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In-Situ Chemical Oxidation Pilot Injection Program Design Plan

Abandoned Chemical Sales Facility Site #828105

June 2014

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Prepared for:
New York State Department of
Environmental Conservation

Prepared by:
Malcolm Pirnie, Inc.
855 Route 146
Suite 210
Clifton Park
New York 12065
Tel 518 250 7300
Fax 518 250 7301

Our Ref.:
00266397.0000

Date:
June 2014

Malcolm Pirnie, Inc. was acquired by ARCADIS in July 2009.

Table of Contents

Tables

Figures

Appendices

1. Introduction

The Abandoned Chemical Sales Facility (New York State Department of Environmental Conservation [NYSDEC] site number 828105) in Rochester, New York consists of a 2.29 acre property at 1600 Jay Street (site). Chlorinated volatile organic compounds (CVOCs) and benzene, ethylbenzene, toluene, and xylene (BTEX) are present in groundwater at the site, which is in fractured bedrock. This In-Situ Chemical Oxidation (ISCO) Pilot Injection Program Design Plan presents:

- Environmental investigations and design-phase studies completed since the Remedial Investigation (RI);
- An evaluation of chemical oxidant application options; and
- The proposed ISCO pilot injection approach.

2. Site Background

Figure 1 depicts the general location of the site. The commercially-zoned site is situated in a mixed residential, commercial and industrial area of the city. It is generally bordered by Dodge Street to the east, an industrial facility housing the Monroe Fire Extinguisher Company, Inc. to the north, the Rochester and Southern Railroad immediately to the west, Jay Street to the south, and three single- and multi-tenant residential buildings to the southeast. Further to the west, beyond the railroad tracks, lies the Valeo Property, the site of a former GM-Delco Facility, which is also on the NYSDEC's Registry of Inactive Hazardous Waste Disposal Sites (NYSDEC site number 828099).

Prior to being purchased by M.A. Ferrauilo in 1994, the property was owned by the Chemreal Corp and utilized by the Chemical Sales Corporation (a.k.a. Chemcore, Inc.) from November 1952 through September 1994 as a location for manufacturing and distributing chemicals. Chemical Sales Corporation constructed a building on the site from which their operations were conducted. The existing structure on the site has two primary tenants. The southern portion of the building is currently utilized by M.A. Farrauilo Plumbing, a plumbing, heating and ventilation contractor. A high performance motor shop is located in the northern portion of the structure.

The site is generally flat, with a gradual slope from west to east. Surface elevations vary by less than five feet across the site. With the exception of a grassy area in the northern portion, the majority of the site is covered with an asphalt and gravel parking surface and a building. The northern third of the site is covered by a grassed lawn, with a few trees present. The middle portion of the site contains the 11,000 square foot (sf) single-story concrete masonry unit (CMU or concrete block) commercial building and appurtenant supply storage trailers. The building is founded on a concrete slab. An approximately 5,000 square foot fenced, asphalt-paved parking and storage area is located immediately east of the building, and gravel parking lots and driveways are present to the west, north and east of the building. The southern portion of the site contains an approximately 3,800 square foot asphalt-paved parking area and driveways. Vehicular access to the site is provided from Jay Street to the south and Dodge Street to the east.

Overhead electric and buried gas, water, and sewer utilities serving the site run from Jay Street to the southern portion of the site structure. A sewer utility line runs underneath Jay Street and is set approximately 17 feet below the top of bedrock and to approximately 4 feet below the water table.

Overburden soil at the site consists of one to two feet of fill overlying four to eight feet of fill and/or native soil. The fill consists of a dry medium to coarse-grained sand, with trace amounts of silt, some gravel and debris, including concrete, bricks and wood. The native soil ranges from poorly-graded silty sand to gravelly sand. Below this, at a depth of approximately four to eight feet below the ground surface, dolomite bedrock with minor amounts of shale is present. The upper two to three feet of the bedrock is weathered and fractured. Groundwater is generally not observed in the site overburden although perched water is present at the overburden/bedrock interface following precipitation or snow melt.

Bedrock monitoring well locations are shown on Figure 2. Shallow bedrock monitoring wells generally monitor groundwater in the 10-25 feet below ground surface (bgs) interval while intermediate bedrock monitoring wells generally monitor groundwater in the 25 to 45 foot bgs interval. No monitoring of deep bedrock (greater than 45 feet bgs) has occurred at the site.

The investigatory history is detailed in the Remedial Investigation / Feasibility Study (RIFS) Report (EA, 2011) and the Contaminated Soil Removal and Disposal Work Plan (ARCADIS, 2013). The NYSDEC listed the site as a Class 2 site in the New York State Registry of Inactive Hazardous Waste Disposal Sites in 2002 following a preliminary site assessment. The primary contaminants of concern at the site identified during the RI are tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane

(1,1,1-TCA) and their breakdown products [cis-1,2-dichloroethene (cis-1,2-DCE), 1,1-dichloroethene (1,1-DCE), vinyl chloride, 1,1-dichloroethane (1,1-DCA), and chloroethane].

As part of RIFS (EA, 2011) in-situ thermal remediation, monitored natural attenuation (MNA), in-situ chemical oxidation (ISCO) and enhanced anaerobic bioremediation were evaluated as either stand alone or combined alternatives. ISCO followed by enhanced anaerobic bioremediation was recommended in the RIFS report because it:

- Has a relatively short implementation time;
- Is more readily implemented in a fractured rock setting than thermal remediation;
- Is more effective in the short- and long- term than no action and MNA; and
- Has a lower cost than thermal remediation.

The RIFS report also suggested an ISCO pilot test prior to the full-scale implementation to confirm the implementability and effectiveness.

The record of decision (ROD) (NYSDEC, 2011) detailed the proposed remedy for the site, which includes targeted soil excavation and approximately three ISCO injection events to reduce the groundwater contaminant concentrations followed by enhanced bioremediation. The site is currently in the Remedial Design stage. Design phase studies, including treatability and injectability studies discussed herein, are being implemented to evaluate potential remedial approaches and refine the remedial design.

3. Design Phase Studies

Several design phase studies have been conducted since the completion of the RIFS. The results of injection well installation, groundwater sampling, a treatability study, and an injectability study are summarized below.

3.1 Injection Well Installation

Nothnagle Drilling installed four injection wells (MW-16S, MW-16i, MW-17S, and MW-17i) at the site in January 2013. The injection well locations are shown on Figure 3 and boring logs are provided in Appendix A. Two injection wells were completed as 4-inch diameter open boreholes within the shallow bedrock [approximately 10-25 feet below ground surface (bgs)] and two injection wells were completed as 4-inch diameter open boreholes within the intermediate (approximately 25-45 feet bgs) bedrock zone. One injection well cluster is installed in the site parking lot (MW-16S and MW-16i and a second injection well cluster are installed on the south side of Jay Street (MW-17S and MW-17i). The injection wells were installed to collect data to design and implement the ISCO pilot injection program.

