Aztech Environmental
TECHNOLOGIES
Woman Owned Business

Pilot Test Summary Report
and
Proposed Remedial Injection Plan

Jack's Drycleaners Site

Site No. 734112
Village of Brewerton
Town of Cicero
Onondaga County
New York

April 18, 2017

Prepared for:
New York State Department of Environmental Conservation
615 Erie Boulevard West
Syracuse, NY 13204-2400
Attn.: Stephanie Fitzgerald

NEW YORK STATE OF OPPORTUNITY. Department of Environmental Conservation

Prepared By:
Aztech Environmental Technologies

Thomas Giamichael
Hydrogeologist/ Project Manager

For: Bill Toran
Sr. Project Manager

REMEDIATION SOLUTIONS

ENVIRONMENTAL CONSULTING

DRILLING APPLICATIONS

5 McCrea Hill Road
Ballston Spa, NY 12020
p 518.885.5383
f 518.885.5385

aztechenv.com

TABLE OF CONTENTS

APPENDICES

1.0 Introduction

1.1 Project Background

Aztech Environmental Technologies (Aztech), was contacted by the New York State Department of Environmental Conservation (NYSDEC) to perform an injection pilot test study for the application of an enhanced bio-remediation at the Jacks Drycleaner site (NYSDEC Site No. 7-34-112).

The work assignment was conducted under the Callout ID 121119 for the NYSDEC Standby Remedial Contract (C100904). The field activities summarized in this report were perform from June 27 to July 29, 2016.

1.2 Objectives

The purpose of the pilot test investigation was to assess and quantify the parameters under which the site's overburden and bedrock formations may accept the application of enhanced anaerobic bioremediation substrates through varied injection techniques. This information coupled with historical data from the site will assist in the development of a successful full scale remedial injection strategy at the site. The pilot test consisted of installing one (1) overburden injection well, one (1) bedrock injection well, four (4) piezometers and assessing dedicated injection well and direct push injection techniques.

The following sections contain a detailed summary of the injection well installations and a report of findings from the varied injection application techniques. Additionally, a proposed full scale enhanced bio-remediation injection plan is detailed herein.

2.0 Site Background

2.1 Site Location and Description

The site is an active dry cleaning facility located at 9628 Brewerton Road in the Village of Brewerton, Town of Cicero, Onondaga County, New York (**Appendix A - Figure 1**). The general topography is flat with a slight downward gradient to the east-southeast. The Oneida River is located approximately 1,000 feet northeast of the site.

Surrounding site use along Brewerton Road is primarily commercial. The immediate area east and southeast of Jack's Drycleaners consists of low-lying wet areas, open grassy areas and wooded land. A residential subdivision area is located further to the east and southeast.

2.2 Geology and Hydrogeology

Review of the geologic map of New York, Finger Lakes Sheet published by the University of the State of New York, the State Education Department, dated 1970, indicates that the site boundary lies within the Clinton Group, which is Silurian in age, and consists of the Herkimer Sandstone; Kirkland Hematite (grayish-red, quartzose, calcareous, hematitic dolomite); Willowvale Shale (gray to greenish-gray fossiliferous shales); Westmoreland Hematite; Sauquoit Formation (sandstone, shale); and the Oneida Conglomerate.

According to the Natural Resources Conservation Service (NRCS) in Onondaga County, the site is underlain by the Collamer silt loam, 2-6 percent slopes. This soil is usually located within lake plains and is described as being moderately well drained. It has formed from a parent material of silty and clayey glaciolacustrine deposits. The downgradient portion of site is also underlain by the Madrid fine sandy loam, 2-8 percent slopes. This soil is usually located within drumlinoid ridges, hills, and till plains and is described as being well drained. It has formed from a parent material of loamy till derived mainly from sandstone and limestone.

Based on previous subsurface investigations conducted by Aztech and others, the site is underlain by "silt and clay" with alternating layers of fine to coarse sand with fine gravel.

Groundwater at the site is typically encountered at a depth ranging from 2 to 9 feet below ground surface (fbgs).

2.3 Previous Investigations

Previous investigations at the site identified a chlorinated volatile organic compound (CVOC) groundwater contamination plume originating from a septic system located behind the drycleaner building and extending approximately 600 feet to the southeast. The CVOC plume has been identified in the overburden soil and the bedrock at the site (**Figure 2**).

The site has been determined through feasibility studies to be a potentially successful candidate for enhanced bioremediation. Historical groundwater data from the site demonstrates that natural attenuation by microbial de-chlorination at the site has occurred. However, due to the current lack of available electron donors and moderate anaerobic conditions at the site, complete de-chlorination of the site is unlikely to occur without groundwater conditioning enhancements and bio-augmentation.

Additional site background information and enhanced bioremediation feasibility findings can be found in the following documents:

- *Annual 2017 Groundwater Monitoring Report, March 2017*
- *Pre-Remedial Investigation Report*, prepared by Aztech, April 2013
- *Feasibility Study (734112), prepared by EA Engineering, P.C., May 2012*

3.0 Pilot Test Injection Well and Piezometer Installations

3.1 Pilot Test Well Installations

Between June 27 and June 29, 2016, an Aztech drill crew under the supervision of an Aztech geologist installed one (1) overburden injection well, one (1) bedrock injection well and four (4) piezometers at the site. The locations of the pilot test injection wells were installed within an area determined to be representative of the site subsurface formation. Additional location factors were determined based upon site access and proximity to the existing onsite well infrastructure. The locations of the injection wells and piezometers installed during this event are presented on **Figure 3**.

Installation methods and construction details for each injection well are described in the following section.

3.1.1 Overburden Injection Well Construction

The overburden injection well (OBIW-1) was installed using a 3230 track-mounted Geoprobe® drill rig. Soil sampling was completed in the overburden material using hydraulically driven direct-push soil core sample techniques. Continuous soil samples were retrieved in acetate liners using a 2 ¼-inch outer diameter (O.D.) Macrocore® sampler 60-inches in length.

Soil samples were classified by an Aztech geologist and analyzed for total VOCs during boring operations using a photo-ionization detector (PID), equipped with a 10.6 eV lamp and calibrated to an isobutylene standard. Representative portions of soil core samples obtained during the boring advancement were sealed in clean re-sealable plastic bags and classified. After allowing for equilibration of the samples, the headspace in each sample was scanned with the PID by inserting the probe tip into the plastic bag. Soil headspace readings in OBIW-1 ranged from 2.0 parts per million (ppm) to 3.4 ppm at depth ranging from 5 fbg to 19.5 fbg, respectively.

Continuous soil samples were terminated at a depth of approximately 20 fbg. At this depth direct push refusal was encountered and samples retrieved consisted of weathered bedrock shale.

The borehole was then over drilled from the surface to 20 fbg using 4 ¼-inch hollow stem augers to accommodate installation of the injection well. The injection well was completed as a two (2) inch diameter PVC well with 10 feet of 0.020-inch well screen. The annular space surrounding the well screen was packed with clean #1 filter pack sand to a depth above the screened interval and a hydrated bentonite seal placed immediately above the sand pack. To further protect the well from failure during injection, the remainder of the annular space above the seal was filled with cement grout.

Injection well OBIW-1 was fitted with a 2-inch male camlock and expandable gripper cap. The well was completed at the surface with a flush mount roadbox.

Details of the well construction, headspace readings and soil classification are presented in **Appendix B – Boring Logs and Well Construction Details**.

3.1.2 Bedrock Injection Well Construction

The Bedrock injection well (BRIW-1) was installed using a 3230 track-mounted Geoprobe® drill rig. Soil sampling was completed in the overburden material using hydraulically driven direct-push soil core sample techniques. Continuous soil samples were retrieved in acetate liners using a 2 ¼-inch O.D. Macrocore® sampler 60-inches in length.

Soil samples were classified by an Aztech geologist and analyzed for total VOCs during boring operations using a PID. Soil headspace readings in BRIW-1 ranged from 1.0 ppm to 2.3 ppm at depths ranging from 3.4 fbg to 15 fbg, respectively.

Continuous soil samples were terminated at a depth of approximately 19.1 fbg. At this depth direct push refusal was encountered and samples retrieved consisted of weathered bedrock shale.

The borehole was then over drilled from the surface to 20 fbg using 4 ¼-inch hollow stem augers. A 3 ⅞-inch roller bit was advanced to 33 fbg to create a rock socket to accommodate the installation an injection well. The socket was flushed with clean water to remove all debris prior to setting the well.

The injection well was completed as a two (2) inch diameter PVC well with 10 feet of 0.020-inch well screen. The annular space surrounding the well screen was packed with clean #1 filter pack sand to a depth above the screened interval but still within the observed bedrock and sealed with hydrated bentonite immediately above the sand pack. The remainder of the rock socket located within weather bedrock and the overburden borehole annulus were filed with a cement grout mixture to further seal and protect the well from failure during injection.

Injection well BRIW-1 was fitted with a 2-inch male camlock and expandable gripper cap. The well was completed at the surface with a flush mount roadbox.

Details of the well construction, headspace readings and soil classification are presented in Appendix B – Boring logs**.**

3.1.3 Piezometer Construction

A total of four (4) piezometer wells (P-1 to P-4) were installed at radial distances of 5, 10, 15 and 20 feet from the overburden injection well OBIW-1. The location of each piezometer is presented of Figure 3.

Each piezometer was installed using a 3230 track-mounted Geoprobe® drill rig. Soil boring advancement and sampling was completed in the overburden material using hydraulically driven direct-push soil core sample techniques. Continuous soil samples were retrieved in acetate liners using a 2 ¼-inch O.D. Macrocore® sampler 60-inches in length.

Soil samples were classified by an Aztech geologist and analyzed for total VOCs during boring operations using a PID. The highest observed soil headspace readings in ranged from 6.1 ppm to 6.4 ppm in piezometers P-2 and P-1, respectively.

Continuous soil samples were terminated at a depth of approximately 20 fbg at each of the four (4) locations. Sampling was terminated at this depth to match the overburden well OBIW-1. However, refusal was encountered shallower than 20 fbg in borings P-2 (19.5 fbg) and P-4 (19.0 fbg)

Following sampling, each piezometer well was completed as a one (1) inch diameter PVC well with 10 feet of 0.020-inch well screen. The annular space surrounding the well screens was packed with clean #1 filter pack sand to a depth above the screened interval. The remainder of the borehole annulus was filled with a hydrated bentonite seal placed immediately above the sand pack and to the ground surface.

Each piezometer was fitted with a 1-inch expandable gripper cap and completed at the surface with a flush mount roadbox.

Details of the well construction, headspace readings and soil classification are presented in Appendix B – Boring logs**.**

3.2 Well Development

The newly installed injection wells and piezometers were developed by surging and bailing to remove fines and increase communication with the surrounding aquifer. Additionally a Waterra® pump and $^3/_8$-inch diameter tubing equipped with a check valve was utilized to evacuate purge water from the wells. A minimum of 10 well volumes were removed from each well. However, the bedrock injection well (BRIW-1) went dry after removing approximately 15 gallons of water.

No non-aqueous phase liquid (NAPL) or odor was observed during well development activities. Development water was discharged directly to the ground surface.

4.0 Pilot Test Summary

4.1 Pilot Test Overview

Between July 26 and July 29, 2016, Aztech performed a pilot injection test in the newly installed overburden injection well (OBIW-1), bedrock injection well (BRIW-1), and three (3) direct push injection location (Figure 3).

The injections were performed by connecting to the desired injection point and administering injectate substrate from a batch tank to the injection point through either a centrifugal pump or piston grout pump. A data record of flow rates, injection pressures and general observations was maintained at each point throughout the duration of the injections.

Injectate substrate consisted of emulsified vegetable oil (EVO) supplied by Terra System, Inc. and water. The EVO was supplied in two (2) 55 gallon drums and was diluted with water at a ratio of 1:20 using a dosatron® to create a 5% solution of injectate.

A cumulative total of approximately 2,574 gallons of injectate and flush water were distributed between the injection wells and direct push points during the pilot test activities. The following sections detail the observations from each injection point.

4.2 Real-time Data Logging

During the pilot test injections real-time data was collected from four (4) In-situ Aqua Troll 200® data loggers. This model data logger is capable of recording water level, pressure, conductivity and salinity in real-time.

The data loggers were deployed in each of the piezometers, which were previously installed at prescribed radial distances of 5, 10, 15 and 20 feet from overburden injection well OBIW-1.

The data loggers were activated on July 26, 2017 at 11:22 AM, prior to injections, to collect background data and were allowed to record any changes throughout the duration of the pilot test injection process. For the purpose of this pilot test, the data loggers were calibrated to record readings at 5 minute intervals.

