ISBRs for Effective Bioremediation of Chlorinated Hydrocarbons in Deep Aquifers

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Bio-Enhance/E&LP
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Microbial Insights Inc.
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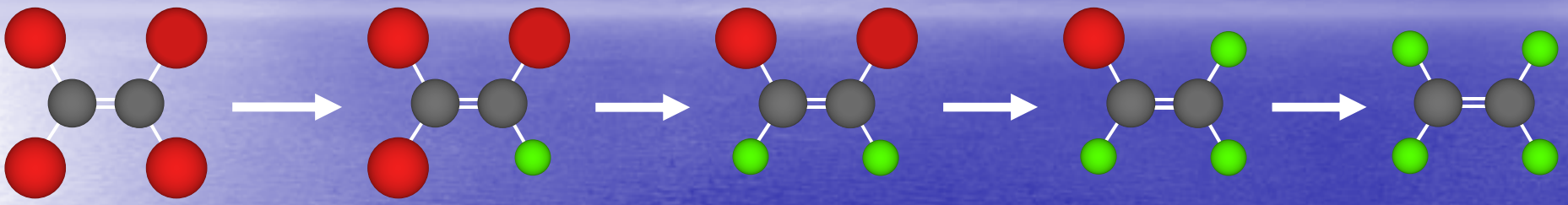
Sustained Anaerobic Bio-Augmentation via Bio-Reactors

Bio-Trap® Sampler with Bio-Sep® Beads

Sustained Anaerobic Bio-Augmentation via Bio-Reactors?

Bio-Trap® Sampler with Bio-Sep® Beads

What is the problem?



PCE **TCE** ***cis*-DCE** **VC** **ETH**

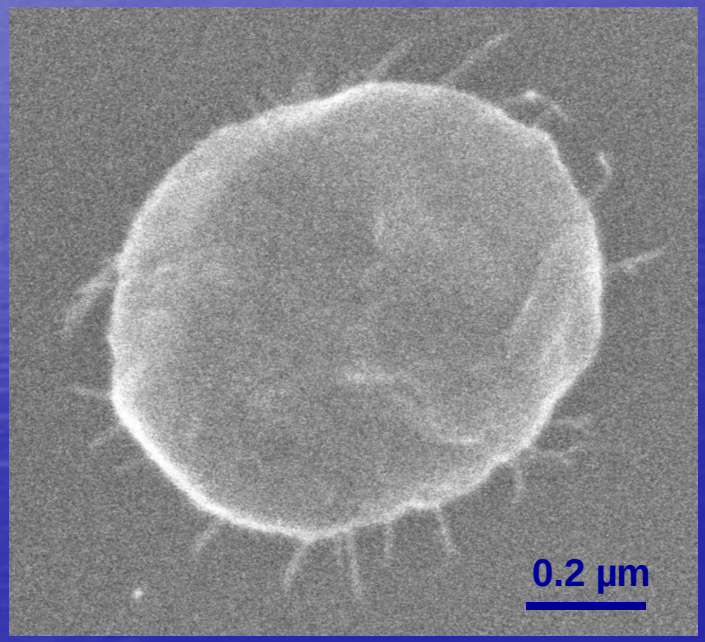
- Under reducing conditions, a variety of microorganisms reductively dechlorinate PCE to TCE or dichloroethenes (DCEs)

- **Stole from Kirsti M. Ritalahti**
- UNIVERSITY of TENNESSEE

For sustained bio-augmentation

1. Fermentation
2. Matrix
3. Contamination

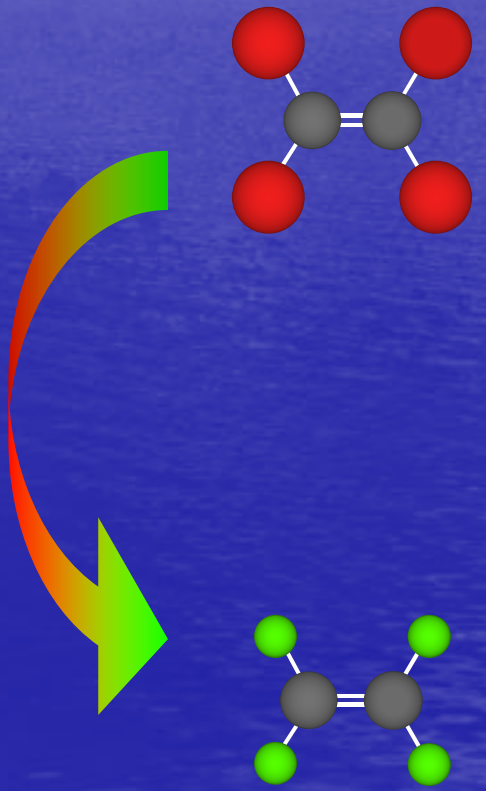
Dehalococcoides



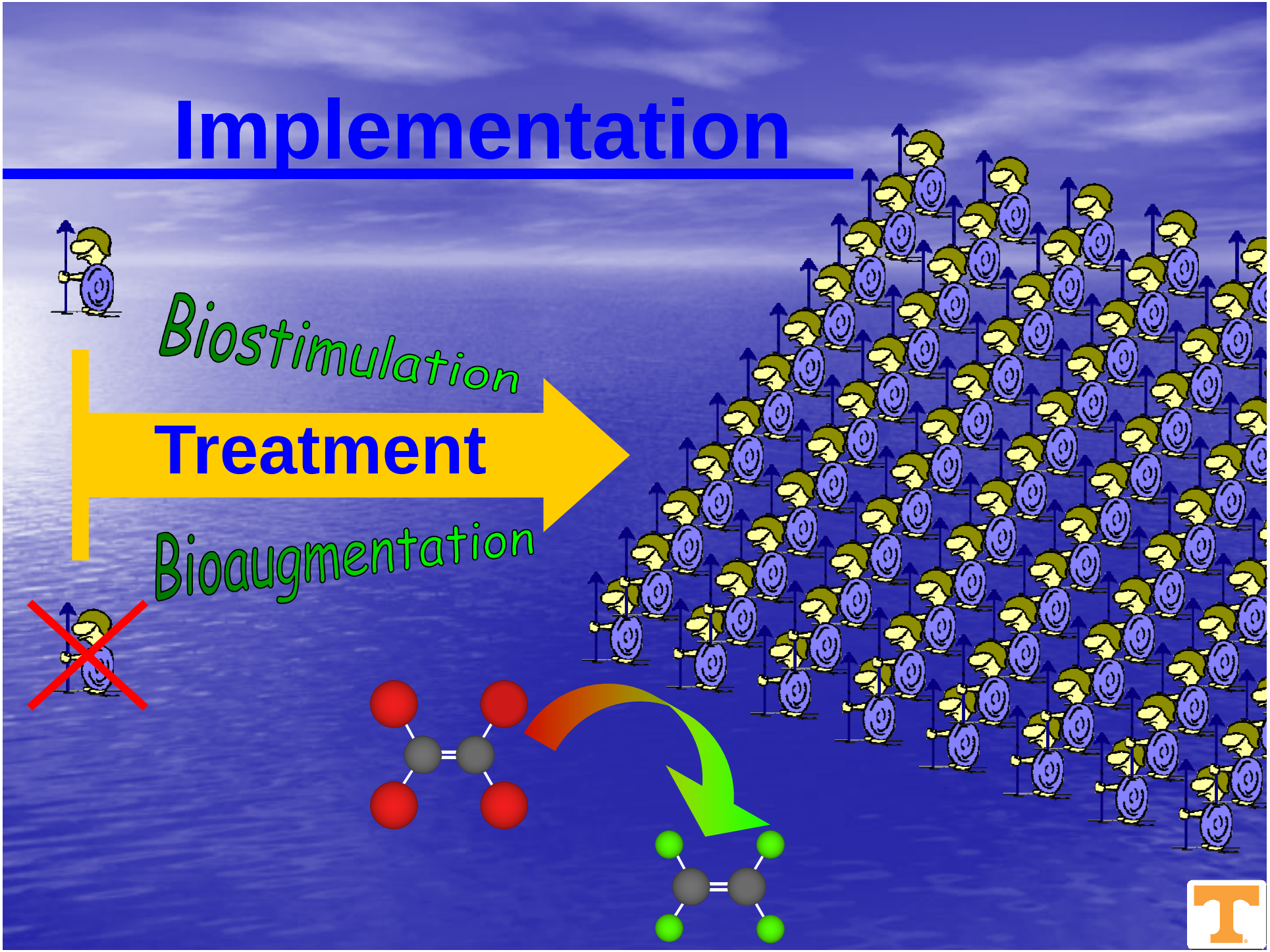
Complete Detoxification

Encouragement

H_2



Implementation

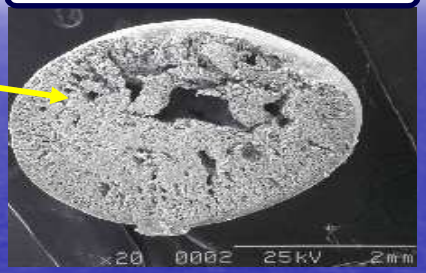


In the beginning…..

Bio-Trap® Sampler with Bio-Sep® Beads

Nomex and PAC

X-Section of Bio-Sep® Bead

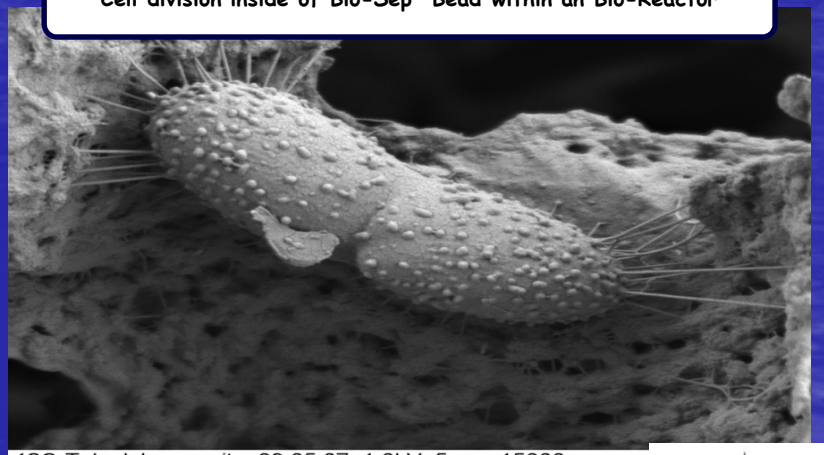


Interior of Bio-Sep® Bead

The Bio-Trap® Sampler:

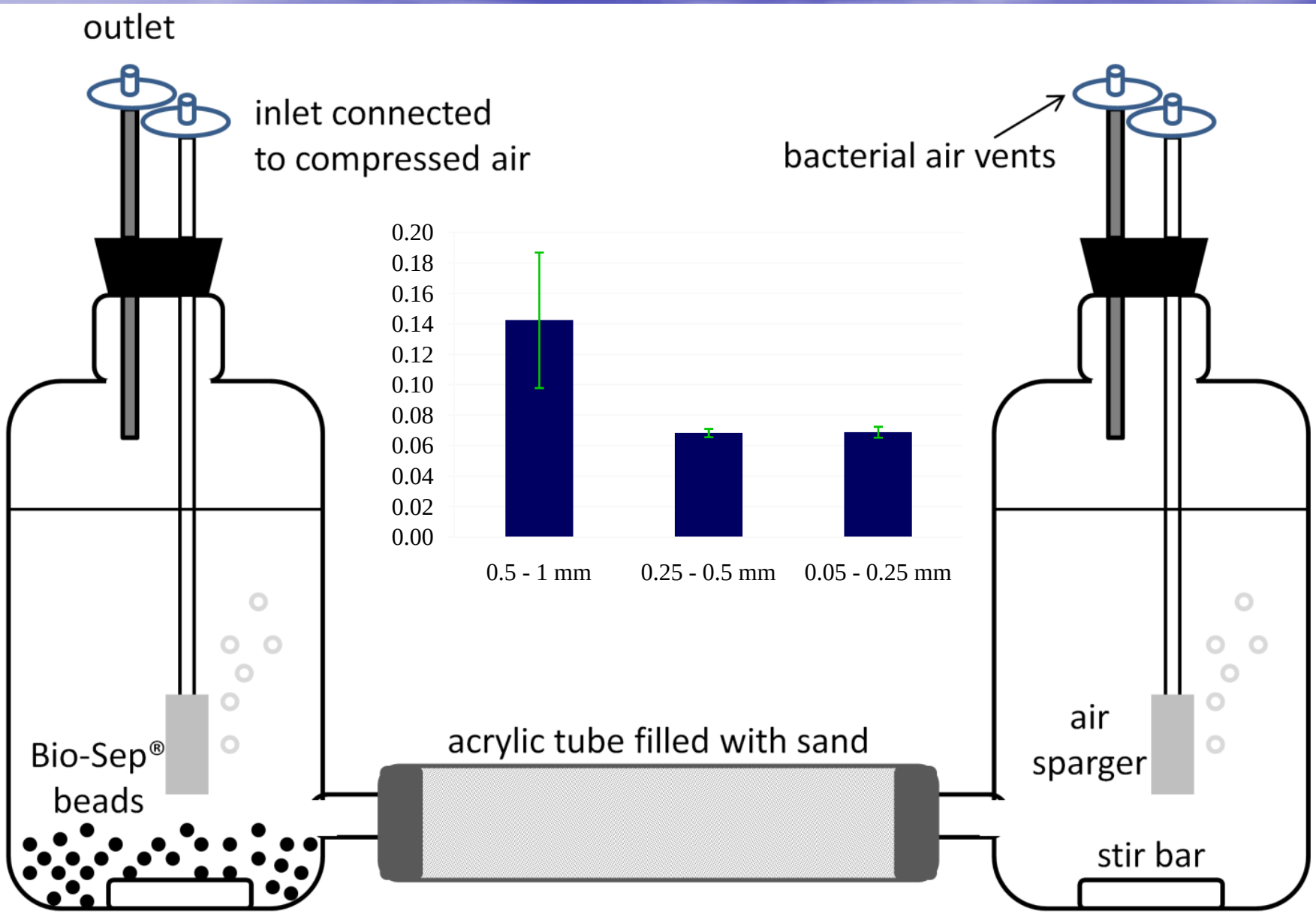
- Rapidly colonized by indigenous bacteria forming active biofilms
- Thousands used worldwide for over a decade for forensic analysis of groundwater microbiology

