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Sent Via Electronic Email

October 29, 2018

Mr. George Jacob
U.S. Environmental Protection Agency, Region II
Emergency and Remedial Response Division
Central New York Remediation Section
290 Broadway, 20th Floor
New York, NY   10007-1866

Subject: **PlumeStop® Injection Work Plan**
York Oil Superfund Site
Moira, New York

Dear Mr. Jacobs:

Attached for your review is the PlumeStop® Injection Work Plan prepared by de maximis, inc. on behalf of Arconic for the York Oil Superfund Site. This Work Plan discusses the implementation of PlumeStop®, a patented colloidal liquid activated carbon (LAC). The LAC component is primarily intended to target BTEX compounds. CVOCs also sorb to the LAC and both the BTEX and cVOCs are ultimately expected to biodegrade, freeing binding sites for continuing sorption and degradation.

This work is currently scheduled to be implemented November 5-9, 2018.
.
Please contact me if you have any questions.

Sincerely,

Bruce Thompson

Enclosure

cc: Mr. Anthony Sturtzer, Arconic
Ms. Samantha Salotto, NYSDEC
Mr. Ryan Kingsley, CDMSmith
Mr. Kent Sorenson - CDMSmith

Work Plan for
PlumeStop Liquid Activated Carbon Injection

York Oil Superfund Site
Moira, NY

Prepared by:

de maximis, inc.

de maximis, inc.
200 Day Hill Road, Suite 200
Windsor, CT 06095

October 2018

Table of Contents

Tables

Figures

Appendices

1. Introduction

The York Oil Site is located in the Town of Moira, Franklin County, New York (Figure 1). The facility was constructed in the 1950s by the York Oil Company, which processed used oils collected from service stations, car dealers, and industrial facilities. The oils, some of which contained polychlorinated biphenyls (PCBs) and solvents, were processed to remove impurities and resold to other businesses. The oil recycling operation was discontinued in the mid-1960s; the property was then used by Pierce Brothers Oil Services, Inc., for used oil storage. The collected oils were stored or processed in eight aboveground storage tanks, three earthen-dammed settling lagoons, and at least one underground storage tank.

For investigation and remediation purposes, the site was divided into two operable units (OUs); the "Site Proper" and the "Contamination Pathways" (OU1 and OU2, respectively). In February 1988, the United States Environmental Protection Agency (EPA) signed a Record of Decision (ROD) selecting a source control remedy for the “Site Proper”. The OU1 ROD required excavation, treatment, and on-site disposal of contaminated soils and sediments, installation of deep groundwater draw-down wells at the edges of the site to collect the sinking plume of phenol-contaminated groundwater; installation of shallow dewatering wells to collect contaminated groundwater and oil during excavation, and treating these liquids prior to discharging the treated groundwater in accordance with state environmental requirements; removing and transporting contaminated tank oils to an EPA-approved facility to be incinerated; cleaning and demolishing the empty storage tanks; and inspecting the site every five years to assure that human health and the environment continue to be protected.

The Contamination Pathways studies resulted in a ROD issued in September 1998. The OU2 ROD required the excavation of lead- and PCB-contaminated sediments from the Western Wetland and from the Northwestern Wetland, followed by solidification/ stabilization and on-site disposal; natural attenuation of the solvents in groundwater in the Southern Wetland; institutional controls (ICs) to prevent the installation and use of groundwater wells in the Southern Wetland; and long-term groundwater monitoring.

Operation of the OU1 groundwater treatment system (GWTS) started in December 2001. Phenol was not found in the influent; the target compounds were volatile organic compounds (VOCs), principally cis-1,2-dichloroethene (cDCE). Alternatives to continued operation of the GWTS were evaluated in 2009, resulting in shut down of the GWTS in favor of in situ treatment.

2. *In Situ* Treatment Methods

An investigation was conducted in the spring of 2009 of the former lagoon area immediately upgradient from the GWTS, which revealed ~2,000 yards^3 of subsurface soil containing total petroleum hydrocarbons (TPH). In addition to the TPH, some soil samples contained cDCE and tetrachloroethene (also called perchloroethene, or “PCE”). PCE degrades to cDCE through an intermediate product, trichloroethene (TCE). PCE and TCE have partitioned into the TPH, and were postulated to be dissolving into the groundwater. TPH could potentially serve as an electron donor that facilitates biological degradation to cDCE.

Previous analysis of monitored natural attenuation (MNA) data identified the lack of electron donor as a limiting factor for successful biological degradation of cDCE, so approaches to increase electron donor were utilized.

2.1 *In Situ* Chemical Reduction (ISCR)

An evaluation of feasible alternatives was performed, and EHC® was identified as a preferred *in situ* remedial option for OU-1 groundwater. EHC® is a patented combination of controlled-release carbon and zero valent iron (ZVI) particles used for stimulating *in situ* chemical reduction (ISCR) of otherwise persistent organic compounds in groundwater.

The EHC® process was proposed to the USEPA at a meeting in February 2009, and a full-scale pilot study was proposed in July 2009 and approved by the USEPA in August 2009. In September 2009, the groundwater extraction and treatment system was shut down on September 21, 2009 and the system was drained for long-term inactivation.

Phase I of the *in situ* chemical reduction pilot study was completed in October 2009 with the installation of a 200-foot long EHC®-amended permeable reactive barrier (PRB) at a targeted depth of 6 to 35 ft. bgs. Quarterly groundwater sampling was initiated following the EHC® injection. Post-injection groundwater level measurements in the vicinity of the PRB did not indicate any changes to the direction of groundwater flow. Groundwater sampling was reduced to semiannual during 2012.

As part of the *In Situ* Chemical Reduction Pilot Study, five new monitoring wells (Figure 2: YO-117S, YO-117D, YO-118, YO-119, and YO-120) were installed in October 2009.

2.2 ISCR – Phase II

In October 2011, in a letter to USEPA, on behalf of Alcoa, *de maximis* proposed a Phase II to the *in situ* chemical reduction pilot study, with the goal of enhancing the performance of the PRB through application of additional EHC®. The EHC® was to be injected using direct push technology (DPT), with locations spaced closer together as compared to Phase I to ensure creation of a continuous treatment zone. In addition, the barrier would extend further to the west to create a greater influence on the YO-12 well cluster area. The total length of the PRB would be approximately 240 ft. and extend to a depth of 6 to 43 ft. bgs. To address the recent detections of benzene, toluene, ethylbenzene and xylene (BTEX) compounds immediately downgradient of the prior EHC® injection area, *de maximis* recommended that an EHC® product containing a sulfate salt be used to further stimulate the degradation of BTEX by anaerobic oxidation via sulfate reduction.

From October 31 to November 1, 2011, Paragon Environmental Construction, Adventus, *de maximis* and CDM Smith were onsite to perform the Phase II EHC® injection via DPT. Numerous attempts were made to direct push to 43 ft. bgs that were ultimately unsuccessful due to subsurface conditions (cobble layer). One injection point was drilled to depth, but the EHC® could not be injected because the injection tip would not open. Once the injection tip was retrieved it was evident the cobble layer had damaged the injection tip, rendering the rod unusable.

After two field days of unsuccessful attempts, the Phase II EHC® injection was abandoned. Adventus, *de maximis*, Alcoa and CDM Smith decided to explore new avenues for possible EHC® injection in spring 2012. Meanwhile, the December 2011 groundwater sampling round indicated only one well where the OU-1 cleanup standards were exceeded. Based on the difficulties encountered during the October 2011 injection attempt and the subsequent improvements in groundwater quality, semi-annual groundwater monitoring was extended through 2014.

2.3 *In situ* Bioremediation via Enhanced Reductive Dechlorination

On November 6th, 2015, on behalf of Alcoa, *de maximis* proposed a Work Plan to the USEPA to inject LactOil® at the York Oil Superfund Site. The lack of an electron donor was targeted as a limiting factor for successful biodegradation of cDCE. From November through December 2015, five new wells were installed in OU-1. YO-121, YO-122, YO-123, and YO-124 are overburden wells used for injection of LactOil®. YO-125R, a bedrock well, is used for monitoring.

An environmental fracturing process was used to emplace enhanced permeability sand lenses out to a radius of approximately 15 to 20 ft. from the injection boreholes. The permeability enhancement injection process (environmental fracturing) caused a “tensile parting” of the soil to emplace a sand and guar mixture in a planar lens extending out from the injection borehole. Once the guar breaks down or is extracted during well development, the sand-filled lens remains to provide a high permeability injection pathway that can be used multiple times to inject electron donor to sustain a biological treatment zone between OU1 and OU2.

The use of injection wells means that instead of the solid / slurry EHC, a liquid reagent was used. A 5% solution of LactOil® was pumped into the four injection wells, with a total of 5,000 pounds, approximately 1,400 gallons of LactOil® injected using hydraulic fracturing into the subsurface in the fall of 2015. Groundwater monitoring occurred in 2016 and 2017 to evaluate effectiveness of this treatment. The following conclusions were made based on these data:

- *In Situ* Bioremediation Treatment Pilot Study - Results indicate reducing conditions were achieved within the injection zone, and a reduction in cDCE has been observed in downgradient wells with the exception of YO-111D and YO-117D. With the change to more reducing conditions, it appears the environment continues to support enhanced biodegradation of cDCE and VC. In fact, ethene concentrations were at all-time highs in YO-117D in 2017.

- As of the end of 2017, the added electron donor was still providing TOC, desired reducing conditions, and complete reductive dechlorination to ethene.

- Recent OU-1 groundwater results have been below OU-1 ROD standards; therefore, OU-1 groundwater standards have been satisfied. Under the OU-1 ROD and Consent Decree, further treatment is not required.

- Increases in BTEX compounds have been observed at some monitoring wells since the injection of EHC®, most notably at downgradient locations YO-12RX, YO-14X, and YO-117D. Several factors potentially associated with the injections could be causing these conditions, including: enhanced preferential pathways, changes in redox conditions and/or co-solubility. As BTEX compounds are readily aerobically degradable, the extent of these impacts is expected to be very limited once these contaminants have migrated beyond the injection zone.

2.4 *In Situ* Treatment with PlumeStop

While continued degradation of cDCE does not immediately require additional electron donor, we wish to proactively address the increasing BTEX concentrations in the upgradient portion of the OU2 Southern Wetlands. Specifically, we propose to treat cDCE and BTEX in situ using a colloidal liquid activated carbon (LAC) product called "PlumeStop®". The LAC component is primarily intended to target BTEX. CVOCs also sorb to the LAC and both the BTEX and cVOCs are ultimately expected to biodegrade, freeing binding sites for continuing sorption and degradation.

Activated carbon is widely used for a variety of environmental remediation applications because it effectively removes a variety of organic compounds from the water matrix. EPA has recognized this as shown in the attached April 2018 remedial technology fact sheet "Activated Carbon- Based Technology for In Situ Remediation (EPA 542-F-18-001 | April 2018).

PlumeStop liquid activated carbon is an innovative groundwater remediation technology designed to rapidly sorb and degrade contaminants in groundwater through microbial processes. PlumeStop is applied as a solution of very fine particles of activated carbon suspended in water through the use of unique organic polymer dispersion chemistry. Once in the subsurface, the material forms a biomatrix by binding to aquifer material, where it then is expected to rapidly remove contaminants from groundwater and subsequently supports contaminant biodegradation.

This remediation approach accomplishes treatment with the use of highly dispersible, fast-acting, sorption based technology, capturing and concentrating dissolved-phase contaminants within its matrix-like structure. Once contaminants are sorbed onto the regenerative matrix, biodegradation processes achieve complete remediation. This is accomplished by creating a dynamic environment where sorption dominates desorption which allows for a continuous local supply, while present in dissolved and sorbed phase, of organic compounds within the matrix. This creates an ideal environment for local or introduced microbes to be in constant contact with organic contaminants.

