BOS 200® CASE STUDIES

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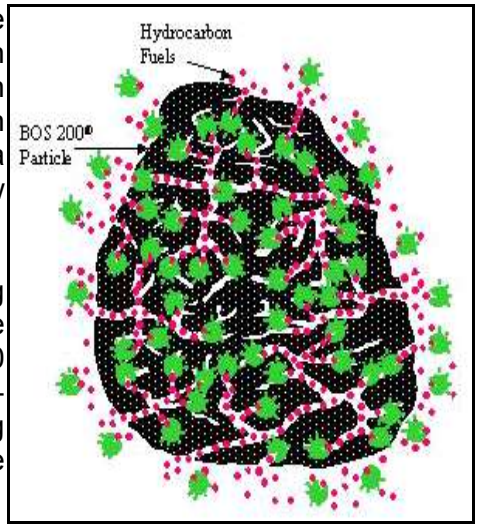
APPENDICES

BOS 200® OVERVIEW - "*TRAP AND TREAT*"

BOS 200® utilizes two (2) proven technologies to effectively remediate petroleum hydrocarbon sites. The two technologies are 1) trapping contaminants via carbon adsorption, and 2) subsequent treatment via biological degradation within the BOS 200® matrix as the product incorporates both aerobic and anaerobic biological processes. These two (2) proven and very powerful remediation mechanisms make what is called the "*Trap and Treat*" process. The "*Trap*" provides the immediate mass reduction and plume control, while the "*Treat*" provides the continued long term remedial degradation. The product comes as a fine grained dry material which consists of: carbon, calcium sulfate, nitrate, phosphate, and ammonia in a proprietary blend. BOS 200® is 77% by weight carbon and up to 19% gypsum, the sulfate source. Gypsum is 79% by weight sulfate which translates to approximately 15% by weight sulfate in BOS 200®. The BOS 200® is mixed with water and a facultative blend of microbes (inoculation with aerobic and anaerobic microbes) to create a solids suspension. This is now an ideal environment for the biological process, where hydrocarbons are adsorbed on to BOS 200® particles made up of:

- Electron Acceptors: oxygen, nitrate, ammonia and sulfate (primary);
- Nutrients - phosphorus and nitrogen; and
- Aerobic and anaerobic blend of microbes (over 26 species of microbes);

The success in achieving cleanup goals is not just in the product installed and proper dosing based upon contaminant mas, but the distribution of the product in subsurface. Distribution is controlled by the injection techniques used (i.e., vertical and horizontal spacing is a function of soil type, high pressure injection vs. low pressure injection, and top down injections).



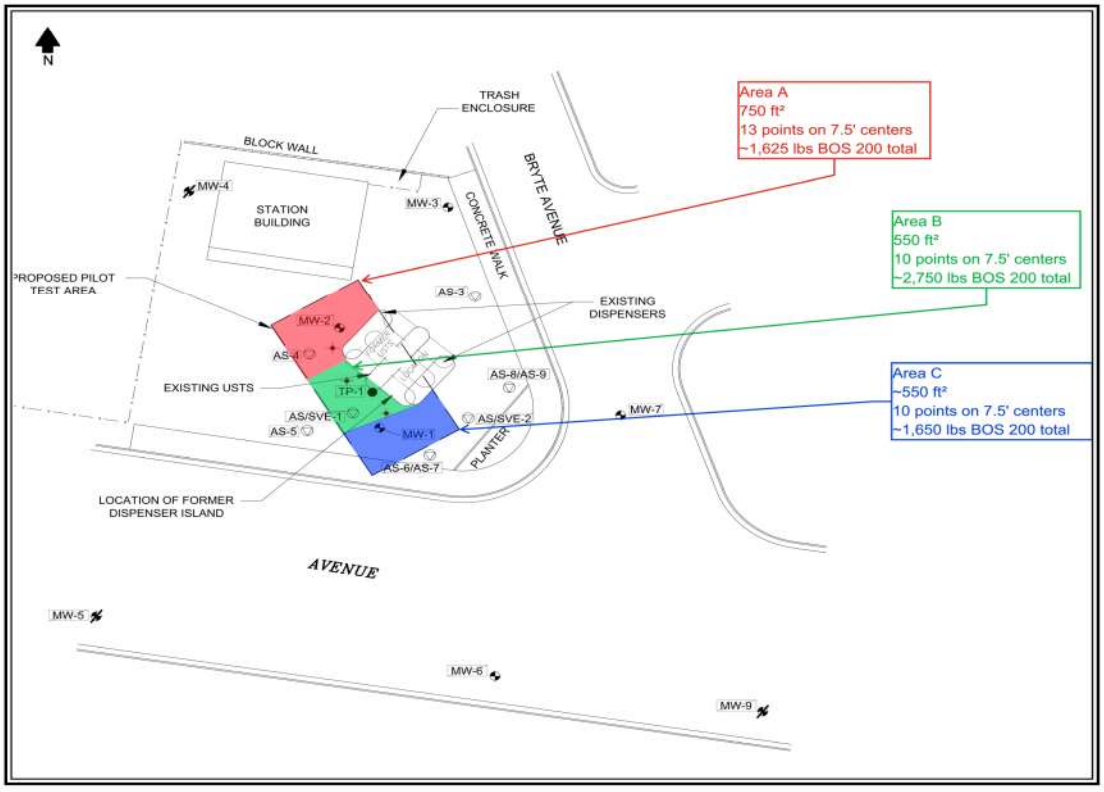
Injection pressures typically vary between 200 to 900 psig (measured at the discharge of the injection pump - the injection system pressure losses are approximately 100 psig – for hoses, valves and injection tips) in soils. In clay-rich soils there is typically a break pressure (soil lifting pressure) that is sustained momentarily and then the pressure drops off.

BOS 200® INJECTION CASE STUDIES

ACTIVE RETAIL SERVICE STATION - SACRAMENTO, CA

1.0 Project Summary

BB&A Environmental (BB&A) was contracted to remediate elevated concentrations of gasoline-range total petroleum hydrocarbons (TPH) and related volatile organic compounds (VOCs) in select areas of an active retail service station in 2013. The dosing of BOS 200® and bacteria concentrate in select areas of the site was determined based on high frequency soil and groundwater analytical data collected during a remedial design characterization (RDC) phase of the project. After completion of an injection design, BOS 200® injections were completed in October 2013. Post BOS 200® injection soil sampling and groundwater monitoring events were conducted. A "No Further Action" (NFA) determination has been requested from the California State Water Quality Control Board (CSWQCB) under the Low Threat Closure Policy (LTCP).



