Draft
Remedial Site Optimization
Alternatives for the
Mr. C's Dry Cleaners Site
NYSDEC Site No. 915157
East Aurora, New York

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Prepared for:

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
625 Broadway
Albany, New York 12233

Prepared by:

ECOLOGY AND ENVIRONMENT ENGINEERING, P.C.
368 Pleasant View Drive
Lancaster, New York 14086

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List of Abbreviations and Acronyms

3DMe 75	Regenesis 3D-Microemulsion® 75
AMSL	above mean sea level
BDI PLUS	Regenesis Bio-Dechlor INOCULUM® Plus
BGS	below ground surface
cm/s	centimeter per second
COC	contaminant of concern
DCE	dichloroethene
DER	Division of Environmental Remediation
DO	dissolved oxygen
EEEPC	Ecology and Environment Engineering, P.C.
ECs	engineering controls
ft/day	feet per day
gpm	gallons per minute
HRC Primer®	Regenesis Hydrogen Release Compound Primer
ICs	institutional controls
LTM	long-term monitoring
µg/L	micrograms per liter
MNA	monitored natural attenuation
NYSDEC	New York Department of Environmental Conservation
NYSDOH	New York State Department of Health
OM&M	operations, maintenance, and monitoring
ORP	oxidation reduction potential
PCE	perchloroethene (also known as tetrachloroethene)
Pilot Study	Enhanced Bioremediation and Bioaugmentation Pilot Study
PRB	permeable reactive barrier
RAO	Remedial Action Objectives
RI	remedial investigation

List of Abbreviations and Acronyms (cont.)

ROD	Record of Decision
RSO	Remedial Site Optimization
Site	Mr. C's Dry Cleaners Site
SPDES	State Pollutant Discharge Elimination System
SSDS	sub-slab depressurization system
SVII	soil vapor intrusion investigation
TCE	trichloroethene
UIC	Underground Injection Control
USEPA	United States Environmental Protection Agency
VC	vinyl chloride
VOC	volatile organic compound

Executive Summary

This draft Remedial Site Optimization (RSO) report was prepared by Ecology and Environment Engineering, P.C. (EEEPC) at the request of the New York State Department of Environmental Conservation (NYSDEC) to evaluate alternatives to the existing remedy at the Mr. C's Dry Cleaner's Site (the Site). According to the Interstate Technology & Regulatory Council, RSO is the "systematic evaluation and enhancement of site remediation processes to ensure that health and the environment are being protected over the long term at minimum risk and cost" (2004). The two main criteria for prioritizing sites for RSO include concerns regarding the protectiveness of the remedy and high annual operations and maintenance costs (ITRC 2004). Remedial site optimization at the Mr. C's Dry Cleaner's is warranted by the declining effectiveness of the existing pump-and-treat remedy (the Site Remedy) selected by the 2000 Explanation of Significant Differences (NYSDEC 2000) due to the movement of contaminants beyond the zone of capture.

An RSO plan may include a critique of the site conceptual model, recommendations to improve a selected remedy, or identification of a better remedy that was not available at the time of the ROD (NYSDCE 2011). For the Mr. C's Dry Cleaners Site, this RSO report has been prepared in the manner of a focused feasibility study to determine whether bioremediation, used alone or in conjunction with the existing Site Remedy, would constitute a significantly better remedy that would facilitate progress toward site closure while improving the effectiveness and cost efficiency of the remedy. Bioremediation, which was not considered in the Mr. C's Feasibility Study (MPI 1996), has been demonstrated to stimulate in situ anaerobic degradation of the volatile organic compounds (VOCs) that comprise the Site's contaminants of concern (COCs): tetrachlorothene (PCE), trichloroethene (TCE), cis-dichloroethene (cis-DCE), and vinyl chloride (VC).

A conceptual site model was not developed for the Mr. C's Site during the RI. The Site contamination was described in the Mr. C's Remedial Investigation (MPI 1995a) as having resulted from the release of dry cleaning fluid from the former Mr. C's Dry Cleaners facility in East Aurora, New York. As a result of changes to waste management practices at the Site prior to implementation of the ROD and the cessation of active dry-cleaning operations in 2012, there is no source for continued release of contaminants from the Site (EEEPC 2014). However, since installation of the pump-and-treat system in 2003, nearly 10 times the volume of contaminated groundwater has been processed and nearly 10 times the mass of

PCE has been removed than the volume and mass identified in the responsiveness summary of the ROD. The ROD recognized that the mass of contamination will never be known, but it is clear that the amount was greater than initially estimated.

Despite the high rate of VOC removal through the existing Mr. C's pumping well system and air stripper (to date, over 90% of influent VOCs have been removed from the air stripper effluent water), the overall concentrations and types of contaminants in the plume remained stable between long-term groundwater monitoring events from 2006 through 2012.

A bioremediation pilot study (Pilot Study) was conducted beginning with injections in 2012. The Pilot Study showed that the largest reduction in plume PCE concentrations occurred in the injection areas around monitoring well MPI-6S, where PCE contamination was degraded to cis-DCE. Pilot study injections in an area with lower initial concentrations at MW-8 successfully reduced PCE and TCE concentrations below groundwater standards (EEEPC 2015a). The Pilot Study demonstrated that bioremediation was technically feasible at the Site. This RSO evaluates the cost effectiveness and appropriateness of the technology for meeting site Remedial Action Objectives (RAOs).

Four alternatives are presented in this RSO: (1) continuation of the existing site pump-and-treat system, (2) continuation of the existing pump-and-treat system for source control with the use of bioremediation for migration control, (3) the use of bioremediation for source control with use of the existing pump-and-treat system for migration control, and (4) the use of bioremediation for both source and migration control.

Continued operation of the existing pump-and-treat system, alone or in conjunction with bioremediation technologies, is subject to several limitations. During the first few years, the pump-and-treat system was very effective at removing contamination; however, fewer pounds of VOCs have been removed annually in recent years despite average VOC removal rates of 90% to 100%. The declining trend in pounds of VOCs removed annually is matched by declines in process volume and average influent concentrations. The decline in process volume relates to system aging and fouling necessitating downtime for maintenance of the system. The decline in influent concentrations may be explained by the size and location of the existing pumping wells and the location of the groundwater plume. The pumping well locations were selected based on the nature and extent of contamination as summarized in the Feasibility Study (MPI 1996); system design was subsequently performed by Malcolm Pirnie. The highest-capacity well is located close to the Mr. C's treatment facility and the original source location, and several lower-capacity wells are located downgradient of the treatment facility in an area with much lower transmissivity. The capacity of the pumps seems to have been based on the transmissivity of the geologic formations. Based on the results of long-term monitoring, the plume's center of mass appears to have migrated since the RI site investigations and is now located in the area of lower transmissivity.

The tail of the plume now extends downgradient of the pumping wells and outside of their radius of influence. Therefore, Alternative 3, which proposed using the existing pump-and-treat system for migration control, was not considered further.

The remaining alternatives are all subject to additional limitations that would prevent them from reaching New York State Class GA groundwater standards throughout the entire contaminant plume, because of the plume's location in a residential and commercial neighborhood with homes and buildings above the plume. The alternatives evaluated in this RAO and their cost estimates are based on the use of these technologies only in those areas where they would be implementable. The source and migration controls proposed in each alternative are intended to address two of the three Site RAOs: reducing the migration of the plume and achieving groundwater standards to the extent practicable. Every alternative also includes long-term monitoring and a soil vapor intrusion investigation (SVII) and mitigation program that is intended to address the remaining site RAO to protect human health from soil vapor intrusion.

Based on the analysis presented in this RSO, EEEPC recommends the use of in situ bioremediation, which offers a substantially more effective means of reducing plume contamination than the existing pump-and treat system, and at a substantially reduced cost. The recommended alternative consists of the following:

1. Installation of downgradient permeable reactive barriers (PRBs) using enhanced bioremediation.
2. Source control through enhanced in situ bioremediation.
3. Shut-off and decommissioning of the existing treatment system.
4. Continued long-term monitoring and SVII and mitigation.
5. A new decision framework for response actions, including if and when additional enhancements are required to maintain degradation rates, if and when the frequency of long-term monitoring can be changed, and when to initiate new SVIIs or implement mitigation measures.

Although not the primary selection factor, EEEPC reviewed the alternatives for consistency with NYSDEC's Green Remediation program policy (DER-31) and determined that in situ, passive technologies such as bioremediation would contribute fewer direct and indirect greenhouse gas emissions than the pump-and-treat system by reducing vehicle miles traveled for operation and maintenance and reducing the demand for electricity. As such, bioremediation is consistent with NYSDEC's current Green Remediation policy.

As this RSO is recommending a fundamental change to the Site Remedy, it must be presented to the NYSDEC commissioner for consideration. Per NYSDEC's RSO policy, a change to the Site Remedy must go through the same rigorous analysis, risk assessment, and community involvement as the original remedy. While this RSO substantially documents the relative benefits and cost effectiveness of the technology, two issues should be resolved before soliciting community involvement:

1. Bioremediation will result in a short-term increase in the overall toxicity of the COCs. While cis-DCE is less toxic than PCE, both TCE and VC are more toxic. The final degradation byproduct, ethene, is non-hazardous. A risk assessment should be performed to determine whether the increased COC toxicity poses an increased risk to human health. For many residences, the overall risk has been reduced through the installation of a sub-slab depressurization system, which removes the exposure pathway for soil vapor intrusion. Groundwater under the site is not a drinking water source; however, the RI identified four properties with wells that were typically used for irrigation and could present a potential exposure route (MPI 1995a),
2. The electron donor supplied to facilitate the degradation of chlorinated ethenes by microbes of the Dehalococcoides genus is also consumed in a competing reaction by indigenous microbes that produce dissolved methane. The biotic production of dissolved methane is referred to as methanogenesis. Methane is non-toxic, but if it partitions out of the groundwater and into soil vapor, it could migrate upward and accumulate, potentially resulting in an explosion risk. Literature reviewed to date by EEEPC has not identified any known instances of methane accumulation to explosive levels under these circumstances; however, the risk remains and may factor into the public's perception of the Alternative. Therefore, EEEPC will investigate the use of continuous methane-monitoring in confined spaces or basements above the plume if electron-donor products that do not inhibit methane-producing microbes are used. EEEPC will also investigate the use of alternative electron-donor products that can inhibit methane-producing microbes, which has the potential to eliminate methane hazards and reduce costs. The results of these investigations will be provided in the final RSO report.

1 Introduction and Background

The New York State Department of Environmental Conservation (NYSDEC) contracted Ecology and Environment Engineering, P.C. (EEEPC) to perform remedial site optimization (RSO) as part of operations, maintenance, and monitoring (OM&M) for the Mr. C's Dry Cleaner's Site (the Site), NYSDEC Site No. 915157. This report presents options for remedial site optimization (RSO) at the Site and was prepared by EEEPC for NYSDEC under the 2015 modification to Work Assignment D007617-11.1, which was approved by NYSDEC's Division of Environmental Remediation (DER) on May 27, 2015.

1.1 Site Description

The Site is located on an approximately 0.5-acre parcel at 586 Main Street in the village of East Aurora, in Erie County, New York (see Figure 1-1). Mr. C's Dry Cleaners formerly occupied the front portion of the building along Main Street, and the remainder of the building was occupied by other commercial businesses.

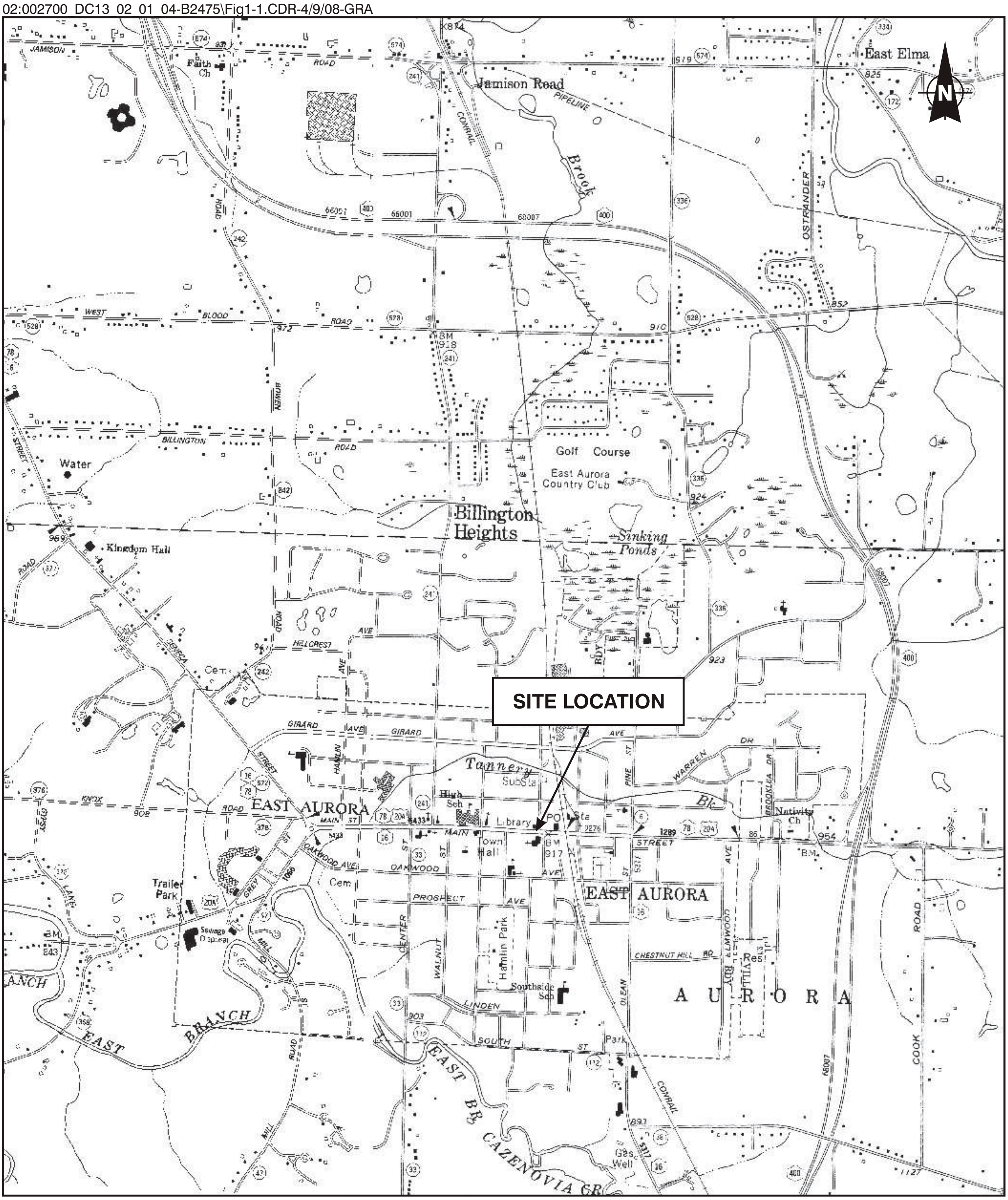
The Site is surrounded by residential homes along Whaley Avenue to the west and Fillmore Avenue to the north. Other commercial businesses are adjacent to the Site on the east side and across Main Street to the south. Groundwater pumping wells and groundwater monitoring wells form a ring around the entire Site.

An expanded site description and history, including associated regulatory information, is presented as part of the Site Management Plan (EEEPC 2015b).

1.2 Remedial Background

Perchloroethene (PCE), also known as tetrachloroethene, and its degradation byproduct are the primary contaminants of concern (COCs) at the Site. The contamination at the Site is the result of improper handling and management of PCE, a solvent used in the dry cleaning process. Poor management practices resulted in contamination of the groundwater beneath and downgradient of the Mr. C's Dry Cleaners facility. Remedial investigations (RIs) were performed between 1993 and 1995 (MPI 1995a, b). A feasibility study was completed in 1996 (MPI 1996).

A Record of Decision (ROD) for the Site was issued by NYSDEC in 1997 and revised in 2000. In the 2000 Explanation of Significant Differences, NYSDEC changed the selected remedy to groundwater pumping and ex-situ air stripping treatment (the Site Remedy). The groundwater pumping well network and the existing air stripper were installed between 2001 and 2003 (NYSDEC 1997, 02:002700_DC13_02_01_04-B2475\Fig1-1.CDR-4/9/08-GRA



SOURCE: NYS Department of Transportation Raster Quadrangle, 1988.

Scale
0 2,000 4,000 Feet

Figure 1-1 General Site Location Map

2000). A Final Engineering Closure Report for the remedial construction was prepared by EEEPC and issued to NYSDEC in March 2005 (EEEPC 2005).

Because of the nature of contamination at the Site, soil vapor intrusion investigations (SVIIs) have been performed beneath the Mr. C's treatment facility and in two downgradient buildings. SSDSs were installed at the First Presbyterian Church in 2004 and at the residential property 27 Whaley Avenue in 2005. As the feasibility of bioremediation was being investigated, a renewed effort to investigate soil vapor intrusion was also undertaken. SVIIs were performed at 16 properties between January 2013 and September 2015. New SSDSs were requested by the New York State Department of Health (NYSDOH) through NYSDEC for seven of these properties, all of which have been installed.

In 2011, after the pump-and-treat system had been operating successfully for 10 years, NYSDEC implemented the Mr. C's Enhanced Bioremediation and Bioaugmentation Pilot Study (Pilot Study). Declines in the efficiency of the pump-and-treat system (see Section 1.6) prompted the investigation of alternate technologies for potential optimization of the Site Remedy. The Pilot Study demonstrated that bioremediation was capable of reducing PCE concentrations at the Site. The Pilot Study concluded in 2014 and is described in the *Summary Report for the Mr. C's Dry Cleaners Site Enhanced Bioremediation and Bioaugmentation Pilot Study* (EEEPC 2015a).

An expanded description of the Site's remedial background is presented as part of the Site Management Plan (EEEPC 2015b).

1.3 Objectives of This RSO

Because chlorinated ethenes are the primary COCs at the Mr. C's Site, anaerobic bioremediation, a technology that was not available at the time of the ROD (NYSDEC 1997), was identified as a technology that could potentially lead to significantly better attainment of the Remedial Action Objectives (RAOs) for the Site, improved cost efficiency, and/or a shorter time to site closure than the chosen remedy. Before an RSO study could be prepared, a Pilot Study was conducted at the Mr. C's Site between 2011 and 2014. The Pilot Study found anaerobic remediation to be effective at reducing the concentrations of chlorinated ethenes (EEEPC 2015a).

This RSO report evaluates the feasibility of alternatives consisting of one or a combination of pump-and-treat technologies using the existing site engineering controls (ECs) and bioremediation technologies. Each alternative is evaluated with regard to implementability, effectiveness, and cost. Costs are estimated using present worth analysis, which is a necessary component of advancing an optimization recommendation for NYSDEC consideration. Limited modeling and calculations were performed to estimate the time the remedy would need to operate to attain site closure. Due to the uncertainty in calculated cleanup time frames, present worth analyses are based on a period of 30 years. Present worth analyses help demonstrate the relative effectiveness of capital investments required under each alternative.

1.4 Geology and Hydrology

The Site is located in a residential/commercial area with both paved and unpaved (lawns and soil fill) sections. The Site is situated on top of fill overlaying glacial deposits from the last glacial ice.

1.4.1 Geology

1.4.1.1 Bedrock

The Site is situated on top of the buried bedrock valley of Cazenovia Creek. The Rhinestreet Shale member of the West Falls Formation is the uppermost bedrock unit beneath the Site and surrounding area. The Rhinestreet Shale consists of slightly petroliferous, fissile-to-massive, black shale interbedded with medium and dark gray shales in the upper third of the Rhinestreet member. Bedrock beneath the Site is estimated to be 150 to 200 feet below ground surface (BGS; MPI 1995a). East and west of the buried valley, bedrock is found at 20 to 30 feet BGS.

1.4.1.2 Overburden

Unconsolidated sediments at the Site consist primarily of fill, glacial outwash, lacustrine deposits, and glacial till. During the 1994 RI, fill was found to extend approximately 11 feet BGS (MPI 1995a). Fill underneath the Site was described as clayey silt with gravel overlaying gravel with clayey silt and trace of brick fragments. The fill is underlain by 4 to 7 feet of glacial till composed of brown clayey silt with varying amounts of shale fragments. The remedial investigation identified three stratigraphic units beneath the fill and till. These stratigraphic units are described below.

A. Gravel and Sand Outwash – Glacial outwash, encountered in each RI borehole, grades from sandy gravel near the top of the unit to very fine sand at the base. The outwash is approximately 27 feet thick and consists of 2 to 26 feet of gravel followed by 1.5 to 12 feet of medium-to-coarse sand with varying amounts of fine sand. Fine and very fine sands were encountered at the base of the outwash unit in most of the RI borings (MPI 1995a).

B. Lacustrine Deposits – The glacial outwash is underlain by lacustrine sandy silt. The lacustrine deposits were encountered at an approximate elevation of 888 feet above mean sea level (AMSL) and ranged in thickness from 11.5 to 14.5 feet. These deposits may liquefy when disturbed, are uniform, and are characterized by mostly silt and fine to very fine sand (MPI 1995a).

C. Stratified Till and Sand – A sequence of stratified, interbedded, fine-grained till and sand underlies the lacustrine deposits. It was encountered at 90 feet BGS in the deepest exploratory RI boring. This layer was found to be approximately 49.5 feet thick. This sequence contains lenses of stratified medium and fine sand interbedded with clayey silt and silty clay till layers. The two lithologies are separated by a sharp contact, with the sand layers ranging in thickness from thin laminae to 3 feet and the till ranging in thickness from thin laminae to layers 5 to 11 feet thick (MPI 1995a).

1.4.2 Hydrostratigraphic Units

Three major hydrostratigraphic units are present at the Site, including an unconfined aquifer of saturated outwash deposits (outwash aquifer); the underlying lacustrine aquifer; and a confining layer consisting of the stratified till deposits (MPI 1995b). The outwash and lacustrine aquifers are hydraulically connected and have nearly the same hydraulic heads. However, they are characterized by different hydraulic conductivities and porosities.

A. Outwash Aquifer – The outwash aquifer is an unconfined aquifer with a saturated thickness of approximately 18 feet. Wells screened across the entire outwash aquifer exhibited a geometric mean hydraulic conductivity of 0.004 centimeter per second (cm/s), equal to 11.3 feet per day (ft/day). Precipitation and infiltration are the main recharge sources for this aquifer, with possible exfiltration from sewers located above the water table (MPI 1995b). Figure 1-2 is a groundwater contour map of the Site based on data collected in October 2014.

B. Lacustrine Aquifer – The lacustrine aquifer is a rather uniform aquifer with a saturated thickness of approximately 13 feet. Wells screened across the lacustrine aquifer exhibited hydraulic conductivities that ranged from 1.5 x 10^{-4} to 4.9 x 10^{-4} cm/s (MPI 1995b), equal to 0.43 to 1.39 ft/day. During the RI, groundwater flow direction in this aquifer appeared very similar to that in the outwash aquifer.

C. Stratified Till Unit – The confining stratified till unit consists of interbedded layers of clayey till and sand. The hydraulic conductivity for the unit was estimated at 8.8 x 10^{-6} cm/s, equal to 9.1 feet per year, based on slug testing performed at well MPI-4D. A previously calculated upward vertical hydraulic gradient for this unit indicated that the outwash and lacustrine aquifers beneath the Site are not the source of recharge to the stratified till unit (MPI 1995b).

Estimates of groundwater velocities for each unit are presented in Table 1-1.

Table 1-1 Groundwater Flow Parameters

Hydrostratigraphic Unit	Hydraulic Conductivity (cm/s)	Average Hydraulic Gradient (ft/ft)	Estimated Groundwater Velocity (ft/day)
Outwash Aquifer	0.004	0.004	0.045
Lacustrine Aquifer	0.00049	0.004	0.006
Stratified Till	0.0000088	0.004	0.0001

Notes:
Hydraulic conductivities are taken from the Mr. C's RI (MPI 1995a).

Key:
cm/s = centimeters per second
ft = feet

1.5 Nature and Extent of Contamination

This section summarizes pertinent characteristics of the nature and extent of contamination, based on a review of site geology, hydrology, and geochemistry and is intended to summarize the fate and transport of contaminants.

The existing building that houses the Mr. C's treatment facility and the former Mr. C's Dry Cleaners is believed to have been built around 1927 and was used as a dry cleaning facility since before 1970 (NYSDEC 1997). It operated as the Mr. C's Dry Cleaners from 1974 to 2012. Since 1985, all dry cleaning wastes from the Site, including filters and sludges, have been disposed of through a commercial disposal firm. Prior to 1985, waste was disposed of via the sanitary sewer. According to the 1995 RI, the cleaning agent used at the Mr. C's Dry Cleaners Site between 1989 and 1991 was a solvent comprised of approximately 99.1 to 100% PCE with traces of 1,2-DCE (20 ppm), tetrachloromethane (50 ppm), and TCE (100 ppm). Solvent usage was reportedly reduced from 1,200 gallons in 1989 to 430 gallons in 1991 when the facility changed over from transfer-type to closed-loop type dry cleaner machines (MPI 1995a). Since 2012, the dry cleaning service has operated strictly as a drop-off and pick-up location; dry cleaning is no longer performed on the Site.

Investigations conducted prior to the 1994 Malcolm Pirnie, Inc., RI detected PCE and other chlorinated solvents in the groundwater, soil gas, and sewers in the vicinity of the Site (MPI 1995a). The highest concentrations of PCE in soil gas and groundwater were found near the Site's sanitary sewer lateral. These investigations identified the Site as the possible source of PCE in the groundwater and soil gas. PCE levels found in the sewers were consistent with a source located at the Site (migration possibly occurring along sanitary sewers). Groundwater was also recognized to be a migration pathway.

The 1994 RI found the highest concentration of PCE beneath the Mr. C's Dry Cleaners building. The RI concluded that substantial volatile organic compound (VOC) contamination is present in the outwash aquifer (upper unconfined aquifer in saturated glacial outwash sand and gravel). It was determined that PCE distribution in the lacustrine aquifer (saturated sand and silt lacustrine deposits) is more localized and at lower concentrations. According to the 1994 RI, "concentrations of PCE in the lacustrine aquifer that appear to increase downgradient of the Site are most likely an artifact of a hydraulic connection along the sand pack of a deep monitoring well." RI analytical data indicated an increase of chlorinated VOCs with depth in the outwash aquifer, with the highest concentrations occurring near the base of the outwash aquifer in a narrow elongated plume extending downgradient (northwest) from the Mr. C's Dry Cleaners building.