Testing by the manufacturer (Regenesis[1]) shows that the carbon in the PlumeStop® becomes bound in the soil matrix within a short distance from the injection area, thus mitigating continued downgradient migration of the sorbed organic compounds. In other words, the PlumeStop® substantially increases the carbon content of the aquifer in the area, enhancing the sorption component of the plume attenuation capacity. Regenesis' product testing also indicates that the carbon provides a medium for enhanced biodegradation of the sorbed VOCs. The continued biodegradation decreases the overall VOC mass on the LAC, freeing carbon binding sites for additional sorption of both VOCs and PFAS.

For this application, the PlumeStop® LAC will be distributed using the existing four injection wells installed in 2015.

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[1] Refer to PlumeStop® product information at https://regenesis.com/.

3. Work Plan Conceptual Approach

As detailed in the attached proposal from Regenesis, they have conceptualized a 120-foot long barrier, with a 20-foot deep vertical treatment interval (from 19 feet below ground surface (BGS) to 39 feet bgs. A total of 8,800 pounds of LAC will be injected, carried in 18,200 gallons of water. The total volume will be evenly divided between the four injection wells, YO-121, YO-122, YO-123 and YO-124.

The LAC / water ratio will likely be adjusted during injection. The expected approach will be an initial application of 60% of the total LAC mass as a high concentration dose, followed by “chasing” that with the remaining 40% of the LAC mass dissolved in significantly more water, which will serve to move the LAC out of the sand zones emplaced during the hydro-fracturing when the injection wells were installed.

LAC injection will be at low-pressure, it will be pumped into the wells at a few gallons per minute per well, sufficient to distribute the reagent into the aquifer formation.

4. Schedule and Reporting

4.1 Schedule and Reporting

Pending USEPA approval, we plan to implement this work in early November. The fall 2018 groundwater sampling round will be conducted in advance of injections and become the “baseline” data for comparison to post-LAC injection. Delivery, mixing, and injection would then be performed as soon as possible following the baseline sampling. It is anticipated that the PlumeStop® LAC injections would occur over a one-week period.

The Spring and Fall 2019 groundwater sampling events will provide data to evaluate the effectiveness of this injection, and results will be documented in the Annual Report.

Tables

Sample ID		**YO-12RX-0418**	**YO-14X-0418**	**YO-14ALX-0418**	**YO-30SX-0418**	**YO-30DX-0418**
Sample Date		**4/26/2018**	**4/25/2018**	**4/25/2018**	**4/24/2018**	**4/24/2018**
Lab Sample ID						
Parameter ID	**Units**					
VOCs						
1,1,1-Trichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,1,2,2-Tetrachloroethane	µg/l	0.5U	0.5U	0.5U	0.5UJ	0.5UJ
1,1,2-Trichloroethane	µg/l	1.5U	1.5U	1.5U	1.5U	1.5U
1,1-Dichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,1-Dichloroethene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
1,2,3-Trichlorobenzene	µg/l	2.5UJ	2.5U	2.5U	2.5U	2.5U
1,2,4-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dibromo-3-chloropropane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dibromoethane	µg/l	2U	2U	2U	2U	2U
1,2-Dichlorobenzene	µg/l	2.5U	1.7J	2.5U	2.5U	2.5U
1,2-Dichloroethane	µg/l	1	0.59	0.56	0.5U	0.5U
1,2-Dichloropropane	µg/l	0.2J	0.47J	1U	1U	1U
1,3-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,4-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,4-Dioxane	µg/l	R	R	R	R	R
2-Butanone	µg/l	5U	5U	5U	5U	5U
2-Hexanone	µg/l	5U	5U	5U	5U	5U
4-Methyl-2-pentanone	µg/l	5U	5U	5U	5U	5U
Acetone	µg/l	5U	5U	5U	5U	5U
Benzene	µg/l	5.8	14	0.76	0.5U	0.5U
Bromochloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Bromodichloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Bromoform	µg/l	2U	2U	2U	2UJ	2UJ
Bromomethane	µg/l	2.5UJ	2.5U	2.5U	2.5U	2.5U
Carbon disulfide	µg/l	5U	5U	5U	5U	5U
Carbon tetrachloride	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Chlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Chloroethane	µg/l	1.3J	2.5U	2.5U	2.5U	2.5U
Chloroform	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Chloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
cis-1,2-Dichloroethene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
cis-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Cyclohexane	µg/l	0.33J	1.9J	10U	10U	10U
Dibromochloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Dichlorodifluoromethane	µg/l	5U	5U	5U	5U	5U
Ethylbenzene	µg/l	2.5U	9.9	2.5U	2.5U	2.5U
Freon-113	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Isopropylbenzene	µg/l	2.5U	1.6J	2.5U	2.5U	2.5U
Methyl Acetate	µg/l	2U	2U	2U	2U	2U
Methyl cyclohexane	µg/l	10U	1.3J	10U	10U	10U
Methyl tert butyl ether	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Methylene chloride	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
o-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
p/m-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Styrene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Tetrachloroethene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Toluene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
trans-1,2-Dichloroethene	µg/l	2.5U	1.3J	2.5U	2.5U	2.5U
trans-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Trichloroethene	µg/l	0.5U	0.3J	0.18J	0.5U	0.5U
Trichlorofluoromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Vinyl chloride	µg/l	1U	0.24J	0.15J	1U	1U
Anions by Ion Chromatography						
Chloride	mg/l	1680	290	39.8	42.2	406
Sulfate	mg/l	58.9	21.8	11.3	20.7	75.2
Dissolved Gases by GC						
Methane	ug/l	1250	9180[1]	15000[1]	---	---
Ethene	ug/l	0.5U	2.44	0.774	---	---
Ethane	ug/l	2.2	3.02	1	---	---
General Chemistry						
Alkalinity, Total	mg CaCO3/L	310	307	378	233	331
Iron, Dissolved	mg/l	0.108UJ	0.0478J-	0.0681J-	0.195J-	0.0764J-
Solids, Total Suspended	mg/l	15	5U	5U	8.3	5U
Nitrogen, Nitrate	mg/l	0.05U	0.05U	0.05U	0.731	0.05U
Total Organic Carbon	mg/l	11.8	12.3	7.98	1.46U	1.01U

Key:
U = Nondetect
J = Estimated
J-= Estimate Biased Low
E=Above Lab Highest Detection Limit
R=Data Rejected
[1] Original test results exceeded lab's highest detection limit, samples were reanalyzed
[2] Sample YO-2509-0418TB was misnamed to YO-2503-0418TB in results from lab. YO-2509-0418TB is depicted on COC
[3] Sample YO-2511-0418TB was misnamed to YO-2502-0418TB in results from lab. YO-2511-0418TB is depicted on COC

Sample ID		YO-56D-0418	YO-56A-0418	YO-57-0418	YO-58-0418	YO-101R-0418
Sample Date		5/1/2018	5/2/2018	5/2/2018	5/2/2018	5/2/2018
Lab Sample ID						
Parameter ID	Units					
VOCs						
1,1,1-Trichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,1,2,2-Tetrachloroethane	µg/l	0.5U	0.5U	0.5U	2.5U	0.5U
1,1,2-Trichloroethane	µg/l	1.5U	1.5U	1.5U	2.5U	1.5U
1,1-Dichloroethane	µg/l	2.5U	2.5U	2.5U	0.5U	2.5U
1,1-Dichloroethene	µg/l	0.5U	0.5U	0.5U	0.29J	0.5U
1,2,3-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	0.5U	2.5U
1,2,4-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	1.5U	2.5U
1,2-Dibromo-3-chloropropane	µg/l	2.5U	2.5U	2.5U	1.7	2.5U
1,2-Dibromoethane	µg/l	2U	2U	2U	2.5U	2U
1,2-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dichloroethane	µg/l	0.17J	0.5U	0.5U	5U	0.5U
1,2-Dichloropropane	µg/l	1U	1U	1U	2.5U	1U
1,3-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	0.5U	2.5U
1,4-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	0.5U	2.5U
1,4-Dioxane	µg/l	R	R	R	R	R
2-Butanone	µg/l	5U	5U	5U	2U	5U
2-Hexanone	µg/l	5U	5U	5U	0.5U	5U
4-Methyl-2-pentanone	µg/l	5U	5U	5U	5U	5U
Acetone	µg/l	5U	5U	1.8J	5U	1.7J
Benzene	µg/l	1.4	0.5U	0.5U	8.4	0.5U
Bromochloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Bromodichloromethane	µg/l	0.5U	0.5U	0.5U	2.5U	0.5U
Bromoform	µg/l	2U	2U	2U	2.5U	2U
Bromomethane	µg/l	2.5U	2.5UJ	2.5UJ	2.5UJ	2.5UJ
Carbon disulfide	µg/l	5U	5U	5U	0.5U	5U
Carbon tetrachloride	µg/l	0.5U	0.5U	0.5U	0.77J	0.5U
Chlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Chloroethane	µg/l	0.77J	2.5U	2.5U	2.5U	2.5U
Chloroform	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Chloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
cis-1,2-Dichloroethene	µg/l	1J	2.5U	2.5U	2.5U	2.2J
cis-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	2.5U	0.5U
Cyclohexane	µg/l	10U	10U	10U	2.5U	10U
Dibromochloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Dichlorodifluoromethane	µg/l	5U	5U	5U	2.5U	5U
Ethylbenzene	µg/l	2.5U	2.5U	2.5U	5U	2.5U
Freon-113	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Isopropylbenzene	µg/l	2.5U	2.5U	2.5U	5U	2.5U
Methyl Acetate	µg/l	2U	2U	2U	0.5U	2U
Methyl cyclohexane	µg/l	10U	10U	10U	0.24J	10U
Methyl tert butyl ether	µg/l	2.5U	2.5U	2.5U	5U	2.5U
Methylene chloride	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
o-Xylene	µg/l	2.5U	2.5U	2.5U	2U	2.5U
p/m-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Styrene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Tetrachloroethene	µg/l	0.5U	0.5U	0.5U	2.5U	0.5U
Toluene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
trans-1,2-Dichloroethene	µg/l	2.5U	2.5U	2.5U	2U	2.5U
trans-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.31J	0.5U
Trichloroethene	µg/l	0.5U	0.5U	0.5U	250U	0.5U
Trichlorofluoromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Vinyl chloride	µg/l	0.39J	0.18J	1U	10U	0.6J
Anions by Ion Chromatography						
Chloride	mg/l	1910	594	1400	2230	1300
Sulfate	mg/l	41	16.6	30.4	25.6	24.6
Dissolved Gases by GC						
Methane	ug/l	1170	---	---	---	---
Ethene	ug/l	0.54	---	---	---	---
Ethane	ug/l	0.986	---	---	---	---
General Chemistry						
Alkalinity, Total	mg CaCO3/L	280	314	165	304	173
Iron, Dissolved	mg/l	0.05UJ	0.05UJ	0.05UJ	0.0193UJ	0.05UJ
Solids, Total Suspended	mg/l	9.1	6.8	5.4	18	5U
Nitrogen, Nitrate	mg/l	0.05U	0.05U	0.05U	0.05U	0.05U
Total Organic Carbon	mg/l	1.89	12.7	5.78	18.3	5.91