The primary objective of the data loggers was to help accurately assess the real-time radius of influence achieved by the injections and accurately disseminate between the injection pressure wave and actual distribution of the EVO by means of changes to conductivity and salinity.

Relevant data from the data loggers for each of the injections conducted is provided in the following summaries. However, data from these devices were primarily used for assessing the distribution of injectate only within the overburden injection well (OBIW-1).

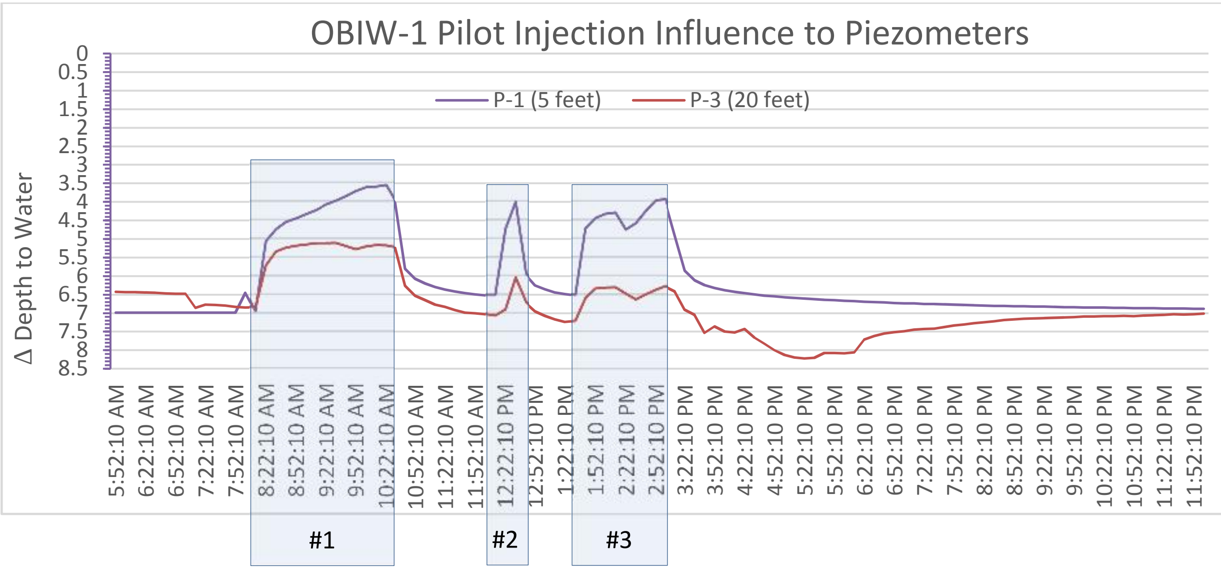
4.3 Overburden Well Injection

On July 27, 2016 Aztech performed three (3) pilot test injections at varying pressures and flowrates on overburden injection well OBIW-1. The tests consisted of injecting EVO, diluted to a 5% solution, into OBIW-1 by means of a trash pump connected to the well head using a cam fitting.

During the tests, Injection pressures varied from 4 pounds per square inch (psi) to 8 psi and Injection flow rates varied from 2.4 gallons per minute (gpm) to 10.2 gpm. The ability of the well to receive the injectate within these parameters was documented by Aztech personnel onsite. A review of the flow rate and pressure data indicated that an injection flow rate of approximately 5 gpm and pressures between 4 psi to 7 psi were optimal. This approximately equates to a 1:1 ratio of pressure (psi) to flow rate (gpm). Minor surfacing of injectate through pathways around the well seal were observed at a sustained injection pressure and flow rate of 8.5 psi and 10.2 gpm, respectively. A combined total of 1,199 gallons of EVO and water were injected in 242 minutes.

During the course of the pilot tests performed on OBIW-1, the In-Situ Aqua Troll 200 data loggers were recording. A review of the data from the loggers indicated that the injectate affected groundwater conditions in Piezometer P-3, which was located 20 feet from injection well OBIW-1. Groundwater elevation within P-3 raised in direct response to injection pressures and flow rates applied to injection well OBIW-1. Additionally, the groundwater parameters of conductivity and salinity increased indicating a minimum measured radius of influence (ROI) of 20' was achieved.

The following graph shows the real-time injection influence on groundwater trends from the three (3) pilot test injections performed. For the purpose of this graph measurements are only shown from piezometers P-1 (5 feet from OBIW-1) and P-3 (20 feet from OBIW-1). The start and stop of each respective injection is indicated on the graph within the boxes labeled #1, #2 and #3.



After the first injection interval (#1) was stopped on OBIW-1, the recess time of injectate mounding was measured. Overall mounding in OBIW-1 was found to recess to near static conditions within 1.6 hours of injection termination.

In summary, the data collected from the injection pilot test performed on OBIW-1 is considered favorable. Application of a full scale injection within the overburden soils and weathered bedrock at the site based on the well design and injection observations from OBIW is possible within this model.

4.4 Bedrock Well Injection

On July 28, 2016, Aztech performed a single pilot test injection on bedrock injection well BRIW-1. The test consisted of injecting EVO, diluted to a 5% solution, into BRIW-1 by means of a trash pump connected to the well head using a cam fitting.

Several unsuccessful attempts were made to administer the injectate using the method describe above. Injectate was recorded at a sustained pressure of 30 psi for 15 minutes at the well head. However, no measurable amount of injection fluid was taken by the well and surrounding bedrock during that time.

In general, this well had been intentionally installed into competent bedrock. This was done to determine if injection was feasible within bedrock wells that were installed into competent rock, representative of the site, with the weathered bedrock properly sealed off. Bedrock well (BRIW-1) demonstrated that bedrock wells at the site constructed exclusively for injection purposes may not be favorable. Rather, a combination overburden and partial bedrock injection well designed to straddle the overburden and weathered bedrock interface may optimize injectate distribution into the formation.

4.5 Direct Push Injections

On July 28, three (3) direct push injections were conducted at the site to determine the feasibility of injecting EVO, diluted to a 5% solution to the subsurface directly through drill tooling. Direct push injections were conducted using a Geoprobe® 6610 drill rig and 2 ¼-inch drill rods equipped with a reusable injection probe. Injection fluids administered directly through drill tooling generally require higher injection pressures. This is due to the compression and smear of soils as the drill tooling is advanced. To allow for higher injection pressures, a Groundhog® piston grout pump model GHG5PF was utilized to deliver the injectate to the injection point. Each injection point was sealed to the surface with bentonite following the injection testing.

4.5.1 Injection Location GP-1

Geoprobe injection point (GP-1) was installed approximately 15 feet downgradient from monitoring wells MW-13 and MW-9. The injection at GP-1 was conducted using a "topdown" injection method. Tooling was initially advanced to four (4) fbg and then injections were briefly performed in two (2) foot intervals to a total depth of 18 fbg. At each depth, the tooling was slightly retracted to expose the injection point.

Influence from the injection was immediately observed in nearby overburden monitoring well MW-9 by the presence of EVO within the well. Minor influence was noted in bedrock monitoring well MW-13. The following table summarizes the injection volumes and pressures observed at the various depths.

GP-1						
Depth	**PSI**	**Gallons**	**Start**	**Stop**	**GPM**	**Notes:**
4'	40	30	8:35	8:38	10.00	Significant Injectate surfacing around drill rods.
6'	40	30	8:45	8:48	10.00	
8'	40	25	8:54	8:56	12.50	
10'	40	110	9:02	9:11	12.22	Formation taking injectate with some surfacing.
12'	55	271	9:20	9:44	11.29	
15'	60	50	10:04	10:08	12.50	
17'	60	50	10:14	10:19	10.00	
18'	40	50	10:26	10:30	12.50	

In summary, the pilot test injection at GP-1 was successful. A total of 616 gallons were injected in 54 minutes at this location. However, at each interval, an initial high pressure of 120 psi was required to get injectate moving through the point. Once the injectate was flowing, the pressure dropped and maintained constant 40 psi to 60 psi throughout the duration. The average injection pressure at GP-1 was 46.8 psi at an average flow rate of 11.38 gpm. This approximately equates into a 4:1 pressure to flow rate ratio, which is significantly higher in contrast to the pilot injection performed at injection well OBIW-1.

4.5.2 Injection Location GP-2

Geoprobe injection point (GP-2) was installed approximately 20 feet cross-gradient from monitoring well MW-7 and 35 feet cross-gradient from piezometer P-3. Based on the previous results experienced at GP-1, this injection point was intended to exclusively target the weathered bedrock zone. The goal was to assess this portion of the formations ability to accept injectate using the direct push method as previously described.

The tooling was advanced to refusal at 23 fbg and retracted back to 22 fbg for the injection. A total of 532 gallons of injectate were administered in 37 minutes at this depth. An initial high pressure of 120 psi was required to get injectate moving through the point. Then maintained a constant pressure of approximately 40 psi throughout the duration of the injection. The average flow rate was approximately 14 gpm.

Influence from the injection was gradually observed in nearby overburden monitoring well MW-7 and piezometer P-3 by the presence of EVO slowly rising toward the surface and spilling out of the well casing. It is suspected that the injectate was traveling through the weathered and fractured rock to the nearby well screens. At the termination of the injection the surfacing fluids immediately retreated.

4.5.3 Injection Location GP-3

Geoprobe injection point (GP-3) was installed approximately 6 feet west of GP-2. This location was approximately 18 feet cross-gradient from monitoring well MW-7 and 28 feet cross-gradient from piezometer P-3. It was determined in the field to advance this point separately from GP-2 as opposed to retracting the tooling to the desired depth in the same borehole as in a "bottom up" fashion direct push injection. The reasoning was because the weathered rock layer at GP-2 was so effective at taking the injectate, that a bottom up injection would likely bypass the targeted overburden soils and take the preferential pathway down the borehole and back to the weathered bedrock.

In an effort compare against the results observed at GP-2, injection point GP-3 was driven shallower and intended to exclusively target the overburden soils. The goal was to assess this portion of the formations ability to accept injectate using the direct push injection method as previously described.

The tooling at GP-3 was advanced to a depth of 13 fbg and retracted back to 12 fbg for the injection. A total of 227 gallons of injectate were administered in 16 minutes at this depth. Again, an initial high pressure of approximately 120 psi was required to get injectate moving through the point. Then the pressure reduced to approximately 40 psi throughout the duration. The average injection flow rate was approximately 14 gpm.

Influence from the injection was observed in nearby overburden monitoring well MW-7 and piezometer P-3 by the presence of EVO slowly rising within the well casings. However, the influence was significantly less that previously observed at GP-2. At the termination of the injection the surfacing fluids immediately retreated.

4.6 Injection Pilot Test Summary and Conclusion

Between July 26 and July 29, 2016, Aztech performed pilot test injections in the newly installed overburden injection well (OBIW-1), bedrock injection well (BRIW-1), and three (3) direct push injections. A total of 2,574 gallons of injectate consisting of a 5% solution of EVO and water were administered to the various points during the injections testing.

The following summarizes relevant data collected and observations during the injection pilot test:

- Overburden Well (OBIW-1) was able to readily accept the injectate without failure or "day lighting" of the injection fluids. The well performed optimally when receiving injectate at a rate of approximately 5 gpm and less than 5 to 7 psi.

- A total of 1,199 gallons of injectate were administered to OBIW-1 in 242 minutes. During that time an observed ROI of greater than 20 feet was readily achieved at OBIW-1 and documented by the data-loggers set within the surrounding piezometers.

- The bedrock injection well (BRIW-1) was installed exclusively into competent rock and was unable to receive a measureable amount of the injectate.

- The three (3) direct push injections received a cumulative total of 1,375 gallons of injectate.

- Direct push injection location GP-1 consisted of a top down injection that ranged from 4 fbg to 18 fbg. Injection at this location required a significantly higher pressures of approximately 120 psi to get injectate flowing through the injection point. Approximately 40 psi was required to maintain the injection at a flow rate of approximately 11 gpm.

- Direct push injection locations GP-2 and GP-3 were advanced to specifically target the bedrock and overburden formations, respectively. Injection pressures of approximately 120 psi were required to get injectate flowing through the injection point and approximately 40 psi was required to maintain the injection at a flow rate of approximately 14 gpm.

- An approximate ROI of 30 feet was observed during the GP-2 and GP-3 injections.

In conclusion, the pilot testing indicated that the overburden injection well (OBIW-1) demonstrate the best characteristics for the injection of an enhanced anaerobic bioremediation substrate to be bio-augmented with dehalococcoides bacteria for the following reasons.