3.2 Groundwater Sampling

Groundwater samples have been collected from the site in 2001, 2007, 2010, 2013, and 2014. The VOC analytical results for these sampling events are summarized on Figure 4 and in Table 1. The chlorinated ethene and ethane analytical data are presented on Figures 5 and 6, respectively. As shown on Figures 4 through 6, the highest groundwater VOC concentrations are to the south of the site building. For a subset of wells (MW-3, -9, -10, -10i, and -16i), the April 2014 sampling event included reducing-oxidizing (REDOX) indicators (dissolved iron [Fe], manganese [Mn], sulfate, sulfide, and methane), terminal CVOC break down products (chloride, ethane, and ethene), and general geochemical indicators of conditions conducive for biochemical breakdown of CVOCs (total organic carbon, pH, and alkalinity) (Table 2).

A pre-injection baseline sampling event was conducted in April 2014 to:

- Document baseline (pre-oxidant injection) groundwater quality;
- Support the design of a field-scale pilot application of a chemical oxidant;
- Evaluate the feasibility and effectiveness of in-situ chemical oxidation remedial strategies; and
- Assess geochemical conditions that could limit natural on-going reductive dechlorination processes (i.e. suboxic or oxic conditions or limited availability of organic carbon).

3.2.1 Baseline Groundwater Quality

As shown on Figures 4 through 6, the CVOC concentrations in the northern portion of the site are generally one or two orders of magnitude lower than in the southern portion of the site. The primary CVOCs in the northern portion of the site generally consist of daughter products, including cis-1,2-DCE, vinyl chloride, 1,1-DCA, and chloroethane.

The general limited presence of parent compounds relative to daughter products indicates that reductive dechlorination processes are ongoing or that the primary source has been degraded. The apparent high degree of reductive dechlorination may have been accelerated by the presence of petroleum hydrocarbon related aromatic compounds (benzene, toluene, ethylbenzene, and xylenes). Mixtures of CVOCs and aromatic compounds promote reductive dechlorination of chlorinated ethenes and ethanes because aromatic compounds (i.e. petroleum hydrocarbons) provide an organic source for aerobic degradation. This, in turn, tends to create conditions favorable for anaerobic degradation, allowing for anaerobic processes (such as reductive dechlorination) to occur.

Groundwater in the southern portion of the site is generally characterized by total CVOC concentrations exceeding 100,000 micrograms per liter. Parent compounds, including PCE, TCE, and 1,1,1-TCA generally constitutes a large proportion of the CVOCs and the CVOCs appear less degraded than in the northern portion of the site. The proportion of 1,2-cis DCE increases in the downgradient direction from MW-16i to MW-10i indicating some breakdown of PCE and TCE. 1,1,1-TCA appears more resistant to breakdown and only limited increases in daughter products are observed from MW-16i to MW10i. Aromatics constitute a small proportion of the total VOC concentrations (generally less than 3%), which in part may explain the more limited reductive dechlorination compared to the northern portion of the site.

3.2.2 Design, Feasibility, and Effectiveness of ISCO – Geochemical Considerations

The presence of both chlorinated ethenes and ethanes presents a challenge to the application of ISCO for groundwater remediation. The ISCO reagents that have been routinely applied in bedrock settings are generally not efficient at treating chlorinated ethanes. Therefore addressing both chlorinated ethenes and ethanes will require either:

- Application of an ISCO reagent that has not been tested in a bedrock setting or that may be associated with a potential for adverse outcomes; or

- Application of ISCO using a reagent that may be less efficient in reducing chlorinated ethane concentration, but has been applied in bedrock settings. This would be followed by longer term enhanced anaerobic bioremediation[1].

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[1] This approach was recommended in the RIFS and selected by NYSDEC in the ROD.

The application of ISCO will quickly lower the chlorinated ethene concentrations in the short term and subsequent enhanced anaerobic bioremediation is expected to further reduce chlorinated ethene and ethane concentrations.

A review of the April 2014 inorganic geochemical data does not indicate significant sinks for the injected oxidizing power that may reduce the effectiveness of ISCO. The alkalinity is relatively elevated in the treatment area at 220 to 340 mg/L. Carbonate is a radical scavenger and limits the effect of ISCO reagents that produce or require free radicals to be an effective oxidant. Dissolved iron is present at concentrations up to 36 mg/L in the treatment area (MW-16i); however, the concentrations of iron in groundwater are insubstantial when considering the oxidizing power per volume of oxidant that is typically associated with ISCO. High iron concentrations in groundwater may, however, indirectly limit the effectiveness of ISCO over time by iron oxide precipitation in fractures. Iron oxide precipitation may reduce the fracture apertures and interconnectedness and thereby make subsequent ISCO (or bioremediation) injections less effective.

3.2.3 Geochemical Conditions Effecting Reductive Dechlorination Processes

Geochemical conditions that may enhance or limit the potential for successful application of reductive dechlorination at the site have been evaluated. Factors limiting the potential for successful reductive dechlorination include:

- Conditions where e.g. elevated ferric iron, manganese, or sulfide/sulfate concentrations will compete for electrons. In addition, this might generate difficulty obtaining the methanogenic geochemical conditions that are considered optimal for enhanced anaerobic bioremediation;

- Absence of ongoing biochemical degradation or incomplete degradation pathways; and

- Geochemical conditions that may limit microbial growth and activity, e.g. low or elevated pH.

REDOX Conditions: The ORP values are low (-18 to -200 mV in MW-3 and MW-10i, respectively) and indicative of geochemical conditions where sulfate reduction and methanogenesis is expected to be prevalent[2]. Dissolved Fe and Mn ranged from less than 0.05 mg/L to 36 mg/L and from 0.007 mg/L to 0.25 mg/L, respectively. The dissolved Fe and Mn concentrations are particularly elevated in the two intermediate depth wells MW-10i (Fe is 4.5 mg/L and Mn is 0.12 mg/L) and MW-16i (Fe is 36 mg/L and Mn is 0.25 mg/L). The data support that iron and manganese reductive dissolution is ongoing.

Sulfide was not detected in the groundwater samples; however, the laboratory limit of quantification was 2 mg/L and about an order of magnitude above the expected sulfide concentrations that would be indicative of ongoing sulfate reduction. The methane concentrations are high and range from 300 to 1,300 µg/L and indicative of ongoing methanogenisis.

Complete Degradation Pathway: The VOC data (Section 3.2.1) indicate that reductive dechlorination of chlorinated ethanes and ethenes are ongoing at the site. Detectable concentrations of terminal breakdown products (ethane and ethene) ranging from 21 to 720 µg/L support that the degradation pathway is complete and the microbes at the site are capable of fully degrading the CVOCs. The ongoing dechlorination processes are also supported by the high chloride concentrations of 97 to 220 mg/L. The chloride concentrations are most elevated at MW-3 and MW-9 where parent CVOC compounds are generally absent.

Other Potential Limiting factors: The pH values are near neutral (6.0 to 7.3 s.u.) and the pH is not expected to limit microbial growth and activity at the site. The alkalinity is relatively high (220 to 460 mg/L) as expected in a fractured carbonate rock. It has been demonstrated that reductive dechlorination of CVOCs is more efficient in low or moderate alkalinity environments; however, the elevated alkalinity alone is not expected to significantly reduce the potential for reductive dechlorination.

