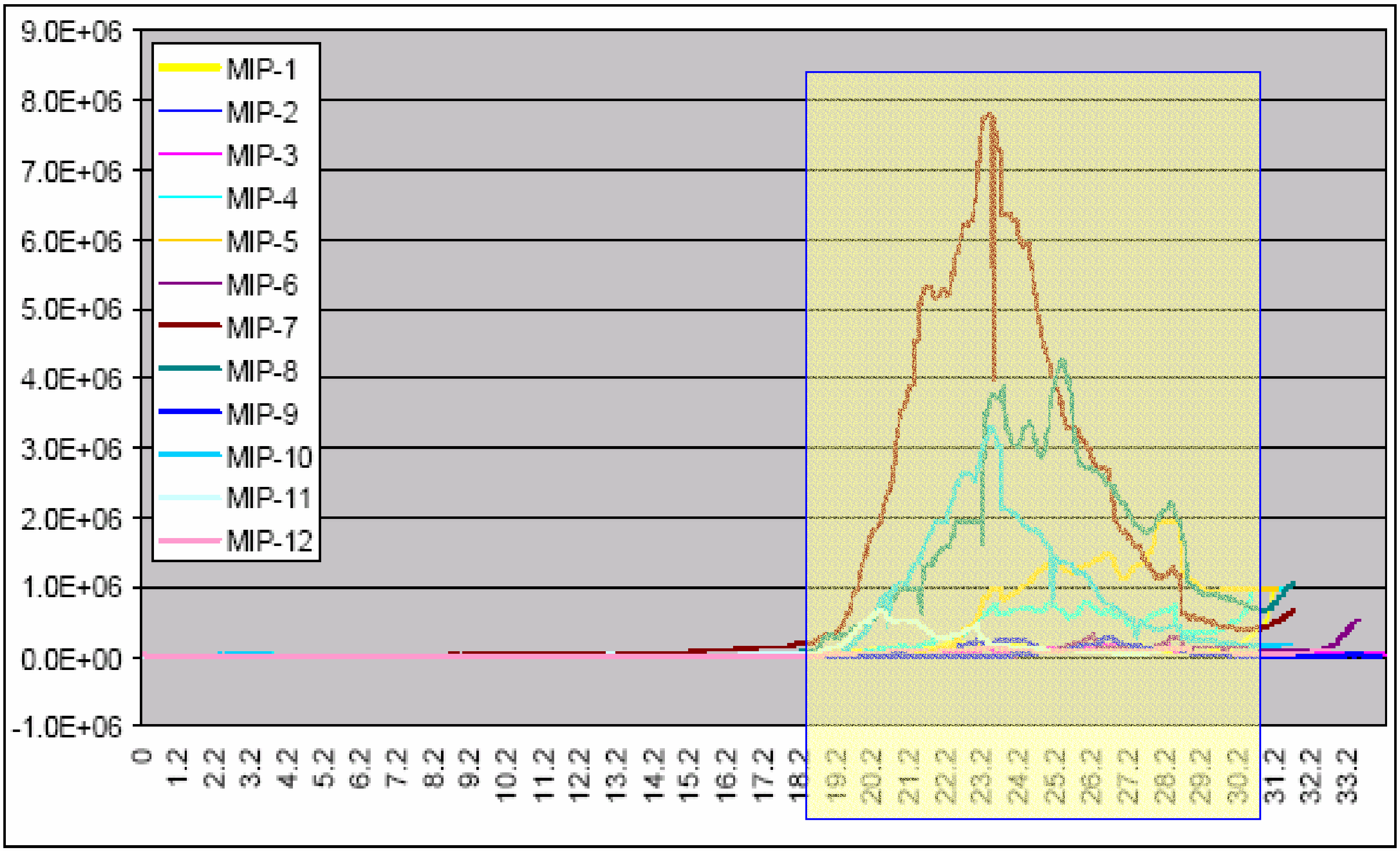
* Soil Type	
0-50	Clean Sand
50-100	Clay-Silt
100-200	Silty-Clays
200 +	Clay

