Cost-Effective In-Situ Remediation

Biostimulation as a Residual Source Mass Remediation Strategy

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November 6-9, 2016 New Orleans, LA

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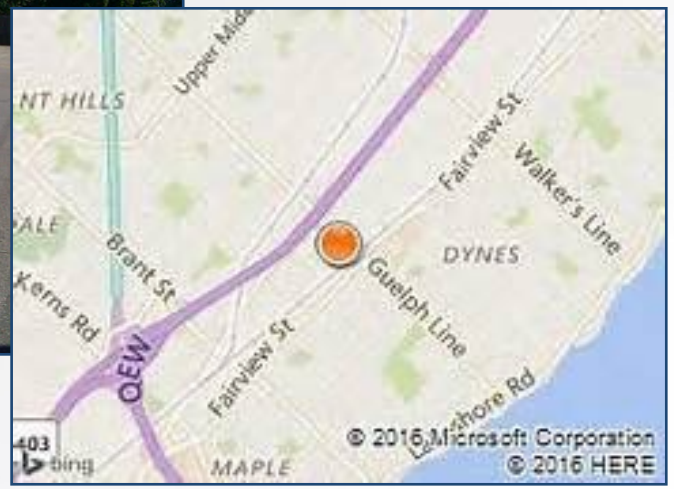
Summary of Site Conditions



Former Dry Cleaner

[PCE] in soils and groundwater above MOECC Table 3 SCS

Residual source mass in saturated soils

Site Conditions

Generally Coarse Textured Soils

Silty Sand w/ Silt Generally moist

0.5m – 4.9m bgs, elevated PID readings

Weathered Shale 5-8m bgs

Bedrock below at ≈8m bgs

Groundwater Conditions

Groundwater flow generally southeast towards Lake Ontario

[PCE] in saturated soils; [PCE] and minimal daughter [cVOCs] in groundwater, total [cVOC] ranged 5,000 – 30,000 ug/L

Pre-evaluation Parent:Parent/Daughter Molar Ratio ≈100%

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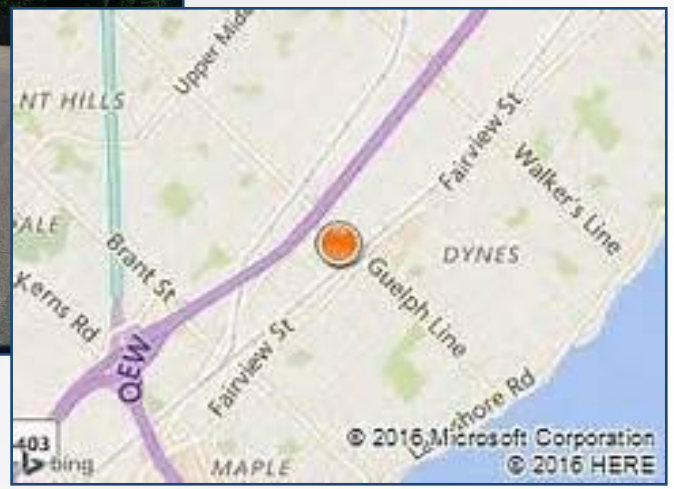
Summary of Remediation Activities



Site Characterization

[PCE] in soils and groundwater above MOECC Table 3 SCS

Residual source mass in saturated soils

Initial Recommendation

Initial Consultant advised Pump-and-Treat

Advised Bioremediation not Appropriate

Geochemistry not supportive of Reductive Dechlorination

Residual Source Mass Present

Advised costs in excess of $500,000 over 30-years

Concluding Recommendation

Biostimulation feasible; designed to adjust Geochemistry; destroys contaminants, <$75K ‘all in’

ERDenhanced components facilitate solubilization

Co-solvent affect resulting from additive utilization by microbial populations

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Why is Biostimulation Cost-Effective?

Biostimulation is a proven remediation strategy that:

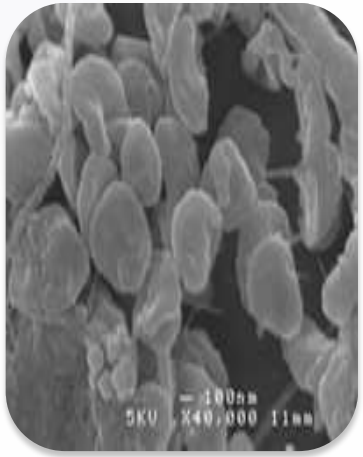
- Nourishes and stimulates native microbial populations
- Expedites solubilization of residual source mass contaminants
- Increases contaminant bioavailability
- Enhances dissolve phase contaminant destruction to
- Realize Long-Term Compliance

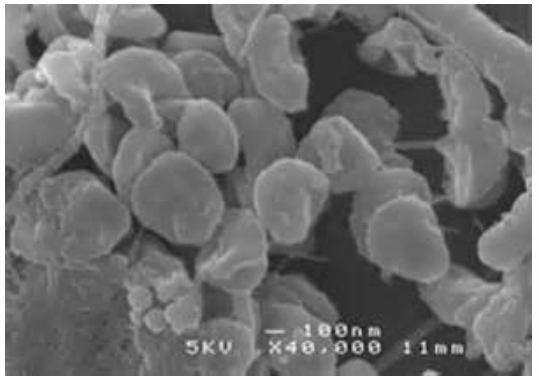
Biostimulation minimizes the impact of remediation by:

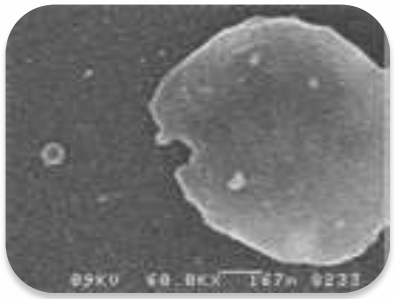
- Minimizing/Eliminate Multiple Deployments
- Eliminate above ground support equipment
- Minimizing off-site removal activities, fuel and energy costs
- Minimizes and eliminates nuisance noise, emissions and vapors

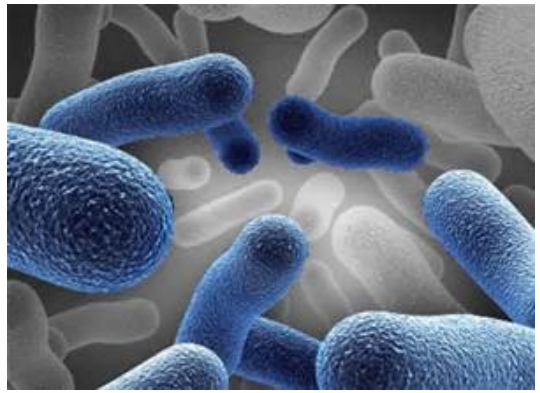
Enhanced Reductive Dechlorination
ERDENHANCED™ Biostimulation

- Biotic Reductive Dechlorination = Substitution of H^+ for Cl^-
- Environmental Conditions
  - ★ Anaerobic (<0.5 mg/L DO)
  - ★ Chemically Reducing (<50 mV ORP)
  - ★ Hydrogen ("Fuel" for Dechlorination)
- Additive Mechanisms
  - ★ Carbon expedites electron scavenging
  - ★ Nutrients enhance microbial activity
  - ★ Carbohydrate supplies food and H^+
  - ★ Creates sustainable reducing conditions which exceed 5-7 years in duration









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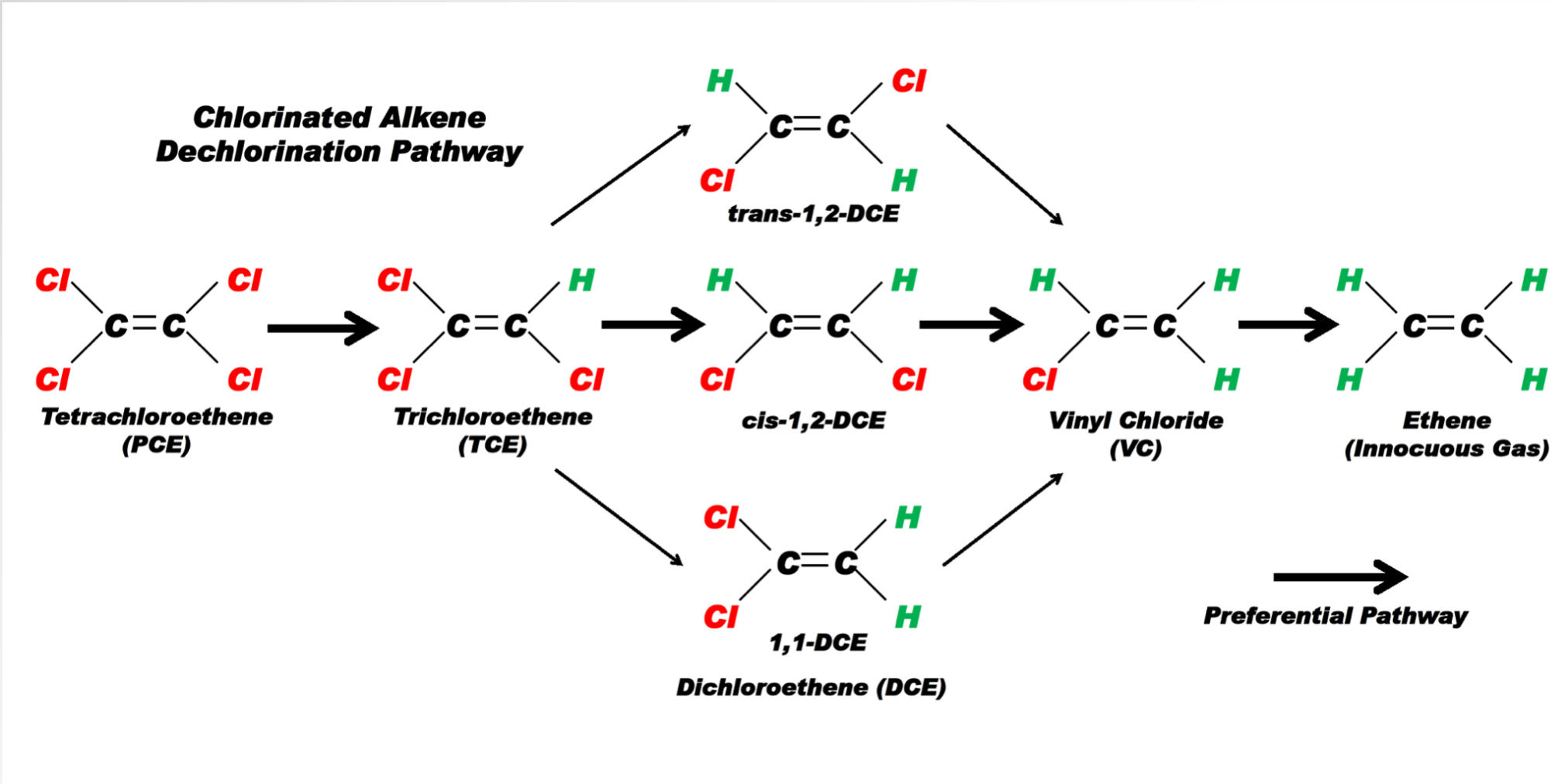
cVOC Biotransformation Pathway