Key:
U = Nondetect
J = Estimated
J-= Estimate Biased Low
E=Above Lab Highest Detection Limit
R=Data Rejected
[1] Original test results exceeded lab's highest detection limit, samples were reanalyzed
[2] Sample YO-2509-0418TB was misnamed to YO-2503-0418TB in results from lab. YO-2509-0418TB is depicted on COC
[3] Sample YO-2511-0418TB was misnamed to YO-2502-0418TB in results from lab. YO-2511-0418TB is depicted on COC

Sample ID **Sample Date** **Lab Sample ID** **Parameter ID**	**Units**	**YO-102R-0418** **4/24/2018**	**YO-110S-0418** **4/24/2018**	**YO-110D-0418** **4/24/2018**	**YO-111D-0418** **5/1/2018**	**YO-112D-0418** **5/1/2018**
VOCs						
1,1,1-Trichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,1,2,2-Tetrachloroethane	µg/l	0.5UJ	0.5UJ	0.5UJ	0.5U	0.5U
1,1,2-Trichloroethane	µg/l	1.5U	1.5U	1.5U	1.5U	1.5U
1,1-Dichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,1-Dichloroethene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
1,2,3-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2,4-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dibromo-3-chloropropane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dibromoethane	µg/l	2U	2U	2U	2U	2U
1,2-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dichloroethane	µg/l	0.62	0.5U	0.5U	0.31J	0.5U
1,2-Dichloropropane	µg/l	1U	1U	1U	1U	1U
1,3-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,4-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,4-Dioxane	µg/l	R	R	R	R	R
2-Butanone	µg/l	5U	5U	5U	5U	5U
2-Hexanone	µg/l	5U	5U	5U	5U	5U
4-Methyl-2-pentanone	µg/l	5U	5U	5U	5U	5U
Acetone	µg/l	5U	5U	5U	5U	5U
Benzene	µg/l	2.4	0.29J	0.5U	0.52	0.5U
Bromochloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Bromodichloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Bromoform	µg/l	2UJ	2UJ	2UJ	2U	2U
Bromomethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Carbon disulfide	µg/l	5U	5U	5U	5U	5U
Carbon tetrachloride	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Chlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Chloroethane	µg/l	0.82J	2.5U	2.5U	2.5U	2.5U
Chloroform	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Chloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
cis-1,2-Dichloroethene	µg/l	2.5U	5.7	2.5U	32	2.5U
cis-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Cyclohexane	µg/l	10U	10U	10U	10U	10U
Dibromochloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Dichlorodifluoromethane	µg/l	5U	5U	5U	5U	5U
Ethylbenzene	µg/l	2.5U	1.5J	2.5U	2.5U	2.5U
Freon-113	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Isopropylbenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Methyl Acetate	µg/l	2U	2U	2U	2U	2U
Methyl cyclohexane	µg/l	10U	10U	10U	10U	10U
Methyl tert butyl ether	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Methylene chloride	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
o-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
p/m-Xylene	µg/l	2.5U	0.85J	2.5U	2.5U	2.5U
Styrene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Tetrachloroethene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Toluene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
trans-1,2-Dichloroethene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
trans-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Trichloroethene	µg/l	0.5U	0.27J	0.5U	0.5U	0.5U
Trichlorofluoromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Vinyl chloride	µg/l	0.13J	1U	1U	3.6	1U
Anions by Ion Chromatography						
Chloride	mg/l	3110	221	672	3520	74.5
Sulfate	mg/l	51.4	16	33.8	17.5	17.2
Dissolved Gases by GC						
Methane	ug/l	---	---	---	442	---
Ethene	ug/l	---	---	---	1.32	---
Ethane	ug/l	---	---	---	0.5U	---
General Chemistry						
Alkalinity, Total	mg CaCO3/L	289	381	338	169	199
Iron, Dissolved	mg/l	0.267J-	0.221J-	0.05UJ	0.142UJ	0.0337J
Solids, Total Suspended	mg/l	12	18	5U	20	5U
Nitrogen, Nitrate	mg/l	0.5U	0.05U	0.05U	0.05U	0.05U
Total Organic Carbon	mg/l	11.2	15.9	1.83U	0.95J	3.88

Key:
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J-= Estimate Biased Low
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R=Data Rejected

[1] Original test results exceeded lab's highest detection limit, samples were reanalyzed
[2] Sample YO-2509-0418TB was misnamed to YO-2503-0418TB in results from lab. YO-2509-0418TB is depicted on COC
[3] Sample YO-2511-0418TB was misnamed to YO-2502-0418TB in results from lab. YO-2511-0418TB is depicted on COC

Sample ID **Sample Date** **Lab Sample ID** **Parameter ID**	**Units**	**YO-113D-0418** **5/1/2018**	**YO-114R-0418** **5/1/2018**	**YO-115R-0418** **4/24/2018**	**YO-116S-0418** **4/26/2018**	**YO-116D-0418** **4/26/2018**
VOCs						
1,1,1-Trichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,1,2,2-Tetrachloroethane	µg/l	0.5U	0.5U	0.5UJ	0.5U	0.5U
1,1,2-Trichloroethane	µg/l	1.5U	1.5U	1.5U	1.5U	1.5U
1,1-Dichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,1-Dichloroethene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
1,2,3-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5UJ
1,2,4-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dibromo-3-chloropropane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dibromoethane	µg/l	2U	2U	2U	2U	2U
1,2-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,2-Dichloroethane	µg/l	0.26J	0.5U	0.5U	0.5U	0.5U
1,2-Dichloropropane	µg/l	1U	1U	1U	1U	1U
1,3-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,4-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
1,4-Dioxane	µg/l	R	R	R	R	R
2-Butanone	µg/l	5U	5U	5U	5U	5U
2-Hexanone	µg/l	5U	5U	5U	5U	5U
4-Methyl-2-pentanone	µg/l	5U	5U	5U	5U	5U
Acetone	µg/l	1.5J	5U	5U	5U	5U
Benzene	µg/l	1.7	0.5U	0.5U	0.5U	0.5U
Bromochloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Bromodichloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Bromoform	µg/l	2U	2U	2UJ	2U	2U
Bromomethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5UJ
Carbon disulfide	µg/l	5U	5U	5U	5U	5U
Carbon tetrachloride	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Chlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Chloroethane	µg/l	1J	2.5U	2.5U	2.5U	2.5U
Chloroform	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Chloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
cis-1,2-Dichloroethene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
cis-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Cyclohexane	µg/l	10U	10U	10U	10U	10U
Dibromochloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Dichlorodifluoromethane	µg/l	5U	5U	5U	5U	5U
Ethylbenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Freon-113	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Isopropylbenzene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Methyl Acetate	µg/l	2U	2U	2U	2U	2U
Methyl cyclohexane	µg/l	10U	10U	10U	10U	10U
Methyl tert butyl ether	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Methylene chloride	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
o-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
p/m-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Styrene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Tetrachloroethene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Toluene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
trans-1,2-Dichloroethene	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
trans-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Trichloroethene	µg/l	0.5U	0.5U	0.5U	0.5U	0.5U
Trichlorofluoromethane	µg/l	2.5U	2.5U	2.5U	2.5U	2.5U
Vinyl chloride	µg/l	0.15J	1U	1U	1U	1U
Anions by Ion Chromatography						
Chloride	mg/l	1980	461	4780	60.7	150
Sulfate	mg/l	25.6	13.6	32	4.82	9.64
Dissolved Gases by GC						
Methane	ug/l	---	---	---	---	---
Ethene	ug/l	---	---	---	---	---
Ethane	ug/l	---	---	---	---	---
General Chemistry						
Alkalinity, Total	mg CaCO3/L	304	199	164	456	426
Iron, Dissolved	mg/l	0.05UJ	0.05UJ	5.94J-	0.222J-	0.05UJ
Solids, Total Suspended	mg/l	6.5	5U	10	16	5U
Nitrogen, Nitrate	mg/l	0.05U	0.05U	0.05U	0.05U	0.05U
Total Organic Carbon	mg/l	2.56	3.84	3.58J	19.6	14.5

Key:
ND = Nondetect
J = Estimated
J-= Estimate Biased Low
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R=Data Rejected
[1] Original test results exceeded lab's highest detection limit, samples were reanalyzed
[2] Sample YO-2509-0418TB was misnamed to YO-2503-0418TB in results from lab. YO-2509-0418TB is depicted on COC
[3] Sample YO-2511-0418TB was misnamed to YO-2502-0418TB in results from lab. YO-2511-0418TB is depicted on COC

Sample ID **Sample Date** **Lab Sample ID** **Parameter ID**	**Units**	**YO-116R-0418** **4/26/2018**	**YO-117S-0418** **4/25/2018**	**YO-117D-0418** **4/25/2018**	**YO-118-0418** **4/25/2018**	**YO-119-0418** **4/25/2018**
VOCs						
1,1,1-Trichloroethane	µg/l	2.5U	2.5U	5U	2.5U	2.5U
1,1,2,2-Tetrachloroethane	µg/l	0.5U	0.5U	1U	0.5U	0.5U
1,1,2-Trichloroethane	µg/l	1.5U	1.5U	3U	1.5U	1.5U
1,1-Dichloroethane	µg/l	2.5U	2.5U	2.5J	2.5U	2.5U
1,1-Dichloroethene	µg/l	0.5U	0.5U	1U	0.5U	0.5U
1,2,3-Trichlorobenzene	µg/l	2.5UJ	2.5UJ	5UJ	2.5U	2.5U
1,2,4-Trichlorobenzene	µg/l	2.5U	2.5U	5U	2.5U	2.5U
1,2-Dibromo-3-chloropropane	µg/l	2.5U	2.5U	5U	2.5U	2.5U
1,2-Dibromoethane	µg/l	2U	2U	4U	2U	2U
1,2-Dichlorobenzene	µg/l	2.5U	2.5U	2.7J	2.5U	2.5U
1,2-Dichloroethane	µg/l	0.5U	1.5	11	0.5U	0.5U
1,2-Dichloropropane	µg/l	1U	0.33J	2.4	1U	1U
1,3-Dichlorobenzene	µg/l	2.5U	2.5U	5U	2.5U	2.5U
1,4-Dichlorobenzene	µg/l	2.5U	2.5U	5U	2.5U	2.5U
1,4-Dioxane	µg/l	R	R	R	R	R
2-Butanone	µg/l	2.6J	5U	10U	5U	5U
2-Hexanone	µg/l	5U	5U	10U	5U	5U
4-Methyl-2-pentanone	µg/l	5U	5U	10U	5U	5U
Acetone	µg/l	1.6J	5U	14	5U	1.6J
Benzene	µg/l	0.5U	9.4	55	0.5U	0.5
Bromochloromethane	µg/l	2.5U	2.5U	5U	2.5U	2.5U
Bromodichloromethane	µg/l	0.5U	0.5U	1U	0.5U	0.5U
Bromoform	µg/l	2U	2U	4U	2U	2U
Bromomethane	µg/l	2.5UJ	2.5UJ	5UJ	2.5U	2.5U
Carbon disulfide	µg/l	5U	5U	10U	5U	5U
Carbon tetrachloride	µg/l	0.5U	0.5U	1U	0.5U	0.5U
Chlorobenzene	µg/l	2.5U	2.5U	5U	2.5U	2.5U
Chloroethane	µg/l	2.5U	2.5U	5U	2.5U	2.5U
Chloroform	µg/l	2.5U	2.5U	5U	2.5U	2.5U
Chloromethane	µg/l	2.5U	2.5U	5U	2.5U	2.5U
cis-1,2-Dichloroethene	µg/l	2.5U	19	5.3	2.5U	1.6J
cis-1,3-Dichloropropene	µg/l	0.5U	0.5U	1U	0.5U	0.5U
Cyclohexane	µg/l	10U	0.51J	2.4J	10U	10U
Dibromochloromethane	µg/l	0.5U	0.5U	1U	0.5U	0.5U
Dichlorodifluoromethane	µg/l	5U	5U	10U	5U	5U
Ethylbenzene	µg/l	2.5U	5.4	34	2.5U	2.5U
Freon-113	µg/l	2.5U	2.5U	5U	2.5U	2.5U
Isopropylbenzene	µg/l	2.5U	2.5U	2.1J	2.5U	2.5U
Methyl Acetate	µg/l	2U	2U	4U	2U	2U
Methyl cyclohexane	µg/l	10U	10U	1.2J	10U	10U
Methyl tert butyl ether	µg/l	2.5U	2.5U	5U	2.5U	2.5U
Methylene chloride	µg/l	2.5U	2.5U	5U	2.5U	2.5U
o-Xylene	µg/l	2.5U	2.5U	38	2.5U	2.5U
p/m-Xylene	µg/l	2.5U	2.7	74	2.5U	2.5U
Styrene	µg/l	2.5U	2.5U	5U	2.5U	2.5U
Tetrachloroethene	µg/l	0.5U	0.5U	1U	0.5U	0.5U
Toluene	µg/l	0.73J	1.8J	160	2.5U	2.5U
trans-1,2-Dichloroethene	µg/l	2.5U	1.1J	4.9J	2.5U	2.5U
trans-1,3-Dichloropropene	µg/l	0.5U	0.5U	1U	0.5U	0.5U
Trichloroethene	µg/l	0.5U	0.36J	0.61J	0.5U	0.26J
Trichlorofluoromethane	µg/l	2.5U	2.5U	5U	2.5U	2.5U
Vinyl chloride	µg/l	1U	16	5.2	0.3J	1.7
Anions by Ion Chromatography						
Chloride	mg/l	9710	390	1960	4.02	12.4
Sulfate	mg/l	1.63	4.24	4.64	27	3.96
Dissolved Gases by GC						
Methane	ug/l	---	11100[1]	8800[1]	26.6U	2500
Ethene	ug/l	---	34.9	213	0.5UJ	2.44
Ethane	ug/l	---	15.4	22.5	0.5UJ	1.41
General Chemistry						
Alkalinity, Total	mg CaCO3/L	306	368	359	230J-	194
Iron, Dissolved	mg/l	0.036UJ	0.0522UJ	0.106UJ	0.0324J-	0.38J-
Solids, Total Suspended	mg/l	8.1	36	30	5U	15
Nitrogen, Nitrate	mg/l	0.05U	0.05U	0.05U	0.182	0.05U
Total Organic Carbon	mg/l	19.3J	22.2	34.6	1.99	10.5