Total organic carbon (TOC) is present in moderate concentrations ranging from 3.4 to 6.4 mg/L. That is about an order of magnitude below the concentrations typically targeted during enhanced biochemical degradation. Based on a review of the aggregate geochemical data, limited availability of organic carbon appears to be the

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[2] The measured oxygen concentrations ranged from 0.3 to 14.8 mg/L and are inconsistent with the measured negative ORP values and aggregate geochemical data. Therefore the DO data is not included in this discussion.

likely limiting factor of natural attenuation by reductive dechlorination in the southern portion of the site and biochemical degradation may be significantly enhanced by injection of an organic carbon source. Sulfate appears to represent the main competitor for electrons at the site and the sulfate concentrations should be taken into account when designing the enhanced biochemical degradation pilot that is intended to be implemented subsequent to ISCO.

In conclusion, based on the data presented above:

- Iron and manganese reductive dissolution and methanogenisis are ongoing at the site;
- Reductive dechlorination of chlorinated ethanes and ethenes and conversion to degradation daughter products is ongoing at the site;
- pH is not expected to limit microbial growth and activity at the site;
- The elevated alkalinity found at the site is not expected to significantly reduce the potential for reductive dechlorination; and
- The lower TOC concentrations present at the site need to be considered when designing the enhanced biochemical degradation pilot.

Therefore, it appears that the geochemical conditions at the site are favorable for ISCO to be effective at reducing VOC concentrations in the bedrock and implementation of the pilot injection program is encouraged.

3.3 Treatability Study

The ARCADIS Treatability Laboratory located in Durham, North Carolina, conducted a treatability study in January and February 2013 to evaluate the application of ISCO of CVOCs at the site. The treatability study methods and results are provided in Appendix B. The ISCO bench-scale test was designed to:

- Enable a quantifiable assessment of the potential effectiveness of ISCO using sodium persulfate;
- Approximate the oxidant and activator dosing requirements for a potential ISCO remedy;

- Evaluate the extent to which persulfate is capable of treating the chlorinated ethenes and ethanes in the site groundwater; and

- Provide information to estimate the cost for implementing ISCO strategies at the site.

As discussed in Appendix B, the treatability study was performed using four combinations of sodium persulfate ($Na_2S_2O_8$) at low dosage (20 grams per liter [g/L]) and high dosage (40 g/L) with and without alkaline activator (sodium hydroxide – NaOH – at initial pH higher than 12). The treatability tests were performed on sample bottles containing crushed site rock and groundwater. The percent concentration reductions after seven days during the four treatability tests are summarized below:

	Percent Concentration Reduction During Treatability Tests – Day 7			
Compound	**Ambient pH Low Dose**	**Ambient pH High Dose**	**Alkaline Low Dose Activation**	**Alkaline High Dose Activation**
PCE	48	69	60	80
TCE	62	84	91	99
cis-1,2-DCE	52	73	80	96
1,1-DCE	>99	>99	>99	>99
1,1,1-TCA	0	0	17	12
1,1-DCA	0	0	45	54

As shown in the above table, alkaline (base) activated high dosage sodium persulfate (40 g/L) was found to be more effective in degrading site groundwater contaminants than non-activated or low dosage activated sodium persulfate. However, a higher 1,1,1,-TCA mass removal with the alkaline activation was expected.

3.4 Evaluation of Oxidants

Following completion of the laboratory treatability study, a number of compounds, potentially suitable for use in the pilot and full-scale ISCO injection programs, were evaluated for potential use at the Abandoned Chemical Sales Facility Site. The following oxidants have been evaluated for use at the site:

- Ozone gas sparging,

- Catalyzed hydrogen peroxide,

- Sodium permanganate,
- Sodium persulfate
- Alkaline activated sodium persulfate,
- Permanganate activated sodium persulfate,
- Peroxide based activation of sodium persulfate, and
- Thermally enhanced hydrolysis.

The following sub-sections summarize the results of the evaluation.

3.4.1 Ozone Gas Sparging

Ozone gas sparging would require continuous injections as well as the construction of an automated system and an on-site ozone generator. Because of the infrastructure and operations and maintenance requirements, the costs for ozone gas sparging are higher than other oxidants. Ozone gas sparging may also increase the potential for soil vapor intrusion because of the increased volatilization and mobilization of VOCs. Ozone's residence time in the subsurface is short due to its reactivity. Furthermore, ozone gas sparging is not expected to address conditions outside the treatment zone. Ozone oxidation has to our knowledge not been applied in a bedrock setting. For these reasons, ozone will not be considered further.

3.4.2 Catalyzed Hydrogen Peroxide

Catalyzed hydrogen peroxide (Fenton's Reagent) can exhibit very fast reaction kinetics capable of generating heat, gas, and oxygen, which can create explosive conditions in the subsurface and at ground surface. Application of Fenton's Reagent may be associated with an increased potential for soil vapor intrusion. Injection of catalyzed hydrogen peroxide would require engineering controls to protect worker's health and safety. Catalyzed hydrogen peroxide's residence time in the subsurface is short due to its reactivity. Case studies have not been identified that incorporate catalyzed hydrogen peroxide oxidation in a bedrock setting. For these reasons, catalyzed hydrogen peroxide will not be retained for further consideration.

3.4.3 Sodium Permanganate

Sodium permanganate is the most widely used chemical oxidant for groundwater remediation and is effective at treating chlorinated ethenes (PCE, TCE, cis-1,2-DCE, and vinyl chloride). Sodium permanganate has a relative slow reaction rate and longer persistence (compared to some of the other screened oxidants) in a variety of hydrogeologic environments (including fractured bedrock). The slower reaction rate may promote downgradient transport of sodium permanganate and destruction of chlorinated ethenes outside the treatment area.

A drawback to the use of sodium permanganate is that it is ineffective at treating chlorinated ethanes, such as 1,1,1-TCA. Moreover, precipitation of manganese oxide, an end product of permanganate ISCO, can reduce the performance of the injection wells and the efficiency of reagent delivery over time. Sodium permanganate will be retained for further consideration.

3.4.4 Sodium Persulfate

Sodium persulfate is a commonly used ISCO reagent that has been widely applied at overburden and bedrock sites. The moderate reactivity of sodium persulfate may promote downgradient treatment outside the injection zone. Injection well fouling by oxidation of dissolved metals can limit injection efficiency over time; however, as sodium persulfate does not provide metals that may oxidize (as permanganate does) fouling is expected to be less of an issue and would be dependent on dissolved metals in groundwater flowing through the treatment area. The treatability test indicated that sodium persulfate with ambient activation was effective in reducing site chlorinated ethene concentrations in groundwater; however, it was ineffective at treating chlorinated ethanes. Sodium persulfate with ambient activation will be retained for further consideration because of its ability to reduce groundwater chlorinated ethene concentrations and its proven track record at overburden and bedrock sites.

3.4.5 Alkaline Activated Sodium Persulfate

Alkaline activated sodium persulfate decomposes more slowly in the subsurface than peroxide based activation. Applications at other sites indicate that it is effective in treating site CVOCs, including chlorinated ethanes. As discussed in Section 3.3 and Appendix B, the alkaline activation high dose sodium persulfate (40 g/L) with alkaline activation (NaOH, pH > 12) achieved chlorinated ethene mass removal exceeding the effect of sodium persulfate without pH adjustment; however, only limited (12%) removal of 1,1,1-TCA was achieved.

There is some uncertainty associated with performing alkaline adjustments in a fractured carbonate rock setting. The rock is expected to offer very little buffer capacity for alkaline solutions and hydroxide that is not utilized in the treatment area may generate downgradient elevated pH conditions. Alkaline activated sodium persulfate will be retained for further consideration.

