

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

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## List of Abbreviations and Acronyms

3DMe	Regenesis 3D Microemulsion®
BDI PLUS	Regenesis Bio-Dechlor INOCULUM® Plus
BGS	below ground surface
cm/s	centimeter per second
CSM	Conceptual Site Model
COC	contaminant of concern
DCE	dichloroethene
DER	Division of Environmental Remediation
DO	dissolved oxygen
EEEPC	Ecology and Environment Engineering, P.C.
EC	engineering control
ft/day	feet per day
gpm	gallons per minute
HRC Primer®	Regenesis Hydrogen Release Compound Primer
IC	institutional controls
ITRC	Interstate Technology & Regulatory Council
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

## List of Abbreviations and Acronyms (cont.)

RI	Remedial Investigation
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 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 (ITRC), 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" (ITRC 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). RSO 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.

According to NYSDEC's RSO guidance, 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 (NYSDEC 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): tetrachloroethene (PCE), trichloroethene (TCE), cis-dichloroethene (cis-DCE), and vinyl chloride (VC).

A conceptual site model (CSM) using contaminant fate and transport processes was developed as part of the Feasibility Study for the Mr. C's Site (MPI 1996). 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, over 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 is 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 (EEEP 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 pump-and-treat system was designed by Malcolm Pirnie, and well locations were selected based on the nature and extent of contamination as summarized in the Feasibility Study (MPI 1996). 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 (LTM), 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 LTM 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 in situ injections of Provectus' antimethanogenic reagent Provect-IR™.
2. Source control through in situ bioremediation using Provect-IR™.
3. Shut-off and decommissioning of the existing treatment system following installation of PRBs and temporary operation to target Pilot Study areas with large cis-DCE concentrations (operating pumping wells PW4, PW5, PW6, PW7, and PW8). Several wells have been shut off to avoid secondary impacts to the treatment system; however, cis-DCE is more mobile than PCE and may be able to be removed more effectively through pumping.
4. Continued LTM 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 LTM 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. 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. Additionally, while groundwater under the site is not a drinking water source, the RI identified four properties with wells that were typically used for irrigation and could present a potential exposure route (MPI 1995a). At the time of writing this RSO, it is unknown whether these wells have been decommissioned or whether the off-site residents are aware of the groundwater use restrictions. Finally, construction workers both on- and off-site may be directly exposed to contaminated soil and groundwater, and site institutional controls that address this exposure pathway should be verified and updated, as necessary.

While this RSO documents the relative benefits and cost effectiveness of the technology, 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 may be warranted to determine whether the increased COC toxicity poses an overall increased risk to human health. For many residences, the overall risk has been reduced through the installation of a sub-slab depressurization system (SSDS), which removes the exposure pathway for soil vapor intrusion.

# 1

## Introduction and Background

The New York State Department of Environmental Conservation (NYSDEC) contracted Ecology and Environment Engineering, P.C. (EEEEPC) 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 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.

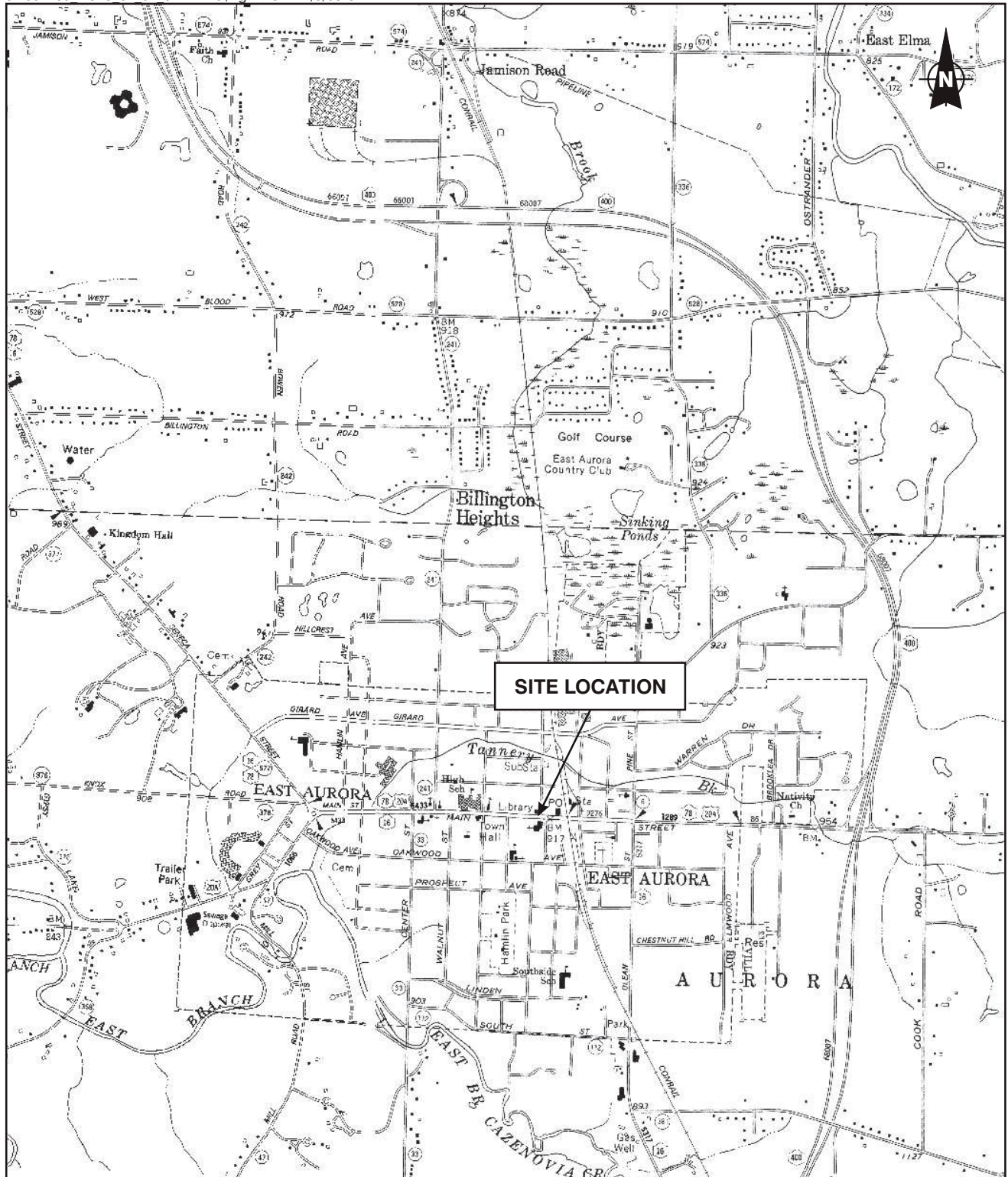
The Site is surrounded by residential homes along Whaley Avenue to the west and Fillmore Avenue to the north. Other commercial businesses are adjacent to the Site on the east side and across Main Street to the south. Groundwater pumping wells and groundwater monitoring wells form a ring around the entire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

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

### 1.2 Remedial Background

Perchloroethene (PCE), also known as tetrachloroethene, and its degradation by-product 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,



SOURCE: NYS Department of Transportation Raster Quadrangle, 1988.

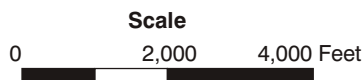


Figure 1-1 General Site Location Map

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

SSDSs were installed at the First Presbyterian Church in 2004 and at the residential property 27 Whaley Avenue in 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. 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 revised 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 aid in comparing upfront capital investments versus recurring costs.

## **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 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. Additional groundwater contour maps of the Site based on data collected prior to the RI in 1994 and during Long-Term Groundwater Monitoring in 2016 are included in Appendix A.
- 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  $1.5 \times 10^{-4}$  to  $4.9 \times 10^{-4}$  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  $8.8 \times 10^{-6}$  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 Conceptual Site Model

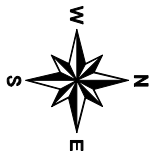
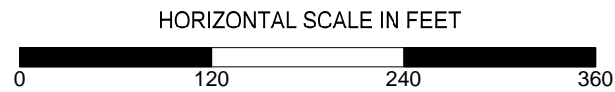
A conceptual site model (CSM) is a written or pictorial representation of an environmental system and the biological, physical, and chemical processes that determine the transport of contaminants from sources through the environmental media to environmental receptors within the system (American Society for Testing and Materials E1689-95). The 1995 RI previously presented the elements of the CSM, including: (1) potential sources of contamination, (2) types of contaminants and affected media, (3) release mechanisms and potential contaminant pathways, and (4) actual/potential human and environmental receptors. These elements were carried over into the 1996 Feasibility Study and used in selecting the remedial alternative for the site.

A CSM is meant to be periodically reviewed and updated as more site data become available, and long-term monitoring (LTM) at the site has additional information with which to refine the Mr. C's CSM. Several initiatives have been undertaken that affect which contaminants are present at the site, their concentrations, and potential contaminant pathways. This section aims to refine the previous presentation of the CSM to identify and set priorities for evaluation of the alternatives presented in this RSO in accordance with DER-10 (NYSDEC 2010).

### 1.5.1 Potential Sources of Contamination

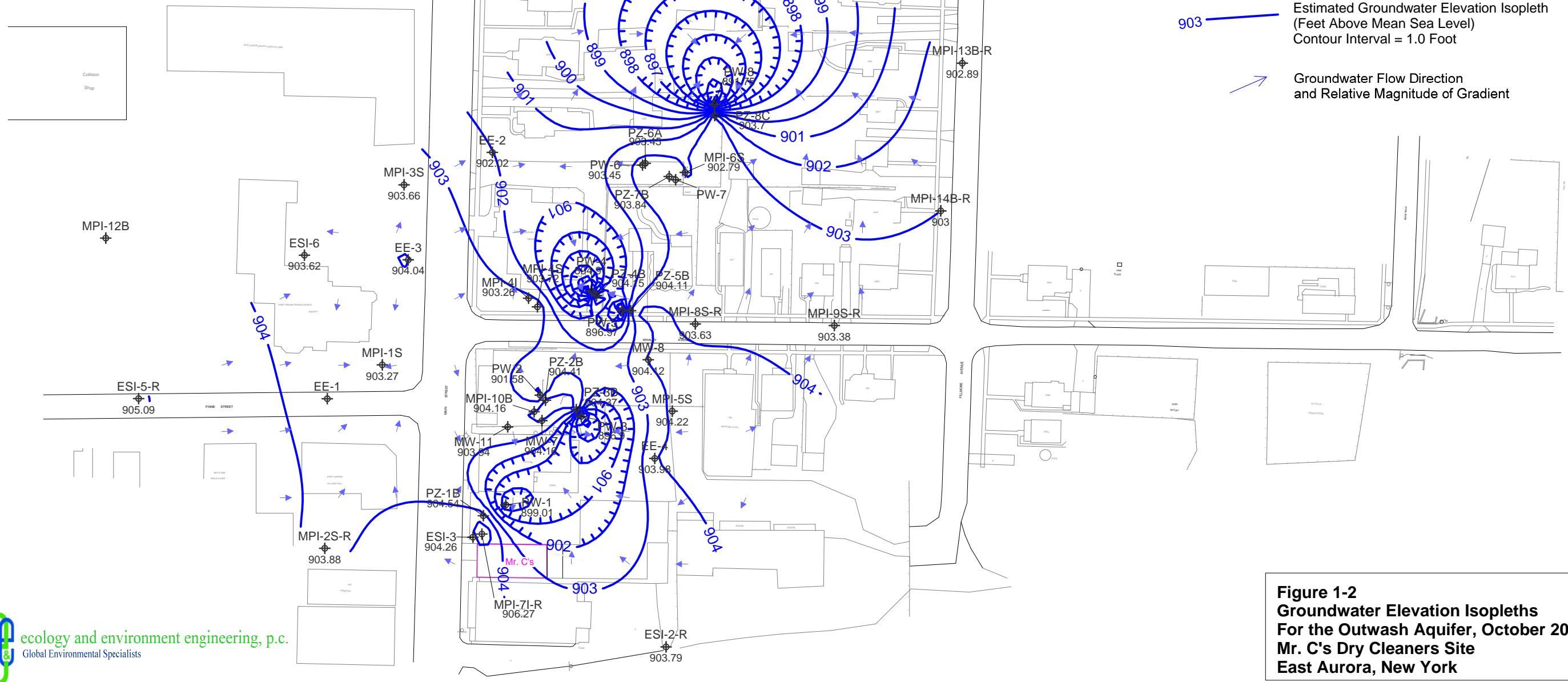
The former Mr. C's Dry Cleaners site is believed to be the primary source of contamination. The existing building that houses the Mr. C's treatment facility and the former Mr. C's Dry Cleaners is believed to have been built around 1927 and was used as a dry cleaning facility since before 1970 (NYSDEC 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 parts per million [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).

Based on previous findings, the primary release mechanism was thought to be infiltration into the groundwater from a leaking sewer lateral. Investigations conducted prior to the 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). 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.



**Legend**

- MW-8  
904.12  
Well ID with Measured Groundwater Elevation in Feet Above Mean Sea Level
- 903  
Estimated Groundwater Elevation Isoleth (Feet Above Mean Sea Level) Contour Interval = 1.0 Foot
- Groundwater Flow Direction and Relative Magnitude of Gradient



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

As such, the primary release mechanism identified in the RI no longer presents a pathway for contaminant release.

The contaminated groundwater plume was recognized to be a secondary contaminant source. The 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 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" (MPI 1995a). 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. The Mr. C's Feasibility Study defined the contaminant source as this secondary source, i.e., the impacted groundwater plume's center of contaminant mass as characterized by elevated PCE concentrations (MPI 1996). LTM results indicate that the groundwater plume continues to be a secondary source, and it has extended in a west-northwesterly direction from the Site (EEEEPC 2016c).

Contaminated subsurface soil was also identified as a potential secondary source. According to the RI, the analytical results for samples collected from three shallow soil borings (roughly 6 to 10 feet BGS) located near the Mr. C's sewer lateral and the former Shoe Repair Shop exceeded the NYSDEC TAGM 4046 PCE standards for soil (MPI 1995a). Soil contamination in other parts of the plume may result from partitioning processes that cause some of the aqueous/dissolved-phase contaminants to adsorb to the outwash aquifer sediments in the upper soil strata.

### **1.5.2 Types of Contaminants and Affected Media**

The RI chose PCE and its degradation products (TCE, 1,1-dichloroethene [DCE], 1,2-DCE, and vinyl chloride [VC]) and chloroform as contaminants of potential concern for the Mr. C's Superfund Site (MPI 1995a). 1,2-DCE would include both cis- and trans- isomers. Compounds associated with petroleum spills at the former Agway property, including benzene, toluene, ethylbenzene, and xylene, had also been found at specific locations near the site, which had mixed with compounds from the dry cleaning operation to create a complex groundwater contamination plume (NYSDEC 1997). The ROD identified the primary COCs to be VOCs, specifically PCE. Current monitoring data, which are summarized in the periodic review report (PRR), are consistent with this selection of the COPCs and COCs (EEEEPC 2014, 2015d).

### **Groundwater**

Based on the analytical results for samples collected in April/May 2016 as part of the long-term groundwater monitoring at the Mr. C's Site, seven VOCs (PCE,

TCE, cis-DCE, trans-DCE, VC, chloroform, and methyl tert-butyl ether) were present in groundwater at levels that exceed their NYSDEC Class GA groundwater standards and the guidance values used to screen the groundwater data (EEEPC 2016c). Each of the identified COPCs were detected, except for 1,1-DCE. However, the range of concentrations detected has changed significantly since the RI (see Table 1-2). In general, the detected concentrations have gone down, except those for cis-DCE and VC, which have increased.

### **Soil Vapor and Indoor Air**

Since the RI, a significant effort has been undertaken to perform soil vapor intrusion investigations within and around the Mr. C's site. Additional information is summarized in the Site's PRRs (EEEPC 2014, 2015d).

### **Subsurface Soil**

According to the 1995 RI Report prepared by Malcolm Pirnie, Inc., soil was analyzed at two locations to identify the source of PCE. One shallow boring (SB-1) was located near Mr. C Cleaners' sewer lateral and the second boring (SB-2) was located near the side entrance of the shoe repair. Two soil samples were collected from SB-1, and one soil sample was collected from SB-2. Detected PCE concentrations ranged from 6,400 to 48,000 parts per billion (NYSDEC 1997).

In 2011, samples from two additional borings were analyzed for VOCs at the location of new wells EE-3 and EE-4 as part of the monitoring well network improvement initiative. Eighteen samples were collected from the soil borings in 2-foot intervals and analyzed for VOCs (GES 2012). The total VOC concentrations detected in these samples were below the highest PCE concentration detected previously. The soil analytical data is presented in Table 1 of the Well Upgrade and Installation Report prepared by Groundwater & Environmental Services, Inc. (2012), which is provided in Attachment C to the Mr. C's Monitoring Well Network Improvements Close-out Report, in Appendix G of the 2012 PRR (EEEPC 2013).

#### **1.5.3 Release Mechanisms**

Based on the available data, a summary of contaminant fate and transport processes was developed as part of the Feasibility Study for the Mr. C's Site (MPI 1996). The Feasibility Study identified the following mechanisms of contaminant transport at the Site:

- Lateral movement of groundwater, particularly in the outwash aquifer; and,
- Volatilization of VOCs from groundwater and/or subsurface soils.

The Feasibility Study also considered infiltration/percolation. It concluded that infiltration of precipitation was not a significant release mechanism for contaminants immediately surrounding the Site or in the commercial areas to the east and south of the site. Infiltration is the primary source of recharge for the outwash aquifer, occurring primarily in the residential areas to the west and north of the Site. It is possible that the sanitary sewer system contributed to recharge of the

outwash aquifer through leakage. However, no dry cleaning wastes had been released to the sewers since 1985, and the sewers were flushed by the Village of East Aurora Department of Public Works in 1992; therefore, this is not a likely pathway for contaminant migration (MPI 1996).

Leaching and volatilization from soil were not considered likely pathways of contaminant migration as the soils underlying the Site are often unsaturated and receive minimal recharge from infiltration (MPI 1996). The hydrogeological setting of the site has not changed and these release mechanisms are consistent with the current understanding of the Site.

### **1.5.4 Exposure Pathway Analysis**

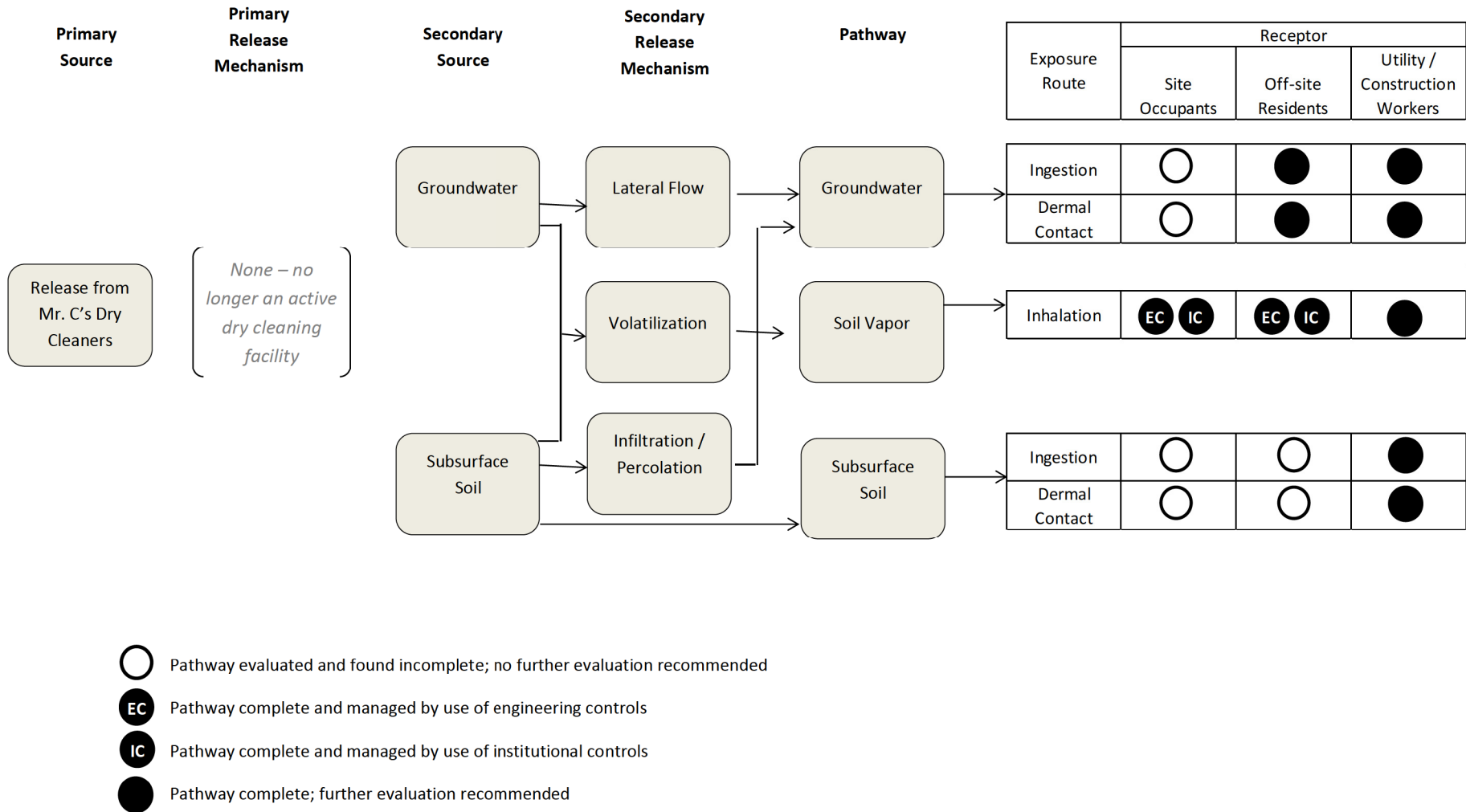
The RI identified several potential routes of exposure by which receptors could come in contact with site COCs. Receptors considered in the RI included site occupants, off-site residents, and municipal workers (MPI 1995a). Pathways considered complete had (1) a source, (2) a contaminant migration pathway, and (3) a point where exposure of a receptor could occur. Toxicological data were also presented for the RI's COCs (since COCs had not yet been selected by the ROD) (MPI 1995a).

Figure 1-3 presents the complete exposure pathways identified in the RI and the means by which they are being managed under the existing site remedy. Figure 1-3 was prepared according to the American Society for Testing and Materials E1689-95 Standard Guide for Developing Conceptual Site Models for Contaminated Sites. The pathways identified in the RI are consistent with the previous and current understanding of the CSM.

No potable water supply wells are currently on or immediately downgradient of the site; the area has been serviced by the Erie County Water Authority since 1980. However, at the time of the RI, several nearby residences had shallow wells, which were used for irrigation purposes. At the time of writing this RSO, it is unknown whether these wells have been decommissioned or whether the off-site residents are aware of the groundwater use restrictions.

Based on indoor air monitoring results, PCE volatilization from groundwater is a source of indoor air contamination in basements. This exposure pathway is being addressed via engineering controls in the form of sub-slab depressurization systems (SSDS) and institutional controls in the form of soil-vapor intrusion investigations. Periodic monitoring of these controls will continue as part of the Site's periodic review reporting. LTM of the site should be performed to determine whether the SSDS systems remain protective of indoor air quality and whether plume migration or changes in plume composition would trigger the need for additional soil vapor intrusion investigations.

Finally, construction workers both on and off-site may be directly exposed to contaminated soil and groundwater. Additional discussion on health exposures and exposure pathways can be found in Section 3.3 of the ROD, Section 1.3.6 of the Feasibility Study, and Section 6 of the RI (NYSDEC 1997; MPI 1996, 1995a).



**Figure 1-3 Complete Exposure Pathways Identified in the Remedial Investigation**

## 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 2015, the Mr. C's pump-and-treat system has achieved 95% operational uptime and removed over 1,600 pounds of VOCs (EEEPC 2016a). 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 1-4).

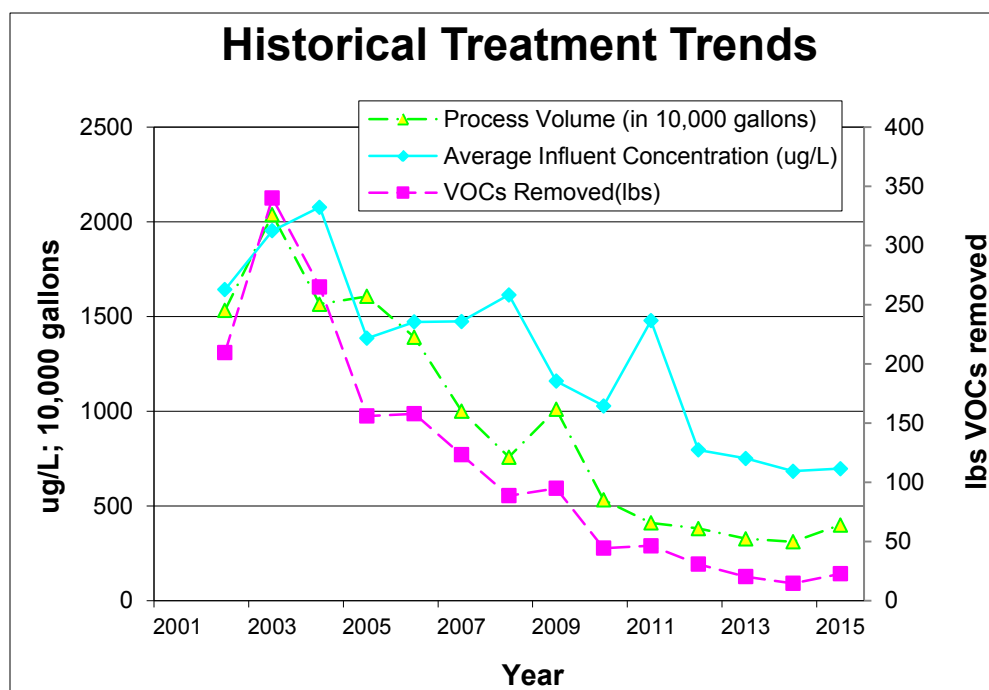


Figure 1-4 Historical Treatment Trends – Mr. C's Dry Cleaners Site

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 December 31, 2015, the cumulative volume of groundwater treated was 129 million gallons, or nearly 100 times the estimated contaminated groundwater volume, with significant contamination still remaining (EEEPC 2016a).

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.

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 December 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 to 100% PCE solution per year, which is over 16,000 pounds of PCE per year. PCE has a density of 1.622 grams per cubic centimeter, or 13.5 pounds per gallon.

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 Site Management Plan. 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 (EEEEPC 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 (EEEEPC 2015a). The PCE contaminant plume, as interpolated from the October 2014 Long-term Groundwater Monitoring data, is presented on Figure 1-5. The total chlorinated VOC plume, as interpolated from October 2014 data, is presented on Figure 1-6.

At the request of NYSDEC, the treatment system was shutdown beginning February 4, 2016, to evaluate the possible rebound of contaminants in groundwater.

The treatment system will be returned to service in early October 2016.

Rebound is a phenomenon usually observed after pump-and-treat processes have stopped and sorbed chemicals equilibrate with aqueous concentrations. Pump-and-treat operations, such as those at the Mr. C's site, have several limitations, one of which is the sorption of chemicals on the soil matrix. Equilibrium is not always achieved instantaneously, but rather over a long period, which would explain why rebound occurs only after pump-and-treat stops. At the Mr. C's site, and especially in the vicinity of the recent bioremediation pilot study, rebound may also occur as PCE and its degradation products are reduced. For example, as the groundwater PCE concentration decreases, PCE sorbed to the soil matrix will move to reestablish equilibrium with the aqueous phase, and groundwater PCE concentrations will increase again, i.e., rebound.

PCE continued to be non-detect in MPI-6S and MW-8 during the most recent Long-Term Groundwater Monitoring in April/May 2016. Because the Pilot Study treated only a limited area within the contaminant plume, groundwater transport of upgradient total VOC contamination or partitioning of VOCs sorbed to the soil in the Pilot Study areas led to Total VOC concentrations in MPI-6S and MW-8 remaining above the groundwater standards in 2016 (EEEEPC 2016c). The PCE contaminant plume, as interpolated from the April/May 2016 Long-term Groundwater Monitoring data, is presented on Figure 1-7. The total chlorinated VOC plume, also interpolated from April/May 2016 data, is presented on Figure 1-8.

The 2016 results showed only limited evidence of PCE rebound stemming from pump-and-treat system shutdown. PCE and Total VOC concentrations increased significantly in the vicinity of PW-5 (concentrations in PZ-5A/PZ-5B nearly doubled from the 2014 results), but in other wells nearby, including MPI-4I and PW-6/PZ-6A, PCE and Total VOC concentrations nearly halved. It is difficult to dis-

cern without further analysis whether the changes in the plume were due to partitioning or transport. The analyses presented in this report are based on the 2014 Long-Term Groundwater Monitoring Results; however, design of the selected alternative would be based on the most current results.

