



Figure 1
Phase 2 Well Locations

Project Highlights

- **TPHENHANCED™** enhances the nutritive capacity of the treatment zone to support indigenous microbial degraders.
- **TPHENHANCED™** supported **>93% REDUCTION [DRO] >98% REDUCTION [Oil-Range] organics.**
- **TPHENHANCED™** expedites flux of bound residual source mass to get the rebound out *up-front*.
- **TPHENHANCED™** supports Quorum Sensing and Signaling (QSS), development of biofilm to realize maximum contaminant destruction.
- **TPHENHANCED™** enhances smear-zone and low-perm contaminant bioavailability/destruction.
- Minimize site liabilities and realize low-impact, cost-effective compliance simply by letting Mother Nature have it!

TPHENHANCED™
Cost-Effective
Long-Term
Low-Impact

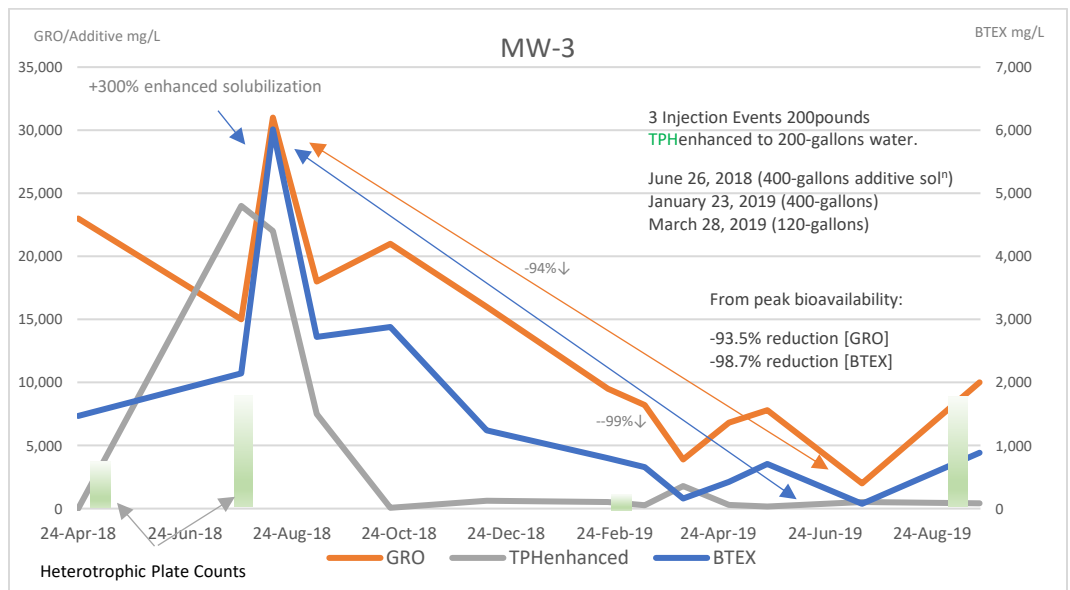
TerraStryke® TPHENHANCED™

In-Situ LNAPL, Petroleum Hydrocarbon Destruction by Indigenous Microbials via Biostimulation Alone.

Simple Additive Delivery Approach; Legacy Contaminant Site, Seattle WA

TerraStryke® Products LLC develop and distribute biostimulation additives proven to cost-effectively maximize performance at any site using biostimulation alone, or in combination with other additive processes. Our additives revive the nutritive capacity of the treatment zone to support indigenous microbial populations and their ability to expedite contaminant destruction, eliminate rebound, and realize long-term compliance; all with minimal impact and **less cost**. **TPHENHANCED** provides respiratory pathways and macro-micro nutritive compounds which allow indigenous microbials to achieve quorum densities, support biofilm development, and realize sustainable contaminant destruction.

Concern: PHC contaminants as residual mass sorbed to soil with dissolved-phase migration from the USTs into adjacent native soils. Groundwater on- and off-site are adversely impacted by Gasoline Range and Diesel Range Organics (GRO/DRO), both residual and dissolved-phase, extending from 10ft to 30ft bgs. Fluctuating groundwater creating vertical smear zone >10ft; downgradient plume extending >60ft from source area.



Results: Groundwater additive availability peaked as HPC densities and Nitrates (NO₃) decreased to below baseline 4-months post injection. Over next 10-months groundwater monitoring recorded additive levels and bulk water microbial densities remained below detection levels (BDL) *however*, during this same period dissolved-phase concentrations GRO/BTEX decreased by 93.5% and 98.7% from peak bioavailability, respectively.



