TERRASTRYKE
bringing the ground to life

Leveraging Microbial Behaviours to Realize Contaminant Destruction via Biostimulation Alone

Environmental Services Association of Alberta ESAA RemTech Symposium 2021

Kent Armstrong – October 14, 2021

Biostimulation

What *is not* biostimulation?

What *is* biostimulation?

Biostimulation

- Enhance nutritive capacity of treatment zone to support indigenous bacteria and the organic destruction of site contaminants.
- The treatment zone is an ecosystem under stress.
- Must eliminate environmental stresses to allow signaling and growth of microbial densities to attain quorum levels.
- Once achieved microbes collectively change phenotype from swimming to sessile, establish biofilms, share genetic information and evolve in real-time.
- As a consortium of adapted bacteria they achieve levels of sustainability and contaminant destruction previously thought unachievable by standard bioremediation.

The Power of the Unicellular

Historically believed

- Prokaryotes/microbes in general to be loners.
- Solitary, capable of little.

We now have a completely different perspective

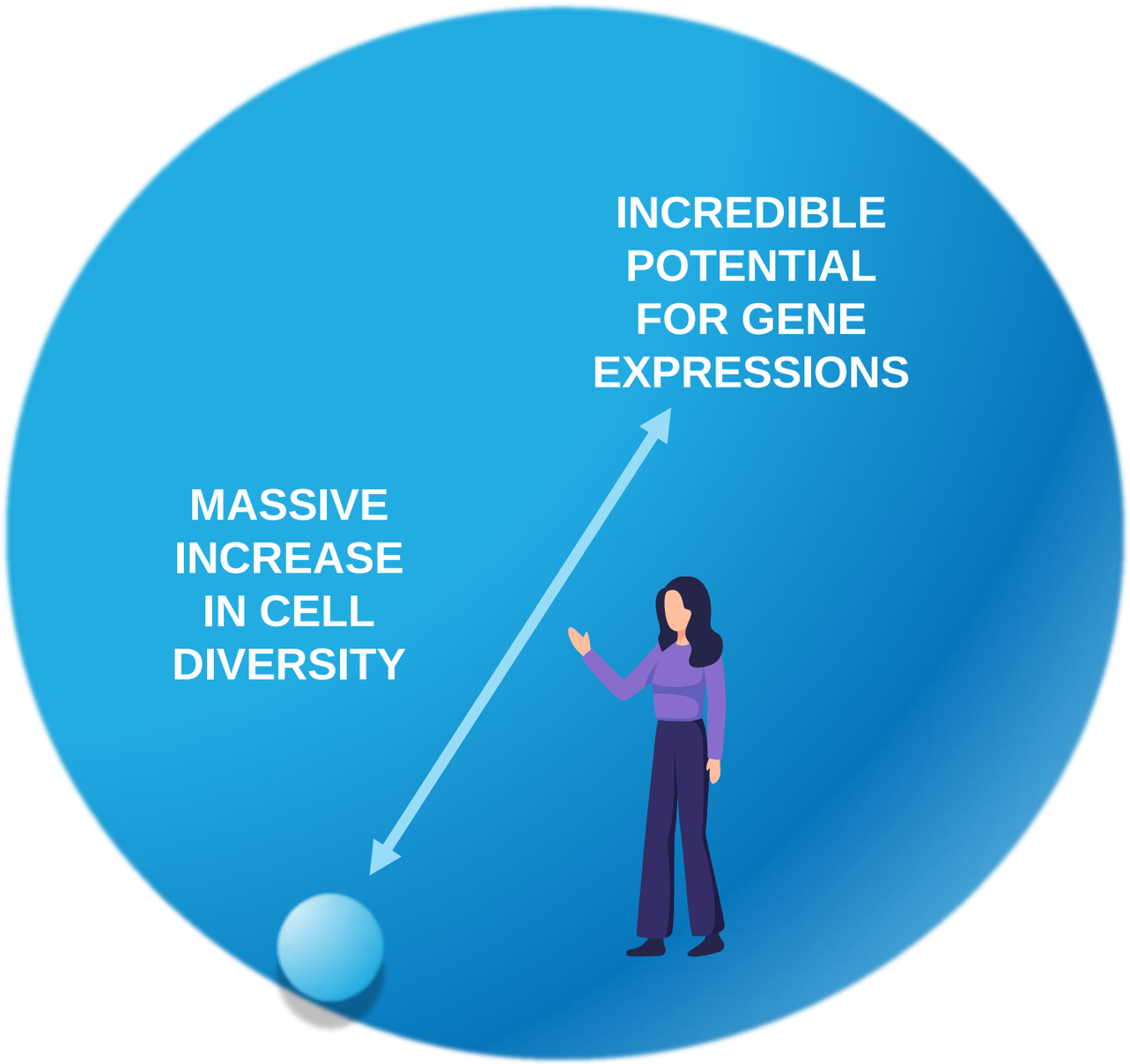
- Individually assess their surroundings
- Take a census of who (intra-inter species) is around.
- Communicate (‘talk’), share information, and recruit.
- Determine what benefits the population as a whole.
- Establish a community with assigned roles, systems for water transport, nutrient recycling, waste recycling and enhanced energy transmissivity.

The Power of the Unicellular

So?
Bioremediation 4.0 allows you to:

- Achieve sustainable contaminant destruction passively
- Eliminate above ground, energy consuming equipment needs
- Enhance your remediation process by sequestering Greenhouse Gasses
- Realize remediation objectives with less-impacts at less-costs
- Bioremediation 4.0 leverages Nature’s 4.5 years of experience

Bacteria vs ‘Human-es’



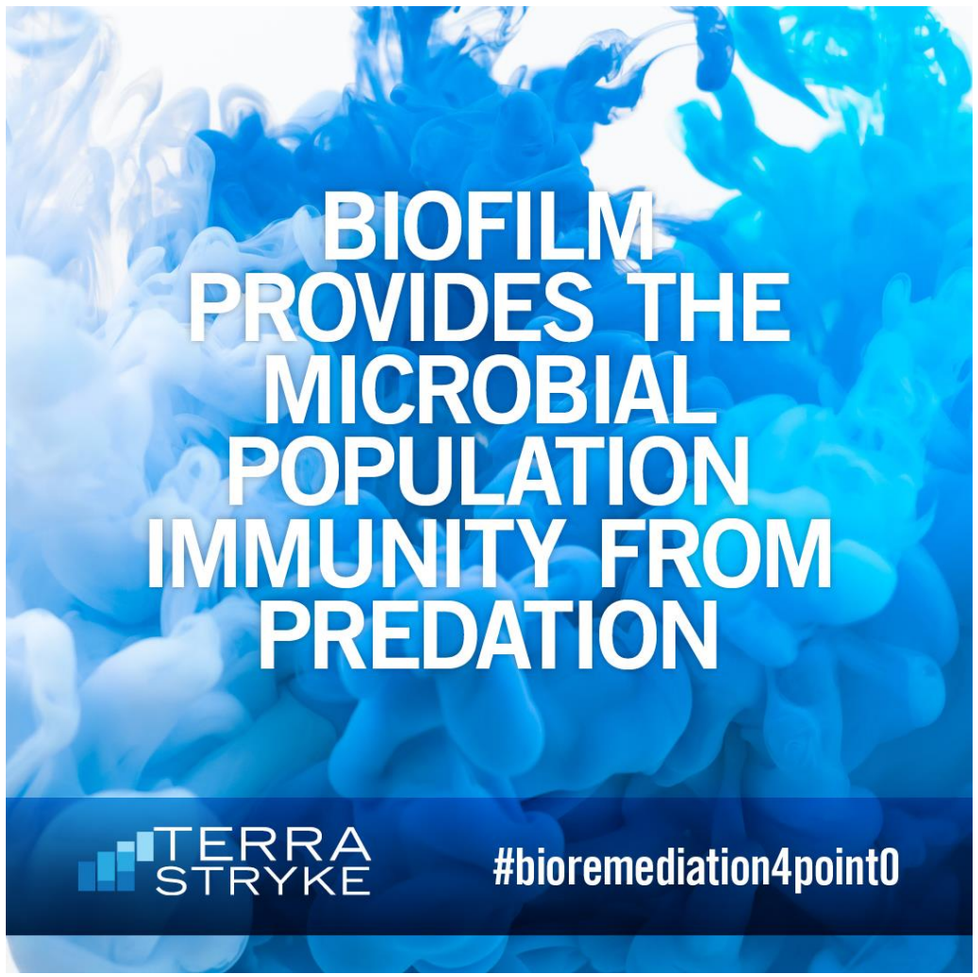
We have ≈1-trillion cells
- defines who we are, how we work, look, and play

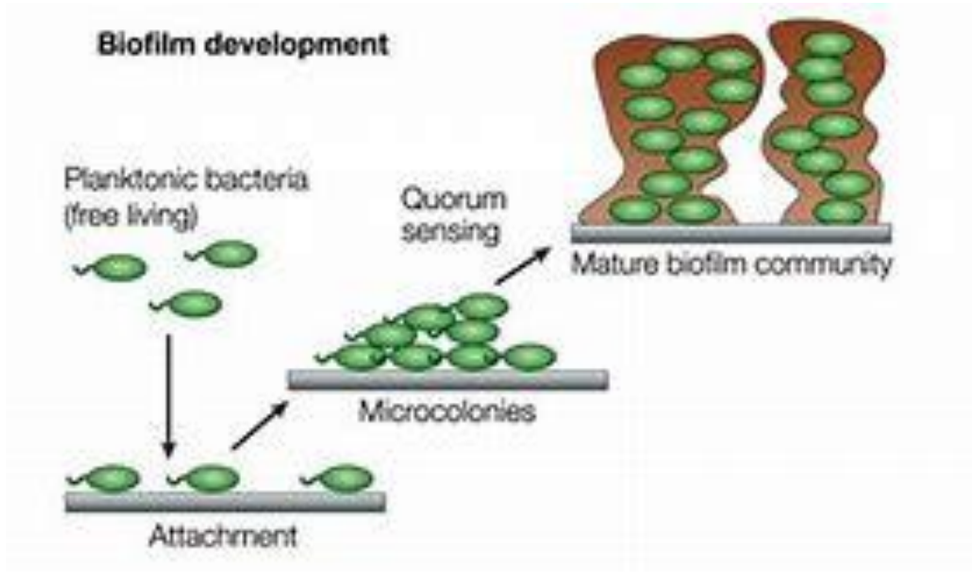
10x Bacteria on the human body
- ≈10-trillion cells

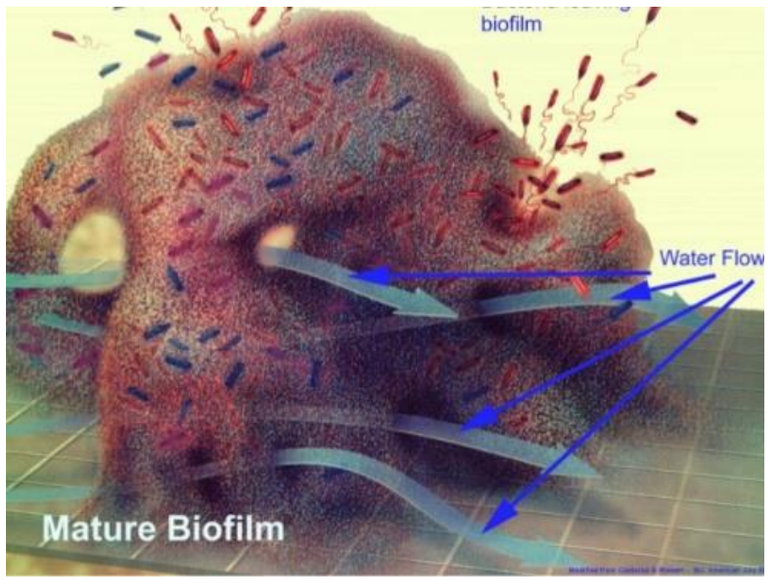
DNA is ultimately what counts: the G, C, T, A
- humans have ≈30,000 genes
- bacteria >100x human genes

Biofilm

Biofilm development theory – a fishy story?