Phase I - PRS Evaluation Process

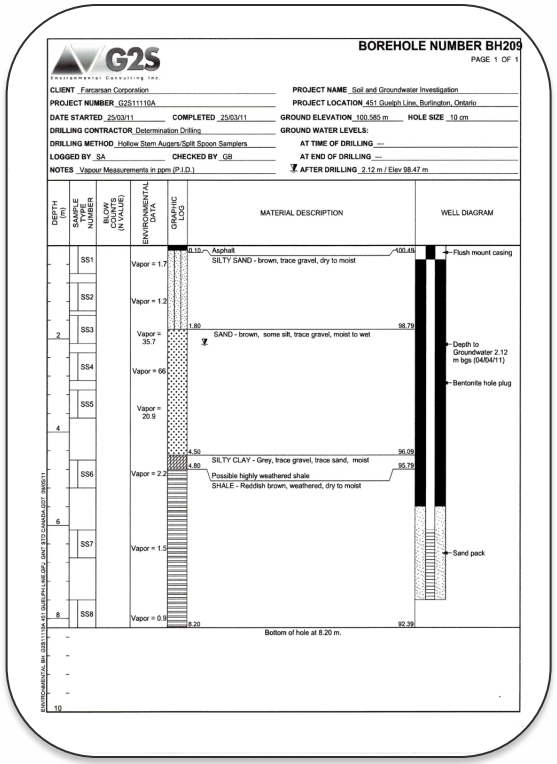
Determine Efficacy Under Actual Biogeochemical Conditions

- On-Site '*Go-no-Go*' <u>on-Site</u> Evaluation
- Low-Cost Low-Risk, no long-term effects to site biogeochemistry
- Additive filled deployment sock suspended directly into existing 2-inch GW monitoring well
- Passively amends casing volume of test well creating an approximate 3-ft area-of-influence

Baseline & Performance Monitoring/Sampling

- *PRS replacement events every 6-8 weeks*
- *5-6 replacement events per evaluation*
- *Performance sample collection/analysis <u>each</u> event*

- Non-purge, low-flow sampling protocols



BOREHOLE NUMBER BH209

PAGE 1 OF 1

CLIENT Farcansan Corporation
PROJECT NUMBER G2S11110A
DATE STARTED 25/03/11 COMPLETED 25/03/11
DRILLING CONTRACTOR Determination Drilling
DRILLING METHOD Hollow Stem Augers/Split Spoon Samplers
LOGGED BY SA CHECKED BY GB
NOTES Vapour Measurements in ppm (P.I.D.)

PROJECT NAME Soil and Groundwater Investigation
PROJECT LOCATION 451 Guelph Line, Burlington, Ontario
GROUND ELEVATION 100.585 m HOLE SIZE 10 cm
GROUND WATER LEVELS:
AT TIME OF DRILLING ---
AT END OF DRILLING ---
AFTER DRILLING 2.12 m / Elev 98.47 m

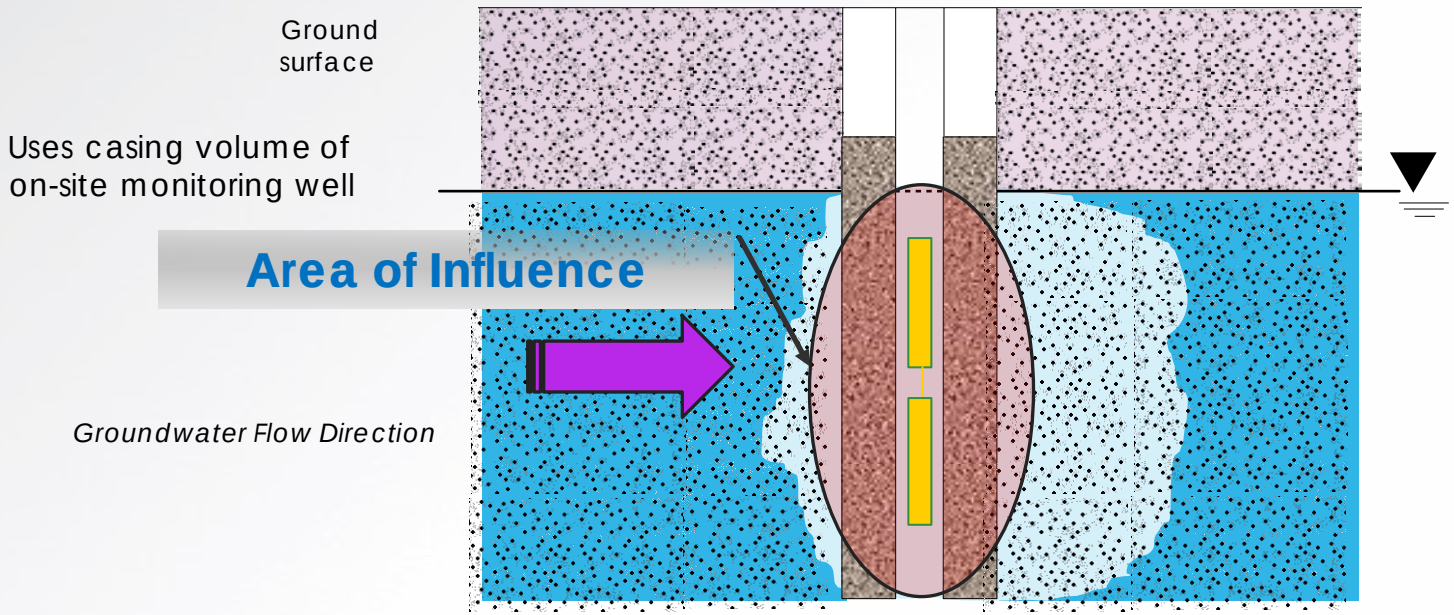
DEPTH (m)	SAMPLE TYPE NUMBER	BLOW COUNTS (N VALUE)	ENVIRONMENTAL DATA	GRAPHIC LOG	MATERIAL DESCRIPTION	WELL DIAGRAM
	SS1		Vapor = 1.7		0.10 Asphalt 100.49 SILTY SAND - brown, trace gravel, dry to moist	Flush mount casing
	SS2		Vapor = 1.2			
2	SS3		Vapor = 35.7		1.80 98.79 SAND - brown, some silt, trace gravel, moist to wet	Depth to Groundwater 2.12 m bgs (04/04/11)
	SS4		Vapor = 66			Bentonite hole plug
	SS5		Vapor = 20.9			
4					4.50 96.09 SILTY CLAY - Grey, trace gravel, trace sand, moist 4.80 95.79	
	SS6		Vapor = 2.2		Possible highly weathered shale SHALE - Reddish brown, weathered, dry to moist	
6	SS7		Vapor = 1.5			Sand pack
8	SS8		Vapor = 0.6		8.20 92.39 Bottom of hole at 8.20 m.	
10						

Phase I - PRS Evaluation Process

Determine Efficacy Under Actual Biogeochemical Conditions

Purpose of PRS based evaluation is to confirm additive efficacy under actual site biogeochemistry

It is not for compliance testing



Eliminates the 'Jar Effect' while saving costs

Is Reproducible, but not scalable to full-scale design

Phase I - PRS Evaluation Process

Determine Efficacy Under Actual Biogeochemical Conditions

- **Indicator Metrics**

  Field Parameters:
  - **ORP, DO, pH, Temperature**

  Geochemistry:
  - **Nitrates (NO3), Sulphates (SO4) , dissolved Iron/Manganese**

  Analytical:
  - **Contaminant of Concern (EPA 8260)**

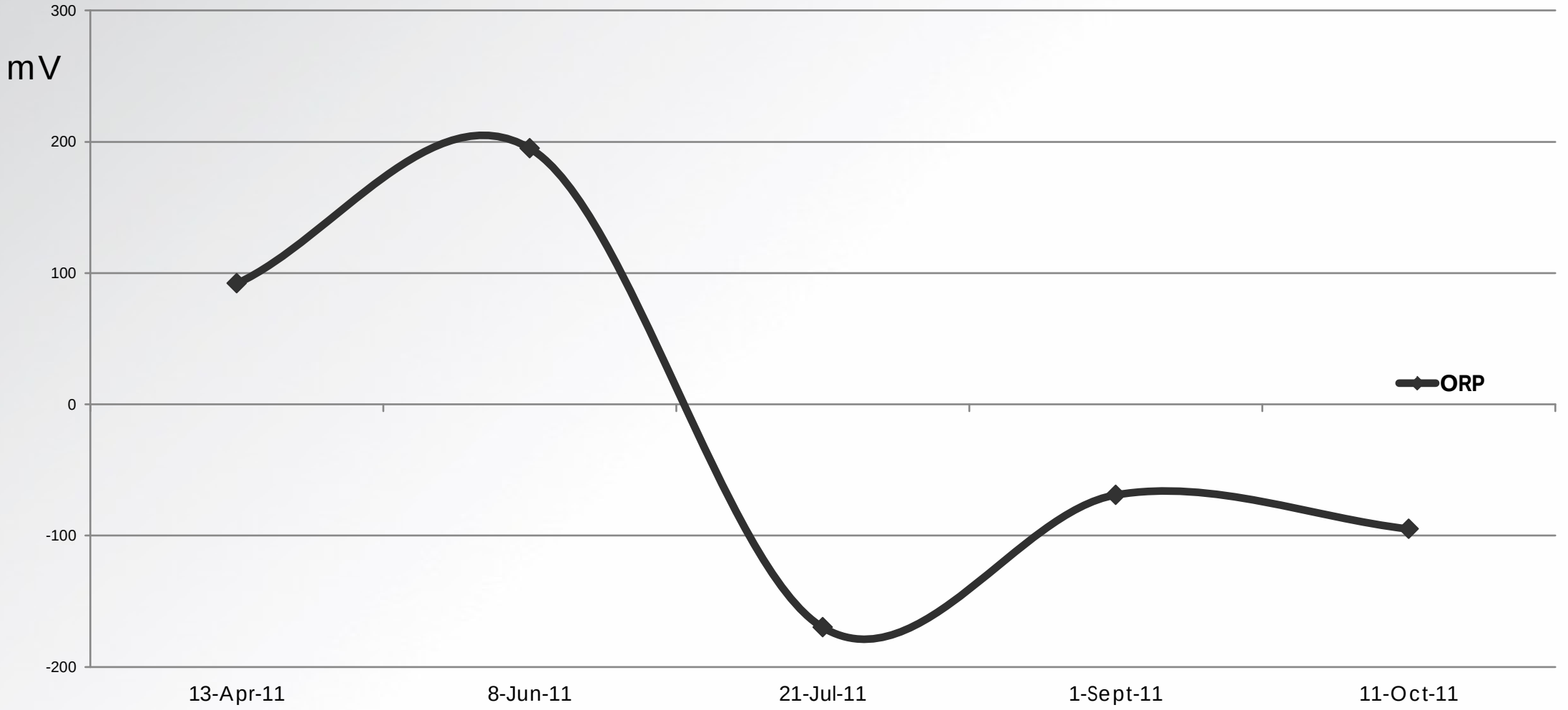
- **Field Indicator Parameters Recorded *Every* Replacement Event**