3.4.6 Permanganate Activated Persulfate

Permanganate activated persulfate is proven effective in the laboratory at treating recalcitrant contaminants, such as 1,1,1-TCA. There are uncertainties associated with the use of permanganate activated persulfate, primarily related to its being a relatively new technique with limited field testing or application in fractured rock. Furthermore, permanganate activated persulfate may be associated with manganese oxide injection well fouling issues similar to a conventional permanganate ISCO approach. Permanganate activated persulfate will be retained for further consideration because it is the oxidant most likely to reduce chlorinated ethane concentrations with a limited potential for adverse outcomes.

3.4.7 Peroxide Based Activation of Sodium Persulfate

Peroxide based activation of sodium persulfate has the same concerns and limitations as catalyzed hydrogen peroxide. As such, peroxide based activation of sodium persulfate will not be considered further.

3.4.8 Thermally Enhanced Hydrolysis

Thermally enhanced hydrolysis combined with ISCO is effective at treating 1,1,1-TCA. Hydrolysis is a chemical reaction in which H_2O or OH^- replaces a chlorine atom on the 1,1,1-TCA compound. The byproducts of TCA hydrolysis are acetic acid (vinegar) and 1,1-dichloroethene (1,1-DCE). The hydrolysis rate is sensitive to temperature. The half-life of 1,1,1-TCA in groundwater is about 12 years at a temperature of 10°C and decreases to about 2.5 years at 20°C and to 10 days at 50°C. This remedial approach would involve the injection of hot water (~50°C) into injection wells and simultaneous extraction of the injected water from a downgradient well. The extracted water could be treated prior to reinjecting into the injection wells. A chemical oxidant could be injected prior to or during the injection of hot water and would be injected following the hot water injection to treat any remaining VOCs in the groundwater. Thermally enhanced hydrolysis with ISCO would require significant infrastructure and costs associated with electricity and maintaining elevated groundwater temperatures, installation and operation of injection and extraction wells, and on-site water treatment. As such, thermally enhanced hydrolysis with ISCO will not be retained for field testing.

Based on the above analysis, sodium permanganate, sodium persulfate with ambient activation, alkaline activated sodium persulfate, and permanganate activated persulfate will be considered for potential use during the ISCO pilot injection program.

3.5 Injectability Tests

Injectability tests, where water is injected into the on-site injection wells (MW-16S, MW-16i, MW-17S, and MW-17i), were conducted in March 2014 to assess the ability of the bedrock to accept an injection solution. The injectability study methods and results are provided in Appendix C. The injectability study was completed to evaluate flow rates and spacing of injection wells for the upcoming chemical oxidation injection pilot events.

The injectability tests indicate limited volumetric flow rates (less than 0.25 gallons per minute [gpm]) at injection pressures up to 17 pounds per square inch (psi) in the two shallow injection wells (MW-16S and MW-17S)[3]. In contrast to the shallow well tests, the intermediate bedrock wells accepted significantly higher volumetric flow rates (up to 3 gpm at 7 psi).

Water levels in nearby monitoring wells were monitored during the injectability tests to assess the injection radius of influence and monitor displacement of groundwater cause by the injections. The water levels in the shallow monitoring wells rose less than 0.65 feet during the injectability tests and the water level in most shallow wells rose less than 0.1 foot. This indicates that there is minimal hydraulic connection between the injection wells (both shallow and intermediate) and the shallow monitoring wells. In contrast, the water level in the intermediate wells located as far away as 50 feet from the injection well rose between 5 to 10 feet while injecting into MW-16i and MW-17i.

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[3] The volumetric flow rates are corrected for the volume of the well casing not initially filled with water.

The injectability study results indicate that gravity injection into the intermediate zone of the bedrock formation would be effective at injecting an oxidant into the intermediate bedrock zone.

4. ISCO Pilot Injection Program Design

As discussed in Section 3.2, the site groundwater contains elevated concentrations of CVOCs including recalcitrant chloroethane and 1,1,1-trichloroethane (1,1,1-TCA). Total CVOC concentrations at several monitoring wells are greater than 100 mg/L (Figure 4). As stated in the ROD (NYSDEC, 2011), ISCO was the selected remedial approach to reduce groundwater VOC concentrations. The ISCO pilot injection program design and the basis of the design is presented below.

4.1 Fractured Bedrock Porosity

Contaminants in fractured bedrock are present in the primary porosity (unfractured rock matrix; n_m) and in the secondary porosity (fractures, n_f). Within the unfractured rock matrix the contaminant can be either dissolved in the porewater or sorbed to organic carbon. The volume of matrix porosity is generally greater than the fracture porosity by about one to three orders of magnitude (USEPA, 2006). Transport in fractures (secondary porosity) is dominated by advection, whereas diffusion is the dominating transport mechanism within the primary porosity.

Literature estimates of the n_m of the Lockport Dolomite ranged from about 3.4% to about 10% (Laughrey et al., 2007 and Maxwell and Smosna, 1985). The n_f is the sum of the fracture apertures (e) within the rock. Little data exist in the literature regarding the Lockport Dolomites fracture apertures. Johnson (1964) found water bearing fractures in the Lockport Dolomite formation in Kentucky to be “widened very slightly by solution of the rock” with apertures between 1/16th and 1/8th of an inch. This is significantly wider than the range of 50 to 200 µm referenced by Parker (1996) and the 50 to 230 µm estimated by Lipson et al. (2005) for undifferentiated sedimentary rock.

Cubic law relates the hydraulic conductivity (K) to fracture aperture as follows:

$$K = \frac{\rho_w g e^3}{12 \mu S}$$

Where ρ_w is the density of water (kg/m^3), g is the acceleration of gravity (m/sec^2), e is the mean fracture aperture (m), µ is the dynamic viscosity of water (Pa · sec), and S is the mean fracture spacing (m). Similar to the hydraulic conductivity values, it is the relative magnitude and distribution of e that is of interest rather than the individual absolute values. The n_f values are derived by dividing the e values by the mean fracture spacing S.

Based on the injection tests, K estimates range from 3.2×10^{-5} to 2.1×10^{-4} centimeters per second (cm/sec) in the two shallow injections wells (MW-16S and MW-17S), and 2.6×10^{-3} to 7.2×10^{-3} cm/sec in the intermediate depth injection wells (MW-16i and MW-17i). The mean fracture spacing ranges from 0.07 m in MW-17S to 0.15 m MW-16i. Applying the cubic law, e ranges from 160 to 290 µm for the shallow borings, which is generally consistent with the fracture aperture estimates from the literature discussed above. The estimated fracture apertures from the intermediate wells range from 730 to 920 µm and well beyond what is typically expected from undifferentiated rock, which could indicate some limited karst widening of the fractures. The widening of the fractures is, however, significantly below estimates reported by Johnson (1964). The corresponding n_f averages 0.002 in the shallow injection borings and 0.005 in the intermediate injection borings.