** Chart is only for reference of soil type and should not be used to describe soil type without confirmation sampling to calibrate the soil conductivity readings.*

MIP Results – Contaminant Mass



MIP PID Results Summary



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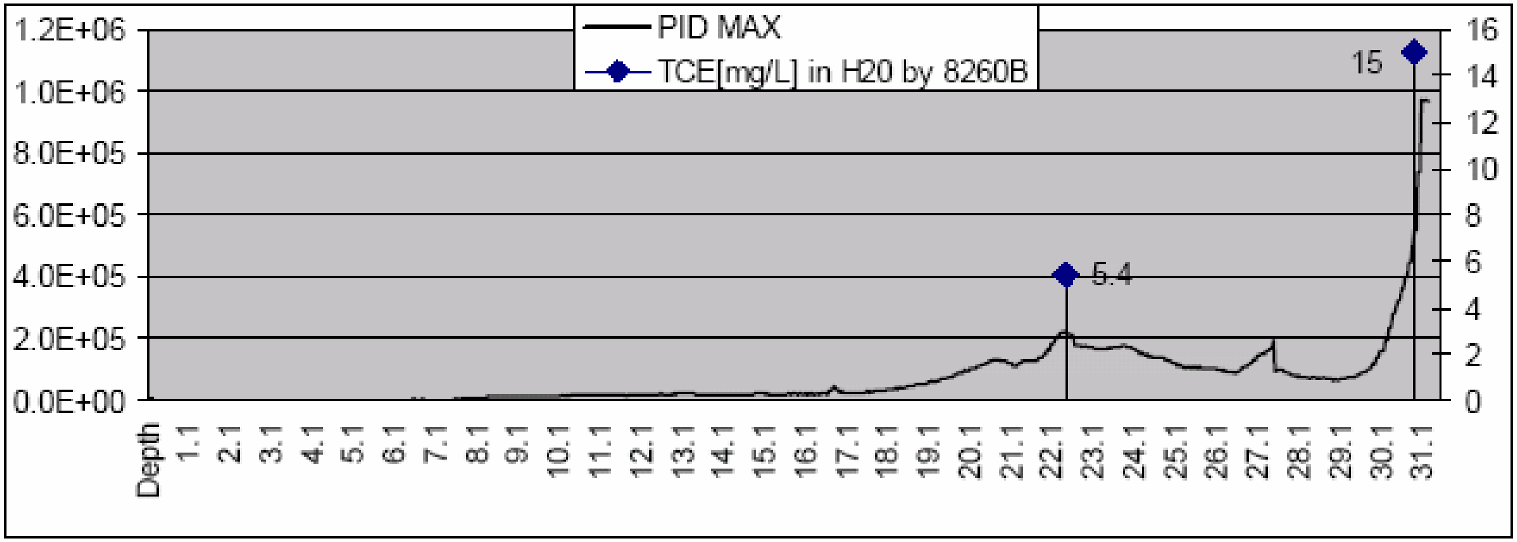
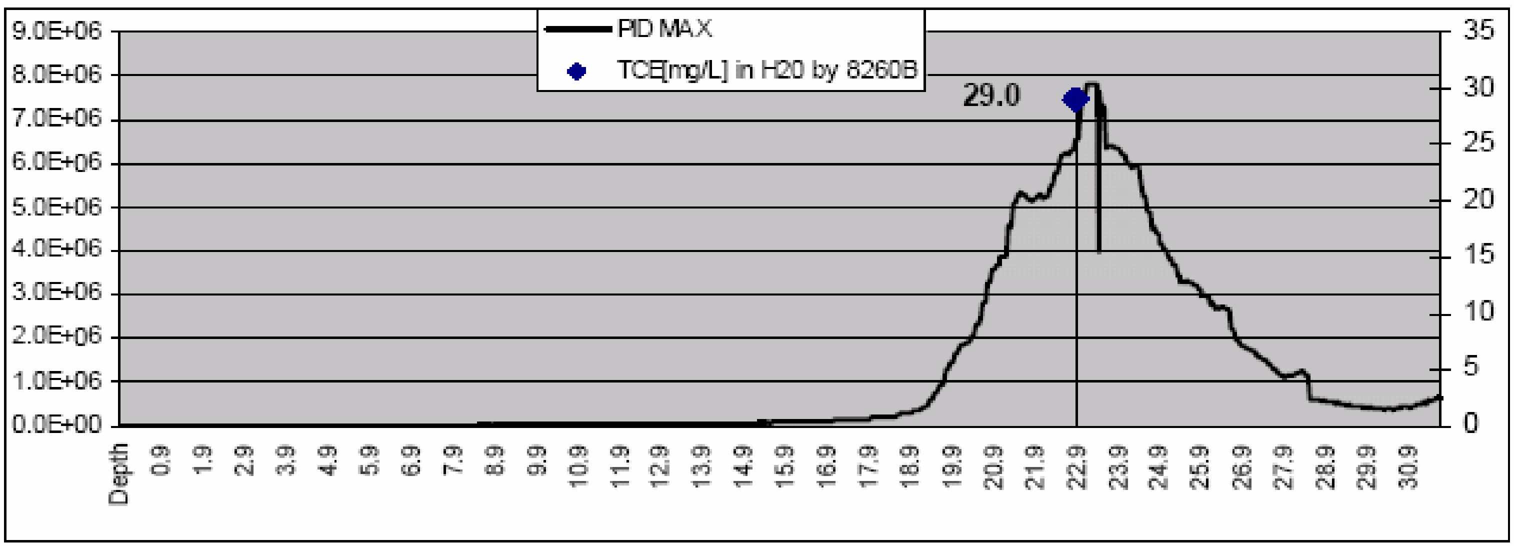
MIP 1 and 7 - GW Confirmation Sampling