- **Non-purge, low-flow sampling protocols**

  - Assists in the evaluation of additive efficacy
  - Also provides input to residual mass presence
  - Solubilization rates
  - Remediation Timeframes

Phase I - PRS Evaluation Process

Determine Efficacy Under Actual Biogeochemical Conditions



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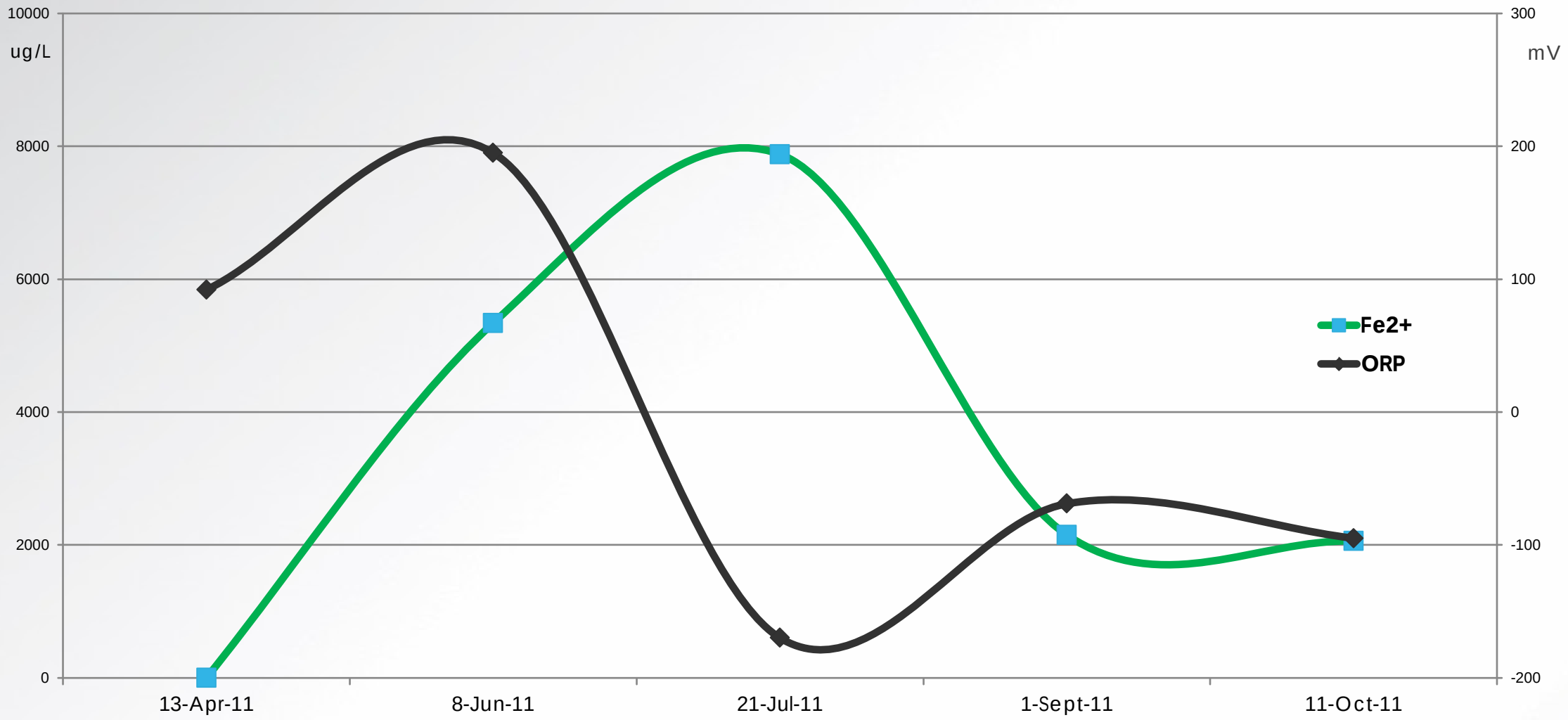

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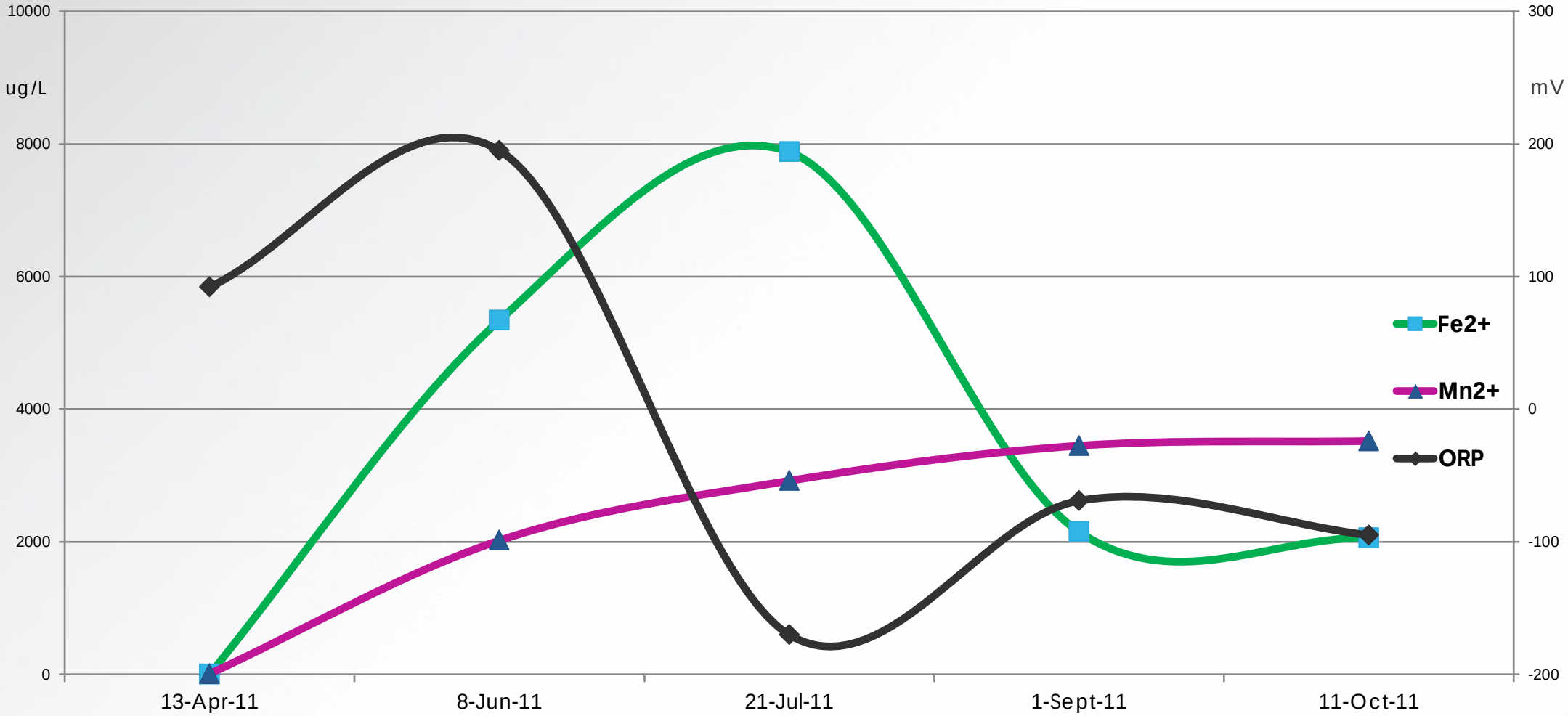

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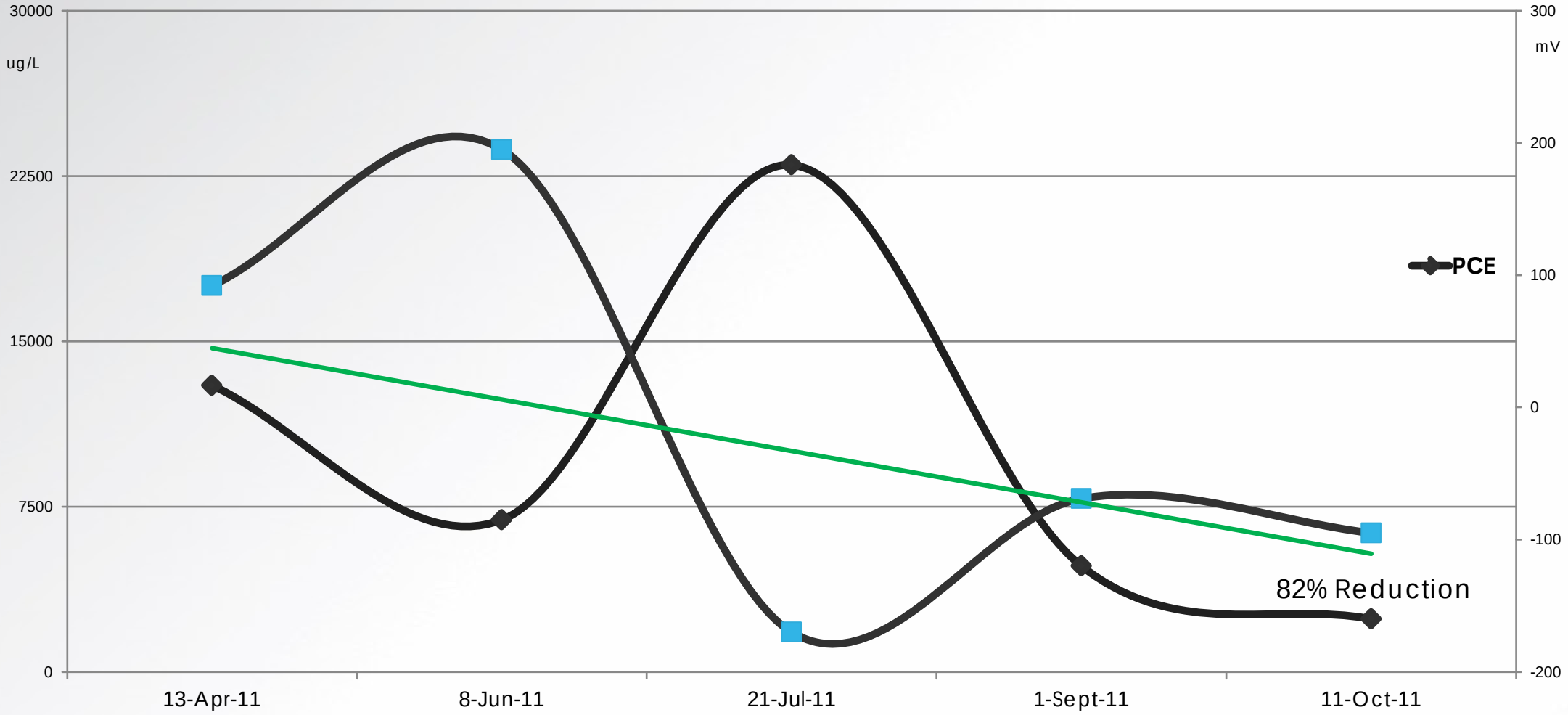