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. Increased migration is a concern particularly near pumping well PW-8, which is located on the downgradient edge of the contaminant plume. The next closest sentinel well downgradient of PW-8 is MPI-15B, which is located several hundred feet to the west, with multiple residential properties in between. Both the natural groundwater gradients and artificial cones of depression created from pumping result in groundwater flow toward PW-8.

The 2016 isopleths shown in Appendix A were developed based on data collected when the groundwater extraction system had been deactivated for three months. Interpretation of the isopleths shows additional evidence of the groundwater divide observed in the RI (refer to Appendix A-1); however, groundwater flow in the vicinity of the monitoring wells in which the highest concentrations of PCE and cis-DCE were detected in 2016 is in line with bulk groundwater flow to the west-northwest.

### **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 VOCs and reduce volatilization into adjacent basements.
3. Achieve NYSDEC groundwater quality standards to the extent practical.

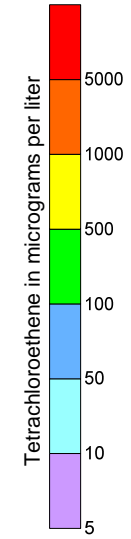
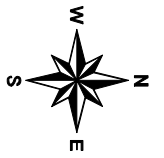
Since no property owners in the vicinity of the Site rely on groundwater-derived potable water, exposure to contaminated groundwater is not a consideration.

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 1-9 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

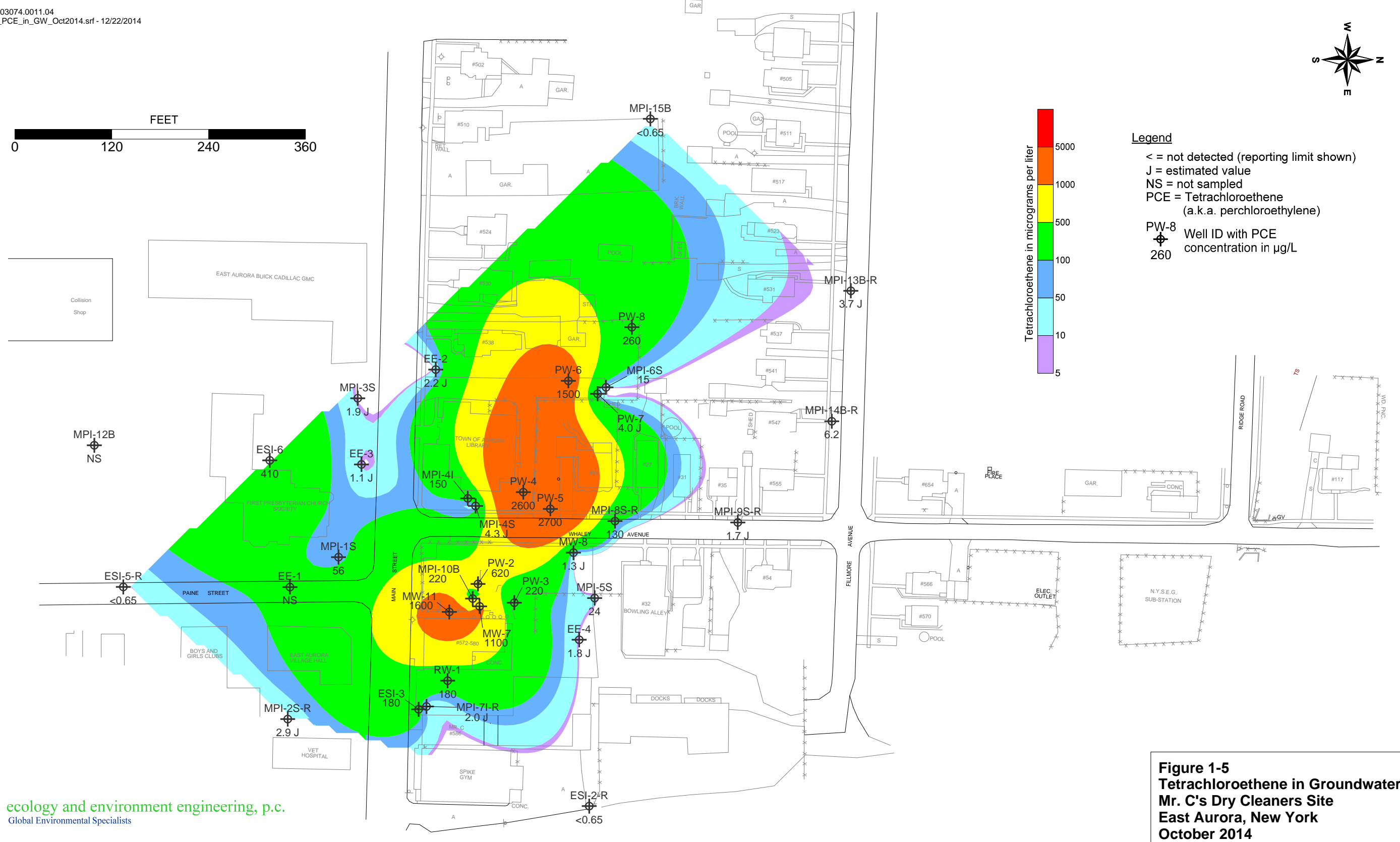
NYSDOH criteria matrix (NYSDOH 2006). If the plume migrates, additional SVIIs should be performed, and SSDSs should be installed, as necessary, to maintain the protectiveness of the Site Remedy. However, implementation of remediation should contain or shrink the plume such that need for additional SVIIs would be limited.

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 ( $\mu\text{g/L}$ ) during the 2014 Long-Term Groundwater Monitoring Event.

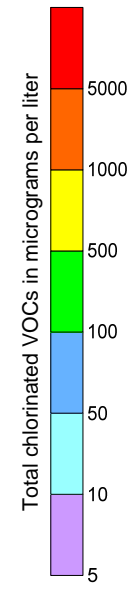
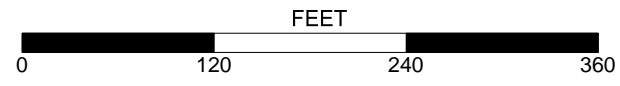
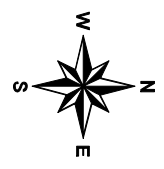
As discussed in Section 1.3, this RSO is focused on the potential use of anaerobic bioremediation to better attain the RAOs in lieu of, or in conjunction with, the existing remedial system.




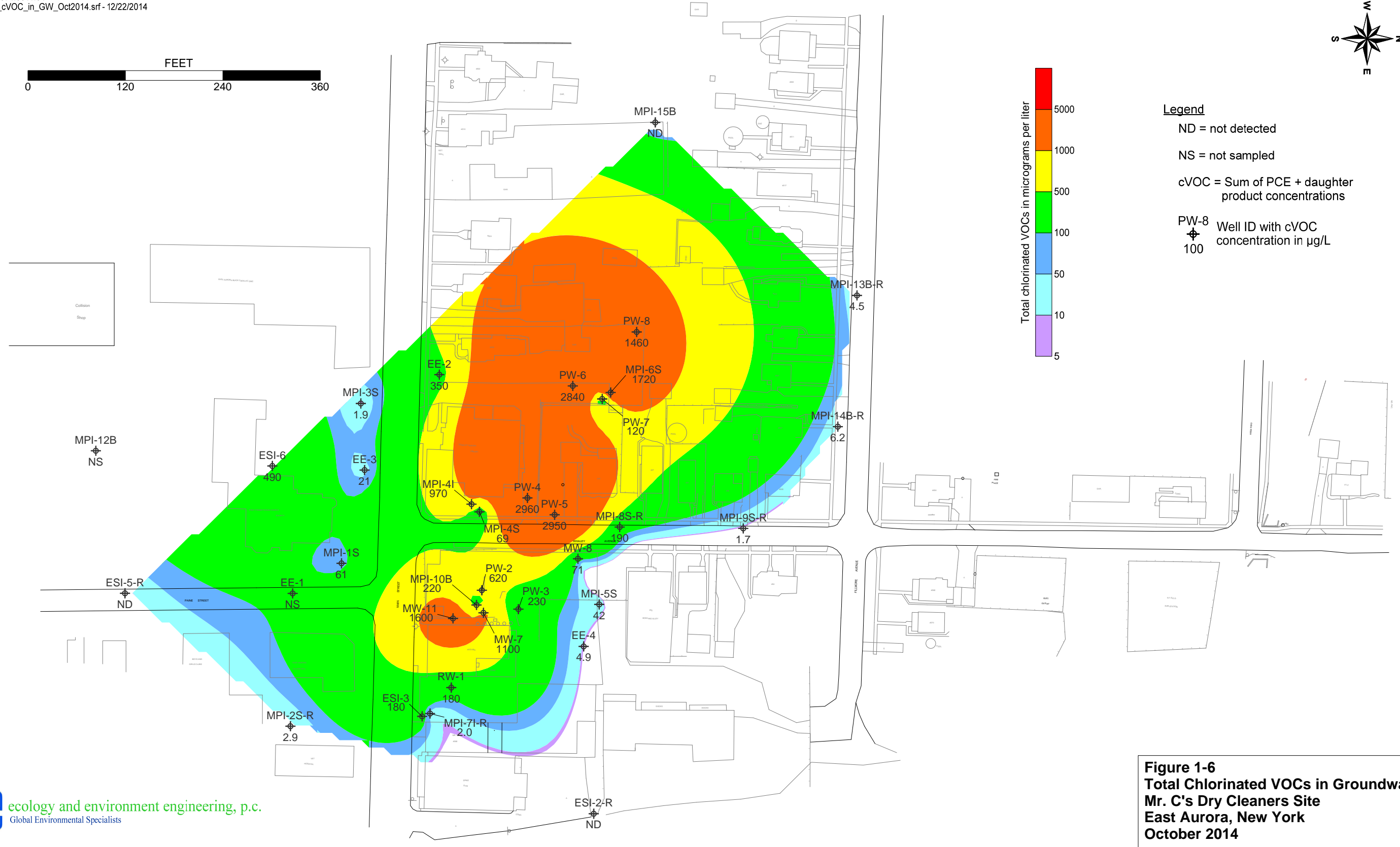
**Legend**  
 < = not detected (reporting limit shown)  
 J = estimated value  
 NS = not sampled  
 PCE = Tetrachloroethene  
 (a.k.a. perchloroethylene)  
 PW-8  
 Well ID with PCE  
 260 concentration in µg/L



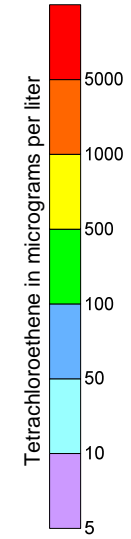
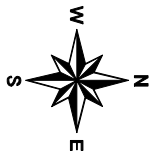
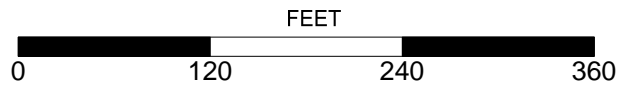
**Figure 1-5**  
**Tetrachloroethene in Groundwater**  
**Mr. C's Dry Cleaners Site**  
**East Aurora, New York**  
**October 2014**



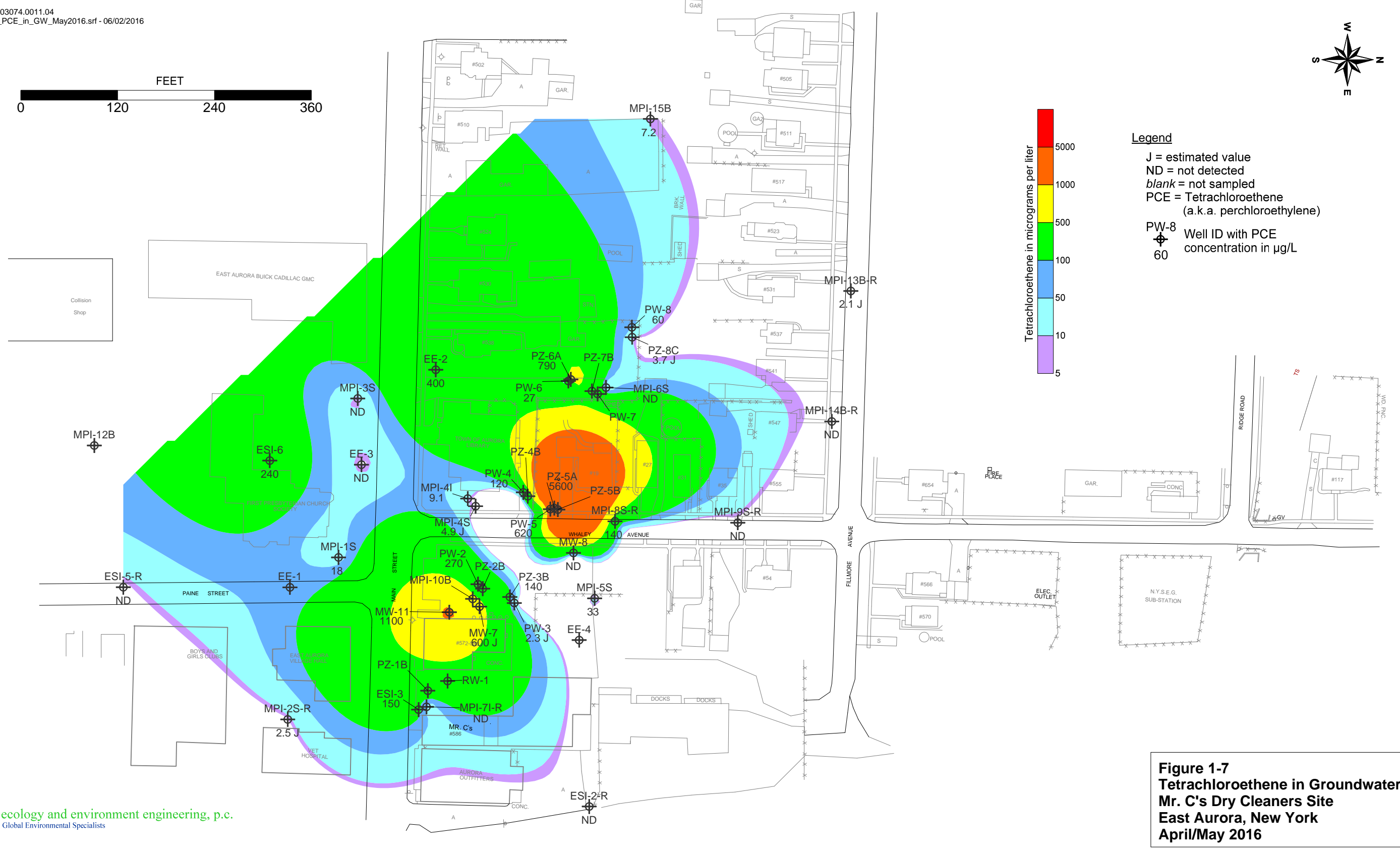
**Legend**  
 ND = not detected  
 NS = not sampled  
 cVOC = Sum of PCE + daughter product concentrations  
 PW-8  
 Well ID with cVOC concentration in µg/L  
 100



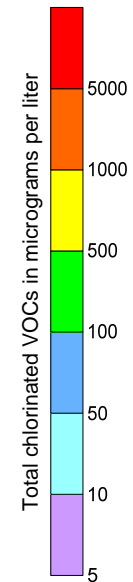
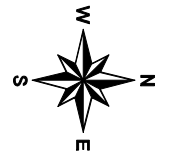
**Figure 1-6**  
**Total Chlorinated VOCs in Groundwater**  
**Mr. C's Dry Cleaners Site**  
**East Aurora, New York**  
**October 2014**



- Legend**
- J = estimated value
  - ND = not detected
  - blank = not sampled
  - PCE = Tetrachloroethene (a.k.a. perchloroethylene)
  - PW-8  
⊕ Well ID with PCE concentration in µg/L
  - 60

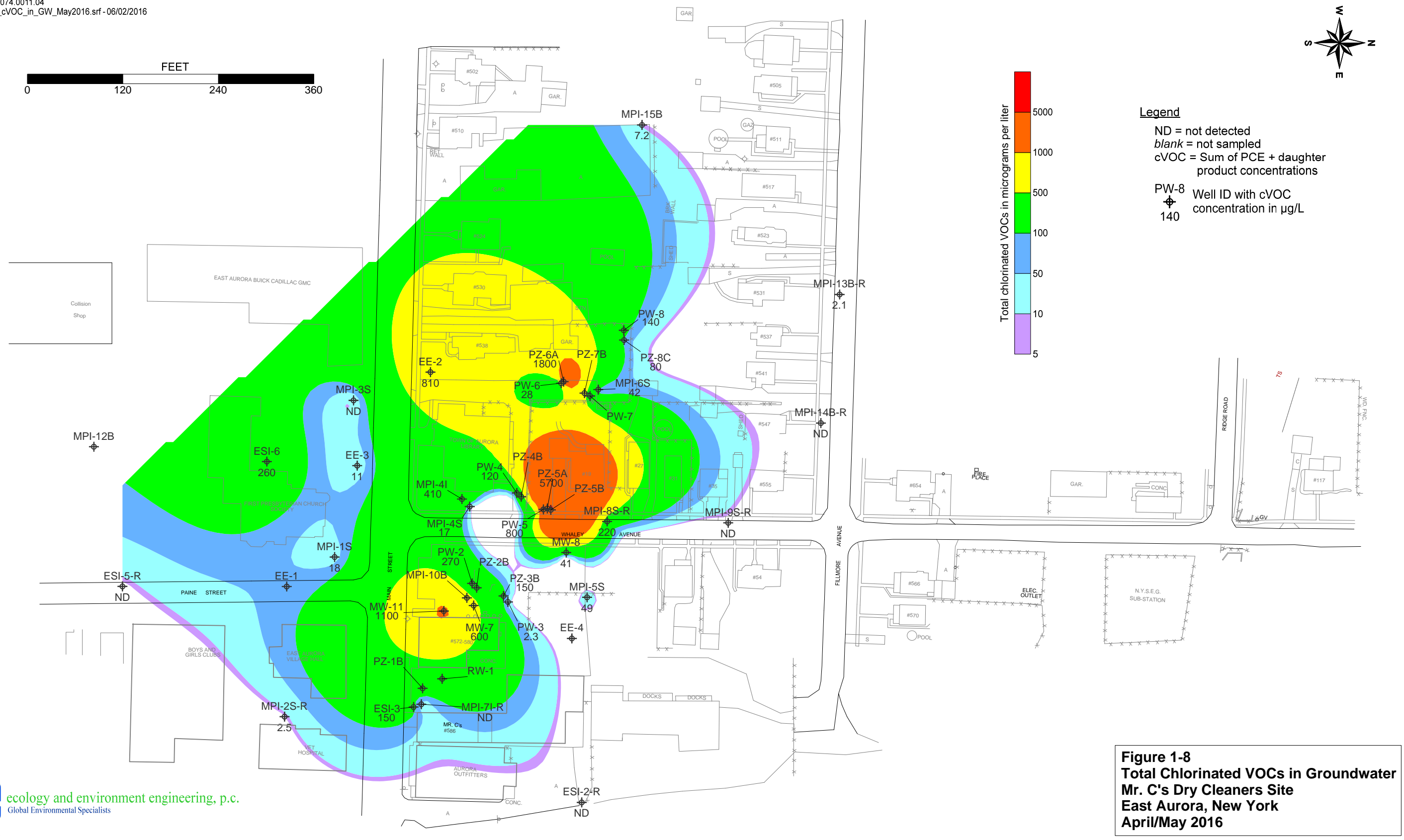


**Figure 1-7  
Tetrachloroethene in Groundwater  
Mr. C's Dry Cleaners Site  
East Aurora, New York  
April/May 2016**

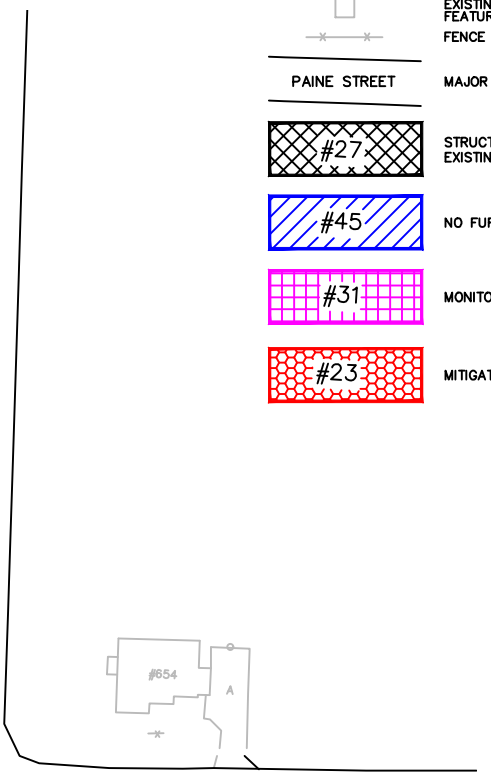
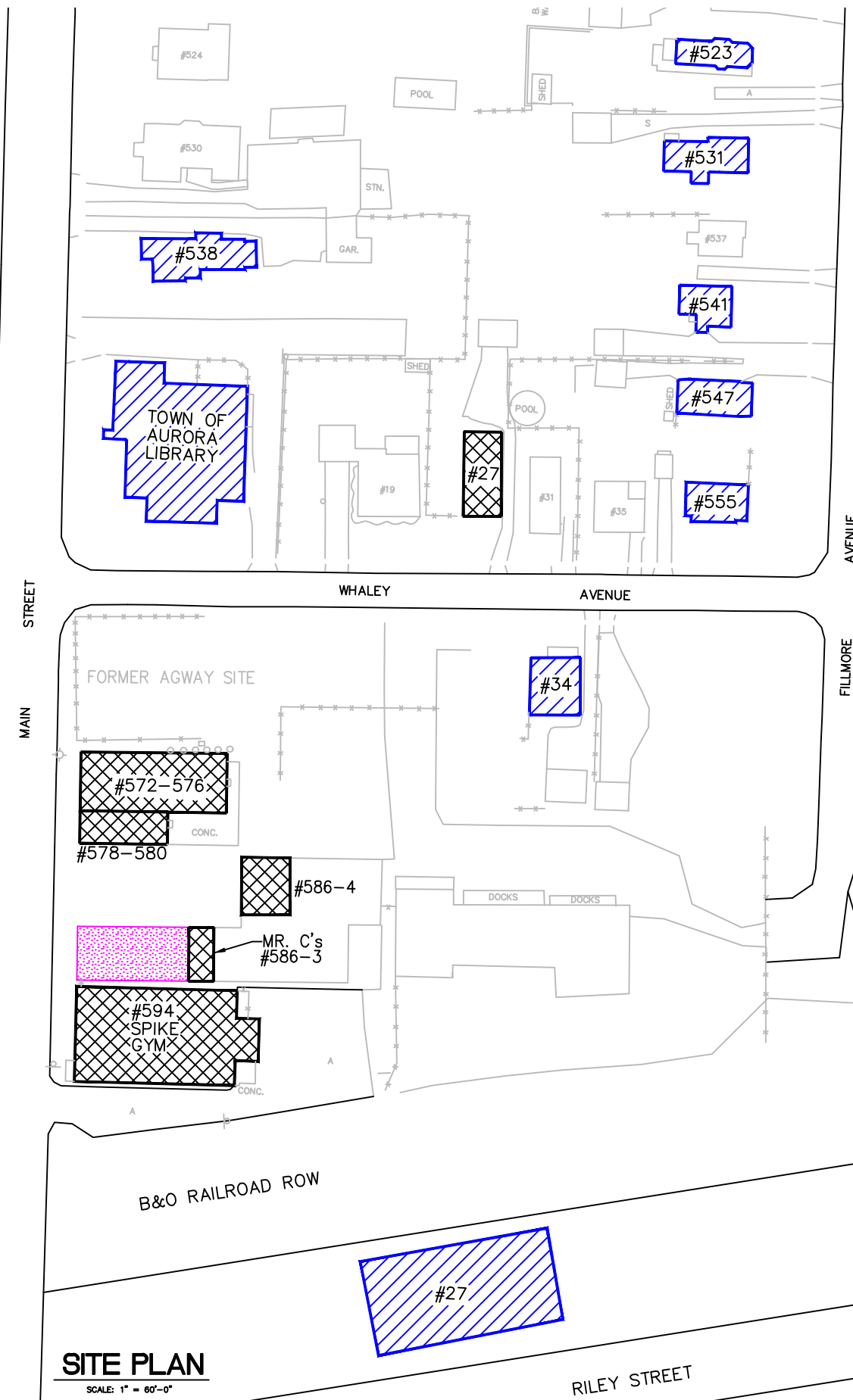
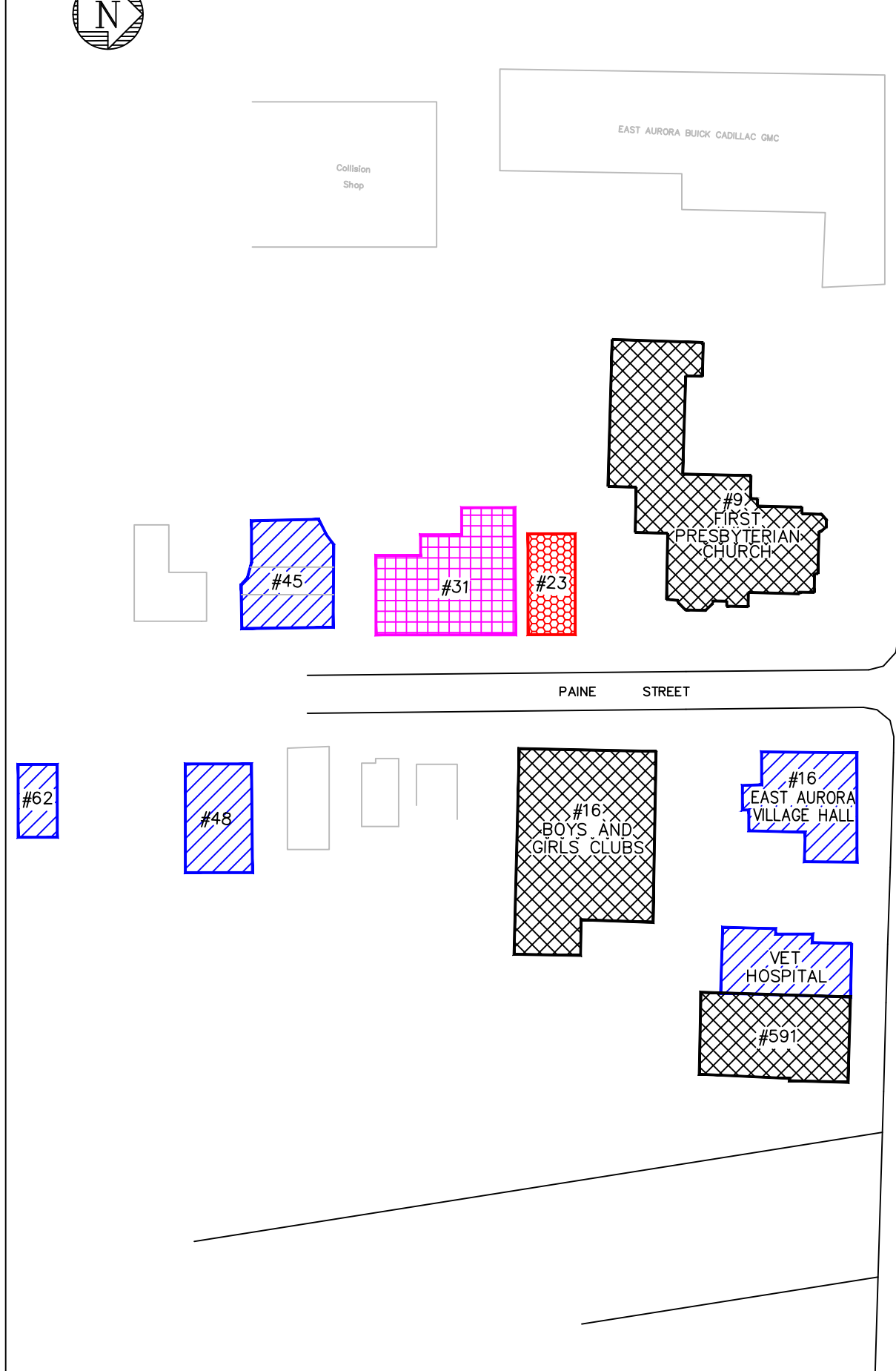


**Legend**

- ND = not detected
- blank = not sampled
- cVOC = Sum of PCE + daughter product concentrations
- Well ID with cVOC concentration in µg/L



**Figure 1-8**  
**Total Chlorinated VOCs in Groundwater**  
**Mr. C's Dry Cleaners Site**  
**East Aurora, New York**  
**April/May 2016**



**LEGEND**

	EXISTING STRUCTURES AND FEATURES
	FENCE
	MAJOR AREA STREETS
	STRUCTURE/ADDRESS WITH EXISTING MITIGATION SYSTEM
	NO FURTHER ACTION
	MONITOR/MITIGATE
	MITIGATE

- 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 (SVI) 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. SVI 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 SVIS PERFORMED IN 2015: 547 FILLMORE AVENUE; 23, 31, 45, AND 48 PAINE STREET; AND 27 RILEY STREET.