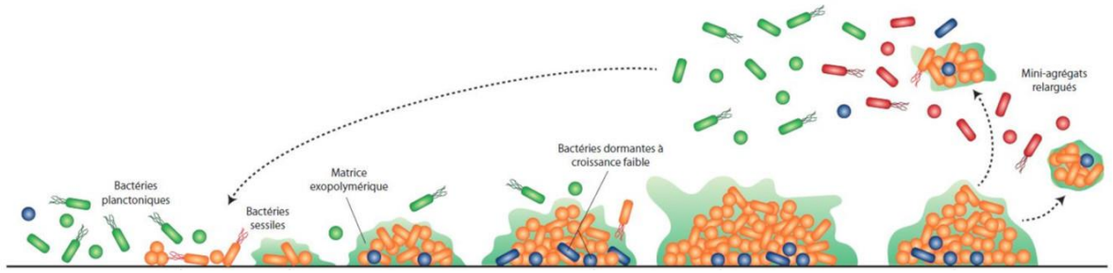


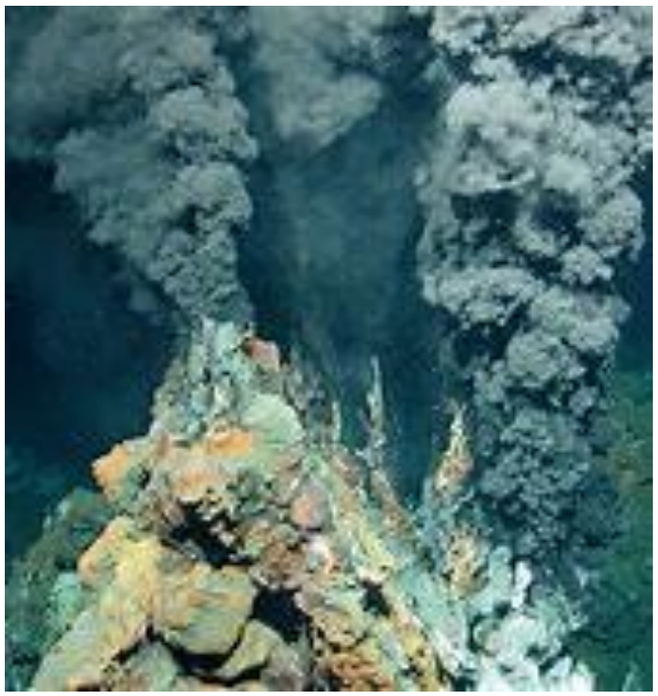


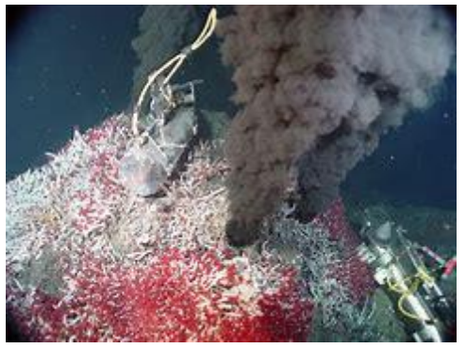
Hypothesis

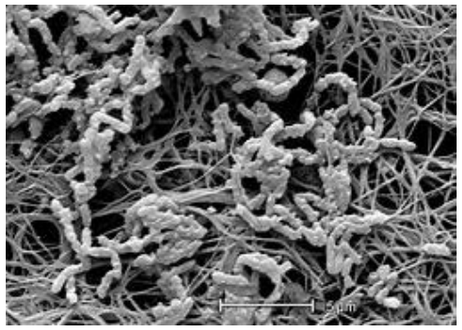
- Must revive nutritive capacity of the microbial ecosystem by providing macro and micro- nutrients to allow attainment of quorum densities.
- In nature, microbes barely exist in the planktonic state; instead, exist as communities of sessile cells that grow as biofilms.
- Biofilms allow microbes to work as a collective free of predation and effects of bulk water surroundings.
- Biofilm is generally universal to all microorganisms.

Benefits of Biofilm









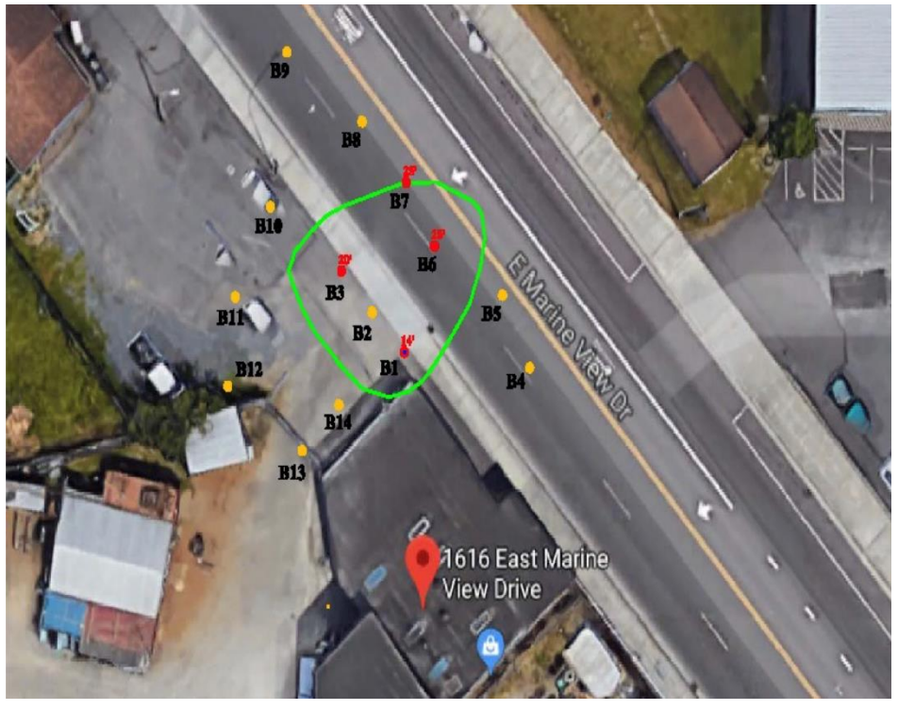
- Enhanced cell-to-cell communication.
- Establishes reservoirs for nutrients, energy and metabolic substances.
- Provides protection from predation, adverse conditions including temperature, pH, salinity.
- Are heterogeneous in nature and consist of multispecies cultures that share genetic information 100-1000x faster than when planktonic.

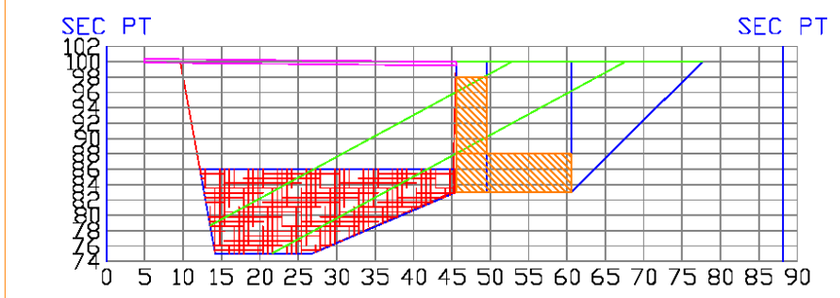
Case Study

Seattle Site

Petroleum Hydrocarbons

- Two former USTs with gasoline and diesel
- Residual soil and groundwater contaminants
- Analytics include GRO / DRO / BTEX / Heavy Oils
  - 5-monitoring wells outside roadway
  - Horizontal Injection wells for Injection inside roadway
- Contaminants exceed Washington Department of Ecology
  - Model Toxics Control Act (MTCA) Methods



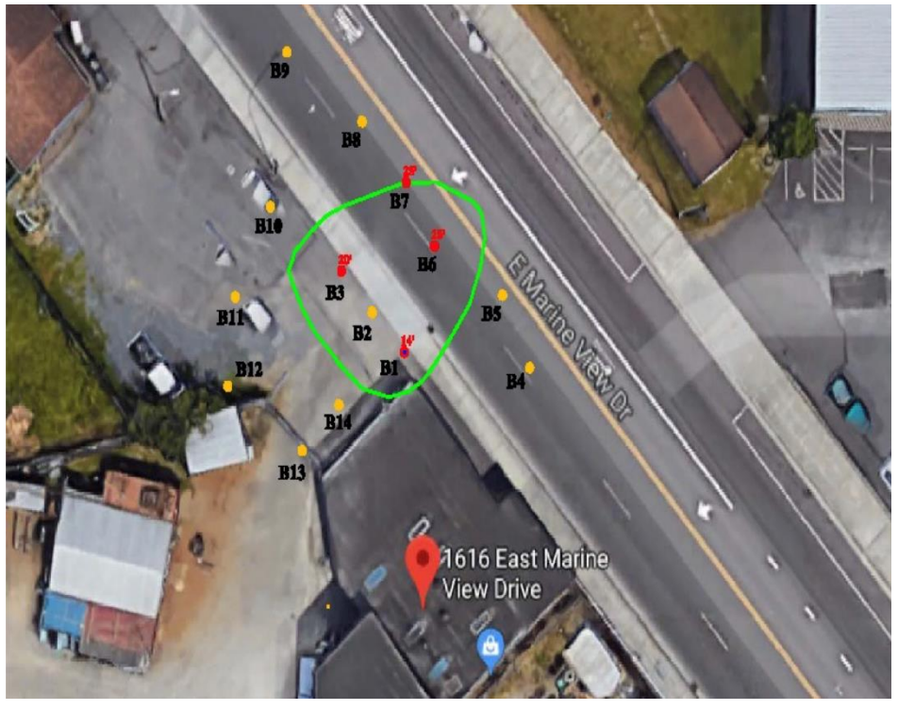


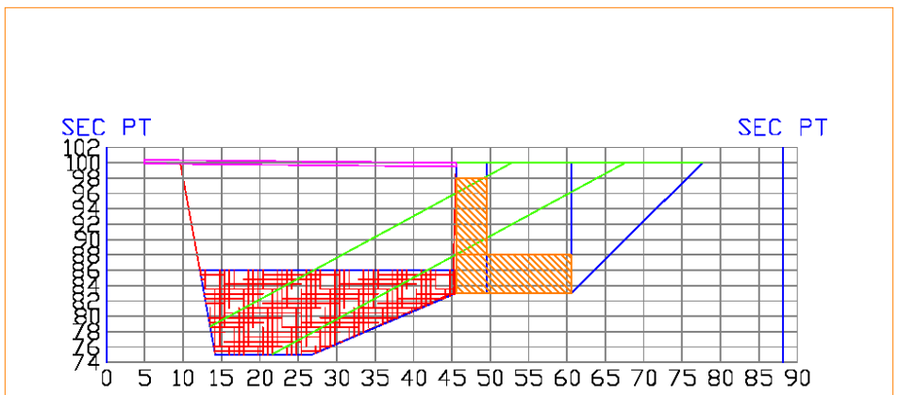
Cross Section A - A'