Cell division inside of Bio-Sep® Bead within an Bio-Reactor



THE UNIVERSITY of TULSA

Microbial Release and Transport Study



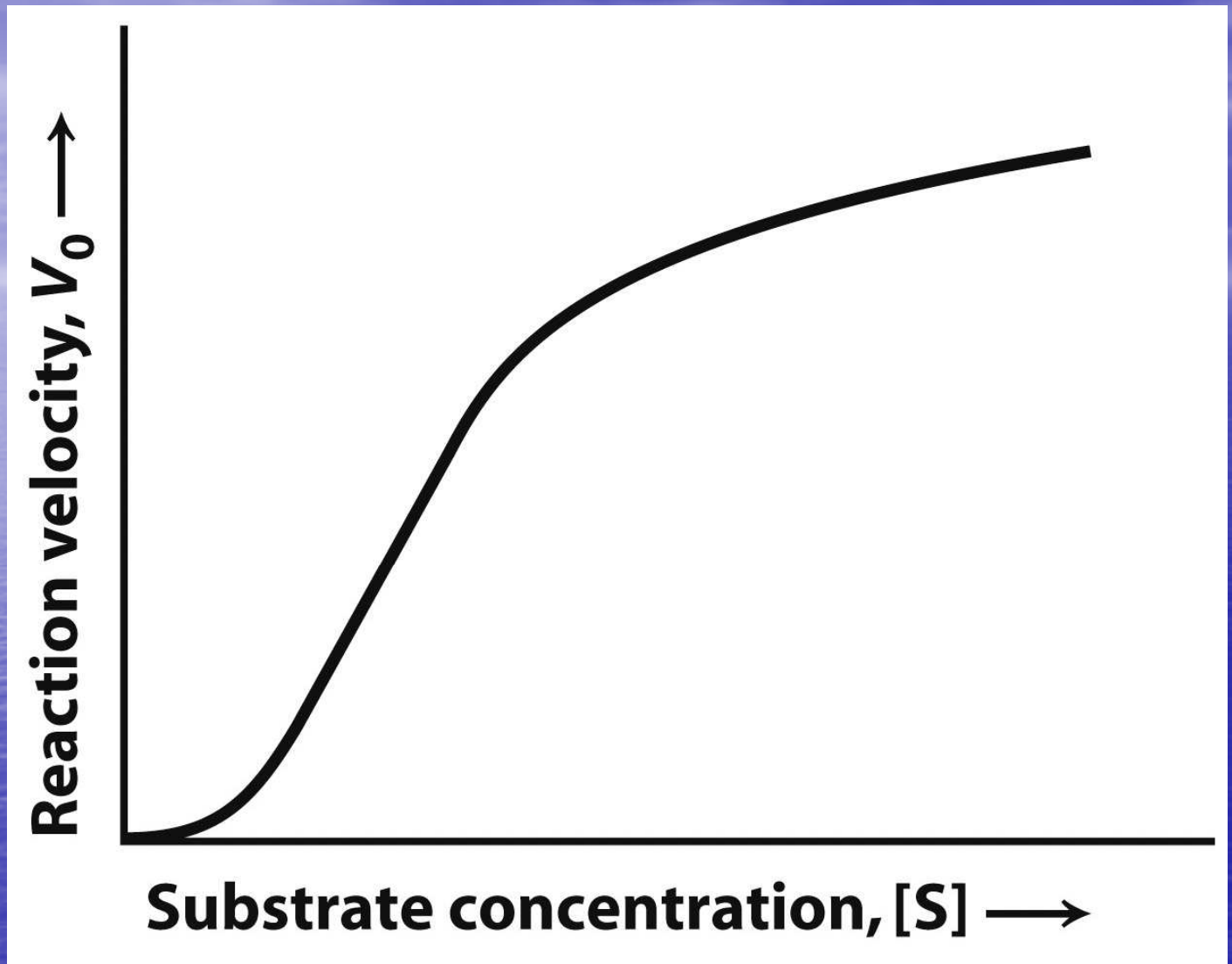


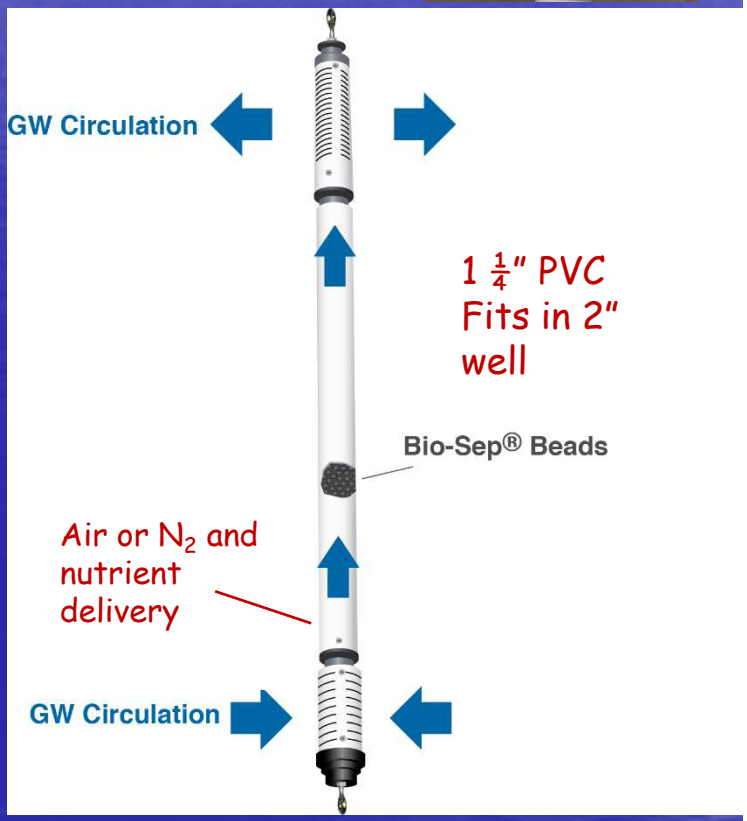
Figure 8.13
***Biochemistry*, Seventh Edition**

The Bio-Sep *In Situ* Bioreactor (ISBR)

- Enhancement of *in situ* bioremediation in groundwater with compact bioreactor installed in-well
- Overcomes common limitations of bioremediation of groundwater
  - **Low contaminant** concentrations
    - A threshold concentration of substrate is required for growth
  - Substrate inhibition
    - At high concentrations some biodegradable contaminants can be toxic to the organisms that have the ability to degrade them

The Bio-Enhance ISBR

- Bio-Sep beads provide an incredible surface area for microbial growth
- Gas sparging (air or N_2) creates an airlift for circulation of groundwater through the bioreactor.
  - Contaminated groundwater is treated as it moves through the column of Bio-Sep beads
- Nutrient addition (N, P, electron donors, electron acceptors) support growth of desired indigenous microbes
- Water exiting the reactor carries contaminant-degrading microbes into the aquifer



BioEnhance

Topside control

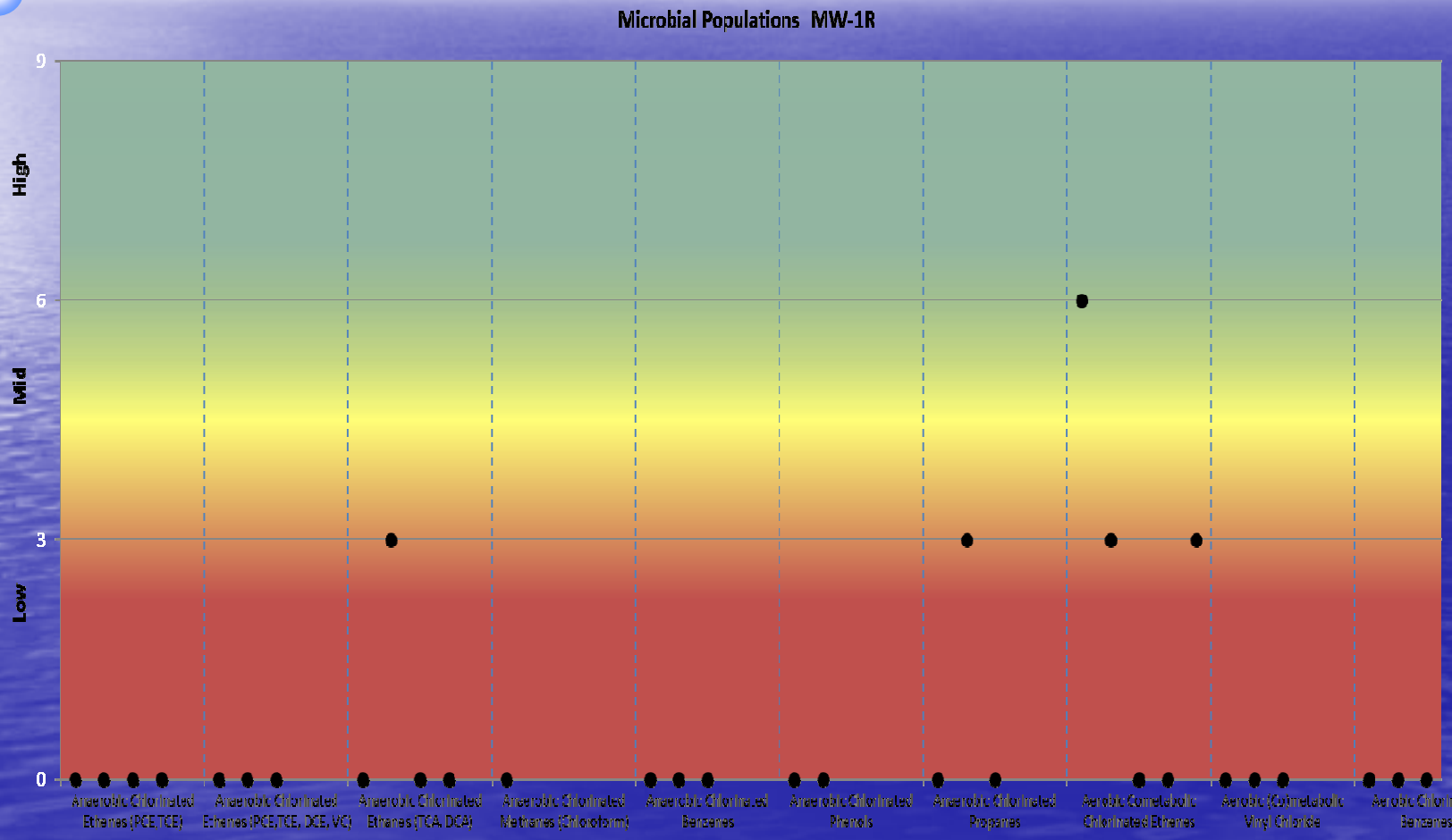
- Nutrient reservoirs and pumps
- Air pump
- Air flow control