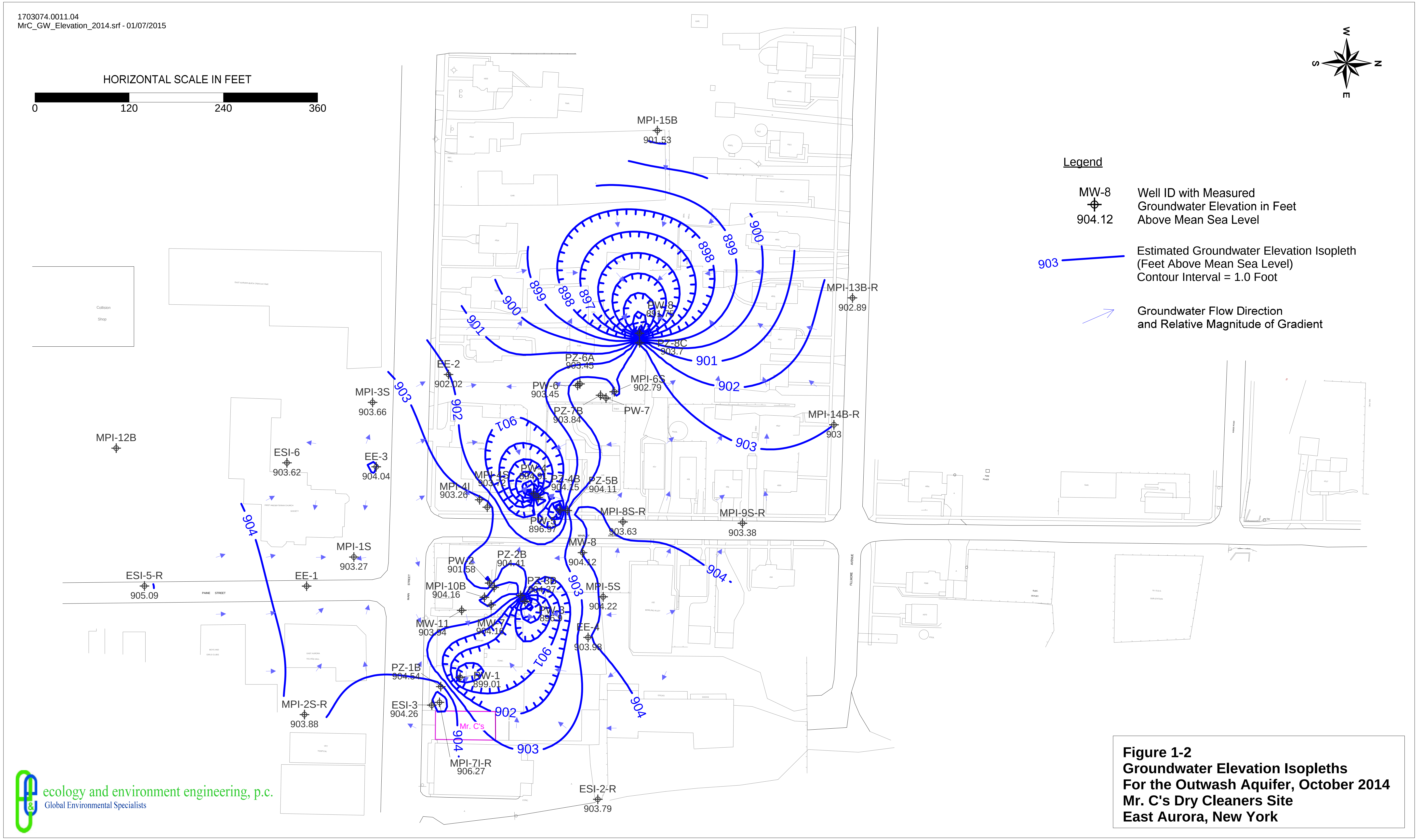


Figure 1-2
Groundwater Elevation Isopleths
For the Outwash Aquifer, October 2014
Mr. C's Dry Cleaners Site
East Aurora, New York

Based on the Site's history, previous investigations, and geology, the nature and extent of contamination at the Site is characterized by the following:

- As of the beginning of the Pilot Study, PCE was the primary contaminant;
- The original source of PCE from the dry cleaning operations has been removed because dry cleaning operations at the Site have ceased;
- The source contamination is now considered to be the impacted groundwater plume's center of contaminant mass, characterized by elevated PCE concentrations;
- Residual contamination remains in the aqueous phase within the outwash aquifer and bound to sediments in the upper soil strata;
- Based on indoor air monitoring results, PCE volatilization from groundwater is a source of indoor air contamination in basements; and
- The plume has extended in a northwesterly direction from the Site due to groundwater gradients.

1.6 Remedy Performance and Progress Made Toward Site Cleanup Goals

1.6.1 Pump-and-Treat System Performance

From the inception of its operation in 2003 to December 2014, the Mr. C's pump-and-treat system has achieved 95.97% operational uptime and removed 1,591.46 pounds of VOCs (EEEPC 2015c). However, due to the migration of the contaminant plume beyond the capture zones of the groundwater pumping wells, the effectiveness of the pump-and-treat system has been declining. In over 10 years of operation it has gone from removing as much as 340 pounds of VOCs in 2003 to removing as little as 30.8 pounds of VOCs in 2012 (prior to the Pilot Study) and 15 pounds of VOCs in 2014 (after the Pilot Study) (see Figure 1-3).

The Mr. C's Feasibility Study estimated the volume of VOC-contaminated groundwater to be 1.3 million gallons (MPI 1996). However, because of tailing and rebound, the Feasibility Study estimated that as much as 10 times this volume would need to be processed by the pump-and-treat system to remediate the contaminated groundwater plume. As of October 6, 2015, the cumulative volume of groundwater treated was 127 million gallons, or 9.8 times the estimated contaminated groundwater volume, with significant contamination still remaining (EEEPC 2015c).

Some VOC contamination within the aquifer partitions and partially adsorbs to the aquifer soils. This is partly responsible for the difference between the expected and actual volumes needed to be processed to remove the contamination.

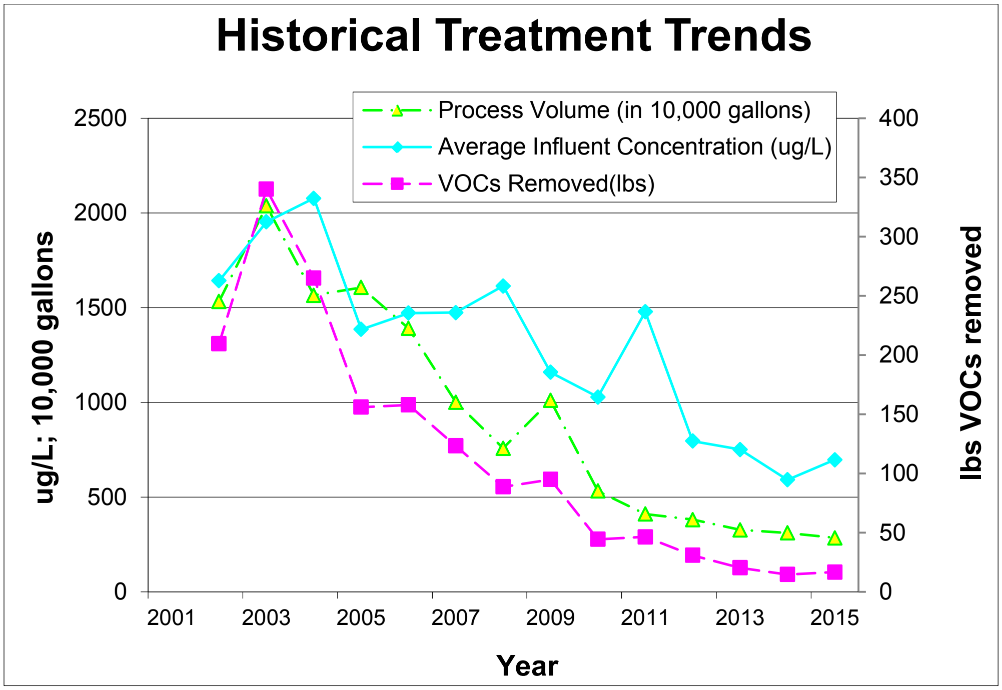


Figure 1-3 Historical Treatment Trends – Mr. C's Dry Cleaners Site

The responsiveness summary in the ROD acknowledged that it is difficult to know exactly how much PCE had been released to the ground but went on to estimate the release at 5 to 10 gallons. Ten gallons of PCE dry cleaning fluid is the equivalent of 135 pounds of PCE, which is far less than the estimated 1,600 pounds of PCE removed through September 2015. Thus, the original conceptualization of the PCE contamination underestimated the volume of PCE contamination. As described in Section 1.5, historical solvent usage at the dry cleaning facility was as high as 1,200 gallons of 99.1 to100% PCE solution per year, which is over 16,000 pounds of PCE per year.

The pump-and-treat system will likely face declining efficiencies in line with current trends. The Pilot Study has changed the aquifer geochemistry, which is expected to contribute to the decline in efficiency. As a result of the groundwater geochemistry, the system has experienced operation issues, particularly from the change in influent VOC concentrations and with fouling of the system, which will lead to increased maintenance costs.

Toward the end of the Pilot Study, cis-DCE concentrations in the pump-and-treat system influent were nearly as high as PCE concentrations, reflecting a similar trend in the aquifer concentrations in the study area. Given the similar concentrations of cis-DCE and PCE, the air stripper has greater difficulty removing cis-DCE because of its lower Henry's Law constant. As a result, the pump-and-treat system removed just 9.0 pounds of total VOCs during the year of performance monitoring for the Pilot Study, and there have been instances of effluent VOC concentrations exceeding the State Pollutant Discharge Elimination System

(SPDES) equivalency permit limits. Adjustments were made to the treatment system's blower fan speed to adjust the system operation to more effectively remove cis-DCE and PCE. The change in the influent concentrations reflects the change in aquifer contaminant concentrations; therefore, similar influent cis-DCE and PCE concentrations can be expected in the future.

In three separate compliance sampling events since the beginning of the Pilot Study, monthly effluent results exceeded the SPDES equivalency permit due either to corrosion in the bag filters or as a result of fine particles that had passed through the bag filters and into the air stripper. These exceedances were addressed through corrective actions as required in the SMP. The impacts on the treatment system suggest that soluble inorganic compounds, especially iron or manganese, have been precipitating in the bag filters and fouling the air stripper treatment system. Naturally occurring inorganic compounds in the subsurface may be reduced to their potentially soluble form during anaerobic biodegradation reactions, such as iron (III) reduction to iron (II), and this reduction is expected to continue during anaerobic bioremediation efforts.

1.6.2 Contaminant Plume Treatment Performance

The extent of the dissolved contaminant plume at the Site was interpolated using the results from long-term groundwater monitoring performed since 2003. From 2003 to 2013, the plume remained fairly stable in size and composition, despite active remediation by the pump-and-treat system. As a result of the bioremediation Pilot Study from 2013 to 2014, significant changes were observed in the plume composition (EEEPC 2015a). Detected VOC concentrations changed from primarily PCE to primarily cis-DCE contamination. By July 2014, PCE and TCE in the injection areas had been effectively reduced to below the NYSDEC Class GA groundwater standards in MPI-6S and MW-8 (EEEPC 2015a). Because the Pilot Study treated only a limited area within the contaminant plume, groundwater transport of upgradient PCE contamination or partitioning of PCE sorbed to the soil in the Pilot Study areas led to PCE concentrations in MPI-6S increasing above the groundwater standards, based on the results of the October 2014 Long-Term Groundwater Monitoring Event (EEEPC 2015c). However, this still represents a reduction of over 95% of the original "hot-spot" contaminant concentrations in this well. Based on the results of the October 2014 Long-Term Groundwater Monitoring Event, PCE concentrations in MW-8 remained below the groundwater standards.

The PCE contaminant plume, as interpolated from the October 2014 Long-term Groundwater Monitoring data, is presented on Figure 1-4. The total chlorinated VOC plume, also interpolated from October 2014 data, is presented on Figure 1-5.

While the Pilot Study was very successful in reducing the PCE mass, implementation of the Pilot Study increases the potential for off-site migration of the contaminated groundwater plume because (1) multiple pumping wells have been locked out and tagged out to prevent pulling the electron donor materials into the treatment system, and (2) the chemically reduced PCE daughter products are lighter and thus more mobile. The potential for increased off-site migration is greatest at PZ-8C, which is a piezometer near the active pumping well PW-8, which is located farther downgradient of the Mr. C's facility than any of the other pumping wells.

The natural groundwater gradients result in groundwater flow toward PW-8. The steeper gradients created by pumping and the resulting cone of depression increase the rate of groundwater flow toward PW-8. Data collected throughout the Pilot Study indicated VOCs were migrating toward PW-8 as a result of these two processes. The next closest sentinel well downgradient of PW-8 is located several hundred feet to the west, with multiple residential properties in between.

1.6.3 Progress Made Toward Cleanup Goals

Per the 1997 ROD for the Mr. C's Site (NYSDEC 1997), the RAOs chosen for the Site include the following:

1. Mitigate human health risk by reducing the potential for inhalation of vapors in on-site and off-site basements.
2. Mitigate the source area of the contaminant plume to prevent further migration of the chlorinated volatile organic compounds and reduce volatilization into adjacent basements.
3. Achieve NYSDEC groundwater quality standards to the extent practical.

Since no property owners in the vicinity of the Site rely on groundwater-derived potable water, exposure to contaminated groundwater is not a consideration.

Mitigation of human health risk from soil vapors and sub-slab vapor intrusion has been addressed separately from the pump-and-treat system by performing SVIIs and, based on the results, installing ECs. The Site ECs include SSDSs installed in structures above the contaminated groundwater plume. Figure 1-6 shows the locations where SVIIs have been performed as part of the site remediation and the locations of the installed SSDSs. For many properties, the results of the soil vapor intrusion samples did not indicate the need for an SSDS, based on the NYSDOH criteria matrix (NYSDOH 2006). If the plume migrates, additional SVIIs should be performed, and SSDSs should be installed, as necessary, to maintain the protectiveness of the Site Remedy.

As described in Section 1.6.2, NYSDEC groundwater quality standards were achieved for PCE and TCE in the Pilot Study wells MPI-6S and MW-8. However, PCE, TCE, cis-DCE, and VC are still being detected at concentrations above groundwater quality standards in the larger plume area, and transport or desorption caused the PCE concentration in well MPI-6S to increase to about 15 micrograms per liter (µg/L) during the 2014 Long-Term Groundwater Monitoring Event.

As discussed in Section 1.3, this RSO is focused on the potential use of anaerobic bioremediation to better attain the RAOs in lieu of or in conjunction with the existing remedial system.

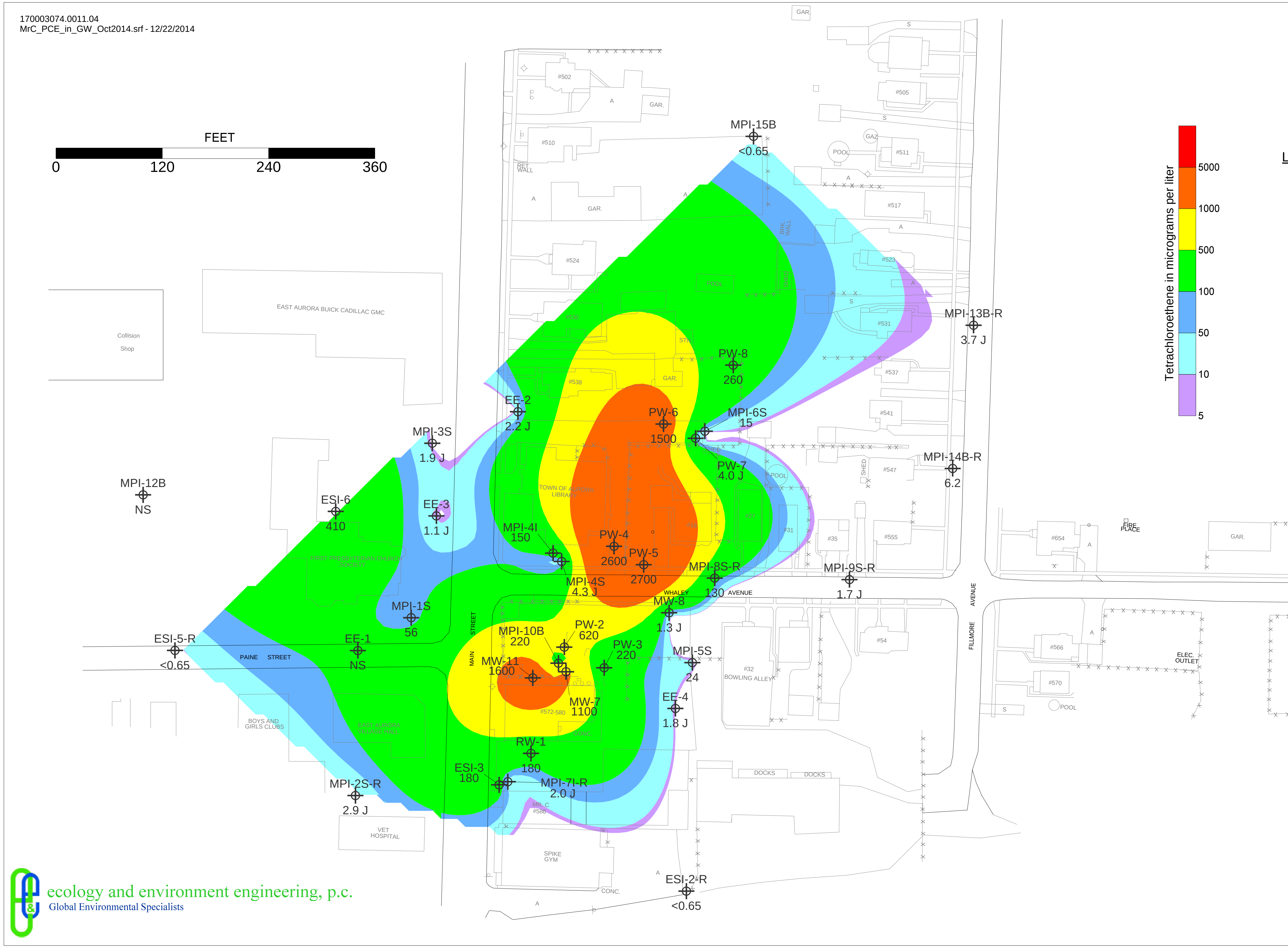


Figure 1-4
Tetrachloroethene in Groundwater
Mr. C's Dry Cleaners Site
East Aurora, New York
October 2014

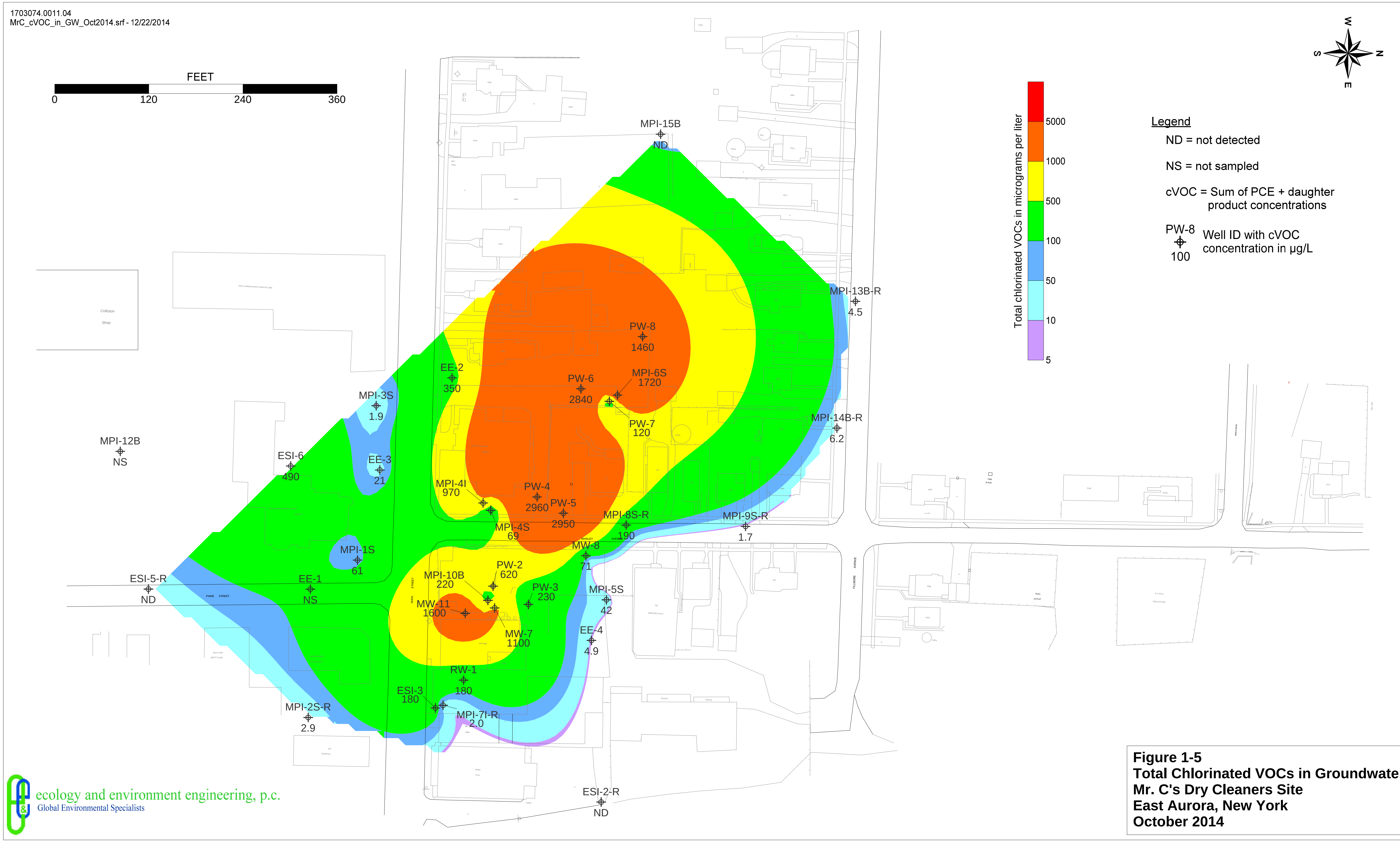


Figure 1-5
Total Chlorinated VOCs in Groundwater
Mr. C's Dry Cleaners Site
East Aurora, New York
October 2014

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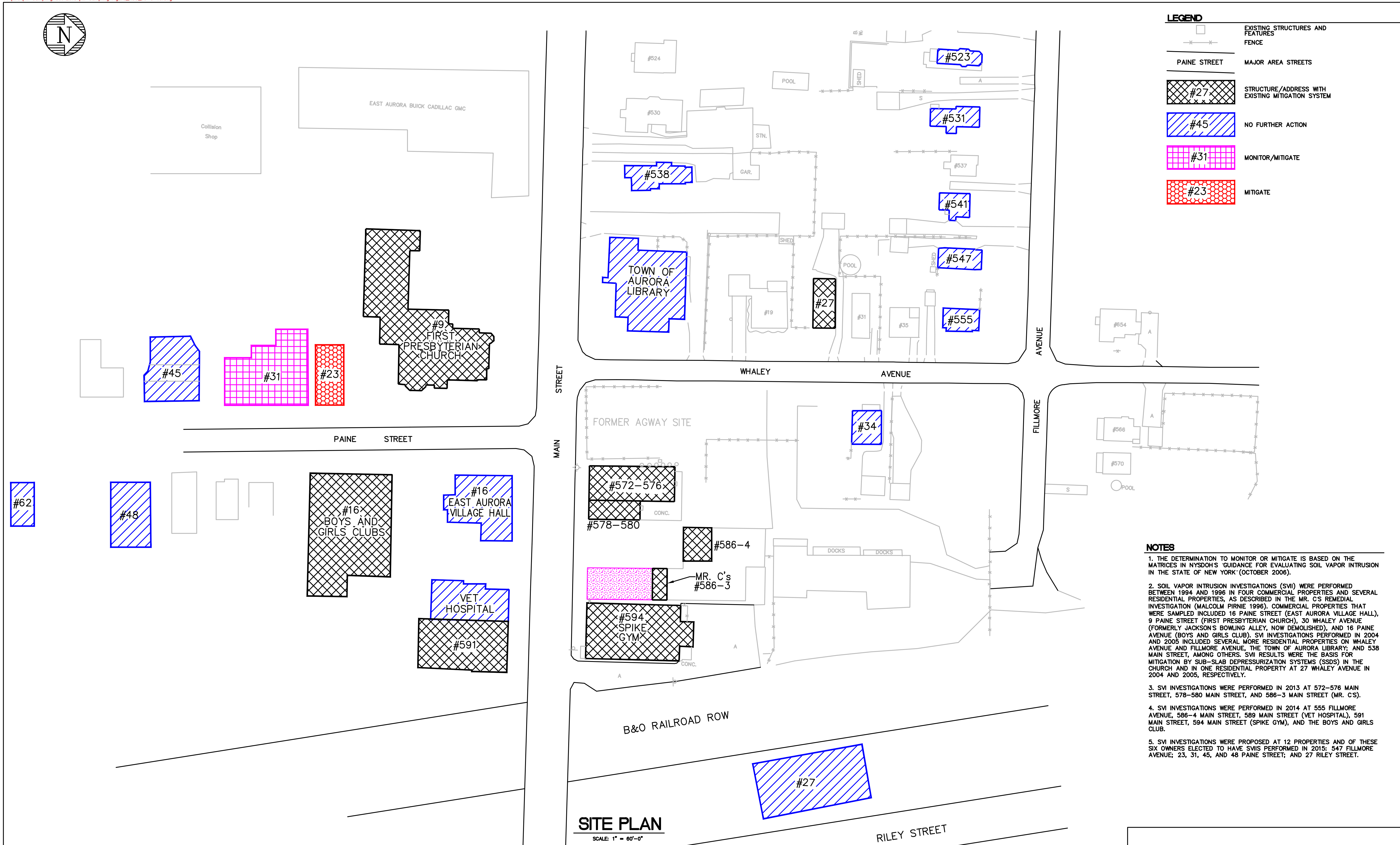


SITE PLAN

SCALE: 1" = 60'-0"

NOTES

1. THE DETERMINATION TO MONITOR OR MITIGATE IS BASED ON THE MATRICES IN NYSDOH'S "GUIDANCE FOR EVALUATING SOIL VAPOR INTRUSION IN THE STATE OF NEW YORK" (OCTOBER 2006).

2. SOIL VAPOR INTRUSION INVESTIGATIONS (SVII) WERE PERFORMED BETWEEN 1994 AND 1996 IN FOUR COMMERCIAL PROPERTIES AND SEVERAL RESIDENTIAL PROPERTIES, AS DESCRIBED IN THE MR. C'S REMEDIAL INVESTIGATION (MALCOLM PIRNIE 1996). COMMERCIAL PROPERTIES THAT WERE SAMPLED INCLUDED 16 PAINE STREET (EAST AURORA VILLAGE HALL), 9 PAINE STREET (FIRST PRESBYTERIAN CHURCH), 30 WHALEY AVENUE (FORMERLY JACKSON'S BOWLING ALLEY, NOW DEMOLISHED), AND 16 PAINE AVENUE (BOYS AND GIRLS CLUB). SVI INVESTIGATIONS PERFORMED IN 2004 AND 2005 INCLUDED SEVERAL MORE RESIDENTIAL PROPERTIES ON WHALEY AVENUE AND FILLMORE AVENUE, THE TOWN OF AURORA LIBRARY; AND 538 MAIN STREET, AMONG OTHERS. SVII RESULTS WERE THE BASIS FOR MITIGATION BY SUB-SLAB DEPRESSURIZATION SYSTEMS (SSDS) IN THE CHURCH AND IN ONE RESIDENTIAL PROPERTY AT 27 WHALEY AVENUE IN 2004 AND 2005, RESPECTIVELY.

3. SVI INVESTIGATIONS WERE PERFORMED IN 2013 AT 572-576 MAIN STREET, 578-580 MAIN STREET, AND 586-3 MAIN STREET (MR. C'S).

4. SVI INVESTIGATIONS WERE PERFORMED IN 2014 AT 555 FILLMORE AVENUE, 586-4 MAIN STREET, 589 MAIN STREET (VET HOSPITAL), 591 MAIN STREET, 594 MAIN STREET (SPIKE GYM), AND THE BOYS AND GIRLS CLUB.

5. SVI INVESTIGATIONS WERE PROPOSED AT 12 PROPERTIES AND OF THESE SIX OWNERS ELECTED TO HAVE SVIIS PERFORMED IN 2015: 547 FILLMORE AVENUE; 23, 31, 45, AND 48 PAINE STREET; AND 27 RILEY STREET.

REFERENCE DRAWINGS

DWG NO.	DATE	DESCRIPTION
DEC 31 ISO.dwg	7/18/94	ISOPOTENTIAL MAP AND CROSS SECTIONS 4/13/94 GROUNDWATER LEVELS MALCOLM PIRNIE INC.
0266G003.dwg	10/17/00	REMEDIAL DESIGN PIPING AND WELL LAYOUT PLAN MALCOLM PIRNIE INC.