Key:
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J-= Estimate Biased Low
E=Above Lab Highest Detection Limit
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[1] Original test results exceeded lab's highest detection limit, samples were reanalyzed
[2] Sample YO-2509-0418TB was misnamed to YO-2503-0418TB in results from lab. YO-2509-0418TB is depicted on COC
[3] Sample YO-2511-0418TB was misnamed to YO-2502-0418TB in results from lab. YO-2511-0418TB is depicted on COC

Sample ID Sample Date Lab Sample ID Parameter ID	Units	YO-120-0418 4/25/2018	YO-125R-0418 4/24/2018	YO-2500-0418 FD 4/25/2018	YO-2501-0418 FD 5/1/2018	YO-2502-0418 FBW 4/24/2018
VOCs						
1,1,1-Trichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U	---
1,1,2,2-Tetrachloroethane	µg/l	0.5U	0.5UJ	0.5U	0.5U	---
1,1,2-Trichloroethane	µg/l	1.5U	1.5U	1.5U	1.5U	---
1,1-Dichloroethane	µg/l	0.76J	2.5U	2.5U	2.5U	---
1,1-Dichloroethene	µg/l	0.5U	0.5U	0.5U	0.5U	---
1,2,3-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	---
1,2,4-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	---
1,2-Dibromo-3-chloropropane	µg/l	2.5U	2.5U	2.5U	2.5U	---
1,2-Dibromoethane	µg/l	2U	2U	2U	2U	---
1,2-Dichlorobenzene	µg/l	2.5U	2.5U	1.7J	2.5U	---
1,2-Dichloroethane	µg/l	0.32J	0.59	0.6	0.27J	---
1,2-Dichloropropane	µg/l	1U	1U	0.47J	1U	---
1,3-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	---
1,4-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	---
1,4-Dioxane	µg/l	R	R	R	R	---
2-Butanone	µg/l	5U	5U	5U	5U	---
2-Hexanone	µg/l	5U	5U	5U	5U	---
4-Methyl-2-pentanone	µg/l	5U	5U	5U	5U	---
Acetone	µg/l	5U	5U	5U	298	---
Benzene	µg/l	3.2	2.5	14	1.6	---
Bromochloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	---
Bromodichloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	---
Bromoform	µg/l	2U	2UJ	2U	2U	---
Bromomethane	µg/l	2.5U	2.5U	2.5U	2.5U	---
Carbon disulfide	µg/l	5U	5U	5U	5U	---
Carbon tetrachloride	µg/l	0.5U	0.5U	0.5U	0.5U	---
Chlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U	---
Chloroethane	µg/l	2.5U	0.81J	2.5U	0.97J	---
Chloroform	µg/l	2.5U	2.5U	2.5U	2.5U	---
Chloromethane	µg/l	2.5U	2.5U	2.5U	2.5U	---
cis-1,2-Dichloroethene	µg/l	1.8J	2.5U	2.5U	2.5U	---
cis-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U	---
Cyclohexane	µg/l	0.42J	10U	1.9J	10U	---
Dibromochloromethane	µg/l	0.5U	0.5U	0.5U	0.5U	---
Dichlorodifluoromethane	µg/l	5U	5U	5U	5U	---
Ethylbenzene	µg/l	2.5U	2.5U	10	2.5U	---
Freon-113	µg/l	2.5U	2.5U	2.5U	2.5U	---
Isopropylbenzene	µg/l	2.5U	2.5U	1.6J	2.5U	---
Methyl Acetate	µg/l	2U	2U	2U	2U	---
Methyl cyclohexane	µg/l	10U	10U	1.2J	10U	---
Methyl tert butyl ether	µg/l	2.5U	2.5U	2.5U	2.5U	---
Methylene chloride	µg/l	2.5U	2.5U	2.5U	2.5U	---
o-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U	---
p/m-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U	---
Styrene	µg/l	2.5U	2.5U	2.5U	2.5U	---
Tetrachloroethene	µg/l	0.31J	0.5U	0.5U	0.5U	---
Toluene	µg/l	2.5U	2.5U	2.5U	2.5U	---
trans-1,2-Dichloroethene	µg/l	2.5U	2.5U	1.4J	2.5U	---
trans-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U	---
Trichloroethene	µg/l	0.96	0.5U	0.31J	0.5U	---
Trichlorofluoromethane	µg/l	2.5U	2.5U	2.5U	2.5U	---
Vinyl chloride	µg/l	0.26J	0.14J	0.25J	0.16J	---
Anions by Ion Chromatography						
Chloride	mg/l	1.95	1510	288	1980	0.178J
Sulfate	mg/l	13.3	18.7	21.9	25.6	0.18J
Dissolved Gases by GC						
Methane	ug/l	4710	1160	9810[1]	---	37.3
Ethene	ug/l	17.6	0.759	2.89	---	0.5U
Ethane	ug/l	1.14	4.04	3.18	---	0.5U
General Chemistry						
Alkalinity, Total	mg CaCO3/L	317	289	316	298	2U
Iron, Dissolved	mg/l	0.11J-	0.124J-	0.127J-	0.05J-	0.05UJ
Solids, Total Suspended	mg/l	22	5.1	5.8	5U	5U
Nitrogen, Nitrate	mg/l	0.05U	0.05U	0.05U	0.05U	0.05U
Total Organic Carbon	mg/l	15.8	11	12.4	2.66	0.37J

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[3] Sample YO-2511-0418TB was misnamed to YO-2502-0418TB in results from lab. YO-2511-0418TB is depicted on COC

Sample ID		**YO-2503-0418 FBW**	**YO-2504-0418 FBW**	**YO-2505-0418 FBW**	**YO-2506-0418 FBW**	**YO-2508-0418 TB**
Sample Date		**4/25/2018**	**4/26/2018**	**5/1/2018**	**5/2/2018**	**4/24/2018**
Lab Sample ID						
Parameter ID	**Units**					
VOCs						
1,1,1-Trichloroethane	µg/l	---	---	---	---	2.5U
1,1,2,2-Tetrachloroethane	µg/l	---	---	---	---	0.5UJ
1,1,2-Trichloroethane	µg/l	---	---	---	---	1.5U
1,1-Dichloroethane	µg/l	---	---	---	---	2.5U
1,1-Dichloroethene	µg/l	---	---	---	---	0.5U
1,2,3-Trichlorobenzene	µg/l	---	---	---	---	2.5U
1,2,4-Trichlorobenzene	µg/l	---	---	---	---	2.5U
1,2-Dibromo-3-chloropropane	µg/l	---	---	---	---	2.5U
1,2-Dibromoethane	µg/l	---	---	---	---	2U
1,2-Dichlorobenzene	µg/l	---	---	---	---	2.5U
1,2-Dichloroethane	µg/l	---	---	---	---	0.5U
1,2-Dichloropropane	µg/l	---	---	---	---	1U
1,3-Dichlorobenzene	µg/l	---	---	---	---	2.5U
1,4-Dichlorobenzene	µg/l	---	---	---	---	2.5U
1,4-Dioxane	µg/l	---	---	---	---	R
2-Butanone	µg/l	---	---	---	---	5U
2-Hexanone	µg/l	---	---	---	---	5U
4-Methyl-2-pentanone	µg/l	---	---	---	---	5U
Acetone	µg/l	---	---	---	---	5U
Benzene	µg/l	---	---	---	---	0.5U
Bromochloromethane	µg/l	---	---	---	---	2.5U
Bromodichloromethane	µg/l	---	---	---	---	0.5U
Bromoform	µg/l	---	---	---	---	2UJ
Bromomethane	µg/l	---	---	---	---	2.5U
Carbon disulfide	µg/l	---	---	---	---	5U
Carbon tetrachloride	µg/l	---	---	---	---	0.5U
Chlorobenzene	µg/l	---	---	---	---	2.5U
Chloroethane	µg/l	---	---	---	---	2.5U
Chloroform	µg/l	---	---	---	---	2.5U
Chloromethane	µg/l	---	---	---	---	2.5U
cis-1,2-Dichloroethene	µg/l	---	---	---	---	2.5U
cis-1,3-Dichloropropene	µg/l	---	---	---	---	0.5U
Cyclohexane	µg/l	---	---	---	---	10U
Dibromochloromethane	µg/l	---	---	---	---	0.5U
Dichlorodifluoromethane	µg/l	---	---	---	---	5U
Ethylbenzene	µg/l	---	---	---	---	2.5U
Freon-113	µg/l	---	---	---	---	2.5U
Isopropylbenzene	µg/l	---	---	---	---	2.5U
Methyl Acetate	µg/l	---	---	---	---	2U
Methyl cyclohexane	µg/l	---	---	---	---	10U
Methyl tert butyl ether	µg/l	---	---	---	---	2.5U
Methylene chloride	µg/l	---	---	---	---	2.5U
o-Xylene	µg/l	---	---	---	---	2.5U
p/m-Xylene	µg/l	---	---	---	---	2.5U
Styrene	µg/l	---	---	---	---	2.5U
Tetrachloroethene	µg/l	---	---	---	---	0.5U
Toluene	µg/l	---	---	---	---	2.5U
trans-1,2-Dichloroethene	µg/l	---	---	---	---	2.5U
trans-1,3-Dichloropropene	µg/l	---	---	---	---	0.5U
Trichloroethene	µg/l	---	---	---	---	0.5U
Trichlorofluoromethane	µg/l	---	---	---	---	2.5U
Vinyl chloride	µg/l	---	---	---	---	1U
Anions by Ion Chromatography						
Chloride	mg/l	0.5U	0.5U	0.5U	0.5U	---
Sulfate	mg/l	1U	0.225J	1U	1U	---
Dissolved Gases by GC						
Methane	ug/l	75.6	2.53J	2.75J	---	---
Ethene	ug/l	0.5U	0.5U	0.5U	---	---
Ethane	ug/l	0.5U	0.5U	0.5U	---	---
General Chemistry						
Alkalinity, Total	mg CaCO3/L	2U	2U	2.1	2U	---
Iron, Dissolved	mg/l	0.05UJ	0.05UJ	0.05UJ	0.05UJ	
Solids, Total Suspended	mg/l	5U	5U	5U	5U	---
Nitrogen, Nitrate	mg/l	0.05U	0.05U	0.05U	0.05U	---
Total Organic Carbon	mg/l	0.17J	0.49J	0.13J	0.43J	---