Case Study 1: Low Levels PCE/TCE in glacial till

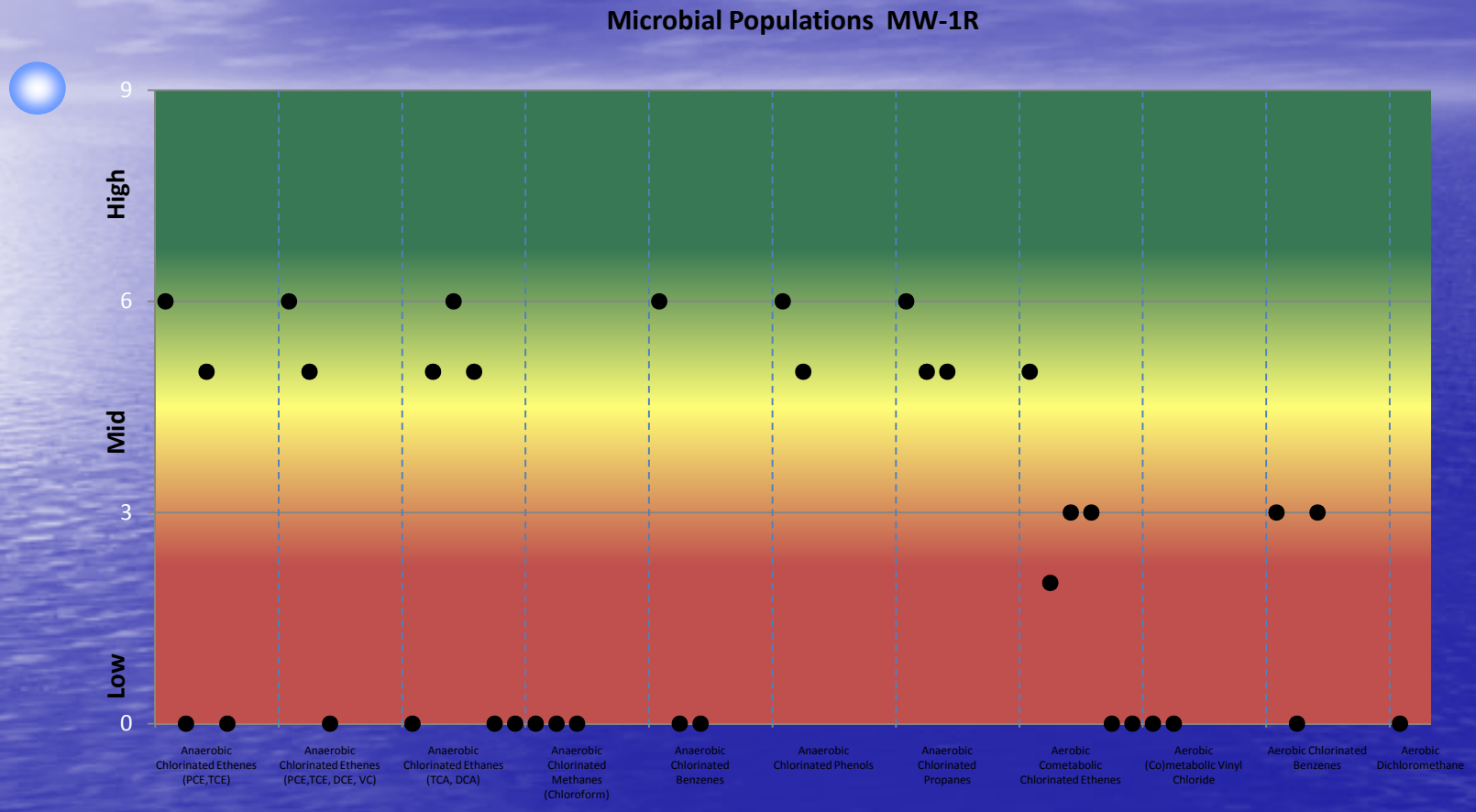
- Low Permeability Soils
  - Fresh Release
- No Reductive Dechlorinating Bacteria Measured

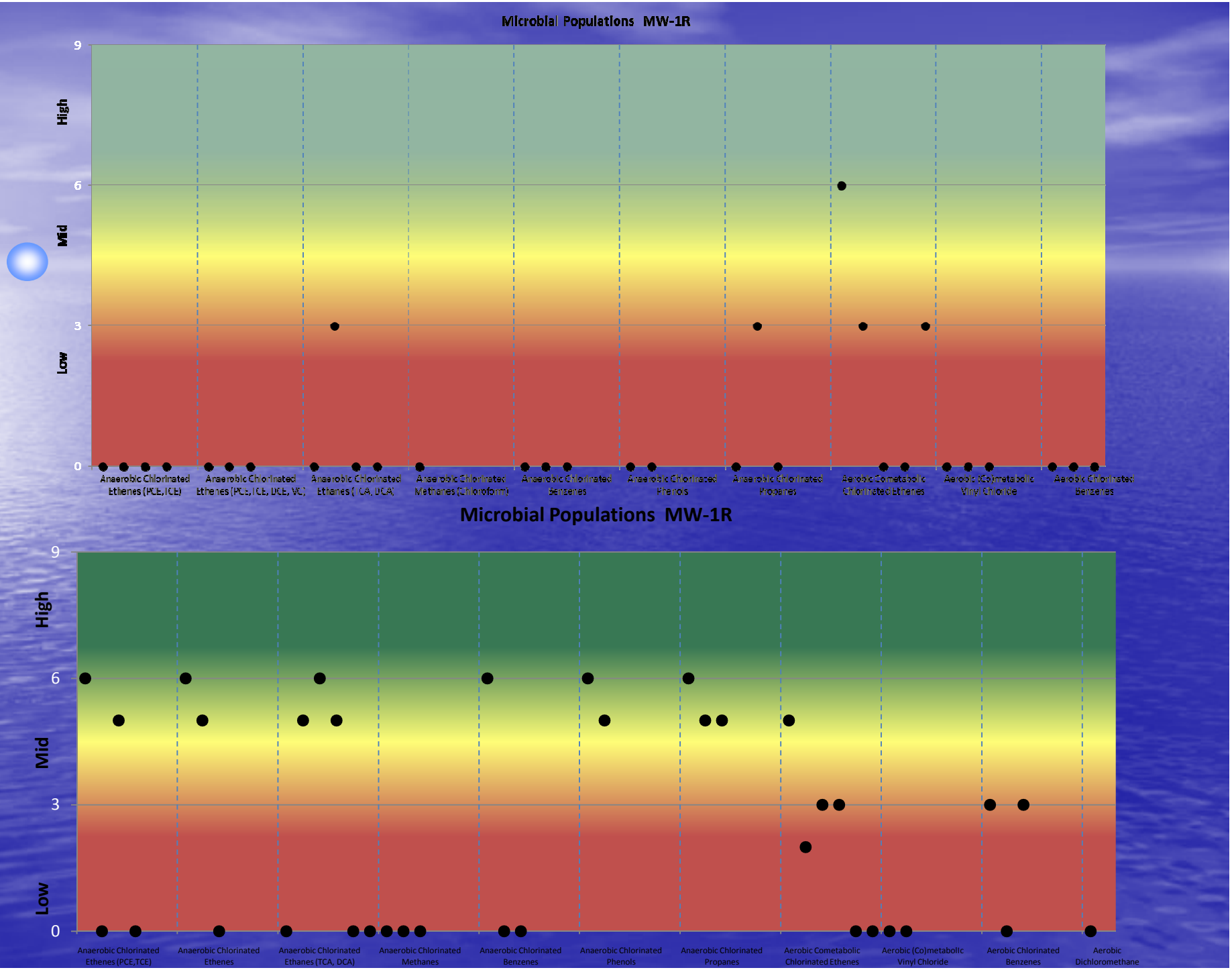
Thanks for Nothing

No Dechlorinating Bacteria
Fresh PCE Release

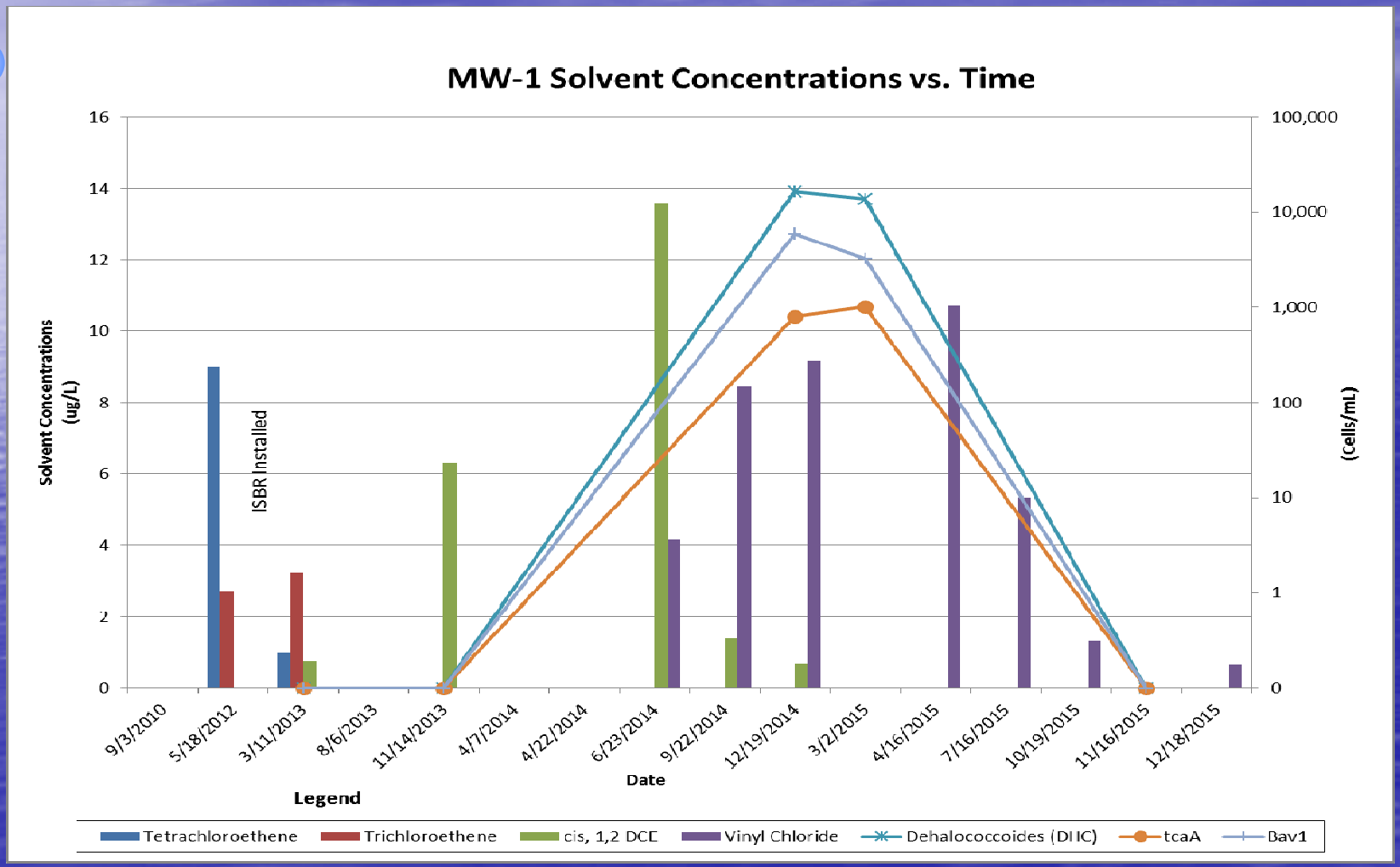


That's not Nothing!!