REVISIONS

NO.	DATE	DWN	APP'D	DESCRIPTION
A	9/8/15	KMK	MGS	ISSUED FOR REVIEW

FIGURE 1-6
SVII AND SSDS APPLICATIONS
MR.C'S DRY CLEANERS SITE LOCATION MAP
EAST AURORA, NEW YORK

ecology and environment engineering p.c.

2 Development of Remedial Optimization Alternatives

This section first describes the general response actions considered in the development of optimization alternatives and then presents the various remedial optimization alternatives under consideration for contaminant migration management and source control at the Mr. C's Site. Optimization alternatives comprise multiple response actions necessary to achieve the RAOs established in the ROD. (The RAOs for the Site are identified in Section 1.6.3.) Each alternative includes long-term groundwater monitoring, ongoing SVIIs, and installation of SSDSs.

2.1 General Response Actions and Technologies

The RAOs for the Mr. C's Site can be met with a combination of institutional controls (ICs) and ECs, which together would comprise the site remedy.

ICs are non-engineered methods of minimizing potential exposure to contamination, usually through the use of administrative and legal controls. ICs in place at the Mr. C's Site include an Environmental Notice, a long-term groundwater monitoring program, and a soil vapor intrusion investigation (SVII) and mitigation program. In order to limit exposure, ICs generally restrict land and resource use and future land development. ICs can be implemented as soon as contamination is discovered and are generally maintained until residual contamination has been reduced to levels allowing for unrestricted exposure and unlimited use. While not adequate for contamination control, ICs used in conjunction with ECs limit present and future risks to human health from contaminant exposure (USEPA 2014).

ECs are designed to control/remove contamination (e.g., through SSDSs) and physically limit contaminant exposure (e.g., through fencing). ECs are designed to control/remove contamination (e.g., through SSDSs) and physically limit contaminant exposure (e.g., through fencing). ECs can be associated with ICs, such as monitoring wells for long-term monitoring programs and SSDS and vapor barriers installed to mitigate soil vapor intrusion identified from a monitoring program. The ECs considered for remediation of a contaminated groundwater plume consist of both source controls and migration controls.

Source controls are actions taken to remove or reduce the highest dissolved contaminant concentrations or residual non-aqueous-phase liquids in the area of the original contaminant release. Three technologies determined to have the potential to provide source control or reduction at the Mr. C's Site are pump-and-treat, enhanced bioremediation, and monitored natural attenuation (MNA). These technologies can be implemented alone or in conjunction with a migration control to comprise a remedial optimization alternative.

Migration controls are implemented outside the source area and are used to prevent contaminant migration. The technologies determined to have the potential to provide migration control at the Mr. C's site are pump-and-treat, a reactive barrier of emulsified oil, and a reactive barrier of emulsified oil with colloidal activated carbon.

The current ICs and ECs are described below in terms of their applicability to the Mr. C's Site, either as part of the existing Site remedy or as a potential optimization of the remedy.

2.1.1 Environmental Notice

The main IC for the Mr. C's site is an environmental notice. The notice refers to non-physical mechanisms designed to:

- Restrict the use or development of the site;
- Limit human exposure to site contaminants;
- Prevent any action that would threaten the effectiveness or operation and maintenance of a remedy at or pertaining to the site; and
- Implement, maintain, and monitor ECs.

In addition to the ICs identified above, the environmental notice also stipulates the following:

- Compliance with the Site Management Plan (EEEPC 2015b);
- Restrictions on the use of groundwater as a source of potable or process water, without necessary water quality treatment as determined by the NYSDOH;
- Periodic certification of ICs and ECs, where present, by the responsible party, unless such party is NYSDEC or NYSDEC's designee; and
- Restrictions on future property use that is no less restrictive than "restricted-residential use" as defined by 6 New York Codes, Rules and Regulations (NYCRR) Part 375.

Permanent access agreements and easements are in place to facilitate the long-term operation and maintenance of the treatment systems and network of groundwater pumping wells associated with the NYSDEC-approved Remedial Design dated October 2000.

All alternatives considered in this RSO report include ICs.

2.1.2 Long-Term Monitoring

Long-term monitoring (LTM) of the Site Remedy is performed to evaluate the effectiveness of the remedy and to assess the overall reduction of groundwater contaminants. Groundwater monitoring is performed at wells located upgradient and downgradient of the contaminant plume, in the source area, in the center-line of the plume, and lateral to the plume. Currently, monitoring of the groundwater plume, on-site treatment system, and off-site SSDSs is performed routinely. The three monitoring programs and their respective schedules are provided in Table 2-1.

Table 2-1 Mr. C's Inspection Schedule

Monitoring Program	Inspection Frequency[1]	ECs[2,3]
Groundwater	Annually	Monitoring wells
Treatment System	Bi-monthly, or as needed	Air stripper and its components, pumping wells, piezometers
Vapor Intrusion	Annually, or as needed	SSDS components, seals

Notes:
1 The inspection frequency will continue as indicated unless otherwise specified by NYSDEC.
2 Specific requirements for inspections are described in Section 4 of the SMP (EEEPC 2015b).
3 Reporting requirements are summarized in Section 5 of the SMP (EEEPC 2015b)

Under the alternatives presented in this report, groundwater samples would continue to be analyzed for VOCs, total organic carbon, and dissolved gases (includes ethene). Sampling for populations of *Dehalococcoides* may be performed at a less frequent rate than in the Pilot Study. Samples would be collected using low-flow sampling methods in accordance with to the SMP. During sampling, monitoring parameters would include oxidation reduction potential (ORP) and dissolved oxygen (DO) levels.

Depending on the recommended alternative, changes to the monitoring program may be warranted. The Office of Solid Waste and Emergency Response Directive 9200.4-17P provides eight specific objectives for the performance monitoring program of an MNA alternative, which also would be applicable to an engineered bioremediation alternative (USEPA 1999, 2004):

1. Demonstrate that attenuation is occurring according to expectations;
2. Detect changes in environmental conditions (e.g., hydrogeologic, geochemical, microbiological, or other changes) that may reduce the efficacy of any of the natural attenuation processes;
3. Identify any potentially toxic and/or mobile transformation products;
4. Verify that the plume(s) is not expanding downgradient, laterally or vertically;
5. Verify there is no unacceptable impact on downgradient receptors;

6. Identify new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy;
7. Demonstrate the efficacy of ICs that were put in place to protect potential receptors; and
8. Verify attainment of remediation objectives.

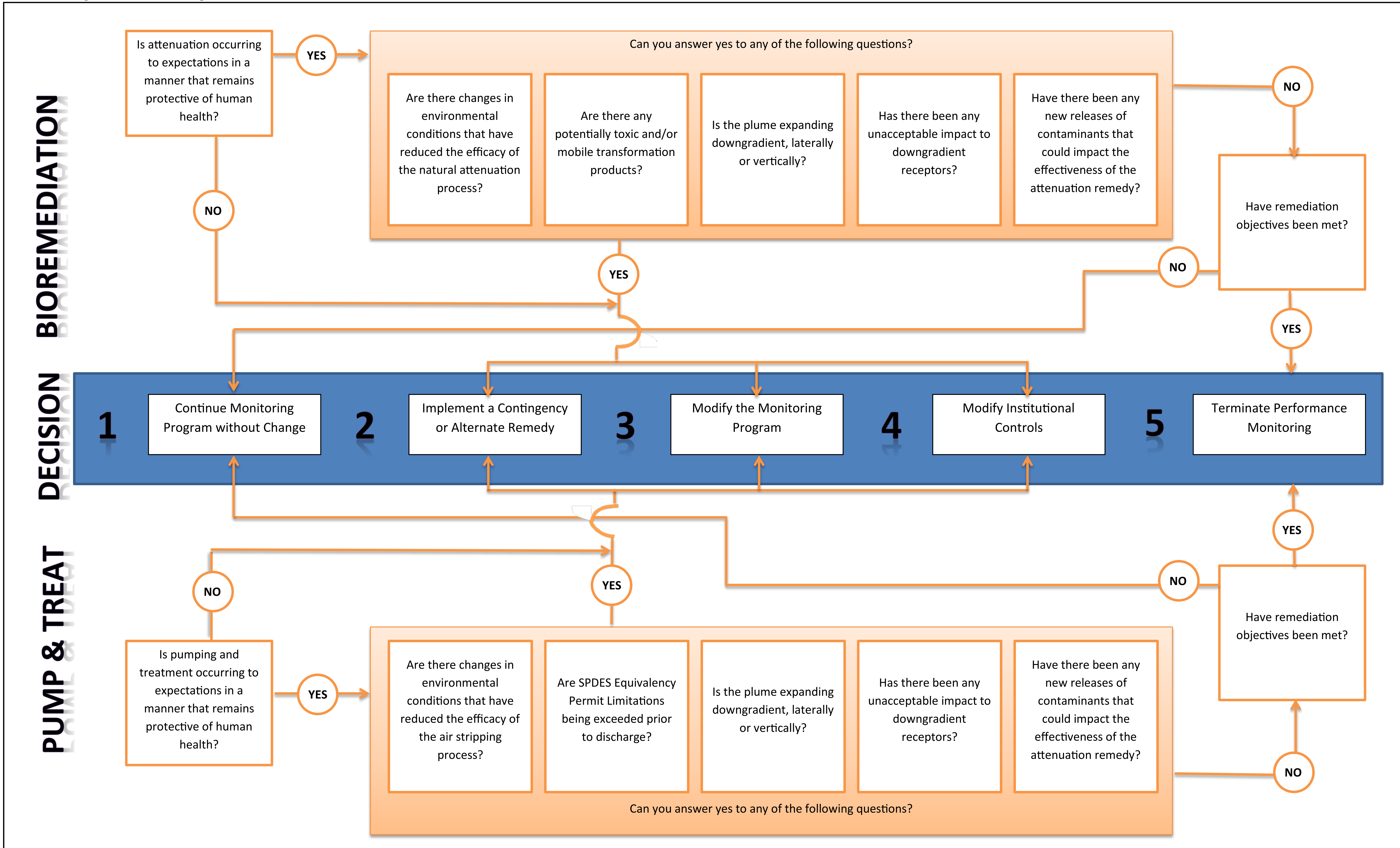
Monitoring activities will continue until remedial objectives have been achieved, at which time monitoring to fulfill objective no. 8 would be undertaken. For example, once RAOs appear to have been met, two additional rounds of periodic monitoring may be performed to verify the attainment of the RAOs. If the Site Remedy fails to meet the RAOs, then continued monitoring or potential response actions must be performed to maintain protection of human health. Figure 2-1 presents a flow chart with a proposed monitoring decision framework, which is based on USEPA guidance (1999, 2004). Additional guidance on developing decision trees for removing wells from monitoring programs was provided by the Interstate Technology & Regulatory Council (ITRC 2004, 2007).

All alternatives considered in this RSO report include LTM. It is assumed that LTM results will be periodically reviewed against site-specific decision frameworks to identify opportunities to reduce costs by mothballing or decommissioning monitoring wells, as warranted, and evaluating the progress toward site closure.

2.1.3 Soil Vapor Intrusion Evaluations and Sub-Slab Depressurization Systems

As the plume of VOCs continues to contaminate soils surrounding the basements of businesses and residences, PCE and its daughter products may volatize and migrate through gaps and cracks in the foundations and walls of the basements into the air, where they could potentially be inhaled by occupants. To protect people from this threat, soil vapor intrusion (SVI) evaluations will be performed prior to the construction of any enclosed structures over contaminated areas to determine whether mitigation measures are necessary to eliminate potential intrusion of vapors into the proposed structure. This would address the first RAO of the 1997 ROD, which is to mitigate human health risk by reducing the potential for inhalation of vapors in on-site and off-site basements. Alternatively, a soil vapor intrusion mitigation system may be installed in the proposed building foundation without conducting an investigation. The mitigation system would include a vapor barrier and passive SSDS capable of being converted into an active system.

An SSDS works by creating a low-pressure area beneath a building to extract VOCs from soil vapors. A fan is used to draw the VOC-contaminated air through a hole cut into the building slab and into pipes, which convey the contaminated air outside the building, where it is released to the atmosphere (MDEP 1995).



United States Environmental Protection Agency (USEPA). 2004. Performance Monitoring of MNA Remedies for VOCs in Groundwater. EPA/600/R-04/027

Figure 2-1 Performance Monitoring Framework

Soil vapor intrusion will be a constant issue throughout the plume remediation process. Therefore, SSDSs will be an important option because they directly address the first RAO. The presence of residences and businesses above the contaminant plume will limit the areas in which remedial actions can access and treat contaminated groundwater. The lack of physical access or access agreements from property owners will limit the capture zone of a pump-and-treat system by restricting the areas where pumping wells can be installed. Similarly, the lack of physical access and access agreements will limit the injection zones for bioremediation alternatives. Because of these limitations, some portions of the plume will be remediated at a far slower rate than other portions. As a result, portions of the plume will remain in place for decades, and it is important to ensure the safety of building occupants in those areas through the use of SVIIs and SSDSs.

In addition, the plume might migrate from its current location depending upon the remedial design. Because of this potential migration, additional SVIIs may be required to ensure that potentially hazardous infiltrations of soil vapor into residences and business are identified and that basements with VOC concentrations exceeding the NYDOH's guidance are mitigated with SSDSs and vapor barriers. Because of these potential vapor intrusion issues, SVIIs will be considered a necessary response action throughout the performance of the remedy, regardless of the remedial optimization choice.

2.1.4 Pump-and-Treat Systems

Pump-and-treat systems primarily provide contaminant migration control. Tailing and rebound have resulted in very long remedial timeframes to meet groundwater cleanup objectives at many pump-and-treat remedial sites. Tailing is the asymptotic decrease in the concentration of contaminants present in groundwater during pump-and-treat remediation, which can be caused by site geology as well as the sorption and desorption of contaminants on soil particles (USEPA 1990). Areas of low permeability in the soil can trap contaminants, reducing their ability to be pumped out of the aquifer. The sorption of contaminants onto soil particles also limits their ability to be removed by the pumping wells, and desorption of the contaminants can pollute uncontaminated groundwater in the area. Rebound is the increase in contaminant concentration that occurs when a pump-and-treat system is shut off and is common when pumping relatively insoluble contaminants such as PCE. When groundwater flow is slow, contaminants can dissolve into the groundwater and approach their solubility limit. The increased groundwater velocity caused by pumping wells decreases this dissolution, which decreases the contaminant concentration present in the groundwater. When the pumps are shut off, groundwater flow slows once more, allowing for greater dissolution and a spike in contamination levels (USEPA 1996). Both tailing and rebound limit the success and cost effectiveness of pump-and-treat systems.

In a pump-and-treat system, pumping wells are installed and connected through conveyance piping to pump contaminated groundwater out of the aquifer and into an aboveground treatment system. The pumping collects contaminated waters to limit plume spread, and the treatment of the collected water reduces the overall amount of contamination. When the treated groundwater meets regulatory requirements, it can be pumped back into the ground or released into a nearby body of water.

Eight active pumping wells currently surround the Mr. C's Site. Each groundwater pumping well is equipped with a Grundfos well pump and level transducer, which is placed 2 feet above the pump intake. The transducers are programmed to turn the pumps on and off at various water levels in order to maintain a cone of depression in the water table and to extract as much of the groundwater contamination as possible. These pumping wells discharge into a pipe that conveys the extracted groundwater to the treatment system.

At the Mr. C's Site, piezometers were installed close to the pumping wells, generally spaced at 5-, 10-, 15-, and 20-foot intervals. The piezometers are used to monitor groundwater levels around an extraction well to ensure that a cone of depression is created in the water table around the pumping well.

The configuration of the network of pumping wells was developed from data collected during the RI and short-term aquifer testing program (MPI 1995a, 1995b). The RI determined that the contaminant plume extended from the Mr. C's building to the west in two branches: one moving to the northwest and extending between 300 and 400 feet beyond the Town of Aurora Public Library, and one moving to the southwest to slightly beyond the First Presbyterian Church. Appendix A provides the isopotential map from the Mr. C's RI, which shows a groundwater flow divide in the center of the site that accounts for the branching of the contaminant plume (MPI 1995a).

To remediate the northwest plume, seven low-yield pumping wells (PW-2, PW-3, PW-4, PW-5, PW-6, PW-7, and PW-8) were installed in a low-transmissivity zone approximately 10 to 30 feet BGS and spread throughout the plume area. One high-yield pumping well was already present in the high transmissivity zone near the Mr. C's Site; this well was repurposed for the pump-and-treat system and labeled RW-1. The collection radius of the high-yield well was to encompass the source area and the area immediately downgradient, including the groundwater beneath the shoe repair shop and hardware store buildings.

The 1996 Feasibility Study estimated pump capacities based on the aquifer tests performed during the RI and proposed a high-yield well with a capacity of 55 gallons per minute (gpm) and several low-yield wells with capacities of 5 gallons per minute (MPI 1996); actual pump capacities are 65 gpm for the high-yield well and 2.75 gpm, 4 gpm, and 4.5 gpm for wells PW-2, PW-5, and PW-7, respectively (EEEPC 2005). The remaining pumping wells were pump tested because the construction contract specified testing for only four wells.

Contaminated groundwater from these wells is pumped into a treatment facility behind the Mr. C's Site where it passes through a bag filter, a 3,000-gallon equalizing tank, and a 150-gpm shallow-tray air stripper. Once treated, the water is discharged through a 1,350-foot-long force main to an outfall on Tannery Brook (EEEPC 2007).

Over time, the highest VOC concentrations have moved to a 480- by 240-foot area centered between PW-5 and PW-6, behind the Town of Aurora Public Library parking lot, and the highest PCE concentrations are centered on PW-5 (EEEPC 2015d). With the plume now moved further from RW-1, groundwater intake from this well dilutes the influent concentration of VOCs into the treatment system, reducing the annual mass removed from the aquifer.
Use of the existing pumping network will be considered in the evaluation of the RSO alternatives in the context of the limitations imposed by the existing locations and capacities of the pumping wells and the current location of the groundwater plume.

2.1.5 Downgradient Reactive Barriers

The primary purpose of a downgradient reactive barrier is to control contaminant migration. Several types of barriers have been installed at contaminated groundwater sites. Two barrier technologies are commonly used, either alone or in combination: (1) a bio-wall trench, which is backfilled with a solid substrate such as mulch or compost, and (2) a series of closely spaced injections of an electron donor product. The reactive barriers would be designed and installed to intercept and treat groundwater flow, preventing impacted groundwater from reaching downgradient receptors. The barrier would need to be installed in a line perpendicular to the direction of flow and should be engineered to provide a long-term source of organic carbon. The design of reactive barriers requires determination of the degradation rates for the COCs as they pass through the barriers and the required residence time for treatment to reach RAOs on the downgradient side of the barrier.

Because the Mr. C’s Site’s is located in a commercial/residential neighborhood, it would be easier to mobilize direct-push injection equipment to this area than the machinery for trenching. Physical restrictions and access limitations would preclude the use of trenching downgradient of the contaminated plume; therefore, options that require trenching are not evaluated further.

Many electron-donor products are available that can stimulate anaerobic degradation of PCE and its degradation products, including non-proprietary products (e.g., methanol, ethanol, molasses, sucrose, and vegetable oils) and proprietary products (e.g., Regenesis HRC, which is a polyacetate ester) (AFCEE 2002a). Electron-donor reagents are not standard products. Each reagent differs in the amount and length of time that it supplies hydrogen to the subsurface, the amount of total organic carbon that it supplies to the subsurface, its ability to provide micro-nutrients or buffering capacity, and its ability to be distributed evenly throughout the subsurface. Because electron-donor products are not standard products, it is recommended that any electron-donor product be field-tested through a site-specific pilot or microcosm study. The Pilot Study conducted at the Mr. C’s Site used a Regenesis emulsified oil product called Regenesis Hydrogen

Release Compound Primer (HRC Primer®) and Regenesis 3D-Microemulsion® 75 (3DMe 75).

So, this RSO report evaluates two different electron-donor product combinations for a reactive barrier wall design:

- Regenesis HRC Primer® and 3DMe 75, and
- Regenesis 3DMe 75 and PlumeStop™.

Final selection of an electron-donor product(s) can be made during the design of the in situ chemical reduction remedy, if such a remedy is selected.

The HRC Primer® is immediately available to microbes that dechlorinate PCE, whereas the 3DMe 75 mixture is a slow-release compound intended to provide a food source to the microbes for the engineered timeframe of two years. The Regenesis product 3DMe 75 includes a buffered solution to protect against the inhibitory effects of pH on degradation reactions. Regenesis PlumeStop™ is comprised of fine particles of colloidal activated carbon suspended in water using organic polymer dispersion technology, which binds the chemicals of concern within the reactive zone. Because contamination binds to the colloidal activated carbon, it remains in the treatment zone longer, and a thinner barrier wall is required. Regenesis product information and application instructions are provided in Appendix B.

The injection of bioremediation products into the subsurface via either permanent wells or temporary direct-push injections requires a Class V Underground Injection Control (UIC) Permit. United States Environmental Protection Agency (USEPA) Region 2 is responsible for issuing and administering UIC permits in New York State.

Downgradient barriers considered in the optimization alternatives presented in this RSO report will be limited to permeable reactive barriers (PRBs) consisting of a series of closely spaced injections of an electron-donor product. However, multiple electron-donor products will be considered as the basis of the cost estimates presented in this RSO report.

2.1.6 Monitored Natural Attenuation

MNA can be used as a contaminant source control only if a site has been thoroughly investigated and the investigations have revealed that contaminant concentrations are decreasing by natural processes, or if an engineered process has stabilized or reduced a contaminant plume and established ongoing conditions favorable for MNA to degrade the remainder of the contamination. In general, MNA alone will take a very long time—on the order of centuries—to reduce contaminant concentrations to below groundwater standards.

The main processes involved in MNA are sorption, evaporation, chemical reactions, dilution, and biodegradation (USEPA 2012). Sorption is the process of contaminants becoming attracted by and sticking to soil particles, removing them from the groundwater. When contaminants evaporate into a gaseous phase, they can leave the soils and groundwater of an area and volatize into the atmosphere. Under ideal conditions, some chemicals will undergo reactions that transform them into compounds that are no longer hazardous. While dilution does not degrade contaminants, in situations with low level contamination it may reduce contaminant concentrations to levels that fall beneath pertinent standards. Biodegradation is the process by which microbes metabolically degrade contaminants. Biodegradation may occur without human intervention at sites where microbes are present that are able to ingest the COC. These microbes may be added to sites that do not have viable microbes present, although this may require altering the site conditions to support microbial growth. This is known as enhanced bioremediation and is described below in Section 2.1.7. At the Mr. C's Site it was determined that unaided natural attenuation was not progressing at a rate sufficient to meet the RAOs set by the ROD.

2.1.7 In Situ Enhanced Bioremediation

During the Pilot Study it was concluded that MNA was not occurring at the Mr. C's Site, but that bioremediation could be stimulated with an engineered technology.

The Pilot Study demonstrated that bioremediation technologies could be effectively employed at the Site to achieve the third RAO (see Section 1.3) by meeting NYSDEC groundwater quality standards. The alternatives presented in Section 2.2 of this RSO report include in situ enhanced bioremediation for source control using the same electron donor product combination used in the Pilot Study: HRC Primer® and 3DMe 75.

To achieve effective distribution within the subsurface, the electron donor can be injected with direct-push technology in a grid pattern. Because of the site geology, a fairly tight injection grid spacing of 10 feet by 15 feet was used during the Pilot Study. The electron donor was injected from 30 feet BGS to 10 feet BGS, which is generally the depth of the outwash aquifer.

When native populations of the microbes capable of reductive dechlorination are absent or present at concentrations that are too low to maintain the desired reaction rate, the subsurface can be augmented with commercially available microbial cultures. Regenesis Bio-Dechlor INOCULUM® Plus (BDI PLUS) was used in the Pilot Study and was shown to increase the population of the *Dehalococcoides* spp. responsible for dechlorination. BDI PLUS was injected in the subsurface with direct-push technology in the same injection locations as the HRC Primer and 3DMe 75. The culture canister was combined with nitrogen-sparged water (to remove the DO) to form an injectable solution. Future bioremediation enhancements can be made without bioaugmentation in the Pilot Study areas, but the use of bioaugmentation may be considered in upgradient areas. Additional injections of 3DMe 75 should be considered every three years to ensure that nutrients are present at sufficient levels in the subsurface to sustain the *Dehalococ-*

coides spp. for the timeframe required to reduce all PCE, TCE, DCE, and VC to ethene.

Injection of bioremediation products into the subsurface via either permanent wells or temporary direct-push injections require a Class V UIC Permit. USEPA Region 2 is responsible for issuing and administering UIC permits in New York State.

The Pilot Study summary report suggested that full-scale injections in the vicinity of MPI-4S would have better success than the Pilot Study, because the geochemistry is initially more favorable for the anaerobic biodegradation to occur (EEEPC 2015a). However full-scale injections in the vicinity of MW-7 would have poorer success than the Pilot Study or cost more to implement, because the geochemistry is initially less favorable for the anaerobic biodegradation to occur (EEEPC 2015a).

Figure 2-2 shows an interpretation of the aquifer ORP values. An ORP in the range of -200 to -400 millivolts is optimal for the fastest dechlorination rates (Moretti 2005).

2.2 Remedial Optimization Alternatives

Table 2-2 presents the remedial optimization alternatives as a matrix of source and migration control technologies. ICs, LTM, continued SVIIs, and SSDS installations as described in Sections 2.1.1, 2.1.2, and 2.1.3 are required elements of each optimization alternative. Each alternative is described below.

Table 2-2 Remedial Optimization Alternatives

Migration Management / Source Control	Pump and Treat with the Existing Air Stripper System	Permeable Reactive Barrier Regenesis 3DMe™ Injections	Permeable Reactive Barrier Regenesis PlumeStop™ Liquid Activated Carbon and 3DMe Injections
Pump and treat with existing air stripper system and increased pump capacity	Alternative 1	Alternative 2a	Alternative 2b
Targeted grid injections for enhanced bioremediation	Alternative 3	Alternative 4a	Alternative 4b

Notes:
1. All alternatives include sub-slab depressurization systems, institutional controls, and long-term monitoring.
2. The Final Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents (AFCEE 2004) states that a down-gradient barrier must be installed at a site prior to full-scale application of a bioremediation remedy for source control.
3. A pump-and-treat system primarily achieves migration management, but can also provide some source control. Migration management by the pump-and-treat system can be supplemented by reactive barriers.