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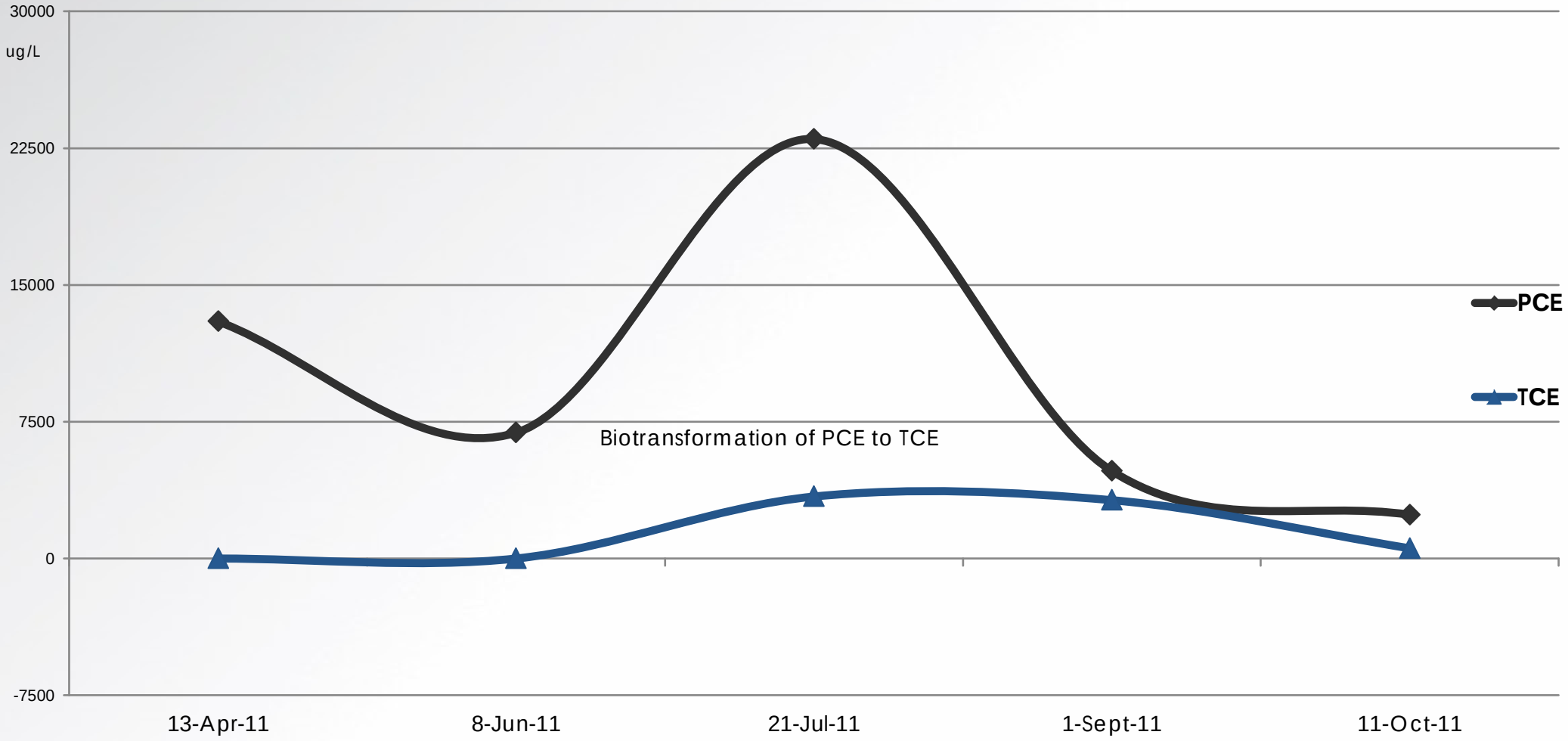

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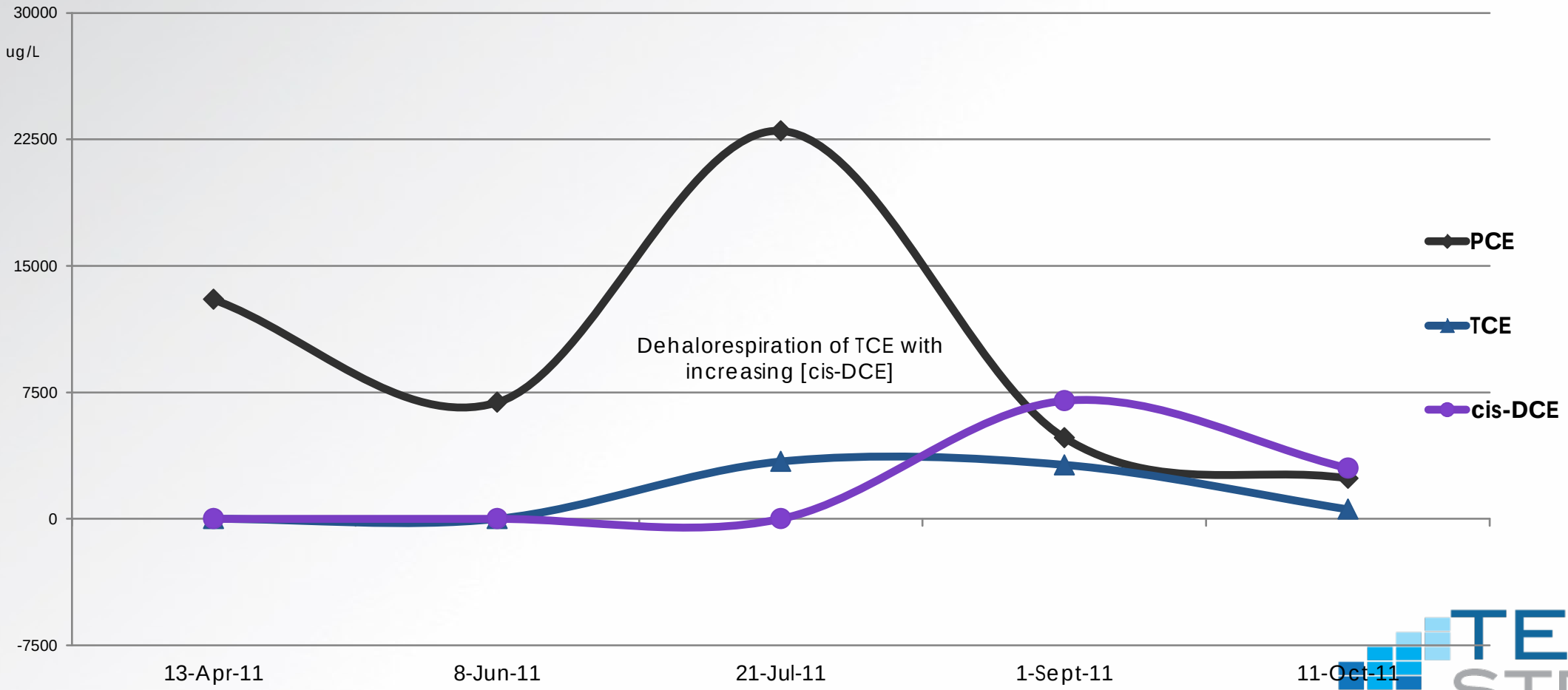