2.0 Site Characterization

Residual Soil Impact

Residual soil contamination was identified adjacent to, and beneath the former USTs and fuel dispensers, located on the southern portion of the site. During a May 23, 2013, investigation, three (3) borings were advanced, and soil samples collected at one (1) to two (2) foot intervals between two (2) and 21 feet below land surface (BLS). The highest residual contaminant concentrations in soil were detected in soil boring B2 (immediately west of the former UST Cavity), primarily between 16 and 18 feet BLS; although residual contamination was identified over a greater extent at deeper

and more shallow depths. The highest detected benzene concentrations in soil from boring B2 included 4.62 parts per million (ppm) at 16 feet BLS, and 7.29 ppm at 18 feet BLS. Based on the detailed and range of analytical data with depth in each of the borings, contaminant mass was calculated to finalize remedial injection design.

Groundwater Impact

Quarterly groundwater monitoring data from monitoring wells MW1 and MW2 (as recent as June 2013), and groundwater data collected from borings B1, B2, and B3 (May 2013 investigation) were used to assess dissolved gasoline contamination in groundwater. Similar to the analytical results for soil, the highest residual contaminant concentrations in groundwater were identified in boring B2, immediately west of the UST Cavity. Identified benzene concentrations in groundwater included 9,600 parts per billion (ppb) in groundwater from boring B2; 2,100 ppb in groundwater from monitoring well MW2 (southwest and downgradient of the UST Cavity); 519 ppb in groundwater from monitoring well MW1; and 303 ppb in groundwater from boring B3.

3.0 Remedial Design

Based upon the results of soil and groundwater data collected during the RDC investigation, the target zone of treatment (vertical distribution of contamination) was estimated to be between eight (8) and 21 feet BLS. Based upon the lateral distribution of contaminant mass, the treatment area was subdivided into Injection Areas A, B, and C. Each area received a specified amount of BOS 200® corresponding to residual contaminant mass identified in that area. The success in achieving cleanup goals is not just in the product installed, but the distribution of the product in subsurface. Distribution is controlled by the injection techniques used (i.e., vertical and horizontal spacing is a function of soil type, high pressure injection vs. low pressure injection, and top down vs. bottom up). Injections were performed using top down techniques using relatively high pressure injections and adjusting the horizontal and vertical injection spacing. Injections were carried out on 7.5 feet centers with alternating depths of 9', 11', 13', 15', 17', 19', and 21' BLS in odd numbered injections points (i.e. IP1, IP3, etc.); and 8', 10', 12', 14', 16', 18', and 20' BLS in even numbered injections points (i.e., IP2, IP4, etc.).

Injection Area A received 13 points with BOS 200® injection loading at 90 pounds (lbs) per injection point. Total loading for Area A was 1,170 lbs. Injection Area B received 10 points with BOS 200® injection loading at 190 lbs per injection point. Total loading for Area B was 1,900 lbs. Injection Area C received 10 points with BOS 200® injection loading at 100 lbs per injection point. Total loading for Area C was 1,000 lbs.

4.0 Results

After injection, site monitoring wells MW-1, MW-2, and MW-3 were sampled on five (5) occasions, air-sparging wells AS-2, AS-6, AS-8, and AS-9 on three (3) occasions, and grab groundwater samples were collected from a hydropunch in borings GW-1 through GW-7. Post injection soil samples were also collected from borings B-1A, B-2A, and B-3A from two (2) to 22 feet BLS adjacent to previous borings B-1, B-2, and B-3. The soil samples from 16 and 18 feet BLS were analyzed by BC Laboratories, Inc., a California certified laboratory. Soil samples collected at all depth intervals were analyzed Remediation Products Inc. (RPI) Quality Assurance Center in Golden, Colorado.

Gasoline-range TPH and benzene decreased to non-detect in MW-1 after injection and remained non-detect through five (5) monitoring events. Gasoline-range TPH and benzene decreased in MW-2 but the reduction of mass at MW-2 was less due to the location of utility lines around MW-2 that reduced the amount of BOS 200® that could be injected in this portion of the site. Contaminant concentrations in MW-3 have remained non-detect. Gasoline-range TPH remained non-detect in AS-2, AS-6, AS-7, AS-8, and AS-9. MtBE remained relatively stable at concentrations below its water quality objective (WQO) in AS-2, and was detected once below its WQO in AS-6. Further, MtBE was detected at 14 ppb (ug/L) in AS-7 pre-injection and at 0.69 ppb in July 2014 (post injection).

	Pre-Injection (6-6-13) **TPHg/Benzene (ppb)**	**Post Injection (1-13-15) - 5th Event** **TPHg/Benzene (ppb)**
MW-1	5,600/860	ND/ND
MW-2	2,100/360	680/400
MW-3	ND/ND	ND/ND

