Injection of BOS 200+® to Remediate Saturated Zone LNAPL at the Former Marshall Iron & Metal Site, Marshall, Michigan

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Background

Previous remedial activities consisting of excavation and disposal of soil and debris was completed in 2015. At this time, light non-aqueous phase liquid (LNAPL) was observed in an offsite monitoring well. In 2016, a remedial investigation (RI) was conducted to delineate the LNAPL. The RI included installation of three (3) soil borings and three (3) monitoring wells and performance of a laser induced fluorescence (LIF) survey at 21 locations.

In the spring of 2021, a quantitative remedial design characterization (RDC), LNAPL bench test and field pilot test were performed. The resulting data were used to refine the LNAPL CSM and a full-scale remedial design to address the LNAPL was developed.

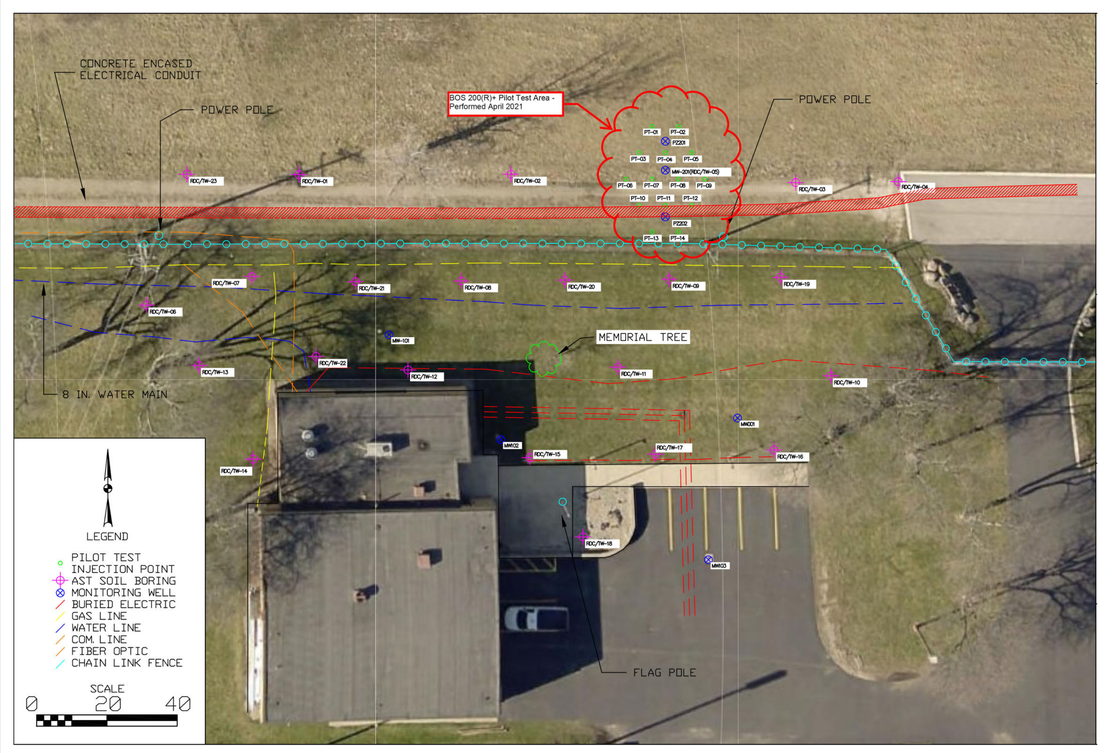


Figure 1. Site Layout with 2021 RDC and Pilot Test Data Points

Project Goals and Objectives

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

Remedial Design Characterization and Bench Test Results

The RDC included installing 23 soil borings and 23 temporary wells, and collection of over 125 soil samples and 30 groundwater samples for TPH analyses. All groundwater samples were below laboratory reporting limits for TPH as expected, given the low solubility of the LNAPL (1.2 to 1.4 mg/L). TPH in soil results were used to develop Figure 2, shown below.