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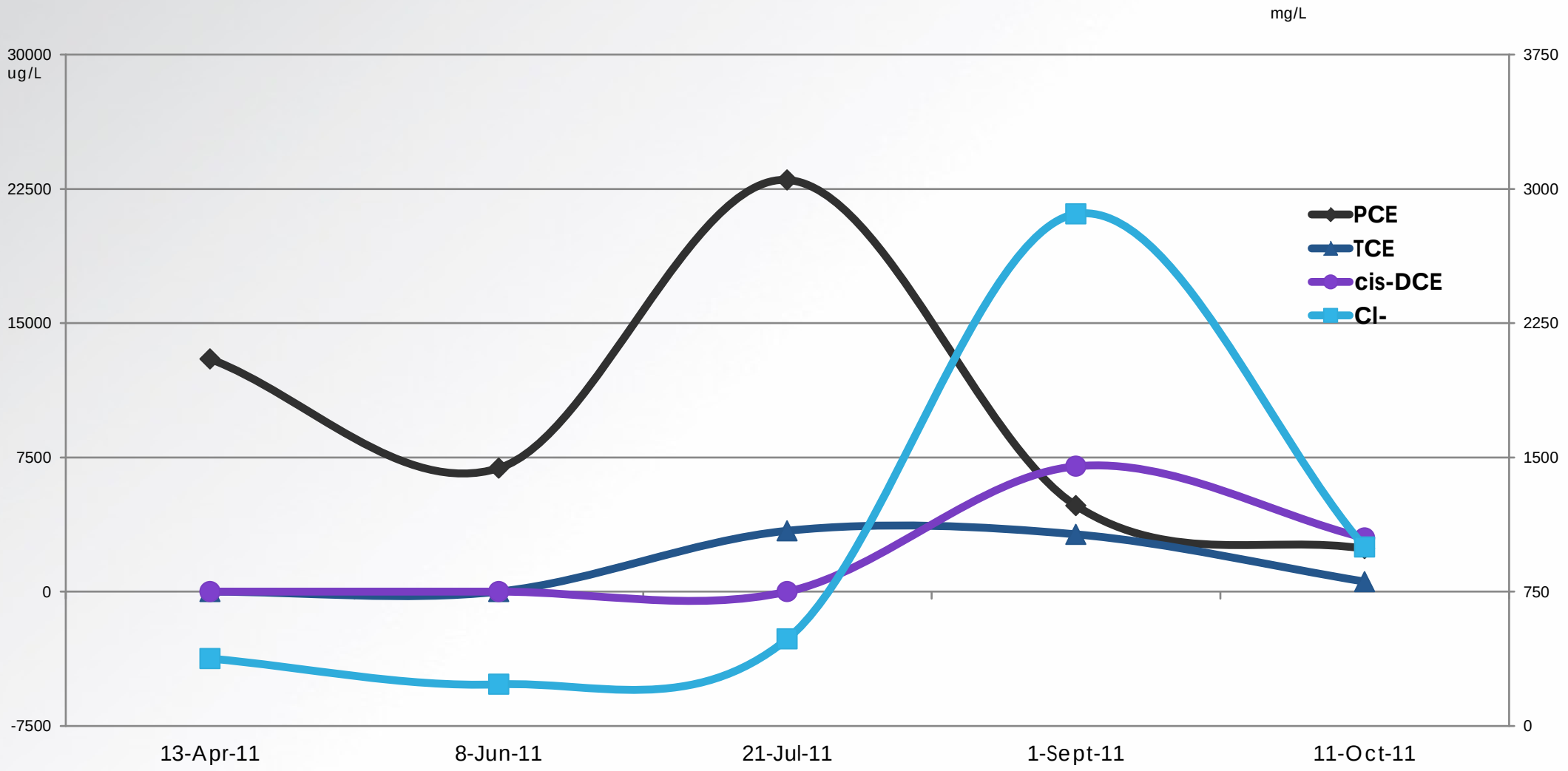
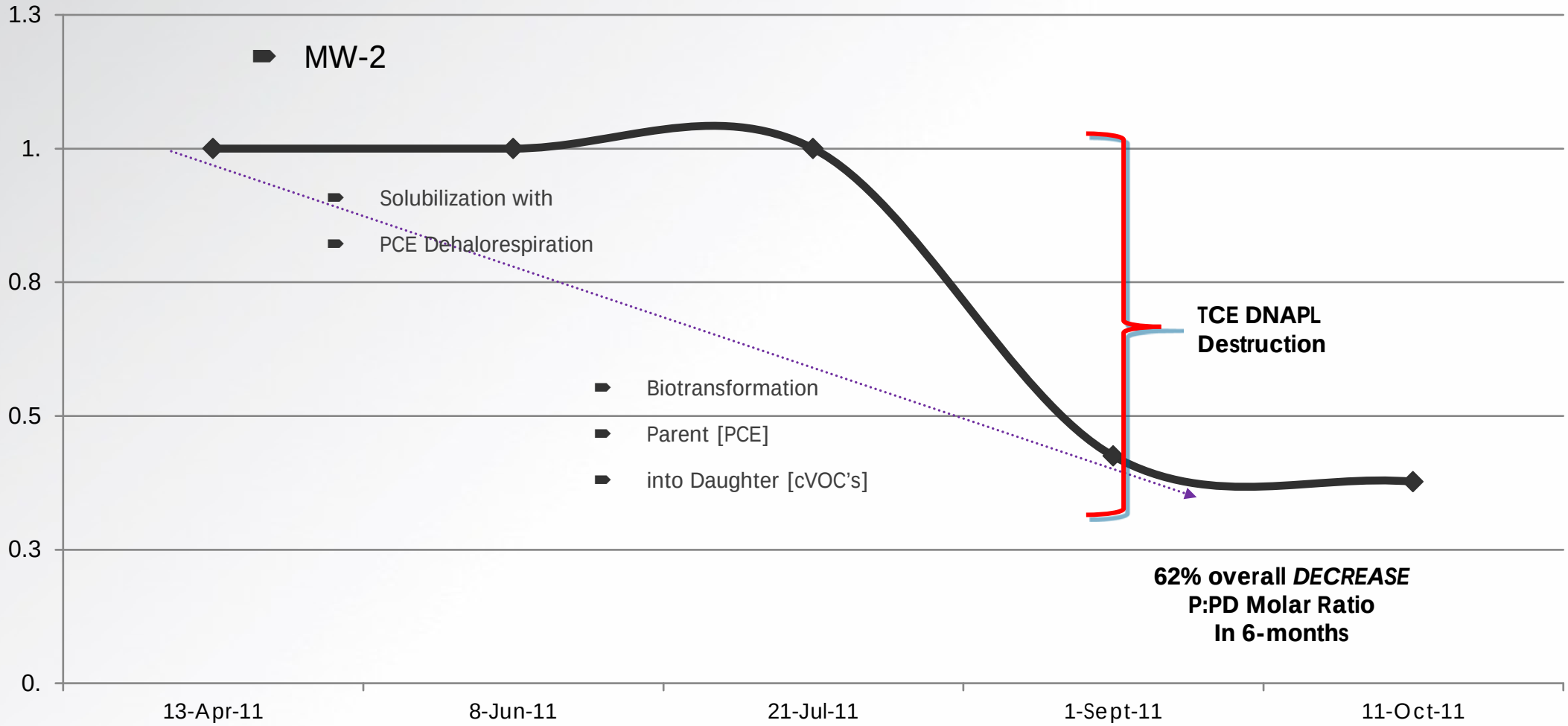
Phase I - PRS Evaluation Process

Determine Efficacy Under Actual Biogeochemical Conditions



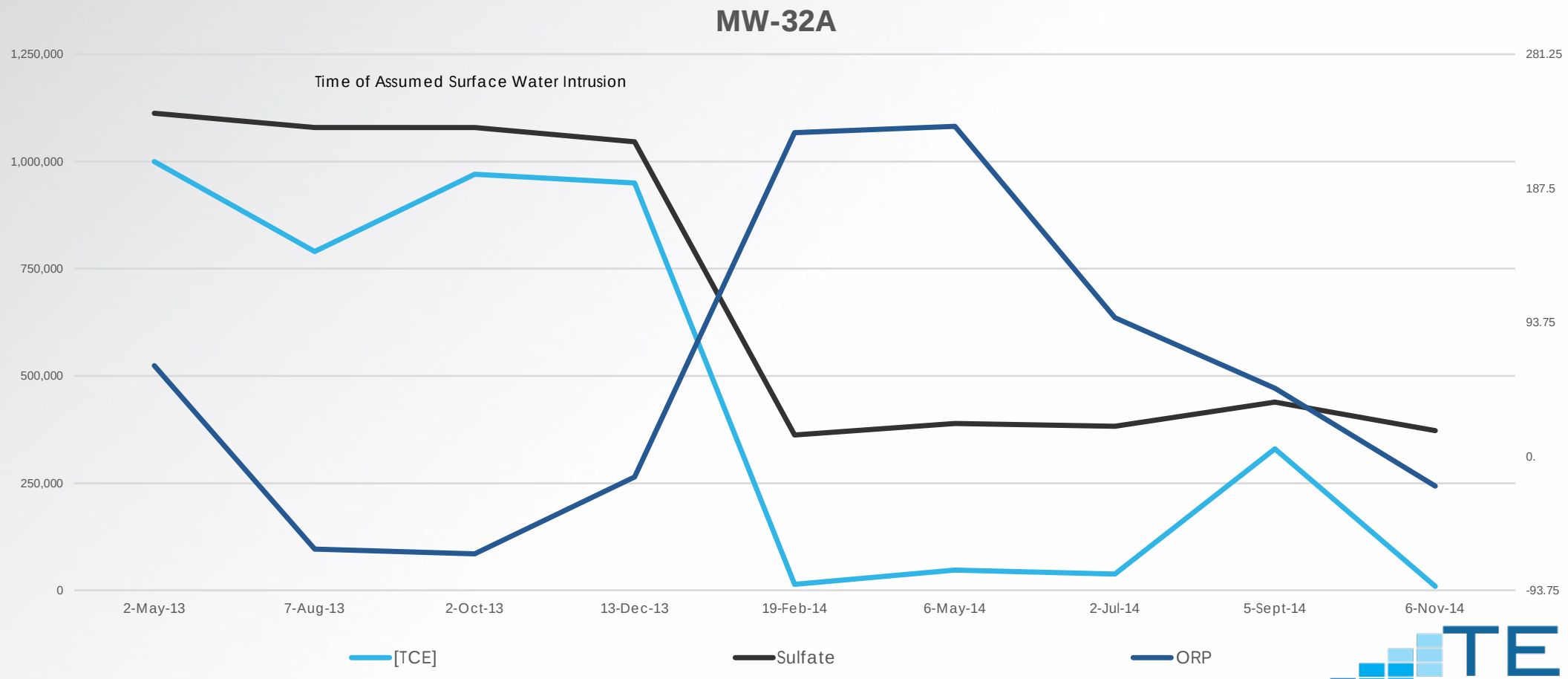
Phase I - PRS Evaluation Process

Determine Efficacy Under Actual Biogeochemical Conditions



Importance of P:PD Ratio

Contaminant Reduction?



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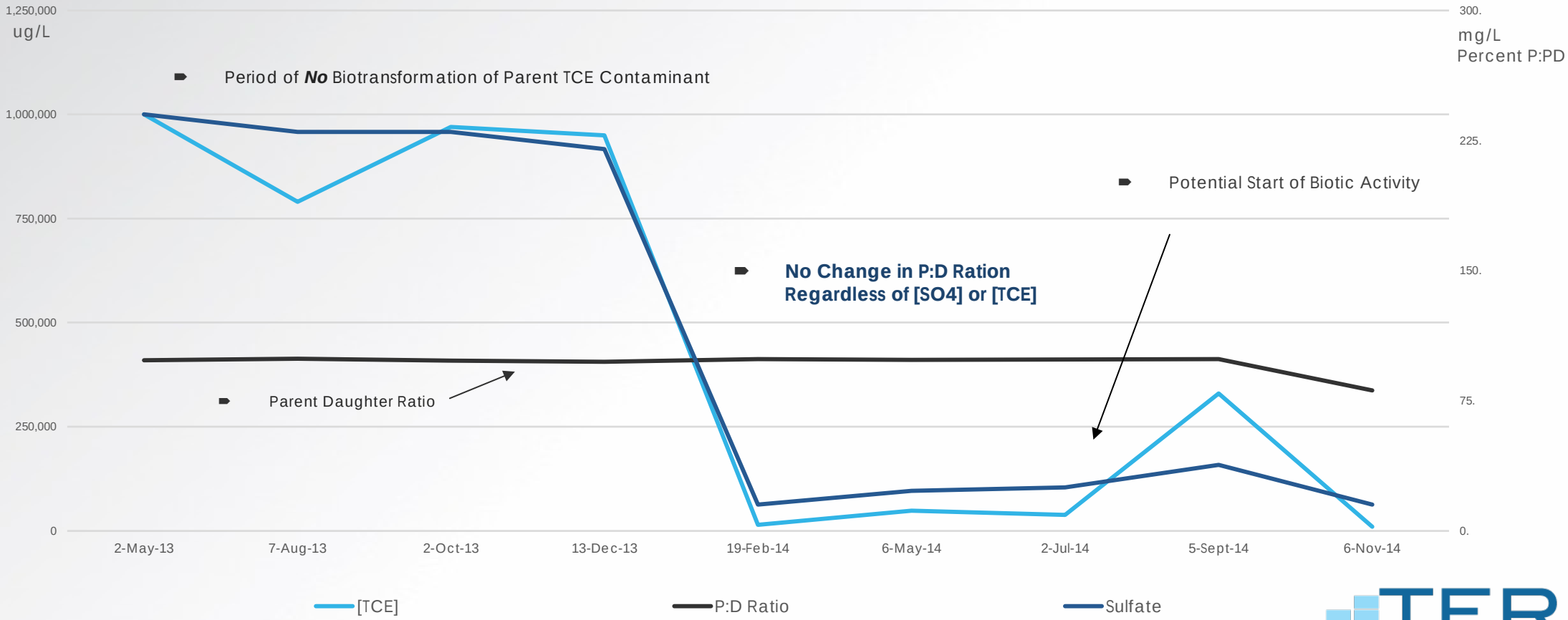
Contaminant Reduction but *NO* Destruction!



