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Sent via electronic mail (hasan.ahmed@dec.ny.gov)

January 14, 2020

Mr. Hasan R. Ahmed
New York State Department of Environmental Conservation
Division of Environmental Remediation
Hunters Point Plaza
47-40 21st Street, Long Island City, New York 11101-5401

Re: Enhanced *In Situ* Bioremediation Pilot Study
Former ACCO Brands Site
32-00 Skillman Avenue, Long Island City, NY 11101
NYSDEC BCP Site Number: C241061

Dear Mr. Ahmed:

This Enhanced *In Situ* Bioremediation Pilot Study was prepared by Arnold F. Fleming, P.E. and Fleming Lee-Shue, Inc. (FLS) for Beam Suntory Inc. (the Participant) to evaluate the effectiveness of bioaugmented remediation at the Former ACCO Brands, Brownfield Cleanup Program (BCP) Site No. C241151.

Former ACCO Brands ("Site") is located in Long Island City, Queens County, New York. The Site is bound by Skillman Avenue to the north, Van Dam Street to the west, Queens Boulevard to the south, and 32nd Place to the east. The Site is defined by the limits of the basement footprint on the south end of the building and is approximately 0.72 acres (31,372 square feet) with the top of basement slab at an approximate elevation of 25 ft. North American Vertical Datum of 1988 (NAVD 88). The workplan certification signed and sealed by the BCP remedial engineer is provided at the end of this letter. Figure 1 shows the Site Location. Figure 2 is a Site Plan depicting monitoring well location.

Purpose and Objectives

Beam Suntory employed Electric Resistance Heating (ERH) to remove trichloroethylene (TCE) to reach the target cleanup goal of 100 ug/L in Site groundwater. However, ERH did not achieve sustained concentrations at or below the cleanup target, rather, only temporary excursions below the target occurred, followed by a large rebound of TCE concentrations. The most recent soil and groundwater sampling results are enclosed in the Remedial Investigation Report dated January 14, 2020.

Anticipating that ERH may not have been able to meet the cleanup goal at all on-Site wells, the remedial action workplan (RAWP) dated March 2015 included the use of enhanced *in situ* bioremediation as a final polish step to meet the remedial goal. As a result, it is now necessary in our professional view to implement a secondary remedial effort to further reduce TCE concentrations and achieve the Site cleanup goal. This secondary remedial effort is enhanced *in situ* bioremediation. We anticipate that it will be the final remedial effort.

In order to evaluate enhanced *in situ* bioremediation as the specified alternative for further TCE reduction, FLS conducted several supplementary Site investigations and post-ERH contaminant delineation, which have been documented and provided to NYSDEC in reports dated October 15, 2018, June 15, 2019 and October 30, 2019. These investigations also included geochemical and microbial analyses and a 25-week bioaugmentation laboratory microcosm study (results of these investigations are addressed in more detail in sections below). These studies show enhanced *in situ* bioremediation, also known as bioaugmentation or "biopolishing," to be a viable alternative for further TCE and chlorinated solvent reduction. In addition, the microcosm study shows that higher subsurface temperatures further enhance chlorinated solvent reduction through increased biological activity around the optimal microbial temperature of approximately 35 to 45 degrees Celsius. FLS next proposes a Pilot Study implementing bioaugmented injections in select sections to confirm the field efficacy of bioremediation.

The objectives of this Pilot Study are as follows:

- Use the existing Site data (TCE soil and groundwater delineation, subsurface temperatures, vapor data, etc.) and microcosm study results to develop a Site injection plan.
- Evaluate the effectiveness of injected bioremediation amendment distribution, contaminant degradation, and degradation rates under actual *in situ* Site conditions. Evaluation includes assessing amendment persistence, capacity of subsurface to accept injected material, effectiveness of performance monitoring wells as injection points, injection radius of influence, injection frequency, contaminant degradability, byproduct generation, and geochemical impacts to aquifer.
- Use Pilot Study data to identify Site-specific challenges and incorporate lessons learned and contingencies into the full-scale remedial design.

Existing Conditions and Site Conceptual Model

Post-ERH Site TCE groundwater concentrations exhibit rebound in the performance monitoring wells within the treatment area. TCE in a number of wells has increased to approximately 10,000 µg/L or more since September 2018 and reached over 100,000 µg/L in two performance monitoring wells (MWR-2S, 9/14/2018 and 9/21/2018 and MWR-4I 1/24/2019 and 1/21/2019) and these rebounded levels have been sustained for several sampling rounds as recently as 11/21/2019. The most recent sampling on 11/21/2019 found TCE in concentrations above 200,000 µg/L in more than one monitoring well within the former ERH treatment zone. Table 1 shows the maximum concentrations measured post-ERH operation in groundwater monitoring wells within the treatment area.