Treatability Study performed in 2018 was implemented to identify a sustainable, low-cost, low-impact remedial strategy to address PHC contaminants in all media – soil, soil vapor, and groundwater. Bioremediation, via biostimulation, was determined the appropriate strategy. The cost-effective and environmentally friendly biostimulation additive **TPHENHANCED** by TerraStryke® was chosen as the amending compound; an industry-leading proprietary blend of macro-micro-nutrients formulated with Nitrates, **TPHENHANCED** amends the nutritive capacity of the microbial ecosystem/treatment zone while supporting respiration of indigenous microbial populations under anaerobic conditions. The amending solution consisted of 460-pounds additive blended 1:1 with water, generating approximately 500-gallons of a 12% solution gravity fed into performance well MW-3 over three (3) injection events using 200-, 200- and 60-pounds additive with water in June 2018, in January and then March 2019.

Geologic Conditions: MW-3 is proximate source zone soils immediately upgradient excavation basin. Geology consists of brown sandy-silt soils with varying amounts of gravel 1-5ft below ground surface (bgs); underlain by dense-very dense sandy-silts, clayey-silts and trace gravel, from 5 to 50 ft bgs. Stringers of more sandy material form occasional permeable lenses within this formation and supports discontinuous perched groundwater ≈14ft bgs within the native soils. PHC contaminants originating from the former USTs are located 4ft to 17ft bgs and have impacts extending downgradient into native soils 10ft to 27ft bgs.

Concern: Groundwater Contaminants-of-Concern (COC) include Volatile Organic Compounds (VOCs): specifically; Benzene, Toluene, Ethylbenzene and Xylenes (BTEX) above State of Washington Ecology MTCA Method A Cleanup Standards. Residual soil and dissolved-phase contaminants extend off-site into right-of-way areas where numerous utilities and sewer lines create multiple preferential pathways.

Process: MW-3 baseline (T_0) recorded at 23,000 micrograms per Liter ($\mu\text{g/L}$) GRO; 1,500 $\mu\text{g/L}$ BTEX. Heterotrophic Plate Counts (HPC) were 1×10^2 colonies per Liter with additive availability, measured as $[\text{NO}_3]$, at <5 milligrams per Litre (mg/L). Four (4) months post-injection HPC densities increased exponentially to $>4 \times 10^6$, while additive availability increased by 328%. Two-months (T_1) post-injection, concentrations dissolved-phase GRO decreased 34.8% whereas concentrations BTEX rose by 40% resulting from amended microbial liberation of sorbed PHC mass. Over the next 2-months, 4-months post injection (T_2), GRO reversed trend increasing 100% over baseline while BTEX increased an additional 187%. As both GRO and BTEX levels reached peak bioavailability (T_2) additive availability in groundwater also peaked then, HPC densities and NO_3 decreased below baseline and remained generally so over the next 10-months with bulk water microbial densities basically absent. During this same period dissolved-phase concentrations of GRO/BTEX decreased 93.5%/98.7% below peak bioavailability with bulk water HPC densities 6-months post deployment (T_3) being less than one-half T_0 pre-injection densities. As we commonly observe, bulk water microbial densities subsequent return, exceeding T_2 levels after dissolved phase contaminants were degraded >93%/98%.

CONCLUSIONS: **TPHENHANCED** restored the nutritive capacity of the treatment zone/microbial ecosystem. In response, microbial densities were able to achieve quorum densities, and signaling levels, concentrated enough to initiate phenotypic changes in the bulk water microbial population, from planktonic to sessile. Collectively, the community of sessile microbes then secrete biosurfactant-like compounds, polysaccharides (PSPs), and peptides to enhance solubilization of bound residual mass, established biofilm, engage in cell-to-cell communication to assume roles and levels of genetic sharing 100x faster than when in the bulk water. Important to site remediation objectives this enhanced biofilm bound microbial population acts as a consortium to maximize energy/contaminant utilization i.e. degradation of source zone and dissolved-phase contaminants fast, effectively, organically.

This case study **CLEARLY** demonstrates **TPHENHANCED** supported the nutritive capacity of the treatment zone to support Quorum Sensing and Signaling (QSS), microbial communications, and genetic information sharing to establish syntrophic communities working harmoniously within a biofilm to realize greater overall performance.