Cost-Effective In-Situ Remediation

Biostimulation as a Residual Source Mass Remediation Strategy

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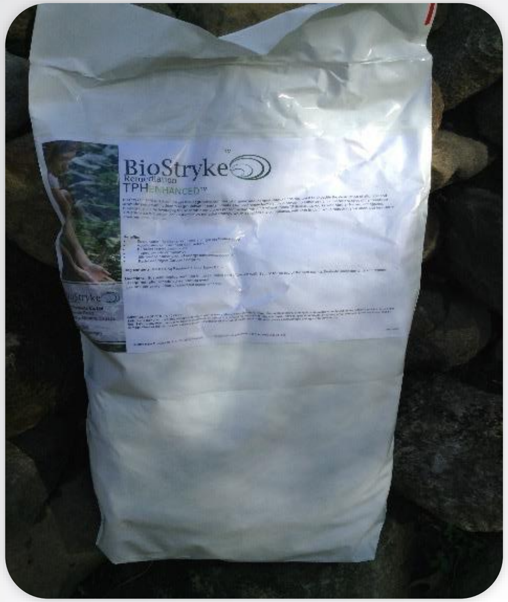

Environmental Services Association of Alberta
ESAA

October 12-14, 2016 Banff, Alberta
Canada

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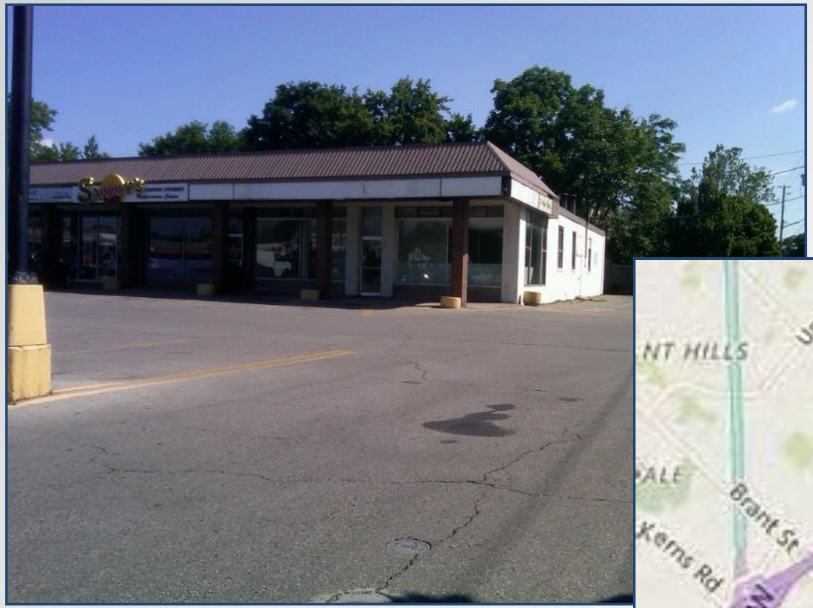
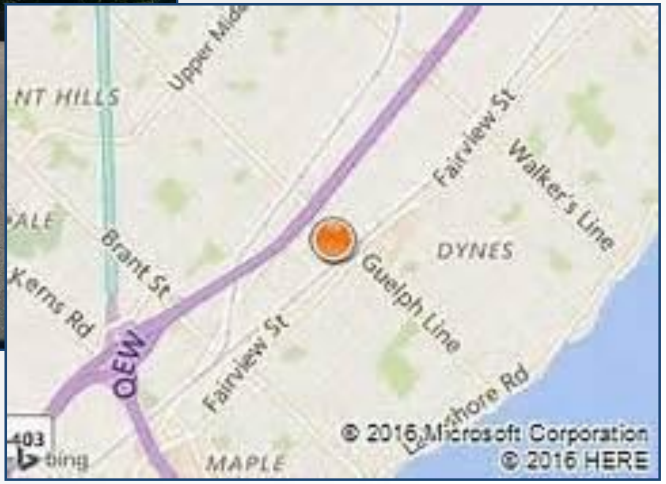
Summary of Site Conditions





Background - 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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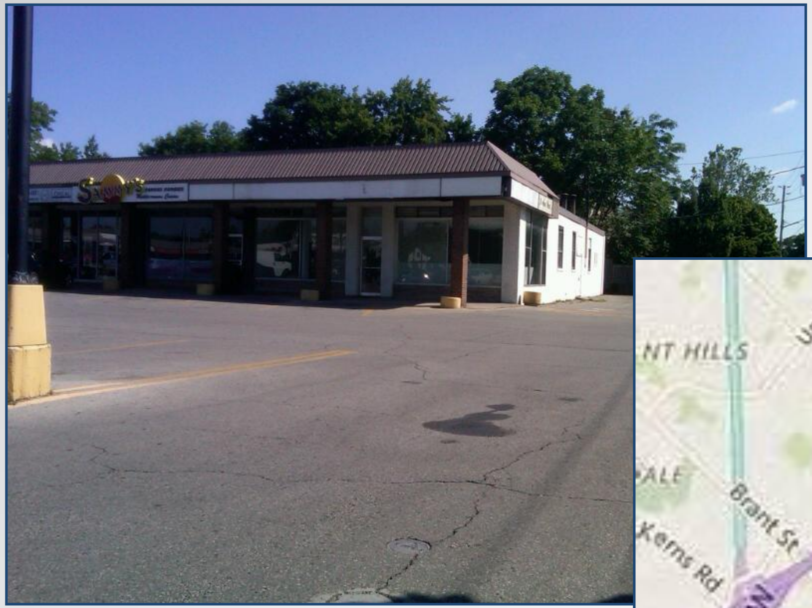
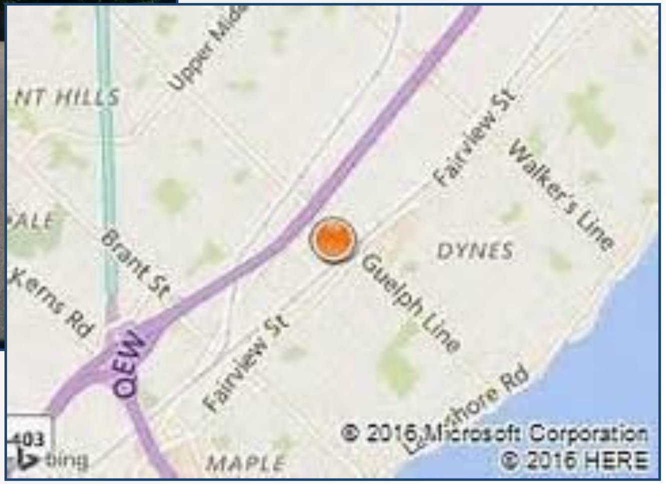
Summary of Remediation Activities





Remediation Goals

Identify low-cost low-impact strategy to address residual mass and dissolve phase contaminants

Avoid secondary contaminant concerns and associated risks

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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Who is TerraStryke® ?
What can we do for YOU?

TerraStryke® Products LLC has been BioStryke Remediation Products LLC for past 7-years developing formulations that assist practitioners to

*I*ncrease project performance, *L*ower costs and *I*ncrease margins

TerraStryke® works to assist the establishment of 'Green' remediation strategies

Helping to realize remediation objectives and reduce site impacts

Proven products and strategies to achieve site remediation goals safely, sustainably and effectively

Why is Biostimulation Cost-Effective?

Biostimulation is a proven remediation strategy that:

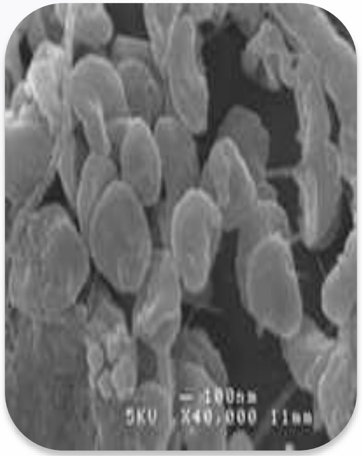
- Nourishes and stimulates native microbial populations
- Expedites solubilization of residual source mass contaminants
- Increases contaminant bioavailability
- Enhances dissolve phase contaminant destruction to
- Realize Long-Term Compliance

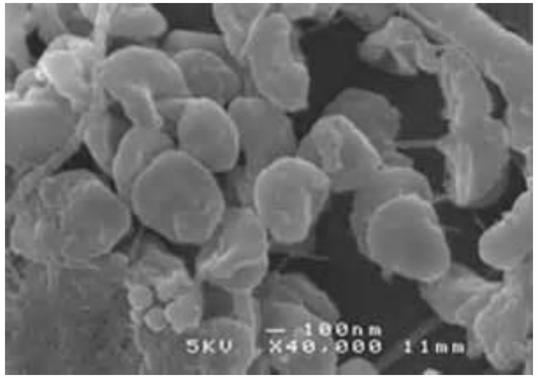
Biostimulation minimizes the impact of remediation by:

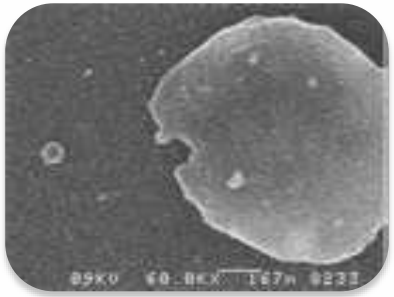
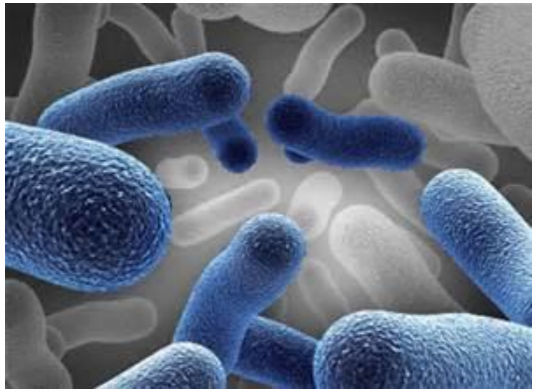
- Minimizing/Eliminate Multiple Deployments
- Eliminate above ground support equipment
- Minimizing off-site removal activities, fuel and energy costs
- Minimizes and eliminates nuisance noise, emissions and vapors

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^+
  - Co-Solvent Effect from assimilation of Carbohydrate
  - Formulation maintains sustainable reducing conditions that have exceeded a ***decade*** in duration