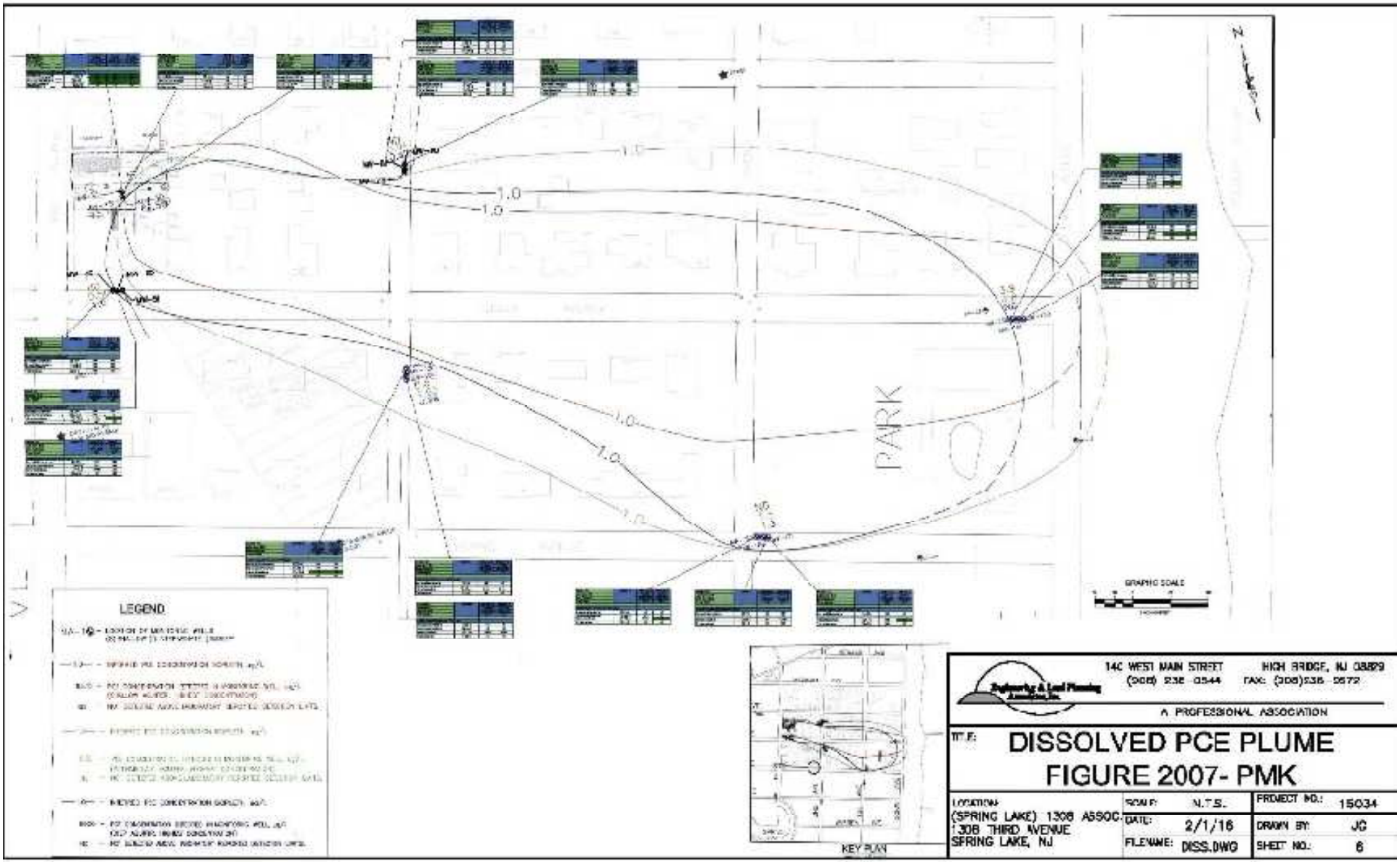

Microbial Populations MW-1R
High
Mid
Low
9
6
3
0
Anaerobic Chlorinated Ethenes (PCE, TCE)
Anaerobic Chlorinated Ethenes (PCE, TCE, DCE, VC)
Anaerobic Chlorinated Ethanes (TCA, DCA)
Anaerobic Chlorinated Methanes (Chloroform)
Anaerobic Chlorinated Benzenes
Anaerobic Chlorinated Phenols
Anaerobic Chlorinated Propanes
Aerobic Cometabolic Chlorinated Ethenes
Aerobic (Co)metabolic Vinyl Chloride
Aerobic Chlorinated Benzenes
Microbial Populations MW-1R
High
Mid
Low
9
6
3
0
Anaerobic Chlorinated Ethenes (PCE,TCE)
Anaerobic Chlorinated Ethenes
Anaerobic Chlorinated Ethanes (TCA, DCA)
Anaerobic Chlorinated Methanes
Anaerobic Chlorinated Benzenes
Anaerobic Chlorinated Phenols
Anaerobic Chlorinated Propanes
Aerobic Cometabolic Chlorinated Ethenes
Aerobic (Co)metabolic Vinyl Chloride
Aerobic Chlorinated Benzenes
Aerobic Dichloromethane

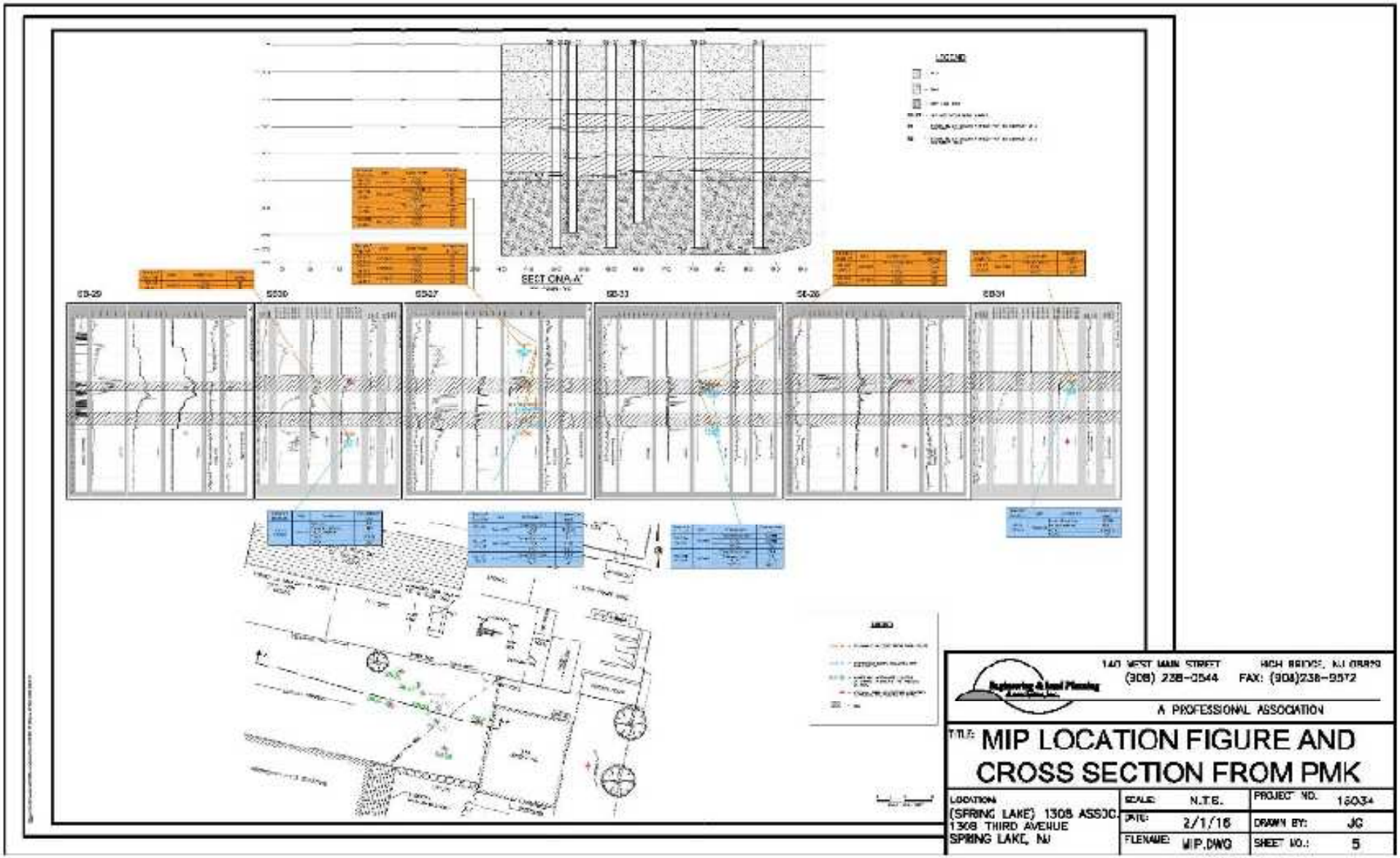
Thanks for Nothing



Case Study 2: Multi-Level Deed Sand Aquifer, combined with Plume Stop

- Dry Cleaner
- Plume Extends 1 Mile Off Site
- Confining Layers Leak


LEGEND
PARK
1.0
GRAPHIC SCALE
KEY PLAN
140 WEST MAIN STREET
HIGH BRIDGE, NJ 08829
(908) 238-0544
FAX: (908)536-0672
A PROFESSIONAL ASSOCIATION
TITLE:
DISSOLVED PCE PLUME
FIGURE 2007- PMK
LOCATION:
(SPRING LAKE) 1308 ASSOC.
1308 THIRD AVENUE
SPRING LAKE, NJ
SCALE: N.T.S.
DATE: 2/1/16
FILENAME: DISS.DWG
PROJECT NO.: 15034
DRAWN BY: JC
SHEET NO.: 6



140 WEST MAIN STREET HIGH BRIDGE, N.J. 08829
(908) 238-0544 FAX: (908)238-9572
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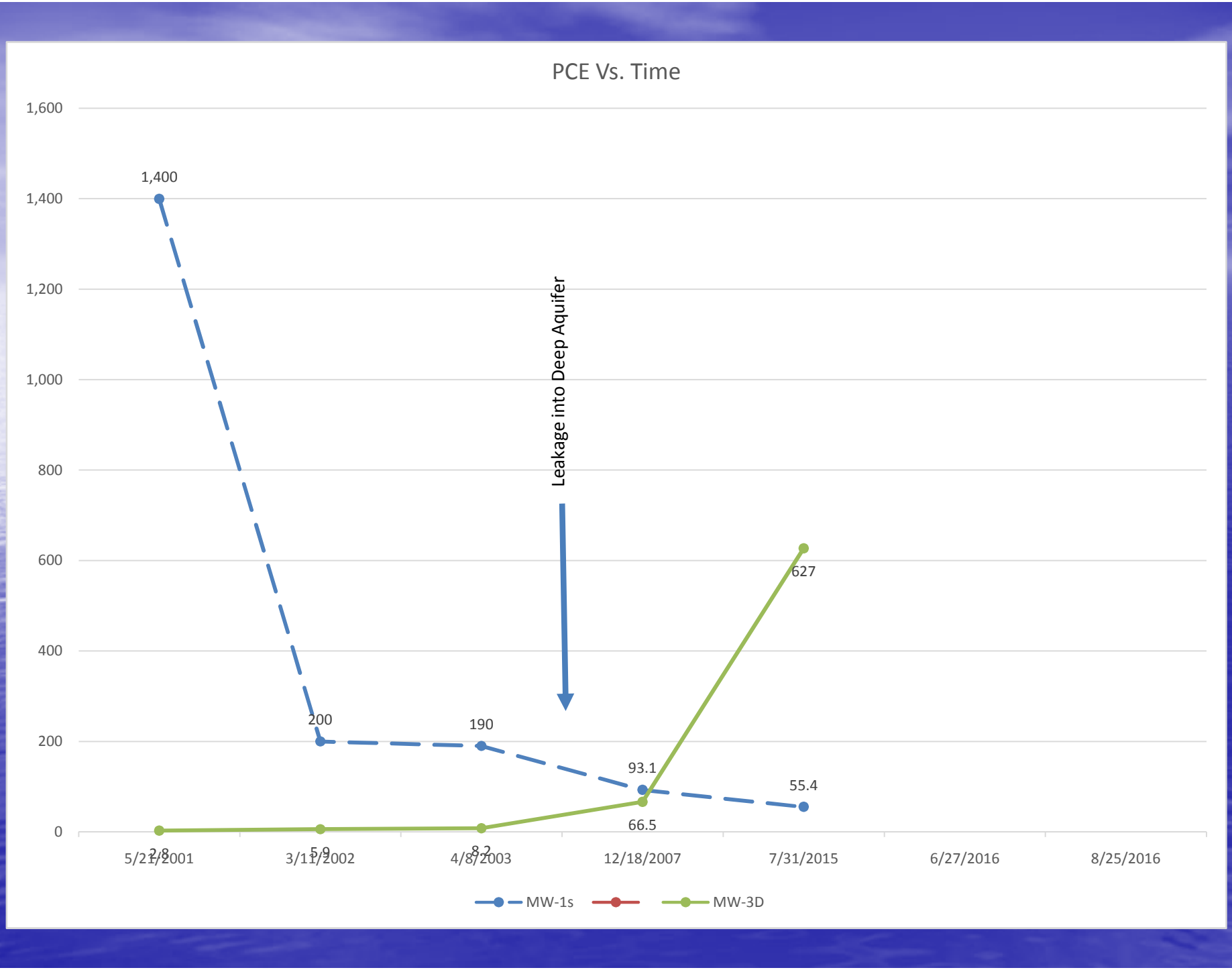
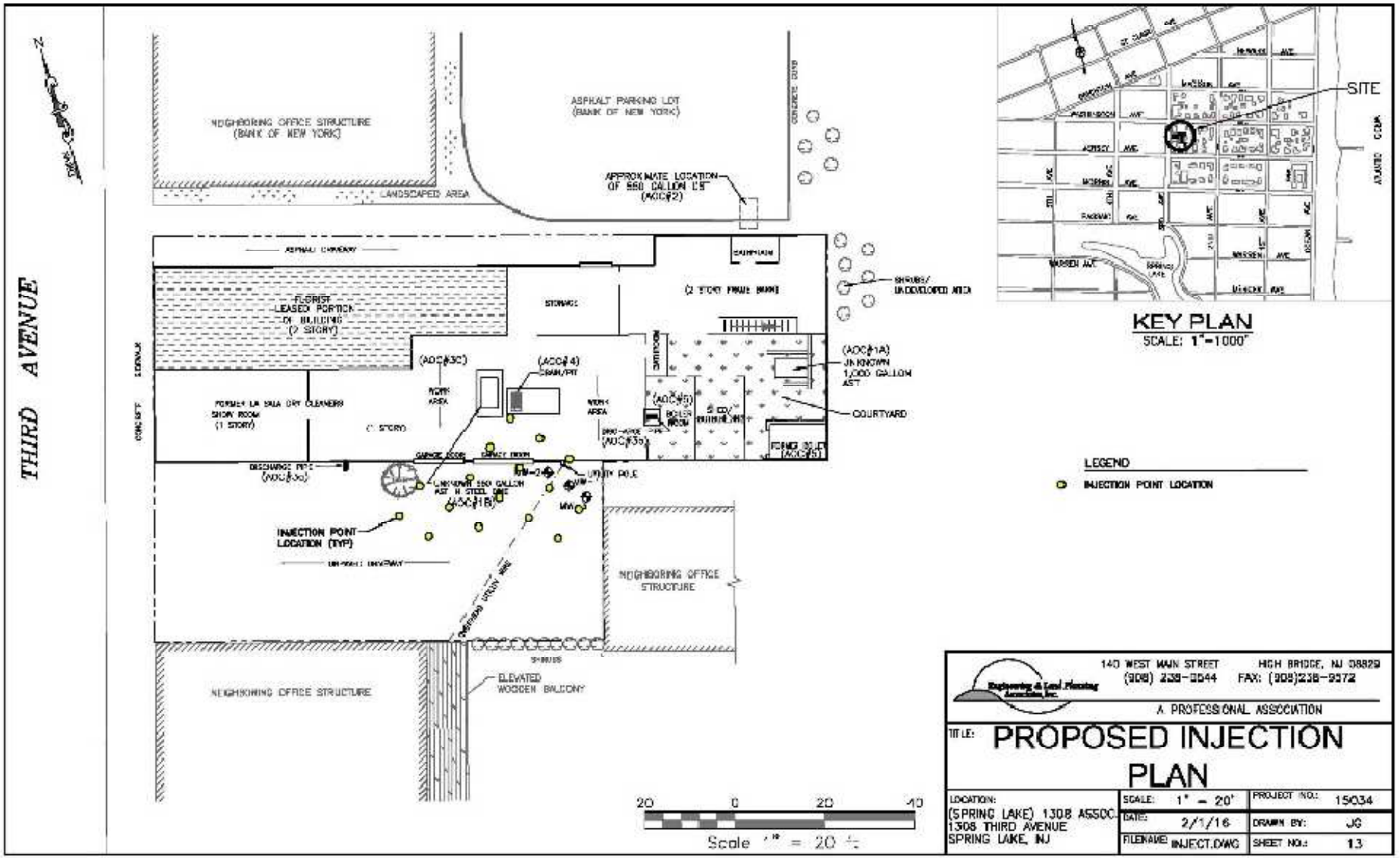
TITLE: MIP LOCATION FIGURE AND CROSS SECTION FROM PMK