Key:
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J = Estimated
J-= Estimate Biased Low
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[3]Sample YO-2511-0418TB was misnamed to YO-2502-0418TB in results from lab. YO-2511-0418TB is depicted on COC

Sample ID **Sample Date** **Lab Sample ID** **Parameter ID**	**Units**	**YO-2503-0418 TB[2]** **4/25/2018**	**YO-2510-0418TB** **4/26/2018**	**YO-2502-0418TB[3]** **5/1/2018**	**YO-2512-0418TB** **5/2/2018**
VOCs					
1,1,1-Trichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U
1,1,2,2-Tetrachloroethane	µg/l	0.5U	0.5U	0.5U	0.5U
1,1,2-Trichloroethane	µg/l	1.5U	1.5U	1.5U	1.5U
1,1-Dichloroethane	µg/l	2.5U	2.5U	2.5U	2.5U
1,1-Dichloroethene	µg/l	0.5U	0.5U	0.5U	0.5U
1,2,3-Trichlorobenzene	µg/l	2.5U	2.5UJ	2.5U	2.5U
1,2,4-Trichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U
1,2-Dibromo-3-chloropropane	µg/l	2.5U	2.5U	2.5U	2.5U
1,2-Dibromoethane	µg/l	2U	2U	2U	2U
1,2-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U
1,2-Dichloroethane	µg/l	0.5U	0.5U	0.5U	0.5U
1,2-Dichloropropane	µg/l	1U	1U	1U	1U
1,3-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U
1,4-Dichlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U
1,4-Dioxane	µg/l	R	R	R	R
2-Butanone	µg/l	5U	5U	5U	5U
2-Hexanone	µg/l	5U	5U	5U	5U
4-Methyl-2-pentanone	µg/l	5U	5U	5U	5U
Acetone	µg/l	1.9J	5U	5U	5U
Benzene	µg/l	0.5U	0.5U	0.5U	0.5U
Bromochloromethane	µg/l	2.5U	2.5U	2.5U	2.5U
Bromodichloromethane	µg/l	0.5U	0.5U	0.5U	0.5U
Bromoform	µg/l	2U	2U	2U	2U
Bromomethane	µg/l	2.5U	2.5UJ	2.5U	2.5UJ
Carbon disulfide	µg/l	5U	5U	5U	5U
Carbon tetrachloride	µg/l	0.5U	0.5U	0.5U	0.5U
Chlorobenzene	µg/l	2.5U	2.5U	2.5U	2.5U
Chloroethane	µg/l	2.5U	2.5U	2.5U	2.5U
Chloroform	µg/l	2.5U	2.5U	2.5U	2.5U
Chloromethane	µg/l	2.5U	2.5U	2.5U	2.5U
cis-1,2-Dichloroethene	µg/l	2.5U	2.5U	2.5U	2.5U
cis-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U
Cyclohexane	µg/l	10U	10U	10U	10U
Dibromochloromethane	µg/l	0.5U	0.5U	0.5U	0.5U
Dichlorodifluoromethane	µg/l	5U	5U	5U	5U
Ethylbenzene	µg/l	2.5U	2.5U	2.5U	2.5U
Freon-113	µg/l	2.5U	2.5U	2.5U	2.5U
Isopropylbenzene	µg/l	2.5U	2.5U	2.5U	2.5U
Methyl Acetate	µg/l	2U	2U	2U	2U
Methyl cyclohexane	µg/l	10U	10U	10U	10U
Methyl tert butyl ether	µg/l	2.5U	2.5U	2.5U	2.5U
Methylene chloride	µg/l	2.5U	2.5U	2.5U	2.5U
o-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U
p/m-Xylene	µg/l	2.5U	2.5U	2.5U	2.5U
Styrene	µg/l	2.5U	2.5U	2.5U	2.5U
Tetrachloroethene	µg/l	0.5U	0.5U	0.5U	0.5U
Toluene	µg/l	2.5U	2.5U	2.5U	2.5U
trans-1,2-Dichloroethene	µg/l	2.5U	2.5U	2.5U	2.5U
trans-1,3-Dichloropropene	µg/l	0.5U	0.5U	0.5U	0.5U
Trichloroethene	µg/l	0.5U	0.5U	0.5U	0.5U
Trichlorofluoromethane	µg/l	2.5U	2.5U	2.5U	2.5U
Vinyl chloride	µg/l	1U	1U	1U	1U
Anions by Ion Chromatography					
Chloride	mg/l	---	---	---	---
Sulfate	mg/l	---	---	---	---
Dissolved Gases by GC					
Methane	ug/l	---	---	---	---
Ethene	ug/l	---	---	---	---
Ethane	ug/l	---	---	---	---
General Chemistry					
Alkalinity, Total	mg CaCO3/L	---	---	---	---
Iron, Dissolved	mg/l				
Solids, Total Suspended	mg/l	---	---	---	---
Nitrogen, Nitrate	mg/l	---	---	---	---
Total Organic Carbon	mg/l	---	---	---	---

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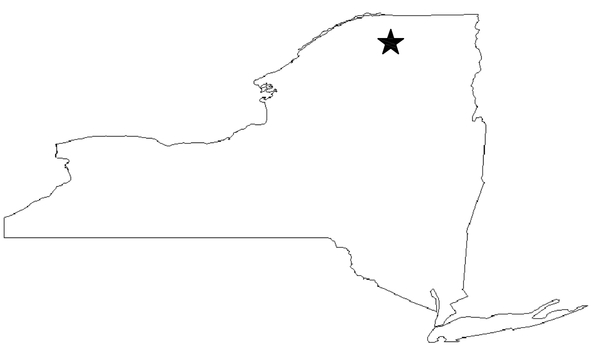
[3] Sample YO-2511-0418TB was misnamed to YO-2502-0418TB in results from lab. YO-2511-0418TB is depicted on COC

Figures



SITE LOCATION MAP

IMAGE SOURCE: GOOGLE EARTH 2016

1" = 1200'

600 0 1200

York Oil Superfund Site - Moira, New York

CDM Smith

Figure 1
York Oil Site Location Map

XREFs: [F11x8.5] Images: [NY_1, YORK OIL LOCATION MAP]
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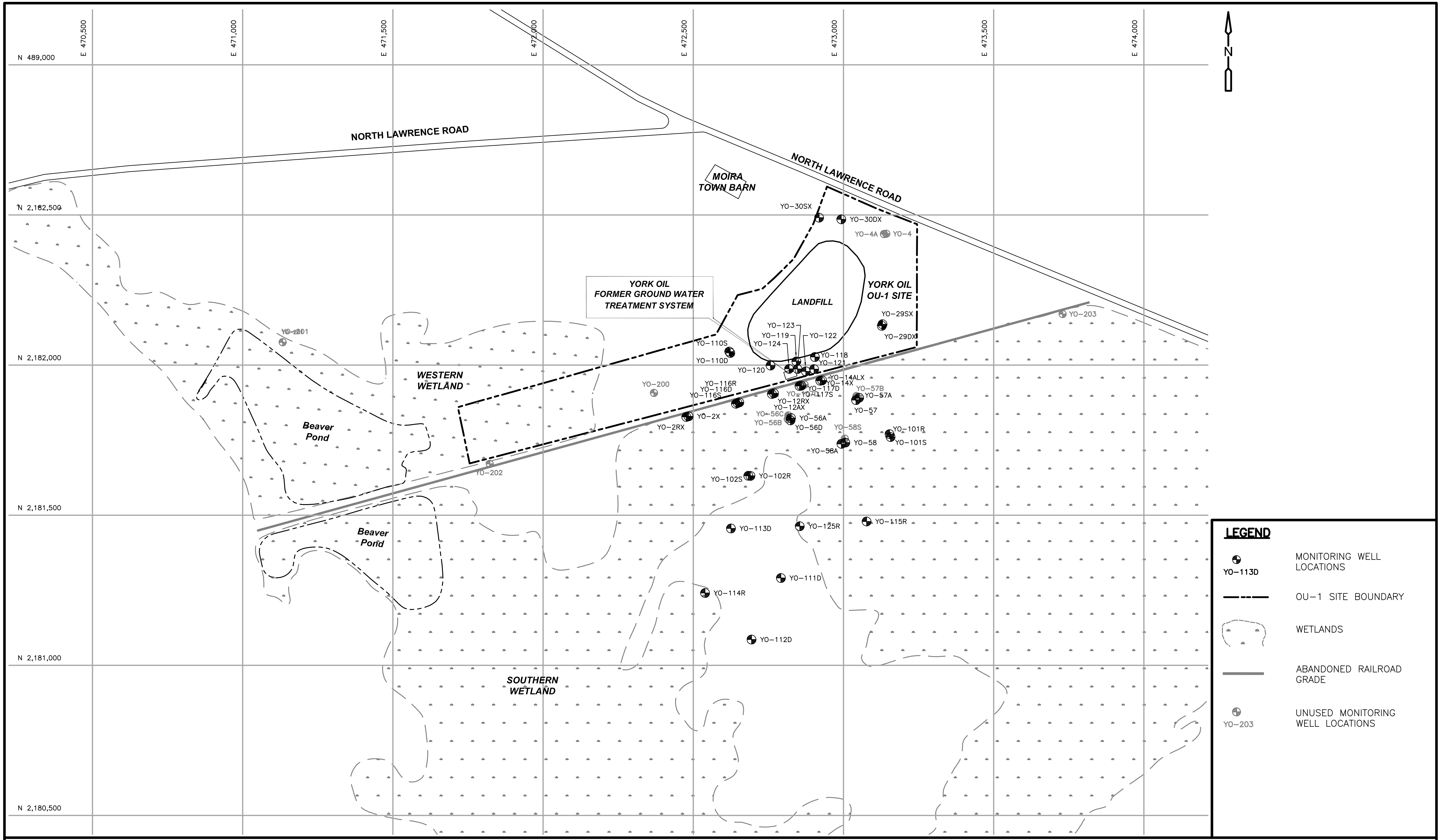

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pw:\\dacpwapp1:PW_XM1\1902\84379\03 Reports and Studies\09 CADD Figures and Graphics\FIG 1-2.dwg