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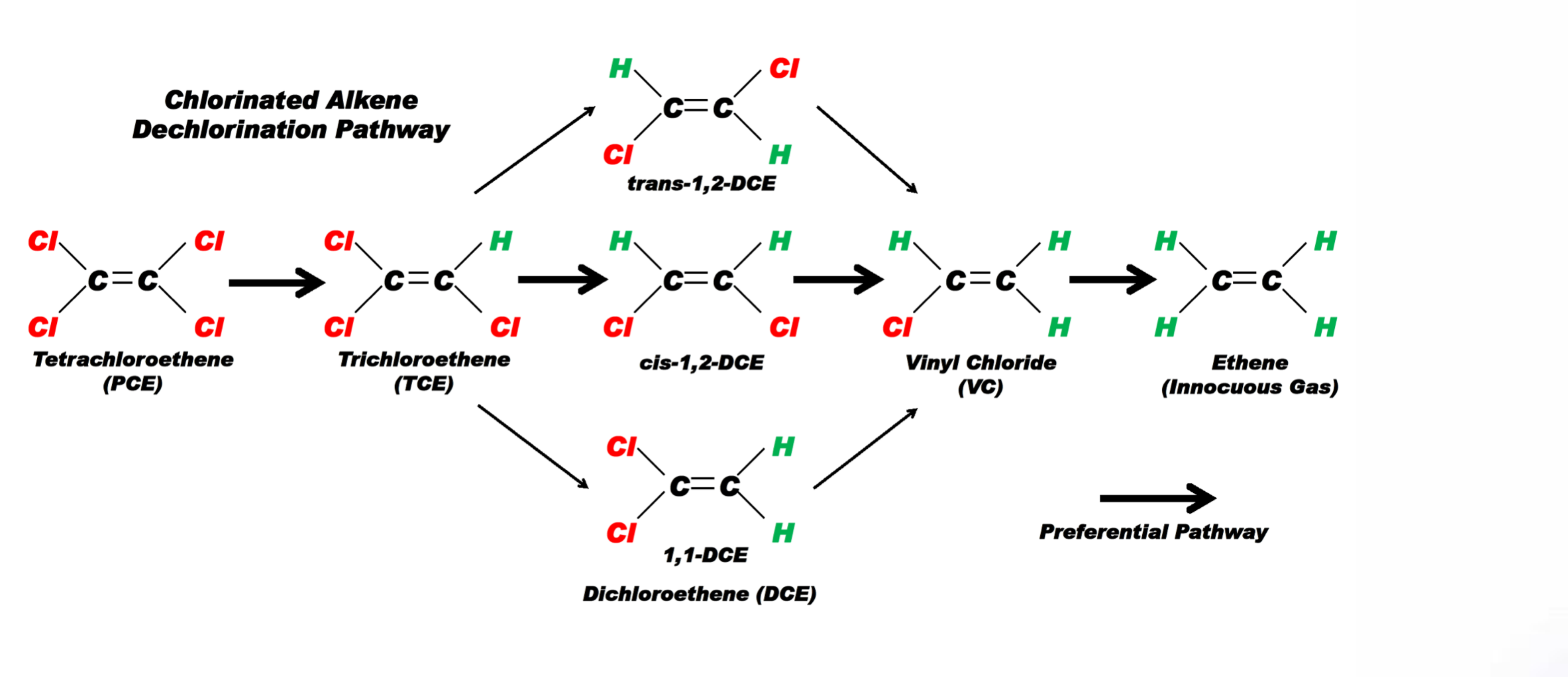
cVOC Biotransformation Pathway



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Pilot Study Microcosm Evaluation
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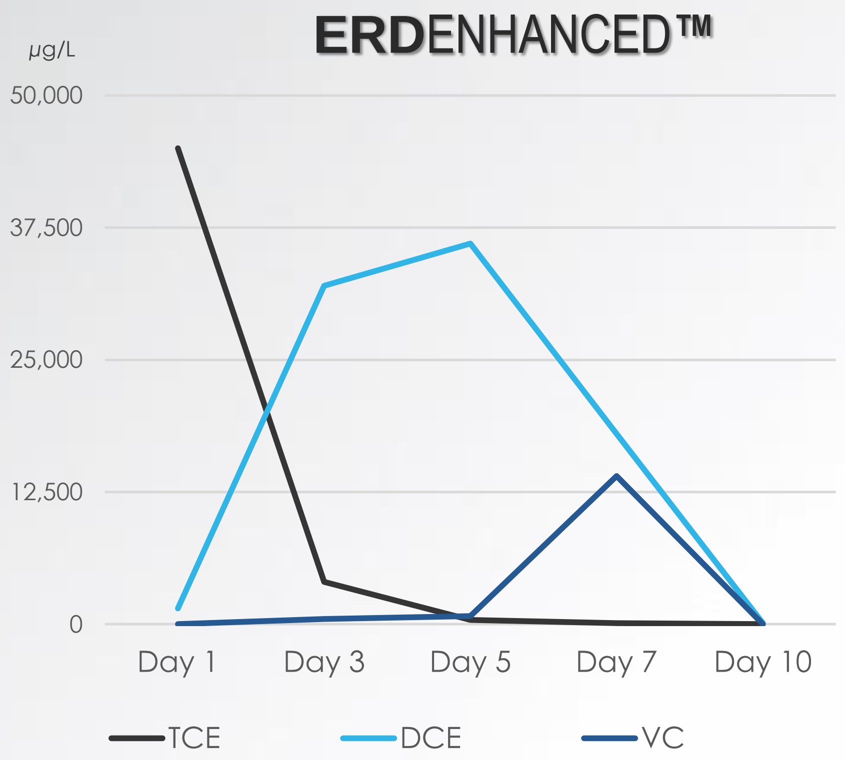
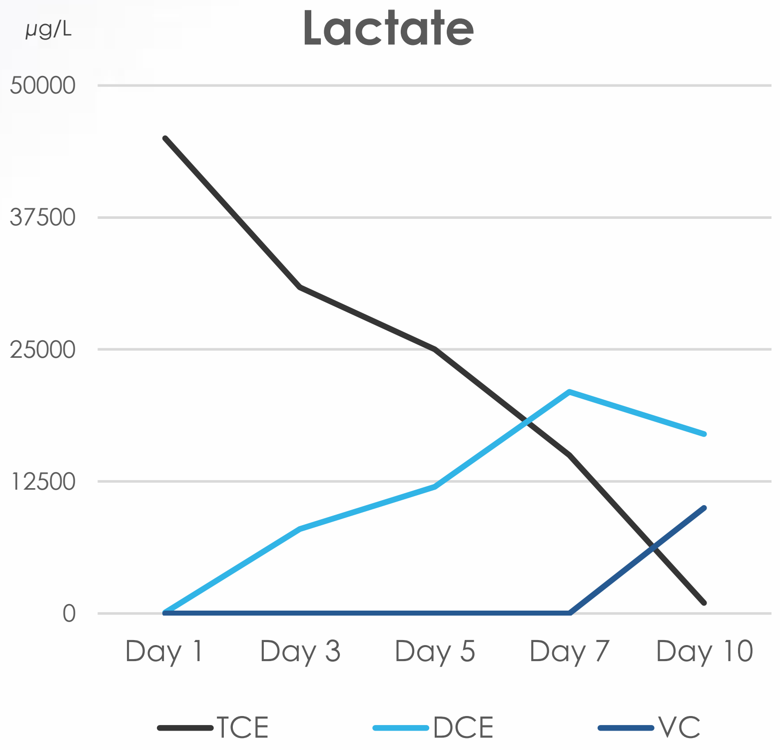
NASA Stennis Space Station - Mississippi



ERDenhanced™ Safe, Sustainable, Effective Complete Biotransformation of Greater Molar Mass of cVOC contaminants



Lactate *did not* yield complete biotransformation during evaluation period

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Pilot Study – Kenosha Wisconsin

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Amendment Comparison Evaluation

- 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

Phase I - PRS Evaluation Process

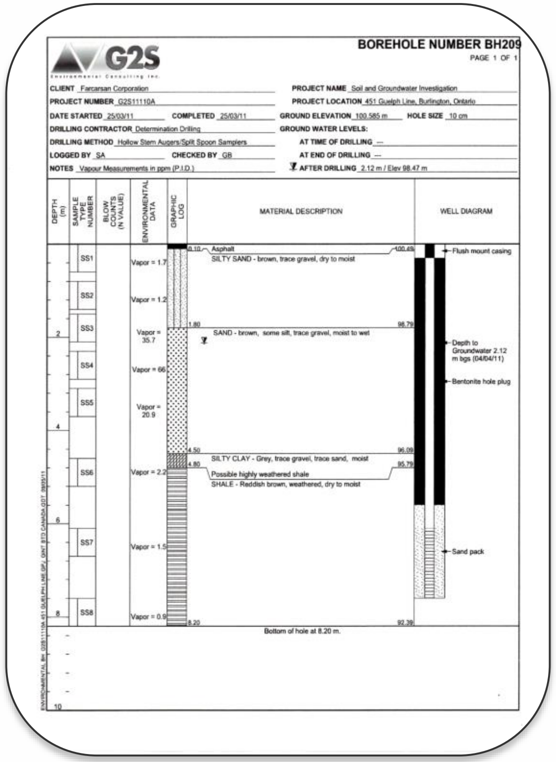
Determine Efficacy Under Actual Biogeochemical Conditions

- On-Site '*Go-no-Go*' <u>on-Site</u> Efficacy 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