Based on currently available data, FLS theorizes that during ERH operation elevated subsurface temperatures dispersed remaining DNAPL within the Site treatment area. While ERH operation was successful in mobilizing and removing more than 5,000 pounds of volatilized TCE through the subsurface, it does not appear to have fully removed the remaining source via vapor recovery. The sustained increase of TCE concentrations in Site groundwater since the ERH system de-energized in 2018 is likely evidence of volatilized contaminant dissolving back into groundwater as Site temperatures continue to cool post-ERH and/or DNAPL having been dispersed through the treatment area by heat and steam convection resulting from prolonged heating and by the release of DNAPL from fine textured strata into more permeable strata. FLS reasons that dispersed DNAPL has had greater contact with groundwater, therefore resulting in increased TCE concentrations in the groundwater.

Soil Contamination

Pre-ERH TCE soil concentrations were above the Commercial Use Soil Cleanup Objectives (CUSCO), with a maximum concentration found in the northern portion of the Site (542 mg/kg). Post-ERH, FLS conducted two soil investigations as a part of the June 2019 *Supplemental Site Investigation Report* (SSI) between MWR-4 and MWR-2 and around MWR-7. Data from these investigations found a notable disparity between TCE concentrations in soil (very low) versus the high levels found in the performance groundwater monitoring wells (a common observation with chlorinated sites). This observation was discussed during the July 16, 2019 meeting with NYSDEC where it was agreed that TCE soil concentrations appear to not serve as a reliable indicator of TCE source material, and therefore more weight should be given to groundwater results in the effort to delineate source TCE.

Typically, when soil results do not show evidence of DNAPL (i.e., concentrations below 425 mg/kg), but the groundwater concentrations are high (i.e., above 11,100 µg/L) and are indicative of DNAPL, much more weight should be given to the groundwater concentrations for evaluating the site conditions and identifying possible source material. This is because TCE is very dense and much less viscous than water such that it typically occurs in very thin, horizontal layers or vertical fingers. This makes it soil concentrations highly variable and very difficult to detect. The elevated TCE concentrations in Site groundwater strongly indicate DNAPL. Pankow and Cherry, 1996, p. 64, point out that almost without exception, groundwater plumes from chlorinated solvents result from solution of persistent DNAPL sources below the water table.[1]

Groundwater Contamination

The highest groundwater concentrations of TCE appear to be within the ERH treatment area and suggest remaining TCE DNAPL source material. TCE in the treatment area is approximately 10,000 µg/L or more in a number of wells and reached over 100,000 µg/L in one well, and these levels have been sustained for several sampling rounds. Sampling during the October - November 2019 Remedial Investigation (RI) found TCE in groundwater over 200,000 µg/L and reaching 475,000 µg/L in one instance.

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[1] Pankow, James, F. and Cherry, John, A. 1996. *Dense Chlorinated Solvents and other DNAPLs in Groundwater.* Waterloo Press. Portland Oregon 97291.

Historically, groundwater has shown elevated concentrations of TCE within the monitoring well network, concentrated primarily in the southwestern portion of the Site. Off-Site groundwater concentrations of TCE have been variable but are approximately an order-of-magnitude or more *lower* than those observed in Site monitoring wells. All the Site and off-Site TCE groundwater concentrations from November 8, 2017 through March 2019, 255 Site and off-Site groundwater TCE concentrations were measured, and our review of all such results supports a finding overall that TCE concentrations on Site are, on balance, 10 times higher than off-Site concentrations for TCE concentrations less than 6,000 µg/L, and approximately 2.5 times higher for TCE concentrations greater than 6,000 µg/L.

Elevated TCE concentrations have been documented in downgradient wells MWR-7S and MWR-7I (8,000 µg/L to 14,900 µg/L) located within the off-Site sidewalk, but within the downgradient edge of the ERH treatment area. The majority of downgradient off-Site monitoring wells display groundwater concentrations around or below the 100 ug/L TCE Site cleanup goal, with the exception of MW-9 off-Site to the west, which has TCE groundwater concentrations higher than in in MWR-7S and MWR-7I.

The most recent groundwater monitoring event was conducted in November 2019 and included four shallow Site monitoring wells that had not been sampled regularly since 2014, which was before the ERH remedy was applied. TCE concentrations are presented on Figures 3A and 3B. On-Site TCE groundwater concentrations were variable across the Site during the July 2019 sampling event and exceeded the 100 ug/L cleanup goal in the ERH performance monitoring wells. Consistent with prior sampling events throughout 2018, the highest TCE concentrations were identified in the southwestern portion of the Site, concentrating near the MWR-4 well cluster (MWR-4I: 232,000 ug/L; MWR-4S: 70,700 ug/L). Concentrations of TCE appear to taper off from this location downgradient towards the MWR-3, MWR-2 and MWR-7 well clusters where concentrations ranged from 5,000 ug/L to 21,000 ug/L. Wells near the perimeter of the ERH treatment area (i.e. MW-1, MW-4) were sampled during this event and displayed lower TCE concentrations (360 ug/L and 2,310 ug/L respectively). Likewise, monitoring wells located on the eastern edge of the Site (MW-5 and MW-16) contained low concentrations at 2.1 ug/L and 184 ug/L, respectively. Collectively, this data further indicates that high level contamination appears to be in the center and western areas of the Site.