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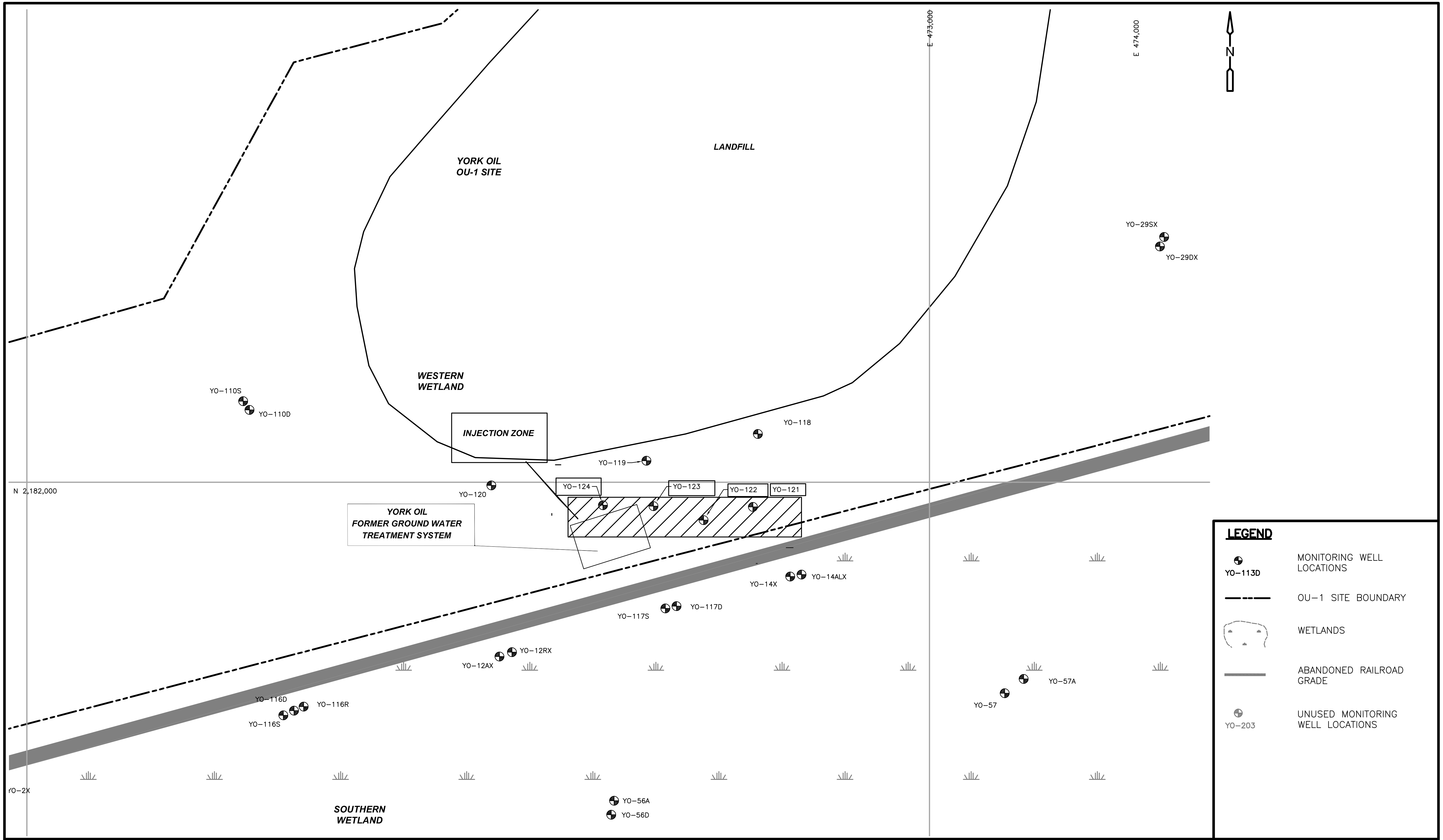
1" = 300'
150 0 300

York Oil Superfund Site - Moira, New York

Figure 2
Overburden Monitoring Well Locations



CDM
Smith

1" = 50'

25 0 50

York Oil Superfund Site - Moira, New York

FIGURE 3
PILOT STUDY AREA DETAILS

XREFs: [site map, F11X17] Images: [e_04682180_24_14400_clr_2003_1]
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Appendix A

EPA Fact Sheet

EPA 542-F-18-001 | April 2018

United States
Environmental Protection
Agency

Remedial Technology Fact Sheet – Activated Carbon-Based Technology for In Situ Remediation

At a Glance

- An emerging remedial technology combining adsorption by activated carbon (AC) and degradation by reactive amendments.
- Several commercial products of various AC particle size and different amendments.
- Synergy between adsorption and degradation for treating chlorinated solvents and petroleum hydrocarbons.
- Applied to treat plumes but also residual source in low-permeability zones.
- Primarily uses direct push injection, including high-pressure in low-permeability zones for granular AC- and powdered AC-based products and low pressure for colloidal AC-based products in high-permeability zones. Injection well has also been used for delivering colloidal AC-based products.
- Requires adequate characterization (i.e., a high-resolution conceptual site model (CSM)) for effective remedial design.
- Adsorption to AC results in rapid concentration reduction in aqueous phase after injection.
- Rebound may occur due to greater contaminant influx than the rate of adsorption and degradation, poor site characterization, or lack of effective distribution.
- Performance assessment may be subject to bias if AC is present in monitoring wells. Other lines of evidence are important.
- Field evidence of degradation is limited but promising. However, persistence and contribution of degradation need further validation.

Introduction

This fact sheet, developed by the U.S. Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation, concerns an emerging remedial technology that applies a combination of activated carbon (AC) and chemical and/or biological amendments for in situ remediation of soil and groundwater contaminated by organic contaminants, primarily petroleum hydrocarbons and chlorinated solvents. The technology typically is designed to carry out two contaminant removal processes: adsorption by AC and destruction by chemical and/or biological amendments.

With the development of several commercially available AC-based products, this remedial technology has been applied with increasing frequency at contaminated sites across the country, including numerous leaking underground storage tank (LUST) and dry cleaner sites (Simon 2015). It also has been recently applied at several Superfund sites, and federal facility sites that are not on the National Priorities List.

This fact sheet provides information to practitioners and regulators for a better understanding of the science and current practice of AC-based remedial technologies for in situ applications. The uncertainties associated with the applications and performance of the technology also are discussed.

What is AC-based technology?

- AC-based technology applies a composite or mixture of AC and chemical and/or biological amendments that commonly are used in a range of in situ treatment technologies.
- Presently, five commercial AC-based products have been applied for in situ subsurface remediation in the U.S.: BOS-100$^{®}$ & 200$^{®}$ (RPI), COGAC$^{®}$ (Remington Technologies), and PlumeStop$^{®}$ (Regenesis) are the four most commonly used commercial products. CAT-100$^{®}$ from RPI is the most recent product, developed based on BOS-100$^{®}$. One research group in Germany also developed a product called Carbo-Iron$^{®}$. Detailed properties and compositions of these products are shown in Exhibit 1.
- The AC components of these products typically are acquired from specialized AC manufacturers. These types of AC have desired adsorption properties for chlorinated solvents and petroleum hydrocarbons. Different products also have different AC particle sizes, which determine the suitable injection approach and the applicable range of geological settings.

How are contaminants treated by AC-based technology?

- AC-based technology involves two contaminant removal processes: adsorption and degradation. AC is responsible for adsorption and reactive amendments are responsible for degradation.
- AC is composed of randomly oriented graphite stacks. The random orientation results in a highly porous matrix having a wide range of pore sizes. Adsorption of typical groundwater organic contaminants (e.g., benzene, trichloroethylene) primarily occurs in micropores (<2 nm in diameter). Large pores, mesopores and macropores, mainly serve as transport conduits for contaminants to reach adsorption sites via intraparticle diffusion (Bansal and Goyal 2005).
- Under typical subsurface temperatures, physical adsorption is the dominant adsorption mechanism, which is a reversible process governed by the van Der Waals force (Karanfil and Kildulff 1999). Contaminant desorption can occur when equilibrium conditions (e.g., pH, plume composition) change, but AC applications in sediment remediation showed that the desorption rate from AC is much slower than that from indigenous sediment materials (Sun and Ghosh 2008).
- Chemical or biological amendments determine the contaminant groups treated and degradation pathways supported. BOS-100® treats chlorinated solvents via zero-valent iron (ZVI)-mediated abiotic dechlorination; BOS-200® treats petroleum hydrocarbons by bioaugmentation. COGAC® treats either group by chemical oxidation and likely subsequent biostimulation; and PlumeStop® treats either group by biostimulation or bioaugmentation depending on the specific amendments applied (Exhibit 1).
- Solid amendments (e.g., ZVI) or bacteria often have much larger size than micropores, the major adsorption sites of AC (Exhibit 2). Therefore, sorbed contaminants must be desorbed and diffuse out of micropores to be degraded. This process is driven by the concentration gradient between sorption sites and bulk liquid phase (Spetel Jr et al. 1989; Tseng et al. 2011).
- Contaminant removal is controlled by the dynamic equilibrium between contaminant influx, adsorption and degradation. This has been suggested to occur in biological activated carbon reactors for wastewater treatment, where the relative contribution of adsorption and biodegradation to contaminant removal varies at different operational stages (Voice et al. 1992; Zhao et al. 1999). Contaminants stay within the treatment zone when combined rates of adsorption and degradation exceed the incoming mass flux.

Exhibit 1: Properties of six AC-based products that have been used for in situ applications

Product	Property	Target Contaminant	Degradation Pathway
BOS-100®	Granular AC (GAC) impregnated by ZVI	Chlorinated solvents	Abiotic reductive dechlorination
BOS-200®	Powder AC (PAC) mixed with nutrients, electron acceptors, and facultative bacteria mix	Petroleum Hydrocarbons	Aerobic and anaerobic bioaugmentation
CAT-100®	BOS-100® and reductive dechlorination bacterial strains	Chlorinated solvents	Abiotic and biotic reductive dechlorination
COGAC®	GAC or PAC mixed with calcium peroxide, and sodium persulfate	Chlorinated solvents or petroleum hydrocarbons	Chemical oxidation, aerobic and anaerobic biostimulation
PlumeStop®	Colloidal AC suspension with an organic stabilizer, co-applied with hydrogen or oxygen release compounds, and/or corresponding bacterial strains	Chlorinated solvents or petroleum hydrocarbons	Enhanced biotic reductive dechlorination for chlorinated solvents and aerobic biodegradation for petroleum hydrocarbons
Carbo-Iron®	Colloidal AC impregnated with ZVI	Chlorinated solvents	Abiotic reductive dechlorination

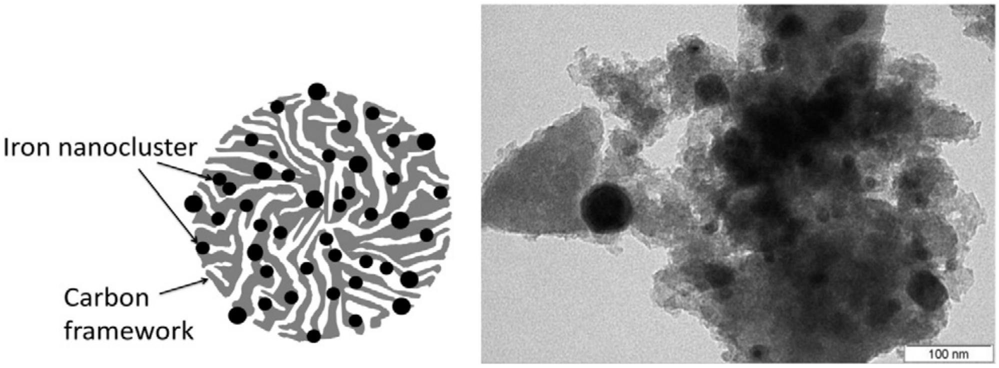

Exhibit 2. (Left) Conceptual structure and (Right) transmission electron micrograph (TEM) of Carbo-Iron® (Adopted from Mackenzie et al. 2016)

What are the potential benefits of using AC-based remedial technology?