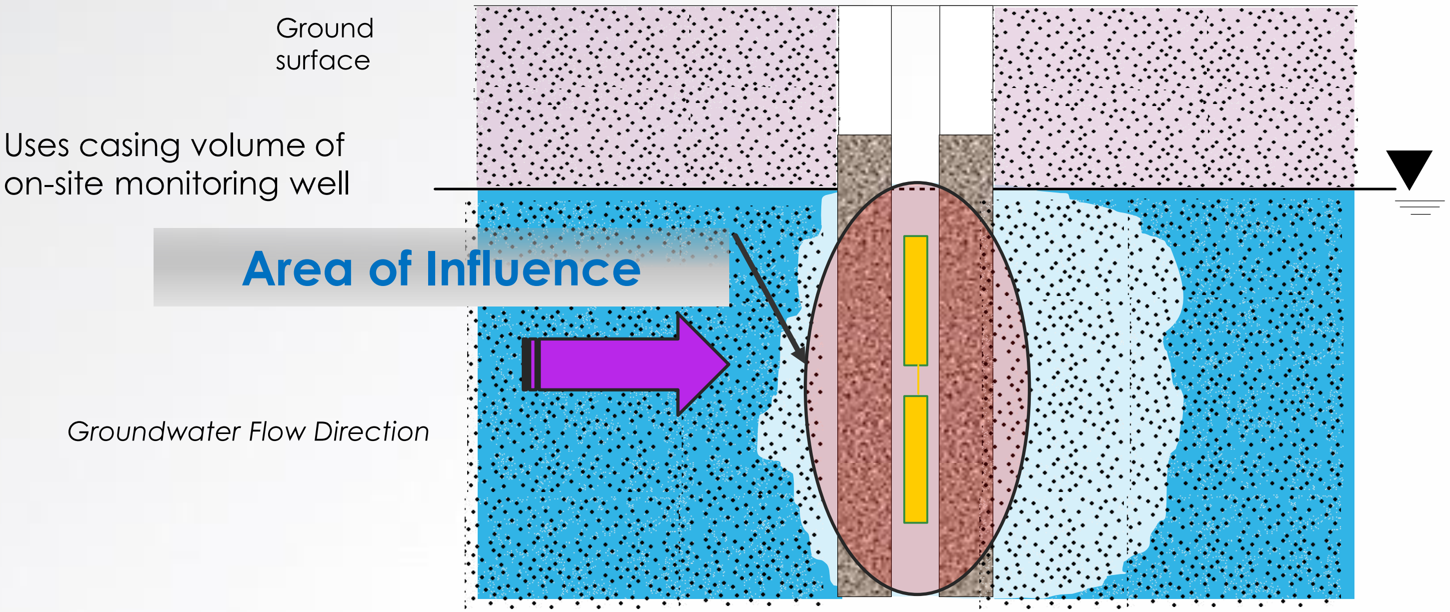


Phase I - PRS Evaluation Process

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)

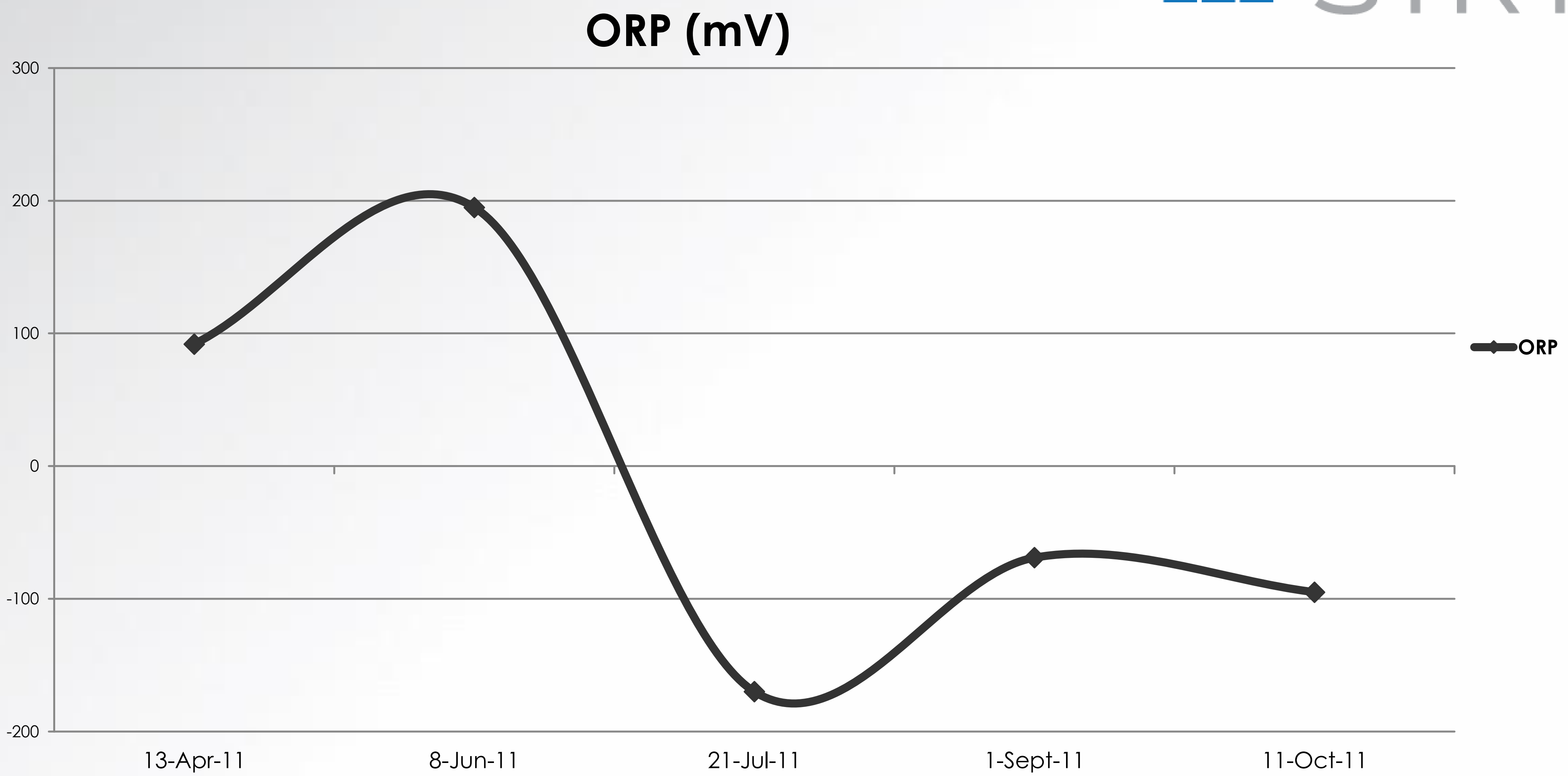
- **Field Indicator Parameters Recorded *Every* Replacement Event**

- **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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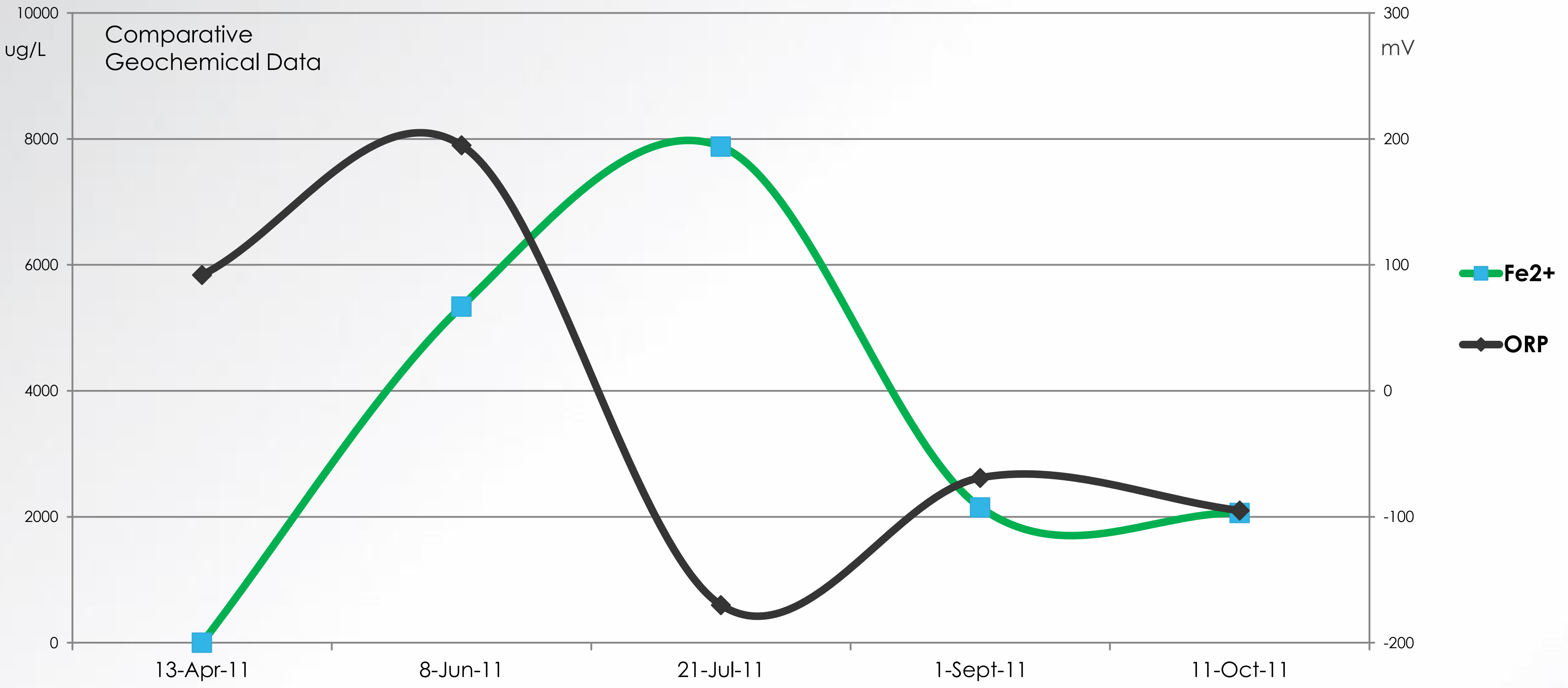