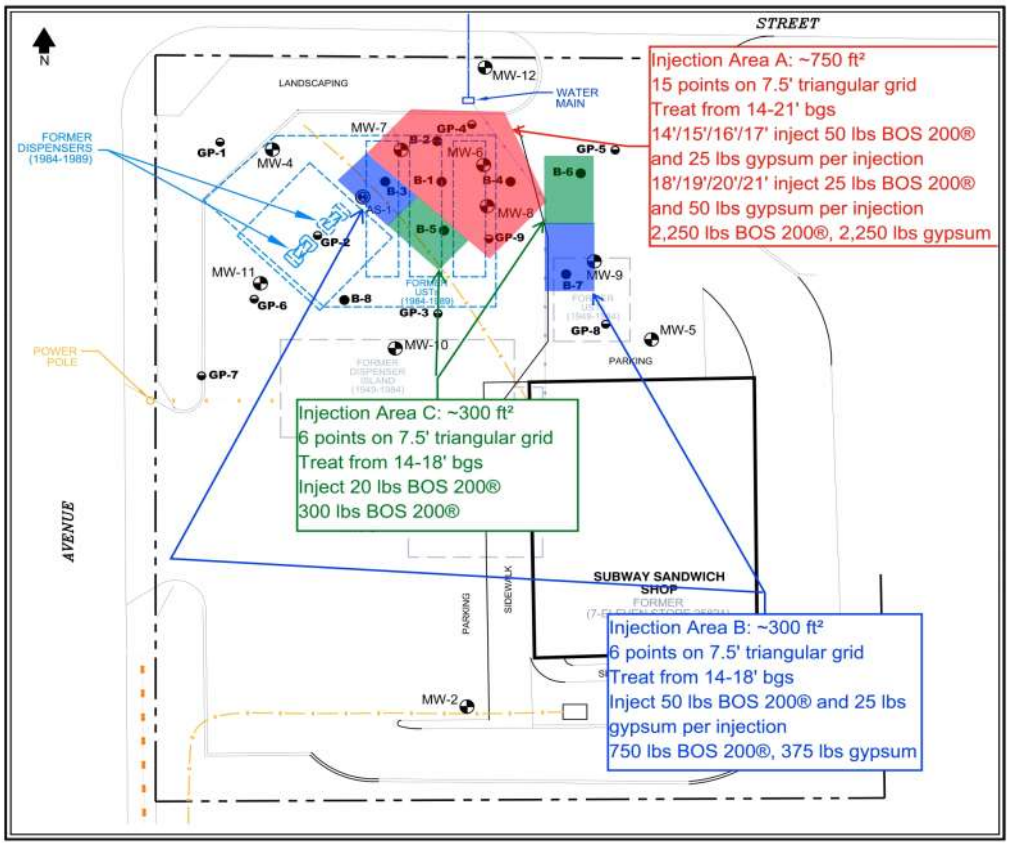
After the injection, gasoline-range TPH and benzene, toluene, ethylbenzene, and xylenes (BTEX) in soil samples collected from B-1A, B-2A, and B-3A were detected at concentrations below those detected in adjacent borings in May 2013 (pre-injection RDC borings). The highest concentrations of gasoline-range TPH were detected in soil samples from 15 to 17.5 feet BLS at B-1A, 14 to 19 feet BLS and 20 to 22 feet BLS at B-2A, and at 16 to 19 feet BLS and 21 feet BLS at B-3A.

Based upon the results of post injection soil sampling, it was estimated that there was a 45 to 85 percent reduction in the mass of gasoline-range TPH from the BOS 200® injection. Greater reduction in mass occurred in saturated soil than in unsaturated soil based on the distribution of BOS 200® in soil.

FORMER RETAIL SERVICE STATION - RICHLAND, WA

1.0 Project Summary

BB&A Environmental (BB&A) was contracted to remediate elevated concentrations of gasoline-range TPH and related VOCs in select areas of a former retail service station in 2014. The dosing of BOS 200® and bacteria concentrate in select areas was determined based on analytical soil and groundwater data provided by the client.



2.0 Site Characterization

Residual Soil Impact

In 2000, gasoline-range TPH and related VOCs were detected in soil above Washington State Department of Ecology (Ecology) Model Toxic Control Act (MTCA) Cleanup Levels (CULs) in borings B1 through B7. Soils consist of sand and silty-sandy gravels.

Groundwater Impact

Recent groundwater data collected in 2014 indicated a primary area of groundwater impact above MTCA A in the vicinity of monitoring well MW-6. Monitoring well MW-6 contained elevated levels of gasoline-range TPH in excess of MTCA A CUL. Depth to groundwater ranges historically ranged from 13 to 17 feet BLS.

3.0 Remedial Design

Based upon the historical soil and groundwater data, the target zone of treatment (vertical distribution of contamination) was estimated to be between 13 and 21 feet BLS. Based upon the lateral distribution of contaminant mass, the treatment area was subdivided into Injection Areas A, B, and C. Each area received a specified amount of BOS 200® and supplemental gypsum (sulfate terminal electron acceptor) corresponding to residual contaminant mass identified in that area. Injections were carried out on 7.5 feet centers with alternating depths of 13', 15', 17', 19', and 21' BLS in odd numbered injections points (i.e. IP1, IP3, etc.); and 14', 16', 18', and 20' BLS in even numbered injections points (i.e., IP2, IP4, etc.).

Injection Area A received 15 points with BOS 200® injection loading at 150 pounds (lbs) and gypsum at 150 lbs per injection point. Total loading for Area A was 2,250/2,250 lbs (BOS 200®/gypsum). Injection Area B received six (6) points with BOS 200® injection loading at 150 lbs and gypsum at 75 lbs per injection point. Total loading for Area B was 900/525 lbs. Injection Area C received 6 points with BOS 200® injection loading at 60 lbs per injection point. Total loading for Area C was 360 lbs.

4.0 Results

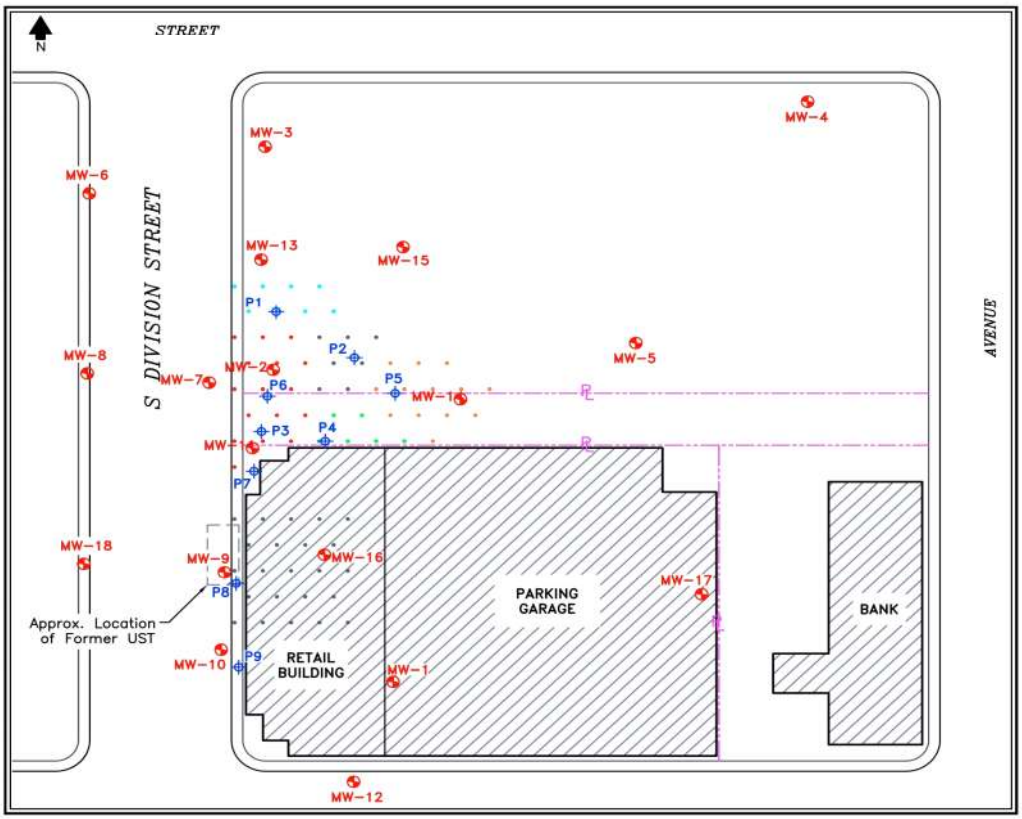
Post injection groundwater sample analytical results are presented below. Confirmation soil sampling and four (4) quarterly groundwater monitoring events have been completed post BOS 200® injection, all indicating concentrations below MTCA CULs. A NFA determination will be requested from the Washington Department of Ecology (DOE).