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MIP Cost Comparison

	Geoprobe 66DT	MIP Unit	EPA Method 8260	Total
MIP	$3,150.00	$1,500.00	$125.00	
Units	2	2	3	
Total	$6,300.00	$3,000.00	$375.00	$9,675.00
Continuous Core Analyze Every 5 Feet	$2,650.00	$1,500.00	$125.00	
Units	3	0	72	
Total	$7,950.00	$0.00	$9,000.00	$16,950.00
Continuous Core Analyze Every 1 Foot	$2,650.00	$1,500.00	$125.00	
Units	3	0	360	
Total	$7,950.00	$0.00	$45,000.00	$52,950.00

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- **To identify target injection intervals and delivery conduit.**

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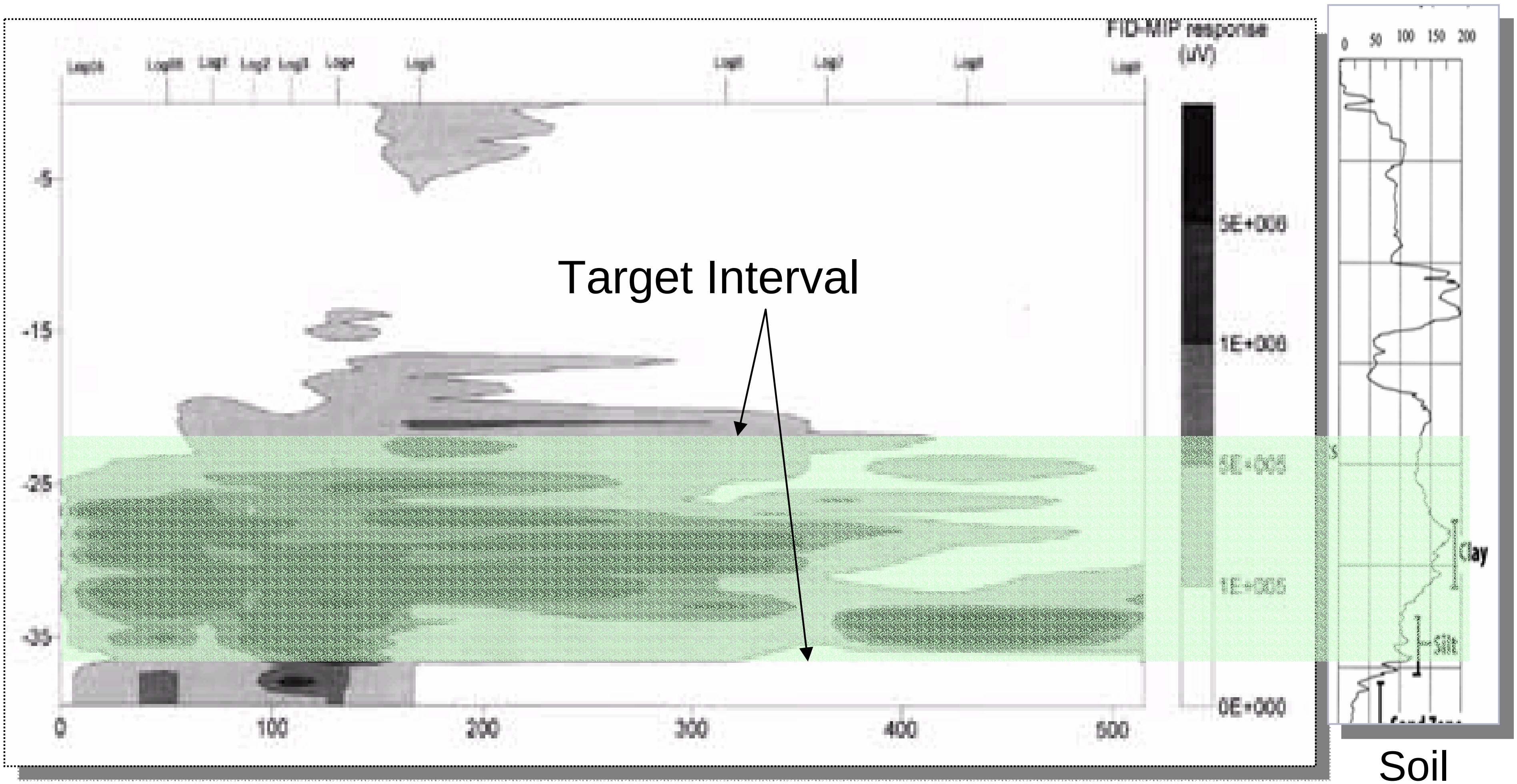
Target Interval Identification