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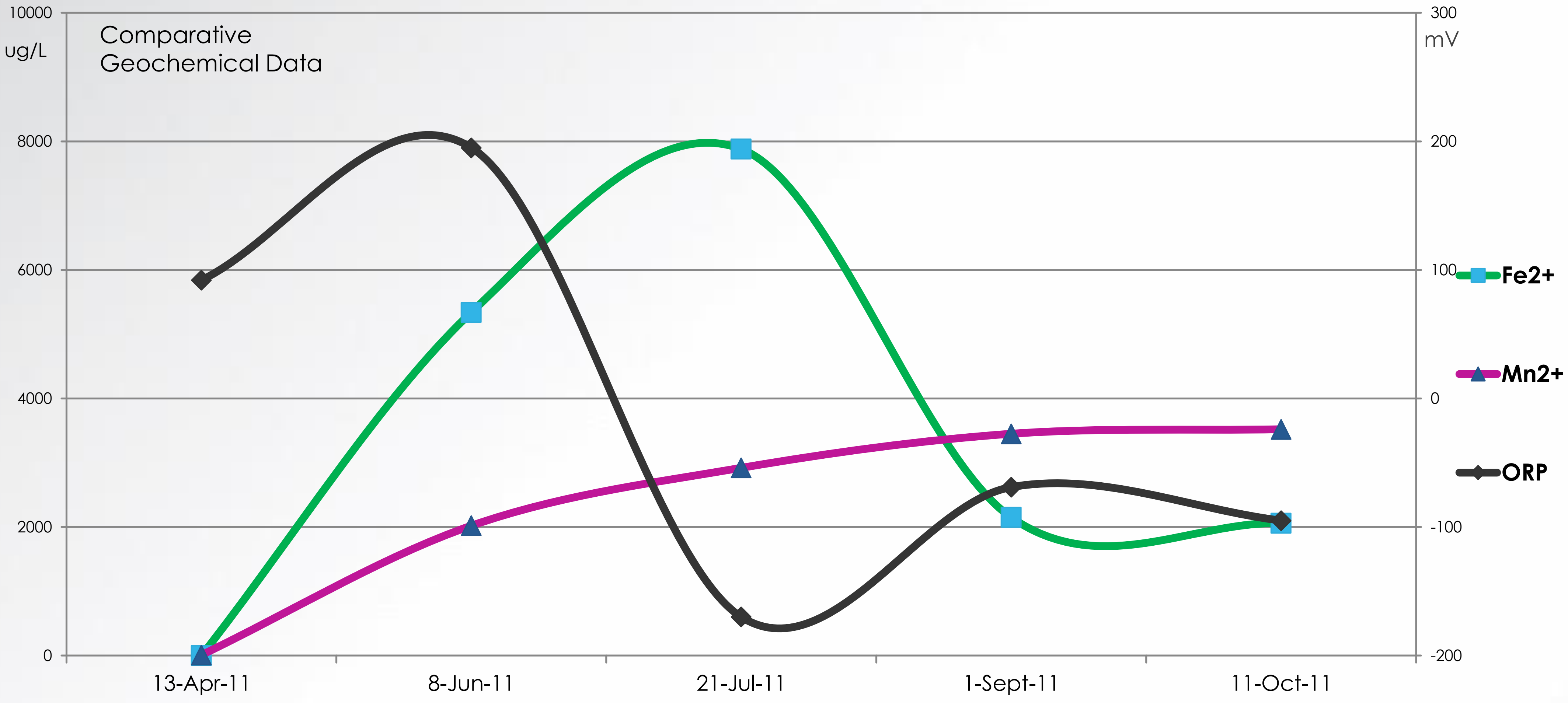

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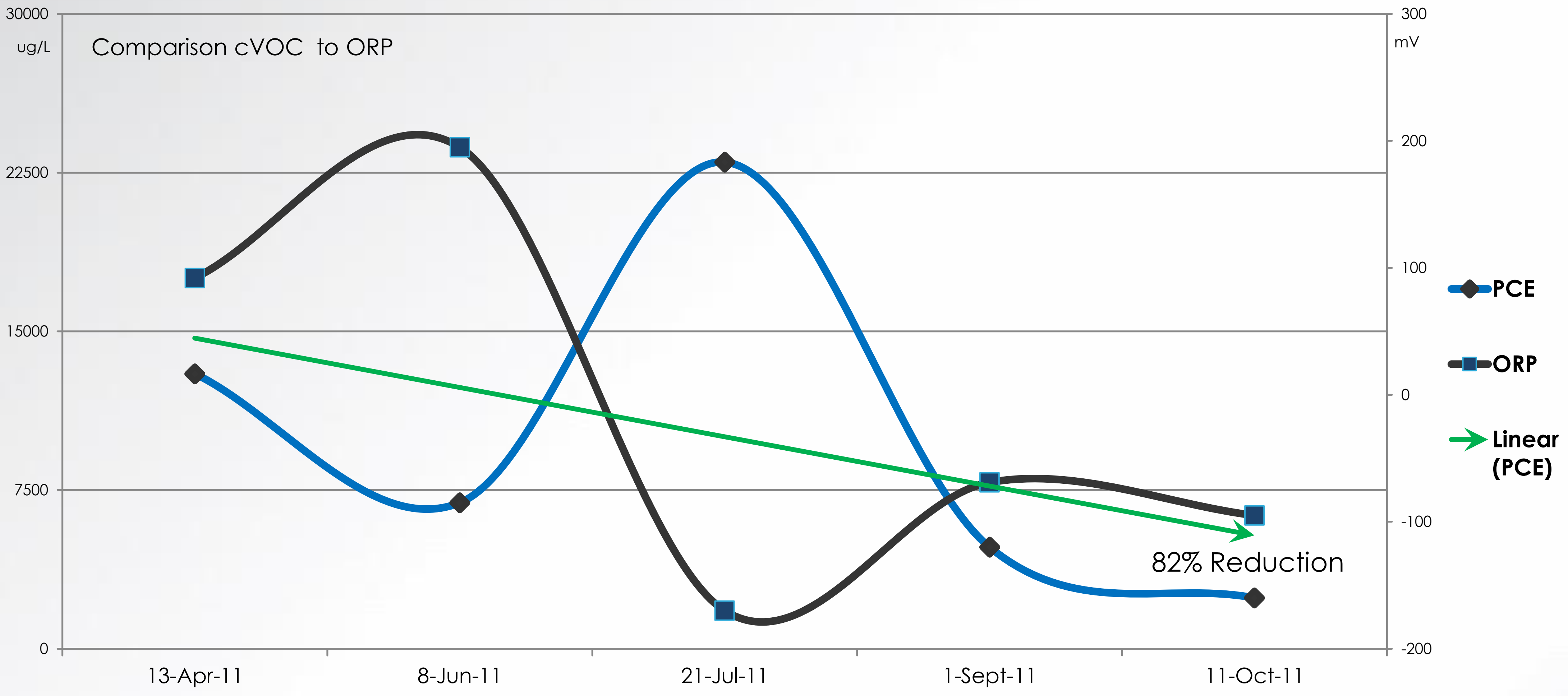

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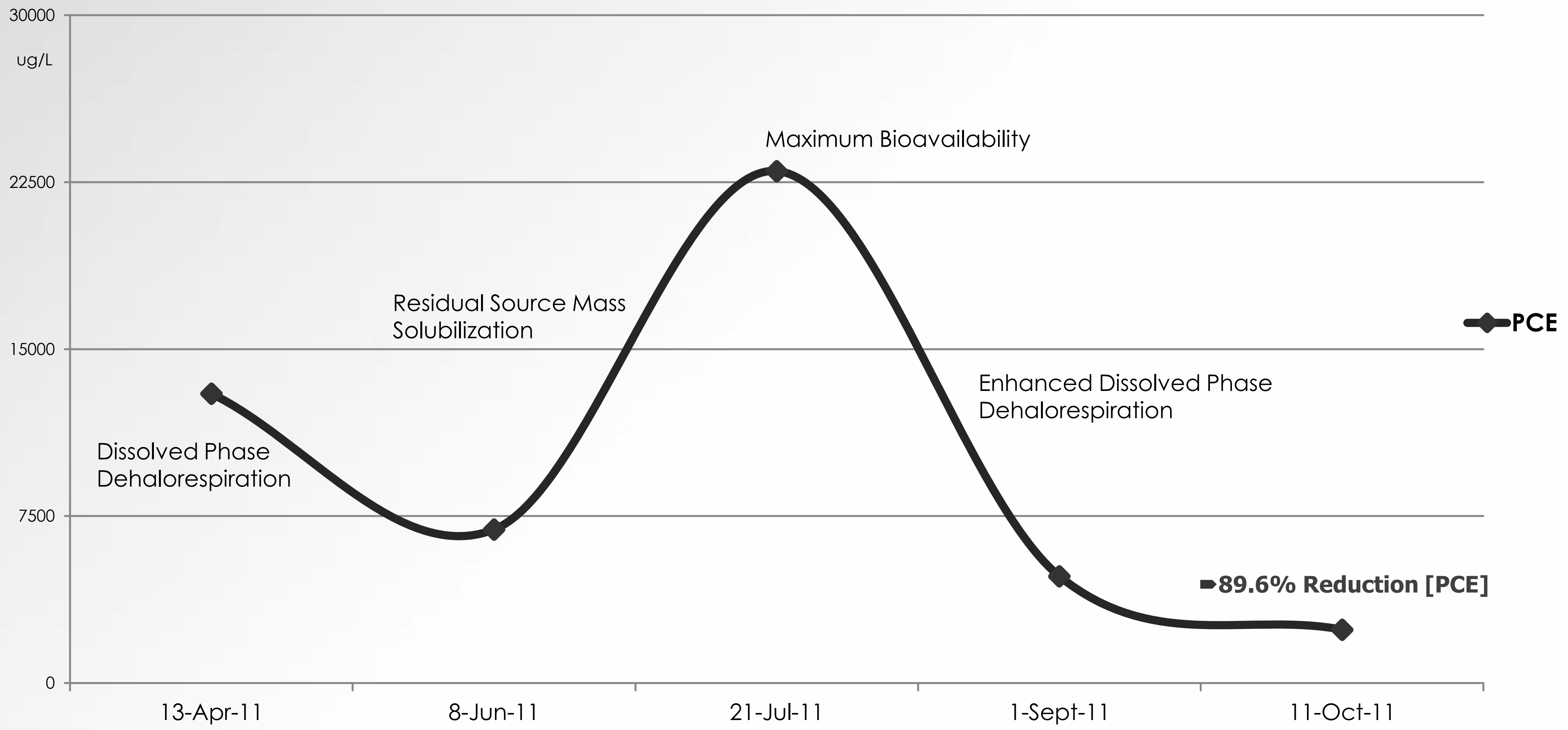