Seattle Site

Petroleum Hydrocarbons

- Sandy-Silt with varying amounts gravel 0-5ft bgs
- Medium-dense, very-dense sandy-silt 5-60ft bgs
- Groundwater
  - 12ft bgs, at times…
  - 35ft bgs at other times…
- [GRO] in soils upwards of 4,900 mg/Kg
- [Benzene] in soil 1-20 mg/Kg
- Groundwater [GRO] up to 87,000 ug/L

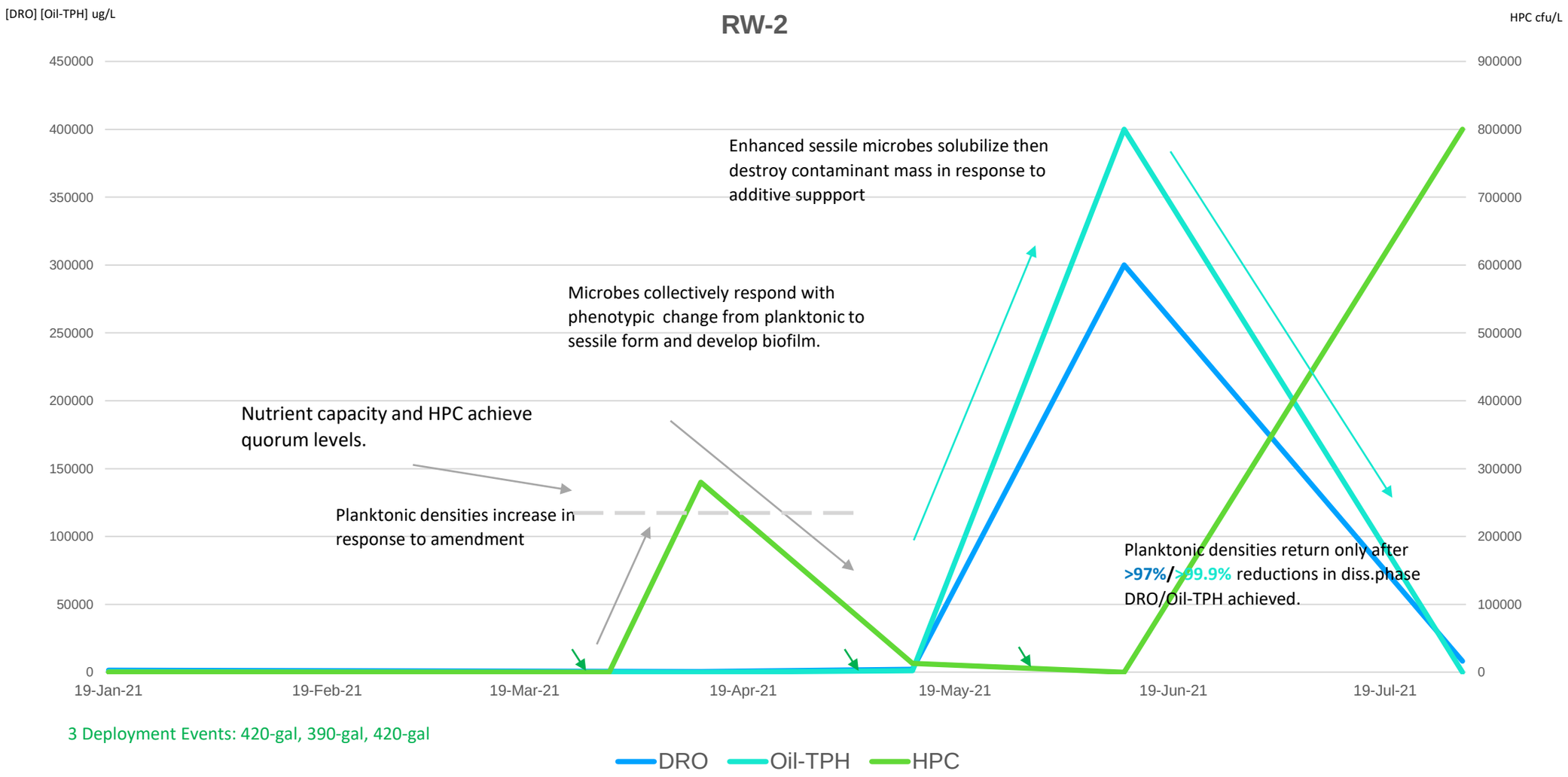




Cross Section A - A'

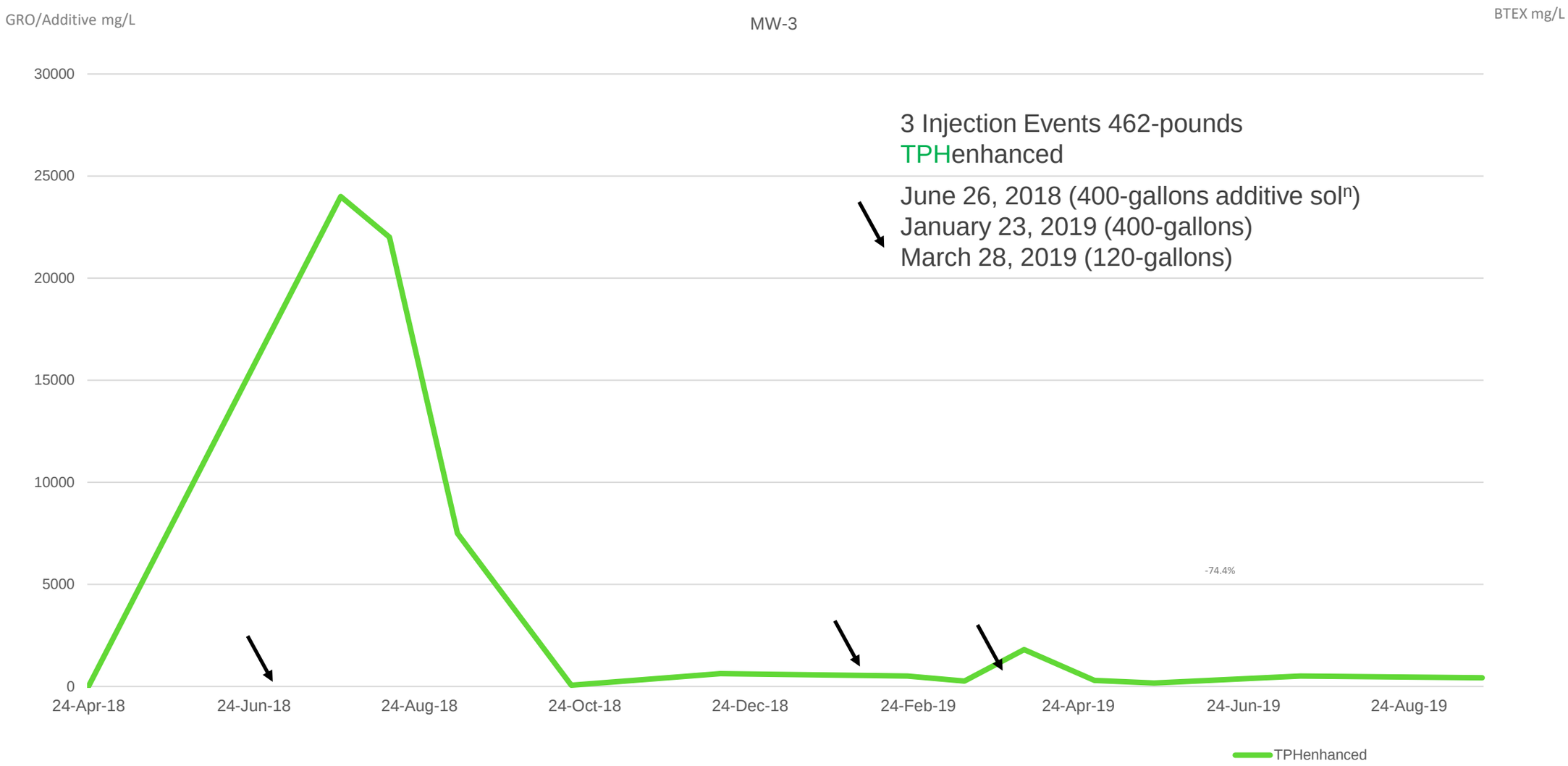
Contaminant Degradation

Again, continued contaminant degradation in the apparent absence of additive and microbial densities.



Contaminant Degradation

Contaminant degradation in the apparent absence of additive and microbial population?