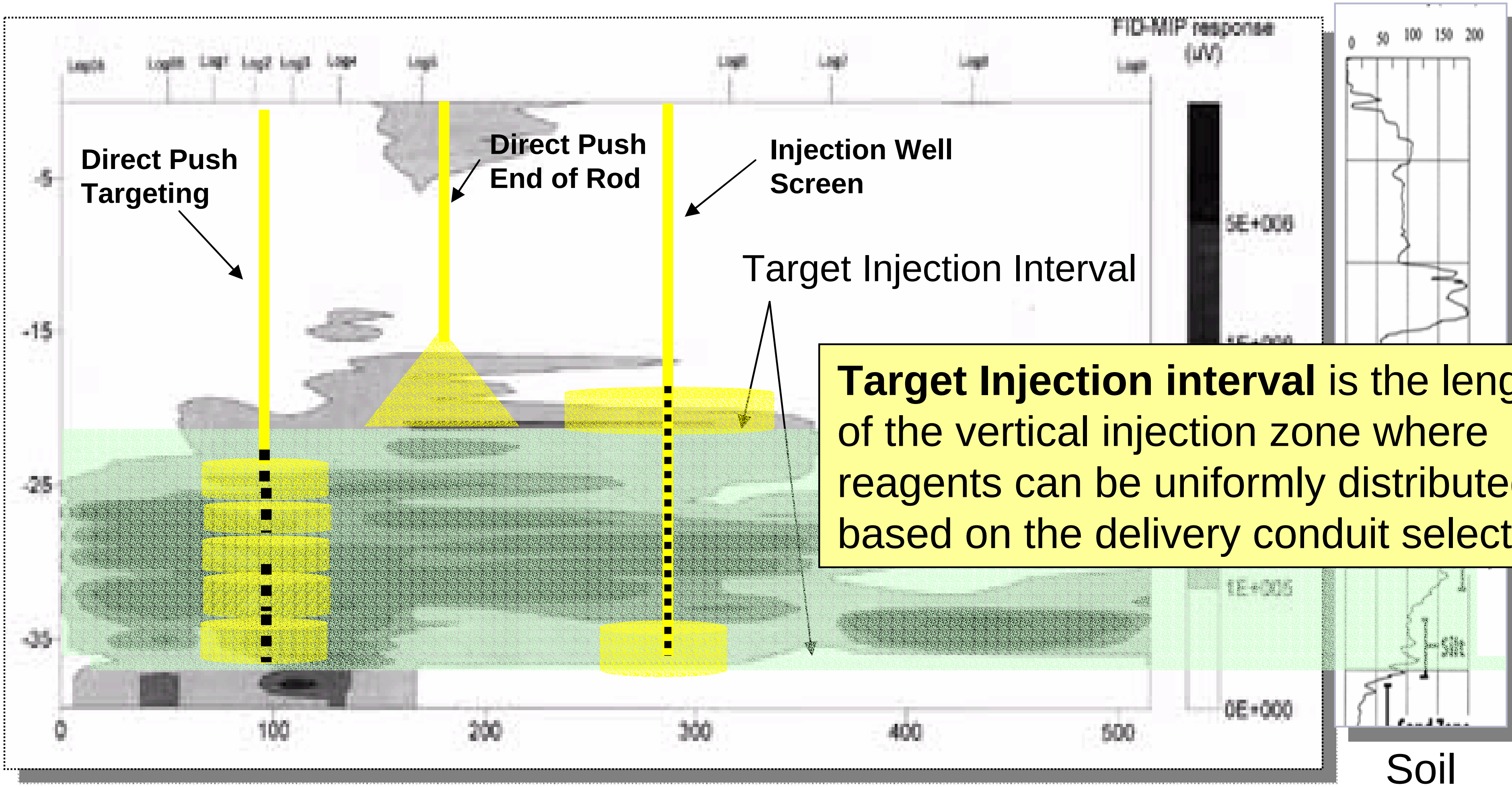
Contaminant Mass

Soil Conductivity

Delivery: Conduit

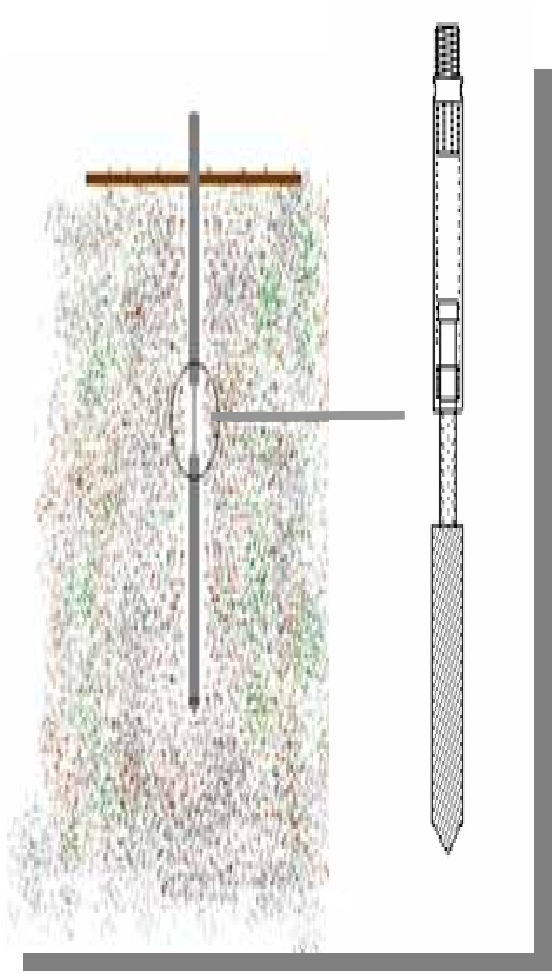
Technology	Injection Zone Targeting	Specifications	Reagent Considerations	Limitations	Injection Locations
DPT	1 foot Interval targeting	1.5" O.D. injection tooling 18,000 to 31,000 lbs of pushing force 40 to 110 feet	Bioremediation – None Oxidant - Peroxide surfacing Persulfate Acidity	Unconsolidated soils and bedrock	Moveable
Injection Wells	Multiple screens Use of packers to isolate deep intervals	1” I.D. to 4” I.D PVC (Schedule 40 or 80), black iron, stainless steel DPT Installed Pre-packed	Bioremediation – Flush well Oxidants - Stainless steel for oxidant heat generation (e.g. DNAPL) Peroxide surfacing	Fixed injection locations Reagents preferential flow to higher permeable intervals within injection screen	Fixed

Target Interval Conduit Strategies



Target Injection interval is the length of the vertical injection zone where reagents can be uniformly distributed based on the delivery conduit selected.

Target Interval: DPT Injection Tooling