Geochemical Conditions

Site geochemical conditions seem to favor reductive dechlorination of TCE and support the reductive pathway, but current conditions are not likely to result in full TCE degradation at each of the wells without intervention via bioaugmentation and biostimulation. Competing electron acceptor groups are in low concentrations, but key geochemical parameters (e.g. alkalinity, carbon dioxide) indicate full reductive dechlorination is not currently on-going. Moreover, with the exception of some potential light methanogenesis-driven reduction (indicated by the high methane and methanogen bacteria colony concentrations), it appears that microbial degradation of TCE on-Site is being inhibited because, we suspect, there are insufficient number and types of naturally occurring bacteria and nutrients to drive complete biodegradation of TCE. These restrictions can likely be addressed through enhanced bioremediation.

The most likely inhibition factor is the high subsurface temperatures (~60^0 C as of August 2019), resultant from ERH, which exceed the temperature range conducive of microbial growth. This is corroborated by the microbial data (discussed in the following section), which found very low concentrations of dehalococcoides bacteria capable of reducing TCE. As Site subsurface temperatures cool, it is likely dehalococcoides bacteria concentrations should increase. The results suggest that a full chlorinated VOC degradation pathway will not occur, regardless of temperature, without bioaugmentation.

Hydrogeology
The groundwater table lies at a depth of approximately 14 to 15 feet below the basement slab finished surface. Groundwater flow is to the west-northwest and south-southwest towards Dutch Kills and Newtown Creek. During ERH groundwater mounded over the Site in response to heating, but has since declined as temperatures cool. Groundwater flow is now returning to its typical groundwater flow direction

Groundwater Temperatures
At ERH's peak performance, Site groundwater temperatures were elevated (i.e. greater than 100° C in some instances). Since ERH was de-energized in August 2018, Site groundwater temperatures within the treatment area have decreased to approximately 39° C - 44° C along the edges of the treatment area and are around 50° C to 60+° C within the treatment area center as of November 2019.

Temperatures peak in the area between the MWR-3 and MWR-4 well clusters and appear to cool radially from this location. Groundwater in the ERH performance monitoring wells remains too hot for microbial activity, ranging from approximately 48º to 63º C as of November 2019. FLS calculates that the optimal microbial temperatures (i.e. 40º C) will be reached throughout the target ERH zone in approximately September 2020, and reach 45º C by June 2020. Some discrete areas have cooled or expected to cool prior to those dates.

The recently installed upgradient perimeter cluster wells MWR-6, MWR-8 and MWR-9 as well as the downgradient perimeter cluster wells MWR-7, have reached optimal microbial temperatures as of the date of this report (i.e., 40º C). They also have elevated concentrations of TCE in groundwater. Combined, these factors make the perimeter wells good candidates for the Pilot Study.

Microbial Investigations

In tandem with supplemental investigation efforts, FLS conducted two separate microbial studies in the laboratory to evaluate the practicality of bioaugmentation alternatives on Site. First, a colony count of existing dehalococcoides species (DHC) (bacteria capable of breaking down chlorinated compounds) on Site was conducted; a second, a 25-week TCE breakdown bioaugmentation microcosm study was completed to evaluate the viability and optimal bioaugmentation conditions for the Site-specific media. The Microbial Insights Census Lab report is included as Attachment 2. The XDD Microcosm Study Report is included as Attachment 3.

Existing Microbial Conditions

July 8, 2019 FLS collected groundwater samples and had them analyzed by Microbial Insights, Inc., for the following:

Analysis	Purpose
Dehalococcoides (DHC)	Provide colony count of bacteria capable of breaking down chlorinated contaminants.
Functional Genes	Test if bacteria present have the functional genes necessary for the breakdown of TCE, and vinyl chloride (VC)
Methanogens	Test for methane producing bacteria.
Total Eubacteria	Test for the total amount of bacteria present in groundwater.

Due to ERH, groundwater temperatures for Site wells within the ERH treatment area remained too high for DHC bacteria at the time of sampling (+70ºC). Instead, FLS sampled the downgradient wells MWR-7I (50ºC), MWR-7S (50ºC), and MW-9 (20ºC) where water temperatures were cooler and TCE concentrations were at equivalent levels. These wells would serve as indicators of background microbial conditions in a high TCE environment (MW-9) outside the ERH treatment area and suggest how Site bacteria colonies might develop Site groundwater cools to lower temperatures.

The result of this study indicated that concentrations of DHC bacteria were low and suggest that complete reductive dechlorination of TCE to ethene on Site would be unlikely given the current existing microbial populations. Corresponding functional gene concentrations were also low and further support this conclusion. However, total bacteria concentrations were comparatively high indicating that microbial colonies are thriving in the vicinity of some of the monitoring wells that are approaching the optimal temperature range. Aside from temperature, the results indicate that stimulating the subsurface environment through the addition of amendments will likely enhance the colonization of these bacteria. Additionally, methanogen data suggests methane producing bacteria are prevalent, explaining on-Site methane concentrations. The following table summarizes results from the Microbial Insights analysis.