Each of the direct push injections exhibited injection pressures that were much too high to sustain the bacteria without destruction. Injection pressures above 7 to 8 psi can be destructive to the live dehalococcoides bacteria. Injection well (OBIW-1) exhibited injection pressures of 5 psi with a flow rate acceptable to distribute the injectate effectively within the subsurface. Overall, this is the most favorable method for injecting the substrate.

Additionally, based on the soil boring logs and injection pilot test observations, it is possible that the approximate five (5) to 10 feet of initial overburden soils are tight enough to act as an upper confining layer within the formation. This in turn may be assisting the injectate to spread lateraly throughout the overburden and weathered bedrock formation at greater distances without significant day lighting at the surface.

5.0 Proposed Full Scale Injection Plan

5.1 Overview

As discussed in Section 2.3, groundwater data from the site has demonstrated that natural attenuation by microbial de-chlorination at the site has occurred. However, due to the current lack of available electron donors and moderate anaerobic conditions at the site, complete reductive de-chlorination of the site has stalled and is unlikely to occur without groundwater conditioning enhancements and bio-augmentation.

Further, complete reductive dechlorination at the site can be achieved through the injection of EVO (electron donor) and the augmentation of dehalococcoides bacteria within the current chlorinated solvent plume extents. By modifying the subsurface groundwater and soil conditions to contain sufficient organic electron donors and the appropriate strains of dehalococcoides, the reductive dechlorination process can proceed until all of the chlorinated solvents are eliminated. In a typical complete dechlorination reduction, trichloroethylene (TCE) or tetrachloroethylene (PCE) are reduced to dichloroethene (DCE) and further reduced to vinyl chloride (VC) and then finally reduced to ethene, a harmless end-product. Historical groundwater data at the site has documented that the reductive dechlorination pattern is stalling out at the DCE and VC stages.

The objective of the pilot test was to assess the ability of the site's formation to accept a 5% injectate solution of EVO and water under various injection methods. Based on the injection pilot test and historical site data, a proposed full scale injection plan for the application of a bio-augmented anaerobic bioremediation is summarized in the following sections.

The following proposed injection plan includes the installation of 31 overburden injection wells and subsequent injection of 3,618 gallons of 60% SRS-SD® EVO, 195 liters (L) of TSI DC® Bio-augmentation Culture and 68,732 gallons of deoxygenated dilution water.

5.2 Injection Substrate Design

Historical and current site data were provided to Terra Systems, Inc. of Claymont, Delaware (Terra Systems) to develop a model for achieving complete reductive dechlorination of the site's contaminants. Dr. Michael Lee of Terra Systems used the Environmental Security Technology Certification Program (ESTCP) substrate estimating tool developed by Parsons Infrastructure & Technology Group (Parsons) to assess various models of enhanced anaerobic biodegradation of chlorinated solvents at the site. The results of the ESTCP substrate estimating tool are included in **Appendix C – Terra Systems Proposal**.

In summary, the model used the current approximate plume dimensions of 600 feet long x 200 feet wide and 11.5' feet thick (Figure 2). Additionally, the model included the average hydraulic conductivity (K value) within the targeted formation of 1.965×10^{-3} centimeters (cm) per second (sec), an average groundwater gradient of 6.2×10^{-3} feet/foot and an effective porosity of 25%. Based on these parameters, the groundwater flowrate at the site is approximately 50.7 ft per year.

The ESTCP model estimated the demand based on the reported VOCs from the January 2017 groundwater analytical data and historical site groundwater data for concentrations of dissolved oxygen, nitrate and sulfate. The model also used results from successful 60% SRS®-SD injections from silimar sites to assume 5 micrograms (mg)/L of manganese, 50 mg/L of dissolved iron and 10 mg/L of methane would be produced.

Based on the results from this model is was determined that 3,618 gallons of 60% SRS-SD® EVO, 195 liters (L) of TSI DC® Bioaugmentation Culture and 68,732 gallons of deoxygenated dilution water are required to achieve successful dechlorination at the site.

Additionally, approximately 2 grams (g)/L of sodium bicarbonate are required to be added to the EVO dilution as a buffer to prevent the pH from dropping as the EVO is fermented in the subsurface to fatty acids. A total of 1,207 pounds (lbs) of sodium bicarbonate are required for the full scale injection.

5.3 Full Scale Injection Well Installation

The following section details the proposed injection well layout, design and installation method for the full scale application of the enhanced bio-remediation substrate.

5.3.1 Proposed Injection Well Spacing

A proposed injection well spacing layout was developed based on data obtained from the injection pilot testing and the calculated groundwater velocity at the site of 50.7 ft per year. The proposed well spacing within the site's chlorinated solvent plume based on the January 2017 groundwater data is presented on **Figure 4**.

The injection well spacing assumes a 20 foot ROI and allows for a 50 foot per year migration of injectate along the downgradient axis of the plume. The cross-gradient injection wells are oriented perpendicular to the plume axis and allow for a 5 foot overlap of the 20 foot ROI. These injection wells are spaced at 35 feet. Based on these parameters, a total of 31 injection well are required to effectively cover the targeted injection area.

5.3.2 Proposed Injection Well Design and Installation

Overburden injection well (OBIW-1) was utilized during the pilot test injection and performed successfully. This well has been used as the model for the full scale injection well design.

A total of 31 injection wells are proposed to be installed at the site to implement the full scale remedy. Each well will be installed to straddle the weathered bedrock and overburden interface. The depth of each well will vary slightly depending on bedrock refusal and field pbservations of soil characteristics. However, each injection well will be constructed using the following specifications.

Each well will be advanced to approximately three (3) or to refusal in the weathered bedrock using 4¼-inch diameter hollow stem augers. The average anticipated terminal depth is approximately 23 fbg. Each well will be constructed with 10 feet of 2-inch diameter 20-slot schedule 40 PVC well screen and riser to the surface. Filter pack sand consisting of #1 sand will be installed a minimum of one (1) foot above the screened section and sealed with two (2) feet of bentonite. Neat cement grout will be placed above the bentonite seal to the surface. The top of the well casing will be fitted with a 2-inch male camlock fitting, expandable gripper cap seal and completed with a flush mount steel roadbox. Construction details for the proposed injection wells are presented on **Figure 5**.

Prior to installing the injection wells, continuous soil core samples will be obtained from a representative portion of the proposed locations. Continuous soil cores will be collected from approximately 15 of the proposed locations using hydraulically driven direct-push soil core (Geoprobe®) sample techniques. Samples will be retrieved in acetate liners using a 2 ¼-inch outer diameter (O.D.) Macrocore® sampler 60-inches in length. An Aztech geologist will analyze the soil samples for grain size, soil type and depth to weather bedrock. The locations will be chosen in the field by the geologist and the data will be used to accurately assess the injection well screen placement.

5.3.3 Well Development and Collection of Groundwater Parameters

Prior to application of the enhanced anaerobic bioremediation substrate, each newly installed injection well will require development to remove particulates, improve communication with the surrounding aquifer and maximize injection capability. Well development will consist of purging a minimum of ten (10) well volumes and surging the screened portion of the well.

Well development methods will utilize the use of a submersible Whale® pump and reusable tubing for evacuating the purge water. The well will be allowed to stabilize prior to injection application for one (1) week after development. Purge water will be containerized onsite and reused later during the injections.

5.4 Full Scale Injection Application

Full scale Injection will consist of injecting the previously prescribed mixture of deoxygenated water, EVO, dehalococcoides bio-augmentation and pH buffer. Based on the 31 proposed well spacing (Figure 4), this equates to approximately 2,330 gallons of injectate solution per well.

The EVO will be diluted onsite with water at a ratio of 1:20 to create a 5% EVO solution. A Dosatron inline dilutor, capable of mixing 20 gallons per minute, will be manifolded to the injection wellhead to achieve direct injection to the overburden formation. The injection system components will include an injection pump, pipe manifolds, water tank, pressure relief valves, pressure gauges and a flowmeter. Three (3) injection wells are anticipated to be injected simultaneously.

To achieve optimal distribution without overloading the formation, inducing well failure or damaging the bio-augmentation culture, the EVO solution will be will be injected at a flow rate no greater than 6 gpm and at a pressure no greater than 8 psi to any single injection well.

The proposed full scale injection will commence at the well located at the most downgradient edge of the plume and will progress northwest (upgradient) towards the source area.

5.4 Deoxygenated Water Mixing

The bio-augmentation culture used in the injection solution requires an anoxic environment of less than 1.0 mg/L of dissolved oxygen (DO) to thrive. As such, the culture needs to be mixed into a low DO solution prior to injecting into the subsurface. Approximately 68,732 gallons of deoxygenated water are be required to create the 5% injectate solution for the full scale remedy. To achieve this, the oxygen scavenger sodium ascorbate will be added to injectate water at a concentration of 0.3 g/L. Sodium ascorbate will not harm the bio-culture and is recommended and distributed by Terra Systems solely for the purpose of creating a low DO water solution.

During the full scale application at the site, water will be obtained from a nearby hydrant and stored onsite in a large batch tank. The sodium ascorbate will be mixed into the batched water a minimum of 24 hours prior to use as an injectate. The DO levels will be periodically monitored using a water quality multi meter (e.g. Horiba® or YSI®).

Additional sodium ascorbate will be added as needed to drive the DO to an acceptable level. This is depended on factors such as temperate, aeration and mineral content of the water received from the hydrant.

5.5 Logistics and Planning

The proposed full scale bio-augmented injection remedy will require significant site preparation prior to implementation.

The majority of the proposed injection wells (Figure 4) are located in a medium densely congested plot of forest located between the Jack's Drycleaners building at the northwest portion of the site and a residential subdivision to the southeast. Several pathways will need to be cleared of brush and small trees to allow access for the drill rig and injection equipment to complete the remedy.

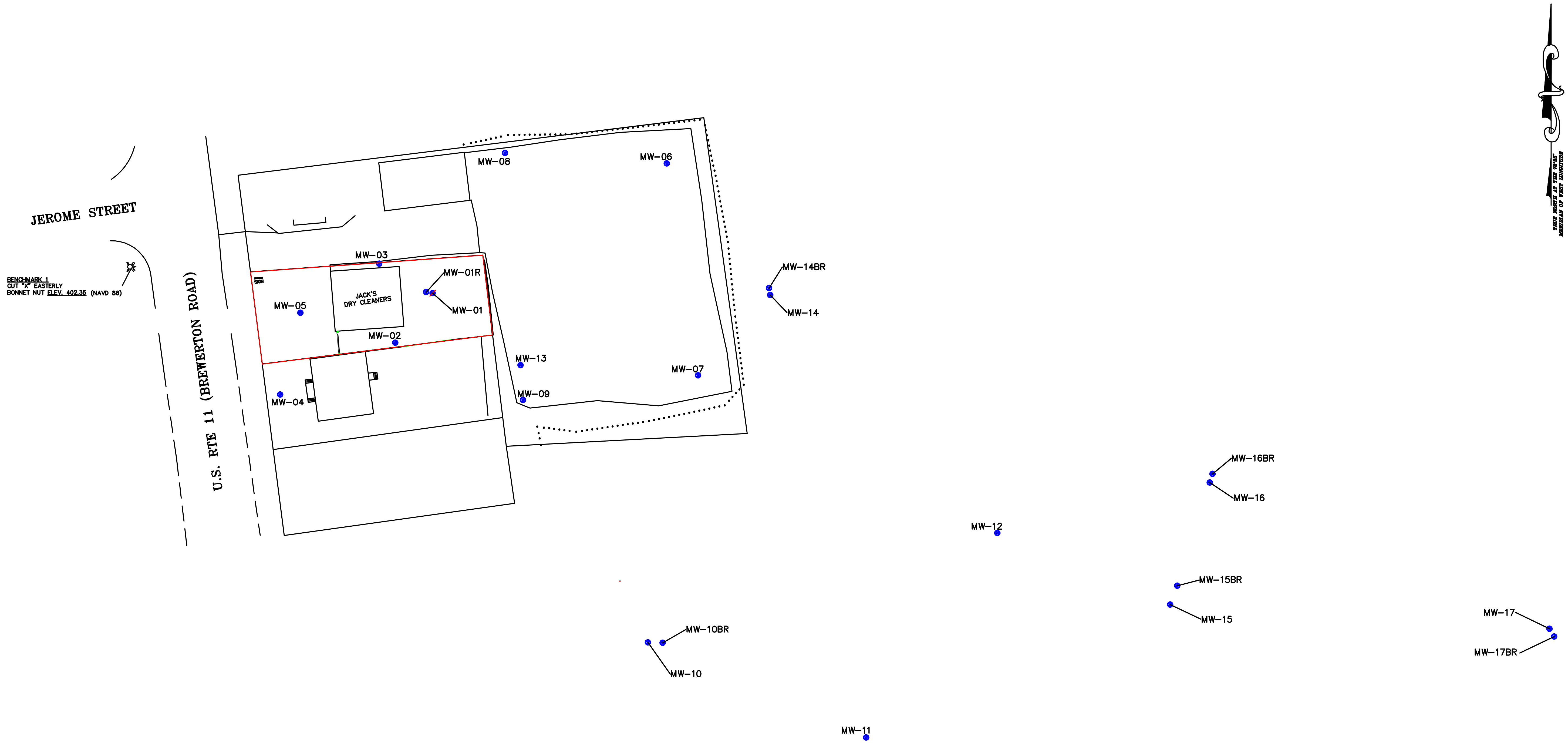
Aztech recommends laying out all proposed injection well locations and identifying appropriate pathways with flagging prior to clearing. Cleared pathways should be a minimum of 12 feet wide to accommodate all equipment entering the forest.