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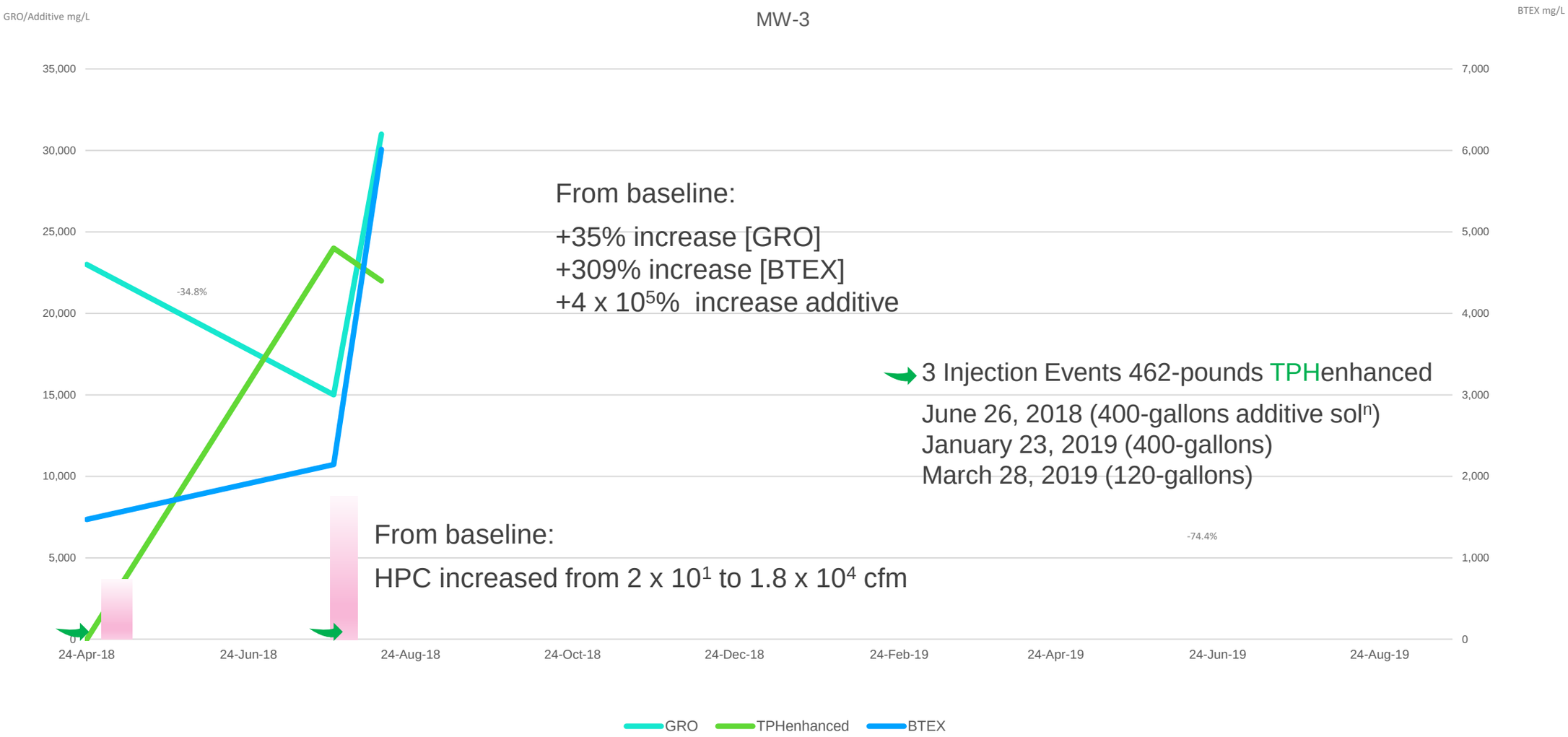

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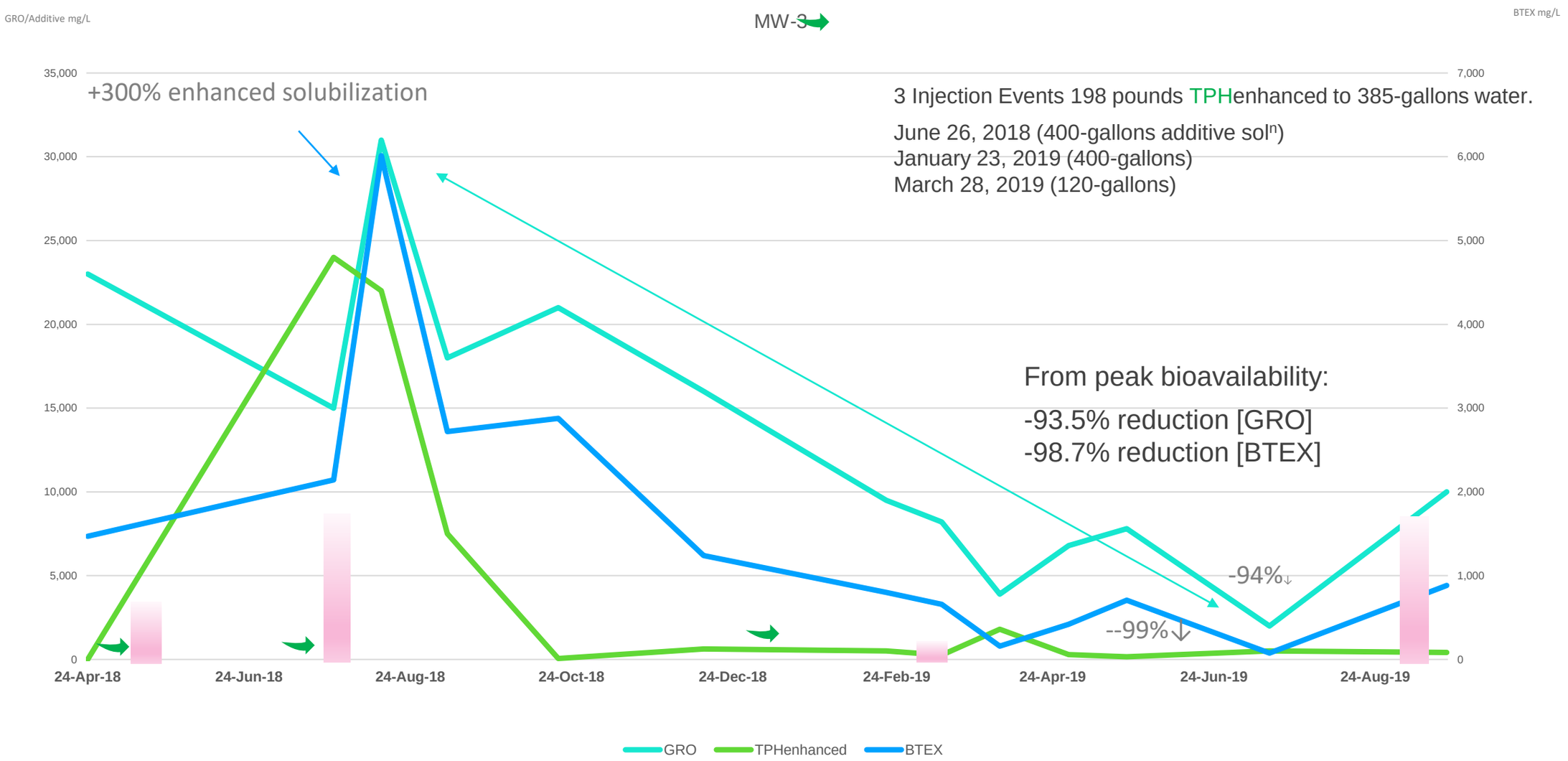

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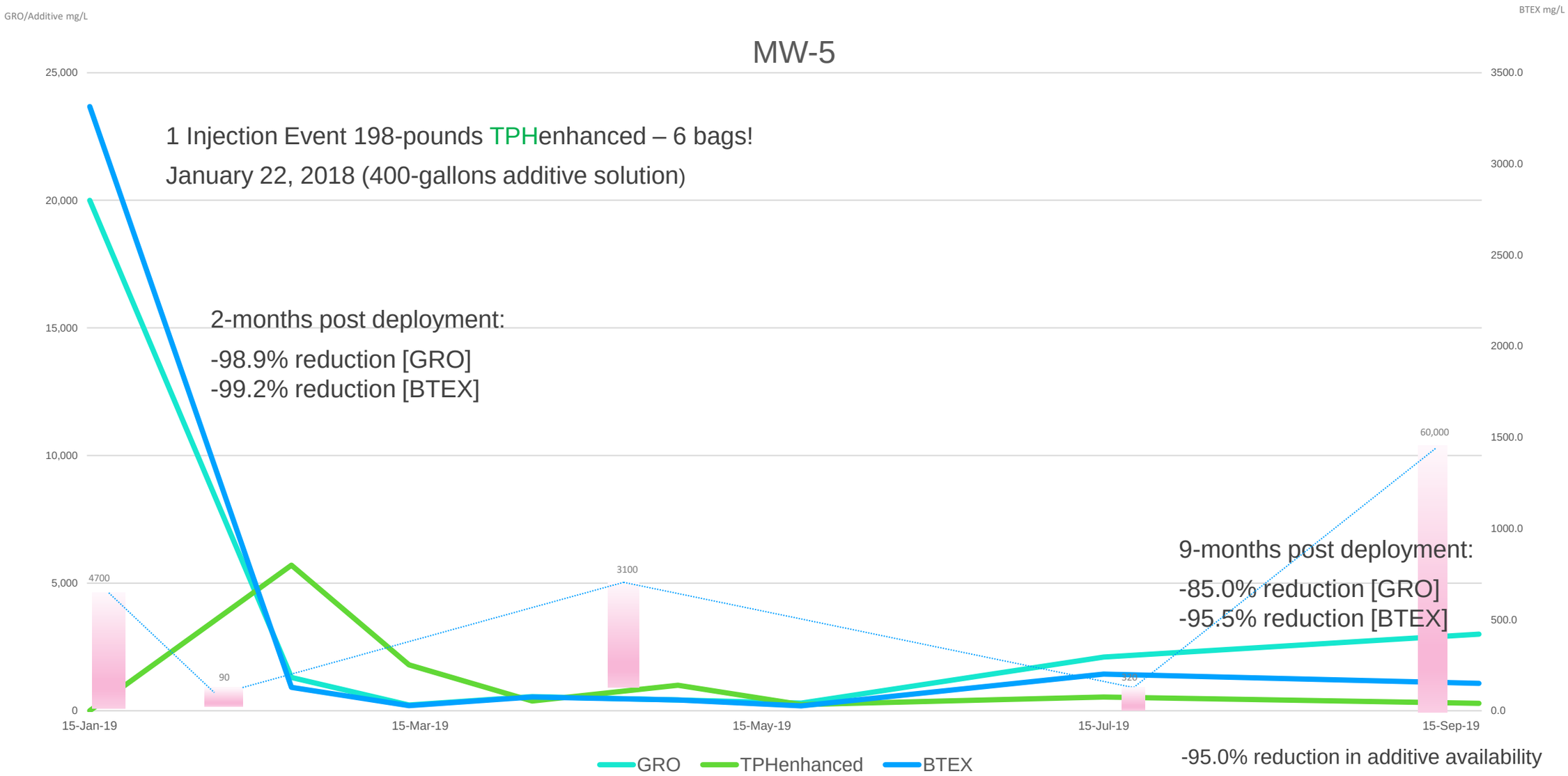


Where Do We Work?