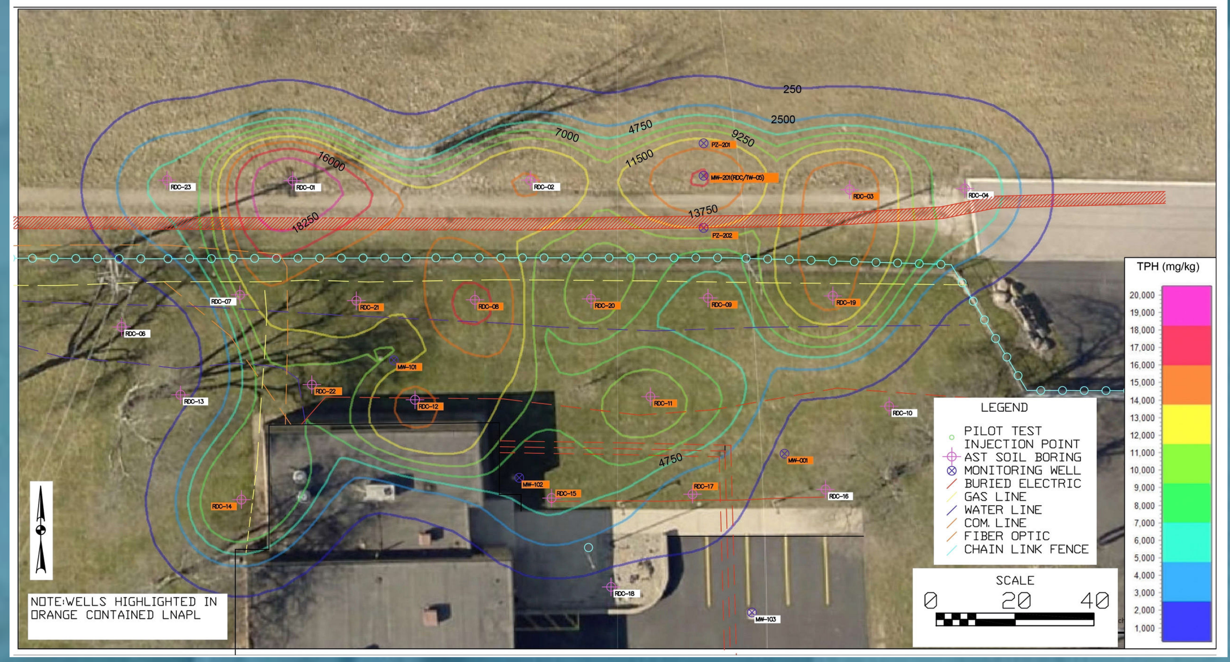
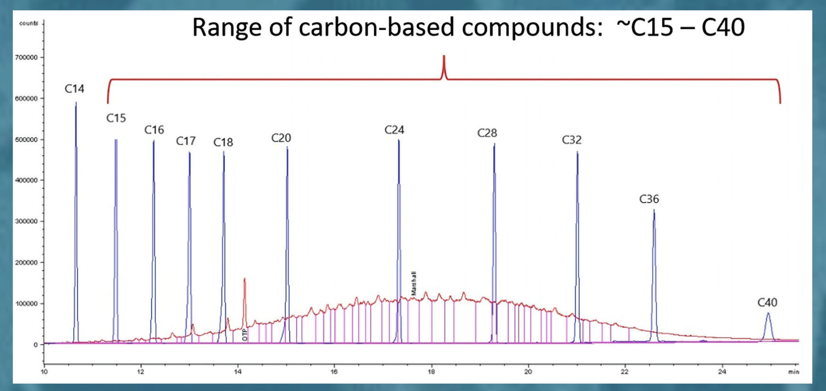


Figure 2. TPH Concentrations in Soil

Bench testing was performed as a component of the RDC to determine LNAPL characteristics including density, solubility, carbon range, and adsorption capacity onto the BOS 200®.