Based on historical observations at the site, the forest floor is consistently wet and soft during the spring and early summer months. In an effort to reduce impacts to the surrounding vegetation and ease site work, the site clearing and injection well installations should occur during the mid-summer to early fall months. The subsequent full scale injection should follow once the wells have been developed.

All site preparation and injection applications activities are anticipated to commence in July 2017.

APPENDIX A

Figures



SITE MAP

Remediation Solutions ● Environmental Consulting ● Drilling Applications

Aztech Technologies, Inc.
Woman Owned Business
5 McCrea Hill Road
Ballston Spa, NY 12020
p 518.885.5383 I f 518.885.5385
info@aztechtech.com I www.aztechtech.com

SITE: Jack's Dry Cleaners
9628 NYS Route 11
Brewerton, NY
NYSDEC Site No. 734112

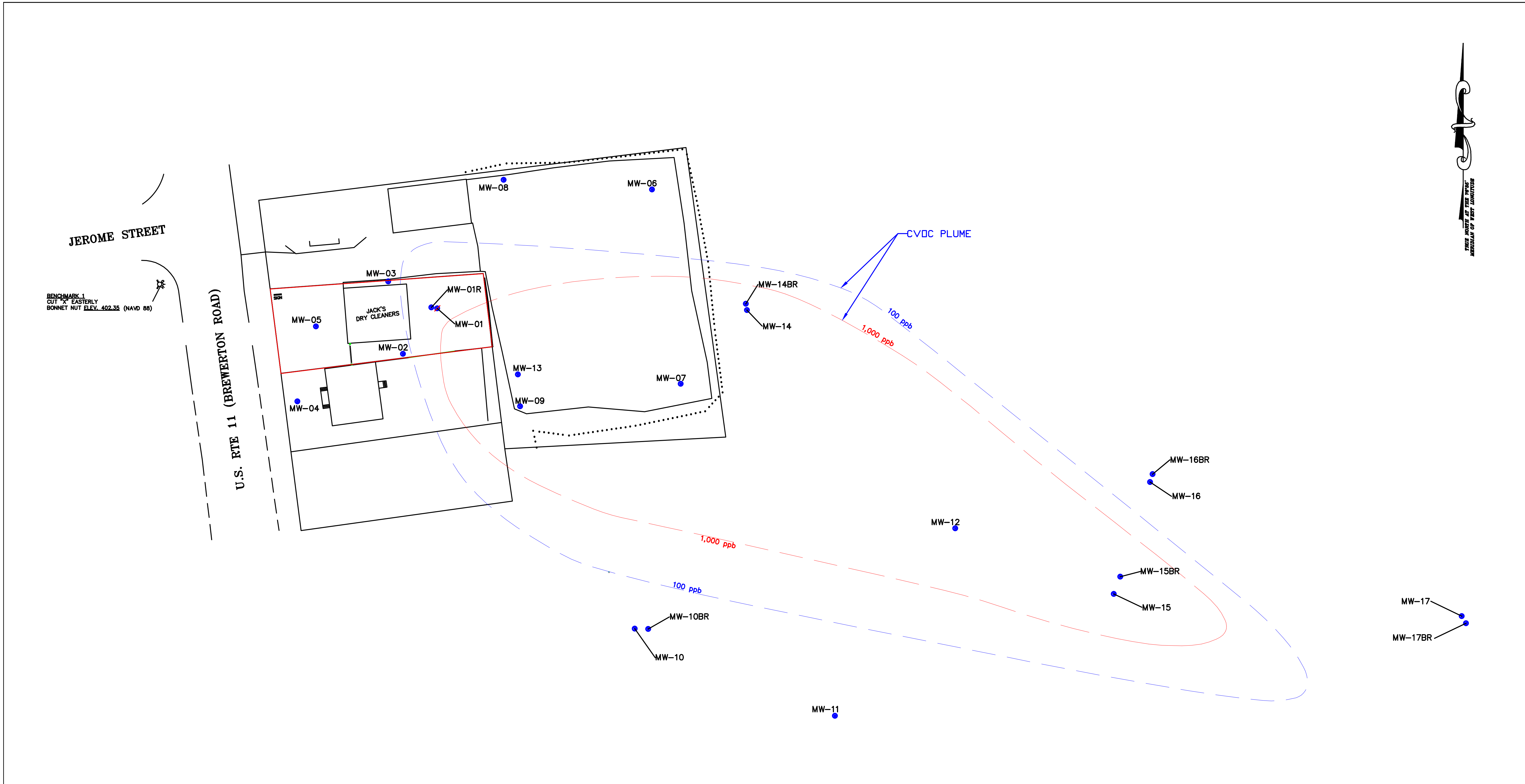
FIGURE 1

DATE: April 2017

Scale (feet) 0 30 60 120 180

LEGEND

- MW–12 - Monitoring Well ID
- ● - Monitoring Well Symbol
- ▭ - Property Boundary



Combined Overburden and Bedrock CVOC Plume

Aztech Technologies, Inc.
Woman Owned Business

Remediation Solutions ● Environmental Consulting ● Drilling Applications

5 McCrea Hill Road
Ballston Spa, NY 12020
p 518.885.5383 I f 518.885.5385
info@aztechtech.com I www.aztechtech.com

SITE: Jack's Dry Cleaners
9628 NYS Route 11
Brewerton, NY
NYSDEC Site No. 734112

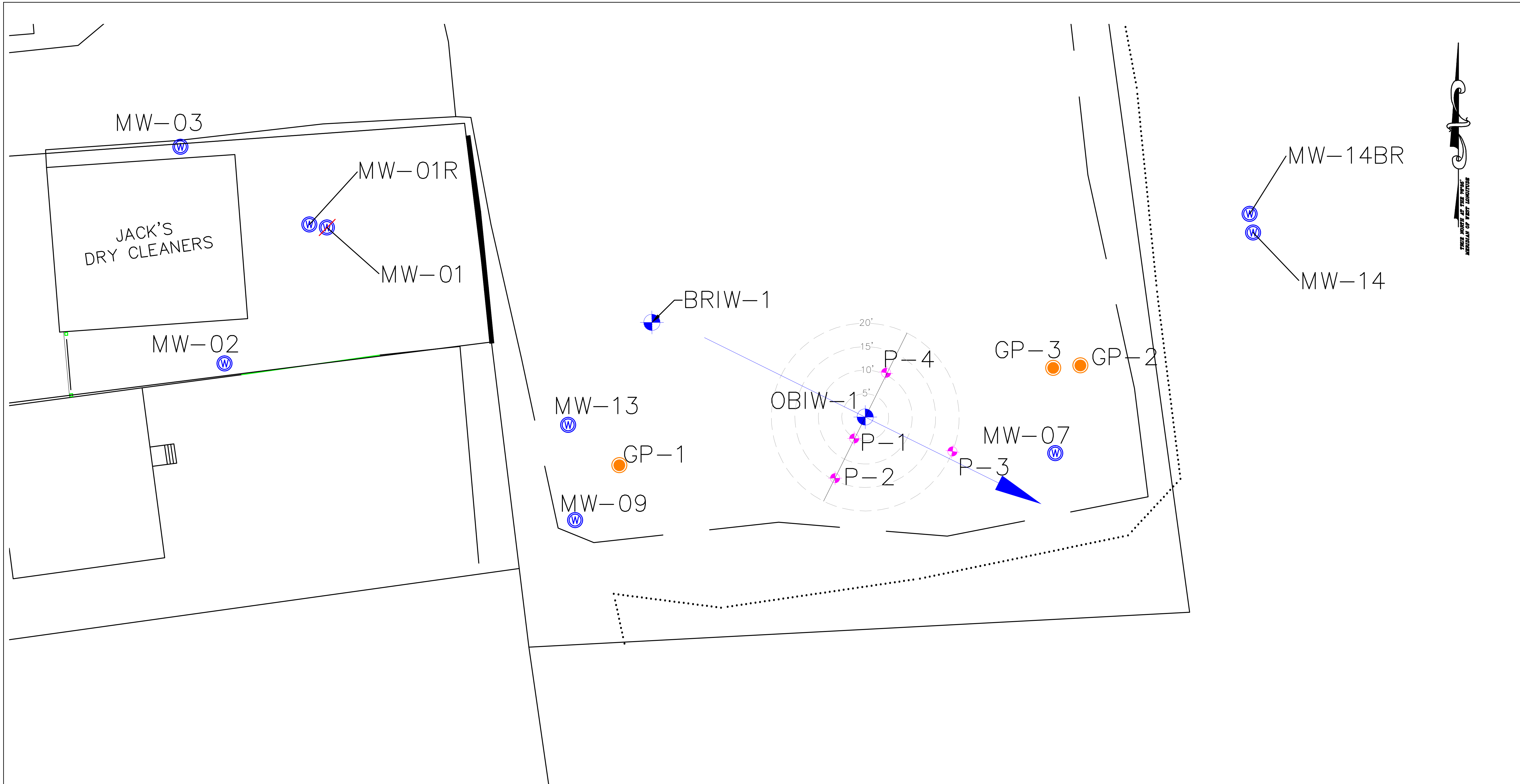
FIGURE 2

DATE: April 2017

Scale (feet) 0 30 60 120 180

LEGEND

MW-12 - Monitoring Well ID
● - Monitoring Well Symbol
- Property Boundary



Pilot Test Injection Well Layout

LEGEND

- Injection Well
- Goundwater Monitoring Well
- Piezometer
- Direct Push Test Injection Point
- Plume Axis

Aztech Technologies, Inc.
Woman Owned Business

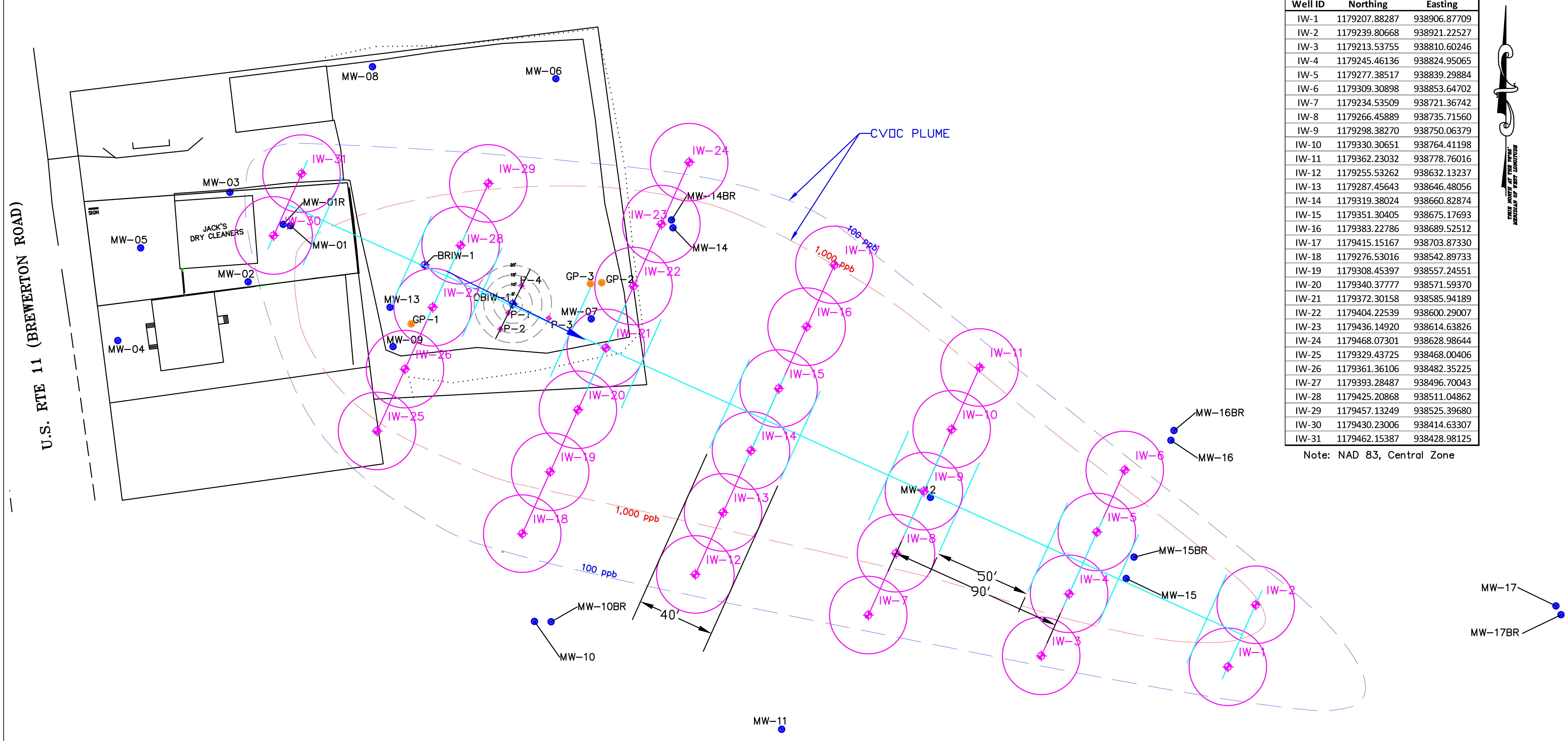
Remediation Solutions ● Environmental Consulting ● Drilling Applications
5 McCrea Hill Road
Ballston Spa, NY 12020
p 518.885.5383 I f 518.885.5385
info@aztechtech.com I www.aztechtech.com