Brownfield Properties

- 450,000 in the U.S. half impacted by PHCs
- Properties with environmental liabilities preventing redevelopment

Gas Stations

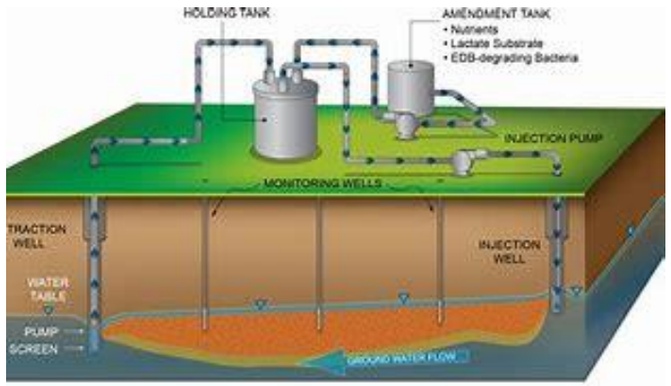
- 121,000+ not including abandoned in the U.S.
- Petroleum Hydrocarbons (PHCs)

Dry Cleaners

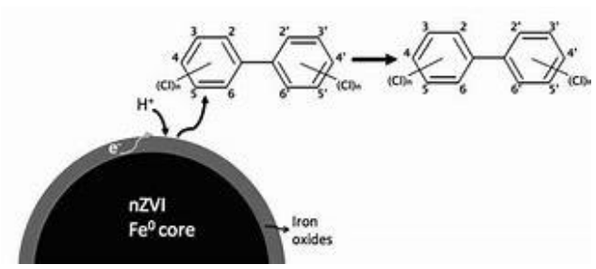
- 35,000+ not including abandoned
- Estimated 70% adversely impacted at $500,000
- Chlorinated volatile organic compounds (cVOC) solvents

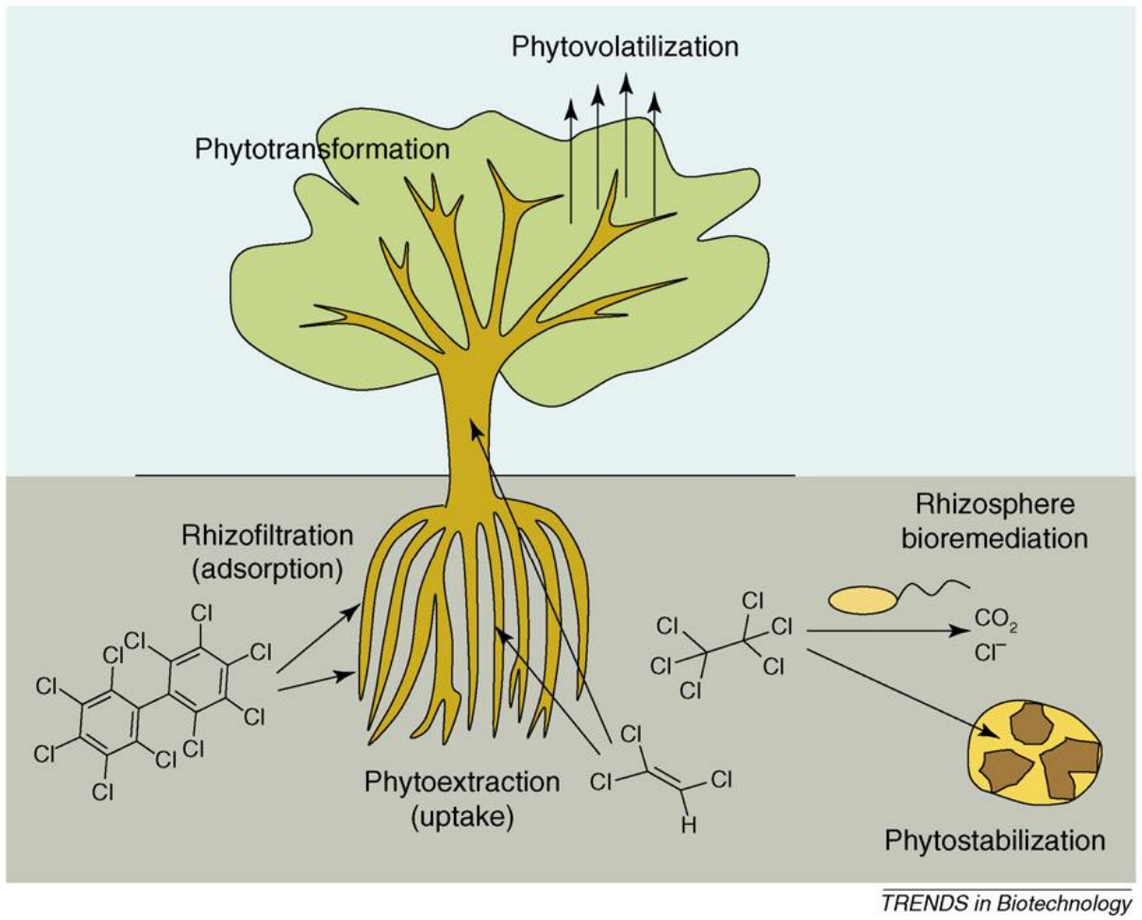
Application

- Passive Release Sock (PRS) Deployment Units
- Amendable to multiple deployment methods using passive gravity feed and/or low-pressure injection:
  - Direct Push
  - Infiltration Gallery
  - Existing Infrastructure
  - Direct Application



Treatment Trains





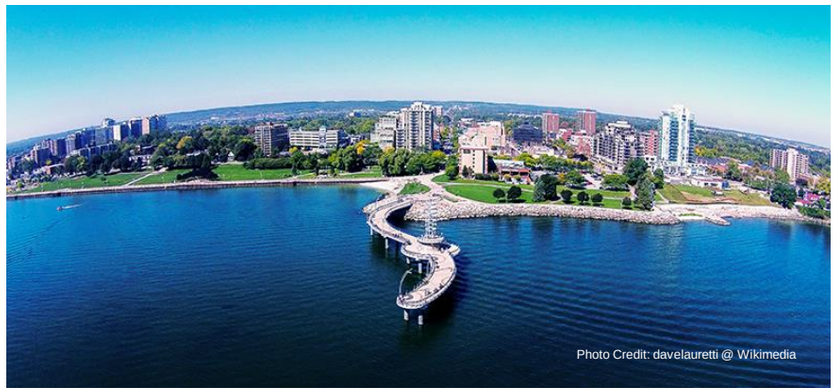
Compatability

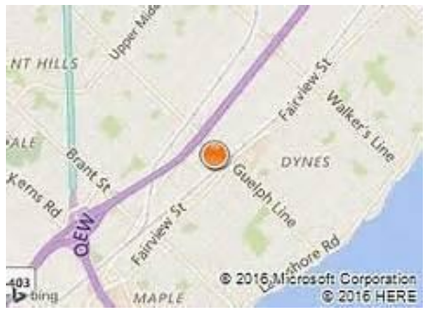
- Stand Alone Applications
  - Soil
  - Groundwater
- Adsorbing Compounds
- Thermal Desorption
- Phytoremediation

Case Study

Burlington, Ontario Site

Former Dry Cleaner





Former Dry Cleaner

- [PCE] in saturated soil/groundwater above MOECC Table 3 SCS
- Residual source mass in saturated soils

Site Conditions

- Generally Coarse Textured Soils
- Highly weathered Shale with Silty-Sand
- Silt Generally moist
- 0.5m – 5m bgs elevated PID readings

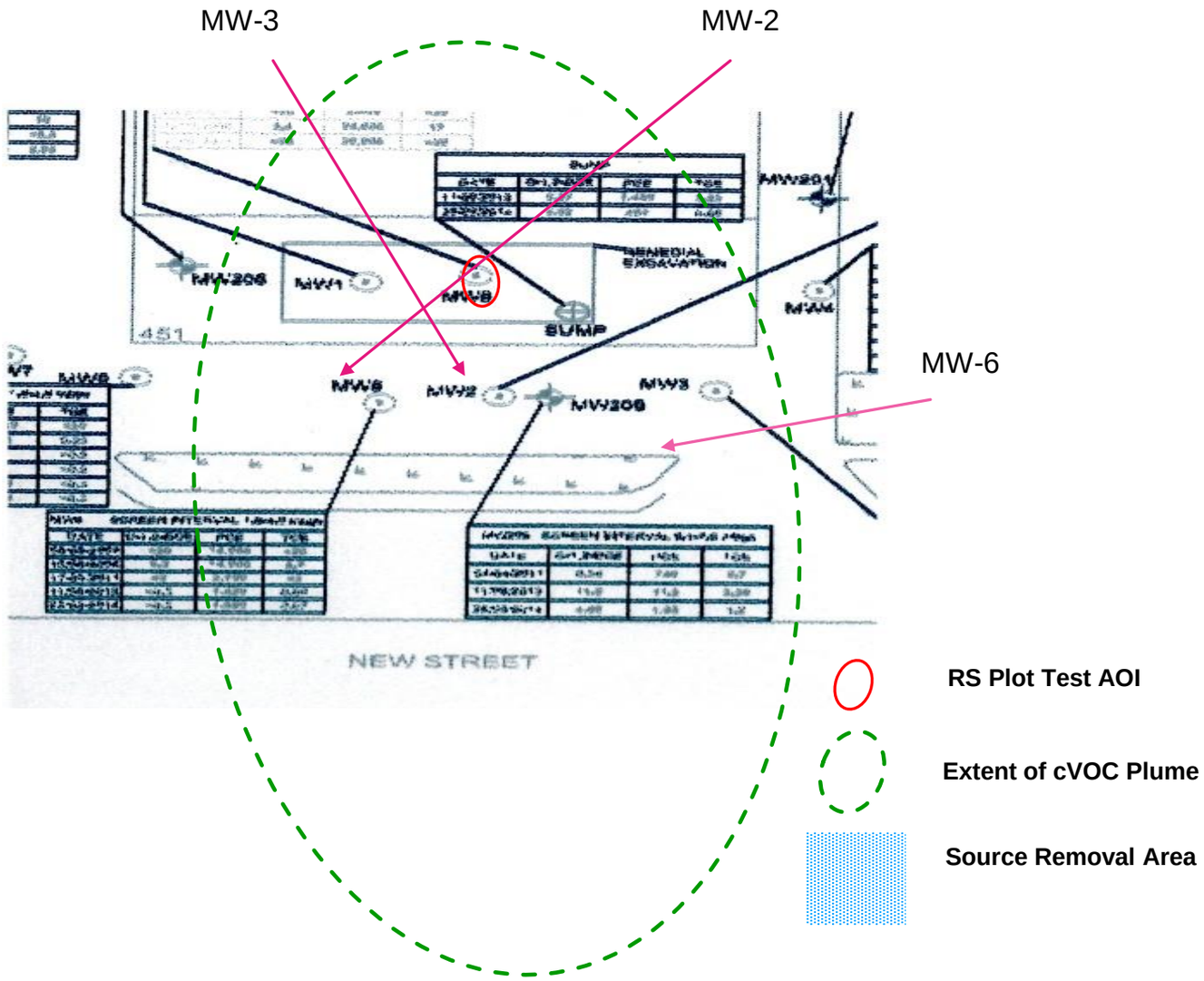
Property Value

- Property attained by Owner thru bankruptcy
- 2011 Appraised Value $680,000

Case Study

Burlington, Ontario Site
Former Dry Cleaner

Full Scale Remediation 2.0 – Biostimulation



Case Study

Burlington, Ontario Site
Former Dry Cleaner

Excavation – Source Removal

- Removed 250m^3 contaminated soils
- Infiltration gallery installed w/in footprint
- Clear stone, 6-inch slotted PVC, 2-3m bgs