Phase I - PRS Evaluation Process

Determine Efficacy Under Actual Biogeochemical Conditions

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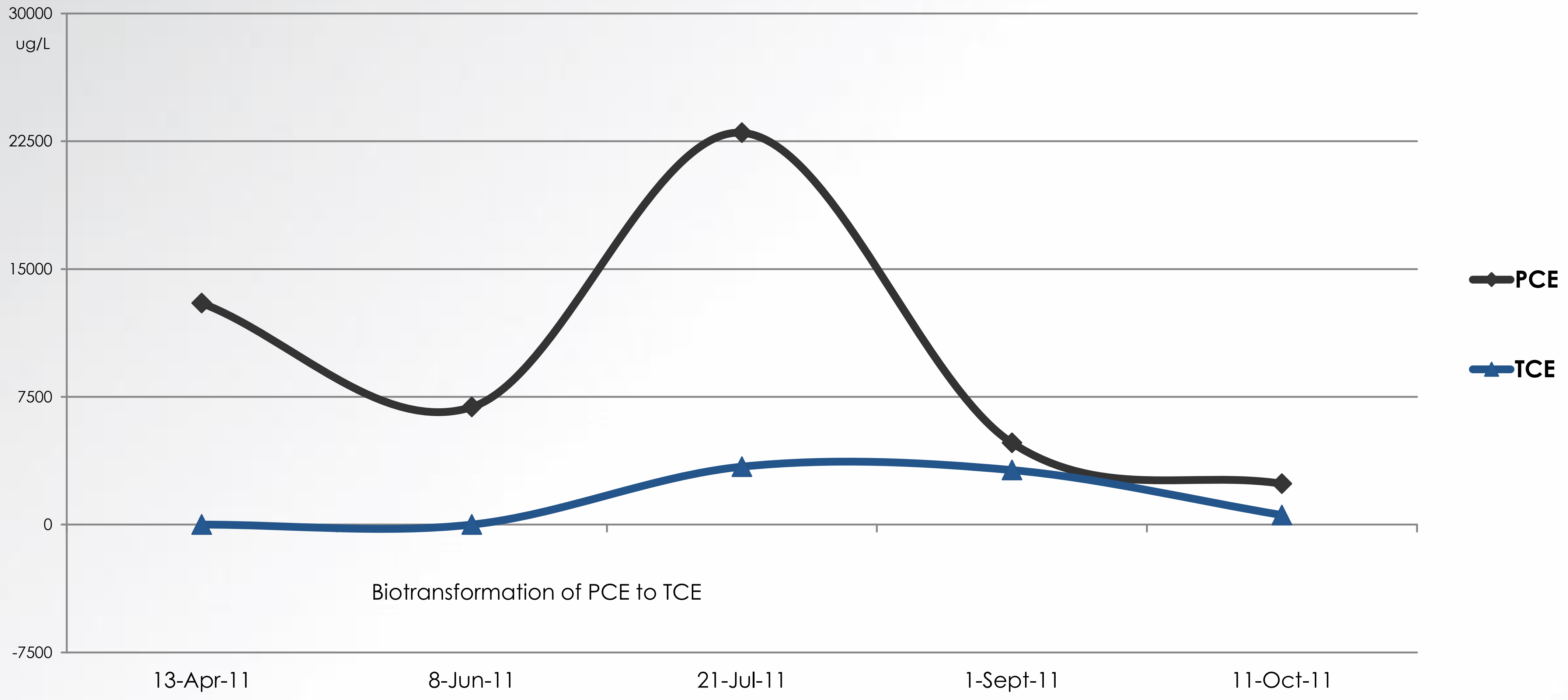

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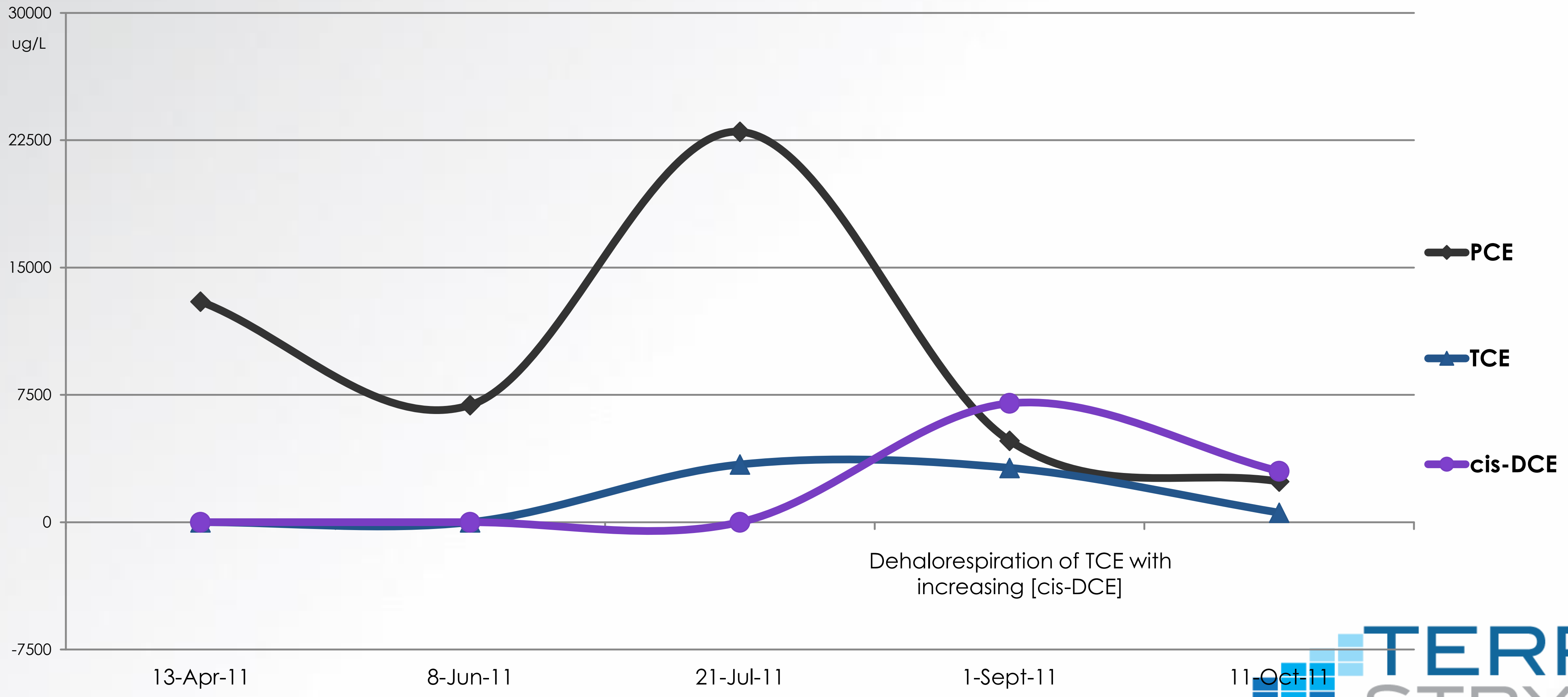

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Phase I - PRS Evaluation Process

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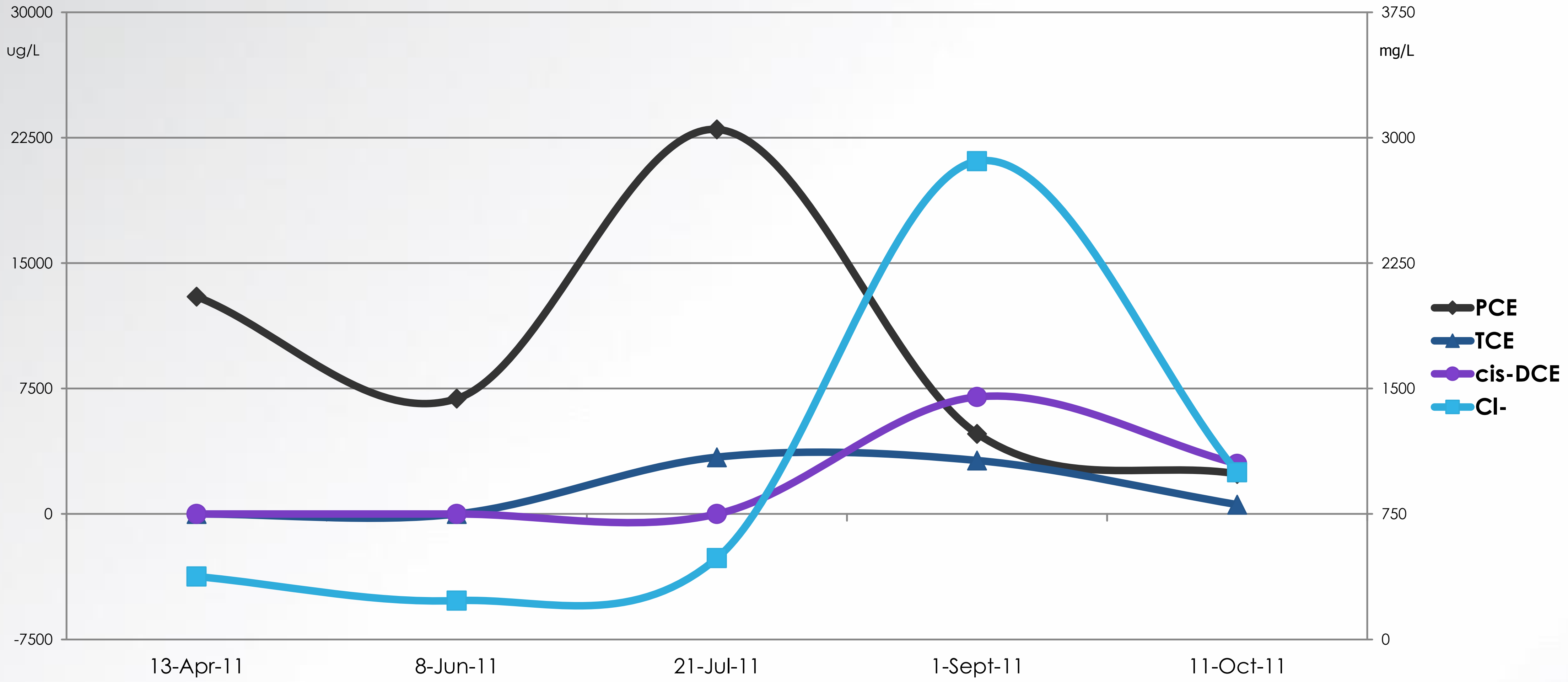