	Pre-Injection (2-6-14) TPH-Gx (ppb)	Post Injection (9-05-14) TPH-Gx (ppb)
MW-6	5,290	ND
MW-7	790	ND

COMMERCIAL PROPERTY - AUBURN, WA

1.0 Project Summary

BB&A Environmental (BB&A) was contracted to remediate elevated concentrations of gasoline-range total petroleum hydrocarbons (TPH) and related volatile organic compounds (VOCs) in select areas of a commercial property in 2013. The dosing of BOS 200® and bacteria concentrate in select areas of the site was determined based on high frequency soil and groundwater analytical data collected during a remedial design characterization (RDC) phase of the project. After completion of an injection design and a pilot test consisting of BOS 200® injections in a focused area, full scale BOS 200® injection was implemented. Due to the location of a buildings and decorate paved streets that prevent uniform injection of BOS-200® and bacteria concentrate, it was understood that cleanup goals would not be attainable in all impacted areas of the site. Post BOS 200® injection groundwater monitoring events indicate sustained groundwater contaminant reductions in areas that received BOS 200®.



2.0 Site Characterization

Residual Soil Impact

Residual soil contamination is present beneath the site at depths ranging from eight (8) to 18 feet BLS. Analytical soil data collected during the June 2013 RDC investigation identified the highest residual soil contamination (above applicable cleanup levels) in soil borings P1 through P7. Elevated levels of gasoline-range TPH and related VOCs were also identified at eight (8) feet BLS

in P8. Low levels of gasoline-range TPH and related VOCs were identified in P9. Soils consist predominately of silt and silty-sands.

Groundwater Impact

Groundwater data collected from the June 2013 RDC investigation indicated the highest residual groundwater impact was between push probes P1 and P8. In general, the extent of dissolved groundwater impact above Washington State Department of Ecology (Ecology) Model Toxic Control Act (MTCA) Cleanup Levels (CUL) appeared to be generally localized in this area. Groundwater is present generally between nine (9) and 14 feet BLS.

3.0 Remedial Design

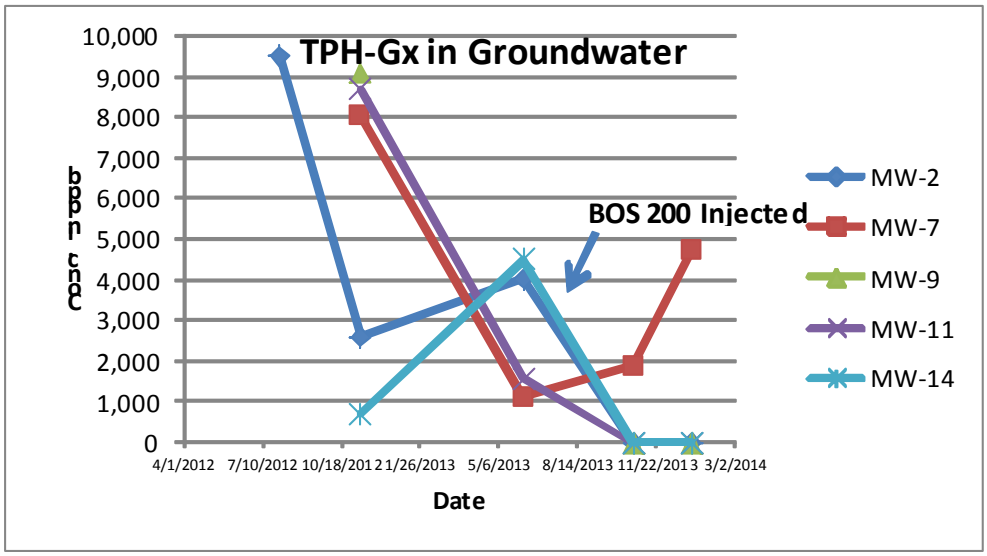
The proposed areas targeted for treatment were assessed to include soil and groundwater impact in the vicinity of the former UST excavation area and to the north-northwest essentially bounded by monitoring wells MW-11, MW14, and MW13. Based upon the variations in contaminant concentrations both vertically and horizontally, six (6) different injection areas were targeted for BOS 200® injection plus one (1) additional injection area for a Pilot Test around monitoring wells MW-2 and MW-11. The target areas primarily differed based upon the distribution of residual contaminant mass. Within the target areas, injection occurred from seven (7) to 10 feet extending downward to 17 to 18 feet BLS.

The area around monitoring wells MW-2 and MW-11 were selected for the Pilot Test based upon the location of these wells, relative high residual soil and groundwater contaminant concentrations, and monitoring history to be used for comparison. A total of 12 injection points, on alternating 10 foot centers, were completed associated with the pilot test. Based upon calculations of residual mass, iron loading, and adsorption isotherms, 25-75 pounds of BOS-200® was injected per injection horizon as recommended by the RPI Group. The sequence of injections were eight (8'), 10', 12', 14', 16', and 18', and seven (7'), nine (9'), 11', 13', 15', and 17' targeting impact between seven (7) and 18 feet BLS. A total of 4,500 lbs of BOS 200® was injected in the Pilot Test area. The remaining six (6) injection areas, identified as A through F, received the following injections all on 10 foot centers:

- **Injection Area A**: Four (4) points with BOS 200® injection loading at 25-75 lbs per injection. Total loading for Area A was 1,500 lbs.
- **Injection Area B**: Eight (8) points with BOS 200® injection loading at 10-75 lbs per injection. Total loading for Area B was 1,550 lbs.
- **Injection Area C**: Seven (7) points with BOS 200® injection loading at 10-50 lbs per injection. Total loading for Area C was 1,100 lbs.
- **Injection Area D**: Six (6) points with BOS 200® injection loading at 60-75 lbs per injection. Total loading for Area D was 1,800 lbs.
- **Injection Area E**: 13 points with BOS 200® injection loading at 10-60 lbs per injection. Total loading for Area E was 1,700 lbs.
- **Injection Area F**: 23 points with BOS 200® injection loading at 10-60 lbs per injection. Total loading for Area F was 4,950 lbs.