Sample Information

Client Sample ID:		**MWR-7S**	**MWR-7I**	**MW-9**
Sample Date:		07/09/2019	07/09/2019	07/09/2019
Units:		cells/mL	cells/mL	cells/mL
Analyst/Reviewer:		HT	HT	HT
Dechlorinating Bacteria				
Dehalococcoides	*DHC*	**4.00E-01 (J)**	**1.20E+00**	**5.00E-01 (J)**
tceA Reductase	TCE	<5.00E-01	<5.00E-01	<5.00E-01
BAV1 Vinyl Chloride Reductase	BVC	<5.00E-01	**1.00E-01 (J)**	<5.00E-01
Vinyl Chloride Reductase	VCR	<5.00E-01	<5.00E-01	<5.00E-01
Functional Genes				
Methanogens	MGN	**3.76E+02**	<4.60E+00	<4.60E+00
Phylogenetic Group				
Total Eubacteria	EBAC	**3.79E+07**	**1.34E+07**	**9.15E+05**

Legend:
NA = Not Analyzed NS = Not Sampled J = Estimated gene copies below PQL but above LQL I = Inhibited
< = Result not detected

It is conceivable that as temperatures reduce further to optimal microbial ranges (30º C-40º C) that numbers of DHC will rise. However, MW-9 data suggests that background conditions (20º C and high TCE content) alone, are not sufficient to generate DHC colony concentrations to levels that could reduce TCE and other chlorinated contaminants to target levels. Instead, bioaugmentation along with addition of amendments will be necessary to stimulate microbial activity to levels necessary to reduce TCE to target levels. This theory is supported by the microcosm study discussed in the section.

Microcosm Study

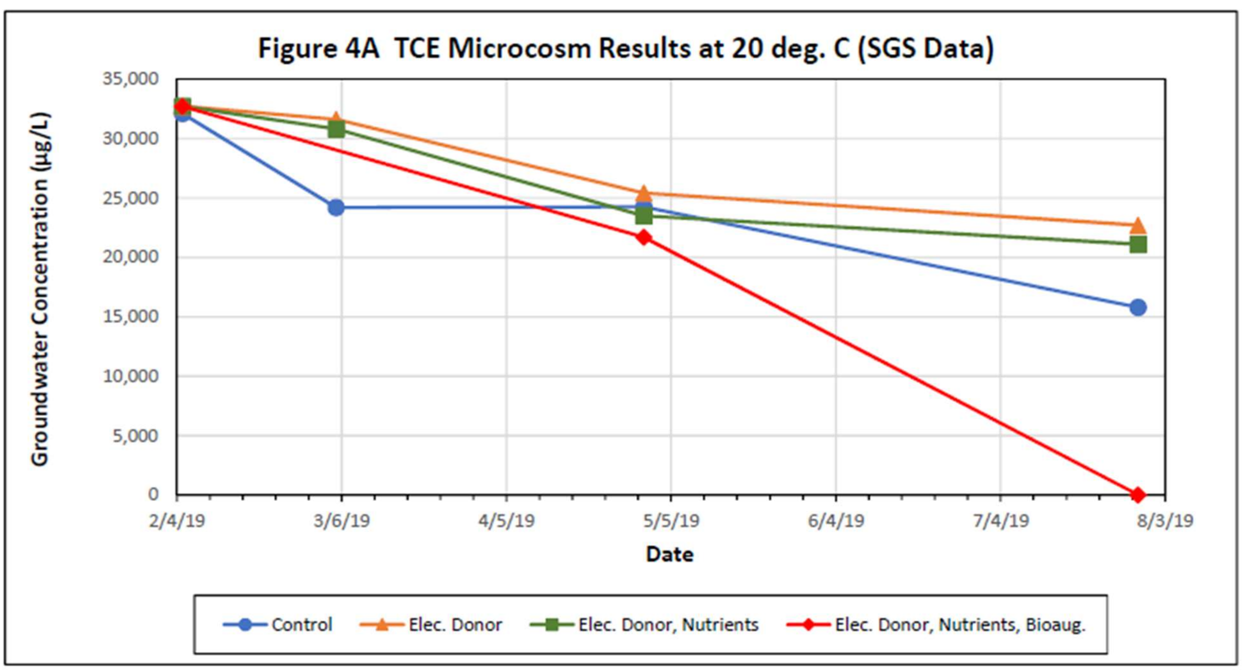
A microcosm study is a laboratory scale study that tests the ability of the Site bacteria to reduce TCE to daughter products and eventually innocuous compounds like ethene and carbon dioxide. A microcosm study conducted by XDD Environmental, Inc. of soil and groundwater collected during the supplemental site investigation began in February 2019 and ran for 25 weeks. The onsite media were divided into four test groups for comparison:

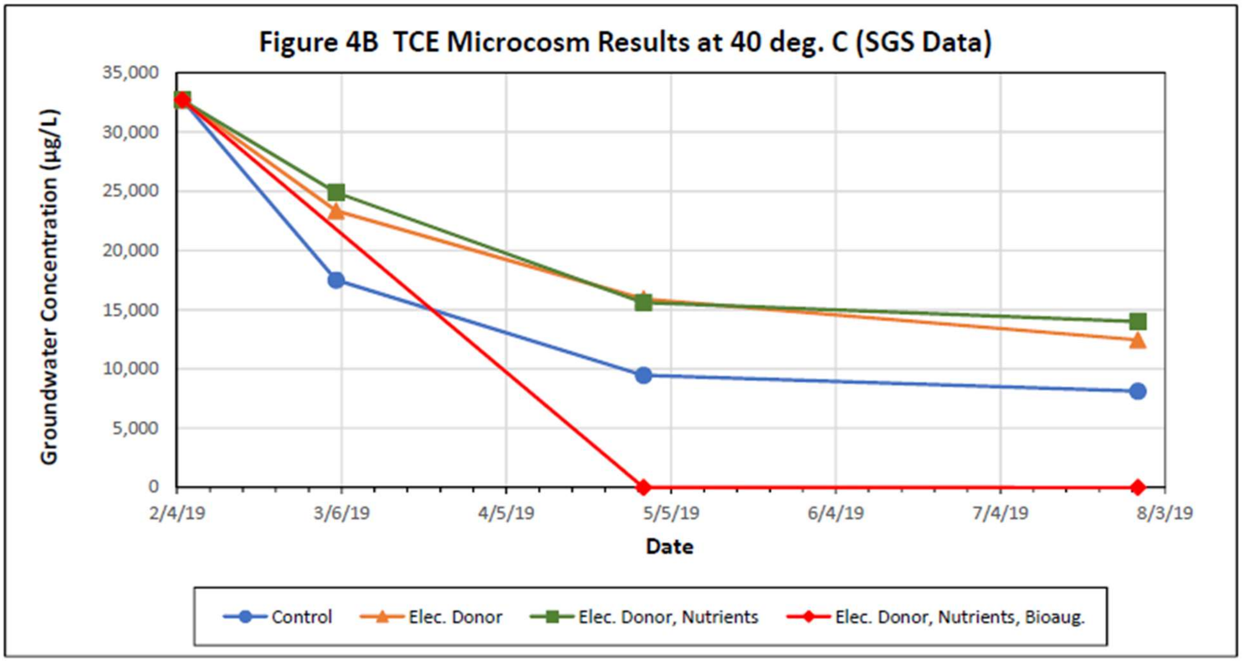
Group	**Purpose**
Control Batch	This is an untreated batch of soil that simulates existing conditions with no augmentation.
Added Food Source	An electron donor (food source) is added to act as food for the existing microbes.
Added Food Source and Nutrients	A food source and nutrients are added to the existing microbes.
Food Source, Nutrients, and DHC Bacteria	A food source, nutrients and a mixture of bacteria are added to the media. The mixture is a blend of different DHC known to fully breakdown chlorinated compounds. This simulates a full bioaugmentation strategy.

In addition to these four groups FLS also had the laboratory run parallel tests at two different temperatures, 20ºC (simulating ambient conditions) and 40ºC (simulating elevated temperatures from ERH).

The results at 25 weeks show biological breakdown of TCE to non-detect levels was viable in both the 40º C and 20º C groups, but only under full bioaugmented conditions (food, nutrients, and DHC bacteria). TCE reductions were insignificant compared to the killed controls for the food, and food & nutrients groups. But clearly the most effective reduction, and the only group to reach non-detect levels, was with the addition of a food source, nutrients and the DHC bacteria mixture (full bioaugmentation). In the fully augmented trials, TCE reduced to non-detect levels in both the 20º C and 40º C groups; however, TCE reductions were more rapid in the 40º C group.

Overall, this supports the theory that Site conditions alone will not support full reduction of TCE. Instead, full bioaugmentation will be required to attain TCE degradation and degradation of daughter products. The most effective bioaugmentation strategy appears to be the addition of electron donors (food), nutrients and a mixture of DHC bacteria when on-Site temperatures reach optimal levels around 40º C. Because temperatures decrease according to the difference between the current temperatures and background temperatures, there will be a long period of warmer groundwater that will promote faster biodegradation. We hope to take advantage of this warming condition to promote faster remediation.





Summary of Site Conceptual Model

Although TCE concentrations have rebounded since de-energizing the ERH system, potential DNAPL source areas appear to still be concentrated in the center-southwestern section of the Site. Specifically, the data shows the highest TCE concentrations are in the area directly west of the SSDS Blower Room, in the center of the former ERH treatment area (Figures 3A & 3B). Groundwater currently flows across the Site southwest and temperatures remain high post-ERH. Groundwater temperatures are largely above 50º C throughout the treatment area, but appear to cool radially from the center (i.e. MWR-2 and MWR-4 well cluster areas).