LOCATION: (SPRING LAKE) 1308 ASSOC. 1308 THIRD AVENUE SPRING LAKE, NJ	SCALE: N.T.S.	PROJECT NO.	16034
	DATE: 2/1/16	DRAWN BY:	JC
	FILENAME: MIP.DWG	SHEET NO.:	5


PCE Vs. Time
1,600
1,400
1,200
1,000
800
600
400
200
0
1,400
200
190
93.1
55.4
627
66.5
2.8
5.9
8.2
Leakage into Deep Aquifer
5/21/2001
3/11/2002
4/8/2003
12/18/2007
7/31/2015
6/27/2016
8/25/2016
MW-1s
MW-3D

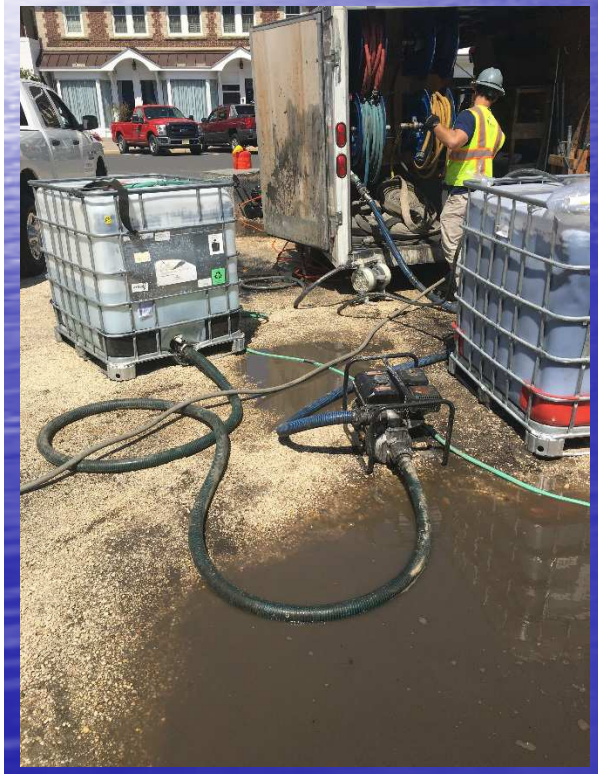


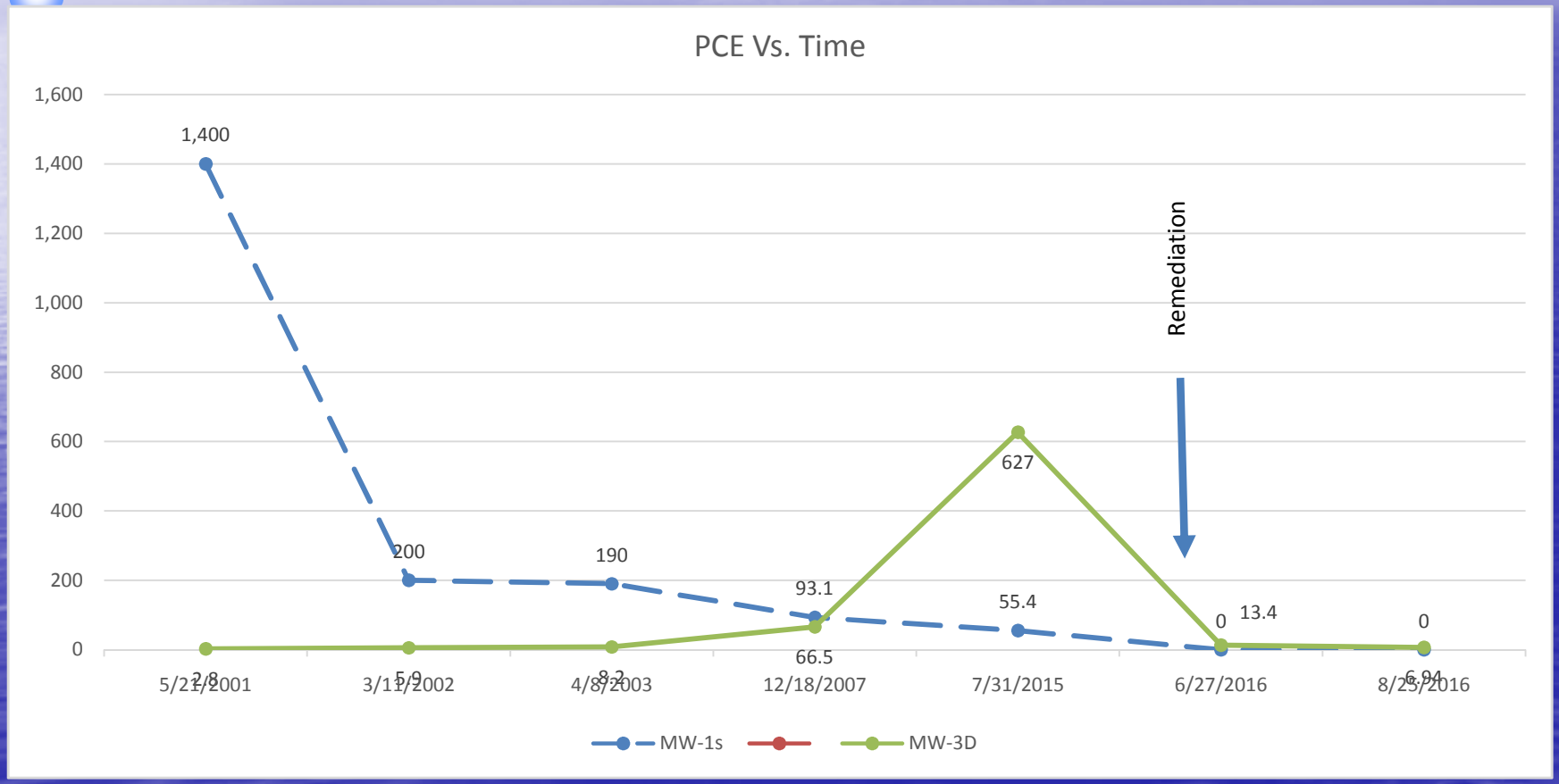
Engineering & Land Planning Associates, Inc.
140 WEST MAIN STREET HIGH BRIDGE, NJ 08829
(908) 238-0044 FAX: (908)238-9372
A PROFESSIONAL ASSOCIATION