Additive Deployment

- Gravity fed 9% additive slurry
- 1,056 lbs to 1,100 gallons chase water March and again June 2014

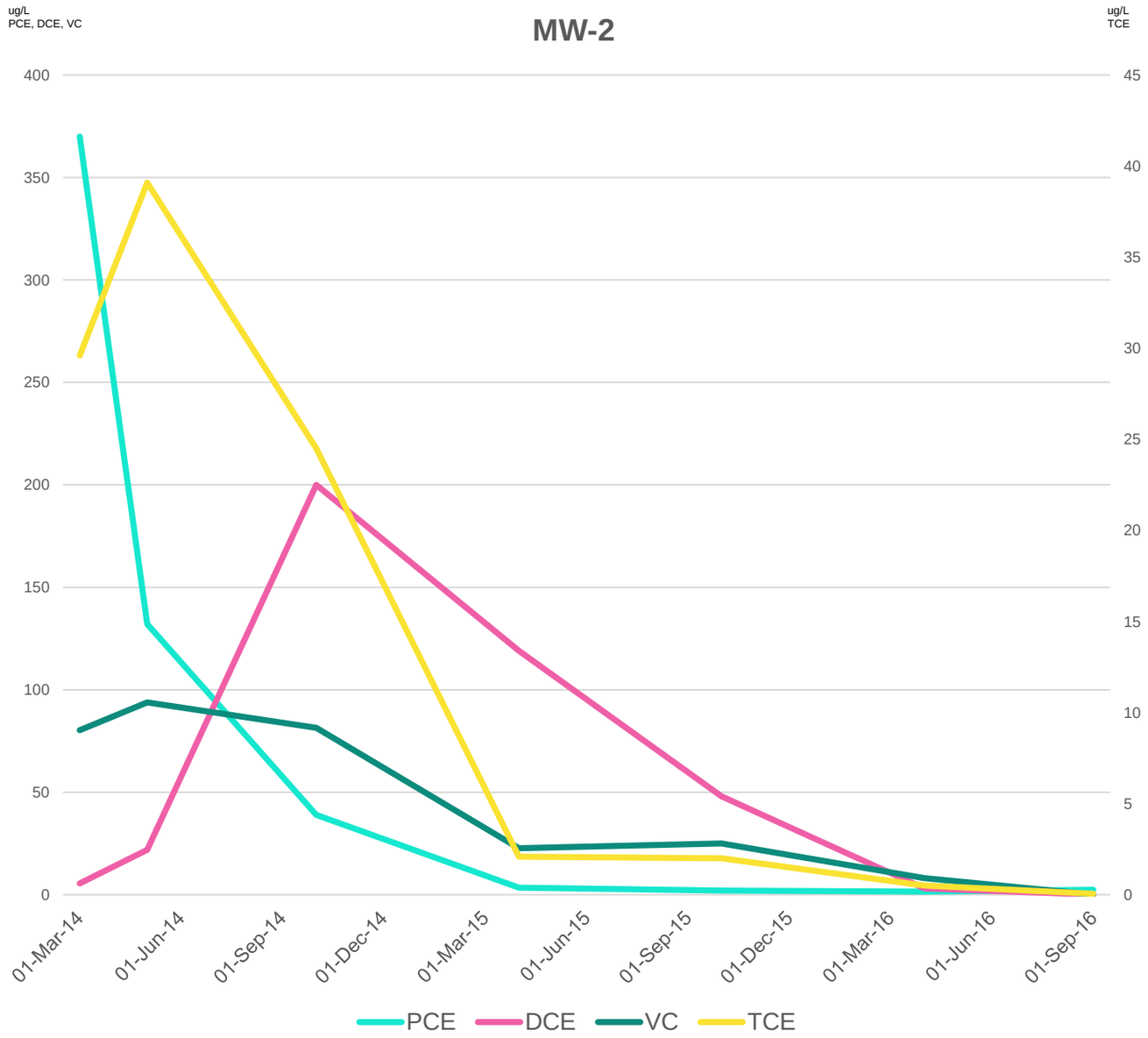
Case Study

Burlington, Ontario Site
Former Dry Cleaner

Results T=2 Years

MW-2 50ft downgradient

- 99.4% reduction [PCE]
- 99.9% reduction [TCE] after 32.1%↑
- ≈100% reduction [cis-DCE] after 3,600%↑
- 99.9% reduction [VC] after 16.8%↑
- 99.5% reduction in [cVOCtotal]
- [Ethene] detected = complete biotransformation
- Safe, sustainable, effective
- Today, all but [cis-DCE] at one location within MOE Criteria (1.6 ug/L)



Case Study

Burlington, Ontario Site
Former Dry Cleaner

- Without contamination issues $680,000
- P&T Costs Estimated $750,000 12-15 yrs (minimum)
- Property Value effectively $-0.00

- **Biostimulation Strategy**
  Total project Costs

Soil removal/gallery install	$38,000
Pilot and Full-Scale Additive	$35,000
Consulting and Analytical	$150,000
	$223,000

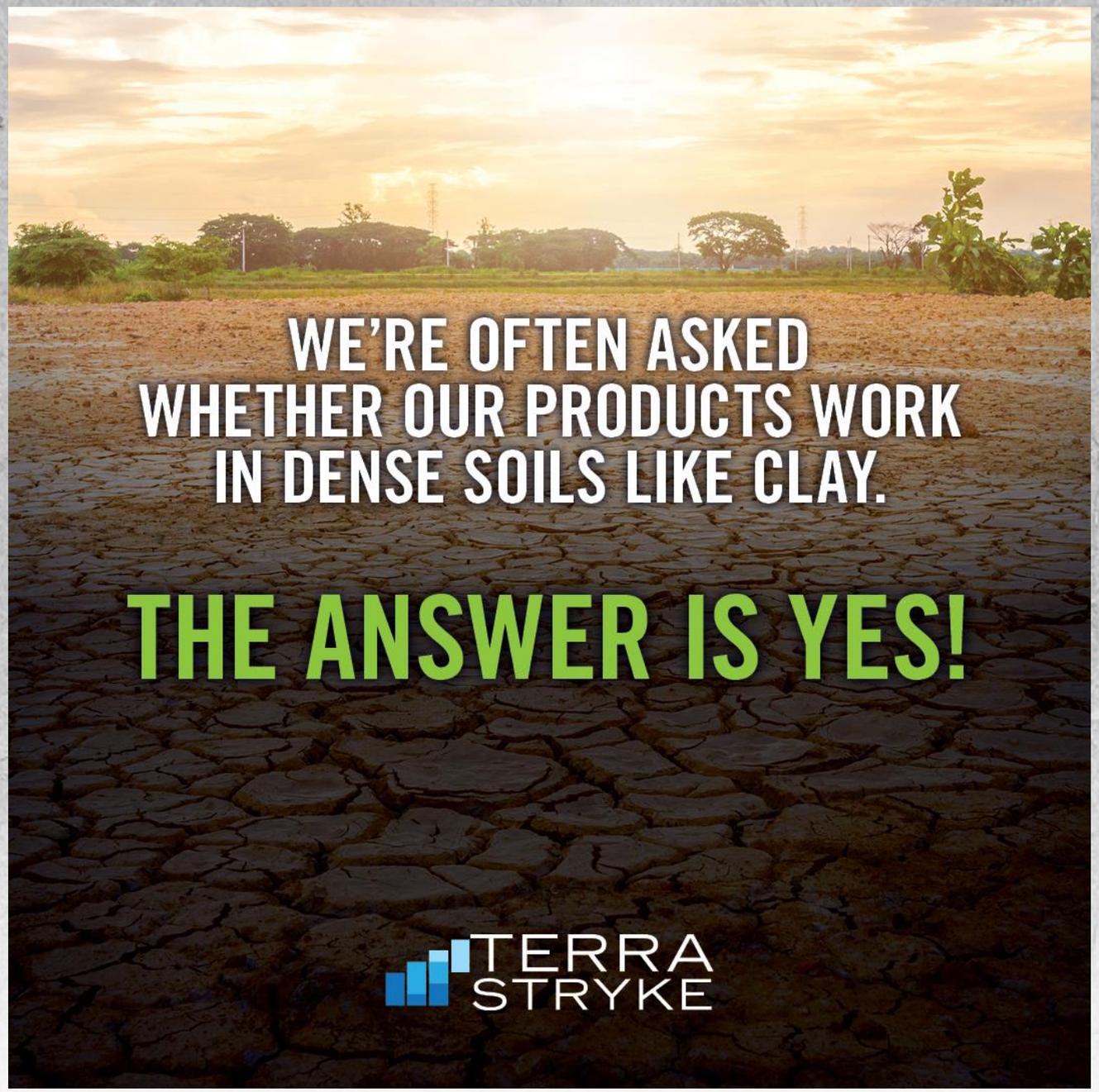
- In less than 4 years Site redeveloped

- Property Manager attributes $1 million of property value increase to remediation strategy

2018 Property Value Assessed at MORE THAN

$2.5 million

FAQs



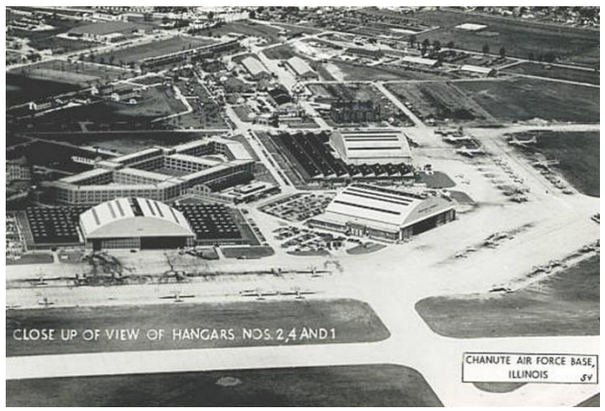
BRINGING THE GROUND TO LIFE. TERRASTRYKE.COM

Chanute Air Force Base

Site 1

Enhance Long-Term Compliance

TPHenhanced®	April 4 (µg/L)	April 18 (µg/L)	May 2 (µg/L)	May 21 (µg/L)	%Reduction
Benzene	606	1,780	8,350	24.6	99.7%
Naphthalene	197	178	302	2.02	99.3%
Toluene	2,360	3,620	8,370	13.4	99.8%
1,2,4-TMB	282	224	843	4.13	99.5%
pH	NT	5.7	5.3	6.1	NA