Currently, geochemical conditions favor reductive dechlorination, but key geochemical parameters (including the existing microbial population counts) indicate this process is likely being inhibited by the current high subsurface temperatures as well as a lack of environmental stimuli in the subsurface to enhance bacteria colonization and growth. As Site temperatures cool, it is likely natural biodegradation of TCE would increase. However, collectively, all microbial data indicates that bioaugmentation will be necessary on-Site in order to meet target contaminant cleanup levels. The microcosm data clearly shows the most effective (i.e. most rapid and complete) bioaugmentation strategy to be the addition of electron donors (food), nutrients and a consortium of bacteria including DHC when onsite temperatures reach optimal levels around 40º to 45^0 C. Logistically, this indicates bioaugmentation injections will be most effective if implemented when on-Site temperatures reach optimal microbial temperatures (i.e. 40^0 to 45^0) estimated to occur around September 2020 within the center of the former ERH treatment area..

Injection Plan

This section summarizes the proposed Pilot Study Injection Plan intended to fulfill the objectives presented in Section 1.2. The section will summarize the planned injection amendment dosing and composition, injection location and rationale, and summarized injection procedures.

Amendment Dosing and Composition

The results of the microcosm study show the optimal bioaugmentation strategy is to inject a consortium of bacteria including DHC, nutrients, and an electron donator "food source" at the 40º to 45^0 C optimal temperature. This Pilot Study seeks to implement this strategy under actual Site conditions and monitor effectiveness of the injections and treatment. XDD Environmental, Inc. was retained to conduct the pilot study and amendment dosing. Pilot Study amendment dosing includes the following:

- Electron donors
    - EOS_{QR} – 110 gallons (https://www.eosremediation.com/download/product_information/eos-products/EOSQR_2017.pdf)
    - EOS_{PRO} – 55 gallons (https://www.eosremediation.com/download/product_information/eos-products/EOSPro-Product-Sheet.pdf)
- Nutrients
    - Vitamin B12
    - Nitrogen
    - Phosphate
    - Trace minerals

- BAC-9 Microbe Consortium ($1x10^{11}$ cells/mL) – 40 liters total (20 liters per well) (https://www.eosremediation.com/download/product_information/eos-products/BAC-9-Product-Sheet.pdf)

Exact ratios and concentrations of these components will be finalized by XDD and FLS prior to injections based upon conditions at that time. Electron donor selection is inclusive of both aqueous (EOS_{QR}) and slow release compounds and hybrid compounds (EOS_{PRO}). Safety data sheets and specifications for the amendments above have been included in Attachment 1. This will provide immediate and long-term sources of electron donors for the dechlorinating microbial population. EOS_{QR} and EOS_{PRO}

Injection Locations
To meet the objectives of this investigation and monitor the chosen bioaugmentation strategy, the chosen location must meet the following criteria.

- Moderate to high concentrations of TCE
- Subsurface temperatures at or near the optimal microbe level (40º C)
- Near existing monitoring wells in order to monitor radius of influence
- Location accessibility for work

Table 1, evaluates each existing monitoring well for these key criteria. As of the date of this report wells within the influence of the former ERH treatment area that meet all criteria are MWR-7S, MWR-7I, MWR-6S, MWR-6I, MWR-8S, MWR-9S, and MWR-9I. The wells consistently show moderate to high TCE concentrations (or high concentrations in the case of the recent RI wells), subsurface temperatures within the optimal range, near potential monitoring wells, anerobic conditions, and are in accessible areas.

The current plan is to study bio-injections at several areas within the former ERH treatment area, or area influenced by ERH, to better understand the application and interaction of the bioaugmentation on the subsurface environment. Given the unique characteristics of this Site having been heated to over 100 degrees Celsius for over one year and still retaining the heat a year later, there are several areas that are candidates for the pilot study. The MWR-7 cluster has the added benefit of being downgradient from the TCE source area, which means bio-injections in this area could serve as a form of "plume control," potentially remediating TCE contamination as it leaves the Site. Monitoring well cluster locations MWR-6 and MWR-9 are located within the immediate vicinity of the TCE "source area" with elevated concentrations of TCE in both soil and groundwater. This area will provide a one-time shot at understanding how bio-injections will work on the high concentrations TCE at the targeted optimal temperature. Other areas of the Site that may be included in the study include MW-4 which may provide information on bio-injection performance in groundwater closer to ambient temperatures and higher oxygen levels immediately outside the treatment area. A copy of the submitted United States Environmental Protection Agency (USEPA) Underground Injection Form is provided under Attachment 4. Proposed injection well areas and well details are provided on Figure 6.