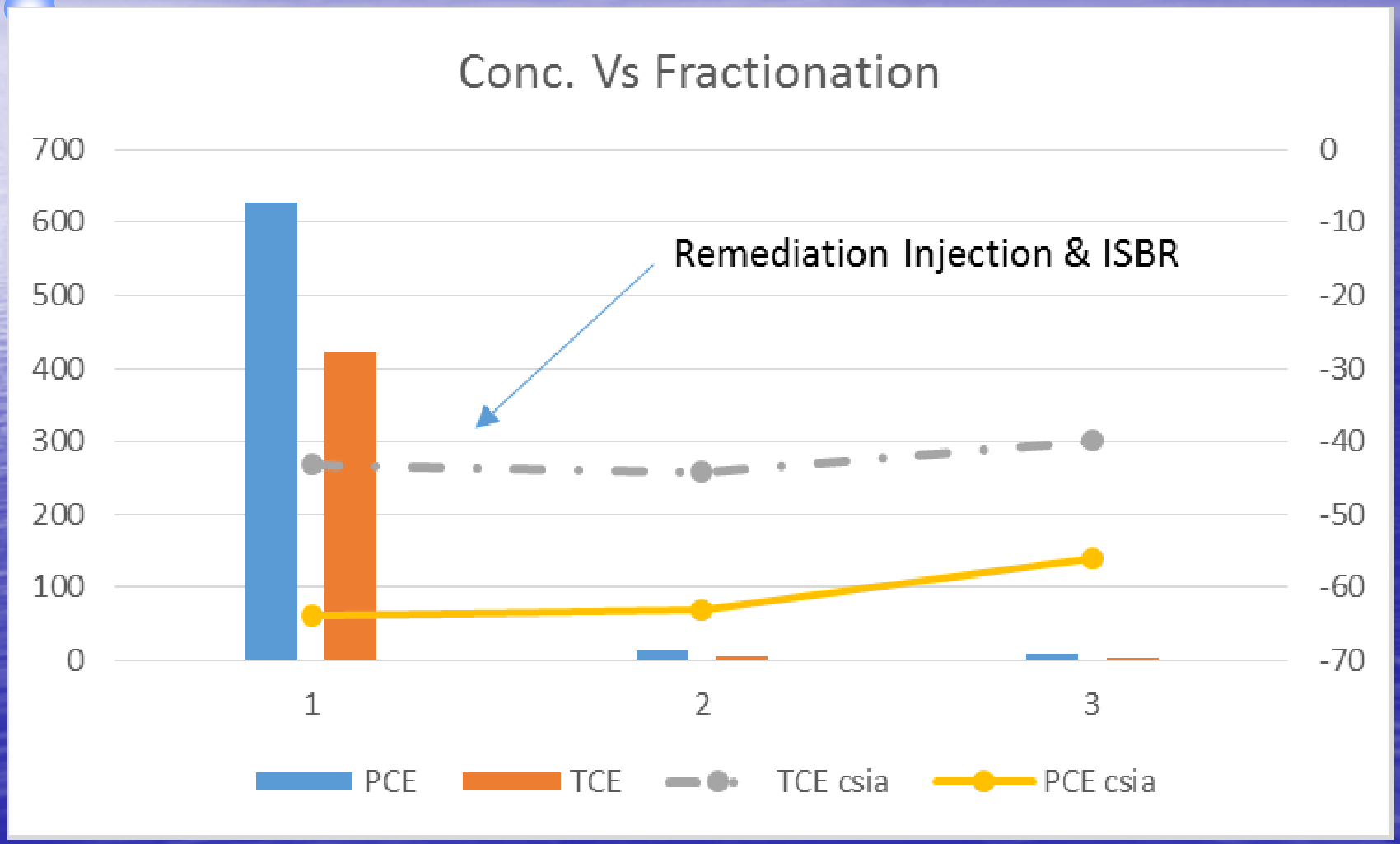
TITLE: **PROPOSED INJECTION PLAN**

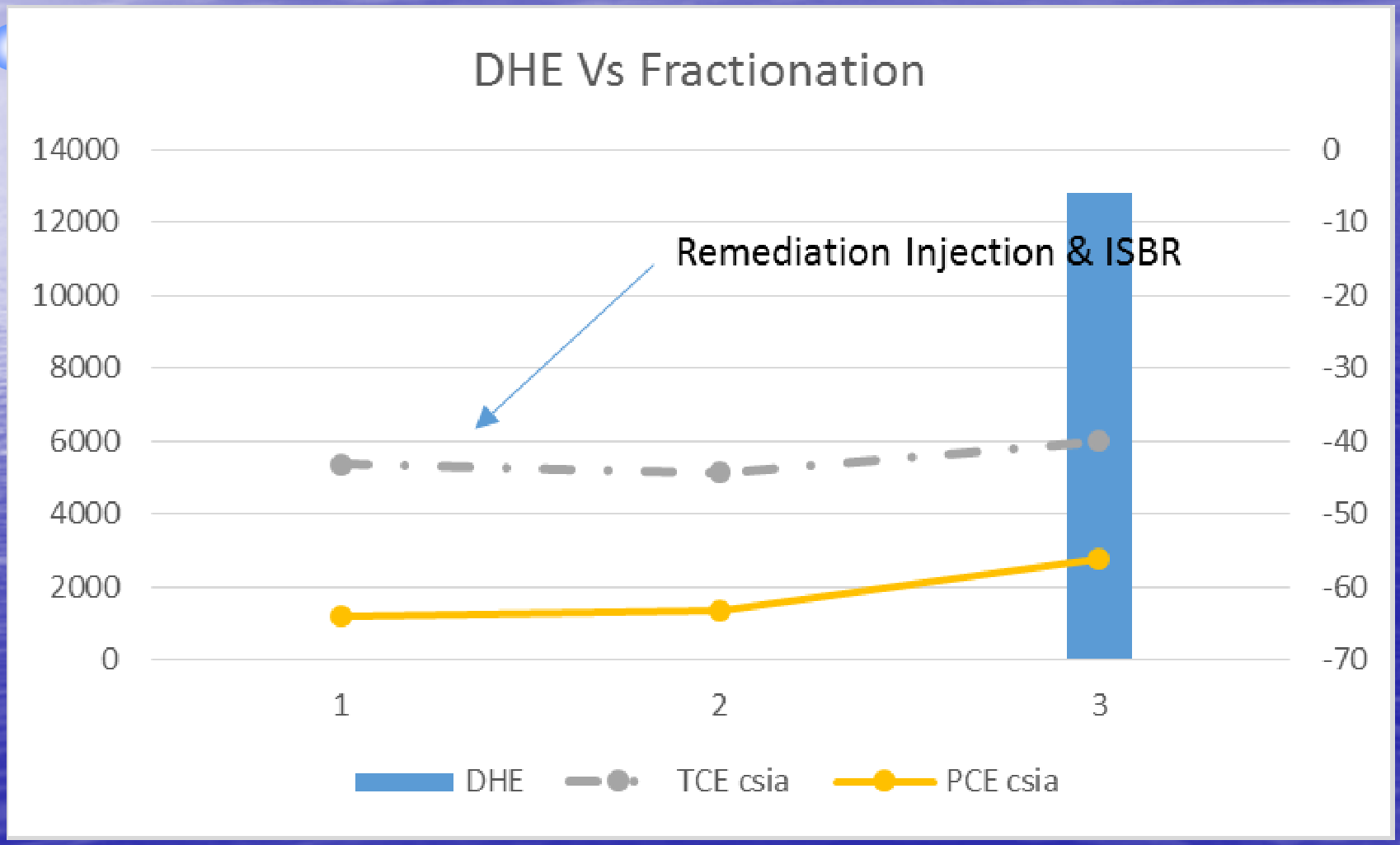
LOCATION: (SPRING LAKE) 1308 ASSOC. 1308 THIRD AVENUE SPRING LAKE, NJ	SCALE: 1" = 20'	PROJECT NO.: 15034
	DATE: 2/1/16	DRAWN BY: JG
	FILENAME: INJECT.DWG	SHEET NO.: 13

Treatment Train, Vintage HRC, Plume Stop and ISBR

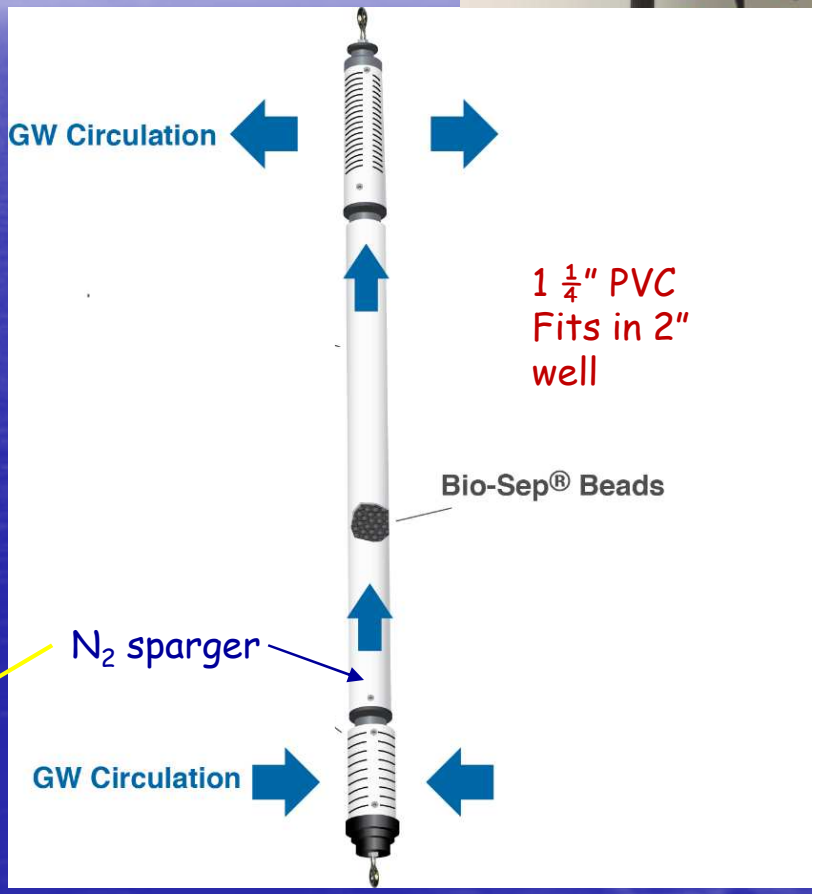



PCE Vs. Time
1,600
1,400
1,200
1,000
800
600
400
200
0
1,400
200
190
93.1
55.4
0
13.4
0
627
66.5
2.8
5.9
8.2
6.94
Remediation
5/21/2001
3/11/2002
4/8/2003
12/18/2007
7/31/2015
6/27/2016
8/25/2016
MW-1s
MW-3D


Conc. Vs Fractionation
700
600
500
400
300
200
100
0
0
-10
-20
-30
-40
-50
-60
-70
Remediation Injection & ISBR
1
2
3
PCE
TCE
TCE csia
PCE csia


DHE Vs Fractionation
14000
12000
10000
8000
6000
4000
2000
0
0
-10
-20
-30
-40
-50
-60
-70
Remediation Injection & ISBR
1
2
3
DHE
TCE csia
PCE csia

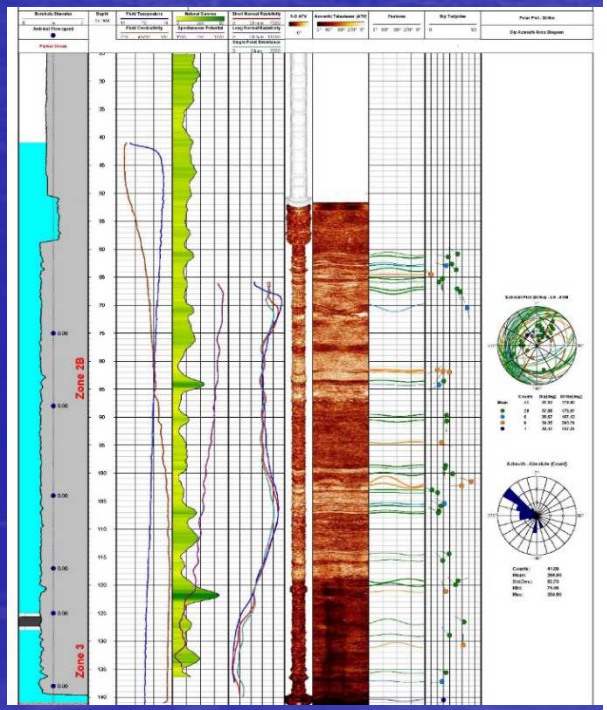
Anaerobic ISBRs, the same but different



Case Study 3: Deep Bedrock Aquifer

Case Study – Anaerobic ISBR

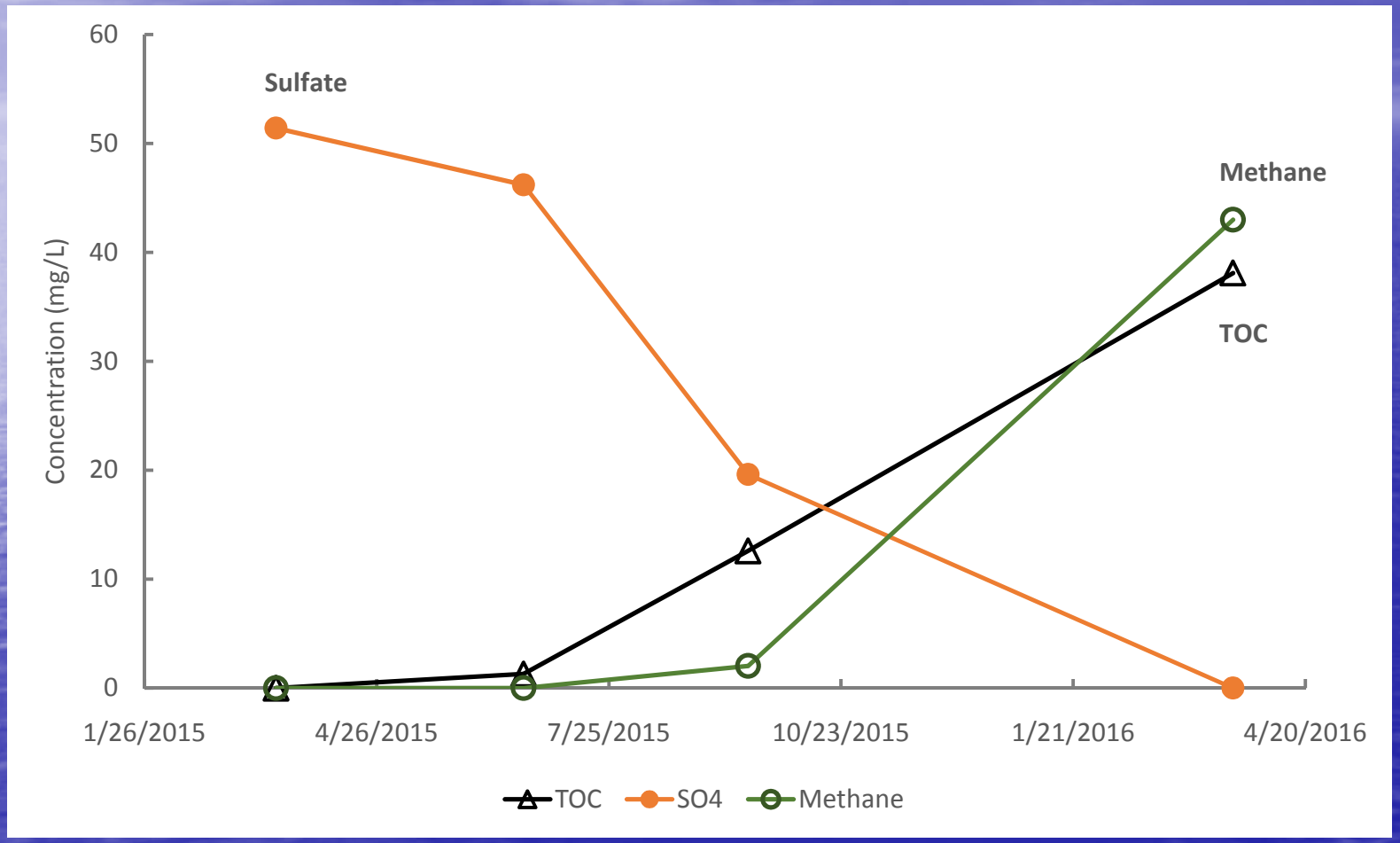
- Chlorinated solvent impacted site
- Fractured bedrock aquifer
- Deep groundwater impacts (140' bgs)
- Unfavorable geochemistry
  - Low but measureable DO
  - DO increase with rain event



