Do You Know Your Site? Qualitative Characterization, Modeling, and Remediation to Predict Site Closure

Bill Brab, C.P.G., P.G. (bbrab@astenv.com) (AST Environmental, Inc., Midway KY, USA)

Roger Paulson (rpaulson@semsinc.net) (Southern Environmental Management & Specialties, Inc., Memphis, TN, USA)

Background

A review of the Statistical Inventory Records in August 1993 indicated a release of fuel had occurred into the environment, five (5) gasoline tanks were documented at the site and were subsequently removed in November 1993 or closed-in-place in June 2004. A series of mobile-enhanced multi-phased extraction events were completed between July 1993 and November 2008. The site is >0.25 miles from a wellhead protection area and is zone commercial and vacant. A dedicated multi-phase extraction unit was deployed at the site beginning in March 2011 and operated until August 2017. Soil gas survey points installed and were below the look-up-values and the volatilization to indoor air is not a complete pathway; however, free product was present in one on-site monitoring well and benzene remained elevated above the site-specific clean-up level (SSCL) in seven (7) monitoring wells on and off-site.

A Remedial Design Characterization was conducted in September 2018 to rapidly characterize the extent of total petroleum mass in soil and groundwater at the site, emergency interim corrective action was approved for in-situ remedial injections in November 2018 and was completed in December 2018. Modeling of the total mass present at the site in soil and groundwater indicated the required time to reach clean-up would be 4-6 years following completion of the interim measures. To evaluate the progress of the interim measures, a high-resolution site characterization (HRSC) was conducted in January 2021 using the laser-induced fluorescence (UVOST®) to identify the potential extent of remaining residual LNAPL at the site. The UVOST survey was utilized to optimize the subsequent qualitative High-Resolution Site Characterization (qHRSC) program completed in June 2021, the qHRSC Program consisted of the installation of eighteen (18) soil borings across the site to establish a new baseline for contaminant concentrations at the site and update the existing conceptual site model (CSM). Using the data from the qHRSC, a surgical injection design was developed for the site using Trap & Treat® BOS 200+®. To expedite the time to site closure, the second injection event was approved in November 2021 and was completed in March 2022. Post-injection performance monitoring of COCs and degradation biproducts were completed from baseline (RDC 2018) thru the current date, microbial diagnostics were completed throughout 2022 to further evaluate conditions and progress at the site.

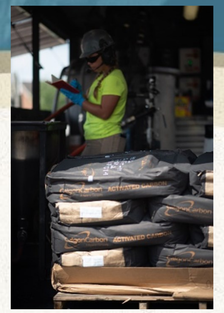
Injection

The activated carbon slurry injectate used during the first event was BOS 200®, manufactured by Remediation Products, Inc. This product is black in color and has 320 mesh particle diameter. Prepared slurries of this product contain small amounts of various nutrients dissolved in the aqueous phase and these compounds can readily be observed in the groundwater.

BOS 200+® was used during the second injection event and it extends the capabilities of BOS 200®. It includes an expanded proprietary consortium of facultative microbes and a pre-conditioned activated carbon base with complex carbohydrates, amino acids, and nutrients. As with BOS 200®, time-released terminal electron acceptors are also included. These changes support vigorous and persistent decomposition of LNAPL, lube oils, crude oil, fuel oxygenates, alcohols, glycols, and cyclic ethers. The technology is a boon for significantly impacted sites and heavy hydrocarbons.

BOS 200+® is the first and only remediation product that leverages microbial nutrition to generate metabolic products that degrade hydrocarbons and build a robust microbial community. The proprietary microbes supplied with BOS 200+® include known hydrocarbon degraders such as Pseudomonas and microbes that support the hydrocarbon degraders. The combination builds a hydrocarbon-degrading community organized around microbial metabolism.

Injections were completed using hydraulic fracturing with a positive displacement pump at a volumetric flow rate of approximately 35 gpm. Injections were completed at specific depths rather than across intervals. Injections occurred in top-down manner and were spaced about every 2 feet vertically. Individual injection points were spaced 6 feet to 7.5 feet apart horizontally.



Project Goals and Objectives

- Reduce LNAPL mobility in short term by establishing an in situ platform for carbon adsorption
- Enhance long-term reduction of VOCs and total volatile petroleum hydrocarbon (TVPH) mass utilizing BOS 200® and BOS 200+® biological processes

Remedial Design Characterization (RDC)

The RDC was completed in two events. The first RDC in 2018 included installing 7 soil borings and 7 temporary wells, yielding over 72 soil samples and 16 groundwater samples for VOCs and TPH analyses. Benzene and TVPH in soil results were used to develop Figure 1 and Figure 2, shown below.