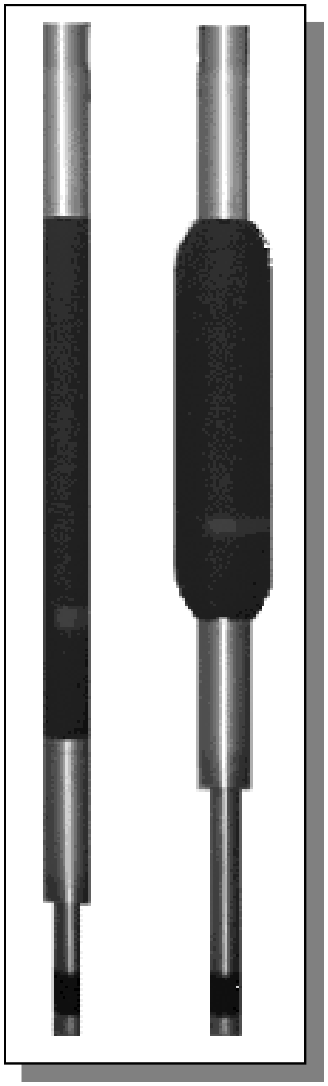


- Target injection zones
- Inject consistently through the formation
- Inject while advancing or retracting
- Check valve retains the compound in the subsurface

Target Interval: Pre-Packed Stainless Steel Injection Wells

Size	Feet
3/4”	2.5, 5
1”	2.5, 5
1-1/4”	2.5, 5
1-1/2”	2.5, 5
2”	2.5, 5

Target Interval: Packer Isolation



- 2" PVC Injection wells to 175'

Methodology Overview

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Delivery: Reagents

Reagent	Injection Concentrations	Catalyzed	Injection Considerations
Hydrogen Release, e.g. HRC, HRC-X	100%	Bio-Augmentation, e.g. INOCULUM	Viscous material requires heating
Oxygen Release, e.g. ORC	30 to 40%	None	None
Hydrogen Peroxide	5 to 17%	Iron Chelated Iron	Gas generation, heat and surfacing Catalyst and peroxide injected separately Gas generation can impede injection rates in fractured bedrock
Potassium Permanganate	3 to 4%	None	None
Sodium Permanganate	10% to 20%	None	None
Sodium Persulfate	10% to 20%	Iron, Chelated Iron, Heat, Peroxide	Catalyst and persulfate can be mixed and injected together. Acidic