4.0 Results

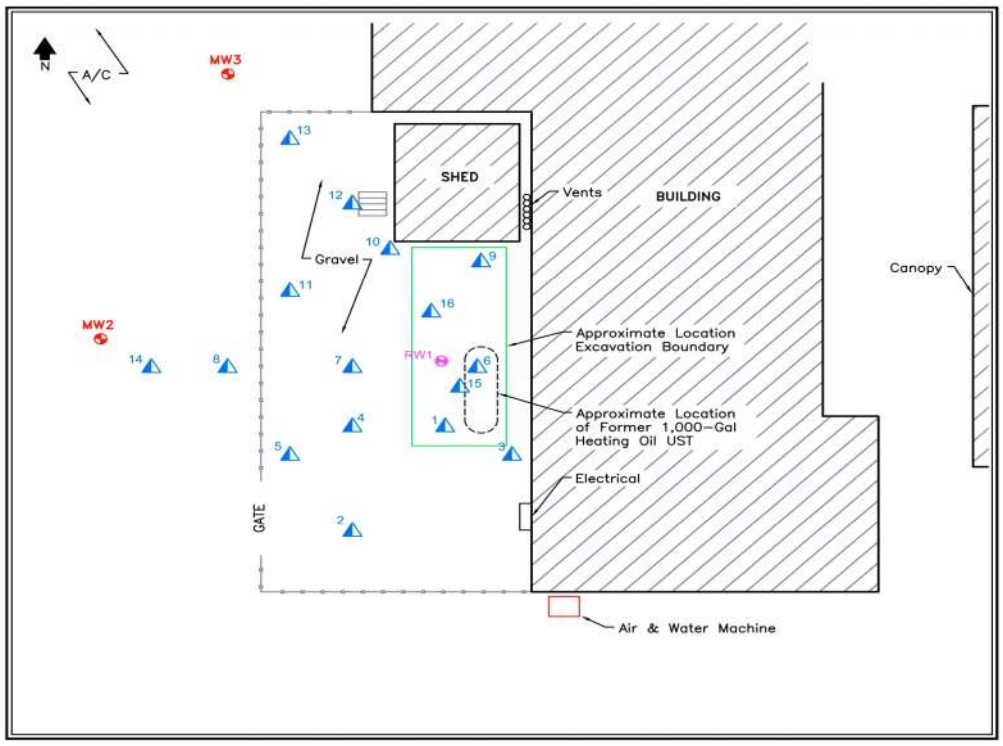
With the exception of monitoring wells MW-7 which lies in the adjacent right-of-way outside the injection grid, gasoline-range TPH decreased to non-detect in all monitoring wells (i.e., MW-2, MW-9, MW-11, and MW-14) after injection, and remained non-detect through two (2) subsequent monitoring events six (6) months post injection as shown in the graph below. BB&A has not obtained any additional groundwater monitoring data beyond January of 2014.



HEATING OIL (DIESEL) LNAPL - BOARDMAN, OR

1.0 Project Summary

BB&A Environmental (BB&A) was contracted to remediate residual light non-aqueous phase liquid (LNAPL diesel) from the groundwater surface and overlying soils beneath a retail facility. The dosing of BOS 200® and bacteria concentrate in the area of a former heating oil UST was determined based on historical soil and groundwater analytical data. After completion of an injection design, BOS 200® injections were completed in December 2014 and January 2015. Post BOS 200® injection groundwater monitoring events were conducted and confirmed the absence of LNAPL, and identified dissolved diesel-range TPH below Oregon Department of Environmental Quality (ODEQ) Risk-Based Concentrations (RBCs). A "No Further Action" (NFA) determination was issued for the site in April 2015 by the ODEQ.



2.0 Background

Records indicated that approximately 1,000 gallons of heating oil was released from the tank in a three (3) day span in early December 2007. In May 2008, the heating oil UST was decommissioned by removal. Several holes were identified along the base of the tank, some as large as approximately one (1) inch in diameter. Due to the relatively loose sand at the subject site, it appeared that heating oil released from the tank infiltrated the soil beneath the tank with minimal lateral spreading.

3.0 Site Characterization

Residual Soil Impact

Initial site characterization included the installation of six (6) geoprobe points (DP-1 through DP-6) to a depth of 45 feet BLS to facilitate both soil and groundwater sample collection. Soil samples were only collected from boring DP-1, completed through the former HOT cavity, at 20 feet, 25 feet and 40 feet BLS. Soil sample analytical results confirmed the presence of diesel-range TPH (TPH-Dx) at 3,970 ppm in soil sample DP-1-20', at 11,500 ppm in soil sample DP-1-25', and at 8,370 ppm in soil sample DP-1-30'. Additional analysis of soil sample DP-1-25' for BTEX constituents indicated the presence of benzene at 0.06 ppm, toluene at 2.41 ppm, ethylbenzene at 4.86 ppm and xylenes at 23.7 ppm. Soils consist of medium sand underlain by sandy gravel below 50 feet BLS.

Groundwater Impact

Groundwater sample analytical results confirmed the presence of TPH-Dx as diesel in sample DP-1-W at 212 ppm, and at 1.12 ppm in groundwater sample DP-3-W. TPH-Dx as diesel and heavy oil were not detected in groundwater samples DP-2-W, DP-4-W, DP-5-W and DP-6-W. Follow-up analyses indicated the presence of BTEX in water sample DP-1-W at 55.2 ppb, 250 ppb, 118 ppb and 631 ppb, respectively, and BTEX in water sample DP-3-W at 43.2 ppb, 110 ppb, 32 ppb, and 167 ppb, respectively. Additional analysis for PAH constituents in water sample DP-1-W indicated the presence of several constituents, most notable were naphthalene at 165 ppb, fluorene at 108 ppb, phenanthrene at 37.2 ppb, fluoranthene at 0.8 ppb and benzo(a)anthracene at 0.3 ppb.