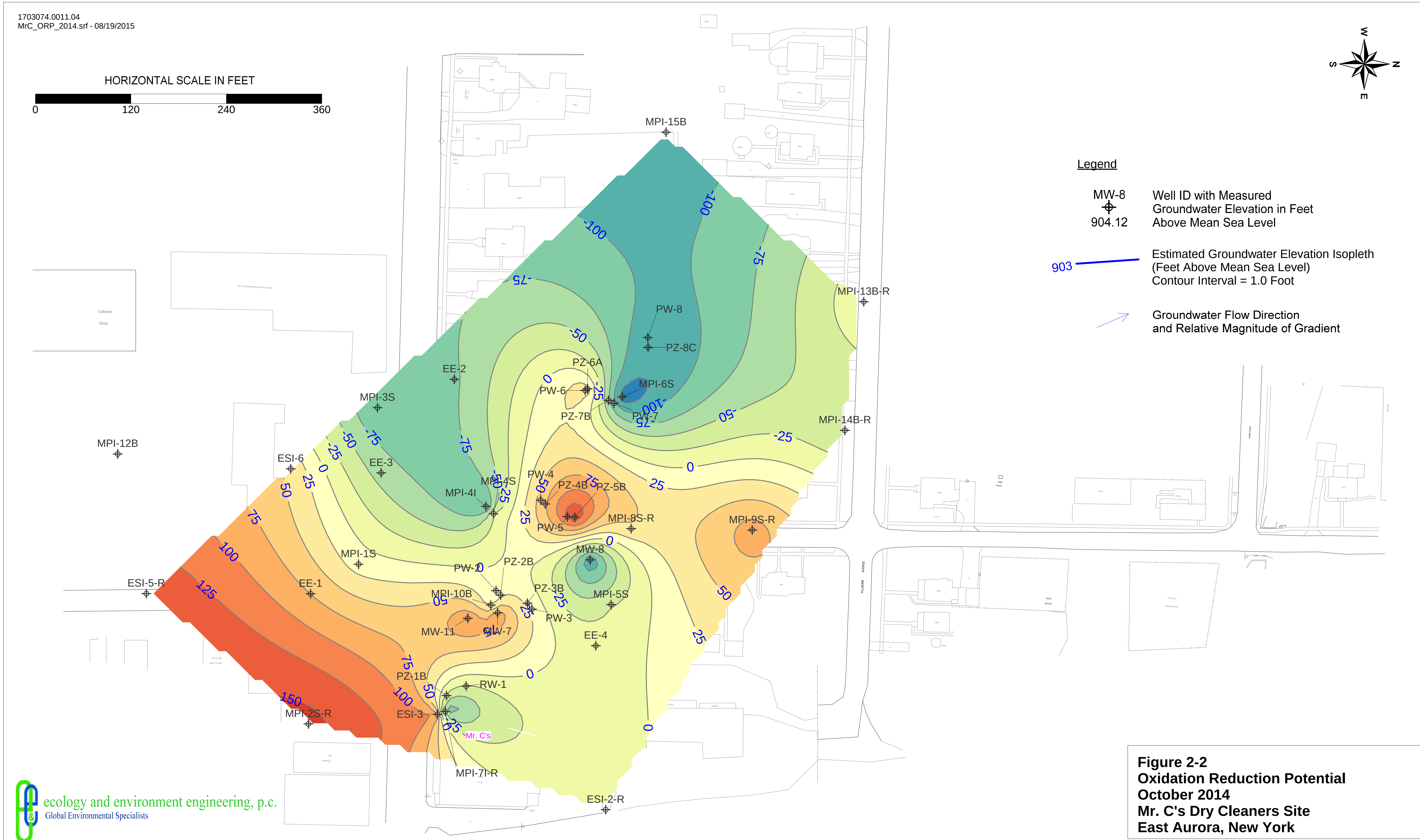


Figure 2-2
Oxidation Reduction Potential
October 2014
Mr. C's Dry Cleaners Site
East Aurora, New York

2.2.1 Alternative 1: Pump and Treat for Source and Migration Control

Alternative 1 is the current pump-and-treat system with the existing air stripper system. The cost estimate for Alternative 1 assumes that new pumps would be installed. The current system has a high-yield well with a pump capacity of 65 gpm and seven low-yield wells. Historical pump test results were reviewed. Pump tests performed on the low-yield wells showed pumping rates between 2.75 and 4.5 gpm. Because the current pump-and-treat system is a batch operation, the pumps turn off when water levels are beneath a certain level and turn back on when groundwater recharge raises the water level. Because of this, pumps do not operate continuously and recharge does not appear to occur fast enough to allow for pumps to operate above historical pumping rates. New pumps would be installed with the same capacity as existing pumps.

Operation of the pump-and-treat system would continue until the RAOs are met, such that:

1. Human health risks have been mitigated through the installation of SSDSs and the long-term monitoring program at the site includes a decision framework for continued protection of human health against soil vapor intrusion until NYSDEC groundwater quality standards are met;
2. LTM has shown that the plume would be stable without pump-and-treat providing migration control; and
3. NYSDEC groundwater quality standards have been achieved to the extent practical.

In the event that Alternative 1 fails to meet the RAOs and the air stripper system has not treated groundwater effectively in over 6 months, a response action would be taken to address the decline in efficiency (see Figure 2-1).

As a caveat, protection of human health from soil vapor intrusion may not be achievable by SSDSs and SVIIs in all residences/buildings above the plume, because property owners have the right to refuse to have an SVII performed on their property, and some have refused. Residences/buildings where SVIIs have not been performed may still have soil vapor intrusion issues, and to stop treating the groundwater would put the occupants of these residences/buildings at risk. Other locations have recently undergone SVIIs, but SSDSs have not yet been installed at those locations. Lastly, the resident at 27 Whaley Avenue has not allowed access for inspection/repair of the SSDS unit at that location. As a result, the SSDS unit may have issues with that prevent it from working properly and venting VOCs as designed. All of these factors necessitate continued operation of the pump-and-treat system.

2.2.2 Alternative 2: Pump-and-Treat Source Control with Permeable Reactive Barriers for Migration Control

Alternatives 2a and 2b consist of the existing pump-and-treat system, the existing air stripper system, the existing low-yield wells equipped with 7 gpm capacity pumps, and permeable reactive barrier walls. Under Alternative 2a, the barrier walls would extend to a depth of 20 feet, have a thickness of 31 feet, and be made from injections of 3DMe 75. Under Alternative 2b, the barrier walls would extend to a depth of 20 feet, have a thickness of 20 feet, and be made from injections of 3DMe 75 and PlumeStop. The proposed barrier locations for migration control are shown on Figure 2-3.

Operation of the pump-and-treat system would continue until the RAOs are met as described under Alternative 1.

2.2.3 Alternative 3: Bioremediation Source Control with Pump and Treat for Migration Control

Alternative 3 consists of the existing pump-and-treat system, the existing air stripper system, and targeted grid injections. The grid injections would consist of HRC Primer and 3DMe 75 throughout the zones and BDI PLUS in zone 3A. BDI PLUS increases the presence of *Dehalococcoides* spp., which are responsible for dechlorination of the contamination. The other zones would already have the bacteria present from previous injections of BDI PLUS during the Bioremediation Pilot Study. The proposed grid locations for source treatment are shown on Figure 2-3.

Engineered bioremediation through enhancement would continue until the RAOs are met, meaning that:

1. Human health risks have been mitigated through the installation of SSDS systems and the long-term monitoring program at the site includes a decision framework for continued protection of human health against soil vapor intrusion until NYSDEC groundwater quality standards are met;
2. Long-term monitoring has shown that the plume is stable; and,
3. NYSDEC groundwater quality standards have been achieved to the extent practical.

Limitations with regard to reducing human health exposure through SSDSs (RAO) 1) are described under Alternative 1. As observed in the Pilot Study, the plume may migrate as PCE is degraded into its lighter, more mobile daughter products; installation of the permeable reactive barriers would mitigate the extent to which the daughter products can travel. The spread of the contaminated groundwater plume has the potential to increase vapor intrusion into the basements of the buildings located above the plume. However, the conversion of PCE to cis-DCE actually has the potential to reduce soil vapor concentrations, because less of the VOC mass is likely to partition into the soil vapor from the groundwater. Thus, a plume contaminated primarily with cis-DCE would likely pose a lower risk for soil vapor intrusion than one that is contaminated primarily with PCE.

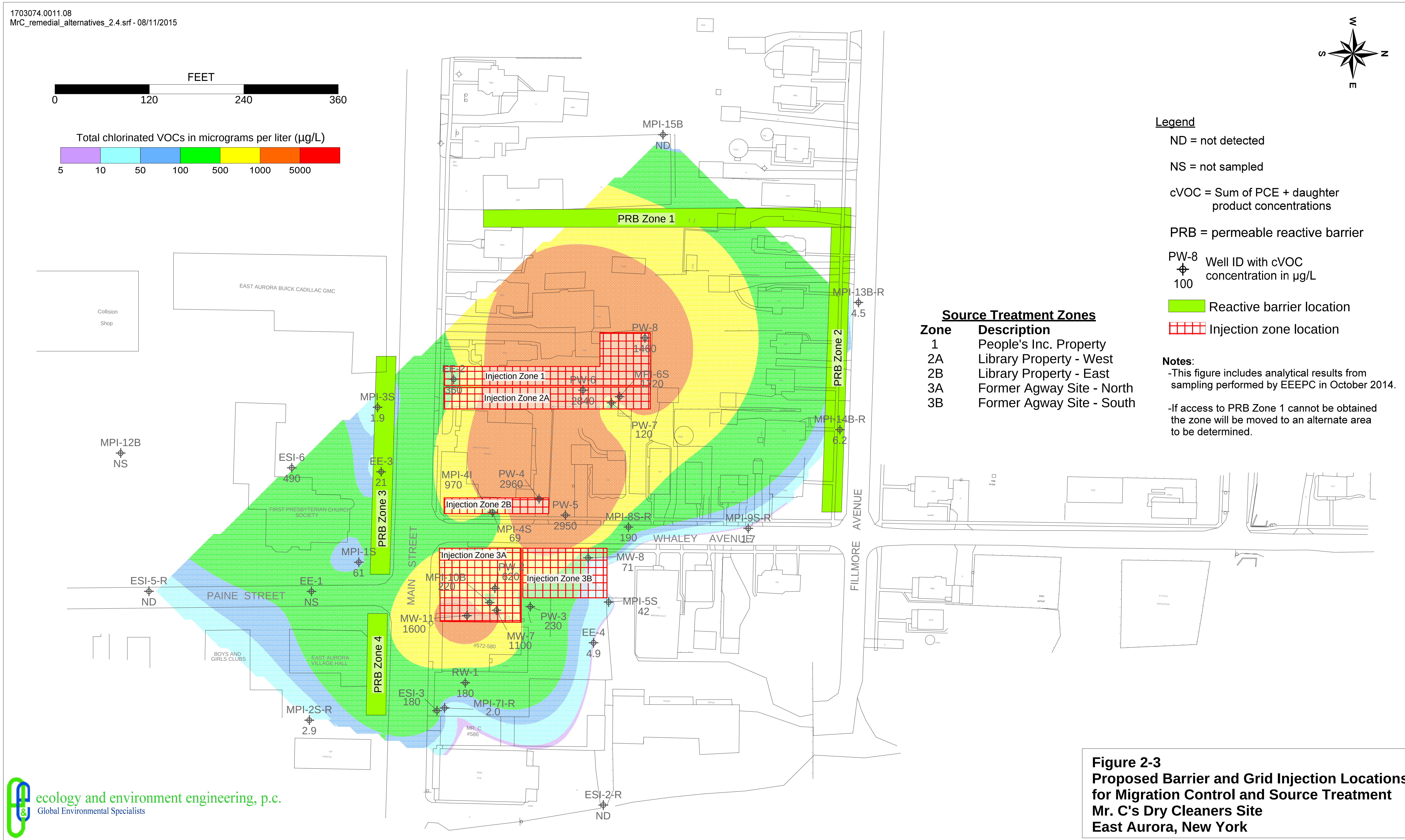


Figure 2-3
Proposed Barrier and Grid Injection Locations for Migration Control and Source Treatment
Mr. C's Dry Cleaners Site
East Aurora, New York

In the event that engineered bioremediation is not proceeding as expected, then a response action must be taken to address the decline in efficiency. Figure 2-1 shows the preliminary decision framework, which would need to be developed further if a bioremediation control is implemented at the Site.

2.2.4 Alternative 4: Bioremediation for Source and Migration Control

Alternatives 4a and 4b are the grid injections from Alternative 3 paired with the permeable reactive barriers of Alternative 2. Under Alternative 4a, the barrier walls would extend to a depth of 20 feet, have a thickness of 31 feet, and be made from injections of 3DMe 75. Under Alternative 4b, the barrier walls would extend to a depth of 20 feet, have a thickness of 20 feet, and be made from injections of 3DMe 75 and PlumeStop. The proposed barrier and grid locations for migration control and source treatment are shown on Figure 2-3.

Engineered bioremediation through enhancement would continue until the RAOs are met as described under Alternative 3. Alternative 4 includes the eventual decommissioning of the existing pump-and-treat system. Shutoff of the system would occur prior to decommissioning at the time the permeable reactive barriers are installed for migration control.

3 Alternative Analysis Methodology and Results

This section describes the modeling and calculations performed to support the evaluation of alternatives in Section 4. Various calculations were performed to determine the cleanup timeframes for pump-and-treat alternatives, enhanced bioremediation degradation rates, permeable reactive barrier thicknesses, and other parameters. These data were then used to evaluate remediation optimization alternatives and develop cost estimates. Three modeling programs (BIOCHLOR, SourceDK, and REMChlor) were screened, and SourceDK was selected to determine the estimated cleanup timeframes for the source bioremediation alternatives.

3.1 General Approach for the Alternatives Analysis

3.1.1 Source Controls

As described in Section 2.1, three principal technologies were considered for source control: (1) pump and treat with the existing remedy, (2) enhanced bioremediation, and (3) MNA. Source controls were evaluated with respect to their ability and efficiency in reducing groundwater COCs to NYSDEC Class GA groundwater standards. A reduction in source concentrations would reduce the contaminant concentration in the downgradient portion of the plume and the time needed to achieve site RAOs.

Pump and Treat

Pump-and-treat alternatives assume continued operation of the existing eight pumping wells and the on-site air stripper treatment system, which has been active since 2003. The system has experienced declining efficiency over time, and significant contamination still remains at the site. The time it would take for a majority of the contaminated groundwater to be pumped out of the aquifer and treated can be determined based on the average pumping rate of the eight pumping wells, the flow of the groundwater on site, and the length of the contaminant plume. The length of time would increase as the plume spreads, and the plume may migrate beyond the capture zone of the pumping wells. It is assumed that all treated groundwater would be remediated to the NYSDEC Class GA groundwater standard for PCE (5 µg/L).

Bioremediation

In areas where bioremediation is enhanced with the addition of an electron donor and/or microbes capable of degrading chlorinated ethenes, a faster degradation rate may be achieved than in the surrounding contaminated areas of the plume. When enhanced bioremediation is used in the areas of the plume with the highest concentrations, it is considered a source control. Treatment of the entire portion of the plume above the 5 µg/L contour (the groundwater standard for PCE), or even above the 1,000 µg/L contour, would not be practicable or implementable because of the businesses and residences located above the plume. Enhanced bioremediation could be implemented only where physical access is available for direct-push equipment and where property owners grant permission to access their property. Figure 2-3 shows the areas proposed for enhanced bioremediation in the Alternatives presented in this report: Zone 1, the grassy area on People's Inc., Property; Zone 2A, the area around MPI-6S behind the Aurora Public Library; Zone 2B, the area around MPI-4I next to the library; Zone 3A, the area around MW-8 on the Former Agway Site; and Zone 3B, the area around MW-11 on the Former Agway Site. These locations are accessible and enhanced bioremediation could be implemented in these source areas.

As mentioned in Section 2.2.3, BDI PLUS is required in Zone 3A to introduce *Dehalococcoides* spp., the microbes capable of dechlorinating PCE and its daughter products. *Dehalococcoides* spp. is already present in the remaining grid injection zones from Pilot Study injections. Injections of HRC primer provide nutrients that are immediately available to the microbes to ensure their growth and ability to dechlorinate upon injection, while injections of 3DMe provide a more continuous, slow-release source of nutrition for continued dechlorination.

The results of future performance monitoring efforts would be used to determine the timing, amount, and locations of re-injections of 3DMe required to maintain the biodegradation rates needed to achieve remediation within the desired timeframe. Injections of 3DMe typically provide a continuous source of electron donor in the subsurface to support microbial growth and activity for up to three years, as suggested by Regenesis product data (Regenesis 2015). The cost estimates for re-injections assume two rounds of re-injection of electron donor three and seven years following the initial injections.

3.1.2 Migration Controls

As described in Section 2.1, three principal technologies were considered for source control: (1) pump and treat with the existing remedy, (2) a reactive barrier of emulsified oil, and (3) a reactive barrier of emulsified oil and colloidal activated carbon. Migration controls were evaluated with respect to their ability to keep the plume from spreading and further contaminating groundwater and soil. Controlling migration will also protect against additional soil vapor intrusions into the basements of homes and businesses above the contaminant plume. Migration controls would, therefore, address the first and second RAOs

Pump and Treat

When properly placed downgradient of groundwater contamination, the capture zones of pumping wells can keep plumes from spreading by pumping contaminated water before it can migrate off the site. For the entirety of the plume to be captured, pumping wells would have to operate continuously and pump at a rate sufficient to ensure that all contaminated groundwater that enters the wells' radius of influence would be captured. Wells would also have to be configured in such a way that all of the migrating contaminant plume would have to pass through a well's radius of influence.

Pump-and-treat alternatives assume continued operation of the existing eight pumping wells and the on-site air stripper treatment system, which has been active since 2003. The wells at the site were designed for source control, not migration control. Although the well are spread throughout the contaminant plume and capture much of the source contamination, they are not present downgradient of the contamination in sufficient numbers to capture the entire migrating contaminant plume. Because the pumps operate in batch, turning on only when groundwater reaches certain levels, there are times that the pumping wells are off and incapable of capturing contamination and controlling plume migration. For this reason, Alternative 3, which consists of using the pump-and-treat technology solely for migration control, was not evaluated further.

Bioremediation

The reactive barriers proposed for the remedial optimization alternatives work similarly to the enhanced bioremediation source controls described above in Section 3.1.1. The difference is that the barriers are placed downgradient of the source to control off-site migration. The thickness of the barrier is determined by the degradation rate that can be achieved and the hydraulic residence time required to reduce the concentrations of contaminants coming into the barrier to below the groundwater standards. The lower the contaminant concentration into a reactive barrier, the thinner a reactive barrier needs to be. The reactive barrier can be augmented with colloidal activated carbon, which will increase the contaminant residence time within the barrier and reduce the thickness of a reactive barrier. Alternatives for reactive barriers both with and without the colloidal activated carbon are considered to determine whether the addition of the colloidal activated carbon is cost effective.

BDI PLUS would be optional in the injections for migration control, because the *Dehalococcoides* spp. microbes would migrate from the upgradient plume to the barriers along with the bulk groundwater flow. HRC Primer would also be optional in the injections for migration control, because while 3DMe does not immediately provide an electron donor, it would likely make them available by the time microbes migrate into the area. Long-term monitoring of the barrier effectiveness would determine when and if reinjection of the 3DMe electron donor would be required.

3.2 Modeling Approach and Limitations

Per the NYSDEC's Draft RSO Guidance, a net present worth analysis is used to support an RSO recommendation for optimization efforts not associated with operation and maintenance (such as installing a new well to decommission two wells) or to advance a recommendation that the selected remedy "is not appropriate, will not reach the remedial goals, or identifies a significantly better remedy that was not available at the time of the ROD" (NYSDEC 2011). The RSO Guidance document describes the net present worth analysis as based on a "realistic projection of the anticipated time that the remedy will need to operate."

For pump-and-treat alternatives, no modeling was performed; instead, the remedy timeframes have been estimated based on the given pumping rates, the volume of contamination that can be removed by the treatment system, and the time for the contamination in the groundwater to move toward the pumping wells. The calculation methodology is described in the USEPA document "Basics of Pump-and-Treat Ground-Water Remediation Technology" (USEPA 1990).

For alternatives employing bioremediation as a source control, modeling was performed to determining the remedial timeframe. Three different models were considered: BIOCHLOR, SourceDK, and REMChlor. The SourceDK model was selected for use because it was the most appropriate for the site as described below. The following sections describe the models in general and in the context of the Mr. C's Site.

3.2.1 BIOCHLOR

BIOCHLOR is a modeling program that simulates the natural attenuation of PCE and its daughter products in groundwater. It is based on the Domenico analytical solute transport model and simulates 1-D advection, 3-D dispersion, linear adsorption, and biotransformation via reductive dechlorination assuming a first-order decay process (AFCEE 2002b).

BIOCHLOR did not generate a valid model for the Mr. C's Site due to assumptions the program makes regarding contaminant plume shape and a field data check that was not supported by the information collected during the Pilot Study.

BIOCHLOR assumes a teardrop-shaped contaminant plume with a hot spot in the middle and one trail of lessening contaminant migrating in the direction of groundwater flow. The Mr. C's Site has two major contaminant hot spots at MPI-6 and MW-11, with groundwater flowing radially toward MPI-6S and varying groundwater flow directions throughout a majority of the site. This unique groundwater flow pattern generates contaminant plumes of varying lengths and widths that disperse in a variety of directions and, on occasion, remain stagnant in water table depressions. Not only does BIOCHLOR create a model based on a vastly different plume shape, but the field data for comparison input requires contaminant concentrations along the centerline of the plume at one instance in time. The monitoring well installations at this site do not allow for sampling along the centerline, and due to the plume shape, there are many different centerlines from which data could be chosen, each of which would yield different results when the model is run. After several runs of the model with varying inputs and a lack of reasonable results, it was concluded that BIOCHLOR modeling is not appropriate for the Mr. C's Site.

3.2.2 SourceDK

Tier 2 of the SourceDK program was used to determine the remedial timeframe for PCE. Tier 2 utilizes an enhanced version of the simple box model developed for the BIOSCREEN model to include source mass estimation and other features (AFCEE 2011). With Tier 2, estimates of source attenuation, mass flux of constituents leaving the source zone, and biodegradation of the source zone generated a remedial cleanup timeframe of one year to degrade PCE to the groundwater standard of 5 µg/L with a factor of safety of 2. This factor of safety does not take into account the generation of daughter products, which will also pose a risk to human health. The Pilot Study provided data on daughter product generation and degradation as a combined rate, but the time it would take to completely reduce PCE and its daughter products to ethene was unclear. Assuming daughter products will degrade throughout the contaminant plume at roughly the same rate as PCE did during the Pilot Study, the plume will degrade to ethene in about four years.

3.2.3 REMChlor

REMChlor assumes that the migration of the plume due to groundwater transport is in one direction, but this is not the case at the Mr. C's site. Due to a groundwater flow divide, the PCE plume breaks into two branches; one moving to the northwest and extending between 300 and 400 feet beyond the Town of Aurora Public Library, and one moving to the southwest to slightly beyond the First Presbyterian Church. REMChlor was designed for single-branch plumes and thus fails to consider both branches.

3.3 Results

Remediation cleanup timeframes were subject to large sources of uncertainty. Treatment times for pump-and-treat alternatives were estimated based on the pumping necessary to facilitate complete plume removal and treatment. However, the rebound of contaminant concentrations in the plume has shown that this underestimates treatment timeframes; therefore, the estimated treatment time was increased by a factor of safety.

Bioremediation has short remedial timeframes, but only in areas where injections are possible, leaving the rest of the plume to naturally degrade. Natural attenuation is not known to have occurred at the Site prior to the engineered attenuation facilitated by the Pilot Study. In the absence of natural or engineered attenuation at the Site, the untreated plume may remain indefinitely. Natural attenuation occurs on most sites; however, the geochemical conditions must be favorable for MNA to clean sites properly and quickly enough (USEPA 2002). Attenuation has been observed in the Mr. C's groundwater plume following the completion of the Mr. C's Pilot Study. This RSO presents alternatives to reduce the source concentrations through additional engineered attenuation.

Once source concentrations are reduced, additional monitoring would be required to determine whether the engineered remedy has established geochemical conditions sufficient for natural attenuation to reduce the remaining contamination within an acceptable timeframe. The decision framework presented in Figure 2-1 would have to be followed to implement response actions to maintain biodegradation rates to reduce contamination in the injection areas within the desired timeframe. Since some areas of the plume would be inaccessible by either pump-and-treat or bioremediation alternatives, long-term monitoring and ICs would have to continue for the foreseeable future. Net present worth analyses were performed using a duration of 30 years for periodic and annual costs describe herein.

3.3.1 Cleanup Timeframe for Pump-and-Treat Alternatives

The Mr. C's Feasibility Study estimated the PCE contaminated plume volume at 1.3 million gallons. The annual volume of contaminated groundwater treated per year by the pump-and-treat system is approximately 3.1 million gallons. The total volume treated would equal the contaminated plume volume in less than a year of treatment; however, contaminant transport processes such as sorption and diffusion affect the time it takes contaminants to migrate to the pumping wells for treatment. The contaminant velocity is proportional to the water velocity, with the difference described by the inverse of the contaminant's retardation factor. Given the assumptions shown in Table 3-1 and based on the methodology described in the EPA's guidance document *Basics of Pump-and-Treat Groundwater Remediation Technology* (1990), EEEPC calculated a cleanup timeframe for the pump-and-treat alternatives of 68 years. Net present worth analyses have been performed using a duration of 30 years for periodic and annual costs.

Table 3-1 Assumptions: Cleanup Timeframe for Pump-and-Treat Alternatives

	Parameter	Assumption / Input Value
D	Contaminant distance from pump (max)	360 ft
S_t	Saturated thickness of contaminated aquifer / depth of plume	20 ft
N	Porosity	0.25
γ_{soil}	Soil bulk density	2.34 g/cm^3 or 146 lbs/cf
Q_{gw}	Groundwater flow	390 ft/yr
	Pumping rate (upgraded pumps)	10 gpm
f_{oc}	Fraction organic carbon[1]	0.00755
K_{oc}	Organic carbon partitioning coefficient[2]	364
γ_{water}	Water density	1 g/cm^3
R	Retardation factor	20
Q_c	Contaminant flow	19 ft/yr
FS	Factor of safety	3

Notes:
1. The average f_{oc} is taken from the 1996 Malcolm Pernie RI.
2. The K_{oc} is based on literature values reported in USEPA, "Basics of Pump-and-Treat Groundwater Remediation Technology", 1990.

Key:
ft = feet.
ft/yr = feet per year.
g/cm^3 = gram per cubic centimeter.
gpm = gallons per minute.

3.3.2 Enhanced Bioremediation Degradation Rates

Three types of first-order attenuation rate constants were considered for plume degradation modeling (USEPA 2002). The first is the point decay rate constant, k_{point}, which represents concentration versus time. k_{point} was used to estimate timeframes for reduction based on Pilot Study data. The second is the bulk attenuation rate constant, k, which represents concentration versus distance and can estimate changes in plume size as a result of sorption, dispersion, and biodegradation. The third is the biodegradation rate constant, λ, which represents biodegradation and contaminant migration. The biodegradation rate constant was generated using BIOCHLOR, but due to limitations of the model discussed in Section 3.2.1, it was not accurate and could not be used for degradation estimates.

Of the rate constants described, k_{point} is the only one that can be used to estimate the time required to reduce the contaminant plume to groundwater standards (USEPA 2002). This is because the rate is created from contamination at specific points in time. The accuracy of k_{point} is limited by the amount of raw data available for its calculation. In general, k_{point} should be generated using well data from the center of the plume, as higher concentrations of contamination will generally take the longest to degrade. For the Mr. C's site, k_{point} was calculated from PCE concentrations over time at MPI-6S. PCE concentrations used in the calculation are taken from the Mr. C's Bioremediation Summary Report (EEEPC 2015a). Site-specific degradation rates for daughter products of PCE were difficult to derive with accuracy from well data because daughter products were being generated and biodegraded simultaneously during the Pilot Study.

First-order kinematic degradation rates were estimated for PCE and its daughter products based on the results of the Pilot Study at MPI-6S. EEEPC calculated a degradation half-life at MPI-6S of 0.84 months for PCE and 8.8 months for TCE. However, these rates were based on the Pilot Study results at MPI-6S, for which degradation of cis-DCE or VC were not observed. Cis-DCE concentrations at MPI-6S fell in October 2014 after the Pilot Study, but it is unclear how much of this is a result of biodegradation or transport. Both degradation and generation were observed from month to month at MW-8. Cis-DCE degradation half-lives calculated at MW-8 during the Pilot Study ranged from 0.7 to 2.1 months.