SITE: Jack's Dry Cleaners
9628 NYS Route 11
Brewerton, NY
NYSDEC Site No. 734112

FIGURE 3

DATE: April 2017

Scale (feet) 0 5 10 20 30



Well ID	Northing	Easting
IW-1	1179207.88287	938906.87709
IW-2	1179239.80668	938921.22527
IW-3	1179213.53755	938810.60246
IW-4	1179245.46136	938824.95065
IW-5	1179277.38517	938839.29884
IW-6	1179309.30898	938853.64702
IW-7	1179234.53509	938721.36742
IW-8	1179266.45889	938735.71560
IW-9	1179298.38270	938750.06379
IW-10	1179330.30651	938764.41198
IW-11	1179362.23032	938778.76016
IW-12	1179255.53262	938632.13237
IW-13	1179287.45643	938646.48056
IW-14	1179319.38024	938660.82874
IW-15	1179351.30405	938675.17693
IW-16	1179383.22786	938689.52512
IW-17	1179415.15167	938703.87330
IW-18	1179276.53016	938542.89733
IW-19	1179308.45397	938557.24551
IW-20	1179340.37777	938571.59370
IW-21	1179372.30158	938585.94189
IW-22	1179404.22539	938600.29007
IW-23	1179436.14920	938614.63826
IW-24	1179468.07301	938628.98644
IW-25	1179329.43725	938468.00406
IW-26	1179361.36106	938482.35225
IW-27	1179393.28487	938496.70043
IW-28	1179425.20868	938511.04862
IW-29	1179457.13249	938525.39680
IW-30	1179430.23006	938414.63307
IW-31	1179462.15387	938428.98125

Note: NAD 83, Central Zone

Injection Well Layout

LEGEND

- Proposed Injection Well
- Groundwater Flow Direction

Aztech Technologies, Inc.
Woman Owned Business

Remediation Solutions ● Environmental Consulting ● Drilling Applications

5 McCrea Hill Road
Ballston Spa, NY 12020
p 518.885.5383 I f 518.885.5385
info@aztechtech.com I www.aztechtech.com

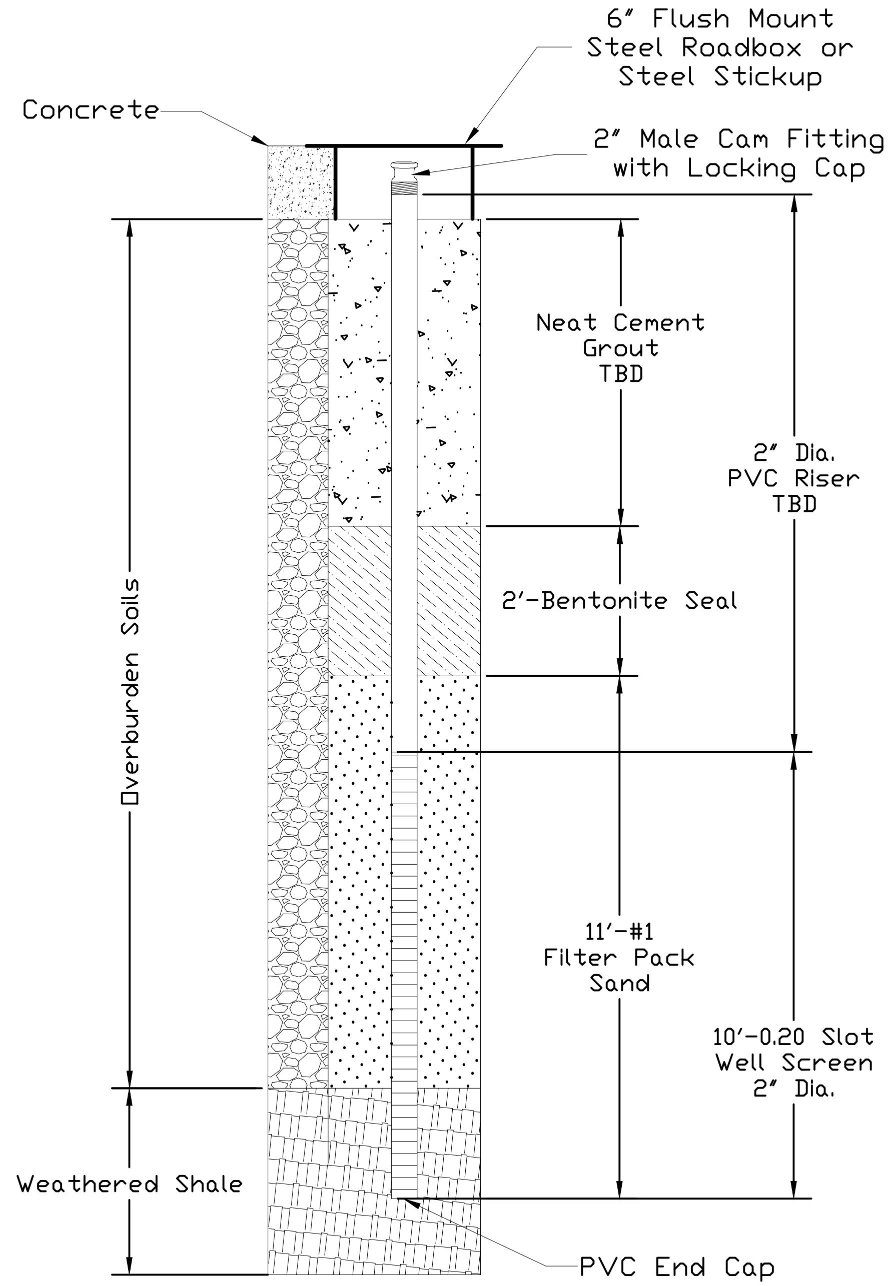
SITE: Jack's Dry Cleaners
9628 NYS Route 11
Brewerton, NY
NYSDEC Site No. 734112

FIGURE 4

DATE: April 2017

Scale (feet) 0 25 50

INJECTION WELL
TYP.



Notes:

1. Wells to be installed using 4.25" Augers.
2. Augers to be advance to refusa within the weathered bedrock in order to straddle the bedrock/overburden interfacer when setting the injection well.
3. Settled grout will be topped off 24hrs after initial install

Aztech Technologies, Inc.
Woman Owned Business

Remediation Solutions ● Environmental Consulting ● Drilling Applications
5 McCrea Hill Road
Ballston Spa, NY 12020
p 518.885.5383 I f 518.885.5385
info@aztechtech.com I www.aztechtech.com

SITE: Jack's Dry Cleaners
9628 NYS Route 11
Brewerton, NY
NYSDEC Site No. 734112

FIGURE 5

DATE: April 2017 | SCALE: NTS

Injection Well Construction Details

APPENDIX B

Boring Logs and Well Construction Details

Aztech Environmental
TECHNOLOGIES
Woman Owned Business

5 McCrea Hill Road, Ballston Spa, NY 12020
518.885-5383 | aztechenv.com

Boring ID: **OBIW-1**

Client: NYSDEC
Project: Jack's Dry Cleaners
Street Address: 9628 Brewerton Road
City / State: Brewerton, NY
Drilling Company: Aztech Environmental
Driller: Bob Gannon
Logged By: Thomas Giamichael

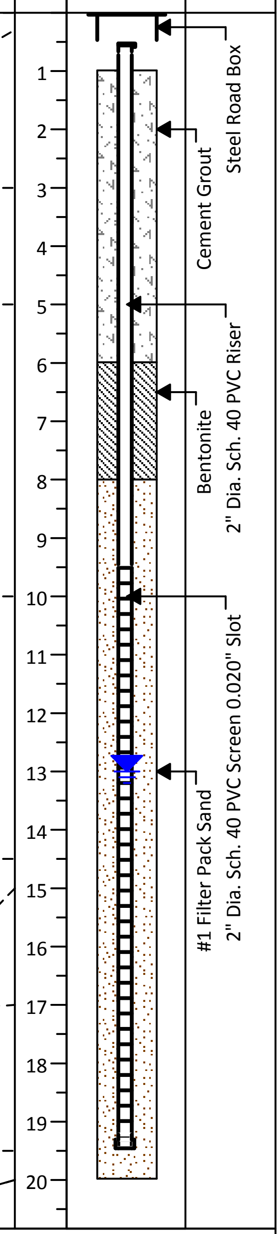
Drilling Method: Direct Push/ HSA
Borehole Diameter: 4.25"
Borehole Depth: 20 fbg
Ground Elevation: 0
Depth to Water: 13 fbg

Start Date: 6/27/2016
Finish Date: 6/27/2016

Depth (Feet)	Sample ID	Sample Interval (Feet)	Recovery (Feet)	Headspace PID (ppm)	Description
0 - 5	S1	(0' - 5')	40"	2.1	(0.0' - 0.3') Grass and Topsoil (0.3' - 3.0') Brown fine SAND and SILT, some Organics, trace fine gravel, firm, moist, no odor. (3.0' - 3.4') Brown to gray SILT and CLAY, some fine Sand and Organics, little fine gravel, medum stiff, moist, no odor.
5 - 10	S2	(5' - 10')	60"	2.0	(5.0' - 10') Brown SILT and CLAY, little fine sand and fine gravel, medium to firm stiffness, moist, no odor.
10 - 15	S3	(10' - 15')	60"	2.2	(10' - 14.5') Brown SILT and CLAY, some fine Sand, medium to soft, moist to wet, no odor. Very soft and water table observed @ ~13 fbg. (14.5' - 15') Gray LIMESTONE fragments, moist to dry, no odor.
15 - 20	S4	(15' - 20')	60"	3.4	(15' - 17') Brown SILT and CLAY, some fine Sand, soft, wet, no odor. (17' - 19.5') Brown to gray fine to medium SAND and fine sub-angular GRAVEL, some SIlt, little clay, compacted, wet, no odor. (19.5' - 20') Gray weathered SHALE, wet.