- Adsorption can significantly retard contaminant migration and decrease dissolved phase concentrations. Retaining contaminants in the AC matrix allows longer residence time for contaminants to be degraded by reactive amendments. The coupling of adsorption and degradation reduces the potential for contaminant rebound that frequently is encountered with conventional treatment technologies (e.g., pump and treat (P&T) or in situ chemical oxidation (ISCO)).
- AC impregnated with nano zerovalent iron (nZVI) is shown to have more persistent reactivity than suspended nZVI particles (Choi et al. 2009). It was suggested that AC may protect nZVI from undesired side reactions with dissolved oxygen and water, which often outcompete contaminant degradation for nZVI because of their greater abundance.
- Adsorption may enrich chemicals (including both contaminants and nutrients) over time to facilitate formation of active biofilm and biodegradation (Voice et al. 1992). The combined effects may significantly reduce the time frame to reach remedial objectives.
- For high concentration of chlorinated VOCs, adsorption onto AC decreases the initial high aqueous contaminant concentration that inhibits biological dechlorination and shortens the lag phase for biodegradation (Aktas et al. 2012).

How is AC-based remedial technology implemented in field?

- Grid injection that targets a well-defined contaminated area commonly is used if the footprint of treatment areas is relatively small, such as some LUST sites or localized hotspots.
- For plume, barrier applications commonly are used. AC-based amendments typically are emplaced in transects to form a series of permeable reactive zones that are perpendicular to the direction of plumes. An external water supply typically is needed to mix and dilute amendments in these barrier wall configurations.
- High-pressure injection (typically 300 to 1000 psi), (i.e., hydraulic fracturing), is used for emplacing Granular AC(GAC)- or Powder AC(PAC)-based amendments due to the need to open up the formation for emplacement of the large particles. As fracturing is more effective in low-permeability formations, GAC or PAC-based amendments typically are injected in tight formations, such as clays and silts (Winner and Fox 2016).
- Less frequently, soil mixing or trenching has also been used for emplacement of GAC or PAC-based amendments provided suitable hydrogeological conditions. For example, BOS-100, a GAC-based product, was emplaced by deep soil mixing in a sandy aquifer during a pilot test at the Vandenberg Air Force Base, after high-pressure injection showed poor amendment distribution (ITRC 2011).
- Colloidal AC-based amendments are emplaced by low-pressure injection (e.g., 30–50 psi) using direct push or permanent injection wells without creating artificial fractures. As a result, the amendment primarily is applied to more permeable formations such as sands and gravels. However, even a low-permeability aquifer may contain permeable (flux) zones that permit application of colloidal AC-based amendment.

How is AC-based amendment distributed in the subsurface?

- For GAC- and PAC-based amendments, high-pressure injection typically produces thin seams or lenses of AC in seemingly random directions. In tight geologies, fractures typically have higher permeability than surrounding formations. This difference may allow contaminant desorption and diffusion from the low-permeability formations into the fractures. The conceptual model is shown on the left in Exhibit 3. Tight injection spacing in both horizontal and vertical directions is recommended to obtain sufficient coverage as it is difficult to control the formation and growth of fractures (Murdoch, 1995). Some recent improvements have been made to better control the direction and development of fractures (i.e., direct push jet injection), but these approaches have not been applied to injecting AC-based amendments.
- For colloidal AC, the particles infiltrate into the permeable zone or formation upon low-pressure injection and eventually deposit onto the surface of soil grains due to surface-surface interactions. The presence of an organic polymer improves the colloidal stability and transport in the subsurface. Therefore, the distribution of amendments in flux zones is expected to be more uniform than induced fracturing of AC-based amendments of larger particle size (Exhibit 3, on right).

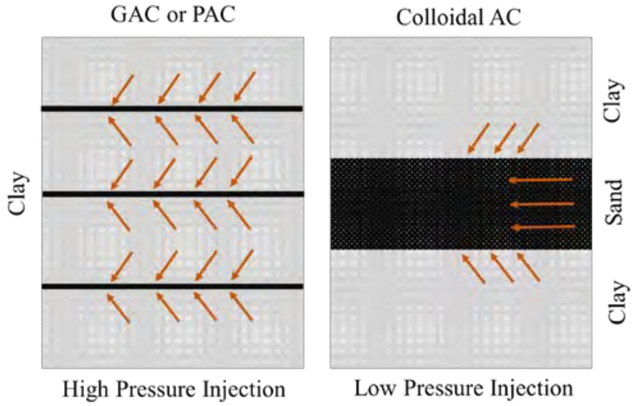

Exhibit 3. Different conceptual distribution patterns between GAC- or PAC-based amendment (left) and colloidal AC-based amendment (right). Dark regions represent the forms of amendment distribution and arrows represent the directions of contaminant flux entering the AC zone. (Adapted from Fan et al. 2017).

What are the key factors to consider during remedial design?

- Design of AC-based remedies primarily focuses on defining optimal injection locations and loadings, which are affected by the treatment approach and objective (e.g., area treatment to reduce mass flux or barrier application to intercept plume). The key to effective remedial design of AC-based technology (or any in situ remedial technology), is to conduct adequate site characterization to create a sufficiently detailed CSM.
- Subsurface geology and contaminant mass distribution are the two major aspects to characterize during remedial design investigation (Winner and Fox 2016). Subsurface hydrogeology can be characterized by grain size distribution analysis, clear water injection, or hydraulic profiling (Birnstingl et al. 2014). Contaminant distribution can be qualitatively determined by various in situ rapid screening tools, such as the membrane interface probe (MIP) (Winner and Fox 2016; EPA 2016); laser induced fluorescence (LIF) technique for non-aqueous phase liquid (NAPL); or a photo ionization detector (PID) for soil screening on-site. Selected samples can be subject to more rigorous laboratory analysis if needed.
- For GAC- and PAC- based amendments, it is important to profile the vertical distribution of contaminant mass as it determines the vertical injection interval and injection loading at each interval, especially when the remedy is designed to treat a residual source area with heterogeneous lithology. At a former manufacturing site in Denver, the initial injection of BOS-100® near the source area did not achieve performance objectives. Further high-resolution site characterization

revealed highly heterogeneous contaminant distribution in the vertical direction. Subsequent injection loading and approach were adjusted to the contaminant distribution pattern, which significantly improved the remedy performance (Noland et al. 2012; Harp 2014).

- For colloidal AC-based amendments, it is important to locate the high-permeability zones and estimate the mass flux across those zones to determine where to apply the amendments, and how much is needed.
- Contaminants associated with soil (e.g., sorbed) and residual NAPL phase represent the majority of the contaminant mass stored in low-permeability zones, and can serve as a long-term source for groundwater contamination. The calculation of contaminant loading needs to consider the rates of back diffusion of source material or the total mass of contamination.
- Laboratory-measured adsorption capacity often serves as a benchmark value to calculate amendment loading. However, the actual adsorption capacity varies with contaminant concentration and can be further complicated by competitive adsorption and potential growth of biofilm.
- Vendors often are willing to actively participate in the remedial investigation and design phases to ensure successful implementation and desired performance of their products. Spreadsheets are available from the vendors to calculate the loading rates of amendments based on estimated contaminant mass (or mass flux), adsorption capacity, remedial objectives, and the designed lifetime of the remedy. However, the calculation is largely empirical due to various uncertainties caused by subsurface heterogeneity. Based on discussion with the vendors, a safety factor of 5 to 20 is recommended for estimating amendment loading.

How does the AC-based remedial technology perform in the field?

- The four commercial AC-based products combined have accumulated more than 1500 applications in North America and Europe as of 2015 (Simon 2015). To date, this technology has been used or selected at four NPL sites and one RCRA corrective action site.
- Field data generally show rapid decrease of aqueous contaminant concentration after emplacement of the amendments when initial contaminant concentration is high. The decrease is more gradual when initial contaminant concentration is low (e.g., <100 ppb). Temporary rebound shortly after injection is common, and may occur when equilibrium is reestablished after enhanced contaminant desorption from aquifer solids, or when plume is temporarily displaced by injection of amendments in large volumes.
- Regenesis evaluated the performance of PlumeStop® applied at 24 sites between 2014 and 2016 by pooling contaminant concentrations from 34 monitoring wells (Davis 2016). Regenesis found more than 65% of wells achieved >95% reduction within 1–3 months after injection. The initial rapid response is most likely due to rapid adsorption process.
- Rebound of contamination has been observed at some sites that applied AC-based amendments. The same study by Regenesis (Davis 2016) found that 15% of the wells examined showed some rebound over an average of 6-month time frame but the rebound is generally <10% of pre-treatment concentrations. Early applications of PAC-based products at LUST sites in Colorado also identified frequent rebound (Fox 2015). Possible reasons cited for rebound include underestimation of contaminant mass due to poor site characterization (Fox 2015); insufficient amendment distribution due to large injection spacing or poor implementation (Fox 2015); or contaminant mass influx exceeding the combination of adsorption and degradation (Mackenzie et al. 2016).
- AC frequently is observed in monitoring wells post injection. Given amendment distribution is likely not uniform, especially when high-pressure injection is used, caution needs to be taken when using impacted monitoring wells for performance evaluation. Concentrations measured in those wells may not accurately represent the aquifer concentrations. In addition, impacted wells also typically should not be used for attainment monitoring because post remediation conditions may not be reached (EPA 2013; EPA 2014)[1]. Other lines of evidence are recommended for confirming the treatment performance achieved in the treatment zone.
- Several measures have been taken to improve confidence in performance assessment using monitoring wells. Examples include preventing or

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[1] "The attainment monitoring phase typically occurs after EPA makes a determination that the remediation monitoring phase is complete. When the attainment phase begins, data typically are collected to evaluate if the well has reached post remediation conditions (i.e., steady state conditions) where remediation activities, if employed, are no longer influencing the groundwater in the well." (EPA 2013)

minimizing well impact using geochemical parameters as early indicators for breakthrough of AC; installing new wells near the existing impacted wells to demonstrate that either amendment distribution is not localized or AC-free wells exhibit similar treatment effects as AC-impacted wells; and monitoring downgradient wells adjacent to the treatment zone to observe for decreasing contaminant trend (Winner and Fox, 2016). Removing AC from impacted wells prior to sampling could be another solution. It has been shown to be moderately successful for colloidal AC but not work for AC with large particle sizes, according to vendors and practitioners.

What is the evidence for degradation?