The literature and field n values suggest ratios of $n_{m\ to}\ n_f$ ranging from about 16:1 to 48:1 for the surface near rock and 6:1 to19:1 for the intermediate depth rock that will be targeted by the ISCO injection activities. The estimates support that matrix porosity represents about one order of magnitude or greater volume for storage of water and contaminant mass as compared to the fractures. Therefore, the contaminant mass present within the unfractured rock matrix would be expected to represent 85% to 98% of the total mass at the site and only a minor portion of the mass is dissolved in water flowing through fractures.

The VOC mass distribution represents a challenge to using ISCO technologies at the site. ISCO only directly addresses the small proportion of VOC mass that is present within the fractures (mobile porosity). The implications of this mass distribution and the potential success of ISCO is discussed in Section 5.2.

4.2 Chemical Oxidation in Bedrock

The movement of injected oxidants into fractured bedrock is less predictable than injection into unconsolidated media. The predictability of oxidant transport in bedrock is reduced by:

- Heterogeneity and uncertainty in fracture characteristics;

- Potential for karst features in the carbonate rock;
- Potential for large vertical hydraulic head gradients; and
- Matrix diffusion processes and adsorption to organic carbon controlling the distribution of contaminant mass as well as mobility of injected oxidant.

As discussed in Section 5.1, ISCO in a fractured rock setting primarily addresses the dissolved VOC mass in groundwater moving through fractures within the injection area sphere of influence and, depending on the oxidant and design, the contaminant mass in fractures downgradient from the injection area. ISCO is not expected to directly reduce VOC mass within the unfractured rock matrix as the reactivity of the chemical oxidation reagents doesn't allow for enough time for significant diffusion of the reagent into the rock matrix. However, ISCO may be associated with indirect reduction of VOC mass in the rock matrix. The degree of mass diffusion from the rock matrix to the fractures is expected to increase with the increasing geochemical gradient as mass is destroyed in the fractures by the ISCO treatment. The additional mass that back-diffuses into the fractures will be available to react with the chemical oxidation reagent.

Therefore, the remedial approach selected in the ROD (NYSDEC, 2011) is aimed at addressing mass within the fracture porosity, which is only a small proportion of the total mass present within the treatment area. This remedial approach has the potential to be effective in reducing concentrations in groundwater within the treatment area and some distance downgradient in the short term. However, a rebound in contaminant concentrations in groundwater moving through fractures is expected once the injected oxidant has been depleted or flushed out of the treatment zone. A sustained reduction in secondary porosity concentrations would require repeated injections in the long-term.

4.3 Proposed Injection Area

The proposed pilot injection areas are shown on Figure 7. The primary proposed injection area, near MW-16i and MW-17i, is approximately 9,000 square feet and was projected based on the results of the injectability tests. During these tests, the influence of the injections was measurable through observation of water levels in monitoring wells in this area. This area was selected because it contains the highest groundwater CVOC concentrations. In addition, an oxidant will also be injected into the excavation areas detailed in the Contaminated Soil Removal and Disposal Work Plan (ARCADIS, 2013). Treatment of other areas of the site with CVOCs in groundwater is not proposed.

During the first pilot injection event, the oxidant solution would be injected into the intermediate bedrock zone, from approximately 25 to 45 feet bgs, at MW-16i and MW-17i. Active oxidant injection into the shallow bedrock wells is not proposed because limited water could be injected into these wells during the injectability tests. The oxidant will not be injected into the monitoring wells because of the potential for clogging of the well screens, the limited oxidant solution volume that could be injected, and the subsequent inability to use the wells as monitoring points.

As discussed in the Contaminated Soil Removal and Disposal Work Plan (ARCADIS, 2013), prior to backfilling the excavation areas, piping will be installed with one or two slotted screens lying horizontally in the bottom of each excavation connected to a vertical riser. During the pilot injection events, the oxidant will be injected into these risers. The oxidant will likely disperse along the top of the bedrock and migrate into the bedrock where there are fractures.

The results of the first pilot injection event will be used to evaluate the injection area, the oxidant, and need for additional injection or monitoring wells during subsequent injection events.

4.4 Proposed Pilot Injection Program Approach

Based on discussions with NYSDEC, a sequenced treatment approach will be implemented at the site because incomplete treatment is expected during the first pilot oxidant application. Incomplete treatment is expected because upgradient contaminated groundwater will likely flow into the injection area (recontamination), untreated contaminant mass in the matrix porosity of the bedrock will diffuse into the fracture porosity (back-diffusion), and the oxidant will likely not come into contact with all of the contaminant mass within the injection area (imperfect oxidant distribution). As such, three pilot oxidant injection events are proposed to evaluate the effectiveness of one or more oxidants.

The objectives of the first ISCO pilot injection event are to:

- Provide data to refine subsequent pilot injection events;

- Assess the persistence of the oxidant following injection;

- Observe a reduction in groundwater VOC concentrations; and

- Evaluate the radius of influence of oxidant injections.

4.4.1 Proposed Oxidant

Multiple pilot injection events are proposed to test various oxidants and evaluate their effectiveness at treating site-related VOCs. As stated in Section 5.4, multiple injection events are also needed because incomplete VOC treatment is expected because of recontamination, back-diffusion, and imperfect oxidant distribution. Sodium permanganate and sodium persulfate (with ambient, base, and permanganate activation) were the oxidants selected in Section 4 for further consideration.

The proposed oxidant to be injected during the first ISCO pilot injection is sodium permanganate. As discussed in Section 5.3, permanganate will be injected into injection wells MW-16i and MW-17i and the excavation areas during the first pilot injection event. As described above, the sodium permanganate effectively remediates chlorinated ethenes (PCE, TCE, cis-1,2-DCE, and vinyl chloride) in groundwater. Following each pilot chemical oxidant injection event, the concentrations of chlorinated ethenes and ethanes (1,1-DCA and 1,1,1-TCA) in groundwater will be evaluated and the remedial approach will be reassessed. As it is expected that 1,1-DCA and 1,1,1-TCA will only be minimally treated during the initial pilot chemical oxidation injection event, the post-injection monitoring results will be used to evaluate the most appropriate course of action for supplemental pilot and full-scale remedial efforts.

4.4.2 Oxidant Injection Volumes

The initial pilot injection well oxidant dosing design is based on the volume of the fracture (mobile) porosity and the geochemistry of the water moving though fractures within the treatment zone. The estimated total solution volume required to demonstrate an effect at monitoring wells from injection wells will vary based on the target treatment aquifer thickness and fracture porosity, and can be calculated with the equation below.

$$V_{inj} = IA \times h \times n_m \times \left(\frac{7.481 gal}{ft^3} \right)$$

Where:

V_{inj} = volume of injection, gallons

IA = injection area (9,000 square feet)

h = target treatment aquifer thickness (25 feet)

n_m = fracture porosity (0.005 for intermediate depth bedrock)

Assuming an intermediate bedrock fracture porosity of 0.5%, one pore volume with the primary injection area is approximately 8,400 gallons. The anticipated initial pilot injection volume for each of the two intermediate injection wells is approximately 4,200 gallons of solution. However, based upon field observations during the course of the injections, the total volume delivered to each injection well may vary. Approximately 8,400 gallons of sodium permanganate at a 3% concentration will be injected into MW-16i and MW-17i during the first pilot injection event. Although active oxidant injection into the shallow bedrock wells is not proposed (Section 5.3), the casing of the shallow injection wells (MW-16S and MW-17S) will be filled with the oxidant solution, and the oxidant will be allowed to flow into the shallow bedrock over time.