End of Log

Well Construction Diagram



Notes:
PID - Photoionization Detector
ppm - Parts Per Million
' - Feet
" - Inches

Aztech Environmental Technologies
Woman Owned Business
5 McCrea Hill Road, Ballston Spa, NY 12020
518.885-5383 | aztechenv.com

Boring ID: **BRIW-1**

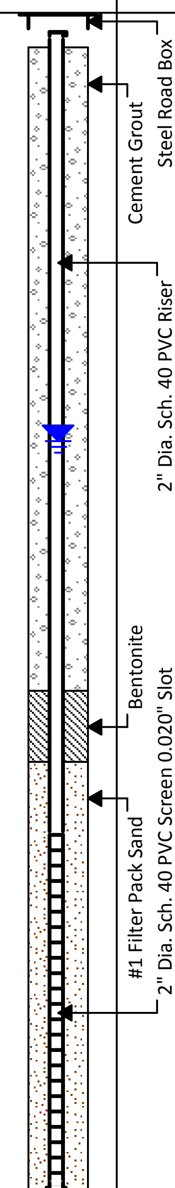
Client: NYSDEC
Project: Jack's Dry Cleaners
Street Address: 9628 Brewerton Road
City / State: Brewerton, NY
Drilling Company: Aztech Environmental
Driller: Bob Gannon
Logged By: Thomas Giamichael

Drilling Method: Direct Push/ HSA/Roller Bit
Borehole Diameter: 4"
Borehole Depth: 33 fbg
Ground Elevation: 0
Depth to Water: 12'

Start Date: 6/28/2016
Finish Date: 6/28/2016

Depth (Feet)	Sample ID	Sample Interval (Feet)	Recovery (Feet)	Headspace PID (ppm)	Description
0 - 5	S1	(0' - 5')	42"	1.0	(0.0' - 0.1') Grass and Topsoil (0.1' - 3.4') Brown fine to medium SAND and SILT, some Clay and Organics, little fine gravel and brick fragments, firm, moist, no odor.
5 - 10	S2	(5' - 10')	60"	1.0	(5.0' - 5.8') Similar soil as above. (5.8' - 11.1') Brown SILT and CLAy, laminated, medium to firm stiffness, moist, no odor.
10 - 15	S3	(10' - 15')	60"	2.3	(11.1' - 15') Brown to gray fine to medium SAND and SILT, some fine to medium sub-angular Gravel, trace clay, firm, moist to wet, no odor. Watertable observed @ 12 fbg.
15 - 20	S4	(15' - 20')	50"	1.5	(15' - 17') Brown to gray fine to medium SAND and SILT, some fine Gravel, little clay, very soft, wet, no odor. (17' - 19.1') Gray weathered SHALE and SILT, becoming densely compacted, moist, no odor.
20 - 33	Roller Bit	(20' - 33')	NA	NA	(20' - 33') Roller bit 3-7/8"rock socket through 4-1/4" augers. No significant fractures noted during roller bit process. Recovered rock cuttings in flush water consisted of limestone fragments.
					End of Log

Well Construction Diagram



Notes:
PID - Photoionization Detector
ppm - Parts Per Million
' - Feet
" - Inches

Aztech Environmental Technologies
Woman Owned Business
5 McCrea Hill Road, Ballston Spa, NY 12020
518.885-5383 | aztechenv.com

Boring ID: **P-1**

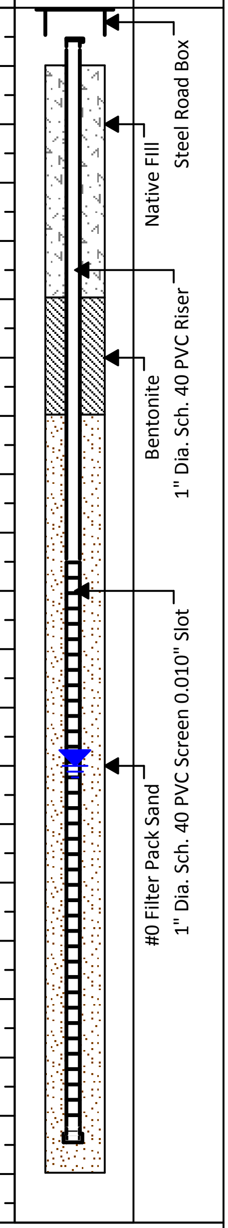
Client: NYSDEC
Project: Jack's Dry Cleaners
Street Address: 9628 Brewerton Road
City / State: Brewerton, NY
Drilling Company: Aztech Environmental
Driller: Bob Gannon
Logged By: Thomas Giamichael

Drilling Method: Direct Push/ HSA
Borehole Diameter: 2"
Borehole Depth: 20 fbg
Ground Elevation: 0
Depth to Water: 13 fbg

Start Date: 6/27/2016
Finish Date: 6/27/2016

Depth (Feet)	Sample ID	Sample Interval (Feet)	Recovery (Feet)	Headspace PID (ppm)	Description
0–5	S1	(0' - 5')	36"	0.0	(0.0' - 0.2') Grass and Topsoil (0.2' - 3.0') Brown fine SAND and SILT, some Organics, little fine gravel, trace clay, medium stiff, moist, no odor.
5–10	S2	(5' - 10')	60"	3.6	(5.0' - 10') Brown SILT and CLAY, little fine sand, medium to firm stiffness, moist, no odor.
10–15	S3	(10' - 15')	42"	6.4	(10' - 13.5') Brown SILT and CLAY, some fine Sand, medium to soft, moist to wet. Very soft and water table observed @ ~13 fbg. (13.5' - 14') Brown to gray SILT and fine to medium SAND, some Clay and fine subrounded Gravel, medium stiffness, wet, no odor.
15–20	S4	(15' - 20')	60"	5.2	(15' - 16.5') Brown to gray fine to medium SAND and SILT, some fine to medium sub-angular Gravel, little clay, very soft, wet, no odor. (16.5' - 19') Gray fine to medium SAND and fine to medium sub-rounded GRAVEL, some Silt, little clay, medium to hard stiffness, weathered SHALE. (19' - 20') Gray fractured SHALE, dry to moist, no odor.
					End of Log

Well Construction Diagram / Annotation



Notes:
PID - Photoionization Detector
ppm - Parts Per Million
' - Feet
" - Inches

Aztech Environmental Technologies
Woman Owned Business
5 McCrea Hill Road, Ballston Spa, NY 12020
518.885-5383 | aztechenv.com

Boring ID: **P-2**

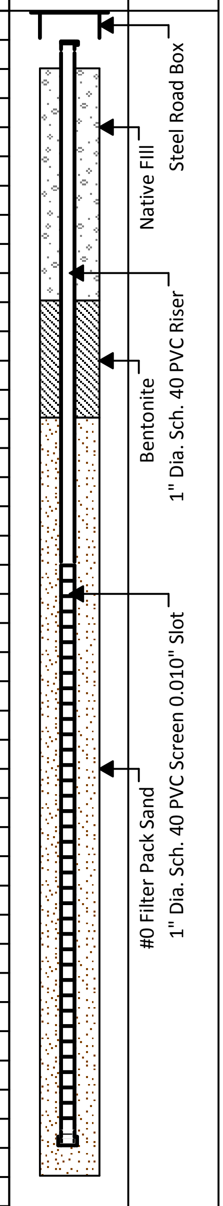
Client: NYSDEC
Project: Jack's Dry Cleaners
Street Address: 9628 Brewerton Road
City / State: Brewerton, NY
Drilling Company: Aztech Environmental
Driller: Bob Gannon
Logged By: Thomas Giamichael

Drilling Method: Direct Push/ HSA
Borehole Diameter: 2"
Borehole Depth: 20 fbg
Ground Elevation: 0
Depth to Water: Exact depth not observed

Start Date: 6/27/2016
Finish Date: 6/27/2016

Depth (Feet)	Sample ID	Sample Interval (Feet)	Recovery (Feet)	Headspace PID (ppm)	Description
0 - 5	S1	(0' - 5')	24"	0.1	(0.0' - 0.1') Grass and Topsoil (0.1' - 2.0') Brown fine SAND and SILT, some Organics, little fine gravel and clay, firm, moist, no odor.
5 - 10	S2	(5' - 10')	60"	0.0	(5.0' - 6.5') Brown SILT and CLAY, very soft, wet, no odor. (6.5' - 7.0') Brown to gray fine SAND and SILT, some Clay, trace fine rounded gravel, medium, moist
10 - 15	S3	(10' - 15')	NA	NA	(10' - 15') No recovery, sampler tip was jammed with a rock fragment.
15 - 20	S4	(15' - 20')	55"	6.1	(15' - 17') Brown fine to medium SAND and SILT, some fine sub-angular Gravel, little clay, very soft, wet, no odor. (17' - 19.5') Gray weathered SHALE and fine SAND, compacted, no odor.
20					End of Log

Well Construction Diagram / Annotation



Notes:
PID - Photoionization Detector
ppm - Parts Per Million
' - Feet
" - Inches

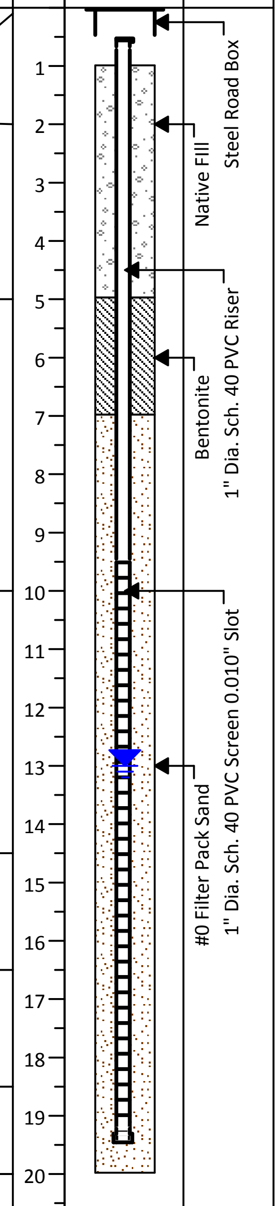
Aztech Environmental Technologies
Woman Owned Business
5 McCrea Hill Road, Ballston Spa, NY 12020
518.885-5383 | aztechenv.com

Boring ID: P-3

Client: NYSDEC		
Project: Jack's Dry Cleaners		
Street Address: 9628 Brewerton Road	Drilling Method: Direct Push/ HSA	
City / State: Brewerton, NY	Borehole Diameter: 2"	
Drilling Company: Aztech Environmental	Borehole Depth: 20 fbg	
Driller: Bob Gannon	Ground Elevation: 0	Start Date: 6/28/2016
Logged By: Thomas Giamichael	Depth to Water: 13 fbg	Finish Date: 6/28/2016

Depth (Feet)	Sample ID	Sample Interval (Feet)	Recovery (Feet)	Headspace PID (ppm)	Description
0 - 5	S1	(0' - 5')	24"	1.0	(0.0' - 0.1') Grass and Topsoil (0.1' - 2.0') Brown fine SAND and SILT, some Organics, little clay, firm, moist, no odor.
5 - 10	S2	(5' - 10')	60"	2.0	(5.0' - 10') Brown SILT and CLAY, firm, moist to wet, no odor.
10 - 15	S3	(10' - 15')	60"	2.1	(10' - 14.5') Brown SILT and CLAY, some fine SAND, very soft, wet, no odor Water table observed @ ~13 fbg. (14.5' - 16.5') Brown to gray CLAY, very soft, wet, no odor.
15 - 20	S4	(15' - 20')	60"	5.3	(16.5' - 18.5') Brown fine to medium SAND and fine Gravel, some Silt and Clay, medium stiff, compacted, wet, no odor. (18.5' - 20') Gray weathered SHALE, moist, no odor.
20					End of Log

Depth (Feet) | Well Construction Diagram | Annotation



Notes:
PID - Photoionization Detector
ppm - Parts Per Million
' - Feet
" - Inches

Aztech Environmental Technologies
Woman Owned Business

5 McCrea Hill Road, Ballston Spa, NY 12020
518.885-5383 | aztechenv.com

Boring ID: **P-4**

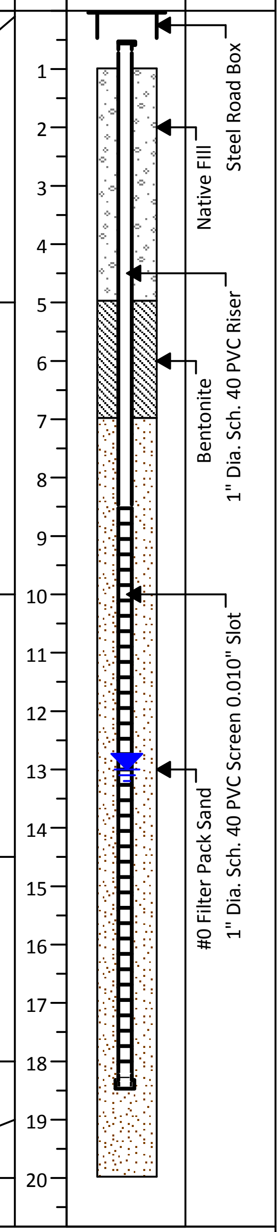
Client: NYSDEC
Project: Jack's Dry Cleaners
Street Address: 9628 Brewerton Road
City / State: Brewerton, NY
Drilling Company: Aztech Environmental
Driller: Bob Gannon
Logged By: Thomas Giamichael