- Degradation is generally an indispensable component of contaminant removal processes by AC-based amendments. Without degradation, AC-based remedial technology may serve only to stabilize the contaminants, and contaminants may break through once adsorption capacity is exhausted or when desorption occurs. Throughout the development of the technology, the uncertainty regarding the importance and persistence of degradation has been a major hurdle for wide acceptance of the technology.
- Bench-scale tests have demonstrated the effectiveness of degradation processes involved in AC-based remedial products (Birnstingl et al. 2014). However, controlled laboratory results may not guarantee field effectiveness, especially for biodegradation that is more variable because of field heterogeneities.
- It is difficult to confirm contaminant degradation in the field. Both adsorption and degradation can result in decreasing contaminant concentrations without the appearance of daughter products, which may also be adsorbed by AC. Use of contaminant data from monitoring wells does not distinguish contaminant removal by adsorption from that by degradation.
- To date, field evidence of degradation has been limited and largely qualitative. For petroleum hydrocarbons, depletion of nitrate or sulfate, and production of volatile fatty acids, have been suggested as evidence of biodegradation.
- For chlorinated solvents, production of chloride has been used to indicate dechlorination, but this line of evidence only applies when background chloride concentration is low or contaminant concentration is very high (i.e., near the source area). In one pilot test of Carbo-Iron, significant elevation of ethene and ethane was used as evidence for abiotic reductive dechlorination (Mackenzie et al. 2016).
- More recently, environmental molecular diagnostic (EMD) tools have shown promise for assessing biodegradation of petroleum hydrocarbons and chlorinated solvents (ITRC 2013). The following recent data was provided to EPA by three vendors of AC-based products to demonstrate degradation:
    - At one chlorinated solvent site where PlumeStop® was injected with a hydrogen release compound (HRC®) and *Dehalococcoides* cultures, the combination significantly increased the abundance of degraders and functional genes in the aqueous phase after injection. The high abundance was sustained for over 500 days, even though the dissolved tetrachloroethene (PCE) remained below the detection limit. This pattern suggests that enhanced concentrations of microbial indicators resulted from enhanced microbial activity in the up-gradient AC barrier.
    - At one petroleum site where COGAC® was injected, groundwater samples were collected one year after injection. In these samples, the abundance of six anaerobic BTEX (benzene, toluene, ethylbenzene and xylenes) and PAH (polycyclic aromatic hydrocarbon) degraders was found to be 2 to 4 orders of magnitude higher in samples collected from wells within the injection influence zone than in samples collected from a well outside the injection influence zone.
    - At one petroleum site where BOS-200® was injected to form a permeable reactive zone, compound specific isotope analysis (CSIA) was conducted on samples collected from wells up- and downgradient of the PRB two years after injection. Compared to the upgradient well, the downgradient wells consistently show small but evident enrichment of C^{13} for several BTEX compounds, indicating occurrence of biodegradation of these compounds.
- Applications of AC in other contaminant removal processes such as wastewater and sediment treatment have suggested that AC enhances biodegradation by promoting the formation of biofilms, which can be attributed to increasing nutrient retention, enhanced resistance to environmental shocks, and increased microbial diversity (Simpson 2008; Kjellerup et al. 2014).

What is the long-term effectiveness of AC-based remedial technology?

- The longevity of AC-based remedial technology is of particular interest because the long-term effectiveness to counter slow and persistent contaminant flux (from diffusion, desorption, and dissolution) is one of the major benefits claimed for this technology.
- Currently, there is lack of sufficient monitoring data to assess the long-term performance due to either recent implementation or the lack of long-term monitoring requirements at many small sites. Thus, the long-term effectiveness of this technology remains to be further evaluated when data become available.
- The relative contribution of contaminant adsorption versus degradation is a critical parameter for evaluating the long-term performance. As contaminant can eventually break through when adsorption capacity becomes exhausted, degradation is the main driver in maintaining the long-term effectiveness of the technology. This aspect remains to be further investigated.
- Competitive adsorption may affect long-term effectiveness. Competitive adsorption refers to a process where strongly sorbed compounds may displace weakly sorbed compounds, resulting in release of the latter. Competitive adsorption should be evaluated for treating comingled plumes or plumes where degradation intermediates are expected to form if degradation stalls or does not proceed to completion. For example, sorbed benzene may be displaced by xylene in a BTEX plume. For a chlorinated solvent plume, daughter products such as *cis*-dichloroethene (DCE) or vinyl chloride may be displaced by PCE or trichloroethene (TCE). This potential desorption behavior again highlights the importance of supporting degradation activity and including (bio)degradation assessment in a long-term monitoring plan.

Where and when should AC-based remedial technology be considered?

- AC-based remedial technology provides an effective approach to address persistent plumes emanating from low-permeability sources, desorption, or dissolution of residual NAPL phase.
- AC-based remedial technology could be considered when other remedial options at a site have demonstrated limited effectiveness. For example, applications of AC-based remediation at LUST sites in Colorado and Kentucky (primarily PAC-based amendments) mainly occurred at sites dominated by low-permeability formations, including fractured bedrock, where soil vapor extraction or bioremediation was not successful (Winner and Fox 2016).
- AC-based remedial technology can serve as a cost-saving alternative to active P&T to prevent plume migration. It may also complement an existing P&T system to contain a plume by reducing the rate or area for pumping.
- Several recent Superfund AC applications used AC only without adding reactive amendments for treating low-concentration chlorinated solvent plumes. The approach was selected to avoid potential generation of poorly sorbed daughter products or avoid secondary groundwater quality issues resulted from changes in subsurface redox conditions due to application of reactive amendments. At one site, the effectiveness of the adsorption mechanism alone is proposed to last sufficiently long to allow time for source treatment. However, long-term monitoring data are required to confirm long-term performance.
- While emplacement of AC-based amendments typically is not considered as a source treatment technology due to concerns of exhausting the adsorption capacity quickly, emplacements of AC in sources or around source areas as a barrier have been applied in the field. The goal is to significantly reduce contaminant mass flux out of the sources to reduce downgradient impacts. The technology can be coupled with source zone treatment technologies, such as in situ thermal treatment, or with excavation when not all contaminated material can be removed.
- In scenarios where fast groundwater flow velocity might limit the effectiveness of soluble amendments due to dilution, colloidal AC-based amendments may be considered since they more rapidly adsorb to aquifer materials and are more likely to remain in the target treatment area.

Where can I find more information?

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This project was supported in part by an appointment to the Internship/Research Participation Program at the Office of Superfund Remediation and Technology Innovation, U.S. EPA, administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and U.S. EPA.

A PDF version of this document, Technical Fact Sheet– Activated-carbon based Technology for In Situ Remediation, is available to view or download at https://clu-in.org/s.focus/c/pub/i/2727/

For further information, contact Technology Assessment Branch, Office of Superfund Remediation and Technology Innovation, Office of Land and Emergency Management.

Appendix B

Regenesis Conceptual Design Approach and Calculations

REGENESIS

Project Info

York Oil (Alcoa) superfund Site
Moira, NY
Diss. Plume btwn OU-1&2
Prepared For:
de maximis

Target Treatment Zone (TTZ) Info	Unit	Value
Barrier Length	ft	120
Top Treat Depth	ft	19.0
Bot Treat Depth	ft	39.0
Vertical Treatment Interval	ft	20.0
Treatment Zone Volume	ft^3	72,000
Treatment Zone Volume	cy	2,667
Soil Type	---	sand (p-fractured+propant)
Porosity	cm^3/cm^3	0.30
Effective Porosity	cm^3/cm^3	0.12
Treatment Zone Pore Volume	gals	161,579
Treatment Zone Effective Pore Volume	gals	64,632
Treatment Zone Pore Volume	liters	611642
Treatment Zone Effective Pore Volume	liters	244657
Fraction Organic Carbon (foc)	g/g	0.005
Soil Density	g/cm^3	1.67
Soil Density	lb/ft^3	104
Soil Weight	lbs	7.5E+06
Hydraulic Conductivity	ft/day	10.0
Hydraulic Conductivity	cm/sec	3.53E-03
Hydraulic Gradient	ft/ft	0.002
GW Velocity	ft/day	0.20
GW Velocity	ft/yr	75

Sources of Hydrogen Demand	Unit	Value
Dissolved Phase Contaminant Mass	lbs	0
Sorbed Phase Contaminant Mass	lbs	0
Competing Electron Acceptor Mass	lbs	121
Total Mass Contributing to H_2 Demand	**lbs**	**122**

Stoichiometric Demand	Unit	Value

Application Dosing	Unit	Value
PlumeStop to be Applied	**lbs**	**8,800**
AquaZVI to be Applied	lbs	0
HRC to be Applied	lbs	0
BDI Plus to be Applied	Liters	0

PlumeStop® Application Design Summary

Diss. Plume btwn OU-1&2

PlumeStop	
Barrier Length (ft)	**120**
Spacing Within Barrier (ft)	30
Number of Lines	1
Application Points	**4**
Application Method	**Direct Push**
Top Application Depth (ft bgs)	19
Bottom Application Depth (ft bgs)	39
PlumeStop to be Applied (lbs)	**8,800**
PlumeStop to be Applied (gals)	995
In Situ Chemical Reduction - AquaZVI	
PlumeStop Volume Totals	
Mixing Water (gal)	18,185
Total Application Volume (gals)	**19,180**
Injection Volume per Point (gals)	4795
Anaerobic Bioremediation - HRC	
Bioaugmentation - BDI Plus	

Technical Notes/Discussion

PSTOP Injection Concentration (mg/L)
8,800

Likely approach will be to use much higher concentration for initla PlumeStop injection at 60% of total volume then chase with 40%

Assumptions/Qualifications

In generating this preliminary estimate, Regenesis relied upon professional judgment and site specific information provided by others. Using this information as input, we performed calculations based upon known chemical and geologic relationships to generate an estimate of the mass of product and subsurface placement required to affect remediation of the site.

REGENESIS developed this Scope of Work in reliance upon the data and professional judgments provided by those whom completed the earlier environmental site assessment(s). The fees and charges associated with the Scope of Work were generated through REGENESIS’ proprietary formulas and thus may not conform to billing guidelines, constraints or other limits on fees. REGENESIS does not seek reimbursement directly from any government agency or any governmental reimbursement fund (the “Government”). In any circumstance where REGENESIS may serve as a supplier or subcontractor to an entity which seeks reimbursement from the Government for all or part of the services performed or products provided by REGENESIS, it is the sole responsibility of the entity seeking reimbursement to ensure the Scope of Work and associated charges are in compliance with and acceptable to the Government prior to submission. When serving as a supplier or subcontractor to an entity which seeks reimbursement from the Government, REGENESIS does not knowingly present or cause to be presented any claim for payment to the Government.

Prepared by: DaP55758
Date: 8/6/2018

PlumeStop® Liquid Activated Carbon™ Technical Description

PlumeStop Liquid Activated Carbon is an innovative groundwater remediation technology designed to rapidly remove and permanently degrade groundwater contaminants. PlumeStop is composed of very fine particles of activated carbon (1-2µm) suspended in water through the use of unique organic polymer dispersion chemistry. Once in the subsurface, the material behaves as a colloidal biomatrix, binding to the aquifer matrix, rapidly removing contaminants from groundwater, and expediting permanent contaminant biodegradation.

This unique remediation technology accomplishes treatment with the use of highly dispersible, fast-acting, sorption-based technology, capturing and concentrating dissolved-phase contaminants within its matrix-like structure. Once contaminants are sorbed onto the regenerative matrix, biodegradation processes achieve complete remediation at an accelerated rate.

Distribution of PlumeStop in water

To see a list of treatable contaminants with the use of PlumeStop, view the Range of Treatable Contaminants Guide.

Chemical Composition

- Water - CAS# 7732-18-5
- Colloidal Activated Carbon ≤2.5 - CAS# µm 7440-44-0
- Proprietary Additives

Properties

- Physical state: Liquid
- Form: Aqueous suspension
- Color: Black
- Odor: Odorless
- pH: 8 - 10

Storage and Handling Guidelines

Storage
Store in original tightly closed container
Store away from incompatible materials
Protect from freezing

Handling
Avoid contact with skin and eyes
Avoid prolonged exposure
Observe good industrial hygiene practices
Wash thoroughly after handling
Wear appropriate personal protective equipment

PlumeStop® Liquid Activated Carbon™ Technical Description

Applications

PlumeStop is easily applied into the subsurface through gravity-feed or low-pressure injection.

Health and Safety

Wash hands after handling. Dispose of waste and residues in accordance with local authority requirements. Please review the Material Safety Data Sheet for additional storage, usage, and handling requirements here: PlumeStop SDS.

REGENESIS

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