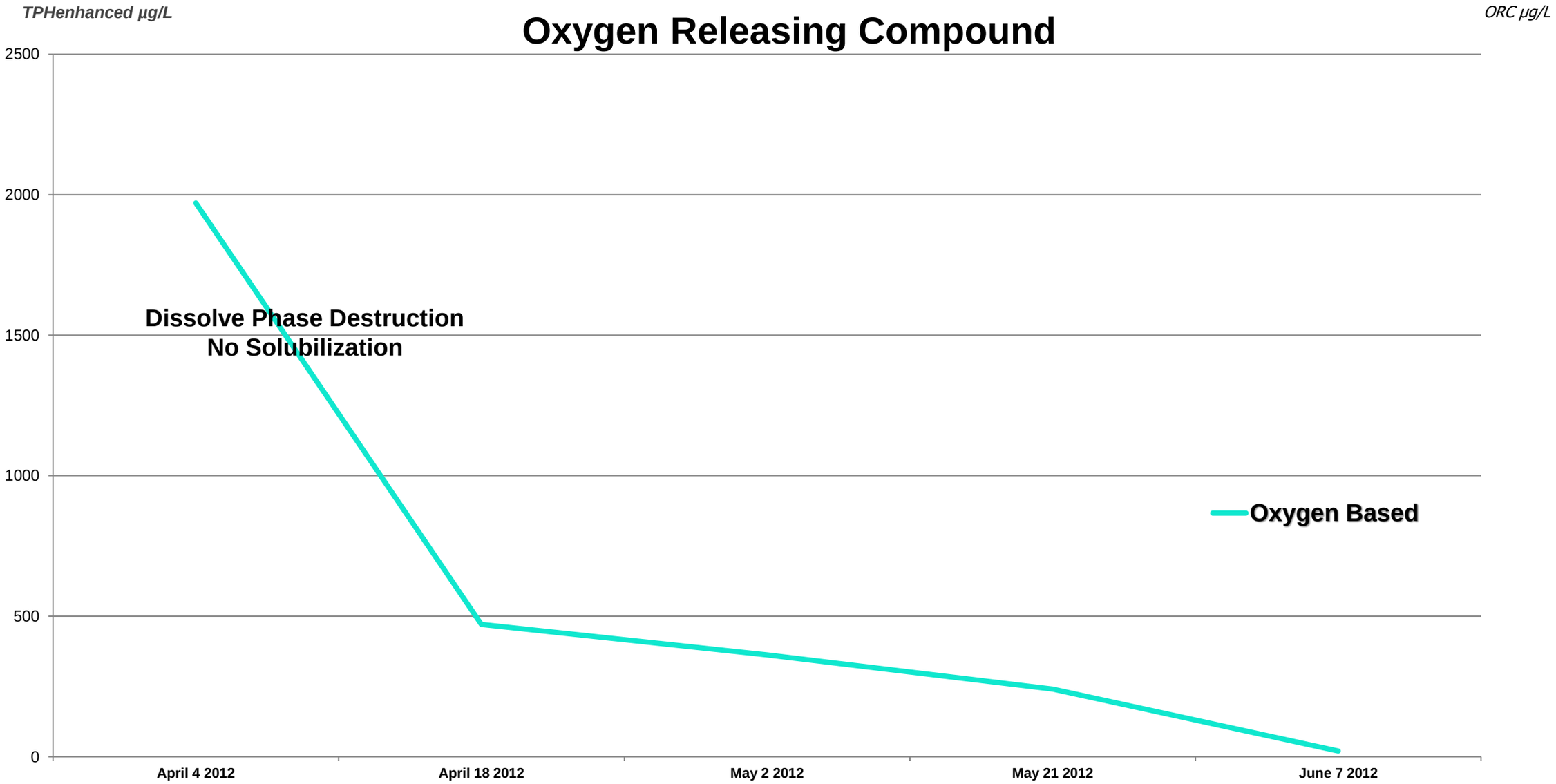


Oxygen Based	April 4 (µg/L)	April 18 (µg/L)	May 2 (µg/L)	May 21 (µg/L)	%Reduction
Benzene	1,970	471	362	241	87.8%
Naphthalene	213	76.7	34.1	8.36	96.1%
Toluene	6,320	1,130	651	385	93.9%
1,2,4-TMB	349	80.7	37.8	17.1	95.1%
pH	NT	9.4	9.8	10.3	11.0

Case Study

Chanute Air Force Base
Site 1

Enhance Long-Term Compliance



Case Study

Chanute Air Force Base
Site 1

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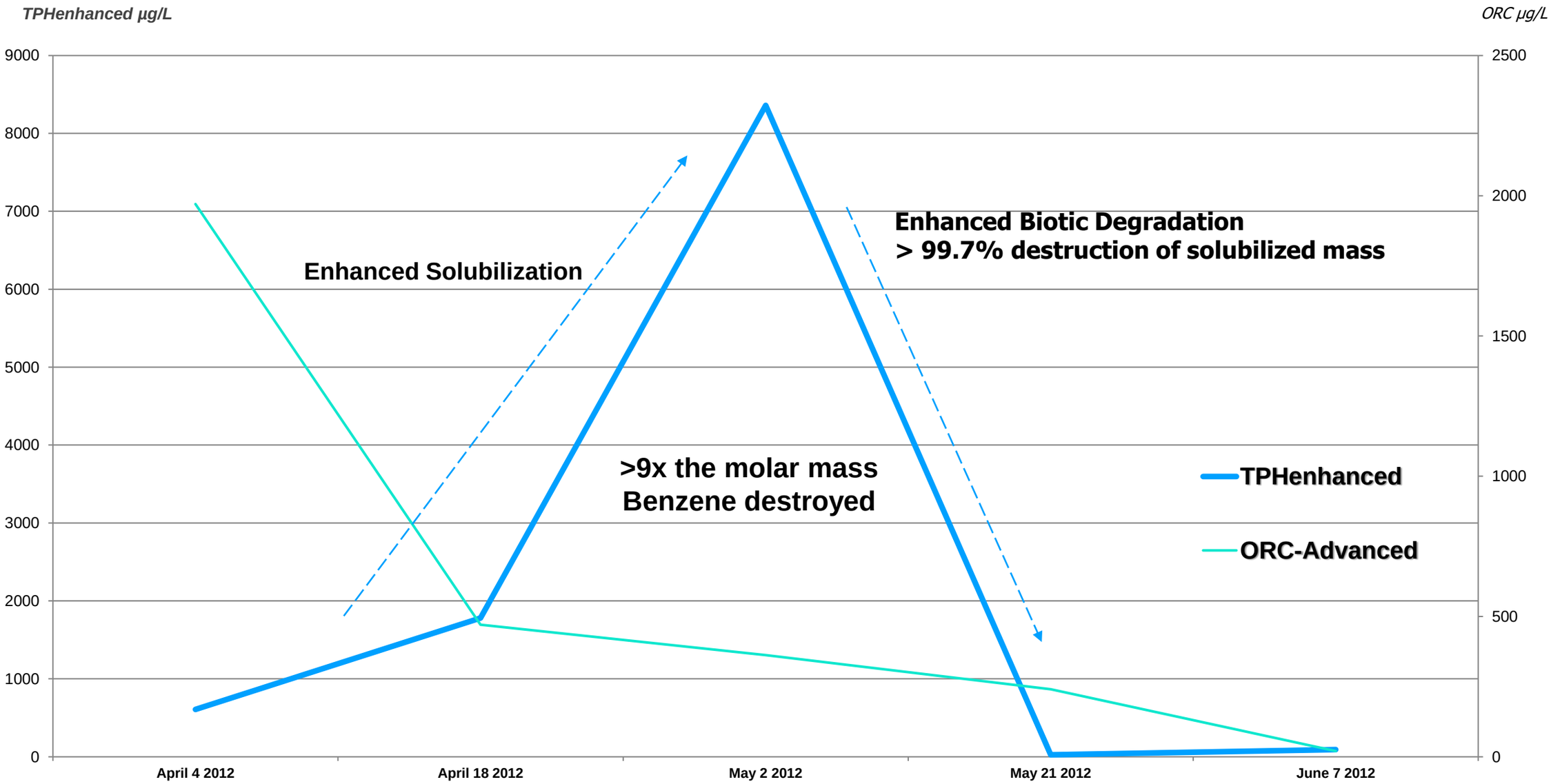

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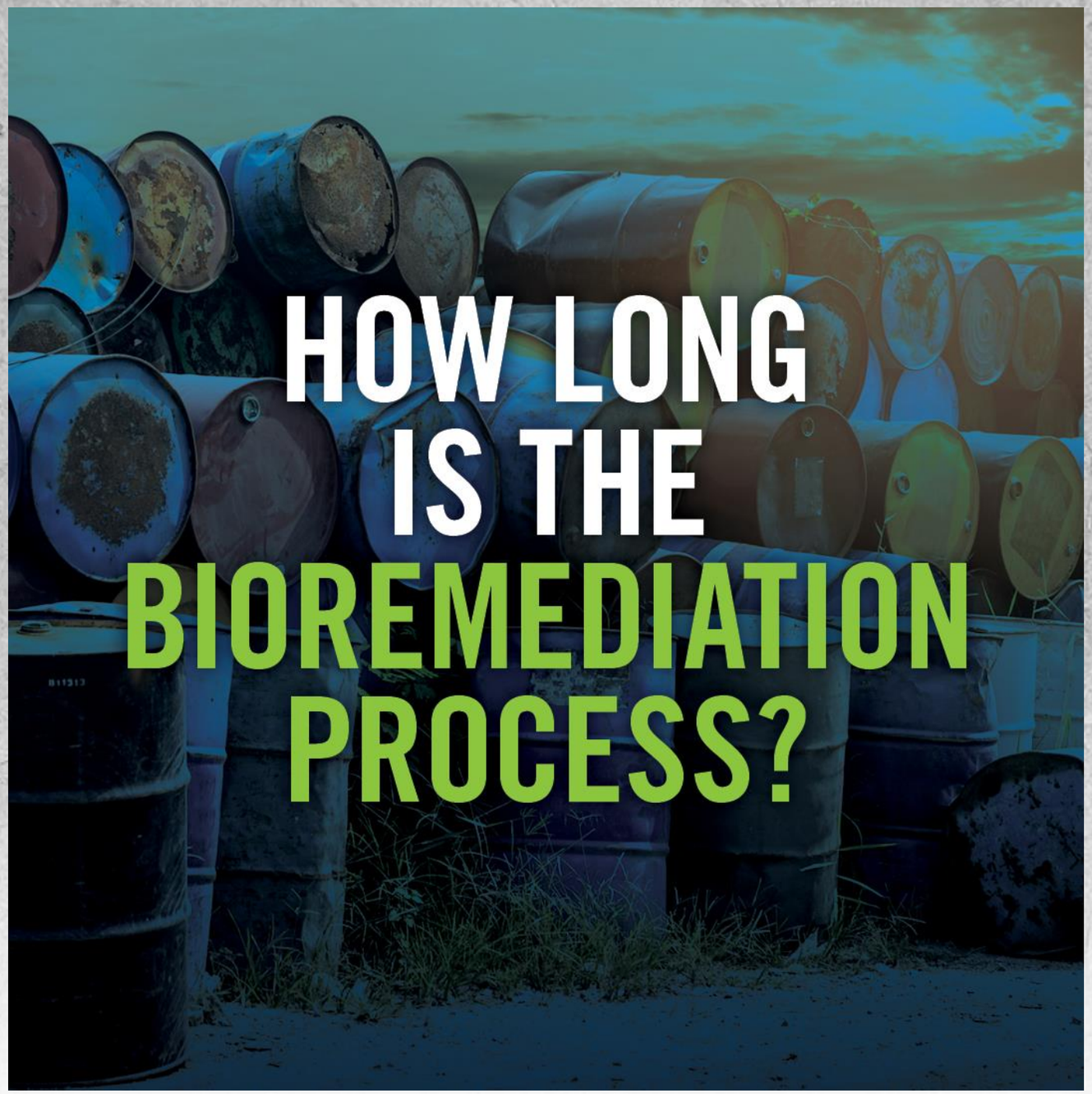