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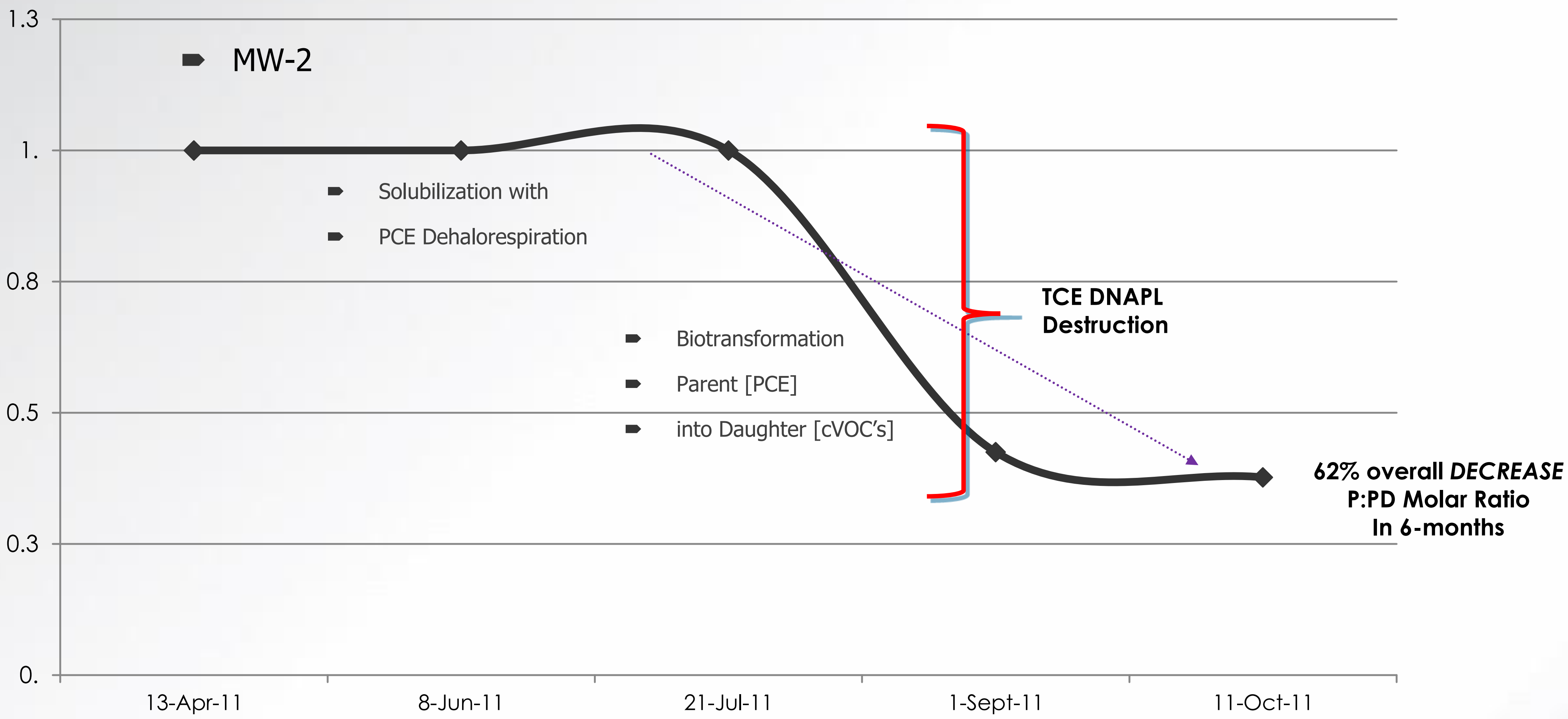

Importance of P:PD Ratio

Biotic Contaminant Reduction?

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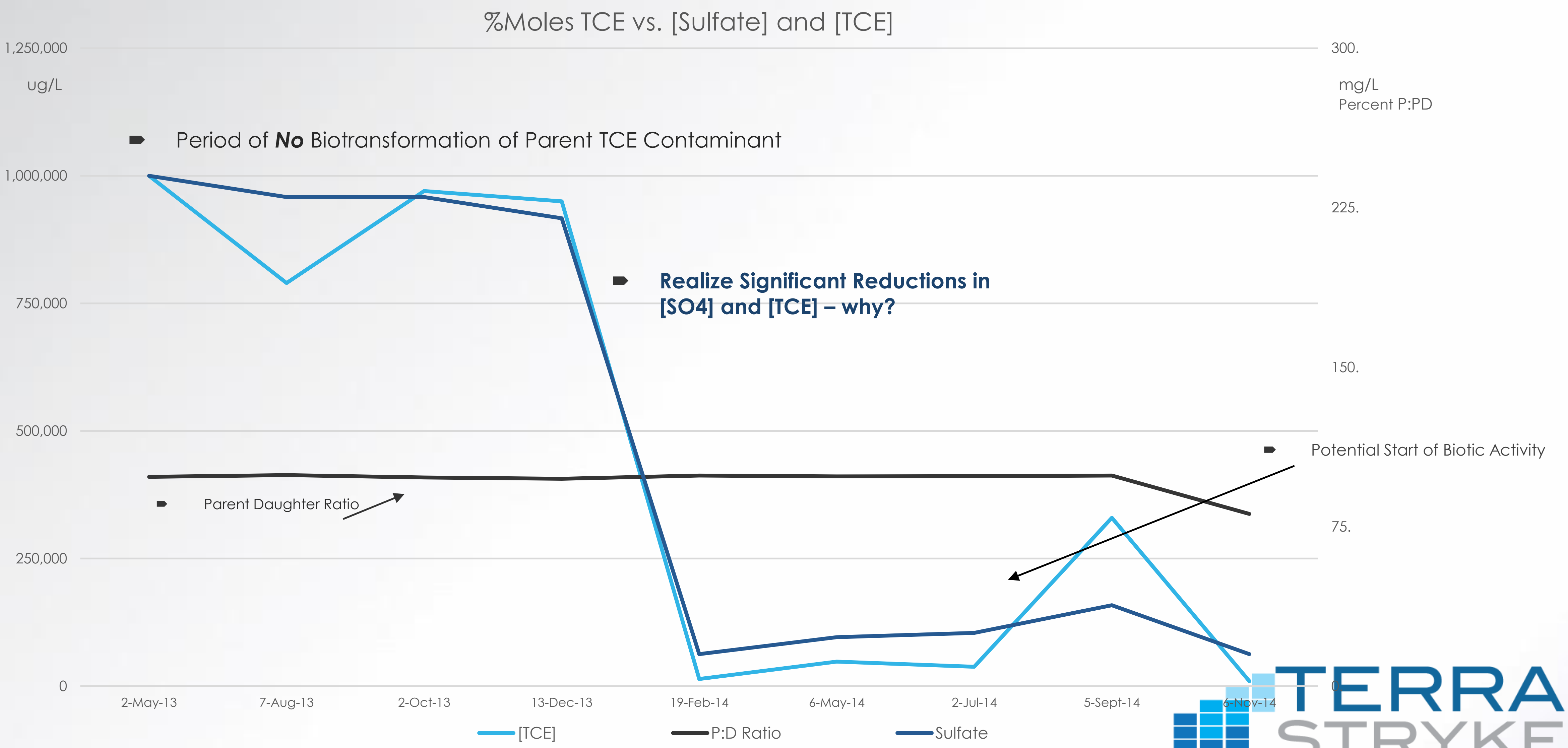
Contaminant Reduction but *NO* Destruction!



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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

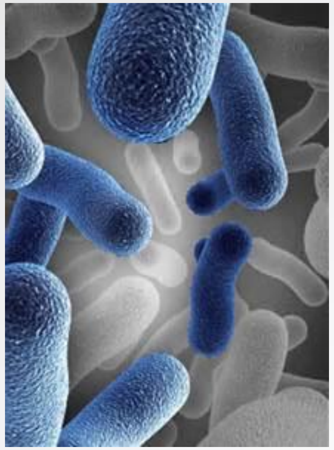
Groundwater Conditions

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: March 2014 July 2014

9% additive slurry gravity fed to subslab gallery

990kg/840kg w/1,000 gallons chase water per deployment

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Phase III In-Situ Biostimulation

Data available to date represents ≈18-months of amendment impact

Amendment Influenced 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
- Includes field geochemical and lab analytical metrics

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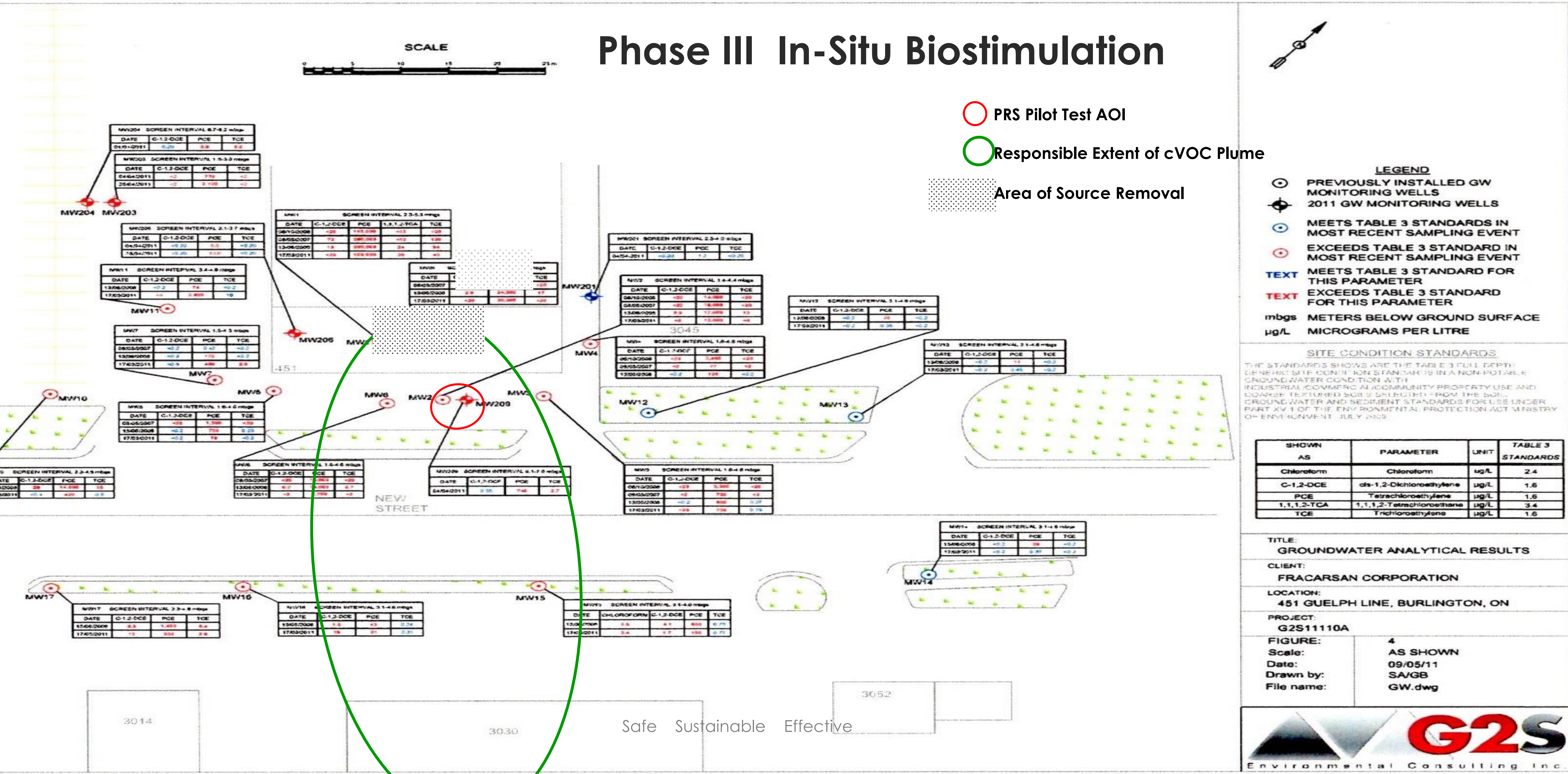
Full Scale Application