**SITE PLAN**  
SCALE: 1" = 60'-0"

DWG NO.	DATE	DESCRIPTION	NO.	DATE	BY	APPD.	DESCRIPTION
DEC 31 ISO.dwg	7/18/94	ISOPOENTIAL 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.	A	9/8/15	KMK	MGS	ISSUED FOR REVIEW
REFERENCE DRAWINGS			REVISIONS				

FIGURE 1-9  
SVII AND SSDS APPLICATIONS  
MR.C'S DRY CLEANERS SITE LOCATION MAP  
EAST AURORA, NEW YORK



# 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 an 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 pumping and treating) and physically limit contaminant exposure (e.g., through fencing). ECs can be associated with ICs, such as monitoring wells for LTM 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 tech-

## 2 Development of Remedial Optimization Alternatives

nologies 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 and a reactive barrier that stimulates PCE degradation. The reactive barrier can be created by the injection of emulsified oil, colloidal activated carbon, zero-valent iron, etc., or a combination thereof.

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 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 Development of Remedial Optimization Alternatives

### 2.1.2 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 <sup>1</sup>	Engineering Controls <sup>2,3</sup>
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:

<sup>1</sup> The inspection frequency will continue as indicated unless otherwise specified by NYSDEC.

<sup>2</sup> Specific requirements for inspections are described in Section 4 of the revised SMP (EEEEPC 2015b).

<sup>3</sup> Reporting requirements are summarized in Section 5 of the revised SMP (EEEEPC 2015b).

Key:

SMP = Site Management Plan

SSDS = sub-slab depressurization system

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 Site Management Plan. 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;

## 2 Development of Remedial Optimization Alternatives

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 would be performed to maintain protection of human health until RAOs are again attained. 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 volatilize 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 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).

**BIOREMEDIATION**  
**DECISION**  
**PUMP & TREAT**

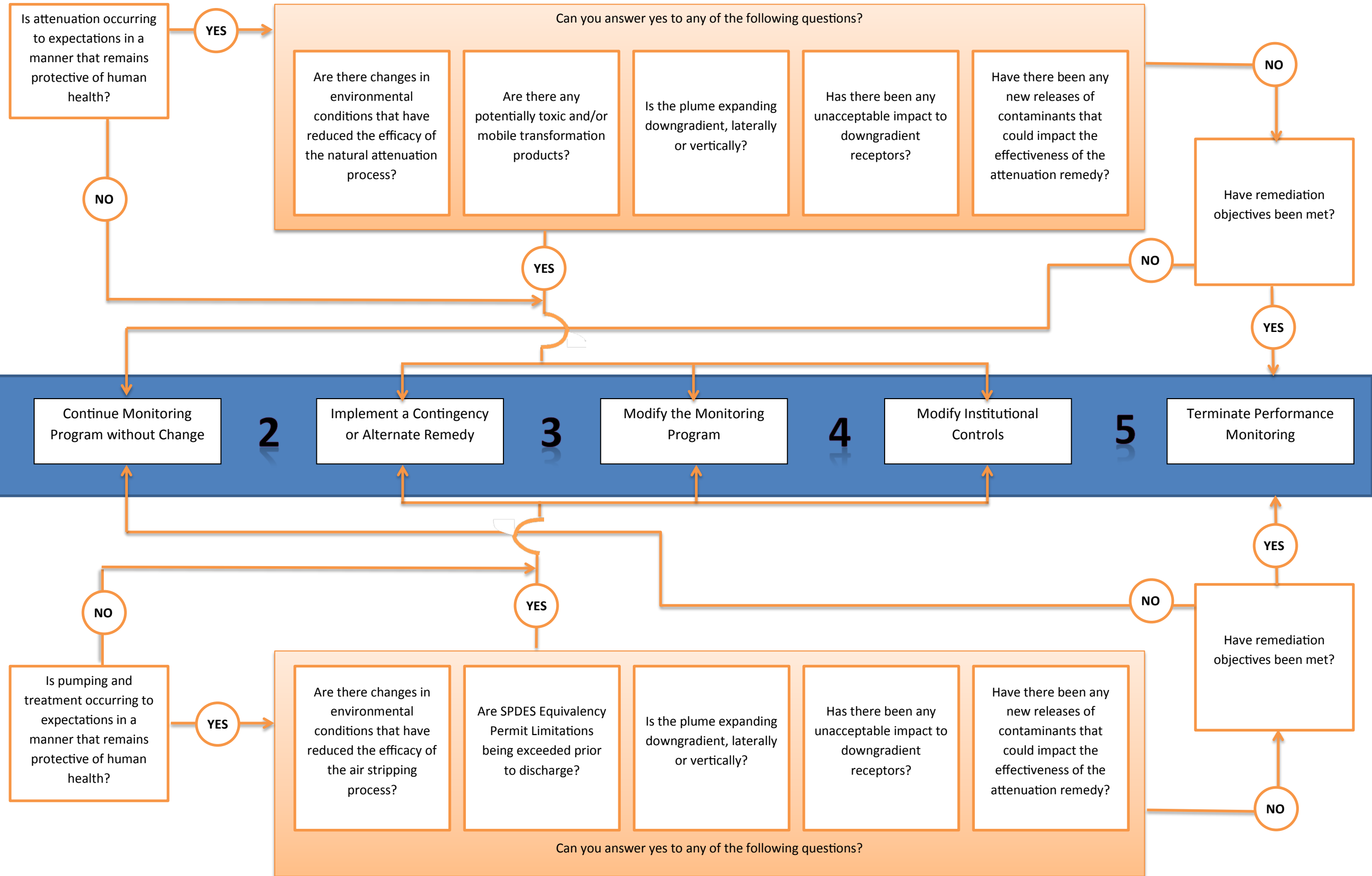


Figure 2-1 Performance Monitoring Framework

## 2 Development of Remedial Optimization Alternatives

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 NYSDOH'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

## 2 Development of Remedial Optimization Alternatives

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 (EEEEPC 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

## 2 Development of Remedial Optimization Alternatives

discharged through a 1,350-foot-long force main to an outfall on Tannery Brook (EEEEPC 2007).

Over time, the highest VOC concentrations 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 (EEEEPC 2015d). With the plume now 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.



## 2 Development of Remedial Optimization Alternatives

The Pilot Study conducted at the Mr. C's Site used a Regenesi s emulsified oil product called Regenesi s Hydrogen Release Compound Primer (HRC Primer®) and Regenesi s 3D-Microemulsion® (3DMe). Based on the results of the Pilot Study, this RSO report evaluates both of these two different electron-donor product combinations for a reactive barrier wall design: (1) Regenesi s HRC Primer® and 3DMe, and (2) Regenesi s 3DMe 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 mixture is a slow-release compound intended to provide a food source to the microbes for the engineered timeframe of two years. The Regenesi s product 3DMe includes a buffered solution to protect against the inhibitory effects of pH on degradation reactions. Regenesi s 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. Regenesi s product information and application instructions are provided in Appendix B. When PlumeStop® is used in conjunction with source control, this RSO assumes that the grid spacing can be designed to achieve both downgradient control and source mitigation in the same locations.

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.

## 2 Development of Remedial Optimization Alternatives

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 volatilize 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, and 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.

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.

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.

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). 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 (EEEEPC 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 (EEEEPC 2015a).

**2.1.7.1 Reductive Dechlorination**

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.

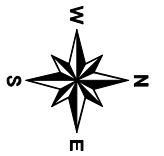
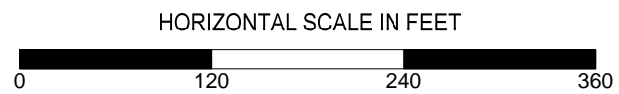
When native populations of the microbes capable of reductive dechlorination are absent or present at concentrations that are too low to maintain the desired reaction rate, the subsurface can be augmented with commercially available microbial cultures. Regensis Bio-Dechlor INOCULUM® Plus (BDI PLUS) was 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. 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.

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. Additional injections of 3DMe should be considered every three years to ensure that nutrients are present at sufficient levels in the subsurface to sustain the *Dehalococcoides* spp. for the timeframe required to reduce all PCE, TCE, DCE, and VC to ethene.




**2.1.7.2 Anti-methanogenic Reagents**

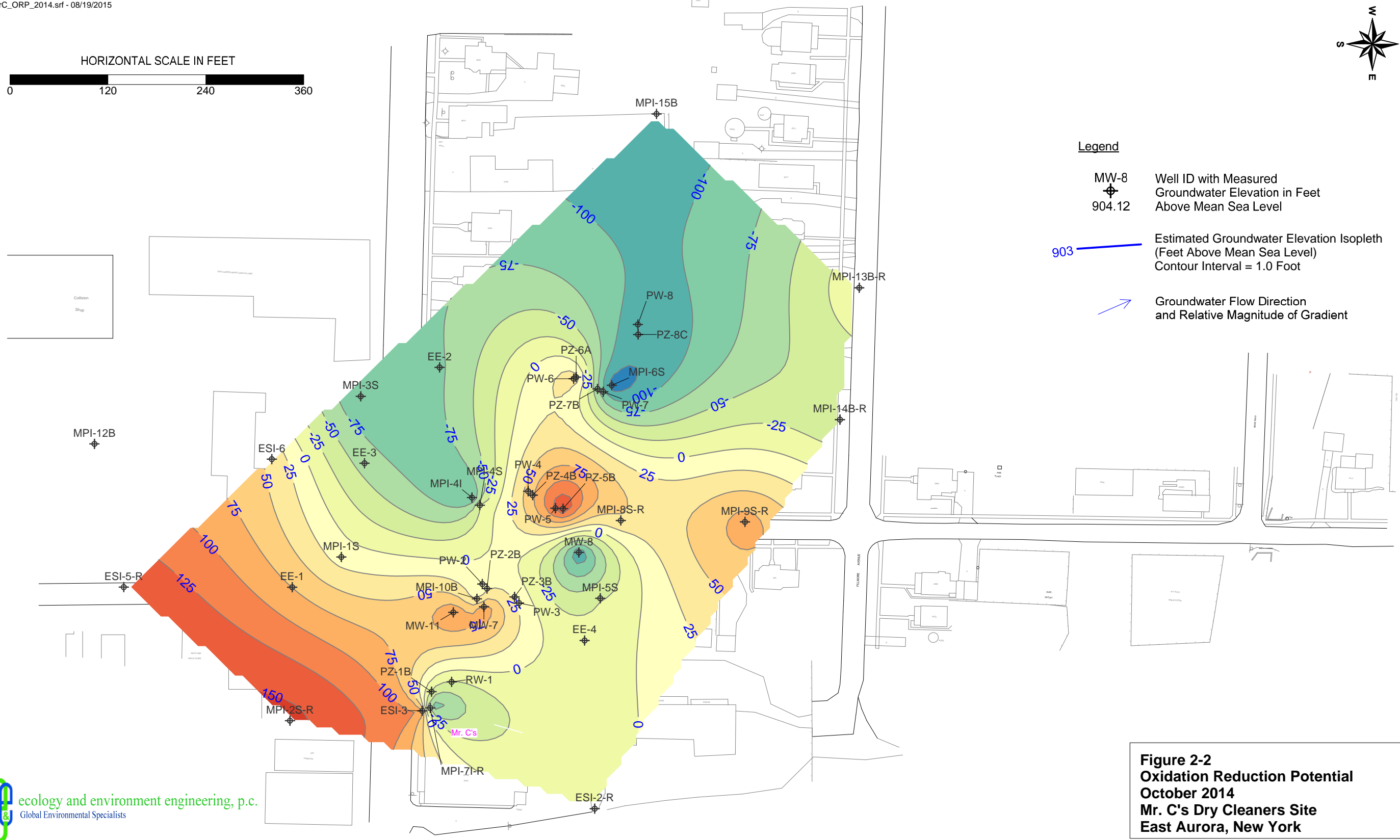
The Regensis electron donor supplied to facilitate the degradation of chlorinated ethenes by microbes of the *Dehalococcoides* genus is also consumed in a competing reaction by indigenous microbes that produce dissolved methane. The biotic production of dissolved methane is referred to as methanogenesis. 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, some risk remains and may factor into the acceptance of the Alternative.

Provectus Environmental Products, Inc., offers a product called Provect-IR®, which is an alternative in situ reagent that inhibits methanogenic bacteria to mitigate the excessive production of methane, such as that observed during the Pilot Study. Provect-IR® combines the stimulation of reductive dechlorination by *Dehalococcoides* spp. with zero-valent iron, chemical oxygen scavengers, and vitamin and mineral sources. The key ingredient that inhibits methanogenesis is a red yeast rice extract, which contains a compound called Monacolin K, which is a naturally occurring statin compound. Statins are also the key ingredient in cholesterol-lowering drugs, and the mechanism of methanogenesis inhibition is similar



**Legend**

-  MW-8 Well ID with Measured Groundwater Elevation in Feet Above Mean Sea Level
-  903 Estimated Groundwater Elevation Isopleth (Feet Above Mean Sea Level) Contour Interval = 1.0 Foot
-  Groundwater Flow Direction and Relative Magnitude of Gradient



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

## 2 Development of Remedial Optimization Alternatives

to the inhibition of an enzyme in the biosynthesis of cholesterol. Provect-IR® has been accepted for use by the Florida Department of Environmental Protection and has been used in other states, including North Carolina. Additional Provect-IR® documentation is provided in Appendix C. This anti-methanogenic reagent was also considered for source and migration bioremediation alternatives.

### 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**

Source Control Migration Management	Pump and Treat with Existing Air Stripper System and Increased Pump Capacity	Targeted grid Injections for Enhanced Bioremediation
Pump and Treat with the Existing Air Stripper System	Alternative 1	Alternative 3
Permeable Reactive Barrier Injections of Regenesis 3DMe®	Alternative 2a	Alternative 4a
Injections of Regenesis PlumeStop® Liquid Activated Carbon and 3DMe®	Alternative 2b PRB injections only	Alternative 4b Source injections only
Permeable Reactive Barrier Injections of Provectus Provect-IR®	Alternative 2c	Alternative 4c

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.

#### 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.

## 2 Development of Remedial Optimization Alternatives

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 LTM 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.

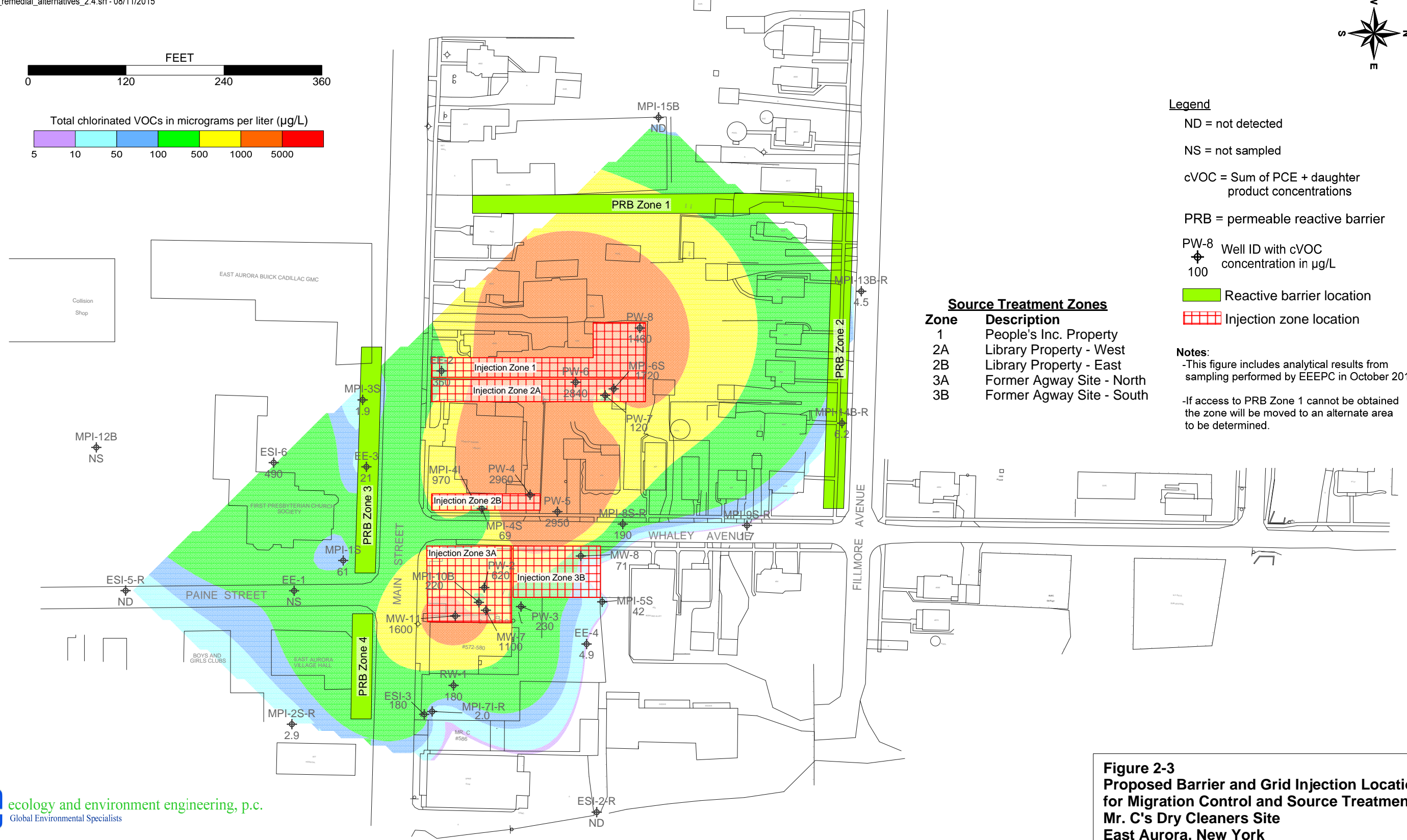
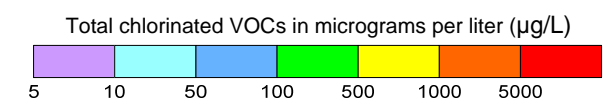
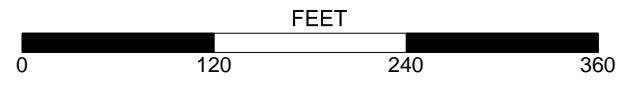
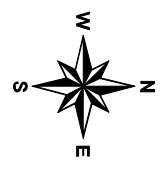
In the event that Alternative 1 fails to meet the RAOs and the air stripper system has not treated groundwater effectively in over 6 months, a response action would be taken to address the decline in efficiency (see Figure 2-1).

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 Bioremediation for Migration Control

Alternatives 2a, 2b, and 2c 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 PRB walls. Under Alternative 2a, the barrier walls would comprise injections of Regenesis 3DMe that extend to a depth of 30 feet with a thickness of 20 feet. Under Alternative 2b, the barrier walls would comprise injections of 3DMe and PlumeStop®. Under Alternative 2c the PRB would comprise injections of Provectus Provect-IR®. Alternatives 2b and 2c would have the same injection zone depth and treatment thickness as Alternative 2a. 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.



**Legend**

ND = not detected  
 NS = not sampled  
 cVOC = Sum of PCE + daughter product concentrations  
 PRB = permeable reactive barrier  
 PW-8 Well ID with cVOC concentration in µg/L  
 100  
 Reactive barrier location  
 Injection zone location

**Notes:**  
 -This figure includes analytical results from sampling performed by EEEPC in October 2014.  
 -If access to PRB Zone 1 cannot be obtained the zone will be moved to an alternate area to be determined.

**Source Treatment Zones**

Zone	Description
1	People's Inc. Property
2A	Library Property - West
2B	Library Property - East
3A	Former Agway Site - North
3B	Former Agway Site - South

**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**

### **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 throughout the zones and BDI PLUS in zone 3A. BDI PLUS increases the presence of *Dehalococcoides* spp. 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 LTM 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 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 PRBs 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.

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, 4b, and 4c all include the grid injections from Alternative 3. For each of Alternatives 4a, 4b, and 4c, injection zone depths and treatment thicknesses would be the same as in Alternative 2. 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 de-



## 2 Development of Remedial Optimization Alternatives

commissioning of the existing pump-and-treat system. Shutoff of the system would occur prior to decommissioning at the time the PRBs are installed for migration control.

### 2.2.4.1 Alternative 4a

Under Alternative 4a, the grid source injections would be paired with the PRB injections from Alternative 2. Injections of Regenesis 3DMe would be performed to facilitate bioremediation via reductive dechlorination. Augmentation of source zones upgradient of the bioremediation pilot study area would also be performed. 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, based on product literature and Pilot Study results.

### 2.2.4.2 Alternative 4b

Under Alternative 4b, source injections of Regenesis 3DMe would be performed with augmentation, as described in Alternative 4a, and with Regenesis PlumeStop®. The PlumeStop® activated carbon would sorb the contaminants in place, reducing the need for a downgradient barrier; therefore, no PRB injections are included in Alternative 4b. The PlumeStop® product would retain the contaminants in place, thereby increasing the efficiency of the bioremediation, reducing the need for maintenance injections.

### 2.2.4.3 Alternative 4c

Under Alternative 4c, Provectus Provect-IR® would be used in both the PRB injection locations from Alternative 2 and the grid source areas from Alternative 3 to mitigate potential impacts from methanogenesis. Injections in the source zones upgradient of the bioremediation pilot study would also be augmented with an inoculum of PCE-reducing microbes. The Provect-IR® reagent mixture is designed to address competition for reagent from methanogenic bacteria, which reduces reagent demand and the amount of methane produced. Maintenance injections may still be required due to dilution of the reagent from bulk groundwater flow; however, product literature indicates longevity of over five years.

# 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, PRB thicknesses, and other parameters. These data were then used to evaluate remediation optimization alternatives and develop cost estimates. Three modeling programs (BIOCHLOR, SourceDK, and REM-Chlor) 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 a reagent and/or augmented with an inoculant, 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, inoculation with the *Dehalococcoides* spp. is required upgradient of the Pilot Study, which means Zone 3A from Figure 2-3. *Dehalococcoides* spp. are already present in the remaining grid injection zones.

The results of future performance monitoring efforts would be used to determine the timing, amount, and locations of re-injections of reagents required to maintain the biodegradation rates needed to achieve remediation within the desired timeframe.

#### 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

### 3 Alternative Analysis Methodology and Results

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 wells 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. LTM 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 determine 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 tailing and 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-

### 3 Alternative Analysis Methodology and Results

and-treat or bioremediation alternatives, LTM and ICs would have to continue for the foreseeable future. Net present worth analyses were performed using a duration of 30 years for the periodic and annual costs described 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 <sub>t</sub>	Saturated thickness of contaminated aquifer / depth of plume	20 ft
N	Porosity	0.25
γ <sub>soil</sub>	Soil bulk density	2.34 g/cm <sup>3</sup> or 146 lbs/cf
Q <sub>gw</sub>	Groundwater flow	390 ft/yr
	Pumping rate (upgraded pumps)	10 gpm
f <sub>oc</sub>	Fraction organic carbon <sup>1</sup>	0.00755
K <sub>oc</sub>	Organic carbon partitioning coefficient <sup>2</sup>	364
γ <sub>water</sub>	Water density	1 g/cm <sup>3</sup>
R	Retardation factor	20
Q <sub>c</sub>	Contaminant flow	19 ft/yr
FS	Factor of safety	3

Notes:

1. The average f<sub>oc</sub> is taken from the 1996 Malcolm Pernie RI.
2. The K<sub>oc</sub> 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<sup>3</sup> = 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,  $k_{\text{point}}$ , which represents concentration versus time.  $k_{\text{point}}$  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,  $\lambda$ , 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,  $k_{\text{point}}$  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  $k_{\text{point}}$  is limited by the amount of raw data available for its calculation. In general,  $k_{\text{point}}$  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,  $k_{\text{point}}$  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 PRBs was calculated by (1) determining the residence time in the PRB required to degrade PCE and achieve the NYSDEC 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 PRBs (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 $\mu\text{g/L}$
$C_{GA}$	Class GA Groundwater Standard for VOCs	5 $\mu\text{g/L}$
$V_{GW}$	Groundwater Velocity	0.045 ft/yr
$FS_{3D}$	Factor of Safety for 3DMe alone	3
$FS_{\text{plume}}$	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)
$\theta$	Residence time in barrier	227 days

Key:

- ft = feet
- ft/yr = feet per year
- kg = kilogram
- $\mu\text{g/L}$  = 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

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

Parameter		Assumption / Input Value
$C_{GWO}$	Average source groundwater concentration at time = 0	1160 $\mu\text{g/L}$
$C_{soil}$	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	$1.5E+05 \text{ ft}^3/\text{yr}$
$\gamma_{soil}$	Soil bulk density	2.34 kg/L
$\lambda$	PCE degradation rate constant	9.33/yr

Key:

- ft = feet
- ft/yr = feet per year
- ft/day = feet per day
- $\text{ft}^3/\text{yr}$  = cubic feet per year
- kg = kilogram
- $\mu\text{g/L}$  = 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 LTM. 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 D.

Table 4-1 Alternative Evaluation

Implementability		Effectiveness	Estimated Time to Reach RAOs <sup>1</sup>	Sustainability	Net Present Value of Life-cycle Costs
<b>Alternative 1 Pump and Treat for Source and Migration Control</b>					
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	
<b>Alternative 2a Pump-and-Treat Source Control with Bioremediation for Migration Control – 3D Microemulsion® PRBs</b>					
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	
<b>Alternative 2b Pump-and-Treat Source Control with Bioremediation for Migration Control – 3D Microemulsion® and PlumeStop® PRBs</b>					
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	Same as 2a	\$4.1 million	

4-3

Table 4-1 Alternative Evaluation

Implementability	Effectiveness	Estimated Time to Reach RAOs <sup>1</sup>	Sustainability	Net Present Value of Life-cycle Costs
<b>Alternative 2c Pump-and-Treat Source Control with Bioremediation for Migration Control – Provect-IR® PRBs</b>				
Feasible; design would accommodate access agreements on private properties.	See Alternative No. 2a. Provect-IR® will increase the efficiency of the Alternative because it reduces competition from methanogenic bacteria for the injected reagents.	Over 30 years	Same as 2a	\$3.8 million
<b>Alternative 3 Bioremediation for Source Control with Pump and Treat for Migration Control</b>				
Poor. Bioremediation as source control would conflict with pump-and-treat operation.	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
<b>Alternative 4a Bioremediation for Source and Migration Control – 3D Microemulsion®</b>				
Feasible; design would accommodate access agreements on private properties.	<p>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.</p> <p>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 byproduct (ethane).</p>	As few as 5 years in injection zones, over 30 years where injections are limited by structures over the plume.	Bioremediation will produce fewer direct and indirect green-house gases than pump-and-treat because less OM&M will be required and no electricity is used.	\$2.6million

4-4

**Table 4-1 Alternative Evaluation**

Implementability	Effectiveness	Estimated Time to Reach RAOs <sup>1</sup>	Sustainability	Net Present Value of Life-cycle Costs
<b>Alternative 4b Bioremediation for Source and Migration Control – 3D Microemulsion® and PlumeStop®</b>				
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.	Same as 4a	Same as 4a	\$2.5 million
<b>Alternative 4c Bioremediation for Source and Migration Control – Provect-IR®</b>				
Feasible; design would accommodate access agreements on private properties.	See Alternative No. 4a. Provect-IR® will increase the efficiency of the Alternative because it reduces competition from methanogenic bacteria for the injected reagents.	Same as 4a	Even fewer green-house gases will be produced than Alternatives 4a and 4b, since methane generation is inhibited.	\$2.1 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
- SVII = Soil Vapor Intrusion Investigation

# 5

## Recommended Alternative for Remedial Optimization

EEEEPC recommends that NYSDEC consider Alternative 4c, Provect-IR® Bioremediation Source Control and PRB for Migration Control, for remedial site optimization at the Mr. C's Dry Cleaners Site. Alternative 4c is recommended because it is the most cost-effective option that meets the evaluation criteria and is readily implementable. Alternative 4c is estimated to cost \$2.1 million dollars over 30 years, whereas Alternative 1, continued pump and treat only, is estimated to cost \$3.4 million dollars over the same time period. Alternative 4c would reduce annual operating costs from an estimated \$197,289 to \$36,633. NYSDEC would break even on the total capital costs and begin to realize the cost savings in year 9 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.