Case Study – Anaerobic Bioreactor

- ISBR installed at a depth of 30' BGS
- "Liquid carbon" electron donor
- Groundwater monitoring
  - Contaminant concentrations
  - Geochemistry
  - qPCR for *Dehalococcoides* and functional genes for reductive dechlorination (bio-traps and groundwater)

Groundwater Geochemistry



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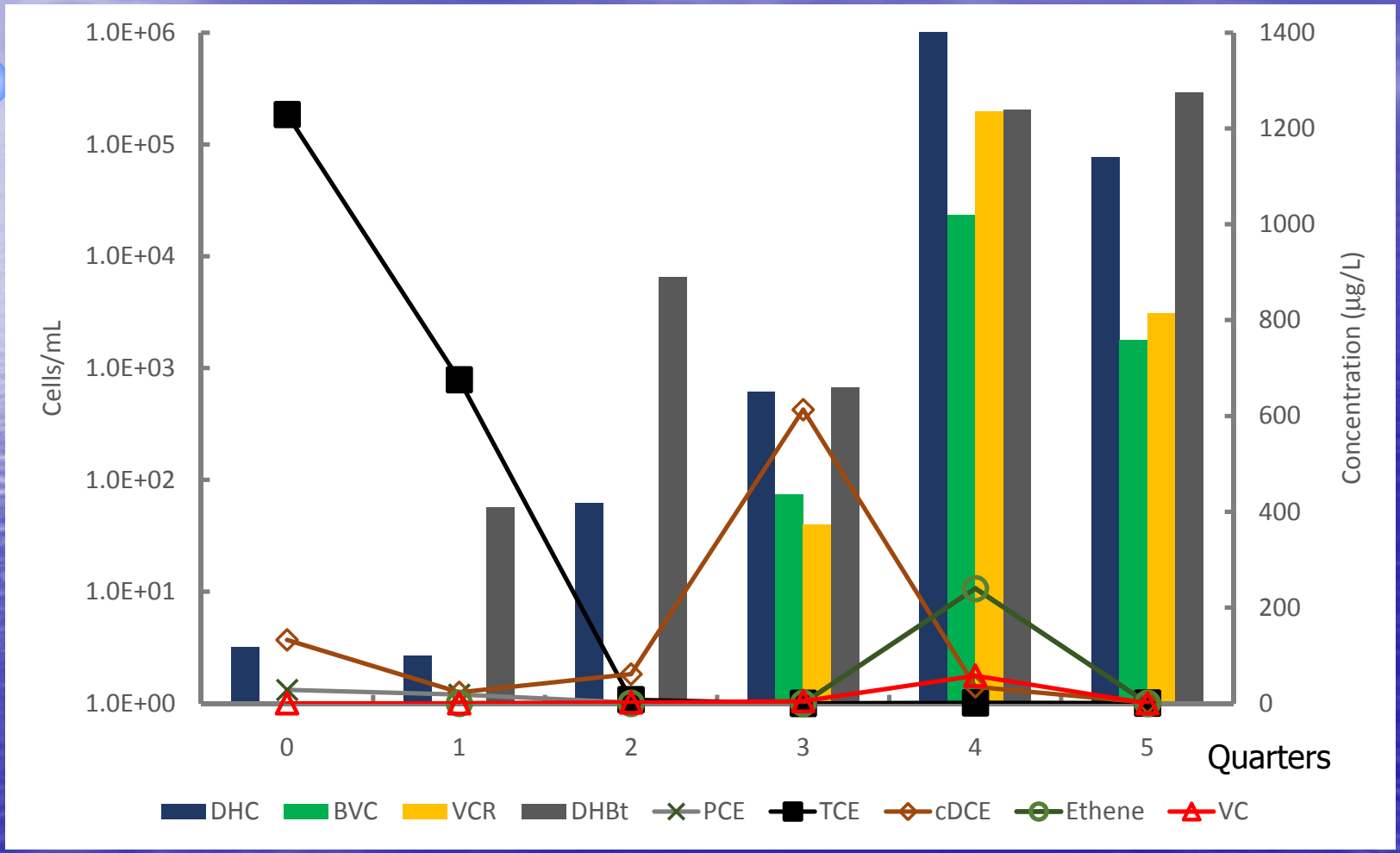
Groundwater Contaminants & Microbiology



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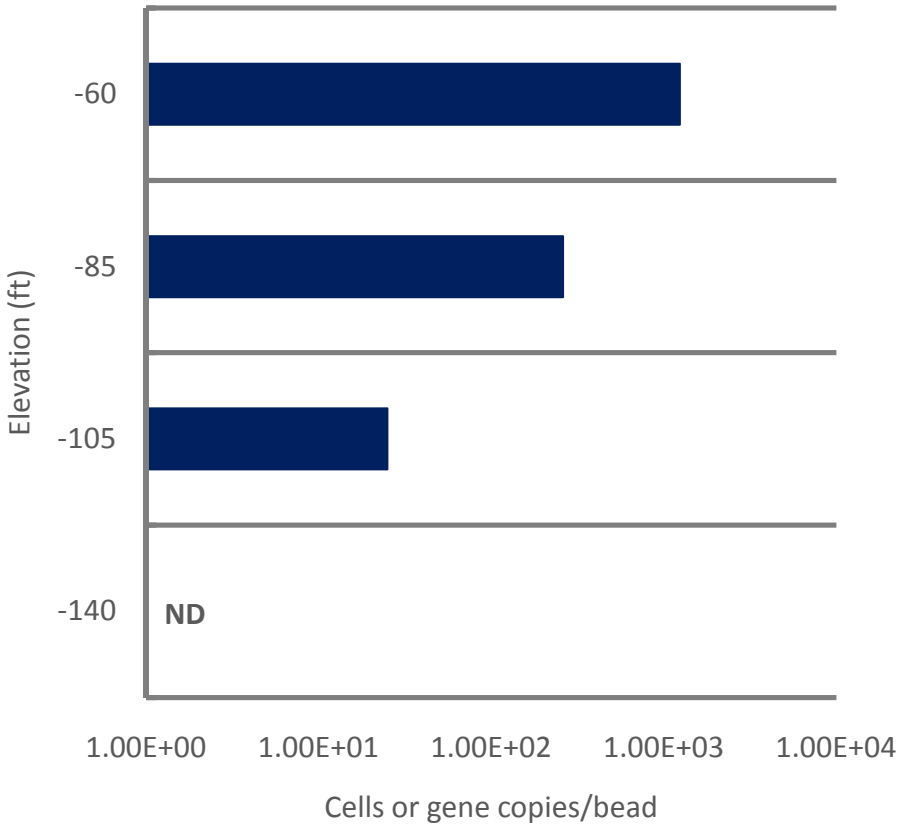
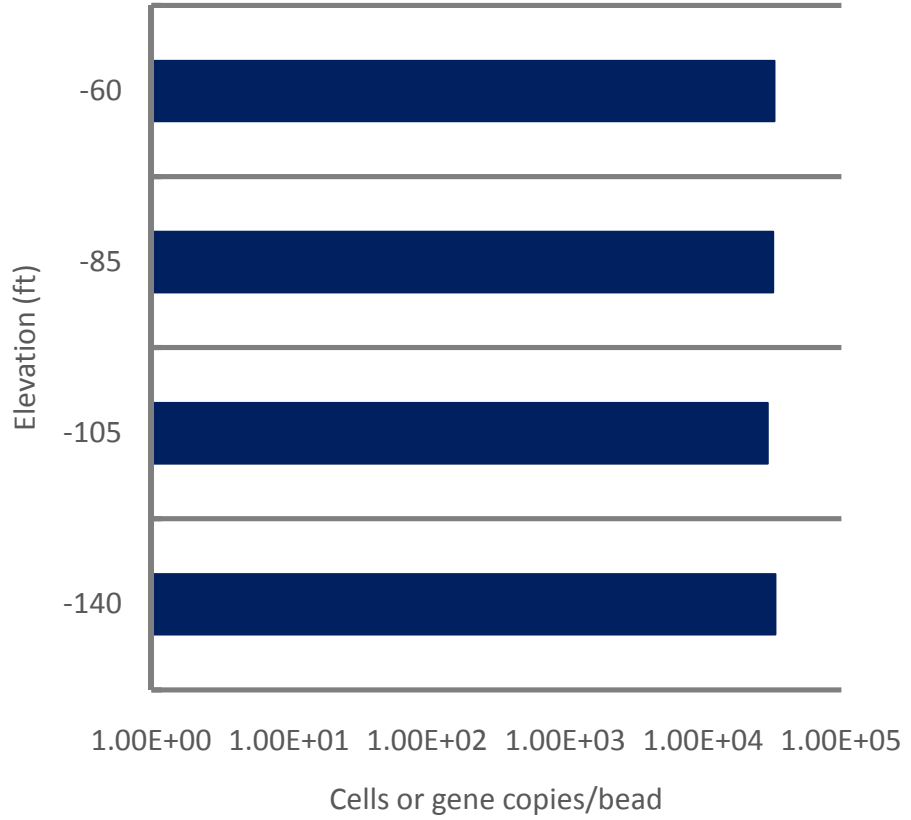
Dehalococcoides (DHC) Concentration with Depth

(Monitored by Bio-traps)