Phase III In-Situ Biostimulation



Safe Sustainable Effective

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 adjacent

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

Post-Additive Introduction [cVOCs] October 5, 2015

Location	[PCE]	[TCE]	[cis-DCE]	[VC]	P:PD Ratio
MW-2	<25 ug/L	<25 ug/L	48 ug/L	<25 ug/L	8.7%
MW-3	51 ug/L	2.7 ug/L	170 ug/L	26 ug/L	0.8%
MW-6	41 ug/L	12 ug/L	130 ug/L	50 ug/L	3.7%
MW-209	NS	NS	NS	NS	NS

1½-years post deployment

Percent Reduction P:PD Ratio Post Deployment

Average **94.9%** *REDUCTION*

>99.99% *REDUCTION* at MW-3

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

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Results Full Scale Application

2 years post additive deployment

Phase III In-Situ Biostimulation

Post-Additive Introduction [cVOCs] April 2016

Location	[PCE]	[TCE]	[cis-DCE]	[VC]	P:PD Ratio
MW-2	1.5 ug/L	<1.0 ug/L	3 ug/L	8.0 ug/L	5.3%
MW-3	230 ug/L	9.2 ug/L	35 ug/L	< 2.0 ug/L	75.6%
MW-6	510 ug/L	15 ug/L	63 ug/L	10 ug/L	76.9%
MW-209	NS	NS	NS	NS	NS

- 90.9% overall reduction P:PD (MW-2)
- MW-3/MW-6 increases in [PCE] and P:PD ratio
- Solubilization of Residual Mass
- P:PD Molar Ratio increased due to concurrent dehalorespiration of daughter products
- 82.9% average reduction in [cVOCtotal]
- 45.9% average reduction in P:PD Molar Ratio
- Septic leak in October 2015
    - Need to better evaluate geochemistry
    - Need to observe possible advection of upgradient off-site cVOC contaminants
    - Monitor degree of residual mass solubilization

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Results Full Scale Application

2½ years post additive deployment

Phase III In-Situ Biostimulation

Post-Additive Introduction [cVOCs] September 2016

Location	[PCE]	[TCE]	[cis-DCE]	[VC]	P:PD Ratio
MW-2	2.4 ug/L	<1.0 ug/L	< 1.0 ug/L	< 1.0 ug/L	100%
MW-3	130 ug/L	3.7 ug/L	7.0 ug/L	< 1.0 ug/L	88.7%
MW-6	8.4 ug/L	1.9 ug/L	26 ug/L	6.9 ug/L	58.8%
MW-209	NS	NS	NS	NS	NS

99.4% reduction [PCE] (MW-2)

87.4% reduction [PCE] (MW-3)

P:PD Molar Ratio increased at each location; with 99.6% and 86.3% reductions in [cVOCtotal]

99.6% reduction [PCE]; 41.1% P:PD, at MW6

97.8% overall reduction [cVOCtotal] MW6

95.2% average reduction in [cVOCtotal]

Geochemical Conditions

- [TOC] <100mg/L at each location
- [Cl^-] range from 130 mg/L to 1,500 mg/L
- Ethene recorded at MW6

Septic, possible advection of upgradient contaminants, expedited Carbon source use

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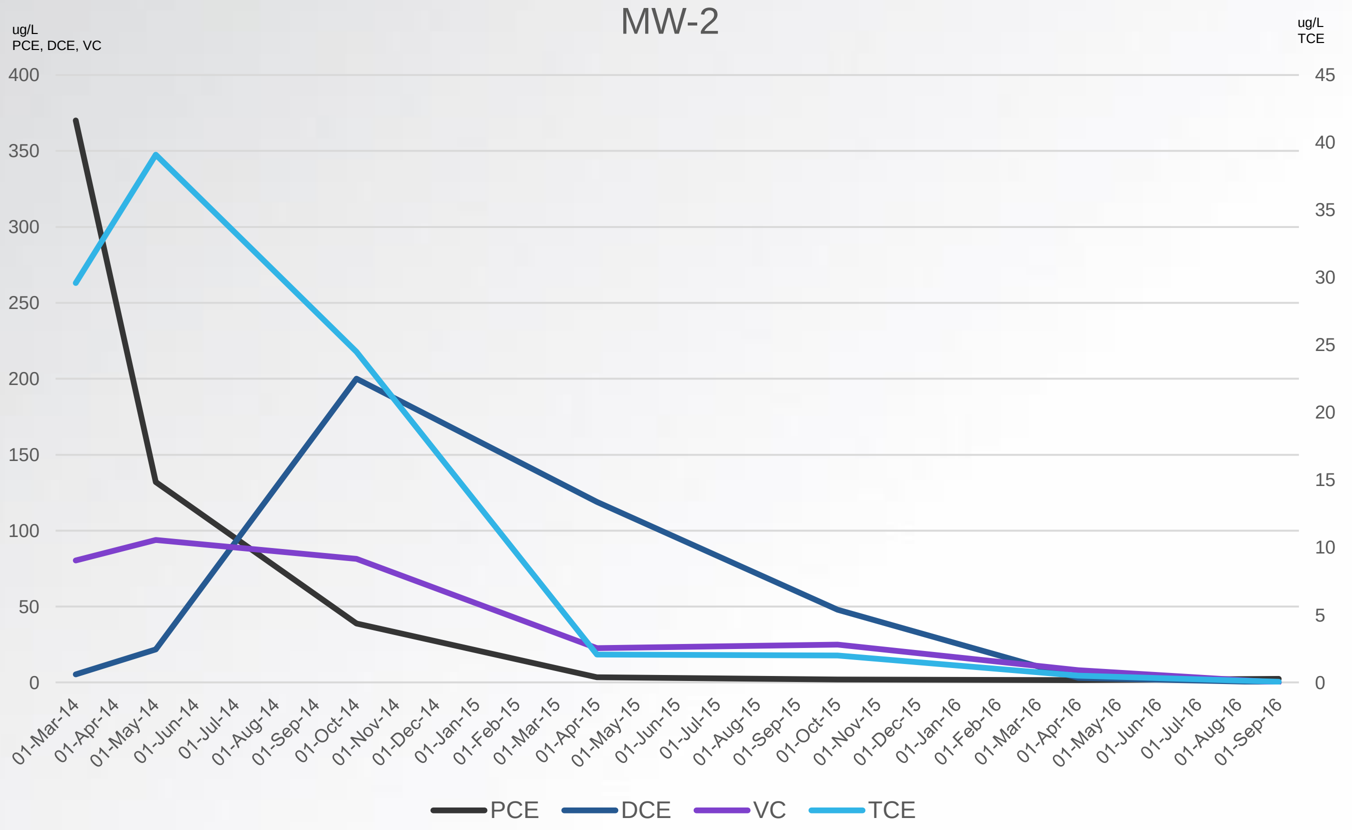
Results Full Scale Application