PRBs 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 PRBs 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 4c 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 el-



## 5 Recommended Alternative for Remedial Optimization

ements 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 after implementation of the Alternative.

OM&M of the SSDSs may in the future be transferred for performance under 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 and should include institutional controls to protect construction and utility workers from potential exposure to site contamination. 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 LTM 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 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 4c includes the eventual decommissioning of the existing pump-and-treat system. The system may be shut off prior to decommissioning at the time the PRBs are installed for migration control. However, prior to shutdown of the treatment system, it could be temporarily operated to target Pilot Study areas with high cis-DCE concentrations (operating pumping wells PW4, PW5, PW6, PW7, and PW8). Several wells have been shut off to avoid secondary impacts on the treatment system; however, cis-DCE is more mobile than PCE and may be able to be removed more effectively than PCE through pumping before secondary impacts on the treatment system become an issue. Increased cis-DCE in the influent may require some adjustments to the treatment system fan speeds during operation.

Implementation of Alternative 4c 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

## **5 Recommended Alternative for Remedial Optimization**

assessment, and community involvement as the original remedy. 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.

While this RSO substantially documents the relative benefits and cost effectiveness of the technology, 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 may 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 SSDS, 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).

# 6

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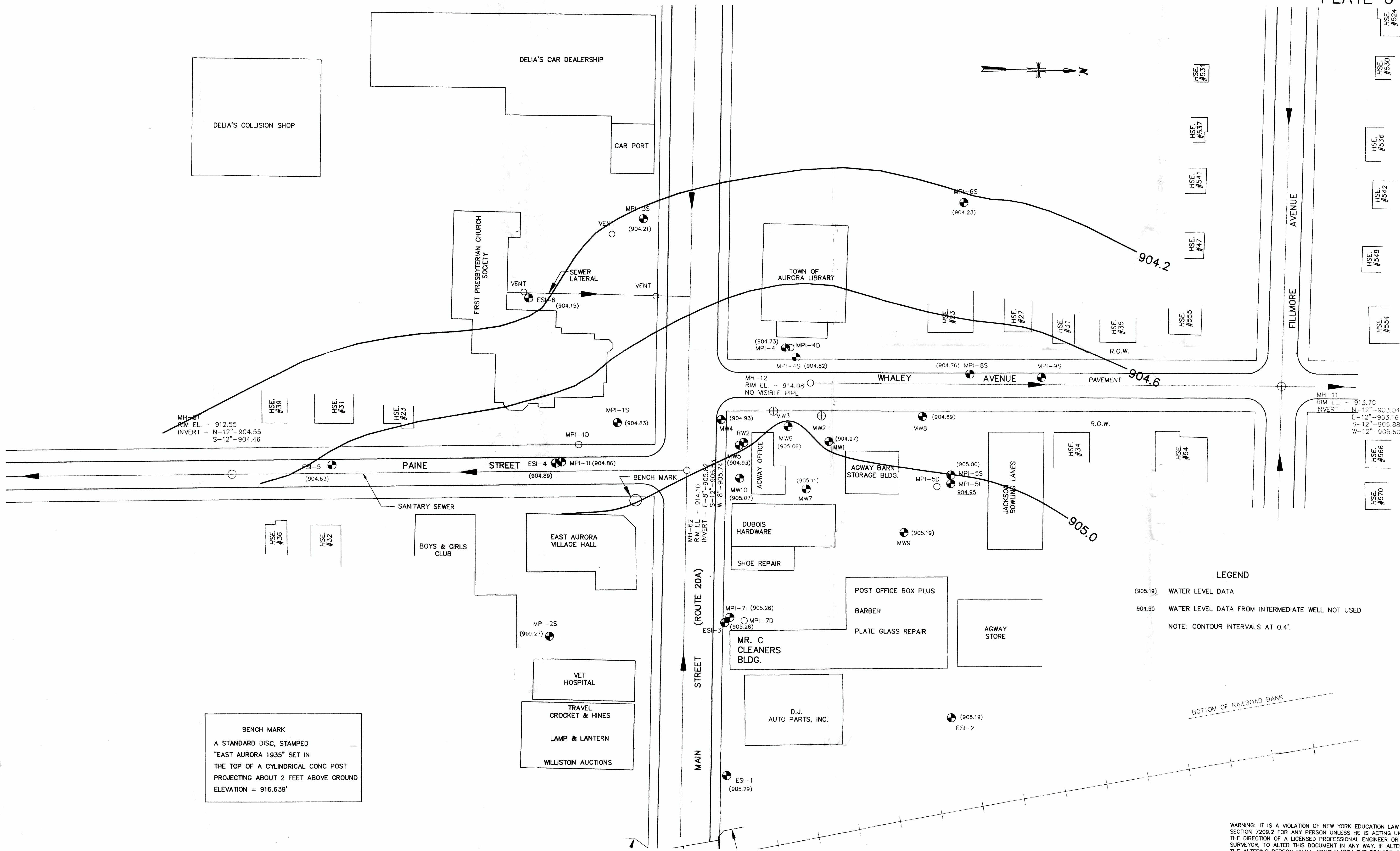
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# A

## Groundwater Isopotential Maps

- A-1 Pre-Remedy Groundwater Isopotentials
- A-2 March 11, 2016, Groundwater Isopotentials during LTGW Purging
- A-3 April 13, 2016, Groundwater Isopotentials during LTGW Purging
- A-4 May 10, 2016, Groundwater Isopotentials during LTGW Purging
- A-5 April 25, 2016, Groundwater Isopotentials during LTGW Purging



**BENCH MARK**  
 A STANDARD DISC, STAMPED  
 "EAST AURORA 1935" SET IN  
 THE TOP OF A CYLINDRICAL CONC POST  
 PROJECTING ABOUT 2 FEET ABOVE GROUND  
 ELEVATION = 916.639'

**LEGEND**  
 (905.19) WATER LEVEL DATA  
 904.95 WATER LEVEL DATA FROM INTERMEDIATE WELL NOT USED  
 NOTE: CONTOUR INTERVALS AT 0.4'

WARNING: IT IS A VIOLATION OF NEW YORK EDUCATION LAW SECTION 7209.2 FOR ANY PERSON UNLESS HE IS ACTING UNDER THE DIRECTION OF A LICENSED PROFESSIONAL ENGINEER OR LAND SURVEYOR, TO ALTER THIS DOCUMENT IN ANY WAY. IF ALTERED THE ALTERING PERSON SHALL COMPLY WITH THE REQUIREMENTS OF NEW YORK EDUCATION LAW SECTION 7209.2.

**MALCOLM PIRNIE**

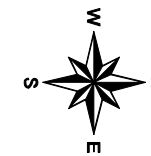
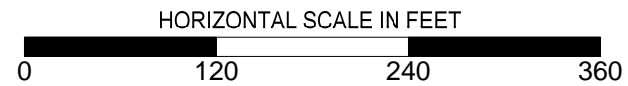
REVISIONS			
NO.	BY	DATE	REMARKS

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  
 CAP. REF. NO. DEC-31-CWL

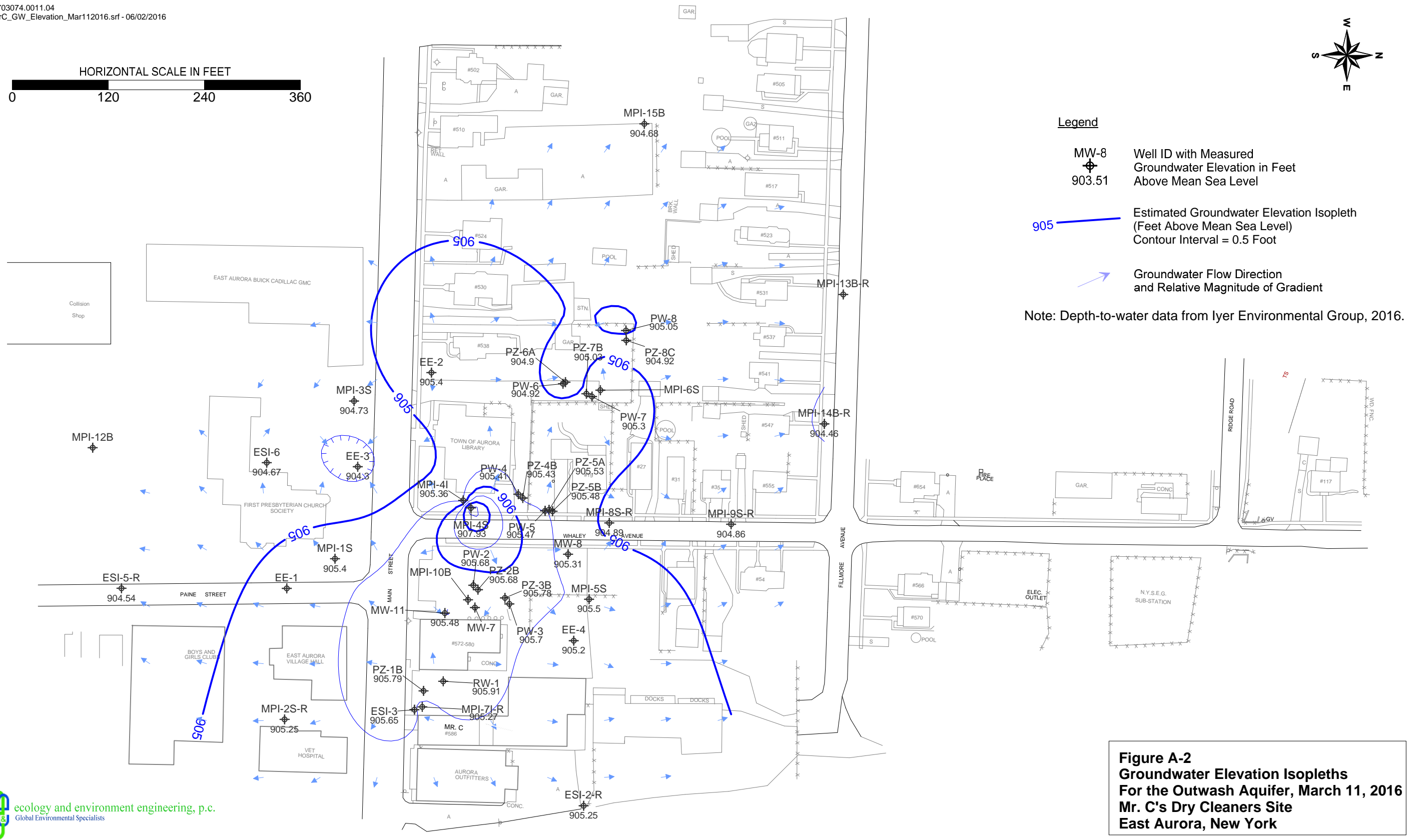




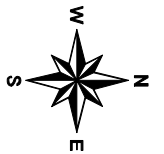
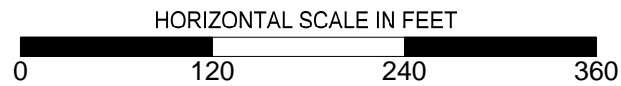
**Legend**

- MW-8  
903.51 Well ID with Measured Groundwater Elevation in Feet Above Mean Sea Level
- 905 Estimated Groundwater Elevation Isoleth (Feet Above Mean Sea Level) Contour Interval = 0.5 Foot
- Groundwater Flow Direction and Relative Magnitude of Gradient




Note: Depth-to-water data from Iyer Environmental Group, 2016.



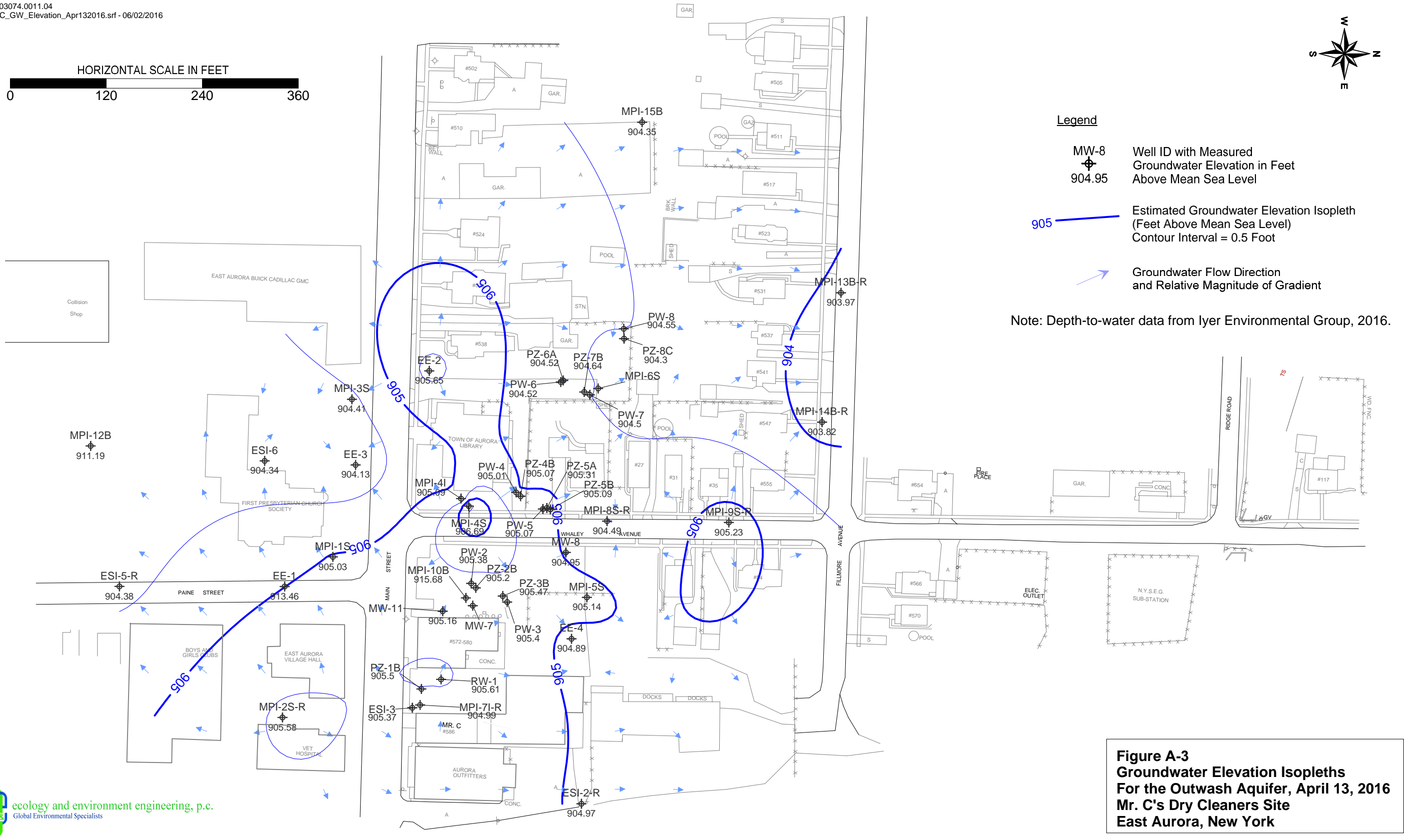
**Figure A-2**  
Groundwater Elevation Isoleths  
For the Outwash Aquifer, March 11, 2016  
Mr. C's Dry Cleaners Site  
East Aurora, New York



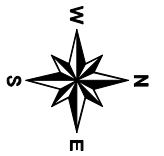
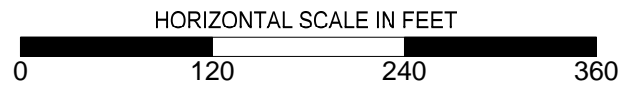
**Legend**

- MW-8  Well ID with Measured Groundwater Elevation in Feet Above Mean Sea Level  
904.95
- 905  Estimated Groundwater Elevation Isopleth (Feet Above Mean Sea Level) Contour Interval = 0.5 Foot
-  Groundwater Flow Direction and Relative Magnitude of Gradient


Note: Depth-to-water data from Iyer Environmental Group, 2016.




**Figure A-3**  
**Groundwater Elevation Isopleths**  
**For the Outwash Aquifer, April 13, 2016**  
**Mr. C's Dry Cleaners Site**  
**East Aurora, New York**



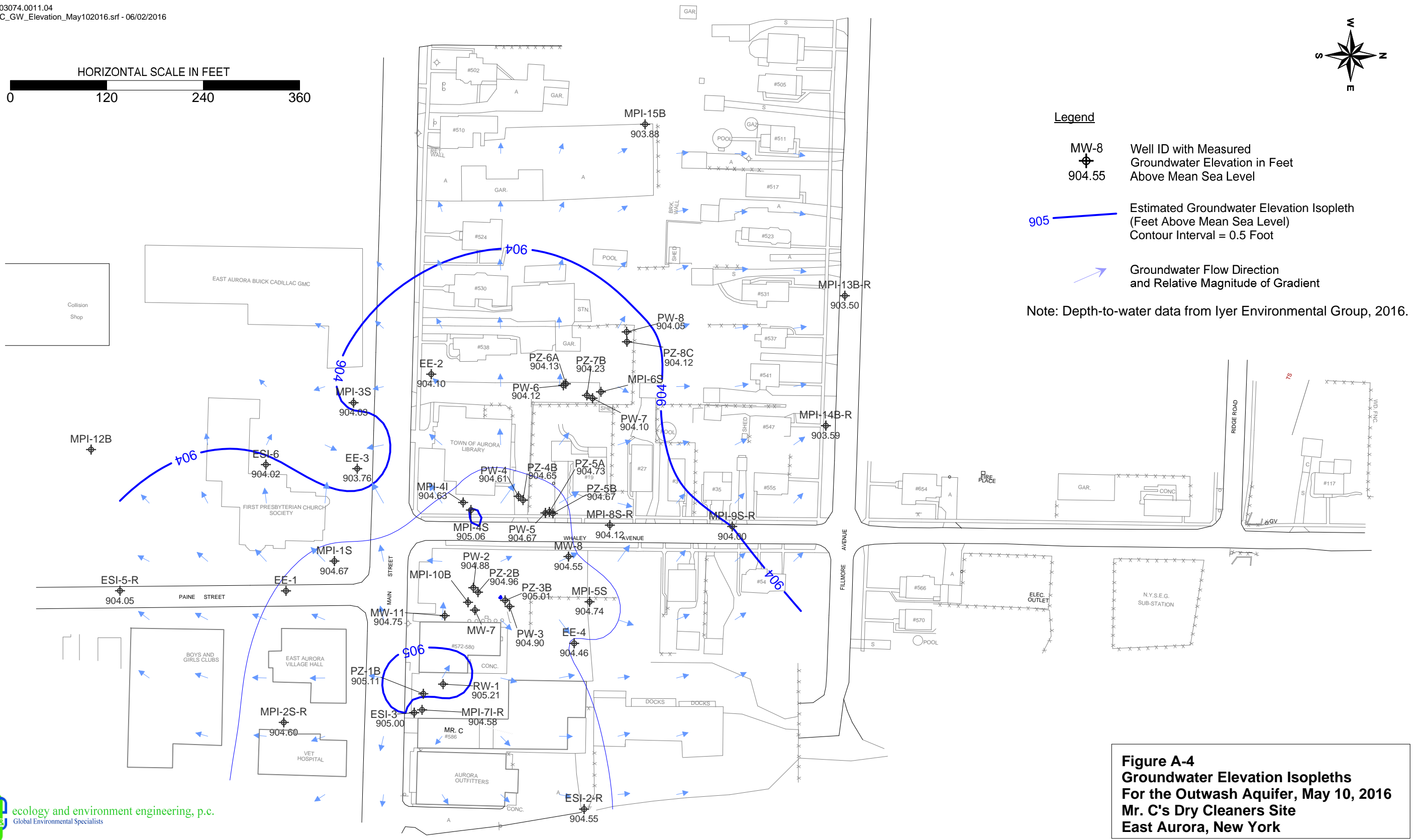
**Legend**

MW-8  
 Well ID with Measured  
 904.55 Groundwater Elevation in Feet  
 Above Mean Sea Level

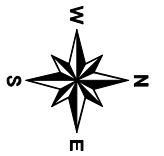
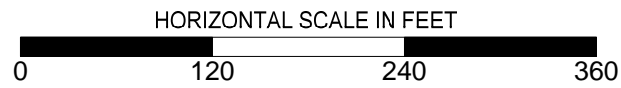
905  
 Estimated Groundwater Elevation Isopleth  
 (Feet Above Mean Sea Level)  
 Contour Interval = 0.5 Foot

 Groundwater Flow Direction  
 and Relative Magnitude of Gradient


Note: Depth-to-water data from Iyer Environmental Group, 2016.





**Figure A-4**  
 Groundwater Elevation Isopleths  
 For the Outwash Aquifer, May 10, 2016  
 Mr. C's Dry Cleaners Site  
 East Aurora, New York



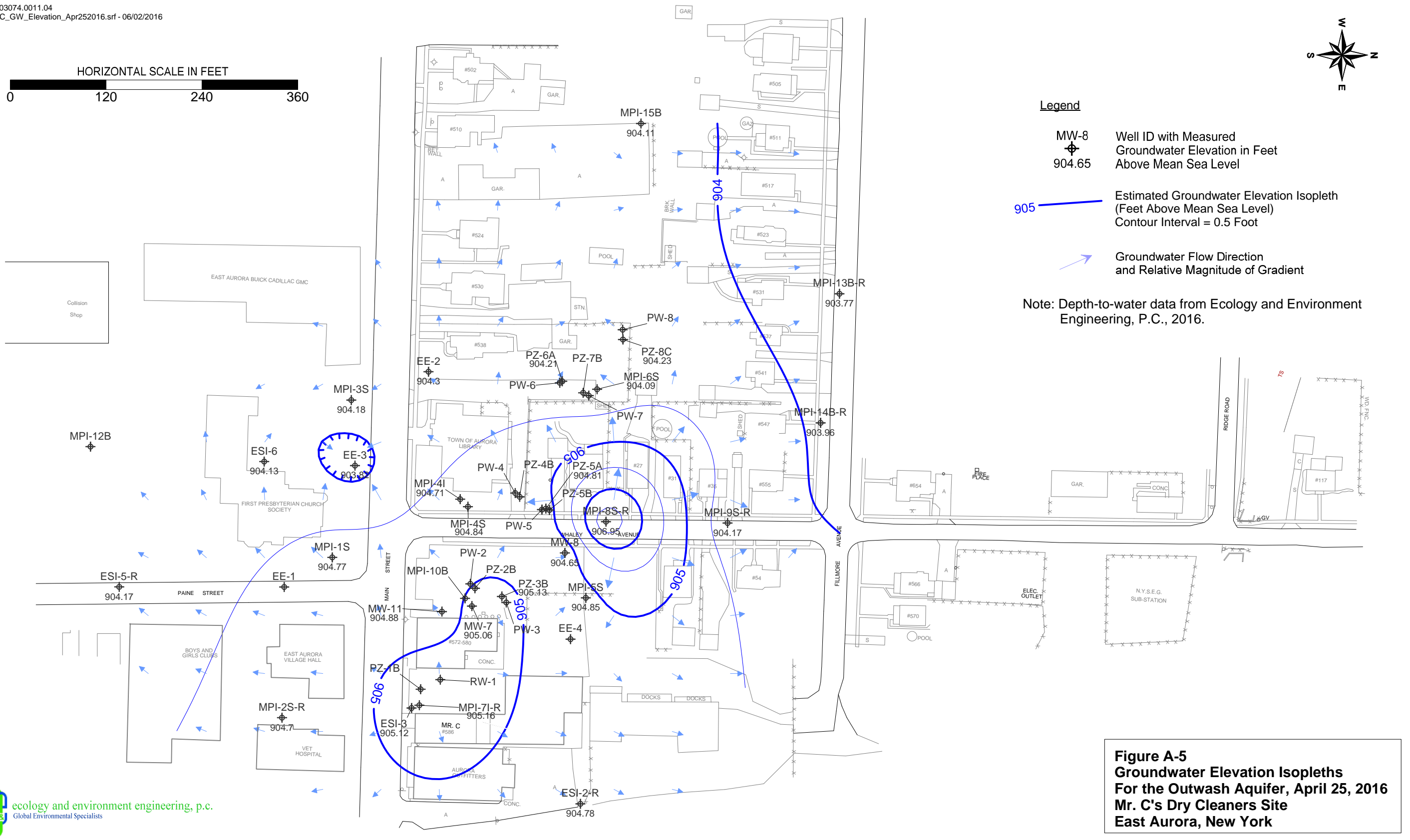
**Legend**

MW-8  
 Well ID with Measured  
 904.65 Groundwater Elevation in Feet  
 Above Mean Sea Level

905  Estimated Groundwater Elevation Isopleth  
 (Feet Above Mean Sea Level)  
 Contour Interval = 0.5 Foot

 Groundwater Flow Direction  
 and Relative Magnitude of Gradient

Note: Depth-to-water data from Ecology and Environment  
 Engineering, P.C., 2016.



**Figure A-5**  
 Groundwater Elevation Isopleths  
 For the Outwash Aquifer, April 25, 2016  
 Mr. C's Dry Cleaners Site  
 East Aurora, New York

# B

## Regenesis Product Information

- B-1 3D 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**



## 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.

**FEATURES & BENEFITS**

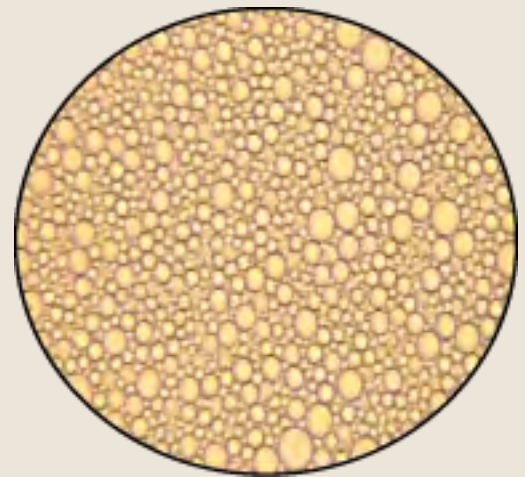
- **3 Stage Electron Donor Release Profile Avoids Multiple Re-applications Saving Time and Money**

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).

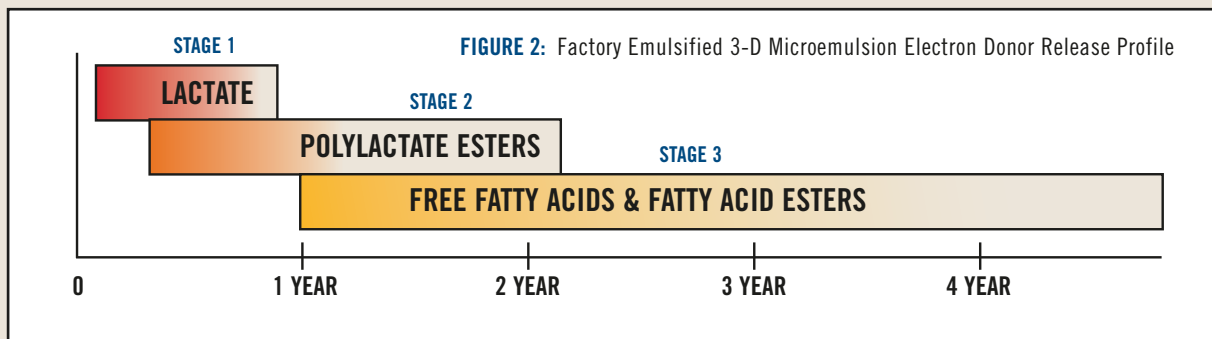
**Stage 1** - Immediately available free lactic acid (lactate) is fermented rapidly

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





## 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.

- **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).



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



# REGENESIS 3-D Microemulsion<sup>®</sup> Factory Emulsified

## Factory Emulsified, pH Neutral, Staged Release, Electron Donor Emulsion

### PRODUCT APPLICATION INSTRUCTIONS

#### 3-D Microemulsion<sup>®</sup> 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 other 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 50°F (10°C). If the user plans to apply the product in cold weather, consideration should be given to warming the material to above 50°F 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.

# REGENESIS 3-D Microemulsion<sup>®</sup> Factory Emulsified

Factory Emulsified, pH Neutral, Staged Release, Electron Donor Emulsion

## PRODUCT APPLICATION INSTRUCTIONS



*3-D Microemulsion<sup>®</sup> 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<sup>®</sup> 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)

**REGENESIS 3-D Microemulsion® Factory Emulsified**  
**Factory Emulsified, pH Neutral, Staged Release, Electron Donor Emulsion**

**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 Regenesys Technical Services.

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

<b>3-D Microemulsion Factory Emulsified (%)</b>	<b>3-D Microemulsion Factory Emulsified (mg/L)</b>	<b>3-D Microemulsion Factory Emulsified (gal)</b>	<b>Clear Water (gal)</b>	<b>Resulting Volume (gal)</b>
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:

# REGENESIS 3-D Microemulsion<sup>®</sup> Factory Emulsified

## Factory Emulsified, pH Neutral, Staged Release, Electron Donor Emulsion

### PRODUCT APPLICATION INSTRUCTIONS

#### On Demand – Dosatron<sup>®</sup> 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<sup>®</sup> 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<sup>®</sup> Website at <http://www.dosatronusa.com/search-results.aspx?QueryExpr=manuals> .