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Injection Design: Reagent Mass

Treatment Zone			Stoichiometric Reagent Requirements (Lbs.)						Injected Reagent Requirements (Lbs)	
Injection Intervals (Ft to Ft bgs)	Treatment Area (Ft^2)	Treatment Interval (YD^3)	Scavenging & NOD	Dissolved Phase	Sorbed Phase	Residual NAPL	Free Phase NAPL	Total	In-Situ Efficiency %	Total Reagent Injected

Treatability Studies

In-Situ Efficiency %

Vendor Calculators

Target Injection Interval is the length of the vertical injection zone where reagents can be uniformly distributed based on the delivery conduit selected.

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Delivery: Pumps - Viscous, Low Volume

	Viscous, Low Volume Reagents, e.g. HRC or HRC-X				
Hydraulic Conductivity	Pumps	Max Injection Pressure	Max Injection Rate	Max ROI	Other Distribution
Low < 3 ft/day	Piston Pump	1500 PSI	9 GPM	2 feet	Advection, Diffusion, Dispersion
High > 3 ft/day	Piston Pump	1500 PSI	9 GPM	2 feet	Advection, Diffusion, Dispersion

Delivery: Pumps - Non-Viscous, Low Volume

	Non - Viscous, Low Volume Reagents, e.g. ORC				
Hydraulic Conductivity	Pumps	Max Injection Pressure	Max Injection Rate	Max ROI	Other Distribution
Low < 3 ft/day	Piston Pump	1500 PSI	9 GPM	2 feet	Advection, Diffusion, Dispersion
High > 3 ft/day	Piston Pump	1500 PSI	9 GPM	2 feet	Advection, Diffusion, Dispersion

Delivery: Pumps – Non-Viscous, High Volume

	Hydrogen Peroxide / Fenton's Reagent - Short Lived				Sodium Persulfate, Permanganate, Hydrogen Donor Compounds - Persistent			
Hydraulic Conductivity	Pumps	Max Injection Pressure	Max Injection Rate	Max ROI	Pumps	Max Injection Pressure	Max Injection Rate	Max ROI
Low < 3 ft/day	Bladder	120 PSI	1 gpm	5 feet	Positive Displace ment	2500 PSI	10 gpm	10 feet + Dispersion
High > 3 ft/day	Bladder	120 PSI	15 gpm	15 feet	Bladder Moyno Positive Displace ment	50 -1600 PSI	30 GPM	20 feet + Dispersion

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Injection Design: ROI and Reagent Volume

Treatment Intervals (Ft-Ft bgs)	Hydraulic Conductivity (Ft/Day)	Reagent (Lbs)	Reagent (Gals)	ROI (FT)	Injection Volume as a % Pore Volume	DPT or Fixed Well	# Injection Locations	Screen Length or Injection target interval (Ft)

Regulatory Issues

DPT Allows More Conservative Spacing

ROI is a function of interval screen length or DPT targeting, injection pressure, reagent/flush volume, reagent persistence, and dispersion. Confirmation through pilot testing.

Injection volume = (reagent mass / reagent solubility) x reagent inefficiency (e.g. gas generation)

Hydraulic Conductivity

- Pneumatic slug tests
- Cone Permeameter

Injection Design: Duration / # of Events

Treatment Intervals (Ft-Ft bgs)	Porosity (%)	Reagent (Gals)	PUMP Pressure (PSI)	Injection Rate (GPM)	Injection Volume as a % Pore Volume	# of Injection Events	Injection Time Per Event (Hrs)	Injection Efficiency (%)	Total Injection Time Per Event (8 hour days)