At each of the soil excavation areas, minimal volume of oxidant will be injected to reduce the potential for daylighting or short circuiting. The volume of oxidant injected into each excavation area will equal the estimated pore space within the backfill material in a four-foot vertical thickness. Using the equation presented previously, a vertical thickness of 4 feet, and a porosity of 0.25, the volume of oxidant to be injected into excavation areas 1 through 4 are 750, 1,200, 3,150, and 750 gallons, respectively, for a total of 5,850 gallons.

4.4.3 Oxidant Injections

The planned injection system will consist of tanks, transfer and injection pumps, transfer and water lines, an inline static mixer, wellhead manifolds and flow meters. All wetted system components, including flow meters, tubing, and chemical oxidant injection pumps, will be compatible for long-term contact with sodium permanganate at up to a 5 percent concentration.

Sodium permanganate will be stored onsite in a dry secure environment on pallets or in a tanker with secondary containment. Injection equipment will be staged and operated in the site parking lot; however, Jay Street may be used, with the permission of the City of Rochester, if additional storage/staging area is needed. Two 500-gallon chemical oxidant storage tanks may be used within a low-permeability temporary secondary containment structure compatible for long-term contact with sodium permanganate.

The secondary containment shall have a minimum holding capacity of 110 percent of the total storage volume of the tanks. The chemical oxidant tanks will be used to contain solution only and will be placarded with a DOT certified 5.1 oxidizer placard and/or equivalent Globally Harmonized System placards. Sodium thiosulfate would be used to neutralize permanganate in case of a spill. The tank(s), if used, will be each rinsed with approximately 25 gallons of water three times once the injections are completed. The rinse water shall then be discharged to an injection well.

If needed, water would be obtained from the spigot at the site building or from a fire hydrant along Jay Street using a certified backflow prevention device. Oxidant solutions/mixtures will be transferred by way of a pneumatic double diaphragm pump, a gas-powered chemical pump, or equivalent to the injection well.

All injection, transfer or water hoses and lines shall be sized appropriately to accommodate the flow rates of chemical oxidant and water desired. The target injection rate will be approximately two gallons per minute (gpm) per injection well during the implementation of this injection for a total of 4 gallons per minute across the two injection wells. Fittings, connections, valves, fasteners, sealants and other appurtenances for the hoses and lines will be similarly chemically compatible and able to withstand up to 150 psi of pressure. Hoses and lines that come in contact with a chemical oxidant shall be separate and distinct from those used for clean water. The entire injection and transfer system will be pressure tested for leaks with water prior to commencement of each injection. A leak check shall be conducted by dead-heading the hoses and lines at the injection wellhead, and then pressurizing the system. All leaks shall be repaired prior to the introduction of chemical oxidant into the system. Additionally, all wellhead manifolds will be fitted with ambient air bleed off valves and pressure gauges.

The flow in the lines and hoses will be metered at the following locations:

1. Discharge to the manifold prior to splitting the flow into two discharge legs.

2. At each individual injection line which leads into the well head manifold.

ARCADIS will utilize a totalizing meter, with readout in gallons per minute and total gallons, in each of the aforementioned segments of the transfer lines, and shall monitor and record the volumes of oxidant solution injected at each injection point. Totalizer meters will be installed on each branch of each transfer line, such that recording of the quantity of chemical oxidant injected in each location may be conducted. All totalizer meters shall be sized appropriately to accommodate the flow rates of chemical oxidant and water desired.

MW-16i and MW-17i will each receive approximately 4,200 gallons of mixed solution. Each injection shall begin at a rate of less than one gpm and then be adjusted upward based upon the results of visual monitoring, groundwater monitoring and injection system response. The system will be properly maintained and monitored during injection operations, including continuous inspection for leaks, observation of the system's overall performance, and monitoring of all flow meters and pressure gauges. It is anticipated that peak system injection rates will be between two to four gpm with up to 7 psi of downward pressure on the wellheads.

The oxidant will be gravity fed into the soil excavation injection points. A tank will be placed next to each excavation and the oxidant solution will be gravity drained into each excavation injection point.

During the injection, ground surface will be observed, particularly in the areas adjacent to build physical features to attempt to identify any occurrence of "daylighting" or "short-circuiting." Features to observe include building foundations, subsurface utilities, storm sewers, surface water drainage courses, manholes, monitoring wells, and other structures that could provide preferential pathways for migration of the injection solution. Daylighting and short circuiting could limit the horizontal or vertical spread of the chemical oxidant into the formation, resulting in:

- Failure to provide remedial benefit to specific subsurface zones;
- The uneven and inefficient application of the chemical oxidant to certain areas; and
- Potential increased health and safety risks associated with aboveground contact with incompatible surface materials or unintended exposure of receptors to the chemical oxidant.

To minimize the potential for occurrence of these issues, these areas and/or features will be monitored at 15 minute intervals during the injection process and for a 30-minute period upon completion to identify the presence of chemical oxidant, if any. If any is identified, the injection of the chemical oxidant will be halted and the procedures for conducting the remainder of the injection will be re-evaluated and adjusted, as necessary, to limit further daylighting or short-circuiting. Any potential health and safety issues associated with the daylighting or short-circuiting shall be ameliorated prior to the resumption of the injection.

4.4.4 Sampling

Pre-injection, during injection, and post-injection monitoring will be performed. Water levels in the shallow and intermediate monitoring wells within 100 feet of the injection wells will be monitored before, during, and after the injections. Water quality parameters, including oxidation reduction potential (ORP), dissolved oxygen (DO), pH and specific conductivity, will be measured at nearby monitoring wells during active injection. Typical field observations indicative of sodium permanganate are an increase in conductivity, pH and dissolved oxygen. The presence of sodium permanganate during injection activities will be evaluated through visual observations of permanganate’s characteristic purple color and the use of sodium permanganate spectrometric field test kits. Measurements and observations will be recorded on a field log.

A groundwater monitoring program will be developed to document groundwater CVOC concentrations. As discussed in Section 3.2, baseline (pre-injection) groundwater sampling has been conducted in April 2014 (in addition to the PSA and RI sampling). Groundwater samples shall be collected 2 months following the first pilot injection event for VOCs using low flow sampling techniques or passive diffusion bags. The sampling event results will be used to evaluate the persistence of the chemical oxidant and document groundwater VOC concentrations. The need for subsequent groundwater sampling events will be evaluated following receipt of the post-injection sampling event results.

4.5 Health and Safety

Prior to mobilization to the site, the site-specific Health and Safety Plan (SSHASP) will be revised for use during the pilot injection and sampling activities. The SSHASP will address provisions for protecting the health and safety of the public, including on-site personnel not associated with the injection.

The safe use and storage of chemical oxidants will be outlined in a SSHASP. Safety data sheets (SDSs) will be obtained for the chemical oxidant and kept onsite throughout the duration of the injection event. Due to the aggressive nature of chemical oxidants, proper and compatible personal protective equipment (PPE) is required during handling of the oxidant solution. During handling of the oxidant solution, full chemical resistant Tyvek suits complete with hoods will be worn in addition to chemical resistant gloves and safety boots. During observation of the oxidant injection at the individual wellheads workers shall wear chemical resistant aprons and safety goggles and/or full face shields to protect from splashes or breaks that could occur in the injection lines.