3.3.3 Permeable Reactive Barrier Thicknesses

The required thickness of the permeable reactive barriers was calculated by (1) determining the residence time in the permeable reactive barrier required to degrade PCE and achieve the NYSNYSDEC Class GA groundwater standard for VOCs and (2) multiplying that residence time by the velocity of the groundwater and a factor of safety. The Interstate Technology & Regulatory Council suggests a factor of safety between 2 and 3 for the design of permeable reactive barriers (ITRC 2011). Due to the contaminant sorbing nature of PlumeStop, the PlumeStop barrier was allocated a factor of safety of 2, while the barrier of 3DMe alone was allocated a factor of safety of 3. Given the assumptions shown in Table

3-2, EEEPC calculated reactive barrier thicknesses of 31 feet for 3DMe and 20 feet for 3DMe and PlumeStop combined.

Table 3-2 Assumptions: Permeable Reactive Barrier Thicknesses

Parameter		Assumption / Input Value
S_t	Saturated Thickness of Contaminated Aquifer / Depth of Plume	20 feet
C_{GW0}	Initial Concentration into Barrier at Time = 0 (max)	2,400 µg/L
C_{GA}	Class GA Groundwater Standard for VOCs	5 µg/L
V_{GW}	Groundwater Velocity	0.045 ft/yr
FS_{3D}	Factor of Safety for 3DMe alone	3
FS_{plume}	Factor of Safety for 3DMe and PlumeStop	2
k_{PCE}	Average PCE degradation rate	0.8270/month (equal to a half-life of 0.84 months)
θ	Residence time in barrier	227 days

Key:

ft = Feet.
ft/yr = Feet per year.
kg = Kilogram.
µg/L = Micrograms per liter.
mg/kg = Milligram per kilogram.

3.3.4 Cleanup Timeframe for Source Bioremediation Alternatives

Cleanup timeframes for source bioremediation alternatives were determined using the modeling program SourceDK. This program used aquifer data and historical PCE cleanup times from the Pilot Study to determine a timeframe for remediation. The various inputs to SourceDK are presented in Table 3-3.

Given the inputs and assumptions in Table 3-3, SourceDK predicted a bioremediation cleanup timeframe of approximately 4 years for PCE. However, based on site experience, this cleanup rate does not consider cis-DCE or VC degradation. Multiple injections of electron donor would be required to maintain degradation rates capable of achieving the cleanup goals in the treated areas within the desired timeframe. However, site access limitations would result in residual contamination in untreated portions of the contaminated plume. Therefore, net present worth analyses were performed using a duration of 30 years for periodic and annual costs.

Table 3-3 Assumptions and Input Parameters: Cleanup Timeframe For Source Bio-Remediation Alternatives

Parameter		Assumption / Input Value
k	Hydraulic conductivity	11 ft/day
i	Gradient	0.004 ft/ft
V_D	Darcy groundwater velocity	16.1 ft/yr
S_l	Source length (maximum)	840 ft
S_w	Source width	480 ft
S_t	Source thickness	20 ft
C_{GWO}	Average source groundwater concentration at time = 0	1160 µg/L
C_{soil}	Average source soil concentration at time = 0	0.21 mg/kg
M_O	Source mass of VOCs at time = 0	112.4 kg
Q	Specific discharge	1.5E+05 ft^3/yr
γ_{soil}	Soil bulk density	2.34 kg/L
λ	PCE degradation rate constant	9.33/yr

Key:

ft = Feet.
ft/yr = Feet per year.
ft/day = Feet per day.
ft^3/yr = Cubic feet per year.
kg = Kilogram.
µg/L = Micrograms per liter.
kg/L = Kilograms per liter.
mg/kg = Milligram per kilogram.

4 Alternatives Evaluation

This section evaluates the remedial optimization alternatives described in Section 2 based on the modeling results discussed in Section 3. The alternatives are evaluated in terms of the following criteria: implementability, effectiveness, costs, and time to achieve the RAOs.

4.1 Evaluation Criteria

- **Implementability:** This includes factors such as access, constructability, microbial biofouling (i.e., the undesirable accumulation of microorganisms on a wetted surface, such as an inner well casing or the air stripper).
- **Effectiveness:** For purposes of this RSO report, the effectiveness of an alternative is defined as the ability of the option to reduce contaminant mobility and protect human health. Human health impacts are considered reduced when toxicity, mobility, and mass of contamination are reduced or when an exposure pathway is incomplete. Bioremediation, while it has the potential for complete degradation of PCE to ethene, a nonhazardous substance, first degrades to its daughter products such as cis-DCE and VC, which have a higher toxicity and cancer risk. In addition, bioremediation may produce secondary water quality impacts such as an increase in dissolved metals contamination or the generation dissolved methane gas and its potential accumulation or vapor intrusion.
- **Costs:** NYSDEC's Draft Remedial Site Optimization (RSO) Guidance indicates that a net present worth analysis is used to support an RSO recommendation for optimization efforts not associated with operation and maintenance (such as installing a new well to decommission two wells) or to advance a recommendation that the selected remedy "is not appropriate, will not reach the remedial goals, or identifies a significantly better remedy that was not available at the time of the ROD" (NYSDEC 2011). The RSO Guidance document describes the net present worth analysis as based on a "realistic projection of the anticipated time that the remedy will need to operate." Screening-level cost estimates were developed for the alternatives and include both capital and long-term annual costs, such as ICs, system operation/maintenance, and long-term monitoring. Feasibility-style cost estimates, such as those presented in this report, have an expected accuracy range from -30 to +50 percent for detailed analysis of alternatives (USEPA 2000). Estimated capital costs are added to the annual costs as total costs and presented in both present value

and life-cycle costs for comparison purposes. The present value is the amount needed to be set aside at an initial point in time (base year) to ensure that funds will be available in the future, assuming a discount factor. Life-cycle costs are the sum of annual costs into the future assuming a discount factors.

- **Time to Achieve the RAOs:** Based on either modeling performed in Section 3 or other measurable goal, the time to achieve RAOs (Class GA Groundwater Standards) were estimated.
- **Sustainability:** The recommended alternative must always meet the thresholds and programmatic requirements for the protection of public health and the environment. The purpose of this criteria is to consider cleanups in the context of the larger environment and consistently and proactively apply more sustainable methods to remediate the site. Per NYSDEC's Green Remediation Program Policy (2010), qualitative green metrics can help determine which alternative has the greatest net benefit or least impact.

4.2 Evaluation of Alternatives

Table 4-1 summarizes and compares the alternatives presented in Section 2 against the evaluation criteria presented in Section 4.1. Cost estimates are provided in Appendix C.

Table 4-1 Alternative Evaluation

Alternative	Implementability	Effectiveness	Estimated Time to Reach RAOs[1]	Sustainability	Net Present Value of Life-cycle Costs
No. 1: Pump and Treat for Source and Migration Control	Readily implementable as the existing remedy is in place.	Pump-and-treat technologies are effective at controlling exposure to PCE due to off-site migration; however, pump-and-treat technologies face declining efficiencies with respect to source control. Therefore, the effectiveness of this alternative to reduce the volume of contaminated groundwater is expected to decrease over time. Site SVIIs and mitigation with vapor barriers and SSDSs will reduce the exposure pathway for VOCs in the properties whose owners agree to them.	Over 30 years	Pump and treat technologies contribute to a higher direct production of green-house gases through vehicle miles travels for OM&M and site visits and a higher indirect production of green-house gases through electricity consumption.	$3.4 million
No. 2a: Pump and Treat for Source Control with PRBs for Migration Control without PlumeStop	Feasible; design would accommodate access agreements on private properties.	As in Alternative No. 1, this Alternative will face declining efficiencies with respect to source. A PRB, when properly designed and implemented, can effectively reduce contaminant mass, toxicity, and migration. However, anaerobic degradation of PCE creates more toxic degradation products before arriving at a non-toxic end product. Anaerobic degradation also has the potential to create secondary water quality impacts such as methane generation. In addition, human health risks may be increase if contamination is not fully degraded before it leaves the permeable reactive zone. Site SVIIs and mitigation with vapor barriers and SSDSs will reduce the exposure pathway for VOCs in the properties whose owners agree to them.	Over 30 years	Pump and treat technologies contribute to a higher direct production of green-house gases through vehicle miles travels for OM&M and site visits and a higher indirect production of green-house gases through electricity consumption.	$3.6 million

Table 4-1 Alternative Evaluation

Alternative	Implementability	Effectiveness	Estimated Time to Reach RAOs[1]	Sustainability	Net Present Value of Life-cycle Costs
No. 2b: Pump and Treat for Source Control with PRBs for Migration Control with PlumeStop	Feasible; design would accommodate access agreements on private properties.	See Alternative No. 2a. PlumeStop will increase the efficiency of the Alternative, because it increases the sorptive capacity of the soil to prevent off-site migration.	Over 30 years	Pump and treat technologies contribute to a higher direct production of green-house gases through vehicle miles travels for OM&M and site visits and a higher indirect production of green-house gases through electricity consumption.	$4.1 million
No. 3: Bioremediation for Source Control with Pump and Treat for Migration Control	Poor implementability; bioremediation as a source control technology would conflict with pump-and-treat operation as a source control option.	This Alternative is not expected to be effective, because the existing pump-and-treat system is not designed for migration control.	NA	This Alternative is not considered effective and is therefore not sustainable.	NA

Table 4-1 Alternative Evaluation

Alternative	Implementability	Effectiveness	Estimated Time to Reach RAOs[1]	Sustainability	Net Present Value of Life-cycle Costs
No. 4a: Bioremediation for Source and Migration Control without PlumeStop	Feasible; design would accommodate access agreements on private properties.	Bioremediation when properly designed and implemented can effectively reduce contaminant mass, toxicity, and migration. However, anaerobic degradation of PCE creates more toxic degradation products before arriving at a non-toxic end product. Anaerobic degradation also has the potential to create secondary water quality impacts such as methane generation. In addition, human health risks may increase if contamination is not fully degraded before it leaves the permeable reactive zone. Site SVIIs and mitigation with vapor barriers and SSDSs will reduce the exposure pathway for VOCs in the properties whose owners agree to them. Alternative 4 would be effective in the long term at reducing both migration through the use of PRBs and reducing toxicity with the transformation of PCE to a non-hazardous by-product (ethane).	As few as 5 years in injection zones, over 30 years where injections are limited by structures over the plume.	Bioremediation will contribute to the direct and indirect production of green-house gases because less OM&M will be required and no electricity is used.	$2.6million
No. 4b: Bioremediation for Source and Migration Control with PlumeStop	Feasible; design would accommodate access agreements on private properties.	See Alternative No. 4a. PlumeStop will increase the efficiency of the Alternative, because it increases the sorptive capacity of the soil to prevent off-site migration.	As few as 5 years in injection zones, over 30 years where injections are limited by structures over the plume.	Less direct and indirect green-house gas production because less OM&M will be required and no electricity is used.	$3.1 million

Notes:

1. The RAO considered is that for reaching the NYSDEC Class GA Groundwater Standards.
2. SVII and SSDS contribute to the remedy effectiveness for each alternative considered by reducing the contaminant exposure pathway via soil vapor intrusion.

Key:

NYSDEC = New York State Department of Environmental Conservation
PRB = Permeable reactive barrier

5 Recommended Alternative for Remedial Optimization

EEEPC recommends that NYSDEC consider Alternative 4a, Bioremediation for Source Control and a 3DMe Permeable Reactive Barrier for Migration Control, for remedial site optimization at the Mr. C's Dry Cleaners Site. Alternative 4a is recommended because it is the most cost-effective option that meets the evaluation criteria and is readily implementable. Alternative 4a is estimated to cost $2.6 million dollars over 30 years, whereas Alternative 1 is estimated to cost $3.4 million dollars over the same time period. Alternative 4a would reduce annual operating costs from an estimated $196,337 to $36,456. NYSDEC would break even and begin to realize the cost savings in year 10 of operation.

Bioremediation source control is an effective long-term control for the PCE plume. Although it increases PCE toxicity in the short term, SSDSs in areas experiencing soil vapor intrusion problems and continuing SVII and SSDS installations will protect human health during this increase in toxicity. It will also protect human health in areas where grid injections are not implementable for plume treatment due to the presence of residential and commercial buildings.

Permeable reactive barriers would provide an effective means to control plume migration. While PlumeStop would increase contaminant residence time in the barriers, it is not necessary for the barrier to be effective and adds a substantial cost, not only for the material but also for injection, which requires personnel to have specialized training from the manufacturer. Currently, the manufacturer requires injection of PlumeStop by an approved contractor, which more than doubles the cost of the PRB injections. As a result, the permeable reactive barriers comprised of 3DMe alone are the most cost-effective migration control. Bioremediation technologies are in line with the objectives of NYSDEC's Green Remediation Program Policy. As an in-situ technology, bioremediation would constitute a green-house gas reduction because less OM&M would be required and no electricity would be used.

Implementation of Alternative 4 would require an update to the Site Management Plan. Sections pertaining to operation, maintenance, and monitoring of the pump- and treat-system would be removed. Updates would clearly define the elements of the monitoring program, response actions, and decision framework presented in Section 2. The monitoring program would be supplemented with additional monitoring parameters for enhanced bioremediation, such as monitoring for secondary groundwater quality impacts and methane generation. Groundwater monitoring is currently performed annually; however, the net present cost analysis for the alternatives presented in this RSO report assumes that groundwater monitoring can be reduced to every 3 years through the life-cycle of the proposed remedy.

OM&M of the SSDSs may in the future be transferred for performance under the NYSDEC's current statewide vapor mitigation system maintenance program. Environmental restrictions must be filed with the Village of East Aurora Clerk for new buildings constructed over the contaminant plume. Periodic reporting on the remedy would continue and serve as the avenue for monitoring the adequacy of these Site ICs.

Monitoring, reporting, and response actions such as maintenance injections would continue until the RAOs are met, meaning that:

1. Human health risks have been mitigated through the installation of SSDS systems and vapor barriers and reduction of PCE; and the long-term monitoring program at the site includes a decision framework for continued protection of human health against soil vapor intrusion until NYSDEC groundwater quality standards are met;
2. Long-term monitoring has shown that the plume is stable; and,
3. NYSDEC groundwater quality standards have been achieved to the extent practical.

Based on this RSO analysis, EEEPC concludes that bioremediation is a substantially better alternative for reducing site contamination at a substantial cost savings. Implementation of bioremediation under Alternative 4a includes the eventual decommissioning of the existing pump-and-treat system. The system may be shut off prior to decommissioning at the time the permeable reactive barriers are installed for migration control.

Implementation of Alternative 4a constitutes a fundamental change to the Site Remedy, which must ultimately be recommended by the NYSDEC Bureau Director to Division management for consideration. Per NYSDEC's RSO policy, a change to the Site Remedy must go through the same rigorous of analysis, risk assessment, and community involvement as the original remedy. While this RSO substantially documents the relative benefits and cost effectiveness of the technology, there are two issues that should be resolved before soliciting community involvement:

1. Bioremediation will result in a short-term increase in the overall toxicity of the COCs. While cis-DCE is less toxic than PCE, both TCE and VC are more toxic. The final degradation byproduct, ethene, is non-hazardous. A risk assessment should be performed to determine whether the increased COC toxicity poses an increased risk to human health. For many residences, the overall

risk has been reduced through the installation of a sub-slab depressurization system, which removes the exposure pathway for soil vapor intrusion.

2. Competing microbial reaction to those that degrade PCE produce dissolved methane. Methane is non-toxic, but if it partitions out of the groundwater and into soil vapor, it could migrate upward and accumulate, potentially resulting in an explosion risk. Literature reviewed to date by EEEPC has not identified any known instances of methane accumulation to explosive levels under these circumstances; however, the risk remains and may factor into the public's perception of the Alternative.

Public participation and community involvement should be solicited for this change in the Site Remedy, especially because site access has not historically been granted for all residential properties. Consequently, all remedies considered, particularly the SVII program, are limited in their ability to protect public health and safety.

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A

Pre-Remedy Groundwater Isopotential Map

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MALCOLM PIRNIE

REVISIONS

NO.	BY	DATE	REMARKS

DES ______
DWN ______
CKD ______

NYSDEC
DIVISION OF HAZARDOUS WASTE REMEDIATION

REMEDIAL INVESTIGATION

MR. C CLEANERS

ISOPOTENTIAL MAP
6/15/94 GROUNDWATER LEVELS

SCALE: 1" = 40'

DATE JULY 1994

SHEET 6 OF 6

CAD REF. NO. DEC-31-GWL

B Regenesis Product Information

B-1 3DMe Microemulsion
B-2 BDI Plus
B-3 HRC Primer
B-4 PlumeStop
B-5 Site Information Provided to Regenesis
B-6 Supporting Cost Information Provided by Regenesis

Appendix B-1

3D Microemulsion Product Brochure

3D Microemulsion Product Application Instructions

3D Microemulsion MSDS

3-D MicroEmulsion® FACTORY EMULSIFIED

STAGED RELEASE, pH NEUTRAL, FACTORY EMULSIFIED ELECTRON DONOR

DESCRIPTION

Factory emulsified 3-D Microemulsion is a unique electron donor material that offers an engineered, 3 stage electron donor release profile, pH neutral chemistry and is delivered on-site as a factory emulsified material. This new molecule also exhibits a novel hydrophile-lipophile balance (HLB) which provides maximum subsurface distribution well beyond that of emulsified vegetable oils.

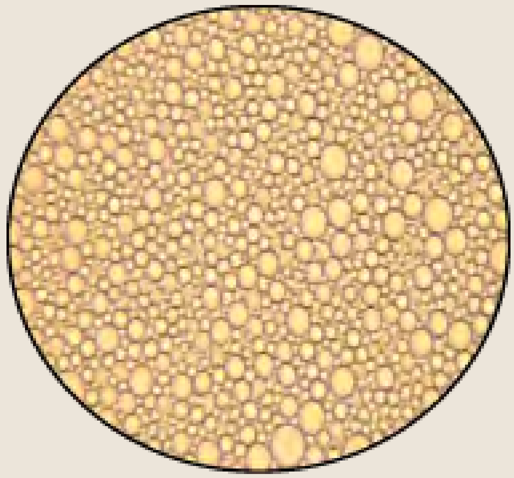

FIGURE 1: Microscopic view of factory emulsified 3-D Microemulsion.

FEATURES & BENEFITS

- **3 Stage Electron Donor Release Profile Avoids Multiple Re-applications Saving Time and Money**

This feature optimizes start to finish timing of the enhanced reductive dechlorination process through an immediate, mid-range and long-term electron donor release. Without a 3 stage release profile, bioremediation efforts are inefficient, causing gaps in electron donor supply and requiring multiple injections. Factory emulsified 3-D Microemulsion offers a 3 stage electron donor release for optimal results (Figure 2).

Stage 1 - Immediately available free lactic acid (lactate) is fermented rapidly

Stage 2 - Controlled-release lactic acid (lactate esters and polylactate esters) are metabolized at a more controlled rate

Stage 3 - Free fatty acids and fatty acid esters are converted to hydrogen over a mid to long-range timeline giving factory emulsified 3-D Microemulsion an exceptionally long electron donor release profile

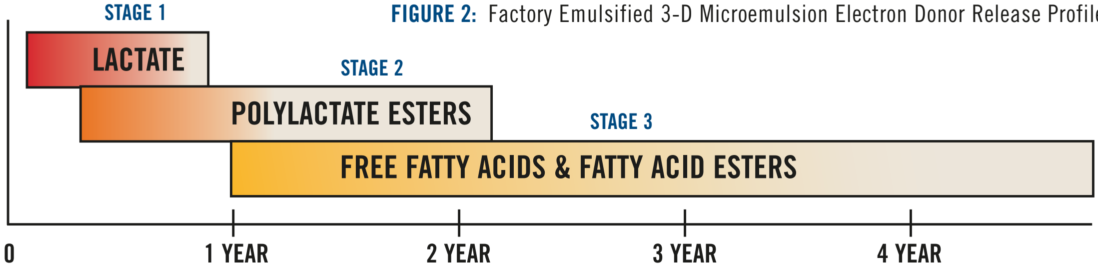

FIGURE 2: Factory Emulsified 3-D Microemulsion Electron Donor Release Profile

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3-D MicroEmulsion® FACTORY EMULSIFIED

STAGED RELEASE, pH NEUTRAL, FACTORY EMULSIFIED ELECTRON DONOR

FEATURES & BENEFITS

- **A Unique Hydrophile/Lipophile Balance (HLB) Enhances Distribution and Limits Reduction in Hydraulic Conductivity**

  The HLB feature allows the product to distribute in the subsurface via micellar movement. During this process, microscopic colloidal aggregates (micelles) continuously propagate from areas of high concentration to those of lower concentration moving the factory emulsified 3-D Microemulsion electron donor material into areas beyond those affected by the initial injection. This enhanced distribution mechanism allows for greater spacing between injection points and less time required for material application. Additionally, due to its unique hydrophile-lipophile balance, applications of factory emulsified 3-D Microemulsion have not resulted in the significant aquifer blockage as seen with the use of emulsified oil products.

FIGURE 3: A 2000 lb. tote of factory emulsified 3-D Microemulsion. The material can be delivered in drums, totes or tanker trucks.

- **Highly Efficient Application Designs**

  When designing an *in situ* remediation project with factory emulsified 3-D Microemulsion, application designs are based on mass balance and stoichiometric demand from the contaminant, competing electron acceptors and a minimum total organic carbon (TOC) loading. This often results in a more efficient dosing requirement compared to design methods employed by other electron donor suppliers.

- **Neutral pH**

  Neutral pH minimizes potentially harmful impacts to beneficial biodegrading microorganisms required to metabolize chlorinated contaminants. This feature can be highly valuable when the microemulsion is used in conjunction with pH-sensitive commercial bioaugmentation cultures

- **Injection-Ready Formulation, Simple and Easy Application**

  3D Microemulsion is delivered on-site as a factory emulsified, injection-ready product. It can be applied as delivered or further diluted and mixed with additional site water to form a higher-volume ready-to-inject microemulsion. This material can be applied through a variety of application techniques including permanent or temporary injection wells and direct-push points.

- **Choose from a Range of Packaging Options**

  Factory emulsified 3-D Microemulsion can be delivered in 400 lb. drums, 2000 lb. totes and large volume tanker trucks making shipping, receiving and application on any site simple and convenient (Figure 3).

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PRODUCT APPLICATION INSTRUCTIONS

3-D Microemulsion® Factory Emulsified

As delivered, the 3-D Microemulsion factory emulsified product is a significant change compared to the physical state of standard 3-D Microemulsion. Whereas the standard 3-D Microemulsion is delivered in a concentrate form that requires an emulsification step prior to application, factory emulsified 3-D Microemulsion is delivered as a ready-to-apply, factory emulsion. It does not require shearing or any another other emulsion making steps. The only pre-application requirement is a quick stir and any required/recommended dilution of the factory emulsified 3-D Microemulsion with an appropriate volume of clear water.

Material Overview Handling and Safety

3-D Microemulsion factory emulsified is shipped and delivered as an emulsion of 2 part water to 3 parts active ingredient. Packaging is available in 275 gallon totes and/or 55 gallon drums.

- Each tote typically has a gross weight of 2,000 pounds
- Each drum has a weight of 400 pounds

At room temperature, 3-D Microemulsion factory emulsified is a liquid material with an appearance and viscosity roughly equivalent to milk. The microemulsion is not temperature sensitive above 50ºF (10ºC). If the user plans to apply the product in cold weather, consideration should be given to warming the material to above 50ºF so that it can be more easily handled. The material should be stored in a warm, dry place. It is common for stored factory emulsified 3-D Microemulsion to settle somewhat in the container while in transit, a quick pre-mix stir using a hand held drill, equipped with paint mixer attachment will rapidly re-homogenize the microemulsion. Factory emulsified 3-D Microemulsion is non-toxic, however field personnel should take precautions while handling and applying the material. Field personnel should use appropriate personal protection equipment (PPE) including eye protection. Gloves should be used as appropriate based on the exposure duration and field conditions. A Material Safety Data Sheet (MSDS) is provided with each shipment. Personnel who operate field equipment during the installation process should have appropriate training, supervision, and experience and should review the MSDS prior to site operations.

PRODUCT APPLICATION INSTRUCTIONS

3-D Microemulsion® Factory Emulsified Field Homogenization using a Cordless Drill Equipped with a Paint Mixing Attachment

Design and Specifications

Designs for 3-D Microemulsion factory emulsified remain unchanged from standard 3-D Microemulsion. An additional application method has been added with the use of a Dosatron® metering system.

Composition and associated physical properties of factory emulsified 3-D Microemulsion are as follows:

Density: is approximately 1 g/cc (8.34 lbs/gallon) at 20°C/68°F
Physical Form: liquid, composed of 2 part water to 3 parts Factory Emulsified 3-D Microemulsion (2:3)

The 3-D Microemulsion factory emulsion can be diluted water a (v/v) volume to volume basis to produce the desired diluted concentration. Most typical concentrations range from 1 to 10% (v:v); more dilute concentrations can be easily produced using the water volumes provided in the table below.

Higher dilution rates are governed by the following technical considerations:

- Factory emulsified 3-D Microemulsion required to treat the estimated contaminant mass
- Target pore volume in which the Factory Emulsified 3-D Microemulsion is applied
- Available application time (aquifer acceptance rate)

PRODUCT APPLICATION INSTRUCTIONS

Although using a more dilute microemulsion will produce a greater volume of the material, it will also lower the delivered concentration. Thus, the benefit of using a higher dilution rate (to affect a greater pore volume of the subsurface aquifer) is offset by the lower factory emulsified 3-D Microemulsion concentration. Another important consideration is the aquifer's capacity to accept the volume of material (i.e., the aquifer's hydraulic conductivity and effective/mobile porosity).

It is important that the user consider the 3-D Microemulsion factory emulsion dilution rate to be employed at a project site. The resulting emulsion volume will dictate the site water requirements and the time required for injection, etc. If the subsurface does not readily accept the volume as designed, the user can simply reduce the amount of water, thereby lowering the volume of subsequent batches. For more information on design and material dilution rates to meet specific site conditions, please contact Regenesis Technical Services.

The following table provides a quick reference to the dilution water necessary for some common application rates:

3-D Microemulsion Factory Emulsified (%)	3-D Microemulsion Factory Emulsified (mg/L)	3-D Microemulsion Factory Emulsified (gal)	Clear Water (gal)	Resulting Volume (gal)
10	100,000	1	9	10
5	50,000	1	19	20
3	30,000	1	32	33
2	20,000	1	49	50
1	10,000	1	99	100

EXAMPLE: Create a 50,000 mg/L factory emulsified 3-D Microemulsion material

- Dilute each gallon of material with 19 gallons of water resulting in a 20 gallon material volume

3-D Microemulsion® Factory Emulsified Dilution

There are two basic approaches for dilution of factory emulsified 3-D Microemulsion. These approaches are referred to as "on demand" and "batched" and are discussed below:

PRODUCT APPLICATION INSTRUCTIONS

On Demand – Dosatron® Metering System

This method consists of the dilution and application of factory emulsified 3-D Microemulsion in "real time". This is typically accomplished at the well head and is used almost exclusively via dedicated injection well applications. These systems are designed to dilute the material "in-line" and on an "as needed" basis. The most common metering system used for this purpose is the Dosatron® System. This is a volume-based metering system that is positioned at the surface and on individual well heads. These units create a targeted dilution of factory emulsified 3-D Microemulsion in water by metering a set volume of the material into a set volume of clear water passing through and powering the device. Thus, fluctuations in the water flow volume or pressure will not result in a change in the rate of factory emulsified 3-D Microemulsion delivered. This device will maintain consistent water to emulsion ratio regardless of water flow rate or pressure.

NOTE: prior to use, each drum or tote of factory emulsified 3-D Microemulsion should be stirred thoroughly using a paint mixer equipped drill.