CSM Parameter	Characterization Methods
LNAPL Physical Characteristics / Chemical Composition	Fingerprinting: - Heavy oil - Low VOC concentrations in groundwater - Site specific TPH value (C15-C40)
	Site Specific LNAPL TPH solubility: 1.38 mg/L
	Specific gravity: 0.89
	Viscosity and visual observations – heavy oil
Relative Intensity of Impacts	Groundwater analysis (site specific TPH, VOCs, Dissolved gasses, anions)
	Soil analysis (site specific TPH)
	Soil gas survey
	LIF (qualitative)
LNAPL Mobility	Recoverability observations
	Soil TPH concentrations and saturations
LNAPL Migration	LIF, DEQ-001/MW-001 sentinel well
	Limited gradient information

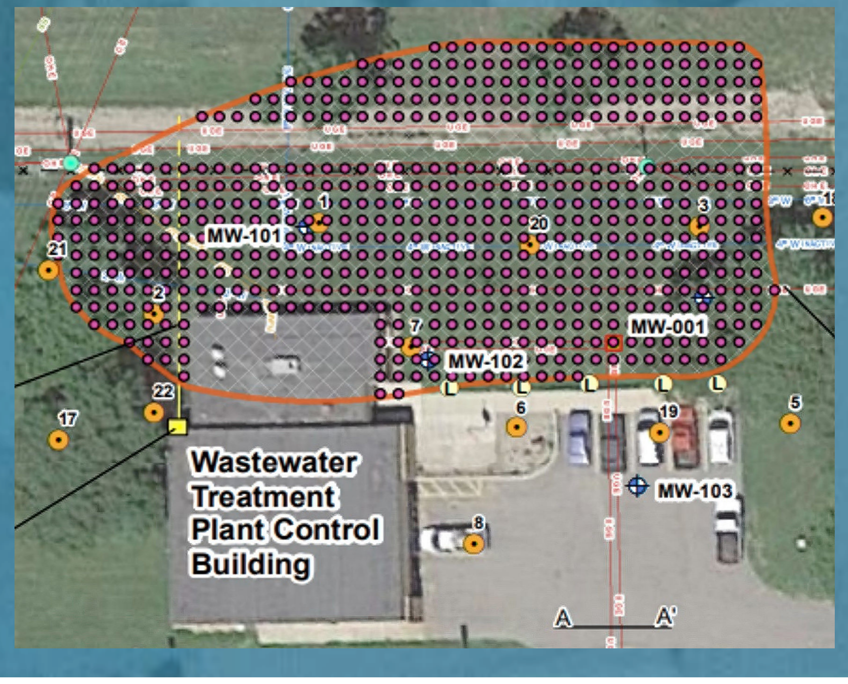


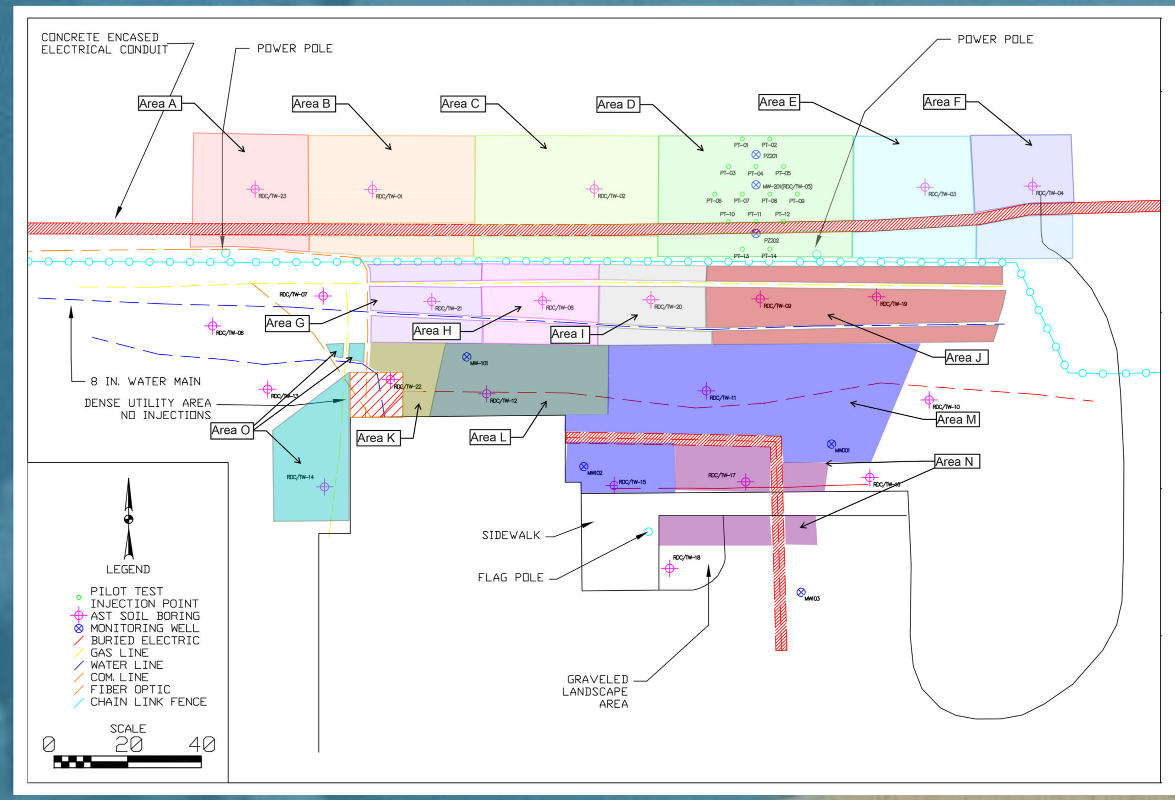
Figures 3A and 3B. LNAPL Bench Test Results Summary

Full-Scale Design and Implementation

Development of the full-scale remedial design was completed using the data from the historical RI work, RDC data and the bench and field pilot tests:

- GAC adsorption demand = >300,000 lbs
- From the Pilot Test - Aquifer capacity = ~60,000 lbs
- Injection point spacing = 7.5 ft
- Injection interval spacing = 2 ft
- ~115 lbs of BOS 200+® per injection interval (60 lbs BOS 200®, combined with magnesium sulfate, calcium sulfate, starch, yeast extract and a facultative bacteria blend in 25-gallon shot volume
- 379 Injection points – ~8 ft to 18 ft bgs





Figures 4A and 4B. Injection Points Layout and Area Groupings

Post Injection Results

The RDC data demonstrated that saturated TPH sorbed mass (> 20,000 mg/kg) varied with depth and lithology. Significant TPH mass was found in the saturated sand and gravel regime. Monitoring well gauging before and after pilot testing and full-scale implementation demonstrated substantial reductions in measured LNAPL thicknesses, as shown in Figure 5.