4.6 Reporting

Following completion of the first pilot injection and subsequent groundwater sampling, a summary report will be prepared documenting the injection and sampling activities. The report will include the recorded field data, including pre- and post-test measurements, injection parameter measurements, laboratory analytical results, and pilot test operational data. This information will include the quantity and concentrations of the chemical oxidant injected at the site. The information provided in this report will be used to design the subsequent pilot oxidant injections.

4.7 Schedule

The general schedule for implementation of the ISCO pilot injection events is summarized below:

Activity	**Month**
NYSDEC Approval of ISCO Design Plan and budget	0
Coordination of, preparations for, and mobilization for the 1st injection event	1-2
1st ISCO pilot injection event	2-3
Groundwater sampling	5
Data evaluation, reporting, and design of 2nd injection event	5-6
2nd ISCO pilot injection event	7
Groundwater sampling	9
Data evaluation, reporting, and design of 3rd injection event	9-10
3rd ISCO pilot injection event	11
Groundwater sampling	13
Data evaluation, reporting, and design of enhanced	13-14

bioremediation injection event	
Enhanced bioremediation pilot injection event	15
Groundwater sampling	17
Data evaluation and final report preparation	17-18

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Tables

TABLE 1
Summary of Groundwater Volatile Organic Compound Analytical Results
Abandoned Chemical Sales Facility (SITE #828105)
Rochester, New York

Well ID	**MW-1**						**MW-2**				**MW-3**					
Sampling Date	**Nov-01**	**Nov-01**	**Nov-07**	**Sep-10**	**Sep-10**	**Apr-14**	**Nov-01**	**Nov-07**	**Sep-10**	**Apr-14**	**Nov-01**	**Nov-07**	**Nov-07**	**Sep-10**	**Sep-10**	**Apr-14**
1,1,1-TCA	720	1000 J	U	U	U	0.23	11		U	3.2	1900 J	U	1100	280	500	6
1,1,2-TCA	U	5 J	U	U	U	U	U		U	U	U	U	U	U	U	U
1,1-DCA	3300	2700 J	48 J	180	33	5.5	630 J	38	57	4.9	22000	17000	15000	4800	11000	320
1,2-DCA	U	8 J	U	U	U	U	U		U	U	U	7.4	U	1.8	U	U
Chloroethane	570	720 J	4300	1200	120	27	100	71	150	U	U	1800	1500	870	1700	27
PCE	U	14	U	U	U	16	630 J	6.1 J	U	530	U	5	U	3.2	U	U
TCE	370 J	460 J	U	U	U	3.7	210 J	5.4 J	U	140	U	5.3	U	4.2	U	1.4
cis-1,2-DCE	18000	7700 J	260	U	170	0.95	900 J	580	87	400	68000 J	55000	41000	11000	2500	390
1,1-DCE	U	94	U	U	U	5.5	U		U	4.9	290 J	340	340 E	73	220	3.1
Vinyl Chloride	1900	2400 J	1200	6.2 J	390	0.52	490 J	310	400	53	23000	25000	16000	11000 J	22000	390
Benzene	U	12	U	U	U	0.27	4 J	U	U	U	U	7	U	4.4	U	0.46
Toluene	7300	3000 J	3500	140	28	0.13	750 J	12 J	7.4	U	11000	7200	5800	1700	4300	20
Ethylbenzene	360 J	420 J	350 J	470	220	0.24	250 J	7.6 J	170	U	U	78	U	31	U	1.2
Xylene, Total	1900	1500 J	1400	690	340	3 U	770 J	U	9.5	U	300 J	440	U	210	230	7.2
Sampling Method	Bailer	Bailer	PDB	PDB	LF	PDB	Bailer	PDB	PDB	PDB	Bailer	LF	PDB	PDB	LF	PDB

NOTES:

U = Not detected

J = Reported concentration is estimated.

LF = Low flow sampling

PDB = Passive Diffusion Bag

E = Exceeded calibration range

* = Result may be biased low because of injectability test conducted in March 2014.

Concentrations are in micrograms per liter (ug/l)

TABLE 1
Summary of Groundwater Volatile Organic Compound Analytical Results
Abandoned Chemical Sales Facility (SITE #828105)
Rochester, New York

Well ID	**MW-4**			**MW-5**				**MW-6**					**MW-6i**			
Sampling Date	**Nov-01**	**Nov-07**	**Apr-14**	**Nov-07**	**Nov-07**	**Sep-10**	**Apr-14**	**Nov-07**	**Nov-07**	**Sep-10**	**Sep-10**	**Apr-14**	**Nov-07**	**Nov-07**	**Sep-10**	**Apr-14**
1,1,1-TCA	U	U	U	U	U	U	U	U	U	U	U	3			U	0.25
1,1,2-TCA	U	U	U	U	U	U	U	U	U	U	U	1 U			U	U
1,1-DCA	U	U	U	11	19	16	10	18 J	17 J	2.9	11	2.8	5.2 J	1.7 J	11	6.9
1,2-DCA	U	U	U	U	U	U	U	U	U	U	U	U			U	U
Chloroethane	U	U	U	U	U	U	U	320	560	U	U	U	17 J	U	U	U
PCE	U	U	U	U	U	U	0.12	U	U	U	0.97 J	23	U	U	U	U
TCE	U	U	U	U	U	U	0.29	U	U	2.3	1.5	14	5 J	2.9 J	0.96 J	0.19
cis-1,2-DCE	U	U	U	3.9 J	2.2 J	4.5	3.2	140 J	23 J	9.1	34	3.8	47 J	26	15	10
1,1-DCE	U	U	U	U	U	U	10	U	U	U	U	2.8			U	6.9
Vinyl Chloride	U	U	U	2.1 J	2.3 J	U	1.5	55 U	17 J	U	21	2	8.5	11	11 J	2.9
Benzene	U	U	U	U	U	U	0.28	U	U	19	U	U	2.4 J	7	U	0.19
Toluene	U	U	U	U	U	U	U	150 J	330	4.1	U	U	1.9	4.1	U	U
Ethylbenzene	U	U	U	U	U	U	U	100 J	200	7.6	U	U	1 J	4.8 J	U	U
Xylene, Total	U	U	U	U	U	U	U	230 J	480	U	U	U	3.1 J	15	U	U
Sampling Method	Bailer	PDB	PDB	LF	PDB	PDB	PDB	LF	PDB	PDB	LF	PDB	LF	PDB	LF	PDB

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PDB = Passive Diffusion Bag

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Concentrations are in micrograms per liter (ug/l)

TABLE 1
Summary of Groundwater Volatile Organic Compound Analytical Results
Abandoned Chemical Sales Facility (SITE #828105)
Rochester, New York