In this method, each delivery point is manifold to a central clear water holding tank via a manifold system as shown below. Typically, a single pump is placed between the holding tank and the manifold, this pump is used to pressurize the system and to maintain the flow of clear water through the manifold and to the individual application points. A flow meter/totalizer, pressure gauge and ball check valve should be present between the manifold effluent and each Dosatron unit to allow the applier to regulate and monitor individual application rates. This will aid in determining each application point's optimal acceptance rate. Please refer to the User's Manual for your Dosatron. Additional information and specific set up information is available on the Dosatron® Website at http://www.dosatronusa.com/search-results.aspx?QueryExpr=manuals .

PRODUCT APPLICATION INSTRUCTIONS

Dilution of the Factory Emulsified 3-D Microemulsion® in a Batched Configuration

Batched

This method consists of preparing a pre-determined volume of dilute factory emulsified 3-D Microemulsion and storing it in a batch tank until applied. Delivery of the dilute microemulsion can be to a single delivery point (or well) or multiple delivery points via a manifold system, in either case the injection location must be plumbed to the factory emulsified 3-D Microemulsion holding tank and account for the issues outlined in the Application Methods introduction (below). The delivery of dilute microemulsion is typically via wells or direct push injection points that are connected to the central diluted microemulsion tank via a manifold system and include a dedicated inline flow meter/totalizer, pressure gauge and ball valve for each well or injection point. Often a single pump is placed between the dilute microemulsion tank and the manifold, this pump is used to pressurize the system and maintain flow of the dilute factory emulsified 3-D Microemulsion through the manifold and application points. The flow meter/totalizer and pressure gauge allow the applier to monitor application rates and back pressure for each well or injection point and thus the aquifer's acceptance rate. A simple manifold system with pressure gauges and flow meter/totalizer is shown below. NOTE: upon dilution the material should be stirred on a periodic and regular basis (as shown above).

PRODUCT APPLICATION INSTRUCTIONS

Factory Emulsified 3-D Microemulsion® Application

The application of the dilute factory emulsified 3-D Microemulsion is typically accomplished by injection via direct-push points (DPI) or dedicated injection wells. Regardless of which delivery option is used, dilution of the factory emulsion prior to application is most appropriate. Application can be performed using pressure or gravity feed.

At a minimum the applier should use the following instrumentation to monitor application:

- Pressure gauges
  - psi range should be selected based site specific conditions
    - aquifer conductivity (anticipated aquifer acceptance rate)
    - pump type (e.g. double diaphragm vs. positive displacement pumps)
    - application methods [Direct Push Injection vs. Injection Wells]
    - not-to-exceed pressures
- In-Line Flow Meters
  - range should be selected based on site specific requirements
- Pressure-Relief Valves for prevention of pressure buildup in various segments of the application tooling
  - positioning of pressure relief valves should be considered in the following locations
    - At or along product delivery lines or manifold
    - The injection well head or direct push injection rod → product delivery hose connection

For direct assistance or more information contact us at 1-949-366-8000 or send an e-mail to tech@regenesis.com

3-D Microemulsion® Factory Emulsified
MATERIALS SAFETY DATA SHEET

Last Revised: November 15, 2011

Section 1 – Material Identification

Supplier:

REGENESIS

1011 Calle Sombra
San Clemente, CA 92673

Phone:	**949.366.8000**
Fax:	**949.366.8090**
E-mail:	**info@regenesis.com**

Chemical Name(s):	Glycerides, tall-oil di-, mono [2-[2-[2-(2-hydroxy-1-oxopropoxy)-1-oxopropoxyl]-1-oxopropoxy]propanoates]
Chemical Family:	**Organic Chemical**
Trade Name:	**3-D Microemulsion® Factory Emulsified**
Synonyms:	**HRC Advanced®, HRC-PED (Hydrogen Release Compound – Partitioning Electron Donor)**
Product Use:	**Used to remediate contaminated groundwater (environmental applications)**

Section 2 – Chemical Identification

CAS#	**Chemical**
823190-10-9	**HRC-PED**
72-17-3	**Sodium Lactate**
7789-20-0	**Water**

Section 3 – Physical Data

Melting Point:	**Not Available (NA)**
Boiling Point:	**100 ºC**
Flash Point:	**> 93.3 ºC using the Closed Cup method**
Density:	**1.0 -1.2 g/cc**
Solubility:	**Soluble in water.**
Appearance:	**White emulsion.**
Odor:	**Not detectable**
Vapor Pressure:	**None**

Section 4 – Fire and Explosion Hazard Data

Extinguishing Media:	**Use water spray, carbon dioxide, dry chemical powder or appropriate foam to extinguish fires.**

Water May be used to keep exposed containers cool.

For large quantities involved in a fire, one should wear full protective clothing and a NIOSH approved self contained breathing apparatus with full face piece operated in the pressure demand or positive pressure mode as for a situation where lack of oxygen and excess heat are present.

Section 5 – Toxicological Information

Acute Effects:	May be harmful by inhalation, ingestion, or skin absorption. May cause irritation.
Sodium Lactate:	Toxicity to Animals: LD50: Not available. LC50: Not available. Chronic Effects on Humans: Not Available. Other Toxic Effects on Humans: Very hazardous in case of skin contact (irritant), ingestion and inhalation.
Soybean Oil:	Health Hazards (Acute and Chronic): Acute: none observed by inhalation. Chronic: none reported.
Inhalation Risks and Symptoms of Exposure:	Excessive inhalation of oil mist may affect the respiratory system. Oil mist is classified as a nuisance particulate by ACGIH.

Skin Absorption Health Risks and Symptoms of Exposure: Sensitive individuals may experience dermatitis after long exposure of oil on skin.

Section 6 – Health Hazard Data

Handling: Avoid continued contact with skin. Avoid contact with eyes.

In any case of any human exposure which elicits a reaction, a physician should be consulted immediately.

First Aid Procedures:

Inhalation: Remove to fresh air. If not breathing give artificial respiration. In case of labored breathing give oxygen. Call a physician.

Ingestion: No effects expected. Do not give anything to an unconscious person. Call a physician immediately. DO NOT induce vomiting.

Eye Contact: Wash eyes with plenty of water for at least 15 minutes lifting both upper and lower lids. Call a physician.

Section 7 – Reactivity Data

Conditions to Avoid: Strong oxidizing agents, bases and acids

Hazardous Polymerization: Will not occur.

Stability: Spontaneous combustion can occur.

Further Information: Hydrolyses in water to form lactic acid and soybean oil.

Hazardous Decomposition Products: None known.

Section 8 – Spill, Leak or Accident Procedures

After Spillage or Leakage:	Neutralization is not required. The material is very slippery. Spills should be covered with an inert absorbent and then be placed in a container. Wash area thoroughly with water. Repeat these steps if slip hazard remains.
Disposal:	Laws and regulations for disposal vary widely by locality. Observe all applicable regulations and laws. This material may be disposed of in solid waste. Material is readily degradable and hydrolyses in several hours.

No requirement for a reportable quantity (CERCLA) of a spill is known.

Section 9 – Special Protection or Handling

Should be stored in plastic lined steel, plastic, glass, aluminum, stainless steel, or reinforced fiberglass containers.

Protective Gloves:	Vinyl or Rubber
Eyes:	Splash Goggles or Full Face Shield. Area should have approved means of washing eyes.
Ventilation:	General exhaust.
Storage:	Store in cool, dry, ventilated area. Protect from incompatible materials.

Section 10 – Other Information

This material will degrade in the environment by hydrolysis to lactic acid and soybean oil. Materials containing reactive chemicals should be used only by personnel with appropriate chemical training.

This material is a non hazardous material in regards to USDOT shipping criteria.

The information contained in this document is the best available to the supplier as of the time of writing. Some possible hazards have been determined by analogy to similar classes of material. No separate tests have been performed on the toxicity of this material. The items in this document are subject to change and clarification as more information becomes available.

Appendix B-2

BDI PLUS Product Brochure

BDI PLUS Product Application Instructions

BDI PLUS MSDS

Accelerate the process of complete dechlorination

BIOAUGMENTATION TO ACCELERATE THE PROCESS OF COMPLETE DECHLORINATION

Bio-Dechlor INOCULUM® is an enriched natural microbial consortium containing species of *Dehalococcoides* sp. (DHC). This microbial consortium has since been enriched to increase its ability to rapidly dechlorinate contaminants during in situ bioremediation processes. Bio-Dechlor INOCULUM has been shown to stimulate the rapid and complete dechlorination of compounds such as tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC). The most current culture of Bio Dechlor INOCULUM PLUS(+) now contains microbes capable of dehalogenating halomethanes (e.g. carbon tetrachloride and chloroform) and haloethanes (e.g. 1,1,1 TCA and 1,1, DCA) as well as mixtures of these halogenated contaminants.

Bio-Dechlor INOCULUM PLUS(+) is provided in a liquid form and is designed to be injected directly into the contaminated subsurface. Once in place, this microbial consortium works to accelerate the extant rate of chlorinated ethene degradation. When faced with an insufficient quantity of critical dechlorinating microbes, Bio-Dechlor INOCULUM PLUS(+) supplies many beneficial chlorinated solvent degraders including the all important DHC required to achieve complete and rapid dechlorination.

This microbial consortium is compatible with most electron donors however it is often optimized with the addition of any of Regenesis' Hydrogen Release Compound (HRC®) products.

SPECIES OF *DEHALOCOCCOIDES* SP. (DHC)

DETECTION AND QUANTIFICATION OF *DEHALOCOCCOIDES* (DHC) IN THE SUBSURFACE

The advent of modern biotechnology has allowed the development of unique and rapid genetic assays for the detection of microorganisms. Bio-Dechlor CENSUS℠, an example of this advance, offers a state-of-the-art technique for the quantitative detection of *Dehalococcoides*, the microbe shown to be required for complete biodegradation of higher chlorinated compounds through to ethene.[1, 2]

Existing analytical technologies offer only a crude qualitative assessment (+/-) of the presence of the required *Dehalococcoides* species. These tests utilize a common technique known as the Polymerase Chain Reaction (PCR), whereby traces of DNA specific only to microbes of interest (their "fingerprint") are amplified from environmental samples such that they can be detected. This approach, unfortunately, does not allow for specific quantification of the existing and present microbial population, leaving the environmental professional with insufficient information for complete site assessment and management.

Regenesis now offers a solution to the quantification dilemma, Bio-Dechlor CENSUS. This census of critical microorganisms is a proprietary analysis and is provided by specialized laboratories in the environmental industry. Bio-Dechlor CENSUS utilizes a process termed "Real-Time PCR" in which the DNA amplification step is actually quantified with a fluorescent signal, indicating the number of target microbes in the sample (Figure 1). This valuable quantitative information allows environmental professionals to properly assess project sites for the potential for natural biodegradation of chlorinated contaminants and the degree of bioaugmentation that may be required.

1. Maymo-Gatell, X.; Y-T Chien; J.M Gossett; S.H. Zinder, Science 1997, 276, 1568-1571.
2. Löffler, F.E.; Q. Sun; J. Li; J.M. Tiedje; Applied Environmental Microbiology 2000, 66(4), 1369-1374.

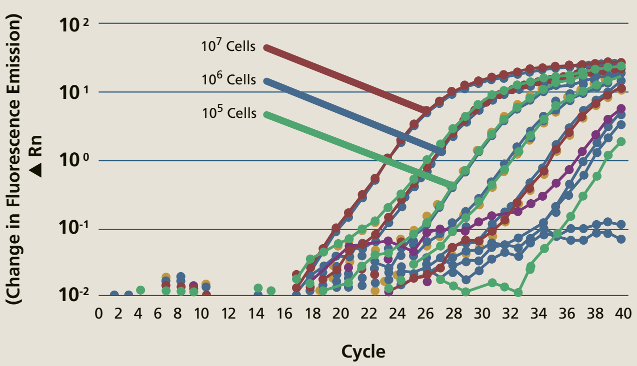

FIGURE 1: REAL-TIME PCR AMPLIFICATION OF 10-FOLD DILUTIONS OF GENOMIC DNA DERIVED FROM *DEHALOCOCCOIDES*

REGENESIS

Advanced Technologies for Groundwater Resources

Bio-Dechlor INOCULUM PLUS

Bio-Dechlor INOCULUM PLUS (BDI PLUS™)

Application Instructions

(Direct-Push Injection)

General Information

Bio-Dechlor INOCUL UM PLUS (BDI PL US™) is an enriched natural microbial consortium containing species of *Dehalococcoides.* This microbial consortium has since been enriched to increase its ability to rapidly dechlorinate contaminants during *in situ* bioremediation processes. BDI PLUS has been shown to stimulate the rapid and complete dechlorination of compounds such as tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC). BDI PLUS also contains microorganisms capable of degrading chloromethanes (carbon tetrachloride and chloroform) as well as chloroethanes like trichloroethane (TCA).

Recent trends in engineered bioremediation indicate that the treatment of chlorinated solvent contamination sometimes results in slow or incomplete degradation of the intermediate compounds. When faced with this circumstance, bioaugmentation with a microbial consortium such as BDI PLUS offers a solution to accelerate or simply make possible the complete dechlorination of these otherwise recalcitrant compounds.

Regenesis believes that the best approach to install BDI PLUS into the subsurface is by direct-push methods. This allows for the BDI PLUS solution to be applied directly into the aquifer material and provides greater coverage/treatment over the life of the project. As a minimum, the following equipment will be needed to perform this type of installation:

- Direct-push drilling unit
- Grout pump (e.g. Geoprobe GS 2000)
- Appropriate hose assembly including a fitting that links a hose from the grout pump to the direct-push rods (provided by Regenesis with shipment)
- One or more 55+ gallon water drums, fitted with an appropriate lid that has at least one bung hole (number of drums depends on size of application)
- Rotary transfer pump (or equivalent) with appropriate amount of hose to connect from 55-gal drum to hopper of grout pump (similar to Grainger No. 1P893, Fill-Rite model #FR112GR))
- Compressed Nitrogen gas tank with appropriate regulator **(0 to 15 pounds per square inch (psi)).** A 300-ft^3 tank should be sufficient for discharge of concentrated or non-concentrated kegs and for nitrogen sparging to deoxygenate batch water.
- Pressure washer (or equivalent) for cleaning

Material Packaging and Safety

BDI PLUS is a mixture of living bacteria including members of the *Dehalococcoides* genus that are capable of anaerobically degrading chlorinated contaminants. The culture has been tested to ensure that it is free of the most common pathogenic bacteria, but like all living cultures it should be handled with due care to prevent contamination of work surfaces or field personnel.

During installation activities, Regenesis recommends that field personnel use at least level "D" personal protection equipment (PPE). A Materials Safety Data Sheet (MSDS) is sent with each shipment and should be reviewed before proceeding with installation activities.

WARNING

- The BDI PLUS container is pressurized to 10 to 15 psi with Nitrogen before shipping.
- Wear suitable eye protection, gloves, respirator and protective clothing.
- Gas cylinders used to dispense culture MUST be equipped with a proper pressure regulator.
- During operation DO NOT exceed the containers maximum working pressure of 15 psi.

UNPACKING

1. Carefully remove the container from shipping cooler and stand upright. DO NOT use the plastic sight tube as a handle.
2. Carefully check the container, connectors, valves and tubing for any damage or defects. If defects or damage is observed, do not use. Report any damage to Regenesis at 949-366-8000. A back up set of quick connects is provided in the packaging material.
3. Check and ensure that all valves are in the CLOSED position.

Culture Keg in Cooler

CULTURE CONTAINER SET-UP

1. Ensure that the VALVE attached to the GREY quick connect is tightly closed.

2. Using an appropriate length of reinforced ¼" ID tubing, connect the GREY quick connect fitting assembly to the gas tank regulator.

3. The GREY connector is designed only for use with the " Gas In" line.

4. Ensure that the VALVE attached to the BLACK quick connect is tightly closed.

5. Using an appropriate length of reinforced ¼" ID tubing, connect the BLACK quick connect fitting assembly to the desired injection point

6. The BLACK connector is designed only for use with the "Liquid Out" line.

Culture Keg with Quick Connects Attached

STORAGE

If the schedule of bacteria application requires adding the bacteria over a period of more than one day, the keg(s) should be stored at a temperature 2-4 °C, but freezing must be avoided. This can normally be achieved by storing the kegs under ice in the provided coolers. Keg should be pressurized with Nitrogen to pressure 10- 15 psi. before storing to ensure a tight seal on the keg cap.

SHIPPING

After completion of operation, please, ship cooler with keg and all attachments back to the following address:
Shaw Environmental, Inc.
17 Princess Road, Lawrenceville, NJ 08648

<u>CUTURE CONTAINER DISCHARGING</u>

1. Set up the gas pressure on the delivery gas (Nitrogen or Argon) tank regulator at 10 to 15 psi.

2. Place the container on a scale or use sight tube to control and monitor culture delivery

3. Attach the GREY connector to the ball-lock fitting on the keg marked “IN” by pulling up the barrel of connector and pushing it all the way down onto the ball lock fitting of the keg. Release the barrel of the quick connect. A Click sound indicates that connector was properly attached to the keg fitting.

4. Attach the BLACK quick connect assembly to the fitting on the keg marked “OUT” the same way as grey connector.

5. Slowly open the valve on “Gas in” line. This action will pressurized the container with delivery gas.

.

6. Gradually open the valve on the “Liquid Out” line to provide the desired flow of bacterial suspension. Delivery of the culture can be monitored by watching the liquid level in the sight window, or by using an installed flow meter (not supplied)

7. After delivery of the desired volume of culture, close the valves on the ‘Liquid Out” line and the “Gas In” line.

8. Disconnect the connectors from container by pulling up on the barrel of the quick connects.

Specific Installation Procedures

1. The BDI PLUS must be added to the previously prepared “oxygen-free” water before it is installed in the subsurface. The desired amount of BDI PLUS should be carefully discharged into the 55-gal drum containing the appropriate amount of “oxygen free” water. The tables provided below indicates the amount of water that a given amount of BDI PLUS should be mixed with.

   The BDI PLUS must be added to “oxygen-free” water before it is installed in the subsurface. To ensure that the water has reached the desired anoxic state prior to mixing with BDI PLUS an appropriate amount of nitrogen sparging into the 55-gal drum containing a given amount of water at least **one hour** prior to adding the BDI PLUS. To ensure that a sufficient quantity of “oxygen free” water is available throughout the day, a large trough of “nitrogen sparged” water can be prepared and additional 55-gal drums can be filled from this trough. The water in the trough can be transferred to the 55-gal drums where the BDI is mixed with the water using a primed transfer pump.

   Nitrogen sparging is accomplished by a gas sparging device equivalent to a fish tank aerator. Adjust the $300ft^3$ nitrogen tank pressure regulator to 3-5 psi and immerse the gas sparger to the bottom of the drum or trough. By internal convection and oxygen stripping processes, the oxygen levels should diminish within an hour. Be careful to not consume too much gas and not have nitrogen to empty the kegs. Keeping an eye on tank pressure loss will indicate when one can trim down on the sparge pressure and conserve the nitrogen.

Volume of BDI PLUS™	**Volume of water**
5 liters	50 gal
1 liter	10 gal

Volume of BDI PLUS™ **concentrate**	**Volume of water**
0.5 liters	50 gal
0.1 liter	10 gal

BDI PLUS Dilution Chart

2. The drive rod assembly should be fitted with a disposable tip on the first drive rod and pushed down to the desired depth. This process should be done in accordance with the manufacturer's standard operating procedure (SOP).

3. A sub-assembly connecting the delivery hose to the drive rods and pump should be used. The sub-assembly should be constructed in a manner that allows for the drive rods to be withdrawn while the material is being pumped.

4. Prior to connecting the hose to the sub-assembly a volume check should be completed to determine the volume and weight of product displaced with each pump stroke.

5. After the drive rods have been pushed to the desired depth, the rod assembly should be withdrawn three to six inches so that the disposable tip has room to be dropped.
    a. If an injection tool is used instead of an expendable tip, the application of material can take place without any preliminary withdrawal of the rods.

6. Fill the annular space of the drive rods with water. This will minimize the amount of air introduced to the system.

7. Insert the telescoping suction pipe on the rotary transfer pump into a bung hole on the lid of the 55-gal drum and make sure that the pipe reaches the bottom of the drum. If possible, attach the suction pipe to the bung hole with the 2" bung adapter to ensure that the pump remains securely in place while pumping the Bio-Dechlor INOCULUM mixture from the drum to the pump hopper.

8. Attach the hose to the outlet of the rotary transfer pump making sure that the opposite end of the hose reaches the pump hopper. Open the opposite bung hole on the drum lid to prevent a vacuum then pump the desired amount of BDI PLUS solution into the hopper of the pump.

9. Connect the hose from the grout pump to the drive rod assembly.

10. Start pumping the BDI PLUS product solution.

11. The initial volume of BDI PLUS solution pumped should only be enough to displace the water within the drive rods. Once this is done the actual injection can start.

12. Begin withdrawing the drive rods, in accordance with the manufacturer's SOP, and start pumping the BDI PLUS solution simultaneously. The dosage should be 0.1 liter per vertical foot or 1 gallon per vertical foot if prepared using the BDI dilution chart. The withdrawal rate should be such that it allows the appropriate quantity of material to be injected into each vertical foot of aquifer being treated. The withdrawal rate should be slow to avoid creating a vacuum. This vacuum can potentially pull a small volume of material to the surface if the drive rods are withdrawn too quickly.

13. In less permeable soils such as clays and silts, there may be difficulty accepting the volume of estimated material. In this case Regenesis recommends using a "step-wise" application approach. For this approach we suggest withdrawing the drive rods in one-foot increments and then injecting the quantity of material required per vertical foot.

14. Look for any indications of aquifer refusal such as:

    - Excessive pump noise or application pressure spikes (e.g. squealing)
    - Surfacing of material through the injection point ("blow-by")

    If acceptance appears to be an issue it is critical that the aquifer is given enough time to equilibrate before breaking down the drive rods and/or removing the hose. The failure to do this can lead to excessive back flow of the BDI PLUS material on personnel, equipment, and the ground surface.

15. If BDI PLUS solution continues to "surface" after the drive rods have been completely removed from the borehole a plug may be necessary. Large diameter disposable tips or wood stakes have been used successfully for this purpose.

16. Drive rods should be disconnected after one rod (typically 4 feet in length) has been withdrawn. The drive rods should be placed in a bucket (or equivalent) after they have been disconnected.

17. Complete the installation of the BDI PLUS solution at the designated application rate across the entire targeted vertical interval.

18. After the injection is completed, an appropriate seal should be installed above the vertical interval where the BDI PLUS solution has been placed to prevent contaminant migration. Typically, bentonite powder or chips are used to create this seal. However, consultants should review local regulations before beginning field installation activities to confirm that this approach can be used.

19. Complete the borehole at the surface as appropriate using concrete or asphalt.

20. Repeat steps 7 through 19 until the entire application has been completed. If additional drums of de-oxygenated water are required, prepare as suggested in Step 1.

21. Prior to the installation of BDI PLUS, all surface and overhead impediments should be identified as well as the location(s) of any underground structure(s). Underground structures include but are not limited to: utility lines (gas, electrical, sewer, etc), drain piping, and landscape irrigation systems.

22. The planned injection locations should be adjusted in the field to account for impediments and obstacles.

23. The actual injection locations should be marked prior to the start of installation activities to facilitate the application process.

24. Using an appropriate pump to install the BDI PLUS product is very critical to the success of the application as well as the overall success of the project. Based on our experience in the field, Regenesis strongly recommends using a pump that has a pressure rating of at least 1,000 psi and a delivery rate of at least 3 gallons per minute.

    If the application involves both HRC and BDI PLUS, two separate pumps may be required to facilitate the process. The pump used to deliver HRC to the subsurface should be in accordance with the specifications outlined in the General Guidelines section of the HRC Installation Instructions.

Additional Information

The internal workings of the grout pump can be cleaned easily by recirculating a solution of hot water and a biodegradable cleaner (e.g. Simple Green) through the pump and delivery hose(s). If additional cleaning and decontamination is required it should be conducted in accordance with the manufacturer's SOP and local regulatory requirements.

Note: Regenesis assumes that all of the material (microorganisms) sent to a site for installation purposes will be used for that particular project and that no material (microorganisms) will be left over at the conclusion of the installation activities.

REGENESIS
Advanced Technologies for Groundwater Resources

1011 Calle Sombra
San Clemente, CA 92673
949-366-8000

REGENESIS

Advanced Technologies for Groundwater Resources

Material Safety Data Sheet (MSDS)

Bio-Dechlor INOCULUM PLUS (BDI PLUS™)

SECTION 1 - MATERIAL IDENTIFICATION AND INFORMATION

Material Name: DHC microbial consortium (SDC-9) MSDS #: ENV 1033

Date Prepared: 1/05/2006 CAS #: N/A (Not Applicable)

Prepared By: Simon Vainberg Formula #: N/A

Material Description: Non-hazardous, naturally occurring non-altered anaerobic microbes and enzymes in a water-based medium.

SECTION 2 - INGREDIENTS

Components	%	OSHA PEL	ACGIH TLV	OTHER LIMITS
Non-Hazardous Ingredients	100	N/A	N/A	N/A

SECTION 3 - PHYSICAL/CHEMICAL CHARACTERISTICS

Boiling Point: 100°C (water)

Specific Gravity (H_2O = 1): 0.9 - 1.1

Vapor Pressure @ 25°C: 24 mm Hg (water)

Melting Point: 0°C (water)

Vapor Density: N/A

Evaporation Rate (H_2O = 1): 0.9 - 1.1

Solubility in Water: Soluble

Water Reactive: No

pH: 6.0 - 8.0

Appearance and Odor: Murky, yellow to grey water. Musty odor.

SECTION 4 - FIRE AND EXPLOSION HAZARD DATA

Flash Point: N/A

Flammable Limits: N/A

Extinguishing Media: Foam, carbon dioxide, water

Special Fire Fighting Procedures: None

Unusual Fire and Explosion Hazards: None

SECTION 5 - REACTIVITY DATA

Stability: Stable

Conditions to Avoid: None

Incompatibility (Materials to Avoid): Water-reactive materials

Hazardous Decomposition Byproducts: None

SECTION 6 - HEALTH HAZARD DATA

HEALTH EFFECTS

The effects of exposure to this material have not been determined. Safe handling of this material on a long-term basis will avoid any possible effect from repetitive acute exposures. Below are possible health effects based on information from similar materials. Individuals hyper allergic to enzymes or other related proteins should not handle.

Ingestion: Ingestion of large quantities may result in abdominal discomfort including nausea, vomiting, cramps, diarrhea, and fever.

Inhalation: Hypersensitive individuals may experience breathing difficulties after inhalation of aerosols.

Skin Absorption: N/A

Skin Contact: May cause skin irritation. Hypersensitive individuals may experience allergic reactions to enzymes.

Eye Contact: May cause eye irritation.

FIRST AID

Ingestion: Get medical attention if allergic symptoms develop (observe for 48 hours). Never give anything by mouth to an unconscious or convulsing person.

Inhalation: Get medical attention if allergic symptoms develop.

Skin Absorption: N/A

Skin Contact: Wash affected area with soap and water. Get medical attention if allergic symptoms develop.

Eye Contact: Flush eyes with plenty of water for at least 15 minutes using an eyewash fountain, if available. Get medical attention if irritation occurs.

NOTE TO PHYSICIANS: All treatments should be based on observed signs and symptoms of distress in the patient. Consideration should be given to the possibility that overexposure to materials other than this material may have occurred.

SECTION 7 - SPILL AND LEAK PROCEDURES

Reportable quantities (in lbs of EPA Hazardous Substances): N/A

Steps to be taken in case of spill or release: No emergency results from spillage. However, spills should be cleaned up promptly. All personnel involved in the cleanup must wear protective clothing and avoid skin contact. Absorb spilled material or vacuum into a container. After clean-up, disinfect all cleaning materials and storage containers that come in contact with the spilled liquid.