**REGENESIS 3-D Microemulsion® Factory Emulsified**  
**Factory Emulsified, pH Neutral, Staged Release, Electron Donor Emulsion**

## 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 applicator 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).

# REGENESIS 3-D Microemulsion® Factory Emulsified

## Factory Emulsified, pH Neutral, Staged Release, Electron Donor Emulsion

### 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@regenesisc.com](mailto:tech@regenesisc.com)

**3-D Microemulsion<sup>®</sup> Factory Emulsified  
MATERIALS SAFETY DATA SHEET**

Last Revised: November 15, 2011

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**Section 1 – Material Identification**

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**Supplier:**



**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-oxopropoxy]-1-oxopropoxy]propanoates]

**Chemical Family:** Organic Chemical

**Trade Name:** 3-D Microemulsion<sup>®</sup> Factory Emulsified

**Synonyms:** HRC Advanced<sup>®</sup>, HRC-PED (Hydrogen Release Compound – Partitioning Electron Donor)

**Product Use:** Used to remediate contaminated groundwater (environmental applications)

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**Section 2 – Chemical Identification**

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<u>CAS#</u>	<u>Chemical</u>
823190-10-9	HRC-PED
72-17-3	Sodium Lactate
7789-20-0	Water

### Section 3 – Physical Data

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

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### Section 4 – Fire and Explosion Hazard Data

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**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.**

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### Section 5 – Toxicological Information

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<b>Acute Effects:</b>	May be harmful by inhalation, ingestion, or skin absorption. May cause irritation.
<b>Sodium Lactate:</b>	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.
<b>Soybean Oil:</b>	Health Hazards (Acute and Chronic): Acute: none observed by inhalation. Chronic: none reported.
<b>Inhalation Risks and Symptoms of Exposure:</b>	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.

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**Section 6 – Health Hazard Data**

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**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.

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**Section 7 – Reactivity Data**

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**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

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**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.**

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### Section 9 – Special Protection or Handling

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**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.

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### Section 10 – Other Information

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**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 Regenesi's Hydrogen Release Compound (HRC®) products.



SPECIES OF *DEHALOCOCCOIDES* SP. (DHC)

BIO-DECHLOR INOCULUM

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<sup>SM</sup>, 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.<sup>1,2</sup>

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.

Regenesi 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.

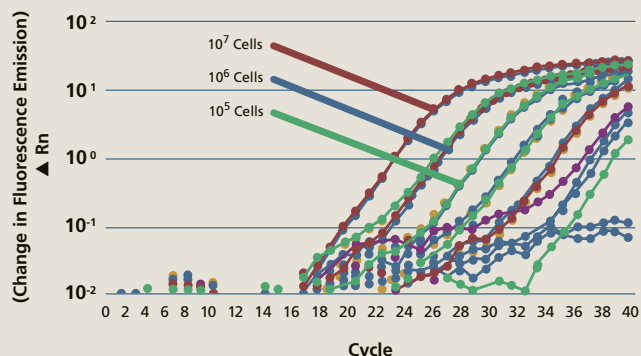


FIGURE 1: REAL-TIME PCR AMPLIFICATION OF 10-FOLD DILUTIONS OF GENOMIC DNA DERIVED FROM *DEHALOCOCCOIDES*

BIO-DECHLOR CENSUS

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.



Advanced Technologies for Groundwater Resources



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## Bio-Dechlor INOCULUM PLUS (BDI PLUS™)

### Application Instructions (Direct-Push Injection)

#### General Information

**Bio-Dechlor INOCULUM PLUS (BDI PLUS™)** 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<sup>3</sup> 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**

REGENESIS BDI PLUS APPLICATION INSTRUCTIONS - 2007  
For Additional Information Please Visit [www.regenesis.com](http://www.regenesis.com) or call 949-366-8000

### CULTURE CONTAINER DISCHARGING

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.



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## 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<sup>3</sup> 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.**



Advanced Technologies for Groundwater Resources

1011 Calle Sombra  
San Clemente, CA 92673  
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Advanced Technologies for Groundwater Resources

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## 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<sub>2</sub>O = 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<sub>2</sub>O = 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 sewerred, 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.

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While the information and recommendations set forth herein are believed to be accurate as of the date hereof, REGENESIS MAKES NO WARRANTY WITH RESPECT HERETO AND DISCLAIMS ALL LIABILITY FROM RELIANCE THEREON.



**Appendix B-3**

**HRC Primer MSDS**

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

**Last Revised:** August 17, 2005

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**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](mailto: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

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**Section 2 – Chemical Identification**

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<u>CAS#</u>	<u>Chemical</u>
201167-72-8	Glycerol Polylactate
50-21-5	Lactic Acid

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**Section 3 - Physical Data**

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<b>Melting Point:</b>	NA
<b>Boiling Point:</b>	ND
<b>Flash Point:</b>	ND
<b>Density:</b>	1.10 g/cc
<b>Solubility:</b>	Water, Acetone and DMSO
<b>Appearance:</b>	Yellow Liquid
<b>Odor:</b>	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 tripoly lactate 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 BIOFX\* 9-4/1970  
85JCAE-,207,1986 85JCAE-,207,1986  
EYE-RBT 126 MG MLD  
EYE-RBT 500 MG/24H MLD

**Toxicity data:** ORL-MUS LD50:4090 MG/KG  
FRZKAP (6),56,1977  
SCU-RBT LD50:100 MG/KG NIIRDN 6,215,1982  
ORL-RAT LD50:12600 MG/KG FEPR7 4,142,1945  
IHL-  
RATLC50:>570MG/M3/1HBIOFX\*9- RCOCB8 56,125,1987  
4/1970 IPR-RAT LD50: 4420 MG/KG ARZNAD  
IVN-RAT LD50:5566 MG/KG 26,1581,1976  
IPR-MUS LD50: 8700 MG/KG ARZNAD  
SCU-MUS LD50: 91 MG/KG 26,1579,1978  
IVN-MUS LD50: 4250 MG/KG NIIRDN 6,215,1982  
ORL-RBT LD50: 27 GM/KG JAPMA8 39,583,1950  
SKN-RBT LD50:>10GM/KG DMDJAP 31,276,1959  
BIOFX\* 9-4/1970  
IVN-RBT LD50: 53 GM/KG NIIRDN 6,215,1982  
JIHTAB 23,259,1941  
ORL-GPG LD50: 7750 MG/KG

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**Section 5 - Toxicological Information (cont)**

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<b>Target Organ data:</b>	Behavioral (headache), gastrointestinal (nausea or vomiting), Paternal effects (spermatogenesis, testes, epididymis, sperm duct), effects of fertility (male fertility index, post-implantation mortality).	
<b>Acute Effects:</b>	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 tripoly lactate have not been investigated. Listed below are the toxicological information for glycerol and lactic acid.	
<b>RTECS#:</b>	OD2800000 Lactic acid	
<b>Irritation data:</b>	SKN-RBT 5MG/24H SEV	85JCAE -,656,86
	EYE-RBT 750 UG SEV	AJOPAA 29,1363,46
<b>Toxicity data:</b>	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
	ORL-GPG LD50: 1810 MG/KG	JHHTAB 23,259,41
	ORL-QAL LD50: >2250 MG/KG	FMCHA2-,C252,91

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.

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**Section 6 - Health Hazard Data**

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**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)**

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**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.

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**Section 9 - Special Protection or Handling**

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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.

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### Section 10 - Other Information

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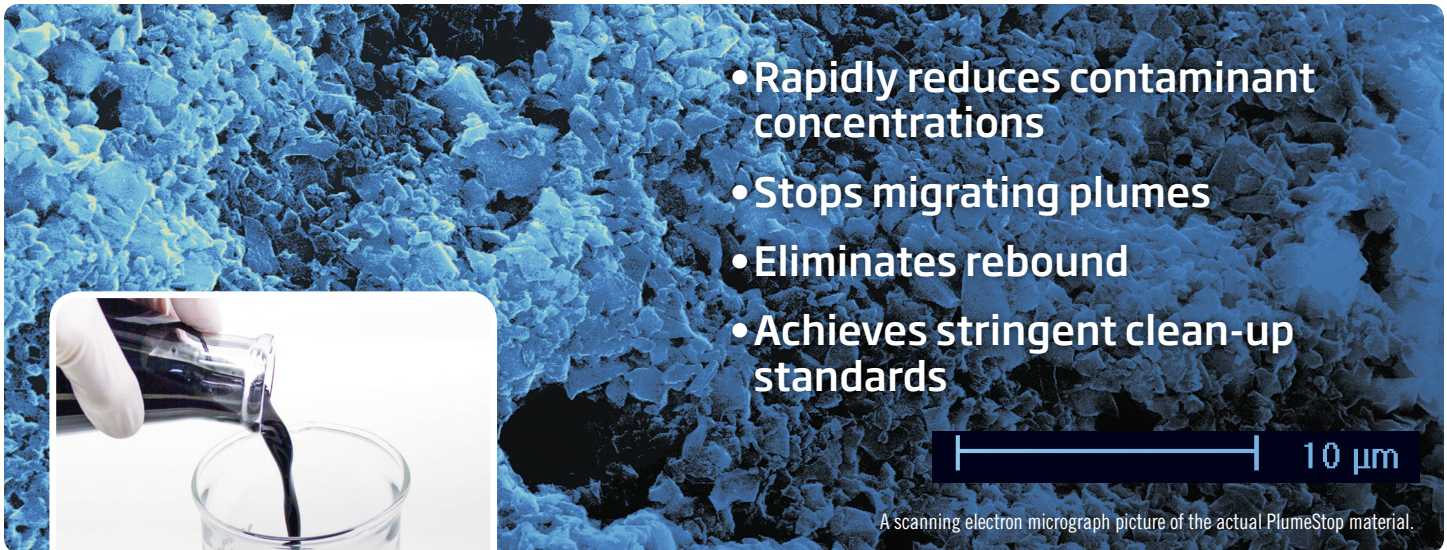
**This material will degrade in the environment by hydrolysis to lactic acid and glycerol. Materials containing reactive chemicals should be used only by personnel with appropriate chemical training.**

**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**



- Rapidly reduces contaminant concentrations
- Stops migrating plumes
- Eliminates rebound
- Achieves stringent clean-up standards

10 μm

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.

To learn more about PlumeStop visit [plumestop.com](http://plumestop.com) or contact your local REGENESIS Remediation Technologies representative.



# PlumeStop® Liquid Activated Carbon™ Technical Description

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

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



Distribution of PlumeStop in water

To see a list of treatable contaminants with the use of PlumeStop, view the [Range of Treatable Contaminants Guide](#).

## Chemical Composition

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

## Properties

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

## Storage and Handling Guidelines

### Storage

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

### Handling

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

# PlumeStop® Liquid Activated Carbon™ Technical Description

## Applications

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

## Health and Safety

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



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**Appendix B-5**

**Site Information Provided to Regensis**

<b>Grid Injections</b>					
	<b>Zone 1</b>	<b>Zone 2A</b>	<b>Zone 2B</b>	<b>Zone 3A</b>	<b>Zone 3B</b>
<b>Injection Area</b>					
# 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
<b>Aquifer</b>					
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
<b>Volatile Organics, unfiltered groundwater</b>					
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
<b>Anions, unfiltered groundwater</b>					
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
<b>Parameters</b>					
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)

**Permeable Reactive Barriers (3DMe and PlumeStop)**

	<b>Zone 1</b>	<b>Zone 2</b>	<b>Zone 3</b>	<b>Zone 4</b>
<b>Injection Area</b>				
# 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
<b>Aquifer</b>				
Hydraulic k	11 ft/day	11 ft/day	11 ft/day	11 ft/day
Hydraulic grad.	0.004	0.004	0.004	0.004
<b>Volatile Organics, unfiltered groundwater</b>				
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
<b>Volatile Organics, potential VOC concentration into barrier zone</b>				
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
<b>Anions, unfiltered groundwater</b>				
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
<b>Parameters</b>				
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 Regensis**



Project Info			PlumeStop® Application Design Summary		
<b>Mr. C - Barrier Areas</b> <b>East Aurora, NY</b> <b>Dissolved phase</b> Prepared For: <b>Ecology and Environment</b>			<b>Dissolved phase</b>		<b>Field App Instructions</b>
<b>Target Treatment Zone (TTZ) Info</b>			<b>Application Method</b>	<b>Direct Push</b>	
Treatment Area	ft <sup>2</sup>	18,720	Spacing Within Rows (ft)	10	
Top Treat Depth	ft	12.0	Spacing Between Rows (ft)	10	
Bot Treat Depth	ft	32.0	<b>Application Points</b>	<b>187</b>	
Vertical Treatment Interval	ft	20.0	Areal Extent (square ft)	18,720	
Treatment Zone Volume	ft <sup>3</sup>	374,400	Top Application Depth (ft bgs)	12	
Treatment Zone Volume	cy	13,867	Bottom Application Depth (ft bgs)	32	
Soil Type	---	sand	<b>PlumeStop to be Applied (lbs)</b>	<b>96,400</b>	
Porosity	cm <sup>3</sup> /cm <sup>3</sup>	0.33	PlumeStop per point (lbs)	516	
Effective Porosity	cm <sup>3</sup> /cm <sup>3</sup>	0.20	PlumeStop per point (gals)	62	
Treatment Zone Pore Volume	gals	924,233	<b>Mixing Water (gal)</b>	<b>120,514</b>	
Treatment Zone Effective Pore Volume	gals	560,141	Mixing Water (per pt)	644	
Fraction Organic Carbon (foc)	g/g	0.002	<b>Total Application Volume (gals)</b>	<b>132,066</b>	
Soil Density	g/cm <sup>3</sup>	1.7	Injection Volume per Point (gals)	706	
Soil Density	lb/ft <sup>3</sup>	108	<b>Anaerobic Bioremediation - HRC</b>		
Soil Weight	lbs	4.0E+07	<b>HRC Application Points</b>	<b>94</b>	
Hydraulic Conductivity	ft/day	11.0	<b>HRC to be Applied (lbs)</b>	<b>14,976</b>	
Hydraulic Conductivity	cm/sec	3.88E-03	HRC per point (lbs)	159	
Hydraulic Gradient	ft/ft	0.004	<b>Total Application Volume (gals)</b>	<b>1380</b>	
GW Velocity	ft/day	0.01	Injection Volume per Point (gals)	14.7	
GW Velocity	ft/yr	2			
<b>Sources of Hydrogen Demand</b>			<b>Technical Notes/Discussion</b>		
Dissolved Phase Contaminant Mass	lbs	27			
Sorbed Phase Contaminant Mass	lbs	57			
Competing Electron Acceptor Mass	lbs	694			
<b>Total Mass Contributing to H<sub>2</sub> Demand</b>	<b>lbs</b>	<b>779</b>			
<b>Stoichiometric Demand</b>			Prepared By: <i>Corinne Ketcham - East Region Technical manager</i> Date: <i>8/27/2015</i>		
Stoichiometric H <sub>2</sub> Demand	lbs	49			
<b>Stoichiometric HRC Demand</b>	<b>lbs</b>	<b>2,196</b>			
Engineering/Safety Factor	--	9			
<b>Application Dosing</b>			<b>Assumptions/Qualifications</b>		
<b>Plume Stop to be Applied</b>	<b>lbs</b>	<b>96,400</b>	In generating this preliminary estimate, Regensis 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.		
<b>HRC to be Applied</b>	<b>lbs</b>	<b>14,976</b>			



Project Information			3-D Microemulsion®, BDI® Plus, CRS® Application Design Summary			
<b>Mr. C - Grid Injection Areas</b> <b>East Aurora, NY</b> <b>Dissolved phase</b> Prepared For: <b>Ecology and Environment</b>			<b>Dissolved phase</b>		<b>Field App. Instructions</b>	
			<b>Application Method</b>		<b>Direct Push</b>	
			Spacing Within Rows (ft)		13	
			Spacing Between Rows (ft)		15	
<b>Target Treatment Zone (TTZ) Info</b>			<b>Application Points</b>	<b>176</b>		
Treatment Area	ft <sup>2</sup>	34,271	Areal Extent (square ft)	34,271		
Top Treat Depth	ft	12.0	Top Application Depth (ft bgs)	12	<b>Field Mixing Ratios</b>	
Bot Treat Depth	ft	32.0	Bottom Application Depth (ft bgs)	32	3DME Concentrate per Pt (lbs)	
Vertical Treatment Interval	ft	20.0	<b>3DME to be Applied (lbs)</b>	<b>49,200</b>	280	
Treatment Zone Volume	ft <sup>3</sup>	685,425	3DME to be Applied (gals)	5,896	Mix Water per Pt (gals)	
Treatment Zone Volume	cy	25,386	3DME Mix %	10%	301	
Soil Type	---	sand	<b>Volume Water (gals)</b>	<b>53,062</b>	3DME Mix Volume per Pt (gals)	
Porosity	cm <sup>3</sup> /cm <sup>3</sup>	0.33	3DME Mix Volume (gals)	58,957	335	
Effective Porosity	cm <sup>3</sup> /cm <sup>3</sup>	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 <sup>3</sup>	1.7				
Soil Density	lb/ft <sup>3</sup>	108				
Soil Weight	lbs	7.4E+07	<b>Total Application Volume (gals)</b>	<b>58,957</b>	Volume per pt (gals)	
Hydraulic Conductivity	ft/day	25.0	Estimated Radius of Injection (ft)	3.8	335	
Hydraulic Conductivity	cm/sec	8.82E-03			Volume per vertical ft (gals)	
Hydraulic Gradient	ft/ft	0.004			17	
GW Velocity	ft/day	11.00	<b>Technical Notes/Discussion</b>			
GW Velocity	ft/yr	4,018				
<b>Sources of 3-D Microemulsion Demand</b>	<b>Unit</b>	<b>Value</b>				
Dissolved Phase Mass	lbs	50				
Sorbed Phase Contaminant Mass	lbs	79				
Competing Electron Acceptor Mass	lbs	1,271				
<b>Stoichiometric 3DME Demand</b>	<b>lbs</b>	<b>1,430</b>				
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				
<b>Total Mass Flux 3DME Demand</b>	<b>lbs</b>	<b>53,274</b>				
<b>Application Dosing</b>			<b>Assumptions/Qualifications</b>			
<b>3-D Microemulsion to be Applied</b>	<b>lbs</b>	<b>49,200</b>	Prepared By: <i>Corinne Ketcham - East Region Technical manager</i> Date: <i>8/27/2015</i> In generating this preliminary estimate, Regenesys 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			Currently Available Packaging Options		
<b>Mr. C - Grid Injection Areas -- Dissolved phase</b>					
<b>3-D Microemulsion Required</b>	<b>lbs</b>	<b>49,200</b>	<u><b>3DME Package Type**</b></u>	<u><b># of packages</b></u>	<u><b>lbs required</b></u>
			400 lb poly drums	123	49,200
			2,000 lb reinforced plastic totes	25	50,000
3-D Microemulsion Cost*	\$	\$145,140			
<b>Total Product Cost</b>	<b>\$</b>	<b>\$145,140</b>			
Estimated Tax and Freight %	%	15%			
Estimated Tax and Freight Cost	\$	<u>\$21,771</u>			
<b>Estimated Total Product Cost</b>	<b>\$</b>	<b>\$166,911</b>			
<b>Estimated RRS Application Cost</b>	<b>\$</b>	<b>\$112,700</b>			
<b>Total Estimated Project Cost</b>	<b>\$</b>	<b>\$279,611</b>			
<b>Estimated RRS Days to Apply</b>	<b>---</b>	<b>20</b>	<b>**Available Package Types are subject to change.</b>		
<p>*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.</p>					



Purchasing Information			Currently Available Packaging Options		
<b>Mr. C - Barrier Areas</b>	--	<b>Dissolved phase</b>			
<b>PlumeStop Required</b>	<b>lbs</b>	<b>96,400</b>	<b><u>PlumeStopPackage Type**</u></b>	<b><u># of packages</u></b>	<b><u>lbs required</u></b>
<b>HRC Required</b>	<b>lbs</b>	<b>14,976</b>	2,000 lb reinforced plastic totes	49	98,000
PlumeStop Cost	\$	\$216,900	400-lb poly drums	241	96,400
HRC Cost	\$	\$104,083			
BDI Cost	\$	\$0	<b><u>HRC Package Type**</u></b>	<b><u># of packages</u></b>	<b><u>lbs required</u></b>
Estimated Tax and Freight %	%	18%	30 lb HDPE pails	500	15,000
Estimated Tax and Freight Cost	\$	\$57,777			
<b>Estimated Total Product Cost</b>	<b>\$</b>	<b>\$378,760</b>			
<b>Estimated RRS Application Cost</b>	<b>\$</b>	<b>\$160,800</b>			
<b>Total Estimated Project Cost</b>	<b>\$</b>	<b>\$539,560</b>			
<b>Estimated RRS Days to Apply</b>	<b>---</b>	<b>28</b>			
<p>*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.</p>			<p>**Available Package Types are subject to change.</p>		

# C

## Provectus Product Information

- C-1 Provect-IR® Technical Data Sheet
- C-2 Provect-IR® Safety Data Sheet
- C-3 Provect-IR® Sampling and Analysis Guide
- C-4 Provect-IR® and Provect-IRM® Longevity Analysis
- C-5 Provect-IR® Handling and Application Guidelines
- C-6 Case Study
- C-7 Florida Department of Environmental Protection June 16, 2014, Letter of Acceptance Re: Provect-IR®

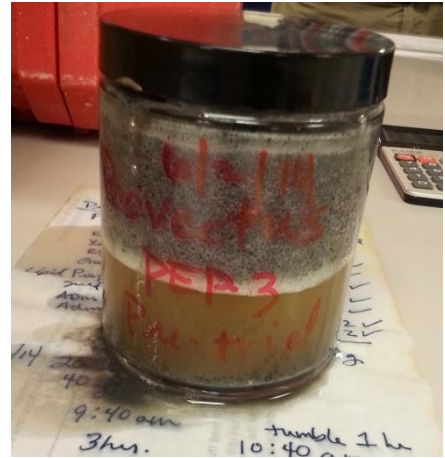
## Provect-IR™

### Antimethanogenic ISCR Reagent

#### TECHNOLOGY DESCRIPTION

Provect-IR is a unique mixture of reagents combined into a single product that optimizes the *in situ* reductive dechlorination of chemicals present in soil, sediment, and groundwater. It acts by promoting synergistic interactions between:

- ◆ Natural antimethanogenic compounds
- ◆ Hydrophilic, nutrient rich organic carbon sources
- ◆ Zero-Valent Iron (ZVI)
- ◆ Chemical oxygen scavengers
- ◆ Vitamin and mineral sources



This distinctive, patented combination of natural and food-grade chemicals promotes ISCR conditions for fast and effective destruction of targeted constituents of interest (COIs) such as chlorinated solvents, organochlorine pesticides, and other halogenated compounds (Brown *et al.*, 2009; Dolfig *et al.*, 2008; US Patent Office Scalzi *et al.* 2012). Notably, Provect-IR is the only ISCR reagent to simultaneously inhibit the production of methane during the requisite carbon fermentation processes (US Patent Office Scalzi *et al.*, 2013, 2014). This promotes more efficient use of the hydrogen donor while avoiding negative issues associated with elevated methane (CH<sub>4</sub>) in groundwater, soil gas, and indoor air.

Current regulations for methane in groundwater vary from ca. 10 to 28 mg CH<sub>4</sub>/L (Indiana Department of Environmental Management, 2014). More State regulations are pending, with several ERD projects which intended to use liquid carbon (emulsified oils) sources failing to receive regulatory approval due to issues associated with excessive production of methane during previous technology applications (Personal Communication - State of California; State of Minnesota). Many remedial practitioners have subsequently been required to establish contingencies for conventional ERD/ISCR implementation in the event that methane exceeds a threshold level ranging from 1 ppm to 10 ppm groundwater. These contingencies often entail expensive and extensive systems for capturing and treating methane in soil gas/vapor captured via SVE systems.

#### MODE OF ACTION – HOW DOES IT WORK?

**What is a Methanogen?** In the 1970s, Dr. Carl Woese (1928 to 2012) and his colleagues at the University of Illinois-Urbana studied prokaryotic relationships using DNA sequences and they found that microbes that produce methane – or methanogens - are Archaea (Woese and Fox, 1977). The identification of this new Domain of microorganism was very important for many reasons, but from our limited perspective herein this vast difference in genetic composition means that methanogens are significantly different from typical heterotrophic bacteria and eukaryotes. In other words, *Dehalococcoides ethenogenes* are as different from methanogens as you are.

**What is a Statin?** A Statin can be defined as “a class of lipid-lowering drugs that reduce serum cholesterol levels by inhibiting a key enzyme involved in the biosynthesis of cholesterol”. Lovastatin is a widely known, potent statin used for decades to lower cholesterol in human blood by inhibiting 3-hydro-3-methylglutaryl-coenzyme A (HMG-CoA) reductase, which is a key enzyme in the cholesterol biosynthesis pathway (Alberts *et al.*, 1980). It was the first statin approved by the United States Food and Drug Administration in 1987 as a hypercholesterolemic drug.

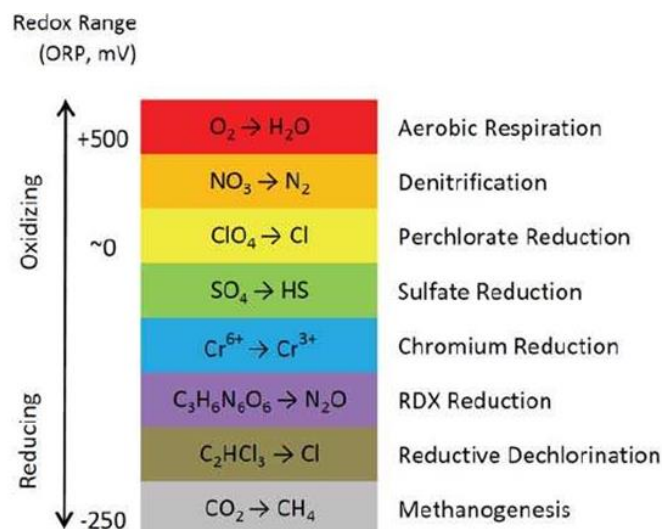
**What is Red Yeast (Rice) Extract?** The red yeast rice (RZR) extract that is component of **Provect-IR** is a substance extracted from rice that has been fermented with a type of yeast called *Monascus purpureus*. Red yeast extract is used as a food coloring, food additive/preservative, and is widely consumed by humans. The RZR extract contains a number of monacolins - most importantly, Monacolin K, otherwise known as Lovastatin or Mevinolin. Monacolin K is the only naturally occurring statin compound. In addition to Monacolin K, RZR extract also contains mono-unsaturated fatty acids and other vitamins that will effectively stimulate anaerobic bacteria in the subsurface.

**So - How Does a Statin Inhibit a Methanogen?** Interestingly, Monacolin K is a potent inhibitor of methanogenic archaera because cell membrane production in archaea shares a similar pathway with cholesterol biosynthesis (Miller and Wolin, 2001). And since methanogens are so uniquely different than bacteria, the inhibitory effect is not observed in microbes that are typically associated with: i) catabolism of organic contaminants (such as pseudomonas species) and/or, ii) halo-respiration/biodegradation of chlorinated solvents (such as dehalococcoides species). RZR has been used in the cattle industry for decades in efforts to manage rumen microbiology and control methane production in cows.

### ATTENUATION PROCESSES – SAFER, MORE EFFICIENT ISCR TREATMENT

*In situ* chemical reduction (ISCR) as defined by Dolfing *et al* (2008) describes the combined effect of stimulated biological oxygen consumption (via fermentation of an organic carbon source), direct chemical reduction with zero-valent iron (ZVI) or other reduced metals. The corresponding enhanced thermodynamic decomposition reactions that are realized at the lowered redox (Eh) conditions allow for more effective mineralization of many COIs.

A number of enhanced reductive dehalogenation (ERD) substrates and other accelerated anaerobic bioremediation technologies exist (e.g., emulsified oils, non-emulsified oils, carbon-based hydrogen release compounds, vegetable matter + ZVI amendments) that purportedly offer similar responses. However, the **Provect-IR** antimethanogenic ISCR substrate is unique in its ability to yield Eh values most conducive to reductive dechlorination while simultaneously preventing methane production - which is a waste of the H being generated and potentially a safety issue under field conditions.