Pre-ISBR



Post-ISBR



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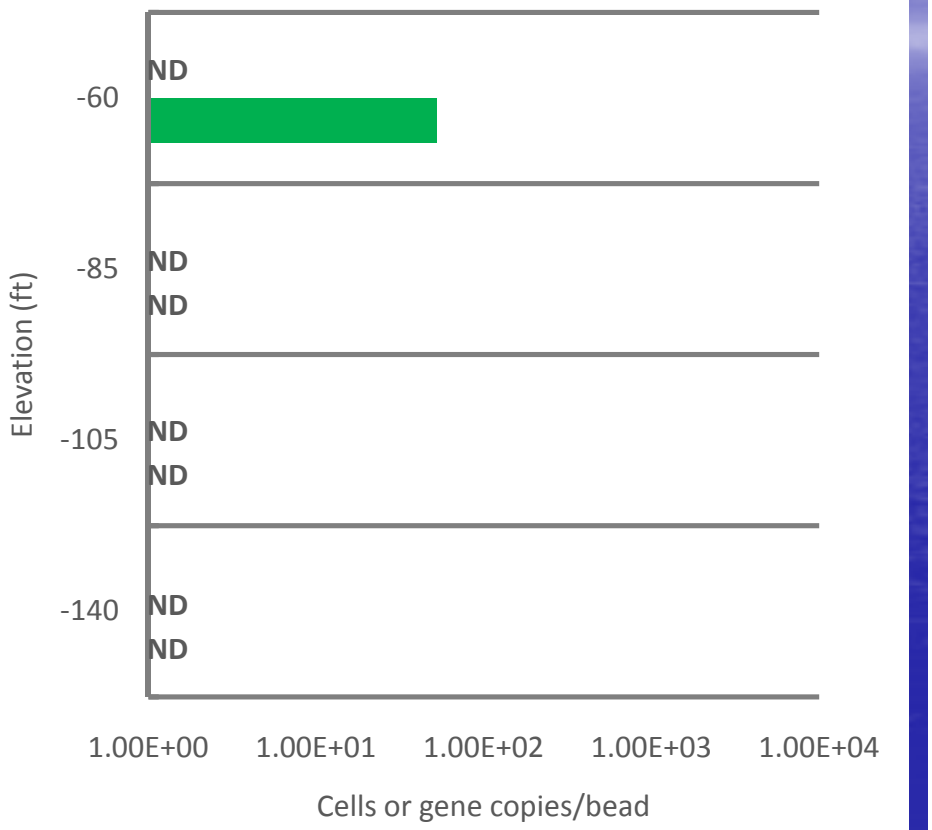
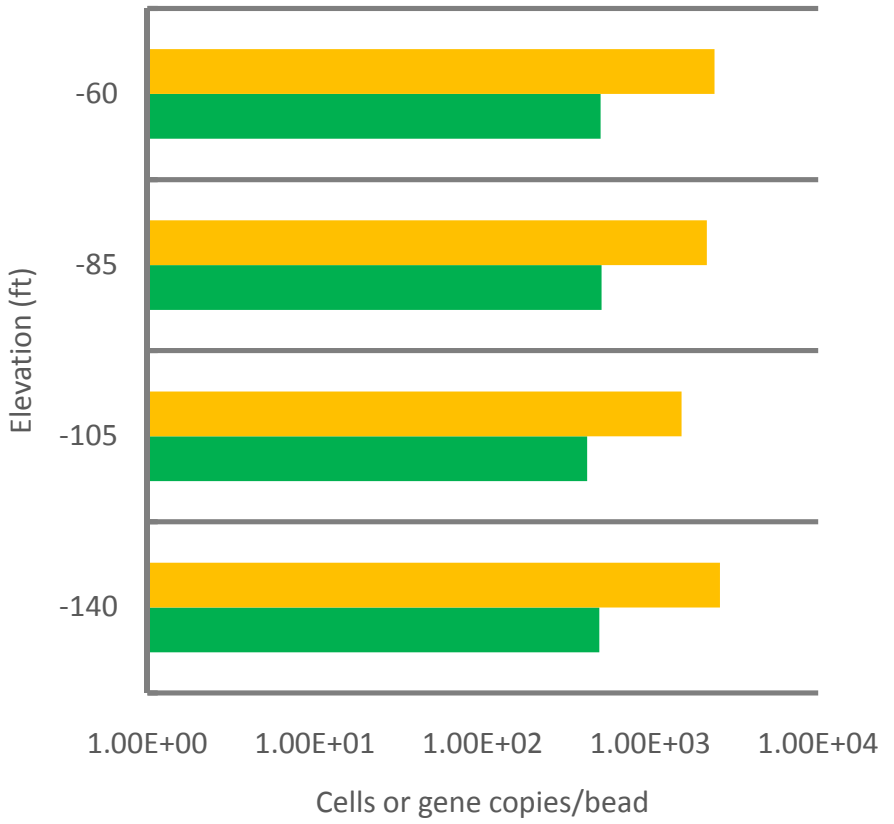
Vinyl Chloride RDases with Depth

Pre-ISBR



Post-ISBR



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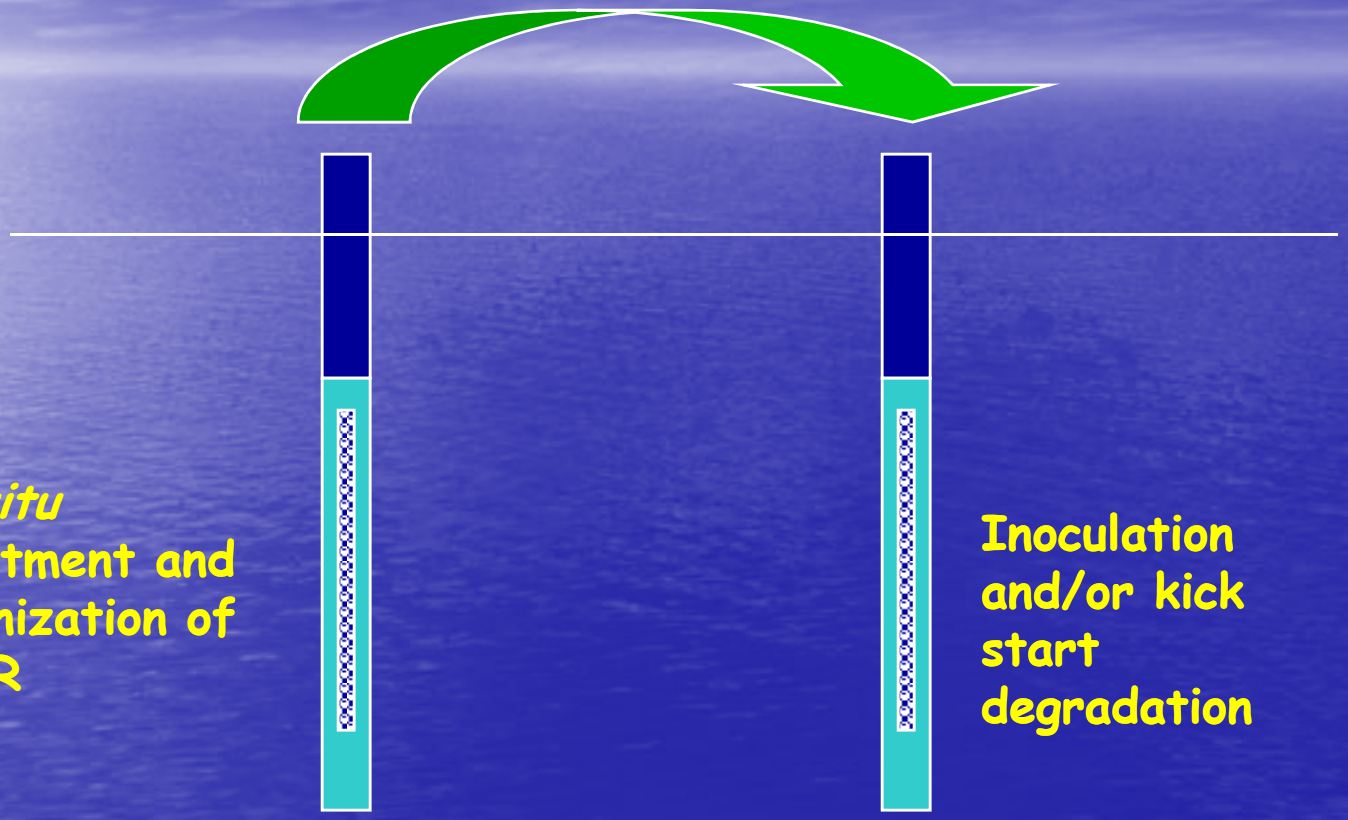
Conclusions

- Generation of anaerobic conditions
- Increases in *Dehalococcoides* and functional genes for reductive dechlorination at each depth over time.
- Sequential reductive dechlorination of PCE to ethene at depth
- ISBR has been moved to another location

Conclusions

- Generation of anaerobic conditions
- Increases in *Dehalococcoides* and vinyl chloride reductase gene copies at each depth over time.
- Sequential reductive dechlorination of PCE to ethene at depth
- ISBR has been moved to another location
  - Why? To transfer degraders

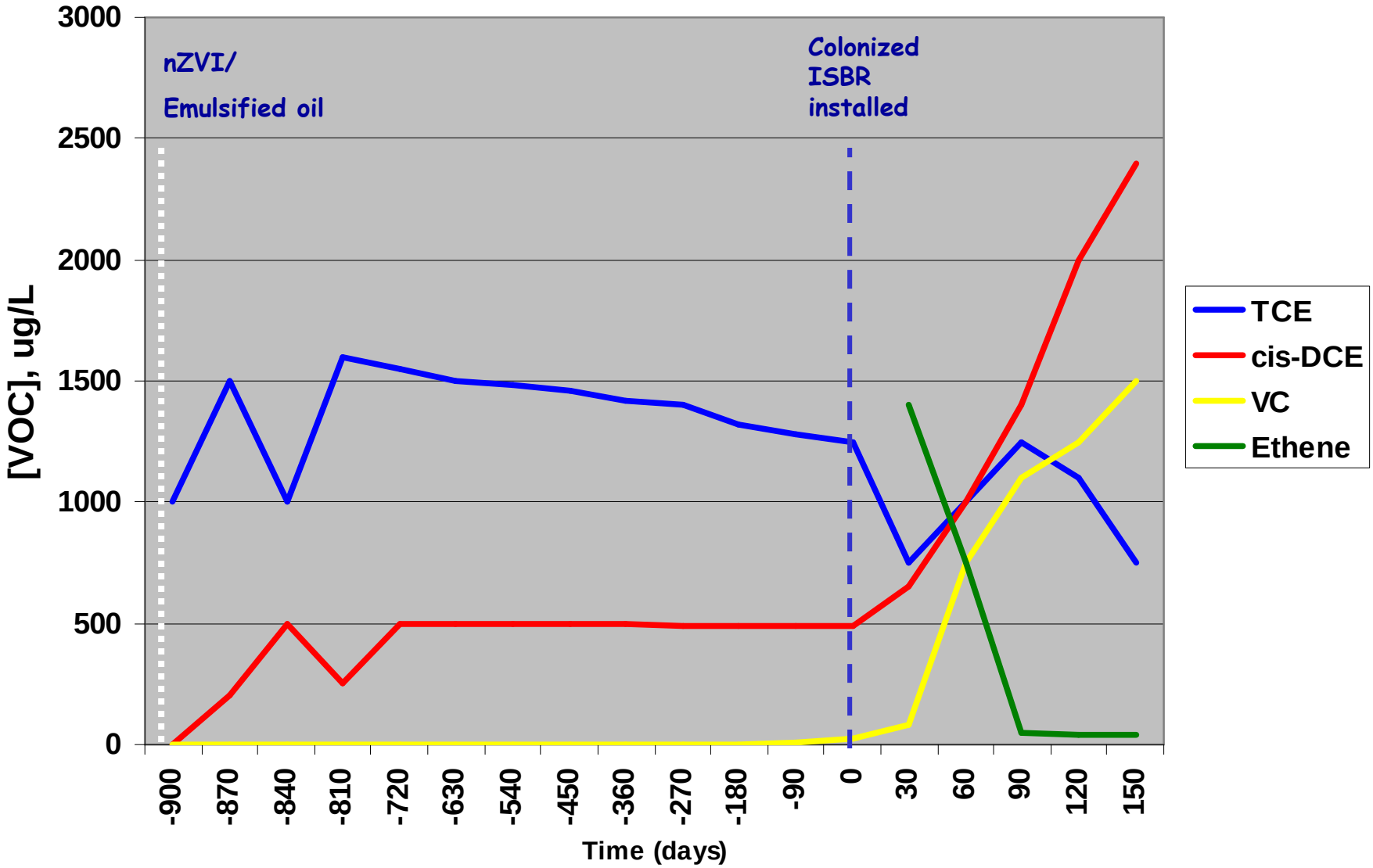
ISBRs Will Transfer Degraders from One Well to Another



In situ treatment and colonization of ISBR

Inoculation and/or kick start degradation

Transfer of DHC in a TCE Plume



When to consider an ISBR

- Inhibitory contaminant concentrations
- Dilute plumes (persistent low levels of contaminants)
- Following ISCO
- Difficult situations
  - Limited physical access
  - Where one-time amendment injection is not feasible
  - Where bioremediation has failed previously

ISBR Limitations

- Aerobic operation limited to low concentrations of reduced iron (fouling)
- Radius of influence decreases with increasing hydraulic conductivity of aquifer matrix
- Works best with contaminants adsorbed by activated carbon

ISBR O&M

- O&M
  - System checks every 2-4 weeks
  - Power
  - Nutrients
  - Water level (ISBR must be totally submerged to function)

ISBR Costs

- Costs
  - Life of project rental
    - $10,000 for one unit (ISBR and controller)
    - $15,000 for two units
    - Decreasing per unit costs with addition of more units at a given site
  - Nominal Rental fee beyond 1 year

BioEnhance

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BioEnhance, LLC
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(918)691-0639

(ISBRs) for Effective Bioremediation of Chlorinated Hydrocarbons in Deep, Fractured Bedrock Aquifers

Eric J. Raes, P.E., LSRP

Properties of Bio-Sep® Beads Useful for Treatment Applications

- Adsorptive surface
  - Concentrates contaminants present at low concentrations
  - Reduces aqueous phase concentrations at high contaminant concentrations
- High porosity and surface area
  - Rapidly colonized by indigenous microbes
  - Release microbes into the aquifer once carrying capacity of the beads is reached

microbialinsights

The University of Tulsa