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Phase II – Contaminated Soil Excavation

Contaminant Location

Contaminated source soils located within building proper

Full soil source removal unfeasible

Subslab excavation limited

Residual Mass Present

Excavation – Source Removal

Limited excavation removed 250m^3 contaminated soils

Infiltration gallery installed w/in footprint

Clear stone, 6-inch slotted PVC, 2-3m bgs

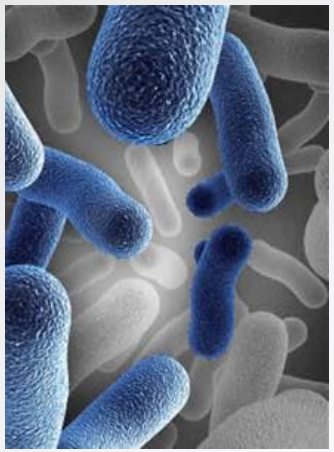
Groundwater Conditions

Residual mass present at levels above PCE solubility

Groundwater concentrations of PCE in area 5,000-30,000 ug/L

No daughter products present

Phase III In-Situ Biostimulation



Remediation Strategy

- Enhance treatment zone geochemistry
- Biostimulate native microbial populations
- Expedite Residual Mass Solubilization
- Increase Dissolve Phase [PCE]
- Leverage momentum of Mother Nature
- Enhance Native Microbial Populations
- Realize enhanced and *complete* biotransformation

Additive Deployment

- Additive deployed twice in March then July 2014
- 9% additive slurry gravity fed to subslab gallery
- 990kg/840kg w/1,000 gallons chase water/deployment

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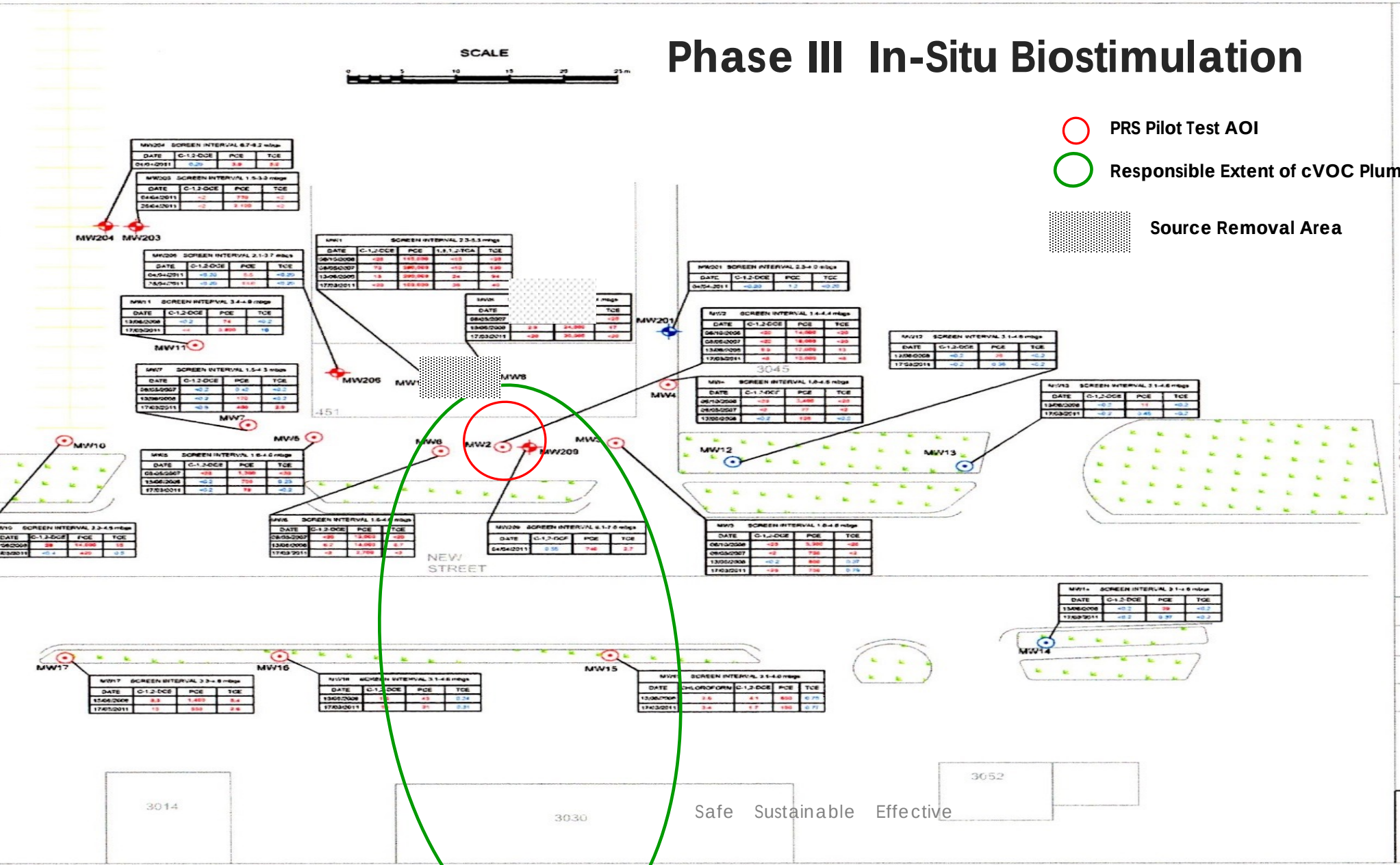
Phase III In-Situ Biostimulation



LEGEND

- PREVIOUSLY INSTALLED GW MONITORING WELLS
- 2011 GW MONITORING WELLS
- MEETS TABLE 3 STANDARDS IN MOST RECENT SAMPLING EVENT
- EXCEEDS TABLE 3 STANDARD IN MOST RECENT SAMPLING EVENT
- TEXT MEETS TABLE 3 STANDARD FOR THIS PARAMETER
- TEXT EXCEEDS TABLE 3 STANDARD FOR THIS PARAMETER
- mbgs METERS BELOW GROUND SURFACE
- µg/L MICROGRAMS PER LITRE

SITE CONDITION STANDARDS

THE STANDARDS SHOWS ARE THE TABLE 3 FULL DEPTH GENERIC SITE CONDITION STANDARDS IN A NON-POTABLE GROUNDWATER CONDITION AT A INDUSTRIAL/COMMERCIAL/COMMUNITY PROPERTY USE AND COARSE TEXTURED SOILS SELECTED FROM THE SOIL, GROUNDWATER AND SEDIMENT STANDARDS FOR USE UNDER PART XV.1 OF THE ENVIRONMENTAL PROTECTION ACT MINISTRY OF ENVIRONMENT JULY 2009

SHOWN AS	PARAMETER	UNIT	TABLE 3 STANDARDS
Chloroform	Chloroform	ug/L	2.4
C-1,2-DCE	cis-1,2-Dichloroethylene	µg/L	1.6
PCE	Tetrachloroethylene	µg/L	1.6
1,1,1,2-TCA	1,1,1,2-Tetrachloroethane	µg/L	3.4
TCE	Trichloroethylene	µg/L	1.6

TITLE: GROUNDWATER ANALYTICAL RESULTS
CLIENT: FRACARSAN CORPORATION
LOCATION: 451 GUELPH LINE, BURLINGTON, ON
PROJECT: G2S11110A

FIGURE:	4
Scale:	AS SHOWN
Date:	09/05/11
Drawn by:	SA/GB
File name:	GW.dwg

G2S Environmental Consulting Inc

Phase III In-Situ Biostimulation

Period of Treatment presented >18-months

Infiltration Gallery Influence Monitoring Wells

- MW-2 (former Pilot location), MW-3, MW-6 and MW-209
- Each located approximately 15-20 meters downgradient
- Extended influence potentially 85-meters downgradient

Five (5) Rounds of Groundwater Monitoring Post Initial Amendment Event

- From March 2014 through October 2015 (17-months)
- Included field geochemical and lab analytical metrics

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Phase III In-Situ Biostimulation

Pre-Additive Introduction [cVOCs] March 25, 2014

Location	[PCE]	[TCE]	[cis-DCE]	[VC]	P:PD Ratio
MW-2*	370 ug/L	29.6 ug/L	5.4 ug/L	80.3	58.8%
MW-3	1,030 ug/L	<0.05 ug/L	<0.05 ug/L	ND	99.9%
MW-6	1,950 ug/L	0.67 ug/L	<0.05 ug/L	ND	99.9%
MW-209	1.93 ug/L	1.2 ug/L	4.66 ug/L	ND	30.4%

Groundwater Conditions

MW-2 is former PRS test location; MW-209 is proximate

MW-3 and MW-6 not effected by PRS evaluation

Non-effected areas with >99% P:PD Ratio

No ongoing biotic activity evident

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Phase III In-Situ Biostimulation

October 5, 2015 17-months post-deployment

Location	[PCE]	[TCE]	[cis-DCE]	[VC]	%Δ[cVOC$_{total}$]	P:PD Ratio
MW-2	<25 ug/L	<25 ug/L	48 ug/L	<25 ug/L	84.1%$_{reduction}$	8.7%
MW-3	51 ug/L	2.7 ug/L	170 ug/L	26 ug/L	78.3%$_{reduction}$	0.8%
MW-6	41 ug/L	12 ug/L	130 ug/L	50 ug/L	88.0%$_{reduction}$	3.7%
MW-209	NS	NS	NS	NS	-%$_{reduction}$	NS

Average 94.9% Reduction P:PD Ratio Post Deployment

Near 100% *REDUCTION* at MW-3

Amended locations demonstrating enhanced reductive dechlorination due to introduction of **ERD**ENHANCED™

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Phase III In-Situ Biostimulation