**Provect-IR** uniquely combines RZR extract with a variety of specially selected reagents in order to induce genuine ISCR conditions and facilitate the destruction of targeted COIs in a safer, more efficacious manner. As outlined below, it can be used to manage environments impacted by chlorinated solvents, pesticides, heavy metals and other COIs.

**Specially Selected Organic Hydrogen Donors:** A variety of hydrophilic, nutrient rich organic carbon sources are incorporated in [Provect-IR](#) that assist in promoting the ISCR process. The [Provect-IR](#) bioremediation amendments consist of slow, medium and long-term release carbon sources. Such a formulation is desirable because it provides both a rapidly utilized electron donor (calcium propionate), slow-release long-term electron donors (kelp meal and yeast extract) and long-term release carbon sources (other cellulose and hemi-cellulose carbon such as soy meal). More specifically,

- ◆ **Calcium propionate and other readily biodegradable carbon sources:** Following the addition of simple carbon sources such as lactate, formate, ethanol or glucose to an aquifer setting these compounds are often converted rapidly to hydrogen and acetate. Although this is the desired response, the process is sometimes too rapid, and this can result in aquifer acidification (due to rapid VFA production) and the liberation of too much hydrogen (which allows methanogens and sulfate reducers to compete effectively with dehalogenators, which tend to grow more slowly). Hence, calcium propionate is used as a readily biodegradable carbon source.
- ◆ **Yeast extract:** This supplement provides a variety of organic hydrogen donors that have slower release profiles (*i.e.*, they are not fermented as rapidly as propionate). Yeast extract also contains biological components that are very useful to anaerobes, but are not available through other carbon-only media. In particular, yeast extract provides an abundant source of priming ATPase along with trace nutrients and vitamin B complexes.
- ◆ **Kelp meal/Cellulose based carbon:** These hydrogen sources are composed of a hydrophilic, solid and complex carbon that ferment more slowly and inherently generate less methane. The hydrophilic organic component of the kelp meal, for example, is composed of cellulose and hemicellulose and it may be treated during the manufacturing process so that some of the components more easily undergo hydrolysis to glucose while maintaining an overall longevity of 3 to 5+ years.

**Chemical Oxygen Scavengers:** The presence of chemical oxygen scavengers such as sodium sulfite helps minimize performance lag phases that are often observed following the injection of remedial amendments. This is due, in part, to the presence of oxygen that is introduced as a result of the field mixing and blending operations. It takes a certain amount of time and reagent consumption to remove that introduced oxygen and allow the ISCR reactions to proceed. [Provect-IR](#) is unique in that it manages this impact chemically, which is a more effective, reliable manner thus allowing the ISCR process to be more effective.

**Zero-Valent Iron:** The presence of ZVI in [Provect-IR](#) is critical to ISCR reactions. The ZVI is added as a reduced material that is oxidized during the reductive dechlorination reactions which use ZVI as the reducing agent. The *beta*-elimination reaction mainly produces (chloro)acetylene, ethane/ethane and chloride ions, without the accumulation of potentially problematic catabolites typical of microbiologically mediated sequential reductive dehalogenation processes (*e.g.*, DCE “stall”). As the ZVI reacts, hydroxyl ions are released and pH increases which is useful in neutralizing the acidity generated during the fermentation of carbon, where acids are generated. Oxidized iron species are also produced, where they are useful in *alpha*-elimination reactions and iron cycling. One limitation to ZVI reactions is that they are surface mediated which means that direct contact is required for direct COI destruction.

**RYR Extract:** [Provect-IR](#) is the only ISCR amendment that will rapidly induce ISCR conditions while simultaneously preventing or significantly minimizing the production of methane. The benefits are notable:

- ◆ **Safer:** Methane is explosive with an LEL of 5% and an UEL of 15%. Production of methane will result from the addition of any conventional ERD or ISCR amendment: excessive and extended production of methane can result in elevated groundwater concentrations (as high as 1,000 ppm have been reported) which can lead to accumulation in soil gas subsequently impacting indoor air. State specific regulations for methane in groundwater have been promulgated, with others pending for soil gas and indoor air.

- ◆ **More Efficient = More Cost Effective:** Production of methane is a direct indication that the hydrogen generated from the organic carbon amendments was used by methanogens and the amendment has been wasted because it was not utilized by acetogens or dehalorespiration. By inhibiting the growth and proliferation of methane producing Archaea, chlororespiring bacteria can become the more dominant bacterial populations.

### PRIMARY FEATURES:

- ◆ **Effective:** No accumulation of dead-end catabolic intermediates as a function of substrate addition (as is common with [emulsified] oils and sources of carbon only).
  - Does not rely on physical sorption/sequestration as a major “removal” mechanism (as is common with oils).
  - Inherently buffered for pH control – will not acidify an aquifer and liberate heavy metals as potential secondary COIs.
- ◆ **Efficient:** Significantly lower costs as a result more efficient amendment utilization and avoidance of contingencies for methane management. No need for additional buffers.
- ◆ **Safe:** Fewer health and safety concerns as compared with use of traditional ERD or ISCR reagents; Avoid issues associated with new and emerging methane regulations.
- ◆ **Ease of Use:** Green and sustainable. All components integrated in a single package. Logistics with no surprises.
- ◆ **Longevity:** Engineered profile of carbon sources for multi-year longevity estimated at 3 to 7 years based on site-specific hydrogeology. Reagent will stay in place and remain active which prevents rebound.
- ◆ **Improved Performance:** More efficient use of hydrogen donors (does not get wasted as methane).
- ◆ **Adaptable Formulations for Heavy Metals:** Will not mobilize arsenic or other heavy metals yielding secondary contaminants (as is common with [emulsified] oils and sources of carbon only). Can be formulated to manage environments that are co-impacted by various inorganic contaminants (e.g., As, [Hg], Ni, Pb, Zn) while simultaneously mineralizing the organic compounds.
- ◆ **Patented Technologies:** Technology end users and their clients are fully protected from all Patent and other legal issues.

### PHYSICAL PROPERTIES:

Particle Size: ranges from ca. <5 to 100 micron (can be manufactured to specifications).

Dry Density: ranges from 0.4 to 0.5 g/cm<sup>3</sup>

29% Aqueous Slurry Density: ranges from 0.9 to 1.0 g/cm<sup>3</sup>

29% Aqueous Slurry Viscosity: ranges from 500 to 1,500 cP

### SLURRY PREPARATION GUIDELINES:

Percent Solids Content	Mass of Provect-IR	Volume of Water (US gallons)
<b>10%</b>	25 lb	27
<b>20%</b>	25 lb	12
<b>30%</b>	25 lb	7

**LITERATURE CITED:**

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Scalzi, M. and McGill, J. 2012. Method for the Treatment of Groundwater and Soils using Mixtures of Seaweed Kelp. US PTO No. 8,147,694 B2 (April 3, 2012).

Scalzi, M. and A. Karachalios. 2013 and 2014. Inhibition of Methane Production during Anaerobic Reductive Dechlorination. US PTO 13/ 785,840 and CIP 14/268,637

Woese, C.R. and G.E. Fox (1977). "[Phylogenetic structure of the prokaryotic domain: the primary kingdoms](#)". *Proceedings of the National Academy of Sciences of the United States of America* 74 (11): 5088–5090.

**CONTACT US FOR A COMPLIMENTARY SITE EVALUATION**

**PROVECTUS ENVIRONMENTAL PRODUCTS, INC.**

**2871 West Forest Road, Suite 2 | Freeport, IL 61032**

**Tel: (815) 650-2230 | Fax: (815) 650-2232 | Email: [info@ProvectusEnv.com](mailto:info@ProvectusEnv.com)**

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## Safety Data Sheet (SDS)

OSHA HazCom 2012 Standard 29 CFR 1910.1200. Prepared to GHS Rev03.

Printing date 05/30/2014

Reviewed on 05/30/2014

### \* 1 Identification

- **Product identifier**
- **Trade name: Provect-IR Antimethanogenic ISCR Reagent**
- **Product description**  
Remediation product for the treatment of soil, sediment and groundwater. Not for use in potable water sources.
- **Details of the supplier of the safety data sheet**
- **Manufacturer/Supplier:**  
Provectus Environmental Products  
2871 W. Forest Road  
Suite 2  
Freeport, IL 61032  
Phone: 815-650-2230  
Fax: 815-650-2232  
www.provectusenvironmental.com
- **Emergency telephone number:** 815-650-2230

### \* 2 Hazard(s) identification

- **Classification of the substance or mixture**  
The product is not classified according to the Globally Harmonized System (GHS).
- **Label elements**
- **GHS label elements** Non-Regulated Material
- **Hazard pictograms** Non-Regulated Material
- **Signal word** Non-Regulated Material
- **Hazard statements** Non-Regulated Material
- **Hazard description:**  
CONTAINMENT HAZARD: Any vessel that contains wetted reagent must be vented due to potential pressure build up from fermentation gases.
- **Classification system:**
- **NFPA ratings (scale 0 - 4)**



- **HMIS-ratings (scale 0 - 4)**

HEALTH	0	Health = 0
FIRE	1	Fire = 1
REACTIVITY	0	Reactivity = 0

### \* 3 Composition/information on ingredients

7439-89-6	iron	5-40%
4075-81-4	calcium dipropionate	2 - 4%
	Proprietary Organic Carbon Sources	48-90%

- **Chemical characterization: Mixtures**
- **Description:** Mixture of the substances listed below with nonhazardous additions.

#### • **Dangerous components:**

8013-01-2	Yeast extracts	STOT SE 3, H335	0.5 - 2%
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(Contd. on page 2)

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(Contd. of page 1)

9000-30-0	Guar gum	⚠ STOT SE 3, H335; Eye Irrit. 2B, H320; Combustible Dust	0.5 - 2%
7757-83-7	sodium sulphite	⚠ Acute Tox. 4, H302	1 - 2%

• **Additional information:** Product contains red yeast rice

### 4 First-aid measures

- **Description of first aid measures**
- **After inhalation:** Remove person to fresh air. If signs/symptoms continue, get medical attention.
- **After skin contact:** Wash off with soap and water. Get medical attention if irritation develops.
- **After eye contact:** Flush with water for 5 minutes
- **After swallowing:**  
Rinse mouth with water and afterwards drink plenty of milk or water. Call a poison control center or doctor immediately for treatment advice.
- **Most important symptoms and effects, both acute and delayed** No further relevant information available.
- **Indication of any immediate medical attention and special treatment needed**  
No further relevant information available.

### 5 Fire-fighting measures

- **Extinguishing media**
- **Suitable extinguishing agents:**  
CO2, extinguishing powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
- **Special hazards arising from the substance or mixture** No further relevant information available.
- **Advice for firefighters**
- **Protective equipment:** No special measures required.

### \* 6 Accidental release measures

- **Personal precautions, protective equipment and emergency procedures** Not required.
- **Environmental precautions:** Do not allow to enter sewers/ surface or ground water.
- **Methods and material for containment and cleaning up:**  
Cover powder spill with plastic sheet or tarp to minimize spreading and keep powder dry. Sweep or vacuum up spillage and place in vented container.
- **Reference to other sections**  
See Section 7 for information on safe handling.  
See Section 8 for information on personal protection equipment.  
See Section 13 for disposal information.

### \* 7 Handling and storage

- **Precautions for safe handling** No special measures required.
- **Information about protection against explosions and fires:** Combustible material
- **Conditions for safe storage, including any incompatibilities**
- **Storage:**
- **Requirements to be met by storerooms and receptacles:**  
CONTAINMENT HAZARD: Any vessel that contains wetted reagent must be vented due to potential pressure build up from fermentation gases.
- **Information about storage in one common storage facility:** Not required.
- **Further information about storage conditions:**  
Keep tightly closed in a dry and cool place. Keep away from open flames, hot surfaces and sources of ignition. Any material that is wetted must be vented due to potential pressure build up from fermentation gases.

(Contd. on page 3)

## Safety Data Sheet (SDS)

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Printing date 05/30/2014

Reviewed on 05/30/2014

**Trade name: Provect-IR Antimethanogenic ISCR Reagent**

(Contd. of page 2)

- **Specific end use(s)** No further relevant information available.

### \* 8 Exposure controls/personal protection

- **Additional information about design of technical systems:** No further data; see section 7.
- **Control parameters**
- **Components with occupational exposure limits:**  
The product does not contain any relevant quantities of materials with critical values that have to be monitored at the workplace.
- **Additional information:**  
Dry or powdered ingredients are combustible. Dispersal of finely divided dust from products into air may form mixtures that are ignitable and explosive. Minimize airborne dust generation and eliminate sources of ignition.
- **Exposure controls**
- **Personal protective equipment:**
- **General protective and hygienic measures:**  
The usual precautionary measures for handling chemicals should be followed.
- **Breathing equipment:** Not required.
- **Protection of hands:** Not required.
- **Eye protection:** Not required.

### \* 9 Physical and chemical properties

- **Information on basic physical and chemical properties**
- **General Information**
- **Appearance:**

<b>Form:</b>	Solid
<b>Color:</b>	Brown to Green
<b>Odor:</b>	Pleasant
- **Odor threshold:** Not determined.
- **pH-value:** Not applicable.
- **Change in condition**

<b>Melting point/Melting range:</b>	Not determined.
<b>Boiling point/Boiling range:</b>	Undetermined.
- **Flash point:** Not applicable.
- **Flammability (solid, gaseous):** Not determined.
- **Ignition temperature:**

<b>Decomposition temperature:</b>	Not determined.
-----------------------------------	-----------------
- **Auto igniting:** Product is not selfigniting.
- **Danger of explosion:** Dry or powdered ingredients are combustible. Dispersal of finely divided dust from products into air may form mixtures that are ignitable and explosive. Minimize airborne dust generation and eliminate sources of ignition.
- **Explosion limits:**

<b>Lower:</b>	Not determined.
<b>Upper:</b>	Not determined.
- **Vapor pressure:** Not applicable.
- **Density:** Not determined.

(Contd. on page 4)

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Reviewed on 05/30/2014

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(Contd. of page 3)

- **Relative density** Not determined.
- **Vapour density** Not applicable.
- **Evaporation rate** Not applicable.
- **Solubility in / Miscibility with Water:** Soluble.
- **Partition coefficient (n-octanol/water):** Not determined.
- **Viscosity:**
  - Dynamic:** Not applicable.
  - Kinematic:** Not applicable.
- **Solvent content:**
  - Organic solvents:** 0.0 %
  - Solids content:** 100.0 %
- **Other information** No further relevant information available.

### 10 Stability and reactivity

- **Reactivity** No further relevant information available.
- **Chemical stability** Product is stable under normal conditions.
- **Thermal decomposition / conditions to be avoided:** No decomposition if used according to specifications.
- **Possibility of hazardous reactions** No dangerous reactions known.
- **Conditions to avoid** No further relevant information available.
- **Incompatible materials:** No further relevant information available.
- **Hazardous decomposition products:** No dangerous decomposition products known.

### \* 11 Toxicological information

- **Information on toxicological effects**
- **Acute toxicity:**
- **Primary irritant effect:**
- **on the skin:** No irritant effect.
- **on the eye:** Product dust may cause eye irritation.
- **Sensitization:** No sensitizing effects known.
- **Additional toxicological information:**  
The product is not subject to classification according to internally approved calculation methods for preparations:  
When used and handled according to specifications, the product does not have any harmful effects according to our experience and the information provided to us.
- **Carcinogenic categories**

#### · **IARC (International Agency for Research on Cancer)**

None of the ingredients is listed.

#### · **NTP (National Toxicology Program)**

None of the ingredients is listed.

#### · **OSHA-Ca (Occupational Safety & Health Administration)**

None of the ingredients is listed.

### 12 Ecological information

- **Toxicity**
- **Aquatic toxicity:** No further relevant information available.

(Contd. on page 5)

## Safety Data Sheet (SDS)

OSHA HazCom 2012 Standard 29 CFR 1910.1200. Prepared to GHS Rev03.

Printing date 05/30/2014

Reviewed on 05/30/2014

**Trade name: Provect-IR Antimethanogenic ISCR Reagent**

(Contd. of page 4)

- **Persistence and degradability** No further relevant information available.
- **Bioaccumulative potential** No further relevant information available.
- **Mobility in soil** No further relevant information available.
- **Additional ecological information:**
- **General notes:** Water hazard class 1 (Self-assessment): slightly hazardous for water
- **Results of PBT and vPvB assessment**
- **PBT:** Not applicable.
- **vPvB:** Not applicable.
- **Other adverse effects** No further relevant information available.

### 13 Disposal considerations

- **Waste treatment methods**
- **Recommendation:** Smaller quantities can be disposed of with household waste.
- **Uncleaned packagings:**
- **Recommendation:** Disposal must be made according to official regulations.
- **Recommended cleansing agent:** Water, if necessary with cleansing agents.

### \* 14 Transport information

- **UN-Number**
- **DOT, ADR, ADN, IMDG, IATA** Non-Regulated Material
- **UN proper shipping name**
- **DOT, ADR, ADN, IMDG, IATA** Non-Regulated Material
- **Transport hazard class(es)**
- **DOT, ADR, ADN, IMDG, IATA**
- **Class** Non-Regulated Material
- **Packing group**
- **DOT, ADR, IMDG, IATA** Non-Regulated Material
- **Environmental hazards:**
- **Marine pollutant:** No
- **Special precautions for user** Not applicable.
- **Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code** Not applicable.
- **UN "Model Regulation":** -

### 15 Regulatory information

- **Safety, health and environmental regulations/legislation specific for the substance or mixture**
- **Sara**

· **Section 355 (extremely hazardous substances):**

None of the ingredients is listed.

· **Section 313 (Specific toxic chemical listings):**

None of the ingredients is listed.

· **TSCA (Toxic Substances Control Act):**

7439-89-6	iron
4075-81-4	calcium dipropionate
8013-01-2	Yeast extracts
9000-30-0	Guar gum
7757-83-7	sodium sulphite

(Contd. on page 6)

## Safety Data Sheet (SDS)

OSHA HazCom 2012 Standard 29 CFR 1910.1200. Prepared to GHS Rev03.

Printing date 05/30/2014

Reviewed on 05/30/2014

**Trade name: Provect-IR Antimethanogenic ISCR Reagent**

(Contd. of page 5)

• **Proposition 65**

• **Chemicals known to cause cancer:**

None of the ingredients is listed.

• **Chemicals known to cause reproductive toxicity for females:**

None of the ingredients is listed.

• **Chemicals known to cause reproductive toxicity for males:**

None of the ingredients is listed.

• **Chemicals known to cause developmental toxicity:**

None of the ingredients is listed.

• **Carcinogenic categories**

• **EPA (Environmental Protection Agency)**

None of the ingredients is listed.

• **TLV (Threshold Limit Value established by ACGIH)**

None of the ingredients is listed.

• **NIOSH-Ca (National Institute for Occupational Safety and Health)**

None of the ingredients is listed.

• **GHS label elements** Non-Regulated Material

• **Hazard pictograms** Non-Regulated Material

• **Signal word** Non-Regulated Material

• **Hazard statements** Non-Regulated Material

• **National regulations:**

The product is subject to be labeled according with the prevailing version of the regulations on hazardous substances.

• **State Right to Know**

7439-89-6	iron	5-40%
4075-81-4	calcium dipropionate	2-4%
8013-01-2	Yeast extracts	0.5-2%
	⚠ STOT SE 3, H335	
9000-30-0	Guar gum	0.5-2%
	⚠ STOT SE 3, H335; Eye Irrit. 2B, H320; Combustible Dust	
7757-83-7	sodium sulphite	1-2%
	⚠ Acute Tox. 4, H302	
	Proprietary Organic Carbon Sources	48-90%

All ingredients are listed.

• **Chemical safety assessment:** A Chemical Safety Assessment has not been carried out.

### 16 Other information

This information is based on our present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship.

• **Date of preparation / last revision** 05/30/2014 / 6

• **Abbreviations and acronyms:**

ADR: Accord européen sur le transport des marchandises dangereuses par Route (European Agreement concerning the International Carriage of Dangerous Goods by Road)

IMDG: International Maritime Code for Dangerous Goods

DOT: US Department of Transportation

IATA: International Air Transport Association

(Contd. on page 7)

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(Contd. of page 6)

ACGIH: American Conference of Governmental Industrial Hygienists  
EINECS: European Inventory of Existing Commercial Chemical Substances  
ELINCS: European List of Notified Chemical Substances  
CAS: Chemical Abstracts Service (division of the American Chemical Society)  
NFPA: National Fire Protection Association (USA)  
HMIS: Hazardous Materials Identification System (USA)  
Acute Tox. 4: Acute toxicity, Hazard Category 4  
Eye Irrit. 2B: Serious eye damage/eye irritation, Hazard Category 2B  
STOT SE 3: Specific target organ toxicity - Single exposure, Hazard Category 3

• **\* Data compared to the previous version altered.**

SDS / MSDS Created by MSDS Authoring Services ([www.MSDSAuthoring.com](http://www.MSDSAuthoring.com))

## PROVTECT-IR™

### Antimethanogenic ISCR Reagent

Provect-IR™ (US patents 7,828,974; 8,147,694; patent pending) integrates a source of Monacolin K and other natural statins that inhibit the growth and proliferation of Archaea (*i.e.*, methanogens) with multiple, controlled-release hydrophilic organic carbon sources and micro-scale zero-valent iron (ZVI) and other unique ingredients to yield *in situ* chemical reduction (ISCR), as defined by Dolfing *et al* (2008). This unique mixture of reagents combined into a single product optimizes the *in situ* chemical reduction (ISCR) of halogenated chemicals present in soil, sediment, and groundwater. It acts by promoting synergistic interactions between:

- ◆ Natural antimethanogenic compounds
- ◆ Hydrophilic, nutrient rich organic carbon sources
- ◆ Zero-Valent Iron (ZVI)
- ◆ Chemical oxygen scavengers
- ◆ Vitamin and mineral sources



## PROVTECT-IRM™

### Solid, Antimethanogenic Reagent for ISCR and Heavy Metal Stabilization

Provect-IRM™ (patents pending) employs this proven ISCR technology to facilitate established adsorption and precipitation reactions for heavy metal immobilization. It is composed of multiple reagents in a single product:

- ◆ Provect-CH4™ (a proprietary source of Monacolin-K and other natural statins that act as methanogenic inhibitors)
- ◆ Multiple, hydrophilic, nutrient rich organic carbon sources (plant materials, kelp, calcium propionate) → 390 g H /lb product.
- ◆ Small (*ca.* 10 to 25 micron) ZVI → 25 ft reactive ZVI surface area / lb product
- ◆ Chemical oxygen scavengers to help maintain reduced conditions during mixing
- ◆ Integrated vitamins, minerals mineral sources (yeast extracts) specially selected for the growth and development of anaerobes
- ◆ Potassium magnesium sulfate to help promote formation of iron-sulfide mineral complexes, where needed
- ◆ Powdered activated carbon (PAC) to help sequester organo-metal complexes





Most notably, **Provect-IRM™** uniquely inhibits the activity of methanogens (Scalzi *et al*, 2013, 2014) during the synergistic ISCR processes. This greatly reduces the biosynthesis of highly toxic, mobile methylated (organo) metals, which is a very negative consequence of conventional ISCR reactions / immobilization practices. As such, all metal species are quickly sequestered for safe, long-term, stable immobilization of heavy metal contaminants. In addition to avoiding the safety issues associated with elevated methane in groundwater, soil gas, and indoor air, **Provect-IRM™** also promotes more efficient use of the hydrogen donor for more cost-efficient, more effective remedial actions.

## BASELINE SAMPLING AND PERFORMANCE MONITORING GUIDELINES

Following the addition of Provect-IR or Provect-IRM ISCR Reagent to an aquifer environment, a number of physical, chemical and microbiological processes combine to create an extremely reduced environment that stimulates dehalogenation and ultimately mineralization of otherwise persistent compounds. As outlined below, a combination of field measurements and laboratory analyses can be used to determine effectiveness of the ISCR processes.

### Field Parameters: Sampled Frequently

Field parameters are comparatively inexpensive measurements that can be collected on a frequent basis to monitor general progress of the ISCR process. They are also useful in assessing general zone of influence of the added amendments.

Field Parameter	Analytical Method	Desired Range	Data Use
pH	Field probe	6 to 8	Excessive fermentation can acidify aquifer and impede microbiological activity and yield secondary plumes
Turbidity (nephelometric)	Field probe	Generally <1 NTU, or site specific standards	Excessive turbidity compromises data; indicates need for filtration; Gas bubbles (CH <sub>4</sub> ) can cause high readings
Water level / temperature	Field probe	+/- 10% baseline readings	Notable variations can indicate change in contaminant loading rates and are useful in interpreting COI data
DO/ORP or Eh (see note below)	Field probe (corrected for SHE, if required)	< -200 mV (be mindful of recording values as Eh or ORP; ORP + 200 mV = Eh)	Rapid reductions in redox should be observed in the zone influenced by the ISCR reagent; Field ORP values as low as -400 mV have been observed
Well head gases CH <sub>4</sub> , CO <sub>2</sub> , H <sub>2</sub> S, O <sub>2</sub> [N <sub>2</sub> ]	GEM2000, GEM 5000, biogas5000, TVA2020 Total gas analyzers	< 5% CH <sub>4</sub>	Excessive methane production represents inefficient use of H donor and potential health and safety problems

<http://www.ysi.com/media/pdfs/T608-Measuring-ORP-on-YSI-6-Series-Sondes-Tips-Cautions-and-Limitations.pdf>

Thermo/Foxboro TVA-1000B PID/FID Analyzer (PID sensitive to 2,000 ppm CH<sub>4</sub>; FID sensitive to 50,000 ppm CH<sub>4</sub>) and a LandTec GEM5000 Landfill Gas (LFG) Meter (infrared detector calibrated to 15% methane). Equipment purchase see <http://diamondsci.com> Equipment rental options see <http://www.fieldenvironmental.com>

### Critical Parameters: Sampled Quarterly

Critical parameters are initially used to assess the general applicability of an ISCR approach, and they establish an important baseline for subsequently measuring technology effectiveness. Groundwater samples should be collected according to standard protocols (trip blanks, field blanks) and shipped under proper conditions (preservatives, proper containers, chain-of-custody) to an analytical laboratory for timely analysis.

Critical Parameter	Analytical Method	Data Use
RCRA Metals - DISSOLVED (include iron, calcium, magnesium, manganese. Hg optional)	SW846 6010B 0.45 micron filtered, no preservatives	Baseline values help determine reagent requirements. Changes over time indicate presence of ISCR reagents and help document effectiveness.
RCRA Metals - TOTAL (include iron, calcium, magnesium, manganese. Hg optional)	SW846 6010B	Baseline values help determine reagent requirements. Changes over time indicate presence of ISCR reagents and help document effectiveness.
Total Iron	US EPA 200.7	Indicates presence of ISCR reagents and microbiological activity
Other heavy metals – DISSOLVED AND TOTAL	Arsenic 200.9/200.8 Cyanide 335.4/9010 Lead 200.9/200.8 Mercury 7470A Nickel 200.9/200.8	As determined necessary based on site-specific conditions
CVOCs	SW846 8260	Baseline values help determine reagent requirements. Changes over time indicate presence of ISCR reagents and help document effectiveness.
Anion Scan – chloride, sulfate, nitrate, nitrite	US EPA 300	Competing electron acceptors will affect the loading requirements
Total Organic Carbon, TOC	SW846 9060 US EPA 415.1 / 415.2	Indicates presence of ISCR reagents and microbiological activity
Dissolved gasses (CH <sub>4</sub> , CO <sub>2</sub> , ethane, ethene)	SW846 3810 (See link below)	Document effectiveness; helps determine presence of ISCR reagents

[http://www.clu-in.org/download/contaminantfocus/dnapi/Treatment\\_Technologies/Ethene-ethane-methane-analysis.pdf](http://www.clu-in.org/download/contaminantfocus/dnapi/Treatment_Technologies/Ethene-ethane-methane-analysis.pdf)

Baseline TOC, DOC, VFAs and Fe data could be compared to post-injection levels to determine that the groundwater is influenced by Provect-IRM. Elevated levels of these parameters would indicate effective product placement. Elevated levels of TOC, DOC and Fe would be expected almost immediately following the Provect-IRM emplacement.

**NOTE:** purging at least three well volumes is recommended in order to ensure collection of formation water when sampling. Monitoring wells must be free of sediment or other deposits which may contain precipitated heavy metals.

**Non-Critical Parameters: Sampled Quarterly, or as Needed**

Various non-critical parameters are optional, but they provide general information about the soil and water chemistry that may be useful when analyzing and interpreting performance monitoring data. However, baseline measurements are needed in order to make best use of these complementary data.