Case Study

Site 5

Contaminated Soils and Groundwater

Active retail shopping center

- Shallow groundwater (vertical impact 6-16ft bgs).
- Pre-excavation soil concentrations in 2019:
  - DRO 4,700 mg/Kg
  - GRO 100 mg/Kg
  - ORO 12,000 mg/Kg
  - BTEX 1 mg/Kg
- Baseline groundwater concentrations:
  - DRO 2,140 ug/L
  - GRO 3,340 ug/L
  - ORO 2,020 ug/L
  - BTEX 0.1-50 ug/L
- Excavated impacted soils where possible due to utilities and structure.

Case Study

Site 5
Active Retail Shopping Center

Application

- Directly applied TPHenhanced to open excavation.
- Mixed using excavator bucket.
- Backfilled with clean soils with high porosity value.
- 4 quarterly sampling rounds over next 12-months.

Results

- Excavation confirmatory samples recorded below regulatory limits.

GRO
DRO
ORO
BTEX

Below Detection Levels

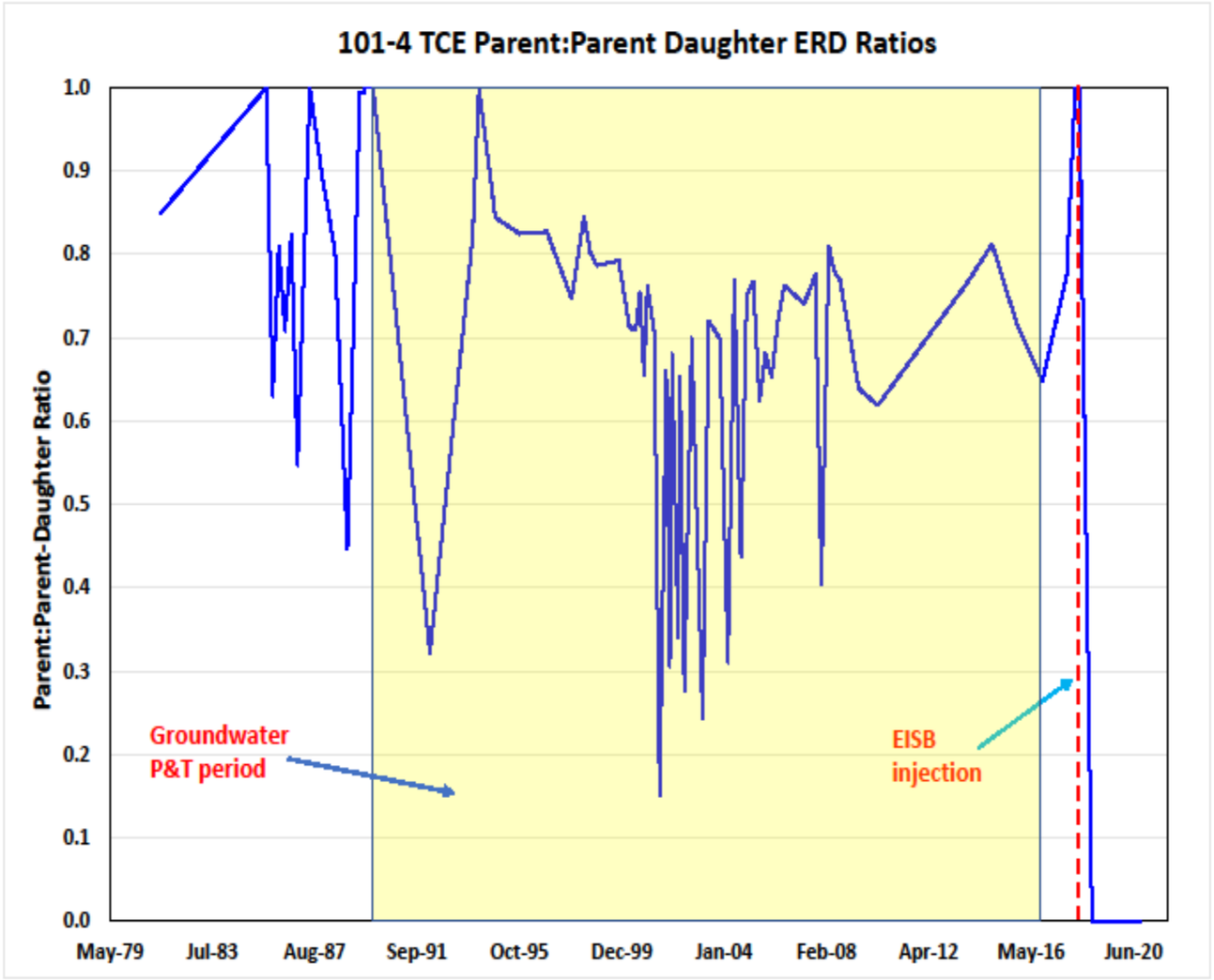
Case Study

Missouri Superfund Site
cVOC contaminants

Fractured Limestone Bedrock

25-years of P&T

- Baseline [cVOC] 28,000 mg/L
- No daughter products P:PD = 100%
- Parent-Parent Ratio Fluctuates throughout the groundwater effort
- Turn off the P&T System Dec.2017
- [TCE] return to baseline
- P:PD Ratio returns to 100%
- December 2018 deploy 33lbs additive slurry = **ERD**ENHANCED
- 12-months post deployment
- [VC] 15 ug/L
- P:PD Ratio 0%
- Complete Biotransformation



Product Line

ERDenhanced™

Supports reducing conditions for decades after single injection program

APPLICATIONS:
Dry cleaner, manufacturing, tool-dye

Product Line

TPHenhanced™

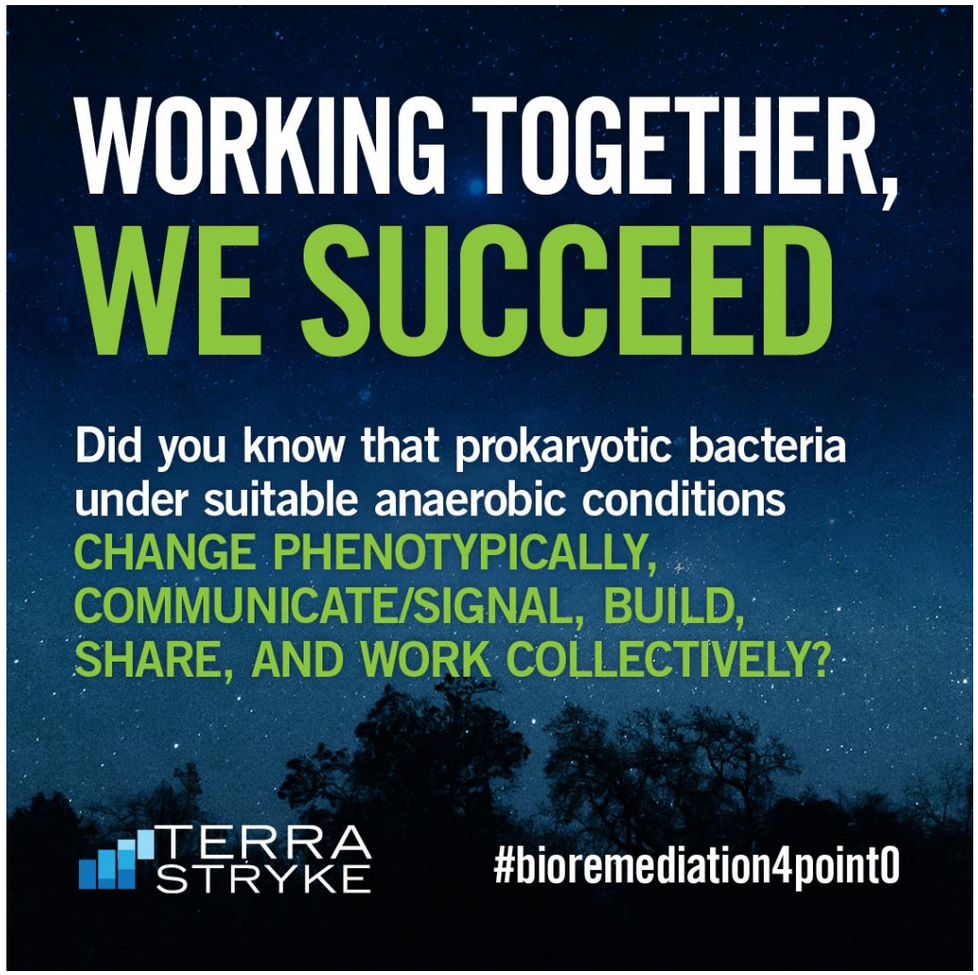
Passive-Aggressive
Contaminant Mass Destruction

APPLICATIONS:
Petroleum Hydrocarbons(PHCs)
Polychlorinated Aromatics (PAHs)
Naphthalene, MtBE, Creosoles

Conclusions

TerraStryke biostimulation additives support the subsurface ecosystem of prokaryotic bacteria.

- Supports the nutritive capacity of the microbial ecosystem
- Allows planktonic densities to achieve quorum levels
- Supports Quorum Sensing and Signaling and the establishment of biofilms
- Expedites LNAPL/DNAPL solubilization
- Enhances use of electrons/protons to support expedited disolved-phase contaminant utilization.
- Maximize microbial population's ability to use organic contaminants as electron donors/acceptors efficiently.



Conclusions

There are lots of options out there

Contact Information

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