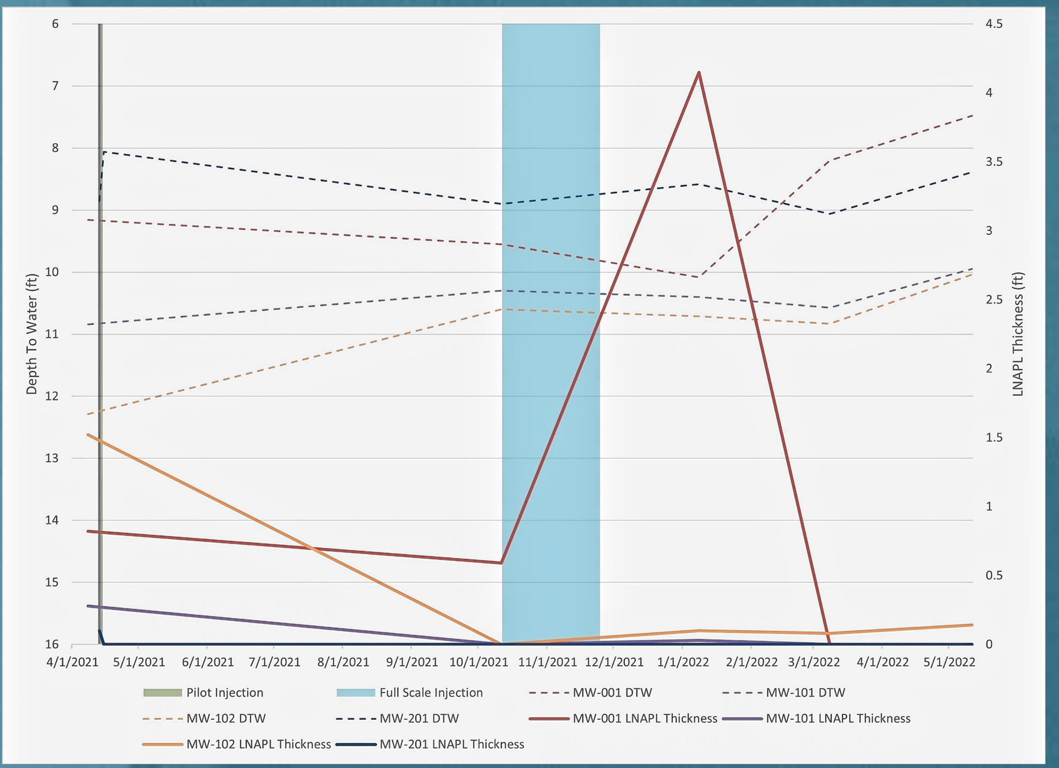


Figure 5. LNAPL Thickness Measurements in Monitoring Wells

Note: Percent reductions in LNAPL range from 91 to 100% based on measurements collected at baseline (April 2021) and 7 months post full-scale injection (May 2022)

Genomic sequencing determined that native bacteria were present to support the biological degradation of the predominant petroleum compounds prior to injections; however, the richness of the microbial population was relatively limited. Post-implementation microbial testing demonstrated an increase in microbial abundance and richness. At 6 and 12 months after full-scale injection, an abundant and rich population of degraders and supporting microbes persists, as shown in Figure 6 below.

Impacted Control

Smithella sp. F21	93.27
Methanoregula formicica SMSP	2.63
Pseudomonas graminis	1.41
Sulfuricurvum kujiense DSM 16994	1.05
Pseudomonas sp. GM21	0.97
Candidatus Sulfuricurvum sp. RIFRC-1_u_t	0.68
Acidovorax defluvii	0.00
Acidovorax soli	0.00
Acidovorax sp. BoFeN1	0.00
Acidovorax sp. NO-1	0.00
Aeromonas_u_t	0.00
Alicycliphilus_u_t	0.00
Arcobacter suis CECT 7833	0.00
Arcobacter venerupis	0.00
Azospira sp. I09	0.00
Nitrosarchaeum koreense MY1	0.00

BOS 200+

Acidovorax sp. BoFeN1	23.81
Acidovorax defluvii	19.64
Geobacter daltonii FRC-32	9.10
Rhodoferax ferrireducens T118	8.51
Thermomonas fusca DSM 15424	7.20
Pseudomonas sp. JL972	5.99
Cellvibrio sp. KY-YJ-3	5.44
Hydrogenophaga sp. T4	2.85
Methylotenera mobilis 13	2.73
Desulfovibrio putealis DSM 16056	2.55
Sphingobium sp. E09	2.26
Polaromonas sp. AER18D-145	2.15
Rhodoferax sp. OTU1	1.06
Acidovorax soli	1.05

Figure 6. Genomic sequencing