2½ years post additive deployment

Phase III In-Situ Biostimulation



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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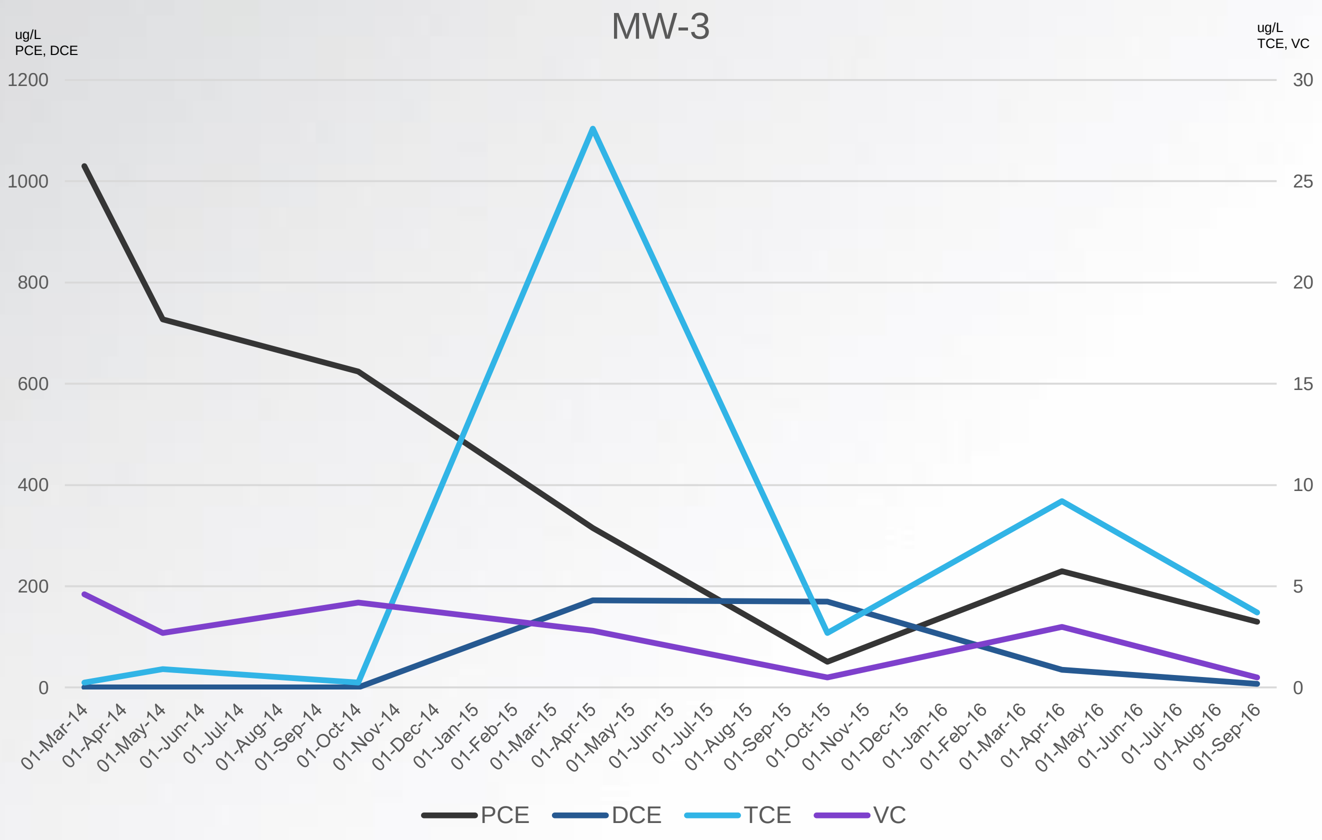
Results Full Scale Application

2½ years post additive deployment

Phase III In-Situ Biostimulation



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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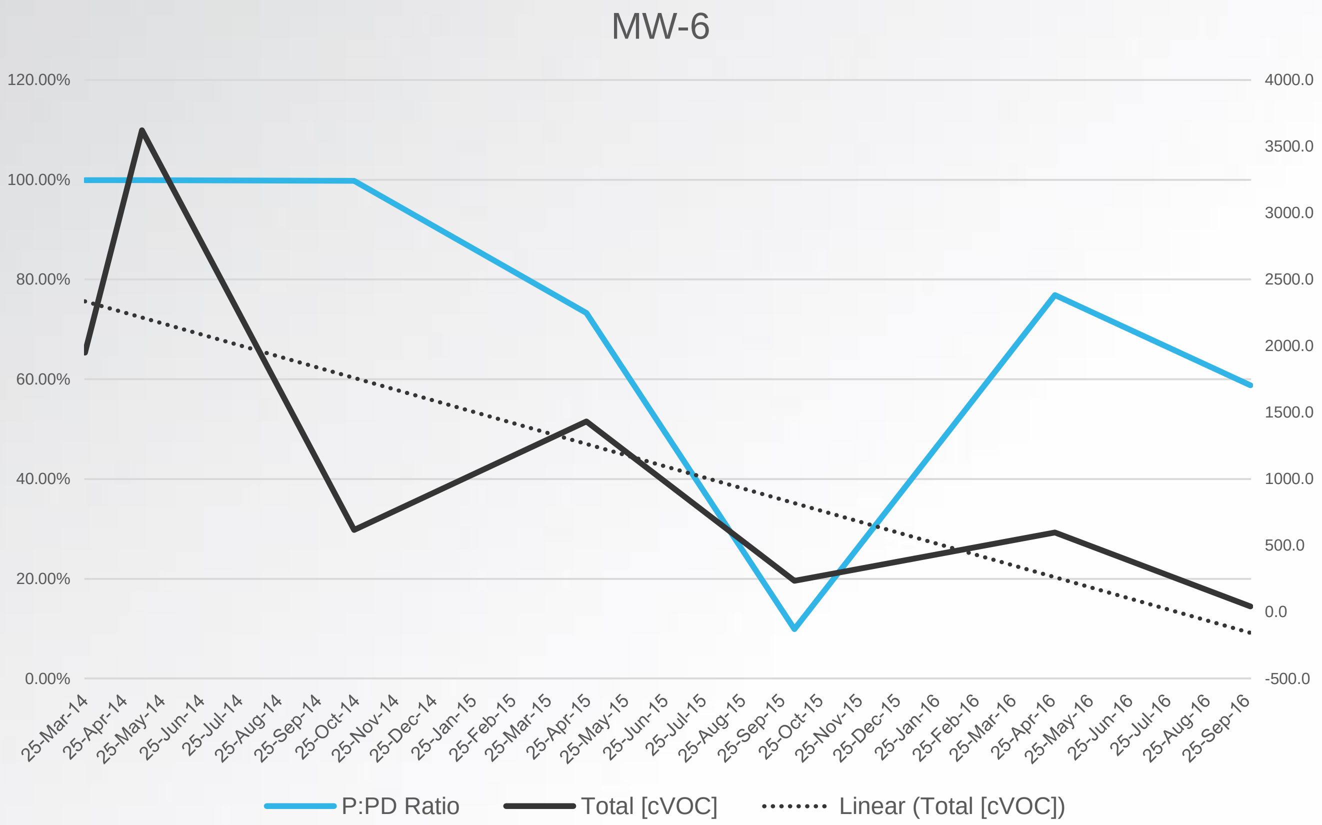
Results Full Scale Application

2½ years post additive deployment

Phase III In-Situ Biostimulation



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 demonstrates the dehalorespiration and subsequent destruction of cVOC molecules

Concurrent with reductions in dissolve phase [cVOC]

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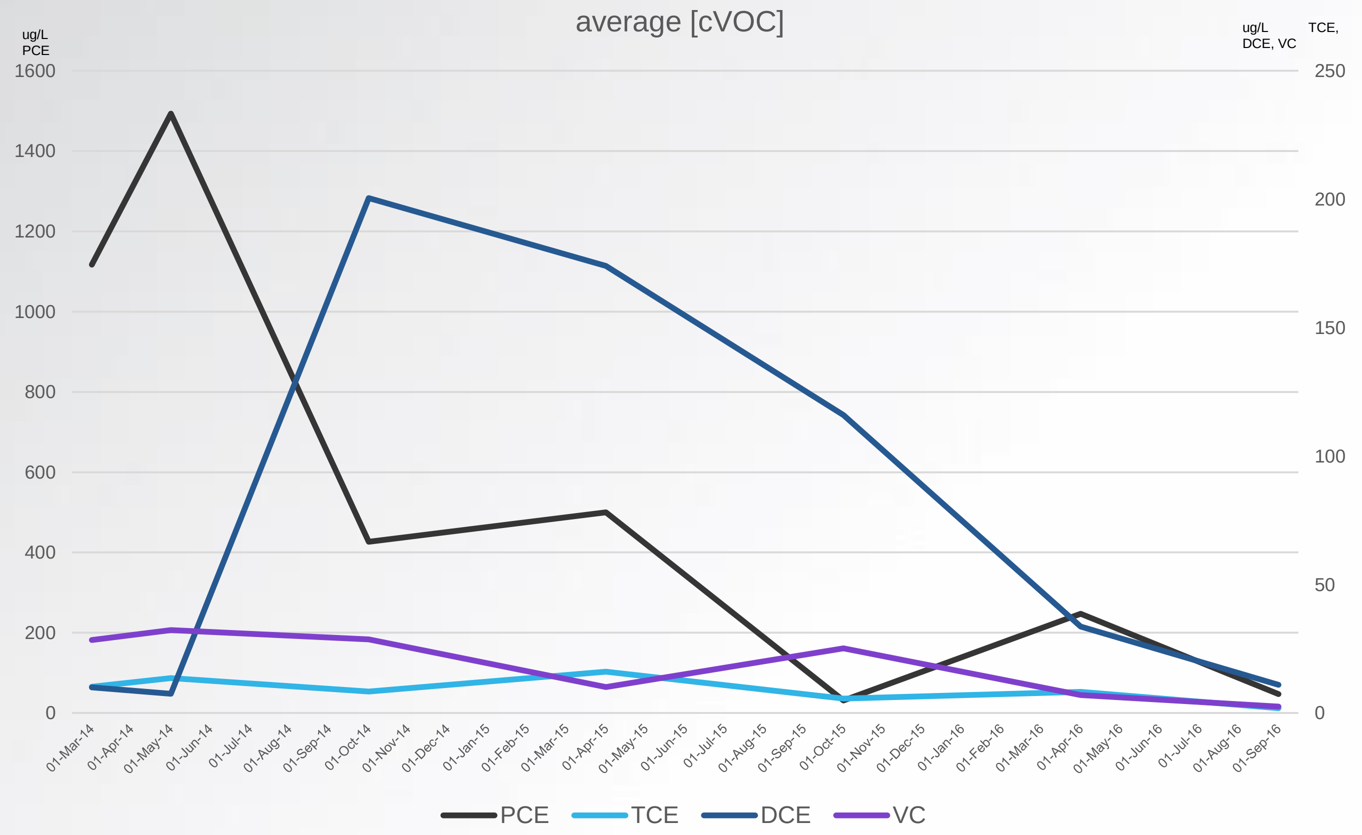
Results Full Scale Application

2½ years post additive deployment

Phase III In-Situ Biostimulation



Plot average [cVOC] within apparent amended treatment zone, ∆[MW2, MW3, MW6]

96.9% reduction [∆PCE] after several solubilization/reduction events

[∆TCE] increased ≈60% T=18-months; with 88.2% decrease by evaluation end

[∆DCE] increased >1,600% T=18-months 94.5% reduction from peak bioavailability

[∆VC] remained stable through T=12-months; decreased 68.7% T=18-months; increased ≈150% then, by evaluation end, [∆VC] decreased >92.3%

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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 and Extended Carbon Source
- **Sustainable**
  - Maintains Enhanced Reducing Conditions for over a Decade
  - Realize Complete cVOC Biotransformation w/ Minimal Impacts
  - Eliminates Multiple Deployments
  - Enhance Project Performance and Increase Project Margins
  - Safe, Sustainable, Effective