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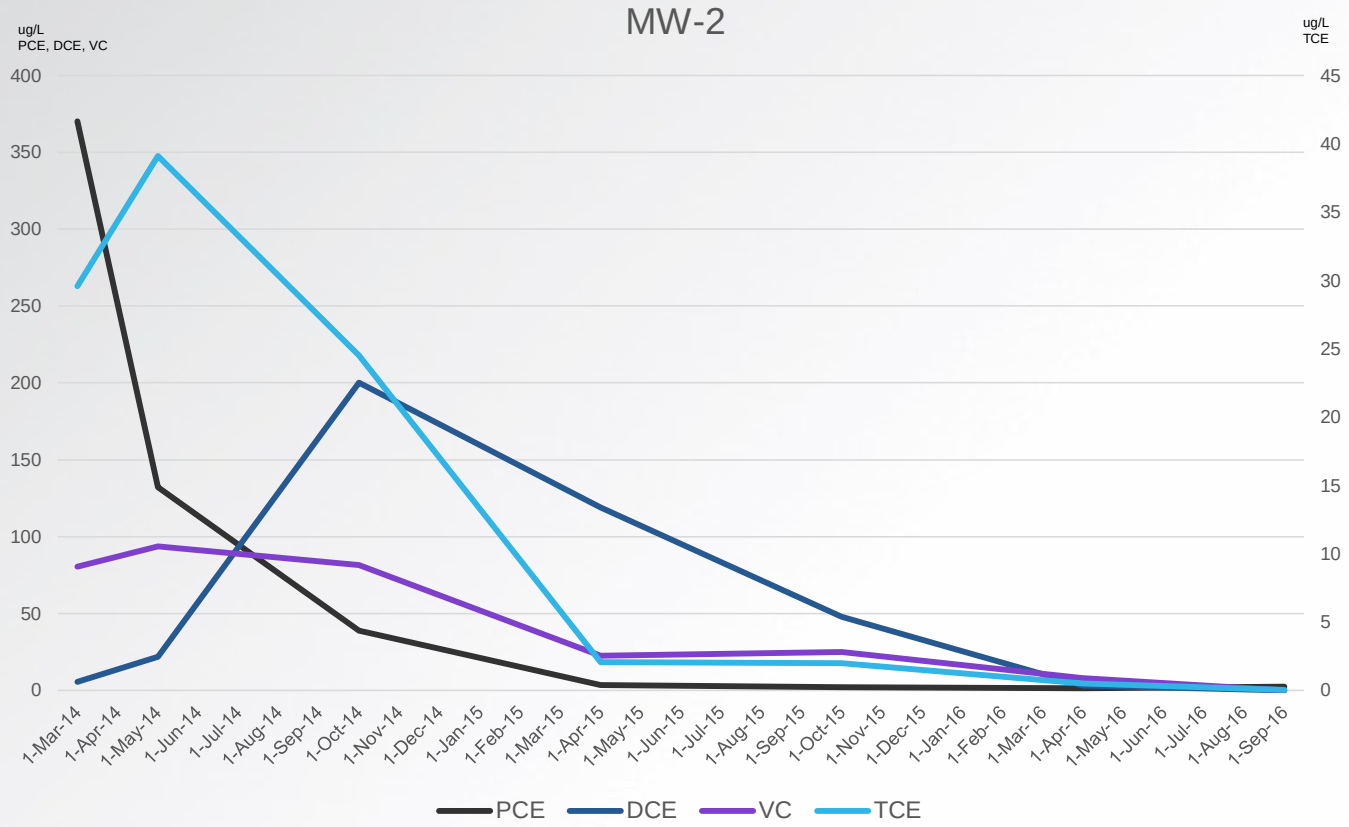
Results Full Scale Application

2½ years post additive deployment



- 99.4% reduction [PCE]
- Initial 32.1% increase in [TCE] followed by 99.9% reduction
- 3,600% increase [DCE] followed by ≈100% reduction by evaluation end
- Initial 16.8% increase in [VC] followed by 99.9% reduction
- 99.5% reduction in [cVOCtotal]
- Demonstrates dehalorespiration of parent and subsequent biotransformation into daughter products
- Sample location is now within compliance

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Phase III In-Situ Biostimulation

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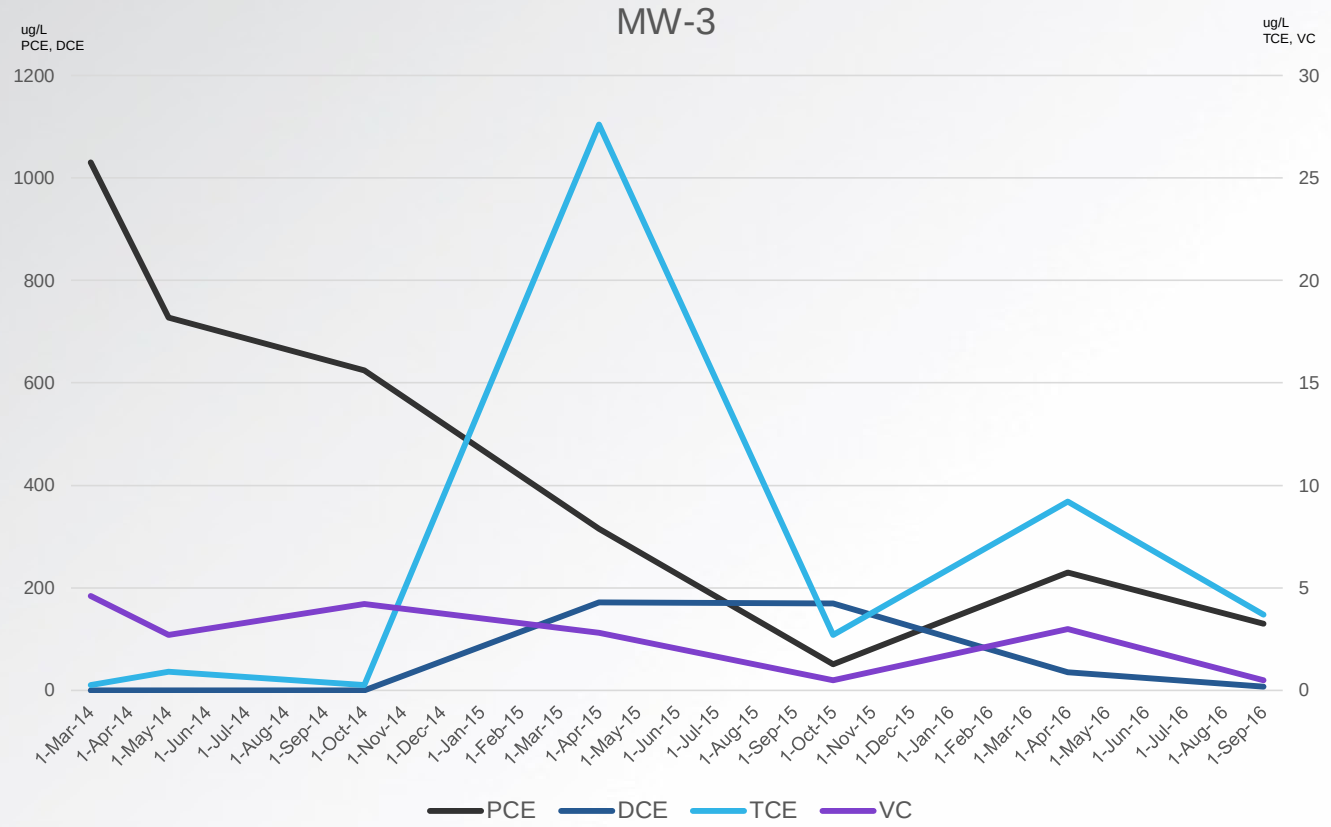
Results Full Scale Application

2½ years post additive deployment



- Maximum reduction [PCE] >95% (T=18-months)
- Overall reduction [PCE] 87.4%
- Five Order-Magnitude Increase [TCE] April 2015
- 90.2% subsequent reduction 6-months later
- Overall 86.6% reduction [TCE] from April 2015
- Similar Five Order Magnitude Increase [DCE] through October 2015; 6-months after TCE peak
- 95.9% reduction [DCE] from T=12-months to evaluation end
- [VC] maximum increase ≈500% with overall 89.1% reduction

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Phase III In-Situ Biostimulation

April 2016 2-years post deployment

Location	[PCE]	[TCE]	[cis-DCE]	[VC]	%Δ[cVOC$_{total}$]
MW-2	1.5 ug/L	<1.0 ug/L	3 ug/L	8.0 ug/L	99.5%$_{reduction}$
MW-3	230 ug/L	9.2 ug/L	35 ug/L	< 2.0 ug/L	86.4%$_{reduction}$
MW-6	510 ug/L	15 ug/L	63 ug/L	10 ug/L	98.8%$_{reduction}$
MW-209	NS	NS	NS	NS	NS

- **99.5% Percent Reduction [cVOC$_{total}$] 2-years Post Deployment MW-2**
- MW-3 and MW-6 [PCE] slightly increased, as did P:PD; however, [cVOC$_{total}$] decreased 86.4% and 97.8%
- Septic leak in October may have caused loss of reducing conditions
  - advection of upgradient contaminants
  - solubilization of residual mass
- Decreases in [daughters] still occurring concurrent with parent [PCE] increases

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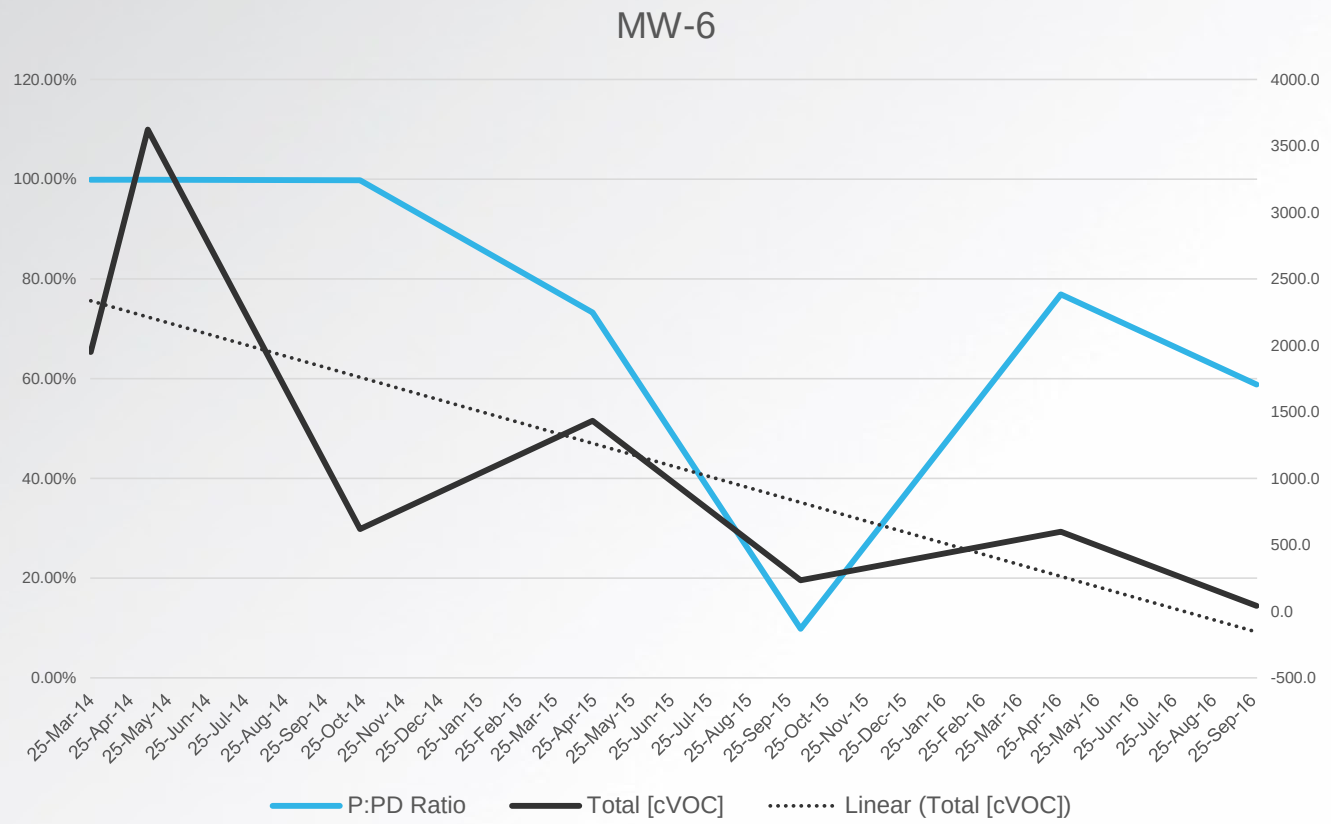
Phase III In-Situ Biostimulation