Drilling Method: Direct Push/ HSA
Borehole Diameter: 2"
Borehole Depth: 20 fbg
Ground Elevation: 0
Depth to Water: 13 fbg

Start Date: 6/28/2016
Finish Date: 6/28/2016

Depth (Feet)	Sample ID	Sample Interval (Feet)	Recovery (Feet)	Headspace PID (ppm)	Description
0 - 5	S1	(0' - 5')	12"	0.0	(0.0' - 0.1') Grass and Topsoil (0.1' - 1.0') Brown fine to medium SAND and SILT, some Organics, little fine gravel and clay, firm, moist, no odor.
5 - 10	S2	(5' - 10')	36"	1.1	(5.0' - 8') Brown SILT and CLAY, medium to firm, trace organics, moist, no odor.
10 - 15	S3	(10' - 15')	60"	2.0	(10' - 14.5') Brown SILT and CLAY, medium to firm, moist to wet, no odor. Water table observed @ ~13 fbg. (14.5' - 18') Brown to gray fine to medium SAND and SILT, some Clay and weathered Shale, soft, wet, no odor.
15 - 20	S4	(15' - 20')	50"	3.1	(18' - 19') Gray weathered SHALE, very compact, moist, no odor.
20					End of Log

Well Construction Diagram / Annotation



Notes:
PID - Photoionization Detector
ppm - Parts Per Million
' - Feet
" - Inches

APPENDIX C

Terra Systems Design Proposal

Michael Free
VP, Sales and Marketing
Terra Systems, Inc.
130 Hickman Road, Suite 1
Claymont, Delaware 19703
Cell: 484-889-2214
Office: 302-798-9553
Email: mfree@terrasystems.net

Tuesday April 11th, 2017

Tommy Giamichael
Senior Hydrogeologist/Project Manager
Aztech Environmental Technologies
5 McCrea Hill Road
Ballston Spa, NY 12020
Cell: 518-337-7635
Email: tgiamichael@aztechenv.com

Reference: Terra Systems Proposal for Aztech's Jack's Cleaners in Brewerton, NY.

Good afternoon Tommy:

Terra Systems is pleased to respond to Aztech's request to supply Terra Systems patented 60% SRS®-SD small droplet emulsified vegetable oil substrate to be injected at Jack's Cleaners in Brewerton, NY.

Dr. Mike Lee used the ***ESTCP Substrate Demand Tool*** and the data you provided to calculate the proper carbon loading using our patented 60% SRS®-SD small droplet emulsified vegetable oil (EVO). I have summarized the key parameters below, which drive demand or are important for the dechlorination process.

- *The size of the area to be treated*
- *The concentration of the competing electron acceptors, which will compete for the oil*
- *The concentration of COC's*
- *The pH*
- *The groundwater flow rate, which we calculate from the hydraulic conductivity, hydraulic gradient and the porosity*
- *The presence or absence of vinyl chloride, ethene and ethane, which helps determine if bioaugmentation will be required*

Mike reviewed the data from Jack's Cleaners and converted the chlorinated ethene data to micromolar units by dividing by the molecular weight in the Jack's.xlsx Excel file. The following wells have shown good dechlorination of PCE and TCE to cis-DCE and VC: MW-7, MW-9, MW-13 (little VC), MW-14 (little VC), and MW-14BR. Wells MW-12 and MW-15BR show increasing concentrations of PCE, TCE, and cis-DCE with little VC production.

The well spacing and locations of the injection wells look appropriate to me.

- I reran the ESTCP Substrate Design Tool for Enhanced Anaerobic Biodegradation of Chlorinated Solvents using the 200 feet wide, 600 feet long, by 11.5 feet thick plume dimensions and the new K and gradient data.
- The groundwater flowrate is 0.14 ft/day or 50.7 ft/yr.
- The ESTCP model estimated a demand based upon the January 2017 VOC concentrations and the average concentrations of dissolved oxygen, nitrate, and sulfate from the 2013 report (I didn't see any more recent data).
- Based upon results from other 60% SRS®-SD injections, I assumed 5 mg/L of manganese, 50 mg/L of dissolved iron, and 10 mg/L of methane would be produced.

The output from the model was for 1,602 gallons (12,963 pounds) of 60% SRS®-SD which would supply 288 mg/L of linoleic acid or about 221.5 mg/L TOC. We generally recommend that a minimum of 500 mg/L TOC be injected to achieve adequate distribution and longevity of the 60% SRS®-SD. This would increase the demand to **3,618 gallons (29,266 pounds)** of 60% SRS®-SD. Assuming the 60% SRS®-SD was diluted 1 part 60% SRS®-SD to 19 parts water (20:1), a total of 68,732 gallons of chase water would be injected.

For this volume of aquifer, we calculated the TSI-DC® Bioaugmentation Culture demand to be **195 L**. The TSI-DC® is shipped in 19 L kegs so this would require 20 kegs and 20 shipments at $220 per shipment. The culture can be concentrated 2X to reduce the shipping costs. You would adjust your work plan to inject half the amount of culture. If the work plan called for injecting 1 L per point of unconcentrated culture you would actually inject 0.5 L per point of a 2X culture. We would recommend that the dilution water for bioaugmentation be treated with 0.3 g/L sodium ascorbate (Vitamin C) to condition it and drive the water anaerobic (negative ORP and dissolved oxygen less than 1 mg/L). We stock sodium ascorbate. We prefer sodium ascorbate over other chemical reductants as the loading is typically lower and the ascorbate does not inhibit microbes like sodium sulfite or sodium bisulfite.

We recommend that 2 g/L of sodium bicarbonate be added to the 60% SRS®-SD and dilution water as a buffer to prevent the pH from dropping as the 60% SRS®-SD is fermented to volatile fatty acids. The volumes of 60% SRS®-SD, dilution water, TSI-DC, sodium ascorbate, and sodium bicarbonate are shown in the attached file, TSI Summary. Pricing for these components is shown below.

Table I: 60% SRS®-SD, TSI DC, Sodium Ascorbate and Sodium Bicarbonate Pricing

Terra Systems Recommended Product	Quantity	Unit Price	Total (does not include FL sales or use tax)
60% SRS®-SD Demand to Achieve 500 mg/L TOC (gallons/pounds)	3,618 gallons 29,266 pounds	$9.71 per gallon	$35,130.78
TSI DC® Bioaugmentation Culture	195 L's in 11 kegs	$115.00 per L	$22,425.00
Sodium Ascorbate	181pounds	$7.00 per pound	$1,267.00
Sodium Bicarbonate	1,250 pounds in (25) 50# bags	$0.50 per pound	$625.00
Shipping for 60% SRS®-SD, Sodium Ascorbate and Sodium Bicarbonate	Dedicated Truck - Requires fork-lift and pallet jack for unloading		$1,000.00
Overnight Shipping of TSI DC	11 kegs	$220 per keg	$2,420.00
Optional 2X Concentration: Overnight Shipping of TSI DC	6 kegs	$220 per keg	$1,320.00 Optional
Total			**$62,867.78**

We recommend our patented *injection ready* 60% SRS®-SD small droplet (0.6 µm) emulsified vegetable oil substrate, which contains 72.5% fermentable organic material for the following reasons:

- The SRS®-SD small droplets will provide the maximum radius of influence for what appears to be a tight formation
- The non-ionic surfactant package formulation will not adsorb to the soil particles to maximize the substrate distribution
- The mixture of soybean oil and biodegradable surfactants will provide excellent longevity compared to more soluble substrates like ethyl lactate or fatty acid methyl esters
- The small droplet and non-ionic emulsifier are less likely to clog the aquifer.
- SRS®-SD contains sodium lactate to rapidly generated anaerobic conditions
- SRS®-SD contains yeast extract and inorganic nutrients that provide important vitamins, nitrogen, and phosphorus for growth of the anaerobic microbial population
- SRS®-SD contains Vitamin B_{12}, an important cofactor needed by *Dehalococcoides* for reductive dechlorination
- All components of SRS®-SD are biobased, food grade additives and are manufactured in the United States. Terra Systems' SRS®-family of substrates has been certified by the USDA BioPreferred Program.

We also recommend our TSI DC *Dehalococcoides mccartyi* Bioaugmentation Culture®, which is an enriched natural bacteria culture that contains >1 x10^{11} *Dehalococcoides* species cells/L for bioaugmentation. This culture dechlorinates tetrachloroethene (PCE) and trichloroethene (TCE) to the non-toxic product ethene. The culture also biodegrades 1,1,1-trichloroethane to 1,1-dichloroethene, 1,1-dichloroethane, and chloroethane. It also can biodegrade carbon tetrachloride and chloroform to methylene chloride and innocuous products. It can be used at sites where bacteria capable of complete reductive dechlorination are not present or there is a need to decrease the remediation time frame. It is estimated that *Dehalococcoides* are not present in 10 to 40 percent of chlorinated solvent contaminated sites.

II. Picture of Terra Systems Manufacturing Facility

A couple of key points regarding Terra Systems:

- Terra Systems is the only EVO supplier who owns and operates their manufacturing facility. We make our patented 60% SRS®-SD in a controlled environment in Claymont, DE and have strict QA processes to ensure a consistent and documented small droplet emulsion. Other suppliers use toll producers, which limits their ability to both control and measure droplet size. We use a specialized piece of equipment to achieve a 0.6 µm droplet size. Self -emulsifying oils typically do not produce a tight small droplet distribution pattern, which is required for adequate distribution. .

- Each of our clients receive a ***QA Sheet*** (see attached) for the actual product that we ship to your site, which includes:
  - *Manufacturing Date* - EVO will begin to ferment if it sits around, which results in a drop in pH, so ideally you want a freshly manufactured product shipped to your site.
  - *Mean Droplet Size* - We measure the actual droplet size of the product that is shipped to your site. This is different than suppliers who use toll producers and only measure it once a year for their specification sheet.
  - *pH - dechlorination activity declines with pH so we* measure and provide you with the actual pH of the product that is shipped to your site.
  - *Ingredients and the Lot #'s*

PM's give a copy of the sheet to their clients, which we have received compliments on.

- At the PM's request and at no additional cost, we can add buffer (2-4 g/L) during the manufacturing process to help maintain optimal pH conditions as the fermentation process occurs.
- 60% SRS®-SD is registered and certified under the USDA ***BioPreferred Program***
- As part of Terra Systems' ***Sustainability Partnership Program***, we purchase carbon offsets for our Family of SRS® emulsified vegetable oil substrate products. Again, the PM's typically include this in the data package they provide their client.

Terra Systems patented 60% SRS®-SD arrives ready to inject and contains:

- A slow release carbon source of **60 percent vegetable oil** (soybean)
- A quick release soluble carbon source of **at least 5.5%**
- A proprietary nutrient package with yeast extract, nitrogen, and phosphorus to support growth of the anaerobic microbial population
- A proprietary non-ionic emulsifier package for ease of injection and maximum ROI
- At least **0.25 mg/L B_{12}**, which He et al. 2007 demonstrated is an important micronutrient to enhance dechlorination activity. Technical paper is attached as reference.
- Has a neutral pH.
- 60% SRS®-SD has a mean droplet size of **0.6 µm** for ease of injection and maximum radius of influence in the formation for the client
- At your request and at no additional cost we can also add 2-4 g/L of sodium bicarbonate during the manufacturing process to counter the acids produced during the fermentation process, which helps to maintain optimal pH conditions.

If you have any questions, please do not hesitate to call me on my cell at **484-889-2214**. Email also works if that is easier for you and my email address is mfree@terrasystems.net.