<b>Non- Critical Parameter</b>	<b>Analytical Method</b>	<b>Data Use</b>
VFAs	Specialty – see link below	
Biological Oxygen Demand, BOD 5 day	SW 846 5210B	Indicator of microbiological activity
Chemical Oxygen Demand, COD	US EPA 410.4	Indicator of redox and oxygen demand
Cation Scan - Calcium, Magnesium, Potassium, Sodium	US EPA 200.7	Indicates presence of ISCR reagents and microbiological activity
Bicarbonate 2310B	Bicarbonate 2310B	Indicates presence of ISCR reagents and microbiological activity – buffering capacity
Total Dissolved Solids (TDS)	SW846 2540C	Indicates presence of ISCR reagents and microbiological activity
Hardness	US EPA 2340B	Indicates presence of ISCR reagents and microbiological activity
Alkalinity	SW846 2310B US EPA 310.1	Indicates presence of ISCR reagents and microbiological activity

<http://www.microseeps.com/pdf/monitoringvfas.pdf>

As the organic carbon moieties of Provect-IR and Provect-IRM degrade, elevated levels of VFAs would be observed. In addition, as the bacteria grow on the organic particles, they ferment carbon and release a variety of volatile fatty acids (acetic, propionic, butyric, pyruvic, lactic, pentanoic and hexanoic). These are useful forms of hydrogen donors for desired microorganisms.

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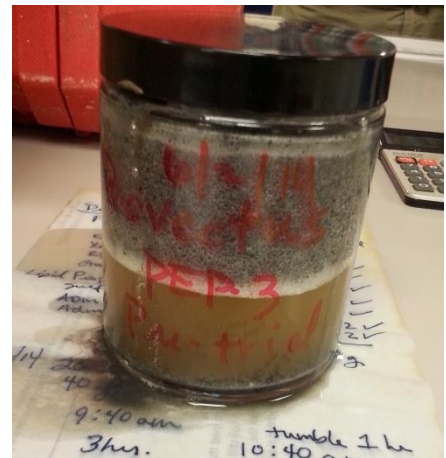
**Multiple remedial contracting options available via strategic providers**

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## Provect-IR™ Antimethanogenic ISCR Reagent

Provect-IR is a unique mixture of reagents combined into a single product that optimizes the *in situ* reductive dechlorination of chemicals present in soil, sediment, and groundwater. It acts by promoting synergistic interactions between:

- ◆ Natural antimethanogenic compounds
- ◆ Multiple hydrophilic, nutrient rich organic carbon sources
- ◆ Zero-Valent Iron (ZVI)
- ◆ Chemical oxygen scavengers
- ◆ Vitamin and mineral sources



This distinctive, patented combination of natural and food-grade chemicals promotes *In Situ* Chemical Reduction (ISCR) conditions for fast and effective destruction of targeted constituents of interest (COIs) such as chlorinated solvents, organochlorine pesticides, and other halogenated compounds (Brown *et al.*, 2009; Dolfig *et al.*, 2008; US Patent Office Scalzi *et al* 2012). Notably, Provect-IR is the only ISCR reagent to simultaneously inhibit the production of methane during the requisite carbon fermentation processes (US Patent Office Scalzi *et al*, 2013, 2014). This promotes more efficient use of the hydrogen donor (>30% more efficient which reduces amendment requirements) while avoiding negative issues associated with elevated methane (CH<sub>4</sub>) in groundwater, soil gas, and indoor air.

### LONGEVITY - HOW LONG DOES IT LAST?

One of the first questions asked regarding the efficacy of the (ISCR) technology is “How long does it last”? Circa 2003, scientists now at Provectus began working with an industrial client and others to develop answers these questions and there have been numerous laboratory and field study publications that have subsequently substantiated the following calculations and estimations.

For this example, groundwater at a hypothetical site contains 2 mg/L DO, 5 mg/L of TCE, 5 mg/L nitrate and 20 mg/L sulfate. The groundwater flow velocity is 0.10 m/day with an aquifer porosity of 0.25. An ISCR treatment zone was established 6 m wide by adding 0.5% (soil mass basis) Provect-IR which contains 90% carbon + 10% ZVI

#### Theoretical Considerations - Iron Consumption

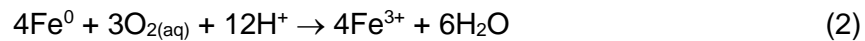
The potential rate of ZVI consumption was calculated using standard reactions with COIs and inorganic electron acceptors present at a hypothetical site (of course the same calculations can be made using site-specific data). The ZVI consumption calculations are based on a unit cell with a face surface area of 1 m<sup>2</sup> of the Provect-IR-amended zone, or a volume of 6 m<sup>3</sup> of amended aquifer material, containing about 11 kg of ZVI. Here, the carbon electron donor was not included

in the electron acceptor consumption calculations. Water corrosion (oxidation) consumes the ZVI, resulting in the generation of ferrous iron, hydrogen gas and hydroxide ion production and an increase in pH and decline in Eh (Eq. 1):



Corrosion rates of various ZVI materials in water range between 0.1 to 0.6 mmol/kg Fe/day (Reardon, 2005). A corrosion rate of 0.3 mmol/kg Fe/day is applied to the particulate ZVI used in Provect-IR. In the field, the iron-water corrosion rate is independent of groundwater flow velocity. Based on the water corrosion rate of 0.3 mmol/kg Fe/day, the annual iron consumption due to water corrosion at this hypothetical site would be about 135 g/yr. This is equivalent to about 1.2% of the total ZVI present in the 6 m wide ISCR treatment zone.

Any dissolved oxygen will also corrode (consume) the ZVI (Eq.2):



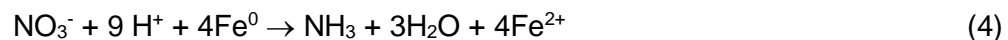
Based on the above assumptions, the annual amount of DO (2 mg/L or 0.063 mmol/L) entering a unit cell of the ISCR treatment zone would be 18 g/yr (0.57 mole/yr). Since, four moles of iron are consumed for every three moles of DO, the annual iron consumption rate would be 43 g/yr (0.76 mol/yr). This iron amount represents about 0.4% of the total ZVI in the ISCR treatment zone.

Complete reductive dechlorination of TCE and the corresponding ZVI oxidation can be expressed by the following (Eq. 3):



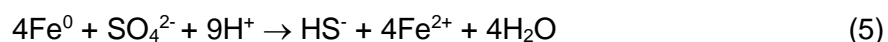
The annual amount of TCE (5 mg/L or 0.038 mmol/L) entering the unit cell of ISCR zone would be 46 g/yr (0.35 mole/yr). Since three moles of iron are consumed for every mole of TCE, the annual iron consumption rate would be 58 g/yr (1.04 mol/yr) or 0.6% of the available ZVI mass in the ISCR treatment zone.

If present, nitrate reduction by granular iron results in the production of ammonia/ammonium (Eq. 4):



Complete reduction of 5 mg/L of nitrate (0.08 mmol/L) by ZVI would result in consumption of an annual nitrate mass flux into the unit cell of the ISCR zone of 46 g/yr (0.74 mol/yr). Four moles of iron are consumed for every mole of nitrate; therefore the annual consumption rate would be equal to 165 g/yr (2.94 mole/yr) or 1.6% of the ZVI available.

Sulfate ( $\text{SO}_4^{2-}$ ) in the presence of iron may undergo reduction to sulfide (Eq. 5):



If complete sulfate reduction occurred due via ZVI oxidation, the annual amount of sulfate (20 mg/L or 0.21 mmol/L) entering the unit cell of ISCR zone would be 183 g/yr (1.9 mole/yr). Since four moles of iron are consumed for every mole of sulfate, the annual iron consumption rate would be 426 g/yr (7.6 mole/yr) or about 4% of the ZVI available.

If electron acceptor reduction and VOC degradation do not compete with water corrosion of ZVI, the annual ZVI consumption rate would be about 7 or 8% of the ZVI available. This would result in a conservative ZVI lifetime in a Provect-IR ISCR treatment zone of about 13 to 15 years at this hypothetical site.

### **Theoretical Considerations - Carbon Consumption**

The carbon component of Provect-IR is comprised in part of process plant materials, kelp/seaweed and other fibrous organic carbon particles. Because of the predominance of cellulose and hemicellulose in the particles, these particles will degrade more slowly (last longer) than more soluble forms of carbon such as lactates, oils, and other glucose based amendments.

Carbon consumption (decay) in the subsurface is often assumed to follow a first order model. Under aerobic soil conditions, cellulose has been shown to persist over several months (Cheshire 1979, Kassim et al, 1981) and will degrade more slowly under anaerobic saturated conditions. In other studies, a first order carbon decay constant (K) of  $1.6E-3 \text{ day}^{-1}$  was obtained in cellulose columns used to promote denitrification exposed to a nitrate flux of about 70 to 75 mg/L nitrate-N at room temperature (Vogan 1993). This equates to a 50% loss of cellulose in about 300 days or 10 months. Lower rates of degradation (K of  $5E-4 \text{ day}^{-1}$ ) were obtained in sawdust columns exposed to the same flux. Sawdust contains a relatively higher proportion of hemi-cellulose and lignin. *In situ* sawdust based denitrifying systems have operated for 15 years at field temperatures (Robertson et al, 2008).

Given that the carbon demand in the above conditions is far greater than that usually occurring in organic contaminant plumes these published carbon degradation rates indicate that the carbon component of Provect-IR should also last for > 5 years in the subsurface.

### **SUMMARY**

Mathematical calculations under theoretical site considerations concluded that the ZVI component of Provect-IR will remain active in a subsurface aquifer environment for at least 10 years, and that organic carbon components will remain active in a subsurface aquifer environment for at least 5 years. Field data have shown longevity of over 4 years. There are many factors that can influence the actual longevity observed at a given site: temperature, groundwater flow velocity, electron acceptor demand, mass applied, installation method, and inorganic chemistry. But based on these factors, it appears that Provect-IR (containing 10% ZVI to 40% ZVI) will persist at least 5 years in most subsurface environments.

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#### OVERVIEW

Provect-IR™ Antimethanogenic *In Situ* Chemical Reduction (ISCR) Reagent is designed to treat persistent organic and/or inorganic contaminants present in the subsurface environment.

It is unique in its composition:

- ◆ Zero-Valent Iron 10% (weight basis), average particle size = 15 µm yields 25 ft ZVI surface area / lb product
- ◆ Integrated Vitamins, minerals and nutrients (yeast extract) specially selected for anaerobes
- ◆ Chemical oxygen scavenger to maintain reduced condition
- ◆ Multiple, Complex, Hydrophilic, Timed-Release organic carbon sources (plant materials, Kelp, Calcium Propionate) @ 390 g H donor / lb product
- ◆ METHANE INHIBITORS to increase safety and efficiency



#### MATERIAL PACKAGING, HANDLING AND STORAGE



Provect-IR can be specially formulated to meet site-specific needs. The standard formulation contains 10% ZVI and is packaged as a dry powder in 50-lb easy-open (NO SHARPS), polyethylene-lined, recycled paper bags or, upon request, in 2,000 lb Supersacks. Typical shipments entail multiple units of 4x4 wooden pallets containing 40 bags x 50 lbs/ bag = 2,000 lbs reagent per pallet. Each pallet is neatly wrapped in water-resistant plastic, but direct exposure to rain should be avoided.

#### GENERAL HEALTH AND SAFETY GUIDELINES

Provect-IR is non-hazardous and safe to handle. The use of standard personal protective equipment is always recommended, including safety glasses, steel-toe boots, gloves, hearing protection (in the proximity of loud machinery) and hard hat. Dust mask may be desired when working with the material under certain conditions. The SDS is posted on our web site at the following link: [Click Here!](#)



**SLURRY PREPARATION**

Provect-IR is mixed with clean water on site to yield an aqueous slurry (see **Table 1** for field mixing guidelines). Experienced injection contractors can easily manage (mix, transport/pump, and inject) slurry containing between 20% and 30% solids (defined as the mass of dry Provect-IR divided by the total mass of slurry, including the water). For situations where more volume is desired, slurry density can be decreased, e.g., using a thinner slurry. Conversely, for situations where less volume is required (for example to minimize surfacing issues), thicker slurry with higher solids can be applied. A slurry containing ca .29% solids will have the following general characteristics:

- ◆ Wet Density = 0.9 to 1.1 g/cm<sup>3</sup>
- ◆ Dry Density = 0.3 to 0.4 g/cm<sup>3</sup>
- ◆ Viscosity = 500 to 1,500 cP

<b>TABLE 1. FIELD GUIDE FOR MAKING SLURRY</b>			
<b>per 50 pound bag</b>		<b>per 25 kg bag</b>	
<b>Target weight %</b>	<b>USG water required</b>	<b>Target weight %</b>	<b>Liters water required</b>
<b>15</b>	<b>34</b>	<b>15</b>	<b>142</b>
<b>20</b>	<b>24</b>	<b>20</b>	<b>100</b>
<b>22</b>	<b>21</b>	<b>22</b>	<b>89</b>
<b>24</b>	<b>19</b>	<b>24</b>	<b>79</b>
<b>26</b>	<b>17</b>	<b>26</b>	<b>71</b>
<b>28</b>	<b>15</b>	<b>28</b>	<b>64</b>
<b>30</b>	<b>14</b>	<b>30</b>	<b>58</b>
<b>32</b>	<b>13</b>	<b>32</b>	<b>53</b>
<b>34</b>	<b>12</b>	<b>34</b>	<b>49</b>
<b>36</b>	<b>11</b>	<b>36</b>	<b>44</b>

## APPLICATION TECHNIQUES

Provect-IR has been employed for source area treatment, plume treatment and/or plume management using permeable reactive barrier (PRBs). The choice of installation method will depend on the site-specific conditions, including treatment depth and geology. The most commonly practiced *in situ* application method has been direct injection of aqueous slurry.

Provect-IR slurry containing 10 to 35% solids has been added to numerous aquifers using a variety of injection methods, including hydraulic fracturing, pneumatic fracturing and direct injection. It can also be added via direct soil mixing using deep soil mixing equipment, or it can be placed directly into an open excavation or trench. ABC-CH4 is a liquid formulation of our antimethanogenic ERD reagent which has been added to existing well screens.

## GENERAL GUIDELINES FOR DIRECT PUSH INJECTION OF AQUEOUS SLURRY

Mixing Equipment. Reagent slurry has been prepared in various ways, ranging from in-line automated mixing systems, to manual mixing using a hand-held drill with a mixing attachment, to more creative processes. Particularly for larger projects, experienced drillers will have some form of mechanical mixing system on site that includes a tank with a paddle-type mixer at the bottom. The slurry is then transferred to a feed tank connected to an injection pump so that slurry can be prepared continuously while injections are being performed (see example, ChemGrout mixing system [www.chemgrout.com/500hp.htm](http://www.chemgrout.com/500hp.htm)). Slurry mixes quickly in these systems (<1 minute), and injections can proceed without interruption.



Pumps. Experienced drillers will have a variety of pumping equipment on site. For injecting slurries, an injection pump capable of generating at least 300 psi of pressure at a flow rate of >5 gpm is desired. Obviously, the pump needs to be able to handle solids, such as piston pumps, grout pumps, and progressing cavity pumps - with a preference towards the piston and grout pumps. Slurry is typically injected at pressures of 100 to 200 psi; however, higher pressures are sometimes required to initiate the injection. It is recommended to have a higher pressure pump available on site that can generate over 500 psi and ca. >10 gpm, as deeper installations often require higher injection pressures.

Tooling. Experienced drillers will have sufficient rod length on site to allow 3 to 5 injection points to be capped overnight to allow pressure to dissipate. This can help prevent backflow and surfacing of slurry as the injection rods are retracted. Likewise, experienced drillers will have on hand a variety of injection tips, some that direct the slurry horizontally (see for example GeoProbe's pressure activated tip at [geoprobe.com](http://geoprobe.com)).



In a “top-down” injection approach, the rods are initially advanced to the top of the targeted depth interval, and a specified volume of slurry is injected while recording flow rate, injection pressure, and slurry volume delivered. The injection rods are then further advanced a distance ranging 2 to 4 feet and the process is repeated to help ensure even distribution of slurry over the targeted depth interval. At the end of each injection point, a small volume of water (15 USG) is often used to clear the rods and the injection tip of any slurry.

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**2871 West Forest Road, Suite 2 | Freeport, IL 61032**

**Tel: (815) 650-2230 | Fax: (815) 650-2232 | Email: [info@ProvectusEnv.com](mailto:info@ProvectusEnv.com)**

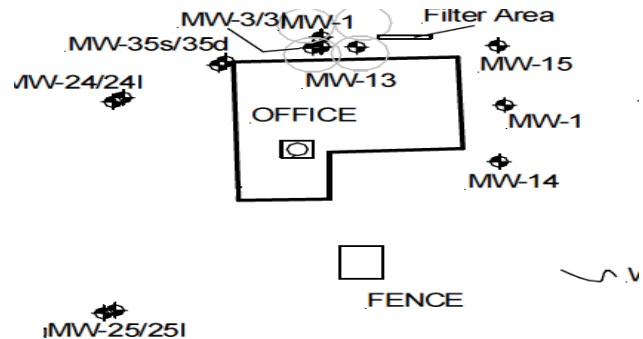
**Multiple remedial contracting options available via strategic providers**

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## Provect-IR™ - Former Dry Cleaners Site - Durham, NC

### Project Summary

Soil and groundwater at a former dry cleaner site in Durham, NC were impacted by tetrachloroethylene (PCE) due to historical releases. In April 2011, a standard version of Provect-IR™ ISCR reagent (without the methane inhibitor) was applied to three open-rock wells from ca. 30 to 40 ft bgs to create a pilot-scale permeable reactive barrier (PRB) treatment zone ca. 15 ft up-gradient of existing monitoring well MW-26 (Figure 1) which was screened from 27 to 37.5 ft bgs. A single inflatable TMA 350 packer system was used to inject the slurried reagent.



### Remediation Implementation

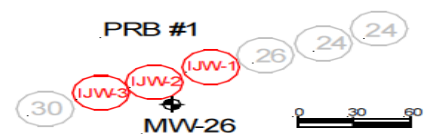


Figure 1. Site map showing three injection points (IJW-1, 2 and 3) to create a pilot PRB proximal to monitoring well MW-26.

### Pilot Test Results

Nine months after the injection event (January 2012), total CVOC concentrations were reduced from 2,540 µg/L to 71.2 µg/L, a 97% reduction (Figure 2). More specifically, there was >99% reduction in PCE (from 2,400 µg/L to 6.2 µg/L) without the Stoichiometric accumulation of catabolic intermediates that is often observed when using non-ISCR reagents.

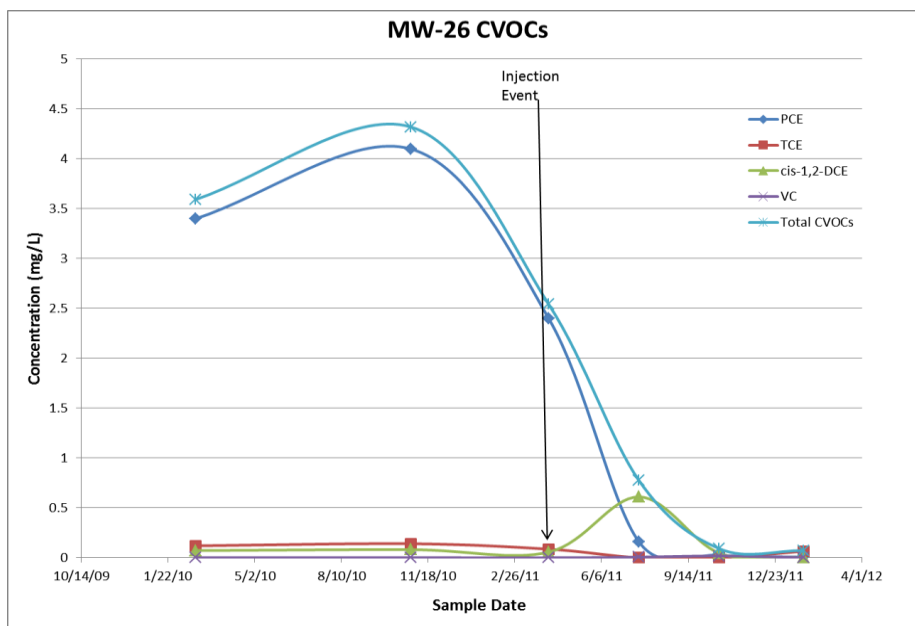
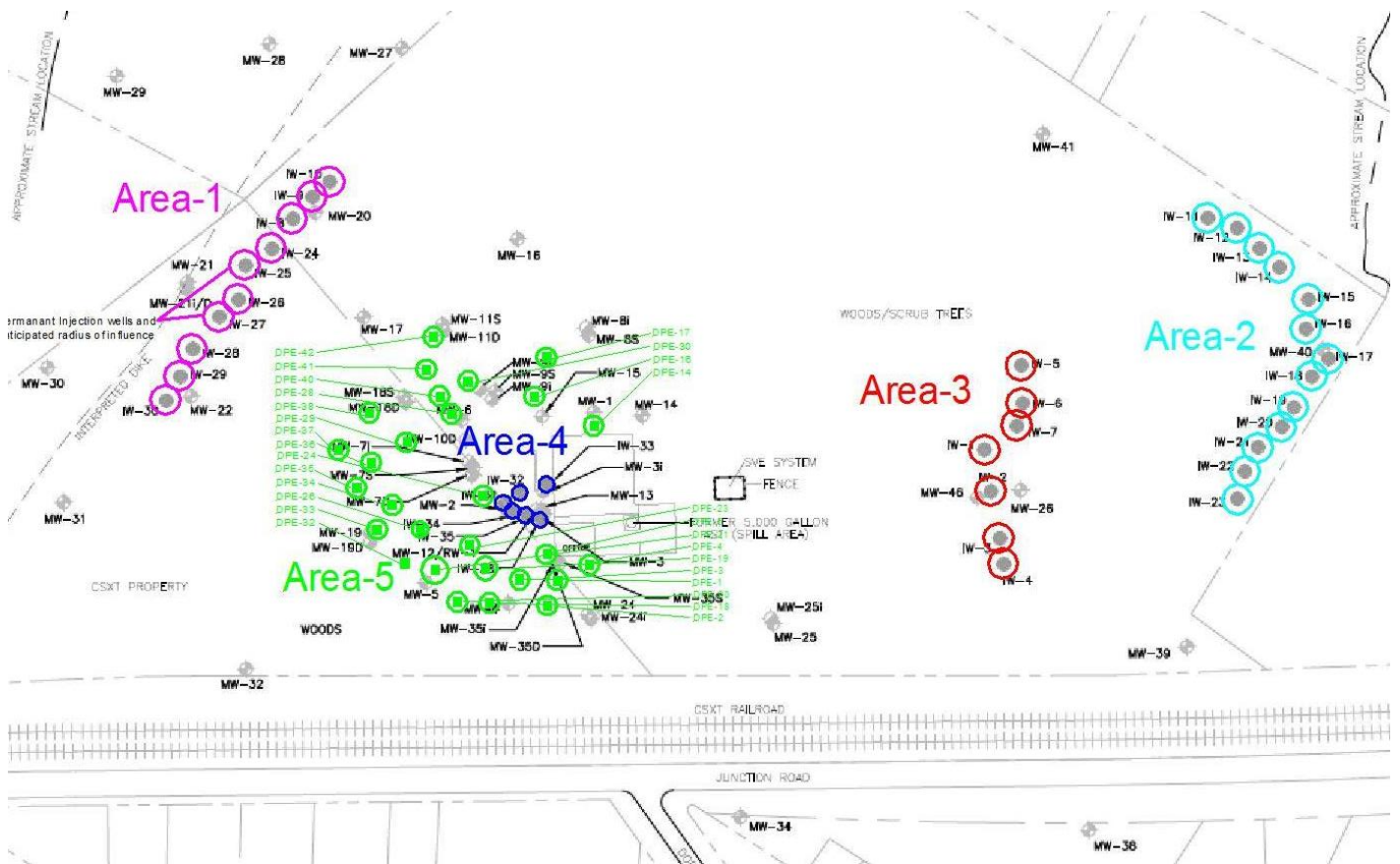


Figure 2. Concentrations (mg/L) in Groundwater vs. Time at MW-26 before and after in-situ injection event.

Full Scale Remedial Action

In December, 2012 a total of 10,100 USG of solution containing ca. 10,815 lbs of “Provect-IR” (without the methane inhibitor) were injected throughout 5 treatment areas via 64 injection points (**Figure 3**The DPE injections were performed at depths of 15-30’ bgs; approximately 150 USG of solution were injected in each point. The injections in the wells across the site (IW) were implemented at depths between 5’ and 45’ bgs; approximately 175 USG of a dilute Provect-IR solution were injected in each well. The pressure of the pre-injection pathway development was approximately between 100 and 150 psi, while the pressure of the post-injection pathway development was around 50 psi. ). Subsequent performance monitoring used data collected from 8 Eight monitoring wells (MW-2, MW-3, MW-4, MW-9S, MW-21, MW-26, MW-40 and MW-46).



**Figure 3. Overview of “Provect-IR” treatment areas.**

Full-Scale Application Results

Data from MW-46 located within Area 3 are presented herein as representative of treatment performance. This treatment zone was designed as permeable reactive barrier located immediately downgradient from a suspected PCE source area and encompassed monitoring wells MW-26 and MW-46.

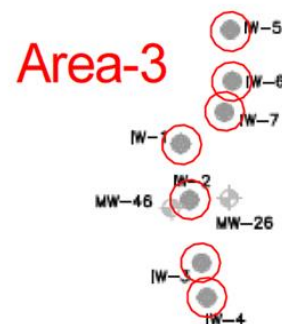


Figure 4. Wells and injection points in Area 3.

MW-46 Data

*Field Parameters and Geochemical Data:* The field parameters and the geochemical data for monitoring well MW-46 are presented in **Table 1**. The pH values remained neutral throughout the treatment process ranging between 7.05 and 9.29 (suspect value) pH units. The ORP values, sulfate and ferrous iron values confirmed that aquifer conditions were mostly reducing. Finally dissolved gases and especially methane have remained elevated as of March 2014, indicating that acetogenic, dehalorespiring and methanogenic bacteria are all active in the vicinity of MW-46 (**NOTE:** The Provect-IR formulation used in 2012 did NOT contain the methane inhibitor).

**Table 1.** Field Parameters and Geochemical Data for MW-46.

MW-46						
Sampling Date	10/10/2012	03/28/2013	07/10/2013	09/17/2013	12/03/2013	03/11/2014
D.O. (mg/L)	0.22	0.16	0.69	0.16	0.74	1.31
ORP (mV)	-90.9	-58.2	+11.1	-23.9	-126.0	-53.0
Conductivity (µs/cm)	888	666	740	741	780	745
pH	7.08	7.05	7.94	9.29	7.14	7.29
Sulfate (mg/L)	0.438	<0.25	0.212 J	2.95	0.288	<4
Total Iron (mg/L)	1.2	0.2	0.2	0.2	0.2	1.4
Dissolved Iron (mg/L)	1.2	0.2	0.2	0.2	0.2	1.4
Methane (µg/L)	1,970	7,840	8,460	NA	5,420	15,000
Ethane (µg/L)	12.3	NA	26.6	NA	7.0	28.0
Ethene (µg/L)	30.7	NA	8.7	NA	1.5	<3.8

NA: Not Analyzed

*CVOC Data:* The concentrations of all CVOCs decreased significantly within 3 months from the time of the injection event, and the PCE concentration has remained below the analytical detection limit of 0.5 ppb since the July 2013 sampling event. The concentrations of the potential daughter compounds TCE, cis-1,2-DCE and vinyl chloride have all continued to decrease as well. The TCE concentrations have been < analytical detection limits, while cis-1,2-DCE and vinyl chloride concentrations have decreased by 99.4% and 99%, respectively, since the baseline sampling event (**Table 2**). The CVOC concentrations immediately proximal to treated areas have, in general, not reflected rebound (**Figure 5**).