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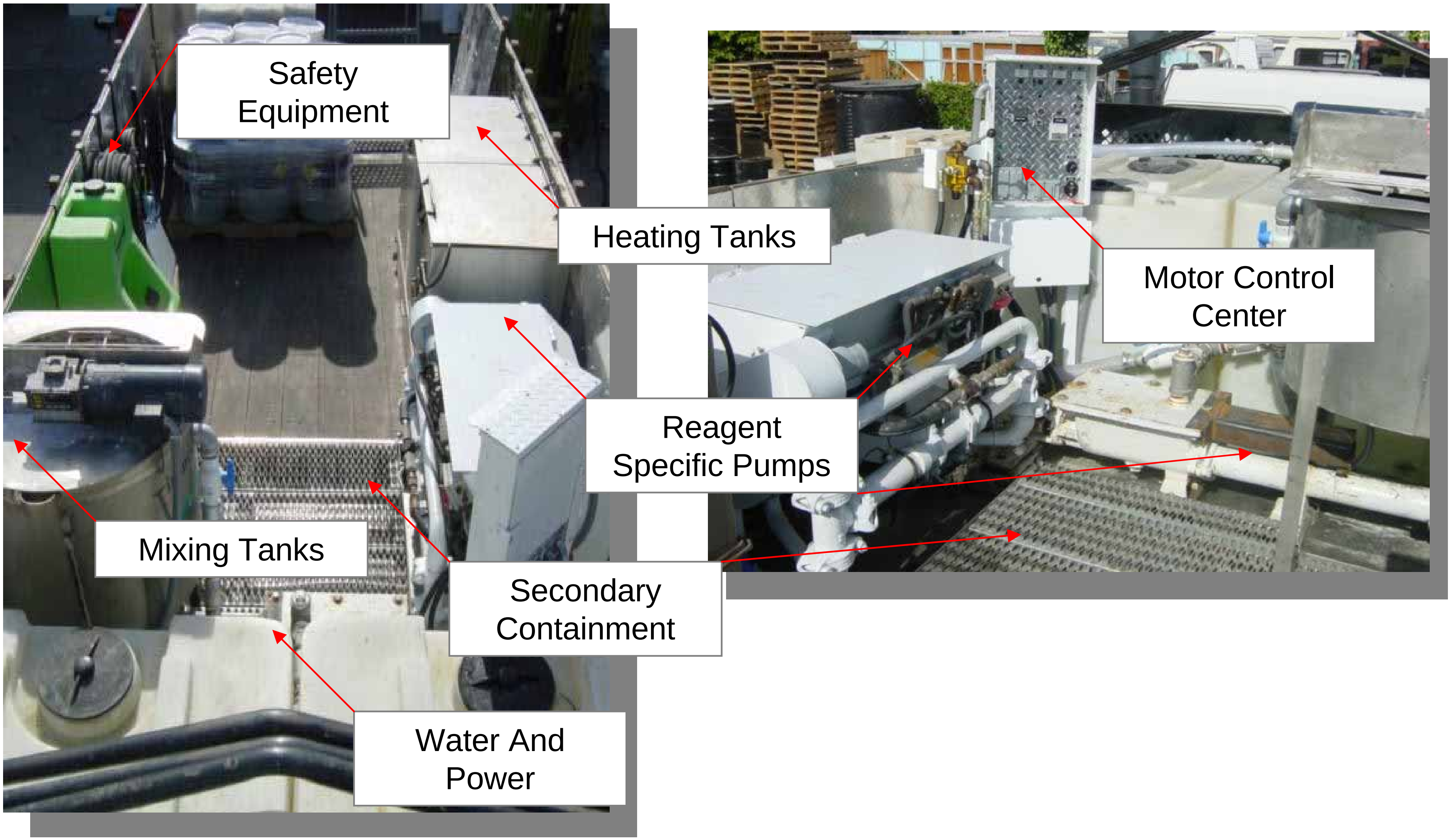
Function Contaminant Ma

Injection Efficiency

Function of Contaminant Contact

Injection efficiency = hours of injection at design rate / available injection hours

Injection Efficiency: Dedicated Injection Rigs



Key Takeaways

- The MIP = definition of target intervals.

- Remediation success = effective delivery of reagents into the target intervals.

- Methodology = Accelerated site closure, improved performance, and reduced costs.