Table 1. Injection Well Criteria

Well ID	Max TCE Concentration (ug/L) in groundwater _Post-ERH 8/31/2018		Temp. C 11/11/2019	
Upgradient & Outside Treatment Area Wells				
Upgradient Site Wells				
MW-1	360		25.6	X
MW-1I	28.4		25.9	X
MW-4	2310	X	20.5	X
MW-5	2.1		18.3	X
MW-16	184		18.1	X
Former ERH Treatment Zone Wells				
MWR-1S	5,390	X	52.5	
MWR-1I	2,000		48.4	
MWR-2S	154,000	X	56.5	
MWR-2I	29,200	X	53.2	
MWR-3S	18,100	X	63.2	
MWR-3I	34,700	X	59.7	
MWR-4S	97,500	X	54	
MWR-4I	261,000	X	53.8	
MWR-5S	50,900	X	56.2	
MWR-5I	3,250		52.6	
MWR-6S	7,750	X	36.8	X
MWR-6I	475,000	X	39.1	X

Well ID	Max TCE Concentration (ug/L) in groundwater _Post-ERH 8/31/2018		Temp. C 11/11/2019	
MWR-7S	9,790	X	44.3	X
MWR-7I	14,700	X	39.1	X
MWR-8S	1,480		40.1	X
MWR-8I	9,540	X	36.7	X
MWR-9S	20,200	X	42.5	X
MWR-9I	61,900	X	38.4	X

X – Indicates the well location meets specific criteria.

Injection Method

Injections will be conducted using pulsed injections using Wavefront's pressure pulse technology (Primawave^{TM}) via the Sidewinder tool (or equivalent). Pulsing maximizes contact between the substrate and amendments and promotes superior distribution throughout the aquifer. This will also provide insight into the potential radius of influence and dispersal capacity and test the capacity of the monitoring wells to act as injection points and/or whether there is a potential for the monitoring wells to short circuit during injections.

Injection Volume and Pressure
Based on the current understanding of TCE contamination in the area surrounding the MWR-6, MWR-7 and MWR-9 well clusters, FLS has calculated approximately 2,000 gallons of amendment per well to be injected during this pilot study. Typical injection pressures during pulsed injections are low, on the order of 2 psi to 15 psi.

Injection Depth Interval
The Pilot Study injections in MWR-7S, which is screened from 25 – 35 ft. bgs, will target the 25-35 ft. bgs interval, and MWR-7I, screened between 35 – 45 ft. bgs will target the 35 – 45 ft. bgs interval. If necessary, packers may be used to isolate screen intervals. Some or all of the screen length may be used to target the injections. The Pilot Study injections in MWR-6S, MWR-6I and MWR-9S and MWR-9I will target the 20 to 30 and 30 to 40-foot interval in the shallow and intermediate wells, respectively.

Schedule & Dosing Frequency Intervals
For the purposes of this Pilot Study, FLS anticipates conducting six injection events lasting approximately 8 days. If groundwater data collected from the other Site monitoring wells indicates favorable temperature conditions for injection these wells may be added on extending the injection event.

Monitoring

FLS plans to conduct two types of monitoring during this Pilot Study: process and performance. Process monitoring will be used to assess whether the system is meeting the design objectives.

Performance monitoring will be used to assess the effectiveness of the treatment in degrading TCE within the treatment area. Proposed process and performance monitoring locations are depicted on Figure 7. Monitoring locations and frequency are summarized in Table 2.

Process Monitoring
Process monitoring will evaluate the operational objectives of the Injection Plan. This includes determining the effective distribution of amendments (i.e. radius of influence) and the retention of the amendments in the target area.

Pressure transducers will be installed into select wells in the area surrounding the injection locations to monitor well head pressure, conductivity, and temperature. Transducer measurements will be used to monitor the progress of the injection and the distribution of the amendment suite from the injection sites. Transducers will be fitted in monitoring wells at varying distances and directions from the injection site so as to provide several "checkpoints" to evaluate amendment distribution and radius of influence. Monitoring wells selected to be fitted with transducers are shown on Figure 8. Pressure transducers will be installed several days prior to injections in order to provide baseline conditions for the process monitoring. Transducers will record pressure, conductivity and temperature readings every 5 minutes from the days prior to, during, and post injection for a period of one month.

In addition to transducer measurements, FLS will field screen geochemical parameters weekly using a flow-through vessel probe (e.g. Horiba). Monitoring wells to be field screened for geochemical parameters are shown on Figure 7. Using a peristaltic pump, FLS will sample groundwater from select monitoring wells and record the following geochemical parameters:

- Temperature
- pH
- Conductivity
- Oxidation reduction potential
- Turbidity
- Dissolved Oxygen
- Total dissolved solids and
- Salinity

Performance Monitoring
Performance monitoring will evaluate the effectiveness of the injection plan on reducing TCE concentrations near the injection site. FLS will sample select groundwater monitoring wells in the area around the injection wells and analyze for Volatile Organic Compounds (VOCs) including TCE and all daughter products, ethane, ethene, carbon dioxide, and methane (Figure 6). Sampling for bacteria and nutrients may be conducted based upon review of performance monitoring results. Performance monitoring will occur at monthly intervals beginning one month after the injections.