In late 2008, three (3) monitoring wells and a recovery well were installed at the site to depths of between 45 and 60 feet BLS. LNAPL was identified in the recovery well RW-1 located at the center of the removed heating oil UST. The groundwater is encountered at approximately 40 feet BLS.

LNAPL Recovery

Between March 2009 and March 2010, approximately 20 gallons of LNAPL was removed from RW-1 using passive techniques. Later a skimmer system and SVE extraction blower were also installed within recovery well RW-1. Various methods of extraction were conducted from RW-1 through October 2013. Based upon information reported, several hundred gallons of LNAPL and several thousand gallons of contaminated groundwater were recovered from subsurface soils and groundwater. However, residual LNAPL remained in RW-1 and the localized area.

4.0 Remedial Design

In an effort to remove remaining LNAPL, BOS 200® was injected around recovery well RW-1 in a grid like pattern to target residual impacted soils above, and at the soil/water interface. BOS 200® was selected as an injectate based upon the following:

- Very localized remaining contaminant mass;
- The ability to effectively deliver BOS 200® and bacteria in a one-time event through temporary injection points rather than additional permanent well installations;
- The ability of BOS 200® to immediately bind residual hydrocarbon mass;

- The relative low cost of BOS 200® and bacteria compared to the acquisition of a new mechanical system and operation and maintenance costs associated with new equipment; and
- The relative time to capture residual free product and achieve compliance with RBCs (i.e., immediately after injection).

On two (2) occasions during the weeks of December 15, 2014, and January 12, 2015, a proprietary mixture of BOS 200® and bacteria, and supplemental gypsum was injected into subsurface soil and groundwater around RW-1 as shown on the figure above. A total of 1,800-pounds of BOS 200®, approximately five (5) gallons of liquid bacteria, and 1,600 pounds of supplemental gypsum (as an additional electron acceptor) was injected at multiple intervals between 23' and 44' feet in 16 discrete borings.

5.0 Results

A few days after initial injections (December 19, 2014), an interim groundwater sample was collected from recovery well RW-1 to assess progress of treatment using BOS-200® and bacteria. As shown in the Table below, LNAPL had been "trapped" by the BOS-200® and the dissolved TPH-Dx concentration had been reduced to 22,600 ppb. Approximately 10 days after the second series of injections, an additional followup sample was collected indicating a further reduction in the dissolved TPH-Dx concentration.

Analytical Results of Groundwater Samples (TPH-Dx, BTEX+N)

Sample ID	TPH-Dx	Heavy Oil	Benzene	Toluene	Ethyl-benzene	Xylenes (total)	Naph-thalene
December 19, 2014							
-MW-1	<75.5	<151	<0.250	<1.0	<0.5	<1.50	<2.0
-MW-2	<75.5	<151	<0.250	<1.0	<0.5	<1.50	<2.0
-MW-3	<75.5	<151	<0.250	<1.0	<0.5	<1.50	<2.0
-RW-1	**22,600**	<769	<0.250	<1.0	<0.5	**5.59**	**5.97**
January 26, 2015							
-RW-1	**8,160**	<180	<2.50	<10.0	<5.0	<15.0	NA
RBC_{wi}	>S	>S	2,800	>S	7,400	>S	10,000
RBC_{wo}	>S	>S	14,000	>S	41,000	>S	16,000

UST TANK CAVITY (DISSOLVED AND LNAPL DIESEL) - VANCOUVER, WA

1.0 Project Summary

BB&A Environmental (BB&A) was contracted to remediate dissolved diesel and LNAPL from groundwater within an active UST cavity. The dosing of BOS 200® and bacteria concentrate in the UST cavity was determined based on the estimated mass of LNAPL and dissolved-phase diesel within the UST cavity. After completion of an injection design, BOS 200® injections were completed in December 2014 and January 2015. Post BOS 200® injection groundwater monitoring events were conducted and confirmed the absence of LNAPL, and verified that all dissolved diesel-range TPH and individual constituent concentrations were below Washington Ecology's MTCA Method A cleanup levels. A "No Further Action" (NFA) determination was issued for the site in January 2012 by Ecology.

2.0 Background and Remedial Action using BOS 200®

In March of 2006, a driver accidently delivered fuel to the wrong UST, without prior measurement of the volume within, and as a result, an estimated 2,211 gallons of fuel overflowed the monitoring riser into the UST cavity. Initial response actions included: multiple, and periodic evacuation operations of LNAPL and groundwater from the UST cavity; use of an automatic floating skimmer pump; injection and recirculation of nutrients, oxymethyl fatty acids, and anaerobic bacteria in groundwater within the UST Cavity; and in-situ chemical oxidation by injection of oxidizing agents (RegenOx® and Oxygen Release Compound [ORC®] produced by Regenesis) into observation wells OB-1, OB-2, and OB-3. Unfortunately, after all the corrective actions conducted, residual diesel-range TPH concentrations in groundwater remained at 3,870 to 4,480 parts per billion (ppb), well above Washington Department of Ecology's MTCA Method A cleanup levels.

On December 15, 2010, approximately 600 pounds of BOS 200® and five (5) gallons of petrophyllic bacteria were injected into the UST cavity via the three (3) observation wells. The BOS 200® activated carbon was premixed at a ratio of one (1) pound of carbon per one (1) gallon of water. The activated carbon, water and petrophyllic bacteria were mixed, and the resulting slurry was pumped (using a grout pump) equally into each of the three (3) observation wells (i.e., OB1, OB2, and OB3). During the injection process, groundwater was pumped from one (1) observation well into the other two (2) wells to maximize radius of influence and circulation of the carbon / bacteria mixture throughout the UST cavity. Further, the injection was conducted at near historical high groundwater levels to ensure maximum contact of the carbon / bacteria mixture with the full vertical range of residual diesel contamination within the UST cavity.

Subsequent quarterly groundwater monitoring identified diesel-range TPH at concentrations ranging between 72 and 752 ppb in groundwater from the three (3) observation wells. Further, laboratory analysis of groundwater for benzene, toluene, ethylbenzene, xylenes (BTEX), and polynulcear aromatic hydrocarbons (PAHs), only detected Chrysene (once) above method-reporting limits. Based on the groundwater analytical results, Ecology issued a no further action (NFA) determination to the site.