**Table 2.** CVOC Data for MW-46.

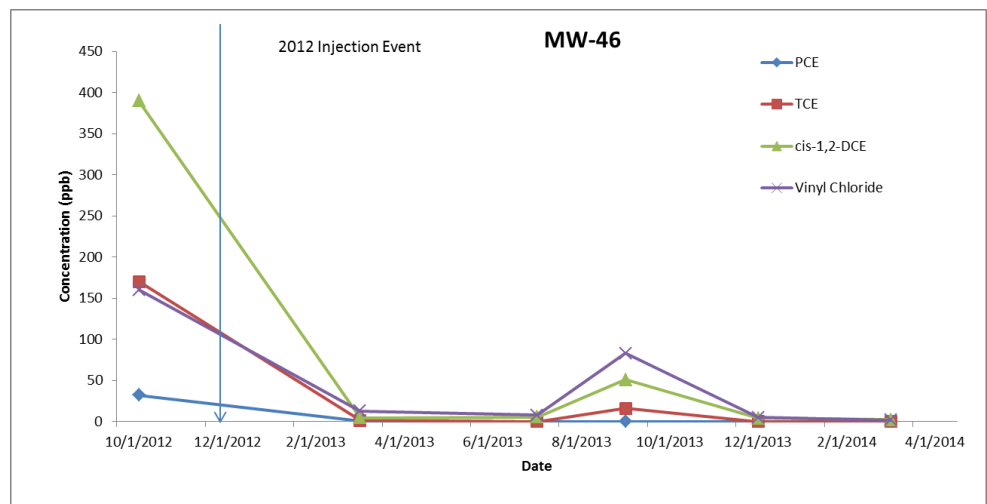
MW-46						
Sampling Date	10/10/2012	03/28/2013	07/10/2013	09/17/2013	12/03/2013	03/11/2014
PCE (µg/L)	32	1.2	<0.7	<0.7	0.44 J	<0.5
TCE (µg/L)	170	1.3 J	<0.28	16	<2.8	0.36 J
cis-1,2-DCE (µg/L)	390	4.7 J	5.6	51	4.4 J	2.2
Vinyl Chloride (µg/L)	160	13	8	83	5.1	2.1

**Conclusion**

In general, performance monitoring data from December 2012 through March 2014 showed that “Provect-IR” led to a significant decrease in PCE and total CVOC concentrations in seven of the eight monitoring wells located within and proximal to the treated areas. Although the concentrations of *cis*-1,2-DCE and vinyl chloride showed some transient increases commonly associated with enhanced reductive

dechlorination, or ERD (and less so with *in situ* chemical reduction, or ISCR), these catabolites were not produced in Stoichiometric amounts. Significant changes in groundwater levels were observed to correlate with transient but notable increase in the concentrations of the targeted compounds, indicating the presence of residual sources that were not fully addressed. Supplemental treatment using Provect-IR is presently being contemplated.

**Figure 5.** CVOC concentration changes in MW-46.



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Enclosure 1  
**FLORIDA DEPARTMENT OF  
ENVIRONMENTAL PROTECTION**  
BOB MARTINEZ CENTER  
2600 BLAIR STONE ROAD  
TALLAHASSEE, FLORIDA 32399-2400

RICK SCOTT  
GOVERNOR

CARLOS LOPEZ-CANTERA  
LT. GOVERNOR

HERSCHEL T. VINYARD JR.  
SECRETARY

June 16, 2014

Via Electronic Mail

Jim Mueller [jim.mueller@provectusenv.com]

Dr. James Mueller, President  
Provectus Environmental Products, Inc.  
2871 West Forest Road, Suite 2  
Freeport, Illinois 61032

Re: **Provect-IR™**

Dear Dr. Mueller:

The Waste Cleanup Program (WCP) hereby accepts the use of Provect-IR™ for the purpose of in-situ reductive dechlorination of chlorinated hydrocarbons in soil, sediment and groundwater. The primary ingredients are iron and a source of carbon. Enclosure 1 provides regulatory information.

The WCP does not provide endorsement of specific or brand name remediation products or processes, but it does recognize the need to determine their acceptability in the context of environmental regulations, safety and the protection of public health. For that reason, the WCP issues an “acceptance” letter, not an approval. In no way shall an acceptance be construed as a certification of performance. Additionally, vendors, upon receipt of an acceptance, must market their product or process on its own merits regarding performance, cost, and safety in comparison to competing alternatives in the marketplace.

Remedial action plans that propose the use of an accepted product or process should include a copy of the acceptance letter in the plan’s appendix, and reference it in the text of the document. It is not a requirement that a particular remediation product or process have an official acceptance letter in order for it to be proposed in a site-specific remedial action plan. The plan, however, must contain sufficient information about the product or process to show that it meets all applicable rules and regulations.

The WCP reserves the right to revoke its acceptance of a product or process if it has been falsely represented. Additionally, WCP acceptance of any product or process does not imply it has been deemed applicable for all cleanup situations, or that it is preferred over other treatment or cleanup techniques in any particular case. A site-specific evaluation of applicability and cost-effectiveness must be considered for any product or process, whether conventional or innovative,



Dr. Mueller  
Page 2  
June 16, 2014

Provect-IR  
Acceptance Letter

and adequate site-specific design details must be provided in a remedial action plan submitted for Department review and approval. If you have any questions, please contact us at the numbers below.

Sincerely,



Gary Millington, P.E.  
Division of Waste Management  
Office of District and Business Support  
gary.millington@dep.state.fl.us  
850.245.7502

enc: (1) Regulatory Information

c: Mubeen Darji, P.E. – WCP/Tallahassee

## ENCLOSURE 1

### REGULATORY INFORMATION

- a. Regulations: Chapters of the Florida Administrative Code (F.A.C.) that may be applicable, either in part or in their entirety, include but are not necessarily limited to Chapter 62-550, F.A.C., for primary and secondary water quality standards; Chapter 62-520, F.A.C., for groundwater classes and standards, and groundwater permitting and monitoring requirements; Chapter 62-528, F.A.C., for Underground Injection Control (UIC), particularly Part V, for Class V, Group 4 aquifer remediation projects; Chapter 62-780, F.A.C., for cleanup criteria; and Chapter 62-777, F.A.C., for cleanup target levels.

Users of Provect-IR shall comply with all applicable regulations. This includes meeting applicable cleanup target levels for residual concentrations of reagent ingredients and any byproducts of concern produced by chemical and biological reactions induced by those ingredients during the timeframe of the cleanup project. For the ingredients of concern that are present in excess of cleanup target levels, the timeframe is that which is permitted for a temporary injection zone of discharge (ZOD) as described below.

- b. UIC and ZOD permits: Per Rule 62-528.630(2)(c), F.A.C., Class V injection-type aquifer remediation wells are exempt from the permitting requirements of Rule 62-528.635, F.A.C., when authorized by a Department-approved remedial action plan or other enforceable mechanism, provided the requirements of the rules governing the remediation project, as well as the construction, operation, and monitoring requirements of Chapter 62-528, F.A.C., are met. Per Rule 62-528.630(2)(c), F.A.C., the issuance of an enforceable, site-specific remedial action plan approval order by the Department for injection-type aquifer remediation constitutes the granting of a Class V injection well construction/clearance permit. And per Rule 62-520.310(8)(c), F.A.C., if a temporary ZOD is necessary, and permissible by way of that rule, then the issuance of the site-specific remedial action plan approval order also constitutes the granting of permission for the temporary ZOD.
- c. UIC notification: Remedial action plans proposing injection-type aquifer remediation shall include information pursuant to Rules 62-528.630(2)(c)1 through 6, F.A.C., for the inventory purposes of the UIC program. Reviewers of those plans, upon issuance of an enforceable remedial action plan approval order by the Department, must submit a completed copy of the UIC inventory notification form to the UIC program in Tallahassee.
- d. General information about temporary ZODs: For groundwater remediation, the composition of an injected material must meet the primary and secondary drinking water standards set forth in Chapter 62-550, F.A.C., and the minimum groundwater criteria of Chapter 62-520, F.A.C., pursuant to UIC Rule 62-528.600(2)(d), F.A.C. Aquifer remediation products that do not meet these requirements must seek relief from water quality criteria by one of two mechanisms. Permission for a temporary ZOD may be obtained via Rule 62-520.310(8)(c), F.A.C. If a ZOD is not permissible by rule, it will be necessary to seek a variance from Department rules in accordance with Section 120.542, Florida Statutes.

Rule 62-520.310(8)(c), F.A.C., allows for a temporary ZOD for closed-loop re-injection systems, for the prime constituents of the reagents used to remediate site contaminants, and for groundwater secondary standards. In order to obtain permission for a temporary ZOD by rule, a site-specific remedial action plan must indicate: (a) the chemical ingredients of concern in the fluid to be injected that will be present in excess of groundwater standards; (b) the size of the ZOD that is needed; (c) the amount of time that the ZOD will be needed; and (d) a plan for monitoring the injected chemical ingredients of concern. The size of the temporary ZOD will usually be the injection well radius of influence when the treatment system is a single injection point. For a multiple point system, the ZOD can usually be expressed and illustrated as the total area of the cluster formed by all the injection points, located side-by-side with overlapping radii of influence.

- e. Specific ZOD information for Provect-IR: A site-specific remedial action plan shall specify the volume and concentration at which the product will be injected, and the size and duration of the ZOD needed. Monitoring requirements for the ZOD are ammonia, iron, pH, TDS and TRPH. Monitoring requirements will also include sodium if the injected material contains more than 4.5% Provect-IR and sulfate if the injected material contains more than 1.5% Provect-IR.

Upon expiration of the time period granted for the ZOD, the concentration of each parameter must meet its respective groundwater standard or its natural-occurring background value at the specific cleanup site, whichever is less stringent.

- g. Utilization of wells: If a remediation site happens to have an abundance of monitoring wells, then the WCP has no objection to the use of some wells for the application of injected products. However, no “designated” monitoring well, dedicated to the tracking of remediation progress (by sampling) shall be used to apply reagents. This will avoid premature conclusion that the entire site meets cleanup goals. By making sure that designated tracking wells are not also used for treatment, there will be more assurance that the treatment process has permeated the entire site and that it did not remain localized to the area immediately surrounding each injection well.
- h. Avoidance of migration: For injection-type, in-situ aquifer remediation projects, pursuant to Rule 62-528.630(3), F.A.C., injection of remediation products shall be performed in such a way, and at such a rate and volume, that no undesirable migration of either the ingredients of concern, site contaminants, or remediation byproducts results.
- i. Abandonment of wells: Upon issuance of a Site Rehabilitation Completion Order, injection wells shall be abandoned pursuant to Section 62-528.645, F.A.C., and the Underground Injection Control Section of the Department shall be notified so that the treatment wells can be removed from the injection well inventory-tracking list.

# D

## Cost Estimates

- D-1 Summary of Total Present Values of Alternatives at the Mr. C's Dry Cleaner Site
- D-2 Cost Estimate for Alternative 1: Pump and Treat for Source and Migration Control
- D-3 Cost Estimate for Alternative 2a Pump-and-Treat Source Control with Bioremediation for Migration Control – 3D Microemulsion® PRBs
- D-4 Cost Estimate for Alternative 2b Pump-and-Treat Source Control with Bioremediation for Migration Control – 3D Microemulsion® and PlumeStop® PRBs
- D-5 Cost Estimate for Alternative 2c Pump-and-Treat Source Control with Bioremediation for Migration Control – Provect-IR® PRBs
- D-6 Cost Estimate for Alternative 4a Bioremediation for Source and Migration Control – 3D Microemulsion®
- D-7 Cost Estimate for Alternative 4b Bioremediation for Source and Migration Control – 3D Microemulsion® and PlumeStop®
- D-8 Cost Estimate for Alternative 4c Bioremediation for Source and Migration Control – Provect-IR®

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

Description	Alternative 1	Alternative 2a	Alternative 2b	Alternative 2c	Alternative 4a	Alternative 4b	Alternative 4c
	Pump and Treat	Pump and Treat with 3DMe 75 PRB	Pump and Treat with 3DMe 75 and PlumeStop PRB	Pump and Treat with Antimethanogenic PRB	Source Bioremediation with 3DMe 75 PRB	Source Bioremediation and PRB with 3DMe 75 and PlumeStop	Antimethanogenic Source Bioremediation and PRB
Capital Cost	\$119,000	\$297,000	\$807,000	\$535,000	\$1,804,000	\$1,701,000	\$1,328,000
Annual Costs <sup>1</sup>	\$3,033,000	\$3,033,000	\$3,033,000	\$3,033,000	\$564,000	\$564,000	\$564,000
Periodic Costs <sup>2</sup>	\$246,000	\$246,000	\$246,000	\$246,000	\$246,000	\$246,000	\$246,000
<b>2016 Total Present Value of Alternative<sup>3</sup></b>	<b>\$3,398,000</b>	<b>\$3,576,000</b>	<b>\$4,086,000</b>	<b>\$3,814,000</b>	<b>\$2,614,000</b>	<b>\$2,511,000</b>	<b>\$2,138,000</b>

Notes:

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

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 D-2: Cost Estimate for Alternative 1: Pump and 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
<b>Capital Costs</b>					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	\$2,278.70	\$2,279
<i>Subtotal</i>					\$2,279
<b>Decommission Old Pumps</b>					
Pump removal - labor		Each	7	\$263.00	\$1,841
<i>Subtotal</i>					\$1,841
<b>System Upgrades</b>					
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
<i>Subtotal</i>					\$68,182
<b>Soil vapor intrusion investigations and SSDS Installation</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Total Capital Cost:</b>					<b>\$119,000</b>
<b>Annual Costs</b>					
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	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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Annual Cost Total:</b>					<b>\$197,289</b>
<b>30-Year Present Value of Annual Costs:</b>					<b>\$3,033,000</b>
<b>3-Year Costs</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>3-Year Total:</b>					<b>\$36,704</b>
<b>30-Year Present Value of 3-Year Costs:</b>					<b>\$208,000</b>

**Table D-2: Cost Estimate for Alternative 1: Pump and 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
<b>5-Year Costs</b>					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	\$500.00	\$8,000
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>5-Year Total:</b>					<b>\$10,464</b>
<b>30-Year Present Value of 5-Year Costs:</b>					<b>\$38,000</b>
<b>2016 Total Present Value Cost:</b>					<b>\$3,398,000</b>

**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 D-3: Cost Estimate for Alternative 2a: Pump-and-Treat Source Control with Bioremediation for Migration Control –  
3D Microemulsion® PRBs  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Capital Costs</b>					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	\$6,584.71	\$6,585
<i>Subtotal</i>					\$6,585
<b>Site Preparation</b>					
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
<i>Subtotal</i>					\$5,674
<b>System Upgrades</b>					
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
<i>Subtotal</i>					\$68,182
<b>Downgradient Permeable Reactive Barriers</b>					
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
<i>Subtotal</i>					\$120,761
<b>Site Restoration</b>					
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
<i>Subtotal</i>					\$7,727
<b>Soil vapor intrusion investigations and SSDS Installation</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Total Capital Cost:</b>					<b>\$297,000</b>



**Table D-3: Cost Estimate for Alternative 2a: Pump-and-Treat Source Control with Bioremediation for Migration Control –  
3D Microemulsion® PRBs  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Annual Costs</b>					
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	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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMean Historical Cost Index:					100.5%
<b>Annual Cost Total:</b>					<b>\$197,289</b>
<b>30-Year Present Value of Annual Costs:</b>					<b>\$3,033,000</b>
<b>3-Year Costs</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMean Historical Cost Index:					100.5%
<b>3-Year Total:</b>					<b>\$36,704</b>
<b>30-Year Present Value of 3-Year Costs:</b>					<b>\$208,000</b>
<b>5-Year Costs</b>					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	\$500.00	\$8,000
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMean Historical Cost Index:					100.5%
<b>5-Year Total:</b>					<b>\$10,464</b>
<b>30-Year Present Value of 5-Year Costs:</b>					<b>\$38,000</b>
<b>2016 Total Present Value Cost:</b>					<b>\$3,576,000</b>

**Assumptions:**

- Present value cost based on annual and periodic costs over: 30 years
- Present value of costs assumes 5% annual interest rate.
- 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.
- Assumes larger pumps will fit in existing pumping well casings.
- 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 or installing new asphalt/ concrete pads, replacing existing well covers, installing new watertight well cap, and removing or replacing portions of cracked casings.
- 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 D-4: Cost Estimate for Alternative 2b: Pump-and-Treat Source Control with Bioremediation for Migration Control – 3D Microemulsion® and PlumeStop® PRBs  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Capital Costs</b>					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	\$18,875.87	\$18,876
<i>Subtotal</i>					\$18,876
<b>Site Preparation</b>					
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
<i>Subtotal</i>					\$5,674
<b>System Upgrades</b>					
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
<i>Subtotal</i>					\$68,182
<b>Downgradient Permeable Reactive Barriers</b>					
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)	LS	1	\$160,800	\$160,800
<i>Subtotal</i>					\$498,461
<b>Site Restoration</b>					
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
<i>Subtotal</i>					\$7,727
<b>Soil vapor intrusion investigations and SSDS Installation</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMMeans Historical Cost Index:					100.5%
<b>Total Capital Cost:</b>					<b>\$807,000</b>
<b>Annual Costs</b>					
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	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

**Table D-4: Cost Estimate for Alternative 2b: Pump-and-Treat Source Control with Bioremediation for Migration Control –  
 3D Microemulsion® and PlumeStop® PRBs  
 Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<i>Subtotal</i>					\$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
	Adjustment from 2015 to 2016 costs based on the RSMMeans Historical Cost Index:				100.5%
				<b>Annual Cost Total:</b>	<b>\$197,289</b>
				<b>30-Year Present Value of Annual Costs:</b>	<b>\$3,033,000</b>

**Table D-4: Cost Estimate for Alternative 2b: Pump-and-Treat Source Control with Bioremediation for Migration Control –  
3D Microemulsion® and PlumeStop® PRBs  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>3-Year Costs</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMMeans Historical Cost Index:					100.5%
<b>3-Year Total:</b>					<b>\$36,704</b>
<b>30-Year Present Value of 3-Year Costs:</b>					<b>\$208,000</b>
<b>5-Year Costs</b>					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	\$500.00	\$8,000
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMMeans Historical Cost Index:					100.5%
<b>5-Year Total:</b>					<b>\$10,464</b>
<b>30-Year Present Value of 5-Year Costs:</b>					<b>\$38,000</b>
<b>2016 Total Present Value Cost:</b>					<b>\$4,086,000</b>

**Assumptions:**

- Present value cost based on annual and periodic costs over: 30 years
- Present value of costs assumes 5% annual interest rate.
- 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.
- Assumes larger pumps will fit in existing pumping well casings.
- 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.
- 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 D-5: Cost Estimate for Alternative 2c: Pump-and-Treat Source Control with Bioremediation for Migration Control – Provect-IR® PRBs  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Capital Costs</b>					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	\$12,312.16	\$12,312
<i>Subtotal</i>					\$12,312
<b>Site Preparation</b>					
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
<i>Subtotal</i>					\$5,674
<b>System Upgrades</b>					
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
<i>Subtotal</i>					\$68,182
<b>Downgradient Permeable Reactive Barriers</b>					
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	120	\$380.00	\$45,600
Provect-IR	materials only	lbs	135,250	\$1.65	\$223,163
	shipping	LS	1	\$20,000	\$20,000
Provectus field support	2-days of field oversight and travel	LS	1	\$3,000	\$3,000
<i>Subtotal</i>					\$296,763
<b>Site Restoration</b>					
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
<i>Subtotal</i>					\$7,727
<b>Soil vapor intrusion investigations and SSDS Installation</b>					
Soil vapor intrusion investigation	Assume twice as many properties are investigated as SSDSs are installed.	Ea	4	\$2,000	\$8,000
New SSDS Installation - Residential	Assume 8% increase from current installations (2). Installation in the future.	Ea	1	\$4,000	\$4,000
New SSDS Installation - Commercial	Assume 8% increase from current installations (12). Installation in the future.	Ea	1	\$6,000	\$6,000
<i>Subtotal</i>					\$18,000
<b>Capital Cost Subtotal:</b>					\$408,657
Adjusted Capital Cost Subtotal for Buffalo, New York Location Factor (1.029):					\$420,509
10% Legal, administrative, engineering fees, construction management:					\$42,051
15% Contingencies:					\$69,384
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Total Capital Cost:</b>					<b>\$535,000</b>
<b>Annual Costs</b>					
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	\$90,850.0	\$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	\$2,592.0	\$2,592
Replacement Equipment	May include the replacement of pumps, blowers, motors, etc. and sequestering agent	Year	1	\$16,000.0	\$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
<i>Subtotal</i>					\$144,548
<b>Annual Cost Subtotal:</b>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Annual Cost Total:</b>					<b>\$197,289</b>
<b>30-Year Present Value of Annual Costs:</b>					<b>\$3,033,000</b>

**Table D-5: Cost Estimate for Alternative 2c: Pump-and-Treat Source Control with Bioremediation for Migration Control – Provect-IR® PRBs  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>3-Year Costs</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>3-Year Total:</b>					<b>\$36,704</b>
<b>30-Year Present Value of 3-Year Costs:</b>					<b>\$208,000</b>
<b>5-Year Costs</b>					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	\$500.00	\$8,000
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>5-Year Total:</b>					<b>\$10,464</b>
<b>30-Year Present Value of 5-Year Costs:</b>					<b>\$38,000</b>
<b>2016 Total Present Value Cost:</b>					<b>\$3,814,000</b>

**Assumptions:**

- Present value cost based on annual and periodic costs over: 30 years
- Present value of costs assumes 5% annual interest rate.
- 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.
- Assumes larger pumps will fit in existing pumping well casings.
- 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.
- 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 D-6: Cost Estimate for Alternative 4a: Bioremediation for Source and Migration Control – 3D Microemulsion®  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Capital Costs</b>					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	\$21,773.64	\$21,774
<i>Subtotal</i>					\$21,774
<b>Treatment System Decommissioning</b>					
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 operator (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
<i>Subtotal</i>					\$64,799
<b>Site Preparation</b>					
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
<i>Subtotal</i>					\$5,674
<b>Source Bioremediation</b>					
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 Inoculum	materials only	Liter	94	\$200.00	\$18,800
<i>Subtotal</i>					\$444,228
<b>Downgradient Permeable Reactive Barriers</b>					
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
<i>Subtotal</i>					\$120,761
<b>Site Restoration</b>					
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
<i>Subtotal</i>					\$33,629
<b>Maintenance Injections</b>					
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
<i>Subtotal</i>					\$670,000

**Table D-6: Cost Estimate for Alternative 4a: Bioremediation for Source and Migration Control – 3D Microemulsion®  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Soil vapor intrusion investigations and SSDS Installation</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Total Capital Cost:</b>					<b>\$1,804,000</b>
<b>Annual Costs</b>					
Monitoring Well Network OM&M		Year	1	\$8,000.00	\$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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Annual Cost Total:</b>					<b>\$36,633</b>
<b>30-Year Present Value of Annual Costs:</b>					<b>\$564,000</b>
<b>3-Year Costs</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>3-Year Total:</b>					<b>\$36,704</b>
<b>30-Year Present Value of 3-Year Costs:</b>					<b>\$208,000</b>
<b>5-Year Costs</b>					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	\$500.00	\$8,000
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>5-Year Total:</b>					<b>\$10,464</b>
<b>30-Year Present Value of 5-Year Costs:</b>					<b>\$38,000</b>
<b>2016 Total Present Value Cost:</b>					<b>\$2,614,000</b>

**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 D-7: Cost Estimate for Alternative 4b: Bioremediation for Source and Migration Control – 3D Microemulsion® and PlumeStop®  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Capital Costs</b>					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	\$40,408.20	\$40,408
<i>Subtotal</i>					\$40,408
<b>Treatment System Decommissioning</b>					
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 operator (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
<i>Subtotal</i>					\$64,799
<b>Site Preparation</b>					
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
<i>Subtotal</i>					\$5,674
<b>Source Bioremediation</b>					
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
PlumeStop	materials only	lbs	176,733	\$2.25	\$397,650
PlumeStop Application	Regenesis staff (required)	LS	1	\$294,800	\$294,800
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
<i>Subtotal</i>					\$1,137,618
<b>Site Restoration</b>					
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
<i>Subtotal</i>					\$33,629

**Table D-7: Cost Estimate for Alternative 4b: Bioremediation for Source and Migration Control – 3D Microemulsion® and PlumeStop®  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Soil vapor intrusion investigations and SSDS Installation</b>					
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
<i>Subtotal</i>					\$18,000
Capital Cost Subtotal:					\$1,300,128
Adjusted Capital Cost Subtotal for Buffalo, New York Location Factor (1.029):					\$1,337,832
10% Legal, administrative, engineering fees, construction management:					\$133,783
15% Contingencies:					\$220,742
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Total Capital Cost:</b>					<b>\$1,701,000</b>
<b>Annual Costs</b>					
Monitoring Well Network OM&M		Year	1	\$8,000.00	\$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
<i>Subtotal</i>					\$26,840
Annual Cost Subtotal:					\$26,840
Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):					\$27,618
10% Legal, administrative, engineering fees:					\$2,762
15% Contingencies:					\$6,076
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Annual Cost Total:</b>					<b>\$36,633</b>
<b>30-Year Present Value of Annual Costs:</b>					<b>\$564,000</b>
<b>3-Year Costs</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>3-Year Total:</b>					<b>\$36,704</b>
<b>30-Year Present Value of 3-Year Costs:</b>					<b>\$208,000</b>
<b>5-Year Costs</b>					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	\$500.00	\$8,000
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>5-Year Total:</b>					<b>\$10,464</b>
<b>30-Year Present Value of 5-Year Costs:</b>					<b>\$38,000</b>
<b>2016 Total Present Value Cost:</b>					<b>\$2,511,000</b>

**Assumptions:**

- Present value cost based on annual and periodic costs over: 30 years
- Present value of costs assumes 5% annual interest rate.
- 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.
- Assumes larger pumps will fit in existing pumping well casings.
- Monitoring well OM&M includes replacing missing or stripped bolts, replacing existing or installing new asphalt/ concrete pads, replacing existing well covers, installing new watertight well cap, and removing or
- 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 D-8: Cost Estimate for Alternative 4c: Bioremediation for Source and Migration Control – Provect-IR®  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Capital Costs</b>					
Construction Management (2.5% of total capital cost)	Includes submittals, reporting	LS	1	\$23,830.64	\$23,831
<i>Subtotal</i>					\$23,831
<b>Treatment System Decommissioning</b>					
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 operator (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
<i>Subtotal</i>					\$64,799
<b>Site Preparation</b>					
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
<i>Subtotal</i>					\$5,674
<b>Source Bioremediation</b>					
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
Provect-IR	materials only	lbs	86,250	\$1.85	\$159,563
	shipping	LS	1	\$10,000	\$10,000
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	174	\$380.00	\$66,120
Provectus Innoculum	materials only, assumed 20% surcharge for shipping	Pounds	173	\$138.00	\$23,874
<i>Subtotal</i>					\$331,437
<b>Downgradient Permeable Reactive Barriers</b>					
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	120	\$380.00	\$45,600
Provect-IR	materials only	lbs	135,250	\$1.65	\$223,163
	shipping	LS	1	\$20,000.00	\$20,000
Provectus field support	2-days of field oversight and travel	LS	1	\$3,000.00	\$3,000
<i>Subtotal</i>					\$296,763
<b>Site Restoration</b>					
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
<i>Subtotal</i>					\$33,629
<b>Maintenance Injections</b>					
Year 5 Re-injection in source	Present value of re-injection in 5 years, excludes innoculum re-injection	LS	1	\$241,000	\$241,000
<i>Subtotal</i>					\$241,000

**Table D-8: Cost Estimate for Alternative 4c: Bioremediation for Source and Migration Control – Provect-IR®  
Mr. C's Dry Cleaner's Site, East Aurora, New York**

Item Description	Comment	Unit	Quantity	Unit Cost	Cost
<b>Soil vapor intrusion investigations and SSDS Installation</b>					
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
<i>Subtotal</i>					\$18,000
Capital Cost Subtotal:					\$1,015,132
Adjusted Capital Cost Subtotal for Buffalo, New York Location Factor (1.029):					\$1,044,571
10% Legal, administrative, engineering fees, construction management:					\$104,457
15% Contingencies:					\$172,354
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Total Capital Cost:</b>					<b>\$1,328,000</b>
<b>Annual Costs</b>					
Monitoring Well Network OM&M		Year	1	\$8,000.00	\$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
<i>Subtotal</i>					\$26,840
Annual Cost Subtotal:					\$26,840
Adjusted Annual Cost Subtotal for Buffalo, New York Location Factor (1.029):					\$27,618
10% Legal, administrative, engineering fees:					\$2,762
15% Contingencies:					\$6,076
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>Annual Cost Total:</b>					<b>\$36,633</b>
<b>30-Year Present Value of Annual Costs:</b>					<b>\$564,000</b>
<b>3-Year Costs</b>					
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
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>3-Year Total:</b>					<b>\$36,704</b>
<b>30-Year Present Value of 3-Year Costs:</b>					<b>\$208,000</b>
<b>5-Year Costs</b>					
SSDS fan replacement	Assume once every 5 years, cost includes fan and labor	EA	16	\$500.00	\$8,000
<i>Subtotal</i>					\$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
Adjustment from 2015 to 2016 costs based on the RSMeans Historical Cost Index:					100.5%
<b>5-Year Total:</b>					<b>\$10,464</b>
<b>30-Year Present Value of 5-Year Costs:</b>					<b>\$38,000</b>
<b>2016 Total Present Value Cost:</b>					<b>\$2,138,000</b>

**Assumptions:**

- Present value cost based on annual and periodic costs over: 30 years
- Present value of costs assumes 5% annual interest rate.
- 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.
- Assumes larger pumps will fit in existing pumping well casings.
- Monitoring well OM&M includes replacing missing or stripped bolts, replacing existing or installing new asphalt/ concrete pads, replacing existing well covers, installing new watertight well cap, and removing or
- 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