Results Full Scale Application

2½ years post additive deployment



- **98.8%** reduction [cVOC] total
- 90.1% maximum reduction in P:PD Molar Ratio T= month-18 (October 2015)
- 41.2% overall reduction P:PD Molar Ratio
- Graph shows dehalorespiration of parent PCE months T1-T20; where lowest P:PD ratio observed
- T20-T26 [$cVOC_{total}$] slightly increases, then decreases to evaluation end; at same time
- P:PD ratio increases, then drops; slight rise in [PCE] caused disproportionate increase in P:PD as [daughters] continues to decrease

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Phase III In-Situ Biostimulation

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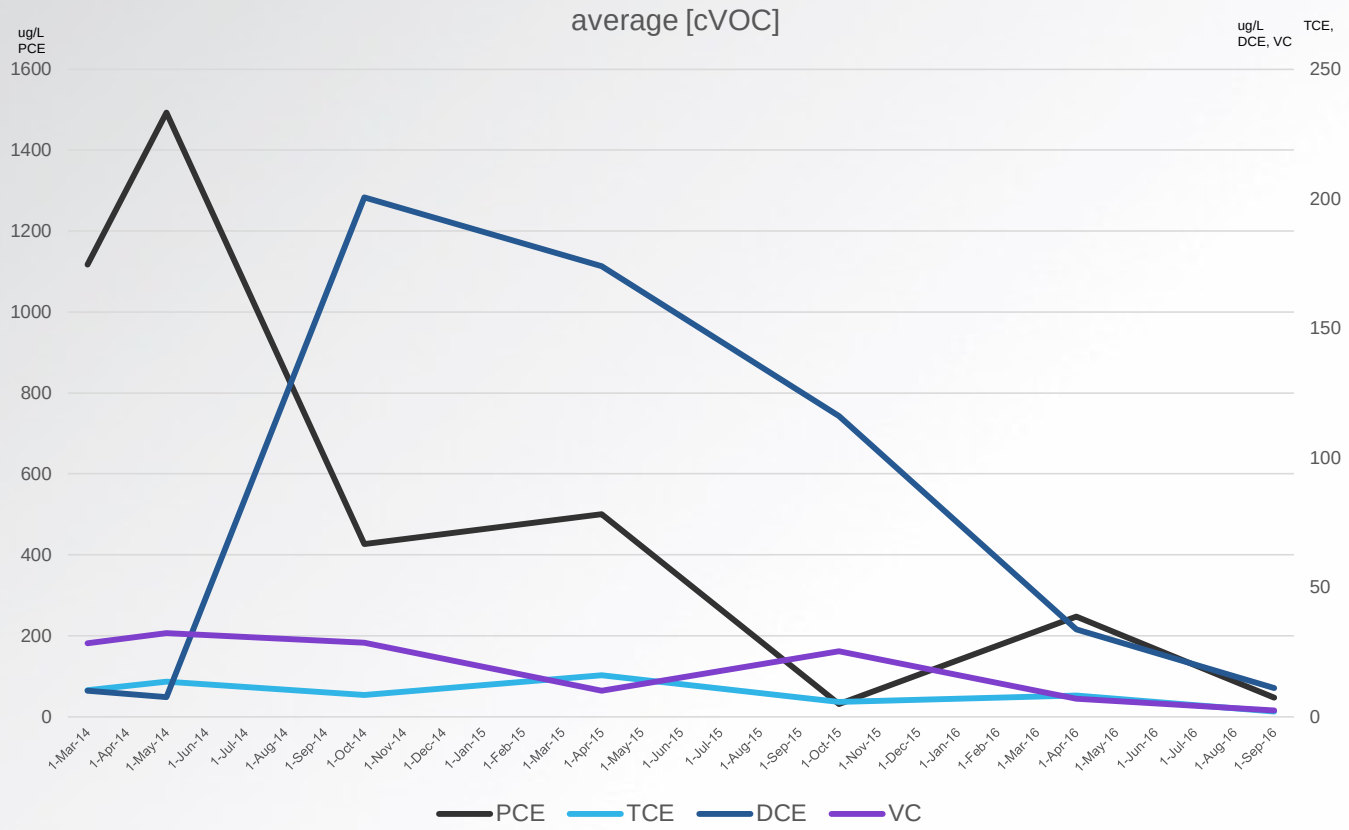
Results Full Scale Application

2½ years post additive deployment



- Plot average [cVOC] within apparent amended treatment zone, avg.[MW2, MW3, MW6]
- **96.9%** overall reduction [avg.PCE]
- [avg.TCE] increased ≈60%; then decreased **88.2%** by after 2+ years post amending
- [avg.DCE] increased >1,600%; followed by a **94.5%** reduction from peak bioavailability
- [avg.VC] decreased **>92.3%** overall after occasional increases/decreases

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Conclusions

- **Safe Sustainable and Effective**
- **Enhances Native Microbial Populations**
  - Enhances Dissolve Phase Dehalorespiration
  - Expedites Residual Mass Solubilization
  - Co-Solvent Effect
  - Inorganic Nutrient Package Recycled Within Treatment Zone
  - Enhances Endogenous Decay
  - Extending Carbon Source/Nutrient Availability
- **Sustainable**
  - Maintains Enhanced Reducing Conditions for over a Decade
  - Realizing Complete cVOC Biotransformation w/ Minimal Impacts
  - Eliminating Multiple Deployments
  - Enhancing Project Cost-Effectiveness

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Pilot Study Microcosm Evaluation

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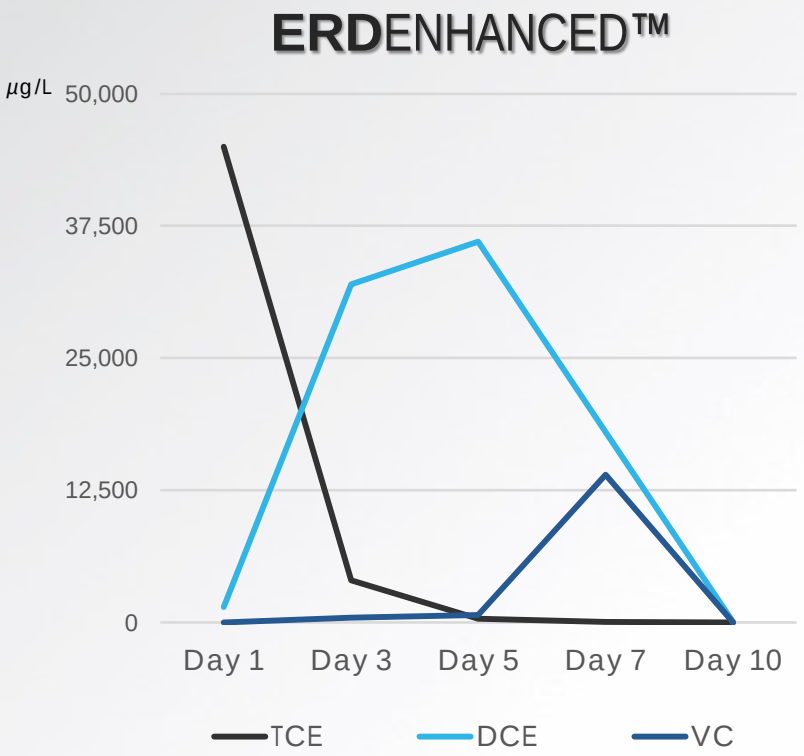
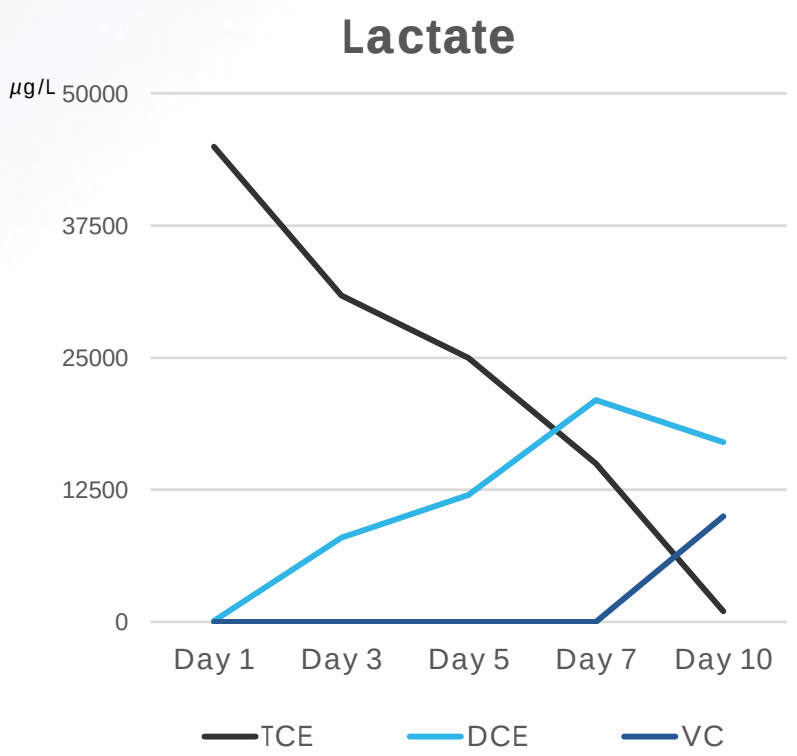
NASA Stennis Space Station - Mississippi



TerraStryke® Safe, Sustainable, Effective Complete Biotransformation of Greater Molar Mass of cVOC contaminants



Lactate *did not* yield complete biotransformation during evaluation period

TERRA STRYKE

Pilot Study – Kenosha Wisconsin

ERDENHANCED™

- Former Chrysler Facility
- **ERD**ENHANCED™
  - 99.8% *DECREASE* in [TCE]
  - 95.0% *DECREASE* in Total [cVOC]
- Increased Dissolved [Iron] indicative of enhanced iron reduction
- Greater Methane Production Indicative of Stimulation of Methanogenesis
- 400% Increase in [Ethene] Indicating Complete Parent cVOC Transformation
- [Chloride] Increased while other locations stable/decreased indicating enhanced biostransformation

METRICS	ERDenhanced	Lactate	Hydrogen Based Compound
Total [TCE]	99.8%-	97.5%-	99.9%-
Total [cVOC]	95.0%-	80.2%-	69.8%-
Dissolved Iron	+	NC	NC
Methane	+++	+	+
Ethene	+400%	NC	NC
Ethane	+99%	NC	NC
Chloride	+	-	NC