Waste Disposal Method: No special disposal methods are required. The material may be sewered, and is compatible with all known biological treatment methods. To reduce odors and permanently inactivate microorganisms, mix 100 parts (by volume) of SDC-9 consortium with 1 part (by volume) of bleach. Dispose of in accordance with local, state and federal regulations.

SECTION 8 - HANDLING AND STORAGE

Hand Protection: Rubber gloves.

Eye Protection: Safety goggles with side splash shields.

Protective Clothing: Use adequate clothing to prevent skin contact.

Respiratory Protection: Surgical mask.

Ventilation: Provide adequate ventilation to remove odors.

Storage & Handling:
Material may be stored for up to 3 weeks at 2-4°C without aeration.

Other Precautions: An eyewash station in the work area is recommended.

Appendix B-3

HRC Primer MSDS

Hydrogen Release Compound Primer (HRC Primer™)
MATERIAL SAFETY DATA SHEET (MSDS)

Last Revised: **August 17, 2005**

Section 1 - Material Identification

Supplier:

REGENESIS
1011 Calle Sombra
San Clemente, CA 92673
Phone: 949.366.8000
Fax: 949.366.8090
E-mail: info@regenesis.com

Chemical Name:	**Propanoic acid, 2-[2-[2-(2-hydroxy-1-oxopropoxy)-1-oxopropoxy]-1-oxopropoxy]-1,2,3-propanetriyl ester**
Chemical Family:	**Organic Chemical**
Trade Name:	**HRC, Glycerol Polylactate Primer**

Section 2 – Chemical Identification

CAS#	Chemical
201167-72-8	Glycerol Polylactate
50-21-5	Lactic Acid

Section 3 - Physical Data

Melting Point:	**NA**
Boiling Point:	**ND**
Flash Point:	**ND**
Density:	**1.10 g/cc**
Solubility:	**Water, Acetone and DMSO**
Appearance:	**Yellow Liquid**
Odor:	**Not detectable**

Section 4 - Fire and Explosion Hazard Data

Extinguishing Media: **Carbon Dioxide, Dry Chemical Powder or Appropriate Foam.**

Water may be used to keep exposed containers cool.

For large quantities involved in a fire, one should wear full protective clothing and a NIOSH approved self contained breathing apparatus with full face piece operated in the pressure demand or positive pressure mode as for a situation where lack of oxygen and excess heat are present.

Section 5 - Toxicological Information

Acute Effects:	**May be harmful by inhalation, ingestion, or skin absorption. May cause irritation. To the best of our knowledge, the chemical, physical, and toxicological properties of the glycerol tripolylactate have not been investigated. Listed below are the toxicological information for glycerol and lactic acid.**	
RTECS#:	**MA8050000 Glycerol**	
Irritation data:	**SKN-RBT 500 MG/24H MLD 85JCAE-,207,1986 EYE-RBT 126 MG MLD EYE-RBT 500 MG/24H MLD**	**BIOFX* 9-4/1970 85JCAE-,207,1986**
Toxicity data:	**ORL-MUS LD50:4090 MG/KG FRZKAP (6),56,1977 SCU-RBT LD50:100 MG/KG ORL-RAT LD50:12600 MG/KG IHL- RATLC50:>570MG/M3/1HBIOFX*9- 4/1970 IPR-RAT LD50: 4420 MG/KG IVN-RAT LD50:5566 MG/KG IPR-MUS LD50: 8700 MG/KG SCU-MUS LD50: 91 MG/KG IVN-MUS LD50: 4250 MG/KG ORL-RBT LD50: 27 GM/KG SKN-RBT LD50:>10GM/KG IVN-RBT LD50: 53 GM/KG ORL-GPG LD50: 7750 MG/KG**	** NIIRDN 6,215,1982 FEPRA7 4,142,1945 RCOCB8 56,125,1987 ARZNAD 26,1581,1976 ARZNAD 26,1579,1978 NIIRDN 6,215,1982 JAPMA8 39,583,1950 DMDJAP 31,276,1959 BIOFX* 9-4/1970 NIIRDN 6,215,1982 JIHTAB 23,259,1941**

Section 5 - Toxicological Information (cont)

Target Organ data:	**Behavioral (headache), gastrointestinal (nausea or vomiting), Paternal effects (spermatogenesis, testes, epididymis, sperm duct), effects of fertility (male fertility index, post-implantation mortality).**
Acute Effects:	**May be harmful by inhalation, ingestion, or skin absorption. May cause irritation. To the best of our knowledge, the chemical, physical, and toxicological properties of the glycerol tripolylactate have not been investigated. Listed below are the toxicological information for glycerol and lactic acid.**
RTECS#:	**OD2800000** **Lactic acid**

Irritation data:	**SKN-RBT 5MG/24H SEV**	**85JCAE -,656,86**
	EYE-RBT 750 UG SEV	**AJOPAA 29,1363,46**
Toxicity data:	**ORL-RAT LD50:3543 MG/KG**	**FMCHA2-,C252,91**
	SKN-RBT LD50:>2 GM/KG	**FMCHA2-,C252,91**
	ORL-MUS LD50: 4875 MG/KG	**FAONAU 40,144,67**
		JIHTAB 23,259,41
	ORL-GPG LD50: 1810 MG/KG	**FMCHA2-,C252,91**
	ORL-QAL LD50: >2250 MG/KG	

Only selected registry of toxic effects of chemical substances (RTECS) data is presented here. See actual entry in RTECS for complete information on lactic acid and glycerol.

Section 6 - Health Hazard Data

Handling: **Avoid continued contact with skin. Avoid contact with eyes.**

In any case of any exposure which elicits a response, a physician should be consulted immediately.

First Aid Procedures

Inhalation: **Remove to fresh air. If not breathing give artificial respiration. In case of labored breathing give oxygen. Call a physician.**

Ingestion: **No effects expected. Do not give anything to an unconscious person. Call a physician immediately.**

Section 6 - Health Hazard Data (cont)

Skin Contact:	**Flush with plenty of water. Contaminated clothing may be washed or dry cleaned normally.**
Eye contact:	**Wash eyes with plenty of water for at least 15 minutes lifting both upper and lower lids. Call a physician.**

Section 7 - Reactivity Data

Conditions to Avoid:	**Strong oxidizing agents, bases and acids**
Hazardous Polymerization:	**None known**
Further Information:	**Hydrolyses in water to form Lactic Acid and Glycerol.**

Section 8 - Spill, Leak or Accident Procedures

After Spillage or Leakage:	**Neutralization is not required. This combustible material may be burned in a chemical incinerator equipped with an afterburner and scrubber.**
Disposal:	**Laws and regulations for disposal vary widely by locality. Observe all applicable regulations and laws. This material, may be disposed of in solid waste. Material is readily degradable and hydrolyses in several hours.**

No requirement for a reportable quantity (CERCLA) of a spill is known.

Section 9 - Special Protection or Handling

Should be stored in plastic lined steel, plastic, glass, aluminum, stainless steel, or reinforced fiberglass containers.

Protective Gloves:	**Vinyl or Rubber**
Eyes:	**Splash Goggles or Full Face Shield** **Area should have approved means of washing eyes.**
Ventilation:	**General exhaust.**
Storage:	**Store in cool, dry, ventilated area. Protect from imcompatible materials.**

Section 10 - Other Information

This material will degrade in the environment by hydrolysis to lactic acid and glycerol. Materials containing reactive chemicals should be used only by personnel with appropriate chemical training.

The information contained in this document is the best available to the supplier as of the time of writing. Some possible hazards have been determined by analogy to similar classes of material. No separate tests have been performed on the toxicity of this material. The items in this document are subject to change and clarification as more information becomes available.

Appendix B-4

PlumeStop Product Brochure

PlumeStop Spec Sheet

PlumeStop™
COLLOIDAL BIOMATRIX

A scanning electron micrograph picture of the actual PlumeStop material.

PlumeStop liquid-based remediation substrate

PlumeStop provides remediation professionals with these additional benefits:

- Eliminates problematic back-diffusing contaminants and associated rebound
- Distributes widely into contaminated zones under low injection pressures (a clear advantage over hard to distribute, powdered activated carbon products)
- Effectively treats a range of petroleum and chlorinated hydrocarbons
- Packaged in liquid form for clean and simple subsurface injection

PlumeStop™ is an innovative, in situ remediation substrate which quickly and effectively treats contaminated groundwater. It does this through the use of highly dispersible, fast-acting, sorption-based technology which captures and concentrates dissolved-phase contaminants within its structure. Once contaminants are sorbed, biodegradation processes proceed at an accelerated rate.

PlumeStop is an environmentally friendly, patent-pending product based on the use of unique, biologically enriching polymers to suspend a colloidal-scale solid sorbent material. This highly dispersible sorbent pulls contaminants directly from groundwater and stimulates their biodegradation in situ.

Once in place PlumeStop is expected to last for decades with minimal impact on aquifer oxidation-reduction potential or geochemistry.

PlumeStop® Liquid Activated Carbon™ Technical Description

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

Distribution of PlumeStop in water

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

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

Chemical Composition

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

Properties

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

Storage and Handling Guidelines

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

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

PLUME STOP
Liquid Activated Carbon

PlumeStop® Liquid Activated Carbon™ Technical Description

Applications

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

Health and Safety

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

REGENESIS

www.regenesis.com
1011 Calle Sombra, San Clemente CA 92673
949.366.8000

Appendix B-5

Site Information Provided to Regenesis

Grid Injections

	Zone 1	Zone 2A	Zone 2B	Zone 3A	Zone 3B
Injection Area					
# injections	44	26	13	60	33
Spacing	15 ft x 10 ft	15 ft x 10 ft	15 ft x 10 ft	15 ft x 10 ft	15 ft x 10 ft
Saturated thickness	20 ft	20 ft	20 ft	20 ft	20 ft
Aquifer					
Hydraulic k	11 ft/day	11 ft/day	11 ft/day	11 ft/day	11 ft/day
Hydraulic grad.	0.004	0.004	0.004	0.004	0.004
Volitile Organics, unfiltered groundwater					
PCE	**980.00 ug/L**	**15.00 ug/L**	**383.00 ug/L**	**1500.00 ug/L**	**220.00 ug/L**
TCE	**360.00 ug/L**	**1.50 ug/L**	**70.20 ug/L**	**5.20 ug/L**	**4.4 ug/L J**
cis-DCE	**880.00 ug/L**	**1300.00 ug/L**	**1040.00 ug/L**	.48 ug/L U	0.48 ug/L U
VC	**2.40 ug/L**	**380.00 ug/L**	<16.1 ug/L	5.00 ug/L U	0.50 ug/L U
Chloroform	0.33 ug/L U	0.33 ug/L U	0.33 ug/L U	0.33 ug/L U	0.33 ug/L U
1,1,1-TCE	0.50 ug/L U	0.50 ug/L U	0.50 ug/L U	0.50 ug/L U	0.50 ug/L U
1,1-DCA	0.25 ug/L U	0.25 ug/L U	0.25 ug/L U	0.25 ug/L U	0.25 ug/L U
1,1-DCE	**2.2 ug/L J**	**3.2 ug/L J**	0.39 ug/L U	0.39 ug/L U	0.39 ug/L U
Anions, unfiltered groundwater					
Sulfate	45.00 mg/L	56.00 mg/L	52.00 mg/L	26.00 mg/L	46.00 mg/L
Nitrate	1.03 mg/L	0.14 mg/L	0.12 mg/L	0.91 mg/L	2.96 mg/L
Parameters					
Oxygen	0.12 mg/L	0.12 mg/L	0.16 mg/L	4.00 mg/L	3.32 mg/L
ORP	-50.00 mV	-10.00 mV	0.00 mV	25.00 mV	25.00 mV

J = estimated value
U = not detected (method detection limit shown)

Permiable Reactive Barriers (3DMe and PlumeStop)

	Zone 1	Zone 2	Zone 3	Zone 4
Injection Area				
# injections	105	79	63	25
Spacing	See sheet "PlumeStop Spacing"			
Surface Area	9792 ft	7344 ft	5875 ft	2448 ft
Length	480 ft	360 ft	288 ft	120 ft
Width	20.4 ft			
Saturated thickness	20 ft	20 ft	20 ft	20 ft
Aquifer				
Hydraulic k	11 ft/day	11 ft/day	11 ft/day	11 ft/day
Hydraulic grad.	0.004	0.004	0.004	0.004
Volitile Organics, unfiltered groundwater				
PCE	**3.7 ug/L J**	**6.20 mg/L**	**1.1 ug/L J**	**56.00 ug/L**
TCE	0.81 ug/L J	0.36 ug/L U	0.36 ug/L U	**2.4 ug/L J**
cis-DCE	0.48 ug/L U	0.48 ug/L U	**20.00 ug/L**	**2.8 ug/L J**
VC	0.50 ug/L U	0.50 ug/L U	0.50 ug/L U	0.50 ug/L U
Chloroform	0.33 ug/L U	0.33 ug/L U	0.33 ug/L U	0.33 ug/L U
1,1,1-TCE	0.50 ug/L U	0.50 ug/L U	0.50 ug/L U	0.50 ug/L U
1,1-DCA	0.25 ug/L U	0.25 ug/L U	0.25 ug/L U	0.25 ug/L U
1,1-DCE	0.39 ug/L U	0.39 ug/L U	0.39 ug/L U	0.39 ug/L U
Volitile Organics, potential VOC concentration into barrier zone				
PCE	260.00 ug/L	260.00 ug/L	150.00 ug/L	1500.00 ug/L
TCE	23.00 ug/L	23.00 ug/L	41.00 ug/L	5.20 ug/L
cis-DCE	980.00 ug/L	980.00 ug/L	650.00 ug/L	0.48 ug/L U
VC	190.00 ug/L	190.00 ug/L	130.00 ug/L	0.50 ug/L U
Anions, unfiltered groundwater				
Sulfate	45.00 mg/L	45.00 mg/L	45.00 mg/L	45.00 mg/L
Nitrate	1.03 mg/L	1.03 mg/L	1.03 mg/L	1.03 mg/L
Parameters				
Oxygen	0.14 mg/L	0.35 mg/L	0.19 mg/L	0.47 mg/L
ORP	-75.00 mV	-25.00 mV	-25.00 mV	110.00 mV

J = estimated value

U = not detected (method detection limit shown)

Appendix B-6

Supporting Cost Information Provided by Regenesis

REGENESIS

Project Info

Mr. C - Barrier Areas
East Aurora, NY
Dissloved phase

Prepared For:
Ecology and Environement

Target Treatment Zone (TTZ) Info	Unit	Value
Treatment Area	ft^2	18,720
Top Treat Depth	ft	12.0
Bot Treat Depth	ft	32.0
Vertical Treatment Interval	ft	20.0
Treatment Zone Volume	ft^3	374,400
Treatment Zone Volume	cy	13,867
Soil Type	---	sand
Porosity	cm^3/cm^3	0.33
Effective Porosity	cm^3/cm^3	0.20
Treatment Zone Pore Volume	gals	924,233
Treatment Zone Effective Pore Volume	gals	560,141
Fraction Organic Carbon (foc)	g/g	0.002
Soil Density	g/cm^3	1.7
Soil Density	lb/ft^3	108
Soil Weight	lbs	4.0E+07
Hydraulic Conductivity	ft/day	11.0
Hydraulic Conductivity	cm/sec	3.88E-03
Hydraulic Gradient	ft/ft	0.004
GW Velocity	ft/day	0.01
GW Velocity	ft/yr	2

Sources of Hydrogen Demand	Unit	Value
Dissolved Phase Contaminant Mass	lbs	27
Sorbed Phase Contaminant Mass	lbs	57
Competing Electron Acceptor Mass	lbs	694
Total Mass Contributing to H_2 Demand	**lbs**	**779**

Stoichiometric Demand	Unit	Value
Stoichiometric H_2 Demand	lbs	49
Stoichiometric HRC Demand	**lbs**	**2,196**
Engineering/Safety Factor	--	**9**

Application Dosing	Unit	Value
Plume Stop to be Applied	**lbs**	**96,400**
HRC to be Applied	lbs	14,976

PlumeStop® Application Design Summary

Dissolved phase

Application Method	Direct Push
Spacing Within Rows (ft)	10
Spacing Between Rows (ft)	10
Application Points	**187**
Areal Extent (square ft)	18,720
Top Application Depth (ft bgs)	12
Bottom Application Depth (ft bgs)	32
PlumeStop to be Applied (lbs)	**96,400**
PlumeStop per point (lbs)	516
PlumeStop per point (gals)	62
Mixing Water (gal)	**120,514**
Mixing Water (per pt)	644
Total Application Volume (gals)	**132,066**
Injection Volume per Point (gals)	706
Anaerobic Bioremediation - HRC	
HRC Application Points	94
HRC to be Applied (lbs)	14,976
HRC per point (lbs)	159
Total Application Volume (gals)	1380
Injection Volume per Point (gals)	14.7

Field App Instructions

Technical Notes/Discussion

Prepared By: *Corinne Ketcham - East Region Technical manager*
Date: *8/27/2015*

Assumptions/Qualifications

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

REGENESIS

Project Information

Mr. C - Grid Injection Areas
East Aurora, NY
Dissolved phase

Prepared For:

Ecology and Environement

Target Treatment Zone (TTZ) Info	Unit	Value
Treatment Area	ft^2	34,271
Top Treat Depth	ft	12.0
Bot Treat Depth	ft	32.0
Vertical Treatment Interval	ft	20.0
Treatment Zone Volume	ft^3	685,425
Treatment Zone Volume	cy	25,386
Soil Type	---	sand
Porosity	cm^3/cm^3	0.33
Effective Porosity	cm^3/cm^3	0.20
Treatment Zone Pore Volume	gals	1,692,021
Treatment Zone Effective Pore Volume	gals	1,025,467
Fraction Organic Carbon (foc)	g/g	0.002
Soil Density	g/cm^3	1.7
Soil Density	lb/ft^3	108
Soil Weight	lbs	7.4E+07
Hydraulic Conductivity	ft/day	25.0
Hydraulic Conductivity	cm/sec	8.82E-03
Hydraulic Gradient	ft/ft	0.004
GW Velocity	ft/day	11.00
GW Velocity	ft/yr	4,018
Sources of 3-D Microemulsion Demand	**Unit**	**Value**
Dissolved Phase Mass	lbs	50
Sorbed Phase Contaminant Mass	lbs	79
Competing Electron Acceptor Mass	lbs	1,271
Stoichiometric 3DME Demand	**lbs**	**1,430**
TTZ Groundwater Mass Flux	L/day	230,499
CVOC Mass Flux through TTZ	lb/yr	657
CEA Mass Flux through TTZ	lb/yr	16,707
Total Mass Flux through TTZ	lb/yr	17,365
Total Mass Flux 3DME Demand	**lbs**	**53,274**
Application Dosing		
3-D Microemulsion to be Applied	**lbs**	**49,200**

3-D Microemulsion®, BDI® Plus, CRS® Application Design Summary

Dissolved phase		Field App. Instructions
Application Method	**Direct Push**	
Spacing Within Rows (ft)	13	
Spacing Between Rows (ft)	15	
Application Points	**176**	
Areal Extent (square ft)	34,271	
Top Application Depth (ft bgs)	12	**Field Mixing Ratios**
Bottom Application Depth (ft bgs)	32	3DME Concentrate per Pt (lbs)
3DME to be Applied (lbs)	**49,200**	280
3DME to be Applied (gals)	5,896	Mix Water per Pt (gals)
3DME Mix %	10%	301
Volume Water (gals)	**53,062**	3DME Mix Volume per Pt (gals)
3DME Mix Volume (gals)	58,957	335
Total Application Volume (gals)	**58,957**	Volume per pt (gals)
Estimated Radius of Injection (ft)	3.8	335
		Volume per vertical ft (gals)
		17

Technical Notes/Discussion

Prepared By: *Corinne Ketcham - East Region Technical manager*
Date: *8/27/2015*

Assumptions/Qualifications

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

Purchasing Information

Mr. C - Grid Injection Areas	--	Dissloved phase
3-D Microemulsion Required	**lbs**	**49,200**
3-D Microemulsion Cost*	$	$145,140
Total Product Cost	**$**	**$145,140**
Estimated Tax and Freight %	%	15%
Estimated Tax and Freight Cost	$	$21,771
Estimated Total Product Cost	**$**	**$166,911**
Estimated RRS Application Cost	**$**	**$112,700**
Total Estimated Project Cost	**$**	**$279,611**
Estimated RRS Days to Apply	**---**	**20**

***Note that the combined tax and freight costs are preliminary estimates only. Please contact your local sales manager or Customer Service at 949-366-8000 to obtain a shipping quote. You will be asked to provide a ship-to address and estimated time of delivery.**

Currently Available Packaging Options

3DME Package Type**	# of packages	lbs required
400 lb poly drums	123	49,200
2,000 lb reinforced plastic totes	25	50,000

****Available Package Types are subject to change.**

REGENESIS

Purchasing Information		
Mr. C - Barrier Areas	--	Dissloved phase
PlumeStop Required	**lbs**	**96,400**
HRC Required	**lbs**	**14,976**
PlumeStop Cost	$	$216,900
HRC Cost	$	$104,083
BDI Cost	$	$0
Estimated Tax and Freight %	%	18%
Estimated Tax and Freight Cost	$	$57,777
Estimated Total Product Cost	**$**	**$378,760**
Estimated RRS Application Cost	**$**	**$160,800**
Total Estimated Project Cost	**$**	**$539,560**
Estimated RRS Days to Apply	**---**	**28**

***Note that the combined tax and freight costs are preliminary estimates only. Please contact your local sales manager or Customer Service at 949-366-8000 to obtain a shipping quote. You will be asked to provide a ship-to address and estimated time of delivery.**

Currently Available Packaging Options		
PlumeStopPackage Type**	**# of packages**	**lbs required**
2,000 lb reinforced plastic totes	49	98,000
400-lb poly drums	241	96,400
HRC Package Type**	**# of packages**	**lbs required**
30 lb HDPE pails	500	15,000

****Available Package Types are subject to change.**

C Cost Estimates

C-1 Summary of Total Present Values of Alternatives at the Mr. C's Dry Cleaner Site
C-2 Cost Estimate for Alternative 1: Pump & Treat for Source and Migration Control
C-3 Cost Estimate for Alternative 2a Pump & Treat Source Control, 3DMe PRB for Migration Control
C-4 Cost Estimate for Alternative 2b Pump & Treat Source Control, PlumeStop PRB for Migration Control
C-5 Cost Estimate for Alternative 4a Bioremediation Source Control with 3DMe PRB for Migration Control
C-6 Cost Estimate for Alternative 4b Bioremediation Source Control with PlumeStop PRB for Migration Control

Table C-1 Summary of Total Present Values of Alternatives at the Mr. C's Dry Cleaner Site

Description	Alternative 1 Pump and Treat	Alternative 2a Pump and Treat with PRB	Alternative 2b Pump and Treat with PRB and PlumeStop	Alternative 4a Source Bioremediation with PRB	Alternative 4b Source Bioremediation with PRB and PlumeStop
Capital Cost	$118,000	$296,000	$804,000	$1,795,000	$2,304,000
Annual Costs [1]	$3,019,000	$3,019,000	$3,019,000	$561,000	$561,000
Periodic Costs [2]	$244,000	$244,000	$244,000	$244,000	$244,000
2015 Total Present Value of Alternative[3]	**$3,381,000**	**$3,559,000**	**$4,067,000**	**$2,600,000**	**$3,109,000**

Notes:

1 - Annual costs include unility and treatment sytem OM&M for the pump and treat system, where applicable, and OM&M on the monitoring well network and periodic review reporting for all alternatives.

2 - Periodic costs include 3-year recurring costs for long-term groundwater monitoring for all alternatives and a 5-year costs for replacing SSDS fans

3 - The Total Present value of Alternative represents the estimated present value of the capital costs and annual and periodic costs throughout the timeframe estimated to reach site RAOs, which are the NYSDEC Class GA groundwater standards.

Table C-2: Cost Estimate for Alternative 1: Pump & Treat for Source and Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
Capital Costs					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	$2,278.70	$2,279
Subtotal					$2,279
Decommission Old Pumps					
Pump removal - labor		Each	7	$263.00	$1,841
Subtotal					$1,841
System Upgrades					
Replace Air Stripper Body	Assume 10-year lifespan, based on experience; Assume body will be replaced with similar model to fit with existing 4-inch process piping and meet original specified height of 7'6" max above finished floor to discharge flange.	Each	3	$20,800.00	$62,400
Pump removal - labor		Each	7	$263.00	$1,841
Pumps - material	Up to 10 gpm capacity	Each	7	$299.99	$2,100
Pump installation - labor		Each	7	$263.00	$1,841
Subtotal					$68,182
Soil vapor intrusion investigations and SSDS Installation					
Soil vapor intrusion investigation	Assume twice as many properties are investigated as SSDSs are installed.	Ea	4	$2,000.00	$8,000
New SSDS Installation - Residential	Assume 8% increase from current installations (2). Installation in the future.	Ea	1	$4,000.00	$4,000
New SSDS Installation - Commercial	Assume 8% increase from current installations (12). Installation in the future.	Ea	1	$6,000.00	$6,000
Subtotal					$18,000
				Capital Cost Subtotal:	$90,302
	Adjusted Capital Cost Subtotal for Buffalo,New York Location Factor (1.029):				$92,920
	10% Legal, administrative, engineering fees, construction management:				$9,292
				15% Contingencies:	$15,332
				Total Capital Cost:	**$118,000**
Annual Costs					
Gas		Month	12	$76.57	$919
Telephone		Month	12	$37.15	$446
Electric		Month	12	$1,241.80	$14,902
OM&M	OM&M for treatment system, pumping system, and monitoring well network.	Year	1	$90,850.00	$90,850
Analytical Services	Includes monthly sampling for VOCs, EPA 8260B, pH, 150.1, Hardness,130.2 and a contingency for four additional samples per year in the event of non-compliance with the SPDES equivalency permit.	Year	1	$2,592.00	$2,592
Replacement Equipment	May include the replacement of pumps, blowers, motors, etc. and sequestering agent	Year	1	$16,000.00	$16,000
SSDS annual inspection and reporting	Assume 1 hour per system	EA	16	$315.00	$5,040
Periodic Review Reporting	performed annually	Year	1	$13,800.00	$13,800
Subtotal					$144,548
				Annual Cost Subtotal:	$144,548
	Adjusted Capital Cost Subtotal for Buffalo, New York Location Factor (1.029):				$148,740
		10% Legal, administrative, engineering fees:			$14,874
				15% Contingencies:	$32,723
				Annual Cost Total:	**$196,337**
		30-Year Present Value of Annual Costs:			**$3,019,000**
3-Year Costs					
Long-term groundwater monitoring - labor	2-people at 8 hr/day; total of 26 monitoring wells and 8 pumping wells; assume 8 wells/day	Hour	80	$130.00	$10,400
Long-term groundwater monitoring - reporting		Hour	80	$130.00	$10,400
Long-term groundwater monitoring - analytical		Year	1	$7,260.90	$7,261
Subtotal					$28,061
				3-Year Cost Subtotal:	$28,061
	Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):				$28,875
		10% Legal, administrative, engineering fees:			$2,887
				15% Contingencies:	$4,764
				3-Year Total:	**$36,526**
		30-Year Present Value of 3-Year Costs:			**$207,000**

Table C-2: Cost Estimate for Alternative 1: Pump & Treat for Source and Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
5-Year Costs					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	$500.00	$8,000
Subtotal					$8,000
				5-Year Cost Subtotal:	$8,000
				Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):	$8,232
				10% Legal, administrative, engineering fees:	$823
				15% Contingencies:	$1,358
				5-Year Total:	**$10,413**
				30-Year Present Value of 5-Year Costs:	**$37,000**
				2015 Total Present Value Cost:	**$3,381,000**

Assumptions:

1. Present value cost based on annual and periodic costs over: 30 years
2. Present value of costs assumes 5% annual interest rate.
3. Unit costs listed were obtained from 2015 RS Means Cost Data, site-specific historical cost from the 2015 Periodic Review Report and 2015 Bioremediation Pilot Study, and engineering judgement.
4. Assumes larger pumps will fit in existing pumping well casings.
5. Treatment system OM&M Includes labor for maintenance and cleaning of air stripper, patching holes, rebalancing blowers, and labor for collection of monthly compliance samples from the treatment system influent and effluent. Pumping system OM&M includes pumping well maintenance and piezometer water level recordings. Monitoring well OM&M includes replacing missing or stripped bolts, replacing existing of installing new asphalt/ concrete pads, replacing existing well covers, installing new watertight well cap, and removing or replacing portions of cracked casings.