Thanks, and best regards,

Terra Systems, Inc., 130 Hickman Road, Suite 1, Claymont, Delaware 19703
COMPANY NAME AND ADDRESS (TYPE OR PRINT)

Michael Free – Vice President of Sales & Marketing
NAME AND TITLE OF AUTHORIZED PERSON

Tuesday April 11th, 2017

SIGNATURE DATE

302-798-9553 484-889-2214 mfree@terrasystems.net
OFFICE PHONE CELL PHONE EMAIL

SUBSTRATE ESTIMATING TOOL FOR
ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2
November 2010

Site Data Input Table	**Calculation Tables**	**Output Summary Table**
TABLE S.1 - INPUT TABLE	Table S.2 - Substrate Calculations in Hydrogen Equivalents	TABLE S.5 - OUTPUT TABLE
	Table S.3 - Hydrogen Produced by Common Substrates	PRINT SUMMARY TABLE
	Table S.4 - Estimated Substrate Requirements for Hydrogen Demand	

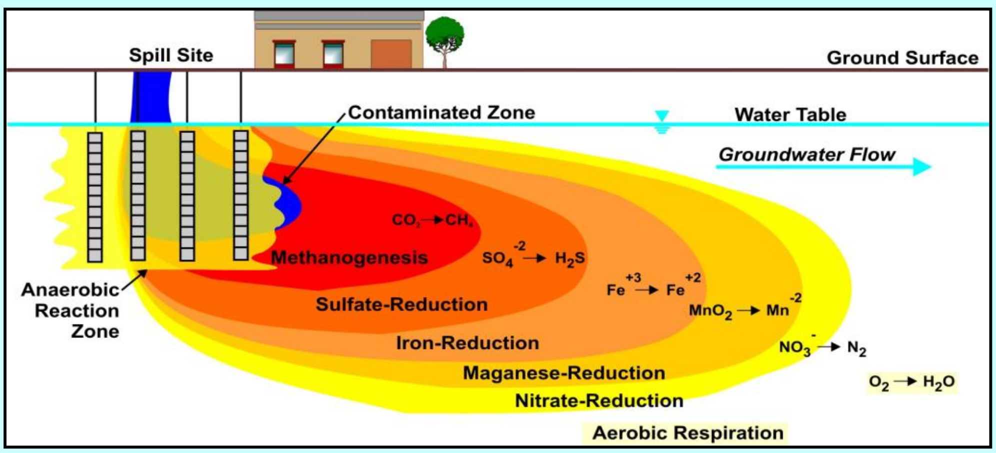


Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Jack's Cleaners, Brewerton, NY

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet	This table is populated with an example site.
Length (Parallel to predominant groundwater flow)	600	1-1,000	feet	Please input your site data.
Saturated Thickness	11.5	1-100	feet	
Treatment Zone Cross Sectional Area	2300	--	ft^2	
Treatment Zone Volume	1,380,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	2,581,290	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	2,581,290	--	gallons	
Design Period of Performance	3.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	
Effective Porosity	25%	.05-50	percent	
Average Aquifer Hydraulic Conductivity	5.6	.01-1000	ft/day	
Average Hydraulic Gradient	0.0062	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.14	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	50.7	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	218,081	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.1	0.01 to 10	mg/L	
Nitrate	0.20	0.1 to- 20	mg/L	
Sulfate	57	10 to 5,000	mg/L	
Carbon Dioxide (estimated as the amount of Methane produced)	10.0	0.1 to 20	mg/L	
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)	5	0.1 to 20	mg/L	
Iron (III) (estimated as the amount of Fe (II) produced)	50	0.1 to 20	mg/L	
4. Contaminant Electron Acceptors				
Tetrachloroethene (PCE)	0.569	--	mg/L	
Trichloroethene (TCE)	0.276	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.874	--	mg/L	
Vinyl Chloride (VC)	0.107	--	mg/L	
Carbon Tetrachloride (CT)	0.000	--	mg/L	
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	
Chloromethane	0.000	--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane	0.000	--	mg/L	
Perchlorate	0.000	--	mg/L	
5. Aquifer Geochemistry (Optional Screening Parameters)				
A. Aqueous Geochemistry				
Oxidation-Reduction Potential (ORP)	-80	-400 to +500	mV	
Temperature	20	5.0 to 30	ºC	
pH	7.5	4.0 to 10.0	su	
Alkalinity	300	10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	
Specific Conductivity	200	100 to 10,000	µs/cm	
Chloride	10	10 to 10,000	mg/L	
Sulfide - Pre injection	0.0	0.1 to 100	mg/L	
Sulfide - Post injection	0.0	0.1 to 100	mg/L	
B. Aquifer Matrix				
Total Iron	10000	200 to 20,000	mg/kg	
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	

NOTES:

Table S.2 Substrate Calculations in Hydrogen Equivalents

Site Name: **Jack's Cleaners, Brewerton, NY**

RETURN TO COVER PAGE

NOTE: Open cells are user input.

1. Treatment Zone Physical Dimensions

	Values	Range	Units
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet
Length (Parallel to predominant groundwater flow)	600	1-1,000	feet
Saturated Thickness	11.5	1-100	feet
Treatment Zone Cross Sectional Area	2300	--	ft^2
Treatment Zone Volume	1,380,000	--	ft^3
Treatment Zone Effective Pore Volume (total volume x effective porosity)	2,581,290	--	gallons
Design Period of Performance	3.0	.5 to 5	year

2. Treatment Zone Hydrogeologic Properties

	Values	Range	Units
Total Porosity	0.25	.05-50	
Effective Porosity	0.25	.05-50	
Average Aquifer Hydraulic Conductivity	5.6	.01-1000	ft/day
Average Hydraulic Gradient	0.0062	0.1-0.0001	ft/ft
Average Groundwater Seepage Velocity through the Treatment Zone	0.14	--	ft/day
Average Groundwater Seepage Velocity through the Treatment Zone	50.7	--	ft/yr
Average Groundwater Flux through the Treatment Zor 0	218,081	--	gallons/year
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3
Soil Fraction Organic Carbon (foc)	0.0005	0.0001-0.1	

3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)

A. Aqueous-Phase Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	0.1	2.15	7.94	0.27	4
Nitrate (denitrification)	0.2	4.31	12.30	0.35	5
Sulfate	57.1	1229.92	11.91	103.27	8
Carbon Dioxide (estimated as the amount of methane produced)	10.0	215.40	1.99	108.24	8
Soluble Competing Electron Acceptor Demand (lb.)				**212.13**	

B. Solid-Phase Native Electron Acceptors (Based on manganese and iron produced)	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Manganese (IV) (estimated as the amount of Mn (II) produced)	5.0	135.00	27.25	4.95	2
Iron (III) (estimated as the amount of Fe (II) produced)	50.0	1349.95	55.41	24.36	1
Solid-Phase Competing Electron Acceptor Demand (lb.)				**29.32**	

C. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.569	12.26	20.57	0.60	8
Trichloroethene (TCE)	0.276	5.94	21.73	0.27	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.874	18.83	24.05	0.78	4
Vinyl Chloride (VC)	0.107	2.30	31.00	0.07	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	0.000	0.00	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand (lb.)				**1.73**	

D. Sorbed Contaminant Electron Acceptors (Soil Concentration = Koc x foc x Cgw)	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.07	10.96	20.57	0.53	8
Trichloroethene (TCE)	107	0.01	2.16	21.73	0.10	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.02	2.88	24.05	0.12	4
Vinyl Chloride (VC)	3.0	0.00	0.02	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)					**0.75**	

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents

4. Treatment Cell Electron-Acceptor Flux (per year)

A. Soluble Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	0.1	0.18	7.94	0.02	4
Nitrate (denitrification)	0.2	0.36	10.25	0.04	5
Sulfate	57.1	103.91	11.91	8.72	8
Carbon Dioxide (estimated as the amount of Methane produced)	10	18.20	1.99	9.14	8
Total Competing Electron Acceptor Demand Flux (lb/yr)				**17.9**	

B. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.569	1.04	20.57	0.05	8
Trichloroethene (TCE)	0.276	0.50	21.73	0.02	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.874	1.59	24.05	0.07	4
Vinyl Chloride (VC)	0.107	0.19	31.00	0.01	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	0.000	0.00	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)				**0.15**	

Initial Hydrogen Requirement First Year (lb)	**262.0**
Total Life-Cycle Hydrogen Requirement (lb)	**298.1**

5. Design Factors

Microbial Efficiency Uncertainty Factor	2X - 4X
Methane and Solid-Phase Electron Acceptor Uncertainty	2X - 4X
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)	1X - 3X
Design Factor	**3.0**
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)	**894.4**

6. Acronyns and Abbreviations

^{o}C =degrees celsius
μs/cm = microsiemens per centimeter
cm/day = centimeters per day
cm/sec = centimeters per second
ft^2 = square feet
ft/day = feet per day
ft/ft = foot per foot
ft/yr = feet per year
gm/cm^3 = grams per cubic centimeter
kg of CaCO3 per mg = kilograms of calcium carbonate per milligram
lb = pounds
meq/100 g = milliequivalents per 100 grams
mg/kg = milligrams per kilogram
mg/L = milligrams per liter
m/m = meters per meters
mV = millivolts
m/yr = meters per year
su = standard pH units
wt/wt H2 = concetration molecular hydrogen, weight per weight

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

RETURN TO COVER PAGE

Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H_2/Mole Substrate
Lactic Acid	$C_3H_6O_3$	90.1	2	0.0448	**2 to 3**
Molasses (assuming 100% sucrose)	$C_{12}H_{22}O_{11}$	342	8	0.0471	**8 to 11**
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	$C_6H_{12}O_6$	180	4	0.0448	**4 to 6**
Ethanol	C_2H_6O	46.1	2	0.0875	**2 to 6**
Whey (assuming 100% lactose)	$C_{12}H_{22}O_{11}$	342	11	0.0648	**11**
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	$C_{39}H_{56}O_{39}$	956	28	0.0590	**28**
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	$C_{18}H_{32}O_2$	281	16	0.1150	**16**

Table S.4
Estimated Substrate Requirements for Hydrogen Demand in Table S.3

Design Life (years): 3

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	3.0	19,983	19,983	9.06E+09	740
Sodium Lactate Product (60 percent solution)	3.0	19,983	41,458	9.06E+09	740
Molasses (assuming 6 0	3.0	18,983	31,639	8.61E+09	703
HFCS (assuming 40% fructose and 40% glucose by weight)	3.0	19,987	24,984	9.07E+09	740
Ethanol Product (assuming 80% ethanol by weight)	3.0	10,220	12,775	4.64E+09	379
Whey (assuming 100% lactose)	3.0	13,794	19,706	6.26E+09	511
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	3.0	15,148	15,148	6.87E+09	449
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	3.0	7,778	7,778	3.53E+09	288
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	3.0	7,778	12,963	3.53E+09	288

NOTES: Sodium Lactate Product
1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH_3-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid ($C_6H_6O_3$) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H2O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product
1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC® weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product
1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: **Jack's Cleaners, Brewerton, NY**

RETURN TO COVER PAGE

1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	600	feet	182.9	meters
Saturated Thickness	11.5	feet	3.5	meters
Design Period of Performance	3	years	3	years

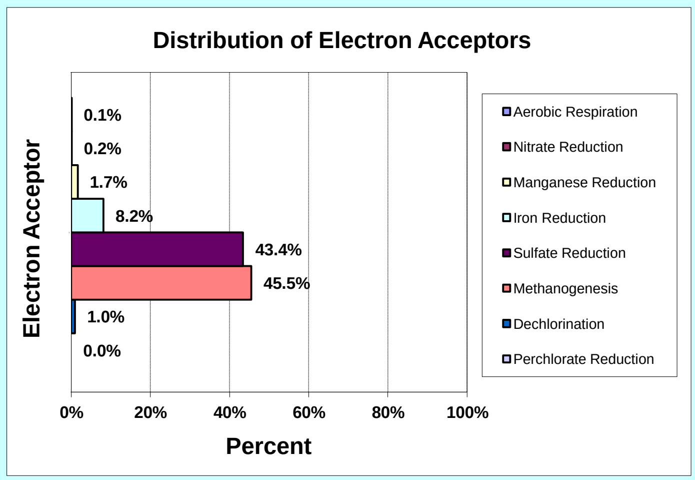
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	5.6	ft/day	2.0E-03	cm/sec
Average Hydraulic Gradient	0.0062	ft/ft	0.0062	m/m
Average Groundwater Seepage Velocity	0.14	ft/day	4.2E+00	cm/day
Average Groundwater Seepage Velocity	51	ft/yr	15.5	m/yr
Effective Treatment Zone Pore Volume	2,581,290	gallons	9,770,973	liters
Groundwater Flux (per year)	218,081	gallons/year	825,504	liters/year
Total Groundwater Volume Treated (over entire design period)	3,235,533	gallons total	12,247,484	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.1%	0.340
Nitrate Reduction	0.2%	0.457
Sulfate Reduction	43.4%	129.441
Manganese Reduction	1.7%	4.954
Iron Reduction	8.2%	24.363
Methanogenesis	45.5%	135.674
Dechlorination	1.0%	2.917
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**298.15**

Hydrogen demand in pounds/gallon:	9.21E-05
Hydrogen demand in grams per liter:	1.10E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	41,458	3,769	740	as lactic acid
2. Molasses Product	31,639	2,637	703	as sucrose
3. Fructose Product	24,984	2,231	740	as fructose
4. Ethanol Product	12,775	1,851	379	as ethanol
5. Sweet Dry Whey (lactose)	19,706	sold by pound	511	as lactose
6. HRC®	15,148	sold by pound	449	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	7,778	997	288	as soybean oil
8. Emulsified Vegetable Oil	12,963	1,662	288	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.