Table 2. Process and Performance Monitoring Locations and Frequency

		Process Monitoring		Performance Monitoring
	Well ID	Transducers	Field Screening	Confirmation Sampling
Off Site	MW-8I	--	--	--
	MW-9	--	--	--
	MW-11I	--	--	--
	MW-17I	--	--	--
	MW-17	--	--	--
	MW-10A	--	Weekly	Monthly
	MWR-7I	--	Weekly	Monthly
	MWR-7S	--	Weekly	Monthly
On Site	MW-1	Continuous*	Weekly	Monthly
	MW-1I	Continuous*	Weekly	Monthly
	MW-16	--	--	Monthly
	MW-4	Continuous*	Weekly	Monthly
	MW-5	--	--	Monthly
	MWR-1I	--	Weekly	Monthly
	MWR-1S	--	Weekly	Monthly
	MWR-2I	Continuous*	Weekly	Monthly
	MWR-2S	Continuous*	Weekly	Monthly
	MWR-3I	--	Weekly	Monthly
	MWR-3S	--	Weekly	Monthly
	MWR-4I	Continuous*	Weekly	Monthly
	MWR-4S	Continuous*	Weekly	Monthly
	MWR-5I	Continuous*	Weekly	Monthly
	MWR-5S	Continuous*	Weekly	Monthly
	MWR-6I	--	Weekly	Monthly
	MWR-6S	--	Weekly	Monthly
	MWR-8I	--	Weekly	Monthly
	MWR-8S	--	Weekly	Monthly
	MWR-9I	--	Weekly	Monthly
	MWR-9S	--	Weekly	Monthly

*Transducer measurements will be collected and logged every 5-minutes from days prior to the injections extending to one-month post-injection.

Findings and Optimization

The results of this Pilot Study, including all process and performance monitoring data, will be compared to the objectives stated in the beginning of this document. A successful pilot test will allow FLS to evaluate the proposed injection plan's effectiveness under actual Site conditions, this includes:

- Determining the injection radius of influence/distribution capacity
- Determining amendment persistence
- Determining optimal injection frequency
- Evaluating contaminant degradability
- Evaluating generation of byproducts
- Evaluating geochemical impact to aquifer

FLS will use this data to identify site-specific challenges and incorporate lessons learned into the full scale enhanced *in situ* bioremediation design in the form of a Remedial Design Plan (RDP). The RDP will adhere to NYSDEC report guidelines, and provide all necessary analyses detailed in this workplan as well as findings from this Pilot Study. The Site will continue to be managed as per the approved the governing documents in the March 2015 Remedial Action Work Plan (RAWP). The remedial action program provided in the March 2015 RAWP including performance monitoring and schedule for enhanced *in-situ* bioremediation is amended with this document and any forthcoming remedial design documents. A schedule for implementation of the pilot study is provided below.

Date	**Task**
March 2020	Enhanced Bioremediation Pilot Study
March - June 2020	Performance Monitoring (16-20 weeks)
June-July 2020	Submit Full Scale Enhanced *in situ* Bioremediation Design Plan

Workplan NYS Remedial Engineer Certification

I, Arnold F. Fleming, P.E., certify that I am currently a New York State registered professional engineer as defined by 6 NYCRR Part 375 and that this Pilot Study was prepared in accordance with all applicable statues and regulations and in substantial conformance with DER Technical Guidance for Site investigation and remediation (DER-10).

I, Arnold F. Fleming, P.E. certify that this Pilot Study was prepared by me or persons working under my direct supervision.

2/27/2020
Date

Arnold F. Fleming
NYS Professional Engineer
License Number 050411

STATE OF NEW YORK ARNOLD F. FLEMING 050411 LICENSED PROFESSIONAL ENGINEER

Please feel free to contact me if you have any questions or need any additional information.

Sincerely,
Fleming-Lee Shue, Inc.

Arnold F. Fleming, P.E.
Remedial Engineer

Daniel DiRocco
Senior Project Manager

Enclosures:

Figure 1	Site Location
Figure 2	Site Plan with Monitoring Well Network
Figure 3A	TCE Groundwater Exceedances Shallow Wells
Figure 3B	TCE Groundwater Exceedances Intermediate Wells
Figure 4A	TCE Microcosm Results at 20°C (in-text)
Figure 4B	TCE Microcosm Results at 40°C (in-text)
Figure 5	Proposed Injection Areas and Process Flow Diagram
Figure 6	Proposed Performance Monitoring Locations
Table 1	Injection Well Criteria (in-text)
Table 2	Process and Performance Monitoring Locations and Frequency (in-text)
Attachment 1	Amendment Safety Data Sheets

Attachment 2 Microbial Insights Census Lab Report
Attachment 3 XDD Microcosm Study Report
Attachment 4 USEPA Underground Injection Form

cc: R. Price/R. Champagne - Beam Suntory, Inc.
J. O'Connell/N. Crawford, P.E. - NYSDEC
M. Ohm/E. Brooks - Bryan Cave Leighton Paisner LLP
D. DiRocco/S. Panter - Fleming-Lee Shue, Inc.