OTHER BOS 200® APPLICATION CASE STUDIES

UST PIT SPRAY - BATTLEGROUND, WA

1.0 Project Summary

BB&A Environmental (BB&A) was contracted to removed multiple USTs from a Retail Service Station and Convenience Store. After removal of the UST system, soil cleanup activities were undertaken to remove soils containing elevated concentrations of gasoline-range TPH and related VOCs. A total of 5,848 tons of petroleum-contaminated soil (PCS) was removed and disposed of off-site at an authorized disposal facility. No groundwater pumping was conducted during soil excavation. A sheen was noted on the groundwater surface in the UST cavity. Based on soil and groundwater corrective actions, soil confirmation analytical results, and findings from the four (4) post cleanup quarterly groundwater monitoring events, a recommendation was made to Ecology that a NFA determination be issued for onsite soil and groundwater. The NFA is currently pending.

2.0 Remedial Design - Batch Spraying UST Excavation

Upon completion of excavation activities, and prior to backfill, groundwater within the UST cavity, and soil along the walls and floor of the excavation were treated using petrophyllic bacteria and BOS 200®. BOS 200® was applied as a “biobarrier” through which groundwater can flow, removing any residual free-phase and dissolved phase petroleum contamination, and preventing contaminated groundwater from migrating beyond the “biobarrier.”

The BOS 200® and bacteria were mixed and applied to the excavation in batches. In each batch, 100 pounds of BOS-200® was mixed with 100 gallons of water in a tank, along with approximately 16 ounces of petrophyllic bacteria. A pump was used to apply the carbon, water and bacteria mixture to the walls of the excavation, and all areas of the excavation with groundwater accumulation to treat potential petroleum contamination in soil and any dissolved-phase contamination in groundwater. A total of 1,500 pounds of BOS200®, was mixed with 1,500 gallons of water, along with approximately 240 ounces of petrophyllic bacteria. Upon completion of all excavation activities, confirmation soil sampling, and treatment using BOS-200® and bacteria, the excavation was backfilled with clean sand and overburden.

3.0 Results

Four (4) consecutive post cleanup quarterly groundwater monitoring events were performed. The analytical groundwater sample results for the final sampling event are presented in the Table below. Laboratory analytical results for the sampling event conducted on November 13, 2013, did not detect any contaminants (i.e., gasoline-range TPH or gasoline-related VOCs) in groundwater from monitoring wells MW1, MW4, MW7, and MW8. As such, no contaminants were detected at concentrations exceeding MTCA Method A or Method B (where Method A is unavailable) cleanup levels. During the past four (4) quarterly groundwater monitoring events, no contaminants have been detected in monitoring wells MW1, MW4, and MW8. In groundwater from monitoring well MW7, contaminant concentrations have shown a steady decrease during the past four (4) quarterly sampling events. Further, during the past four (4) quarterly groundwater monitoring

events, no contaminants were detected above MTCA Method A or Method B (where Method A is unavailable) cleanup levels.

Final Groundwater Analytical Results, November 13, 2013

Contaminants-of-Concern	Monitoring Well ID				MTCA Method A Cleanup Level for Unrestricted Land Use
	MW1	MW4	MW7	MW8	
Gasoline-Range TPH	ND (<100)	ND (<100)	ND (<100)	ND (<100)	800[with Benzene] / 1,000[w/o benzene]
Benzene	ND (<0.25)	ND (<0.25)	ND (<0.25)	ND (<0.25)	5.0
Toluene	ND (<1.0)	ND (<1.0)	ND (<1.0)	ND (<1.0)	1,000
Ethylbenzene	ND (<0.5)	ND (<0.5)	ND (<0.5)	ND (<0.5)	700
Xylenes (Total)	ND (<1.5)	ND (<1.5)	ND (<1.5)	ND (<1.5)	1,000
MTBE	ND (<1.0)	ND (<1.0)	ND (<1.0)	ND (<1.0)	20
1,2-Dibromoethane	ND (<0.5)	ND (<0.5)	ND (<0.5)	ND (<0.5)	0.01
1,2-Dichloroethane	ND (<0.5)	ND (<0.5)	ND (<0.5)	ND (<0.5)	5.0
Naphthalene	ND (<2.0)	ND (<2.0)	ND (<2.0)	ND (<2.0)	160
1,2,4-Trimethylbenzene	ND (<1.0)	ND (<1.0)	ND (<1.0)	ND (<1.0)	No Cleanup Level
1,3,5-Trimethylbenzene	ND (<1.0)	ND (<1.0)	ND (<1.0)	ND (<1.0)	80[B]
Isopropylbenzene	ND (<1.0)	ND (<1.0)	ND (<1.0)	ND (<1.0)	800[B]
n-Propylbenzene	ND (<0.5)	ND (<0.5)	ND (<0.5)	ND (<0.5)	No Cleanup Level

For additional information: 503-570-9484, ext 1.
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APPENDIX A

Chemistry of BOS 200®

TRAP & TREAT® - BOS 200®

Based on years of experience using a variety of injectable technologies, ranging from augmented bioremediation to Fenton chemistry using hydrogen peroxide, it became clear that a better mousetrap was needed. As a consequence of this line of thought, an idealized product was defined having the following characteristics:

- Can reduce contaminant concentrations quickly to regulatory standards;
- Works in a variety of soil and groundwater conditions;
- Is non-toxic and has no adverse impact on soil properties or groundwater quality;
- Is applicable to a variety of contaminants;
- Is reasonably cost-effective, at least in comparison to existing remedies; and
- Is a passive system, easily installed using equipment common to the industry.

The above six characteristics are the heart and sole of RPI's Trap & Treat® concept. The trap portion is designed around an immediate and predictable impact, observable in groundwater and soil after installation of the product. This aspect of BOS 200® is due to the presence of activated carbon in the product. In other words, the "Trap" is absorption by the activated carbon. Significant reductions in contaminant concentrations are typically realized in a matter of hours.

BOS 200® does not stop at stabilization of contamination. Absorption is just the first step in the process. Treatment is accomplished through biodegradation of the absorbed contaminants. In general, whenever the following conditions are present,

Microorganisms + Electron Donors + Electron Acceptors + Nutrients.

The result is metabolic by-products + energy + new microorganisms (Wiedemeier, 1999).