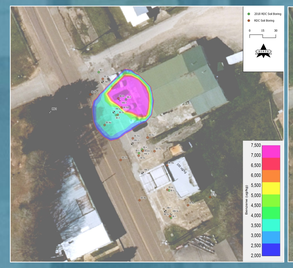


Figure 1 - 2018 Soil Benzene (ug/kg)

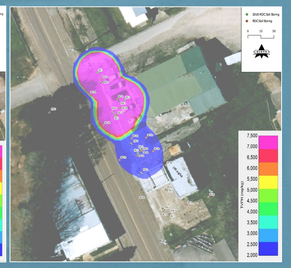


Figure 2 - 2018 Soil TVPH (mg/kg)

quantified High-Resolution Site Characterization (qHRSC)

The second RDC was completed in 2021 and added a 2D and 3D Modeling component. It included installing 18 soil borings yielding over 198 soil samples for VOCs and TPH analyses. Benzene and TVPH in soil results were used to develop Figure 3 and Figure 4, shown below.

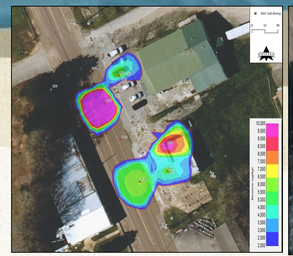


Figure 3 - 2021 Soil Benzene (ug/kg)

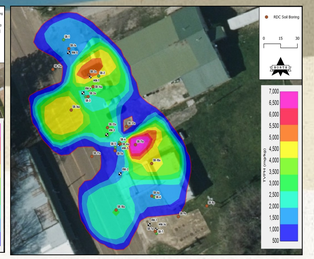


Figure 4 - 2021 Soil TVPH (mg/kg)

Full-Scale Design and Implementation

Development of the two full-scale remedial designs were completed using the data from the historical 2018 RDC and 2021 qHRSC work:

- PAC adsorption demand = >67,150 lbs.
- BOS 200® Installed 2018 = 24,800 lbs.
- BOS 200+® Installed 2022 = 13,850 lbs.
- Injection point spacing = 7.5 ft (2018 Event), 6 ft (2022)
- Injection interval spacing = 2 ft
- 360 Injection points – ~15 ft to 30 ft bgs (2018), ~16 ft to 22 ft bgs (2022)

Post Injection Results

The RDC data demonstrated that significant saturated TVPH sorbed mass (up to 14,500 mg/kg) was present at the site in a relatively thin 1 ft to 2 ft interval between 18 ft bgs to 21 ft bgs. Monitoring well gauging before and after the 2018 full-scale implementation demonstrated elimination of measured LNAPL in all wells at the site, LNAPL has not been observed in any wells since installation.

The qHRSC data demonstrated the site performance matched predicted percent reductions on schedule: ~57% of the total mass (TVPH) was removed between November 2018 to June 2021. This equates to a kinetic degradation rate of ~2,510 lbs. of TVPH per year; without additional augmentation and assuming the rate remains constant, the total mass would be fully removed from the subsurface system in ~2-years.

Genomic sequencing determined that native bacteria were present to support the biological degradation of the predominant petroleum compounds in low to unimpacted areas at the facility; however, the richness of the microbial population was relatively limited. Post-implementation microbial testing demonstrated an increase in microbial abundance and richness. At 10 months after the 2022 full-scale injection, an abundant and rich population of degraders and supporting microbes persists, as shown in Figure 5 and Figure 6 below.

NAME	MW-14_12_...CP048	MW-5_12_...CP048	MW-7_12_...CP048	RW-3_12_...CP048
Extensimonas perlucida	43.33	32.95	1.86	24.07
Smithella_u_s	16.94	26.93	59.73	37.71
Sulfurospirillum cavolei	10.21	0.63	0.54	0.20
Geobacter metallireducens	7.24	0.21	0.02	1.21
Desulfobulbus_u_s	3.87	27.41	7.81	27.28
Rectinema_u_s	2.13	0.03	0.68	0.40
Sulfurospirillum_u_s	2.02	0.14	0.10	0.03
Methanothrix soehngenii	1.78	0.28	17.95	1.41
Pseudomonas_u_s	1.48	1.20	0.00	3.16
Desulfosporosinus_u_s	1.42	0.06	3.38	0.55
Desulfotomaculum profundi	1.14	0.05	0.04	0.04
Geothrix fermentans	1.10	0.63	0.45	0.25

Figure 5 - Many of the microbes are shared across the monitoring wells, but the abundance of S. cavolei in the MW-14 sample is unique as is the dominance of M. soehngenii in MW-7. Consistent with their close special placement MW-5 and RW-3 are very similar. All post-injection, 2nd quarter samples demonstrate degrading communities and share multiple microbial species.