Key:
EPA = Environmental Protection Agency
gpm = gallons per minute
LS = lump sum
OM&M = operations, maintenance, and monitoring
SPDES = state pollutant discharge elimination system
VOC = volatile organic carbon

Table C-3: Cost Estimate for Alternative 2a Pump & Treat Source Control, 3DMe PRB for Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
Capital Costs					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	$6,584.71	$6,585
Subtotal					$6,585
Site Preparation					
Decontamination Pad & Containment	Construction (and removal) of decon pad (including labor and materials)	LS	1	$500.00	$500
Temporary fence	Chain link industrial, 6' H, 6 gauge wire with 3 strands barb wire, to surround staging area (material, labor, equipment)	LF	200	$25.87	$5,174
Subtotal					$5,674
System Upgrades					
Replace Air Stripper Body	Assume 10-year lifespan, based on experience; Assume body will be replaced with similar model to fit with existing 4-inch process piping and meet original specified height of 7'6" max above finished floor to discharge flange.	Each	3	$20,800.00	$62,400
Pump removal - labor		Each	7	$263.00	$1,841
Pumps - material	Up to 10 gpm capacity	Each	7	$299.99	$2,100
Pump installation - labor		Each	7	$263.00	$1,841
Subtotal					$68,182
Downgradient Permiable Reactive Barriers					
Mobilization/Demobilization	Includes Mobilization/demobilization, permits (describe), utility clearance, and work plan and HASP preparation and submittal	LS	1	$5,000.00	$5,000
Geoprobe injections - Enhancement	Cost per direct push injection including all equipment, crew, pumping and mixing of site-ground water with injection products, and direct-push support activities.	Each	96	$380.00	$36,480
Regenesis 3-D Microemulsion (3DMe) Factory Emulsified	materials only	lbs	26,875	$2.95	$79,281
Subtotal					$120,761
Site Restoration					
Surveying Crew	2-person crew and equipment, 8hr/day	Day	2	$805.00	$1,610
Restoration seeding	hydroseeding w/ seed, mulch and fertilizer (material, labor, equipment)	M.S.F.	4	$1.96	$8
Asphalt driveway repair	cold-mix asphalt	S.Y.	356	$17.16	$6,109
Subtotal					$7,727
Soil vapor intrusion investigations and SSDS Installation					
Soil vapor intrusion investigation	Assume twice as many properties are investigated as SSDSs are installed.	Ea	4	$2,000.00	$8,000
New SSDS Installation - Residential	Assume 8% increase from current installations (2). Installation in the future.	Ea	1	$4,000.00	$4,000
New SSDS Installation - Commercial	Assume 8% increase from current installations (12). Installation in the future.	Ea	1	$6,000.00	$6,000
Subtotal					$18,000
				Capital Cost Subtotal:	$226,929
	Adjusted Capital Cost Subtotal for Buffalo,New York Location Factor (1.029):				$233,510
	10% Legal, administrative, engineering fees, construction management:				$23,351
				15% Contingencies:	$38,529
				Total Capital Cost:	**$296,000**

Table C-3: Cost Estimate for Alternative 2a Pump & Treat Source Control, 3DMe PRB for Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
Annual Costs					
Gas		Month	12	$76.57	$919
Telephone		Month	12	$37.15	$446
Electric		Month	12	$1,241.80	$14,902
OM&M	OM&M for treatment system, pumping system, and monitoring well network.	Year	1	$90,850.00	$90,850
Analytical Services	Includes monthly sampling for VOCs, EPA 8260B, pH, 150.1, Hardness,130.2 and a contingency for four additional samples per year in the event of non-compliance with the SPDES equivalency permit.	Year	1	$2,592.00	$2,592
Replacement Equipment	May include the replacement of pumps, blowers, motors, etc. and sequestering agent	Year	1	$16,000.00	$16,000
SSDS annual inspection and reporting	Assume 1 hour per fan	EA	16	$315.00	$5,040
Periodic Review Reporting	performed annually	Year	1	$13,800.00	$13,800
Subtotal					$144,548
				Annual Cost Subtotal:	$144,548
	Adjusted Capital Cost Subtotal for Buffalo, New York Location Factor (1.029):				$148,740
	10% Legal, administrative, engineering fees:				$14,874
				15% Contingencies:	$32,723
				Annual Cost Total:	**$196,337**
		30-Year Present Value of Annual Costs:			**$3,019,000**
3-Year Costs					
Long-term groundwater monitoring - labor	2-people at 8 hr/day; total of 26 monitoring wells and 8 pumping wells; assume 8 wells/day	Hour	80	$130.00	$10,400
Long-term groundwater monitoring - reporting		Hour	80	$130.00	$10,400
Long-term groundwater monitoring - analytical		Year	1	$7,260.90	$7,261
Subtotal					$28,061
				3-Year Cost Subtotal:	$28,061
	Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):				$28,875
	10% Legal, administrative, engineering fees:				$2,887
				15% Contingencies:	$4,764
				3-Year Total:	**$36,526**
		30-Year Present Value of 3-Year Costs:			**$207,000**
5-Year Costs					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	$500.00	$8,000
Subtotal					$8,000
				5-Year Cost Subtotal:	$8,000
	Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):				$8,232
	10% Legal, administrative, engineering fees:				$823
				15% Contingencies:	$1,358
				5-Year Total:	**$10,413**
		30-Year Present Value of 5-Year Costs:			**$37,000**
		2015 Total Present Value Cost:			**$3,559,000**

Assumptions:

1. Present value cost based on annual and periodic costs over: 30 years
2. Present value of costs assumes 5% annual interest rate.
3. Unit costs listed were obtained from 2015 RS Means Cost Data, site-specific historical cost from the 2015 Periodic Review Report and 2015 Bioremediation Pilot Study, and engineering judgement.

4. Assumes larger pumps will fit in existing pumping well casings.
5. Treatment system OM&M Includes labor for maintenance and cleaning of air stripper, patching holes, rebalancing blowers, and labor for collection of monthly compliance samples from the treatment system influent and effluent. Pumping system OM&M includes pumping well maintenance and piezometer water level recordings. Monitoring well OM&M includes replacing missing or stripped bolts, replacing existing of installing new asphalt/ concrete pads, replacing existing well covers, installing new watertight well cap, and removing or replacing portions of cracked casings.

6. Length of fencing assumed a 50' x 50' staging area.

Key:
EPA = Environmental Protection Agency
gpm = gallons per minute
LS = lump sum
OM&M = operations, maintenance, and monitoring
SPDES = state pollutant discharge elimination system
VOC = volatile organic carbon

Table C-4: Cost Estimate for Alternative 2b Pump & Treat Source Control, PlumeStop PRB for Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
Capital Costs					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	$18,875.87	$18,876
Subtotal					$18,876
Site Preparation					
Decontamination Pad & Containment	Construction (and removal) of decon pad (including labor and materials)	LS	1	$500.00	$500
Temporary fence	Chain link industrial, 6' H, 6 gauge wire with 3 strands barb wire, to surround staging area (material, labor, equipment)	LF	200	$25.87	$5,174
Subtotal					$5,674
System Upgrades					
Replace Air Stripper Body	Assume 10-year lifespan, based on experience; Assume body will be replaced with similar model to fit with existing 4-inch process piping and meet original specified height of 7'6" max above finished floor to discharge flange.	Each	3	$20,800.00	$62,400
Pump removal - labor		Each	7	$263.00	$1,841
Pumps - material	Up to 10 gpm capacity	Each	7	$299.99	$2,100
Pump installation - labor		Each	7	$263.00	$1,841
Subtotal					$68,182
Downgradient Permiable Reactive Barriers					
Mobilization/Demobilization	Includes Mobilization/demobilization, permits (describe), utility clearance, and work plan and HASP preparation and submittal	LS	1	$5,000.00	$5,000
Geoprobe injections - Enhancement	Cost per direct push injection including all equipment, crew, pumping and mixing of site-ground water with injection products, and direct-push support activities.	Each	96	$380.00	$36,480
Regenesis 3-D Microemulsion (3DMe) Factory Emulsified	materials only	lbs	26,875	$2.95	$79,281
PlumeStop	materials only	lbs	96,400	$2.25	$216,900
PlumeStop Application	Regenesis staff (required)	-	1	-	$160,800
Subtotal					$498,461
Site Restoration					
Surveying Crew	2-person crew and equipment, 8hr/day	Day	2	$805.00	$1,610
Restoration seeding	hydroseeding w/ seed, mulch and fertilizer (material, labor, equipment)	M.S.F.	4	$1.96	$8
Asphalt driveway repair	cold-mix asphalt	S.Y.	356	$17.16	$6,109
Subtotal					$7,727
Soil vapor intrusion investigations and SSDS Installation					
Soil vapor intrusion investigation	Assume twice as many properties are investigated as SSDSs are installed.	Ea	4	$2,000.00	$8,000
New SSDS Installation - Residential	Assume 8% increase from current installations (2). Installation in the future.	Ea	1	$4,000.00	$4,000
New SSDS Installation - Commercial	Assume 8% increase from current installations (12). Installation in the future.	Ea	1	$6,000.00	$6,000
Subtotal					$18,000
				Capital Cost Subtotal:	$616,920
	Adjusted Capital Cost Subtotal for Buffalo,New York Location Factor (1.029):				$634,811
	10% Legal, administrative, engineering fees, construction management:				$63,481
				15% Contingencies:	$104,744
				Total Capital Cost:	**$804,000**
Annual Costs					
Gas		Month	12	$76.57	$919
Telephone		Month	12	$37.15	$446
Electric		Month	12	$1,241.80	$14,902
OM&M	OM&M for treatment system, pumping system, and monitoring well network.	Year	1	$90,850.00	$90,850
Analytical Services	Includes monthly sampling for VOCs, EPA 8260B, pH, 150.1, Hardness,130.2 and a contingency for four additional samples per year in the event of non-compliance with the SPDES equivalency permit.	Year	1	$2,592.00	$2,592
Replacement Equipment	May include the replacement of pumps, blowers, motors, etc. and sequestering agent	Year	1	$16,000.00	$16,000
SSDS annual inspection and reporting	Assume 1 hour per fan	EA	16	$315.00	$5,040
Periodic Review Reporting	performed annually	Year	1	$13,800.00	$13,800
Subtotal					$144,548
				Annual Cost Subtotal:	$144,548
	Adjusted Capital Cost Subtotal for Buffalo, New York Location Factor (1.029):				$148,740
		10% Legal, administrative, engineering fees:			$14,874
				15% Contingencies:	$32,723
				Annual Cost Total:	**$196,337**
		30-Year Present Value of Annual Costs:			**$3,019,000**

Table C-4: Cost Estimate for Alternative 2b Pump & Treat Source Control, PlumeStop PRB for Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
3-Year Costs					
Long-term groundwater monitoring - labor	2-people at 8 hr/day; total of 26 monitoring wells and 8 pumping wells; assume 8 wells/day	Hour	80	$130.00	$10,400
Long-term groundwater monitoring - reporting		Hour	80	$130.00	$10,400
Long-term groundwater monitoring - analytical		Year	1	$7,260.90	$7,261
Subtotal					$28,061
				3-Year Cost Subtotal:	$28,061
				Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):	$28,875
				10% Legal, administrative, engineering fees:	$2,887
				15% Contingencies:	$4,764
				3-Year Total:	**$36,526**
				30-Year Present Value of 3-Year Costs:	**$207,000**
5-Year Costs					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	$500.00	$8,000
Subtotal					$8,000
				5-Year Cost Subtotal:	$8,000
				Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):	$8,232
				10% Legal, administrative, engineering fees:	$823
				15% Contingencies:	$1,358
				5-Year Total:	**$10,413**
				30-Year Present Value of 5-Year Costs:	**$37,000**
				2015 Total Present Value Cost:	**$4,067,000**

Assumptions:

1. Present value cost based on annual and periodic costs over: 30 years
2. Present value of costs assumes 5% annual interest rate.
3. Unit costs listed were obtained from 2015 RS Means Cost Data, site-specific historical cost from the 2015 Periodic Review Report and 2015 Bioremediation Pilot Study, and engineering judgement.

4. Assumes larger pumps will fit in existing pumping well casings.
5. Treatment system OM&M Includes labor for maintenance and cleaning of air stripper, patching holes, rebalancing blowers, and labor for collection of monthly compliance samples from the treatment system influent and effluent. Pumping system OM&M includes pumping well maintenance and piezometer water level recordings. Monitoring well OM&M includes replacing missing or stripped bolts, replacing existing of installing new asphalt/ concrete pads, replacing existing well covers, installing new watertight well cap, and removing or replacing portions of cracked casings.

6. Length of fencing assumed a 50' x 50' staging area.

Key:
EPA = Environmental Protection Agency
gpm = gallons per minute
LS = lump sum
OM&M = operations, maintenance, and monitoring
SPDES = state pollutant discharge elimination system
VOC = volatile organic carbon

Table C-5: Cost Estimate for Alternative 4a Bioremediation Source Control with 3DMe PRB for Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
Capital Costs					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	$21,773.64	$21,774
Subtotal					$21,774
Treatment System Decommissioning					
Treatment System Inventory		LS	1	$5,000.00	$5,000
Monitoring well demolition	Assume each is 30 vertical linear feet	Ea	4	$547.50	$2,190
Pumping well demolition	Assume each is 30 vertical linear feet	EA	8	$972.50	$7,780
Water line removal	No excavation, up to 12" diameter	LF	30	$10.95	$329
Labor & equipment for demo	2 laborers, 1 equpment opearator (light), 1 backhoe loader	Day	15	$1,916.22	$28,743
Wipe test for disposal	Assumes 24-hour turn-around time and VOC analysis	Ea	3	$144.00	$432
Dumpster, weekly rental	1 dump/week, 40 CY capacity (10 Tons)	Dumpsters	3	$775.00	$2,325
Site Safety Officer	10 hrs/day, 5days/wk, $120/hr; 100% of project duration	manweeks	3	$6,000.00	$18,000
Subtotal					$64,799
Site Preparation					
Decontamination Pad & Containment	Construction (and removal) of decon pad (including labor and materials)	LS	1	$500.00	$500
Temporary fence	Chain link industrial, 6' H, 6 gauge wire with 3 strands barb wire, to surround staging area (material, labor, equipment)	LF	200	$25.87	$5,174
Subtotal					$5,674
Source Bioremediation					
Mobilization/Demobilization	Includes Mobilization/demobilization, permits (describe), utility clearance, and work plan and HASP preparation and submittal	LS	1	$5,000.00	$5,000
Geoprobe injections - Enhancement	Cost per direct push injection including all equipment, crew, pumping and mixing of site-ground water with injection products, and direct-push support activities.	Each	176	$380.00	$66,880
Regenesis Hydrogen Release Compound ® Primer (HRC Primer)	materials only	lbs	27,417	$6.95	$190,548
Regenesis 3-D Microemulsion (3DMe) Factory Emulsified	materials only	lbs	49,200	$2.95	$145,140
Geoprobe injections - Augmentation	Cost per direct push injection including all equipment, crew, pumping site-groundwater, nitrogen-sparging of site-ground water, mixing with injection products, and direct-push support activities.	Each	47	$380.00	$17,860
BDI Plus Innoculum	materials only	Liter	94	$200.00	$18,800
Subtotal					$444,228
Downgradient Permiable Reactive Barriers					
Mobilization/Demobilization	Includes Mobilization/demobilization, permits (describe), utility clearance, and work plan and HASP preparation and submittal	LS	1	$5,000.00	$5,000
Geoprobe injections - Enhancement	Cost per direct push injection including all equipment, crew, pumping and mixing of site-ground water with injection products, and direct-push support activities.	Each	96	$380.00	$36,480
Regenesis 3-D Microemulsion (3DMe) Factory Emulsified	materials only	lbs	26,875	$2.95	$79,281
					$120,761
Site Restoration					
Surveying Crew	2-person crew and equipment, 8hr/day	Day	2	$805.00	$1,610
Restoration seeding	kentucky bluegrass; hydroseeding w/ mulch and fertilizer (material, labor, equipment)	M.S.F.	17	$43.30	$736
Asphalt driveway repair	cold-mix asphalt	S.Y.	1,823	$17.16	$31,283
Subtotal					$33,629
Maintenance Injections					
Year 3 Reinjection in source	Present value of re-injection in 3 years, excludes microbe re-injection	LS	1	$367,600	$367,600
Year 7 Reinjection in source	Present value of re-injection in 3 years, excludes microbe re-injection	LS	1	$302,400	$302,400
Subtotal					$670,000

Table C-5: Cost Estimate for Alternative 4a Bioremediation Source Control with 3DMe PRB for Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
Soil vapor intrusion investigations and SSDS Installation					
Soil vapor intrusion investigation	Assume twice as many properties are investigated as SSDSs are installed.	Ea	4	$2,000.00	$8,000
New SSDS Installation - Residential	Assume 8% increase from current installations (2). Installation in the future.	Ea	1	$4,000.00	$4,000
New SSDS Installation - Commercial	Assume 8% increase from current installations (12). Installation in the future.	Ea	1	$6,000.00	$6,000
Subtotal					$18,000
				Capital Cost Subtotal:	$1,378,865
	Adjusted Capital Cost Subtotal for Buffalo,New York Location Factor (1.029):				$1,418,852
	10% Legal, administrative, engineering fees, construction management:				$141,885
				15% Contingencies:	$234,111
				Total Capital Cost:	**$1,795,000**
Annual Costs					
Monitoring Well Network OM&M		Year	1	$20,000.00	$8,000
SSDS annual inspection and reporting	Assume 1 hour per fan	EA	16	$315.00	$5,040
Periodic Review Reporting	performed annually	Year	1	$13,800.00	$13,800
Subtotal					$26,840
				Annual Cost Subtotal:	$26,840
	Adjusted Capital Cost Subtotal for Buffalo, New York Location Factor (1.029):				$27,618
		10% Legal, administrative, engineering fees:			$2,762
				15% Contingencies:	$6,076
				Annual Cost Total:	**$36,456**
		30-Year Present Value of Annual Costs:			**$561,000**
3-Year Costs					
Long-term groundwater monitoring - labor	2-people at 8 hr/day; total of 26 monitoring wells and 8 pumping wells; assume 8 wells/day	Hour	80	$130.00	$10,400
Long-term groundwater monitoring - reporting		Hour	80	$130.00	$10,400
Long-term groundwater monitoring - analytical		Year	1	$7,260.90	$7,261
Subtotal					$28,061
				3-Year Cost Subtotal:	$28,061
	Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):				$28,875
		10% Legal, administrative, engineering fees:			$2,887
				15% Contingencies:	$4,764
				3-Year Total:	**$36,526**
		30-Year Present Value of 3-Year Costs:			**$207,000**
5-Year Costs					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	$500.00	$8,000
Subtotal					$8,000
				5-Year Cost Subtotal:	$8,000
	Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):				$8,232
		10% Legal, administrative, engineering fees:			$823
				15% Contingencies:	$1,358
				5-Year Total:	**$10,413**
		30-Year Present Value of 5-Year Costs:			**$37,000**
		2015 Total Present Value Cost:			**$2,600,000**

Assumptions:

1. Present value cost based on annual and periodic costs over: 30 years
2. Present value of costs assumes 5% annual interest rate.
3. Unit costs listed were obtained from 2015 RS Means Cost Data, site-specific historical cost from the 2015 Periodic Review Report and 2015 Bioremediation Pilot Study, and engineering judgement.
4. Assumes larger pumps will fit in existing pumping well casings.
5. Monitoring well OM&M includes replacing missing or stripped bolts, replacing existing of installing new asphalt/ concrete pads, replacing existing well covers, installing new watertight well cap, and removing or replacing portions of cracked casings.
6. Length of fencing assumed a 50' x 50' staging area.

Key:
EPA = Environmental Protection Agency
gpm = gallons per minute
LS = lump sum
OM&M = operations, maintenance, and monitoring
SPDES = state pollutant discharge elimination system
VOC = volatile organic carbon
SSDS = sub-slab depressurization system

Table C-6: Cost Estimate for Alternative 4b Bioremediation Source Control with PlumeStop PRB for Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
Capital Costs					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	$34,095.39	$34,095
Subtotal					$34,095
Treatment System Decommissioning					
Treatment System Inventory		LS	1	$5,000.00	$5,000
Monitoring well demolition	Assume each is 30 vertical linear feet	Ea	4	$547.50	$2,190
Pumping well demolition	Assume each is 30 vertical linear feet	EA	8	$972.50	$7,780
Water line removal	No excavation, up to 12" diameter	LF	30	$10.95	$329
Labor & equipment for demo	2 laborers, 1 equipment opearator (light), 1 backhoe loader	Day	15	$1,916.22	$28,743
Wipe test for disposal	Assumes 24-hour turn-around time and VOC analysis	Ea	3	$144.00	$432
Dumpster, weekly rental	1 dump/week, 40 CY capacity (10 Tons)	Dumpsters	3	$775.00	$2,325
Site Safety Officer	10 hrs/day, 5days/wk, $120/hr; 100% of project duration	manweeks	3	$6,000.00	$18,000
Subtotal					$64,799
Site Preparation					
Decontamination Pad & Containment	Construction (and removal) of decon pad (including labor and materials)	LS	1	$500.00	$500
Temporary fence	Chain link industrial, 6' H, 6 gauge wire with 3 strands barb wire, to surround staging area (material, labor, equipment)	LF	200	$25.87	$5,174
Subtotal					$5,674
Source Bioremediation					
Mobilization/Demobilization	Includes Mobilization/demobilization, permits (describe), utility clearance, and work plan and HASP preparation and submittal	LS	1	$5,000.00	$5,000
Geoprobe injections - Enhancement	Cost per direct push injection including all equipment, crew, pumping and mixing of site-ground water with injection products, and direct-push support activities.	Each	176	$380.00	$66,880
Regenesis Hydrogen Release Compound ® Primer (HRC Primer)	materials only	lbs	27,417	$6.95	$190,548
Regenesis 3-D Microemulsion (3DMe) Factory Emulsified	materials only	lbs	49,200	$2.95	$145,140
Geoprobe injections - Augmentation	Cost per direct push injection including all equipment, crew, pumping site-groundwater, nitrogen-sparging of site-ground water, mixing with injection products, and direct-push support activities.	Each	47	$380.00	$17,860
BDI Plus Innoculum	materials only	Liter	94	$210.00	$19,740
Subtotal					$445,168
Downgradient Permiable Reactive Barriers					
Mobilization/Demobilization	Includes Mobilization/demobilization, permits (describe), utility clearance, and work plan and HASP preparation and submittal	LS	1	$5,000.00	$5,000
Geoprobe injections - Enhancement	Cost per direct push injection including all equipment, crew, pumping and mixing of site-ground water with injection products, and direct-push support activities.	Each	96	$380.00	$36,480
Regenesis 3-D Microemulsion (3DMe) Factory Emulsified	materials only	lbs	26,875	$2.95	$79,281
PlumeStop	materials only	lbs	96,400	$2.25	$216,900
PlumeStop Application	Regenesis staff (required)	-	1	-	$160,800
Subtotal					$498,461
Site Restoration					
Surveying Crew	2-person crew and equipment, 8hr/day	Day	2	$805.00	$1,610
Restoration seeding	kentucky bluegrass; hydroseeding w/ mulch and fertilizer (material, labor, equipment)	M.S.F.	17	$43.30	$736
Asphalt driveway repair	cold-mix asphalt	S.Y.	1,823	$17.16	$31,283
Subtotal					$33,629
Maintenance Injections					
Year 3 Reinjection in source	Present value of re-injection in 3 years, excludes microbe re-injection	LS	1	$367,600	$367,600
Year 7 Reinjection in source	Present value of re-injection in 3 years, excludes microbe re-injection	LS	1	$302,400	$302,400
Subtotal					$670,000

Table C-6: Cost Estimate for Alternative 4b Bioremediation Source Control with PlumeStop PRB for Migration Control
Mr. C's Dry Cleaner's Site, East Aurora, New York

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
Soil vapor intrusion investigations and SSDS Installation					
Soil vapor intrusion investigation	Assume twice as many properties are investigated as SSDSs are installed.	Ea	4	$2,000.00	$8,000
New SSDS Installation - Residential	Assume 8% increase from current installations (2). Installation in the future.	Ea	1	$4,000.00	$4,000
New SSDS Installation - Commercial	Assume 8% increase from current installations (12). Installation in the future.	Ea	1	$6,000.00	$6,000
Subtotal					$18,000
				Capital Cost Subtotal:	$1,769,826
	Adjusted Capital Cost Subtotal for Buffalo,New York Location Factor (1.029):				$1,821,151
	10% Legal, administrative, engineering fees, construction management:				$182,115
				15% Contingencies:	$300,490
				Total Capital Cost:	**$2,304,000**
Annual Costs					
Monitoring Well Network OM&M		Year	1	$20,000.00	$8,000
SSDS annual inspection and reporting	Assume 1 hour per fan	EA	16	$315.00	$5,040
Periodic Review Reporting	performed annually	Year	1	$13,800.00	$13,800
Subtotal					$26,840
				Annual Cost Subtotal:	$26,840
	Adjusted Capital Cost Subtotal for Buffalo, New York Location Factor (1.029):				$27,618
			10% Legal, administrative, engineering fees:		$2,762
				15% Contingencies:	$6,076
				Annual Cost Total:	**$36,456**
			30-Year Present Value of Annual Costs:		**$561,000**
3-Year Costs					
Long-term groundwater monitoring - labor	2-people at 8 hr/day; total of 26 monitoring wells and 8 pumping wells; assume 8 wells/day	Hour	80	$130.00	$10,400
Long-term groundwater monitoring - reporting		Hour	80	$130.00	$10,400
Long-term groundwater monitoring - analytical		Year	1	$7,260.90	$7,261
Subtotal					$28,061
				3-Year Cost Subtotal:	$28,061
	Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):				$28,875
			10% Legal, administrative, engineering fees:		$2,887
				15% Contingencies:	$4,764
				3-Year Total:	**$36,526**
			30-Year Present Value of 3-Year Costs:		**$207,000**
5-Year Costs					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	$500.00	$8,000
Subtotal					$8,000
				5-Year Cost Subtotal:	$8,000
	Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):				$8,232
			10% Legal, administrative, engineering fees:		$823
				15% Contingencies:	$1,358
				5-Year Total:	**$10,413**
			30-Year Present Value of 5-Year Costs:		**$37,000**
			2015 Total Present Value Cost:		**$3,109,000**

Assumptions:

1. Present value cost based on annual and periodic costs over: 30 years
2. Present value of costs assumes 5% annual interest rate.

3. Unit costs listed were obtained from 2015 RS Means Cost Data, site-specific historical cost from the 2015 Periodic Review Report and 2015 Bioremediation Pilot Study, and engineering judgement.
4. Assumes larger pumps will fit in existing pumping well casings.

5. Monitoring well OM&M includes replacing missing or stripped bolts, replacing existing of installing new asphalt/ concrete pads, replacing existing well covers, installing new watertight well cap, and removing or
6. Length of fencing assumed a 50' x 50' staging area.

Key:
EPA = Environmental Protection Agency
gpm = gallons per minute
LS = lump sum
OM&M = operations, maintenance, and monitoring
SPDES = state pollutant discharge elimination system
VOC = volatile organic carbon