In this case, petroleum-degrading microorganisms are the "bugs" and hydrocarbon contaminants are the electron donors. Hydrocarbon degraders are very robust and can thrive under a wide range of conditions. In fact, they have been known to withstand pressures of hundreds of bars, pH conditions ranging from 1 to 10, temperatures from 0° to 75° C, and salinities greater than normal seawater (Freeze and Cherry, 1979). In the last decade, a great deal of research has been conducted on the role and importance of electron acceptors and nutrients within hydrocarbon plumes and the consensus is that the rate of biodegradation is limited by a lack of electron acceptors rather than a lack of nutrients. BOS 200® contains selected nutrients including phosphorus and nitrogen, and it contains a variety of electron acceptors that can be utilized under aerobic or anaerobic conditions.

A complete story of the electron acceptors must begin in the mixing tank. The product is shipped as a dry powder, which is mixed with water in the field to prepare an injectable slurry. One feature of activated carbon is that it has quite an affinity for oxygen. It adsorbs oxygen as the BOS 200® is manufactured, stored, and from the aerated water during the mixing operation. In short, the product is saturated with oxygen before injection into the contaminated formation. The product contains additional electron acceptors in the form of nitrate, ammonia and a timerelease source of sulfate. The source of the time-release sulfate is gypsum or calcium sulfate.

Gypsum has been used by farmers for centuries as a soil conditioner and is not very soluble in water. However its solubility is such that a low but persistent concentration of sulfate can be maintained in groundwater for a number of years with a single application. A hidden benefit of this chemistry has to do with phosphorus. During manufacture, a small amount of ammonium phosphate is blended into the mix. This readily dissolves when mixed with water. However, calcium phosphate is virtually insoluble in water and so the available phosphate is rapidly precipitated out of solution, into and onto the activated carbon during the mixing operation. This provides a bio-available form of phosphorus (an essential nutrient) to the microorganisms that cannot be washed out by groundwater seep.

For thermodynamic reasons, microorganisms preferentially utilize those electron acceptors that provide the greatest amount of free energy during respiration (Bower 1992). The driving force for the biodegradation of petroleum hydrocarbons is the transfer of electrons from the donor (hydrocarbon) to the electron acceptor. The organism derives energy from this process and the more energy it can derive, the more attractive the process becomes. The high end of the energy spectrum is represented by aerobic utilization of oxygen as the electron acceptor. An overview of the next stops along the energy path is given by the following.

Nitrate reduction, Fe+3 reduction, Sulfate reduction, and the last stop is given by methanogenic respiration.

The concept of respiration is important in that the organism literally breaths nitrate or sulfate while oxidizing hydrocarbons. In each case above, the energy derived decreases as one moves down from nitrate toward methanogenic respiration. It is clear that if oxygen is available, it will be the preferred electron acceptor. The catch is that organisms must be present that can take advantage of prevailing conditions at any given time. When the material is first injected, it is saturated with oxygen. Consequently, no matter what the prevailing condition is within the plume, the prevailing condition within the BOS 200® is initially aerobic. Once the oxygen is consumed, nitrate will become the next favored electron acceptor, finally settling into sulfate reduction along with some methanogenic respiration. This process can be short-circuited by a persistent source of a higher energy acceptor. For example, if a sustainable source of oxygen is available, the dominant mechanism for degradation will remain aerobic.

This points to an important concept. Much discussion in the literature is devoted to the apparent advantage indigeneous microorganisms have over cultured bacteria that one might add to the mix. It is widely held that existing organisms have become accustomed to the prevailing condition and already “occupy the niche”. As a result, it is very hard for a new organism to take

over or to even get a foothold in the existing biocosm. In fact, the BOS 200 represents a new niche that is very attractive to bacteria. Bugs love activated carbon. We take advantage of this by mixing bacteria with the product when preparing the injectable slurry. The product is innoculated with bacteria before it is installed. This is an important step because the new niche is already occupied by bacteria designed to degrade hydrocarbons before it is installed. Shortly after installation, hydrocarbons are adsorbed and the niche is full.

RPI recommends and uses a specific blend of microorganisms with its product. It is a customized culture of facultative anaerobes that can take advantage of the wide swing in conditions presented by the installed BOS 200®. As a result, there are organisms present that can use the oxygen initially present. Further, there are nitrate reducers, iron reducers, sulfate reducers, fermenters, and methanogens. No matter what condition exists within the activated carbon, there are microorganisms present to take advantage.

Metabolic by-products vary depending on what metabolic pathway is being used for hydrocarbon degradation. Carbon dioxide and water are common although many other compounds are possible, including various alcohols and volatile fatty acids. Acetate turns out to be produced by aerobic conditions as well as by anaerobic fermentation, and under methanogenic respiration. Other products include lactate, formate, butyrate, isobutyrate, pyruvate, and proprionate along with methane.

When BOS 200 is mixed with water, the resulting slurry has elevated concentrations of nitrate, sulfate, and chloride. This results in elevated concentrations in the groundwater wherever the material is injected. Under normal conditions, contaminant levels drop literally overnight. Initially, nitrate levels within the treatment area range from 50 ppm to perhaps as high as 250 ppm with sulfate ranging from 200 ppm to 1500 ppm. Chloride is initially somewhere between 50 ppm and 150 ppm. At first, microbes utilize oxygen. When oxygen is depleted, nitrate is the next highest energy electron acceptor. The first step in the de-nitrification is the formation of nitrite. Over the first month or two (post injection), nitrate levels typically drop and low levels of nitrite are often observed. The nitrite and nitrate are normally consumed within the first two months and nitrate falls to levels below regulatory standards. At about the same time, measurable levels of acetate can begin to show up. Finally, fermentation, sulfate reduction, and methanogenic respiration become the dominant pathways.

Regulators often postulate that the disappearance of nitrate is simply due to the natural dispersion from groundwater movement and diffusion. Chloride can be used as an internal measure of these effects as there are no biological demands for this species nor are there chemical demands that are commonly encountered in groundwater plumes. As a result, the behavior of chloride over time is a good indication of natural forces such as groundwater seep and diffusion. It should be noted that neither chloride nor nitrate is adsorbed by activated carbon. In fact, activated carbon is virtually transparent to charged inorganic species. As described above, nitrate typically plummets over the first two months, falling from an initial value of over 100 ppm to less than 5 ppm. Chloride, on the other hand, typically remains fairly stable over this same time period. Given such performance, it is hard to argue that the disappearance of nitrate is not due to its consumption in anaerobic respiration.