Well ID	**MW-7**				**MW-8**			**MW-8i**				**MW-9**			
Sampling Date	**Nov-07**	**Nov-07**	**Sep-10**	**Apr-14**	**Nov-07**	**Nov-07**	**Sep-10**	**Nov-07**	**Nov-07**	**Sep-10**	**Apr-14**	**Nov-07**	**Nov-07**	**Sep-10**	**Apr-14**
1,1,1-TCA	U	U	U	U	U	U	U	U	U	22	10	800 J	1000	34	23
1,1,2-TCA	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
1,1-DCA	2.5 J	2.3 J	2.2	U	21	47	80	U	59 J	91	61	8600	11000	1400	660
1,2-DCA	U	U	U	U	U	U	U	130 J	U	U	U	2.2 J	U	U	U
Chloroethane	U	U	U	U	160	210	180	U	U	2.3	U	370 E	U	71	86
PCE	U	U	U	0.51	240	240	130	70 J	U	U	U	3.5 J	U	0.75 J	U
TCE	U	U	U	U	42	45	120	2000	44 J	3.2	14	85	U	2.7	U
cis-1,2-DCE	4.4 J	U	1.3	U	370	920	1700	U	4100	2700	4600	19000	15000	1200	1000
1,1-DCE	U	U	U	U	U	U	2.5	5700	U	17	61	340 J	97	9.1	40
Vinyl Chloride	U	U	0.79 J	U	240	620	2600 J	840	590 J	2300 J	680	18000	13000	750 J	510
Benzene	U	U	U	U	2.8 J	4.3 J	4.5	U	U	3.9	U	8.4	U	U	U
Toluene	U	U	U	U	210	700	49	U	32 J	7.6	U	2700	3500	89	92
Ethylbenzene	U	U	U	U	10	36	49	U	U	3.2	U	35	37 J	1.7	U
Xylene, Total	U	U	U	U	28	130	66	U	U	14.1	U	200	230	55	10
Sampling Method	LF	PDB	PDB	PDB	LF	PDB	PDB	LF	PDB	LF	PDB	LF	PDB	PDB	PDB

NOTES:

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J = Reported concentration is estimated.

LF = Low flow sampling

PDB = Passive Diffusion Bag

E = Exceeded calibration range

* = Result may be biased low because of injectability test conducted in March 2014.

Concentrations are in micrograms per liter (ug/l)

TABLE 1
Summary of Groundwater Volatile Organic Compound Analytical Results
Abandoned Chemical Sales Facility (SITE #828105)
Rochester, New York

Well ID	**MW-10**				**MW-10i**					**MW-11**			
Sampling Date	**Nov-07**	**Sep-10**	**Jan-13**	**Apr-14**	**Nov-07**	**Nov-07**	**Nov-07**	**Sep-10**	**Apr-14**	**Nov-07**	**Nov-07**	**Sep-10**	**Apr-14**
1,1,1-TCA	15000	55000	43000	63000	1500 J	15000	13000	36000	26000	990 J	1600 J	310	220
1,1,2-TCA	7	14	U	U	U	1.7 J	U	4.7	U	U	U	1	U
1,1-DCA	2800 J	3100	3200	4900	620 J	3500 J	2900	7700	2200	19000 J	36000 J	690	340
1,2-DCA	U	1.2	3200	U	U	U	U	0.91 J	U	U	9.3	2.7	U
Chloroethane	U	4.8	U	U	U	U	U	6.3	U	U	4600 J	25	U
PCE	1700	6700	3100	7500	16	180	130	2400	1500	U	18	1.9	U
TCE	15000	65000	4500	61000	200	1600 J	2400 J	25000	8700	U	7.5	50	190
cis-1,2-DCE	51000	62000	59000	82000	19000	65000	45000	130000	60000	47000 J	89000	17000	8100
1,1-DCE	1300 E	9800	1800	1200	220 E	1300 J	830 J	8000	600	U	900 J	340	120
Vinyl Chloride	990 J	2200	U	2100	710 U	1500 J	890 J	4700	1400	25000 J	44000	1600 J	540
Benzene	10	10	U	U	2.8 J	5.2	8.8	23	U	U	24	0.53 J	U
Toluene	2200 J	5400	3800	6100	91	450 E	170	7700	2000	6700 J	14000	2.9	36
Ethylbenzene	66	140	U	130	4.3 J	15	16	140	75	U	190	U	U
Xylene, Total	300	580	U	580	17	67	84	580	330	U	910 J	U	U
Sampling Method	LF	PDB	Bailer	PDB	LF	PDB Shallow	PDB Deep	LF	PDB	LF	PDB	PDB	PDB

NOTES:

U = Not detected

J = Reported concentration is estimated.

LF = Low flow sampling

PDB = Passive Diffusion Bag

E = Exceeded calibration range

* = Result may be biased low because of injectability test conducted in March 2014.

Concentrations are in micrograms per liter (ug/l)

TABLE 1
Summary of Groundwater Volatile Organic Compound Analytical Results
Abandoned Chemical Sales Facility (SITE #828105)
Rochester, New York

Well ID	**MW-12**				**MW-13**			**MW-14**		
Sampling Date	**Nov-07**	**Nov-07**	**Sep-10**	**Apr-14**	**Mar-08**	**Sep-10**	**Apr-14**	**Sep-10**	**Sep-10**	**Apr-14**
1,1,1-TCA	970 J	1300 J	260	34	U	1600	2300	U	U	U
1,1,2-TCA	U	U	U	U	U	0.52 J	U	U	U	U
1,1-DCA	690 J	530 J	450	67	U	850 J	1100	U	U	U
1,2-DCA	U	U	U	U	U	1	U	U	U	U
Chloroethane	U	U	52	15	U	4.3	U	U	U	U
PCE	U	U	U	4.6	U	1200	740	U	U	U
TCE	U	U	2.9	9	2200 J	20000	5300	U	0.52 J	U
cis-1,2-DCE	12000	24000	7100	900	110000	140000	150000	U	0.98 J	U
1,1-DCE	U	U	43	67	U	1500	700	U	U	U
Vinyl Chloride	2400 J	2800 J	2700 J	180	4700 J	7600 J	6000	U	U	U
Benzene	U	U	U	U	U	32	U	2.2	U	U
Toluene	550 J	790 J	2.9	21	U	1400	1100	U	U	U
Ethylbenzene	U	U	44	11	U	100	U	U	U	U
Xylene, Total	U	U	140	22	U	180	U	U	U	U
Sampling Method	LF	PDB	PDB	PDB	LF	PDB	PDB	PDB	LF	PDB

NOTES:

U = Not detected

J = Reported concentration is estimated.

LF = Low flow sampling

PDB = Passive Diffusion Bag

E = Exceeded calibration range

* = Result may be biased low because of injectability test conducted in March 2014.

Concentrations are in micrograms per liter (ug/l)

TABLE 1
Summary of Groundwater Volatile Organic Compound Analytical Results
Abandoned Chemical Sales Facility (SITE #828105)
Rochester, New York

Well ID	**MW-15**			**MW-16S**			**MW-16i**		**MW-17S**		**MW-17i**	
Sampling Date	**Sep-10**	**Sep-10**	**Apr-14**	**Oct-13**	**Oct-13**	**Apr-14**	**Oct-13**	**Apr-14**	**Oct-13**	**Apr-14**	**Oct-13**	**Apr-14**
1,1,1-TCA	U	U	U	50	51	68	28000	33000	12000	5100	2000	230
1,1,2-TCA	U	U	U	U	U	U	U	U	U	U	U	U
1,1-DCA	U	U	U	190	200	190	3200	2300	4400	1700	4800	77
1,2-DCA	U	U	U	U	U	U	U	U	U	U	U	U
Chloroethane	U	U	U	U	U	U	U	U	U	U	U	U
PCE	U	U	U	17	18	12	6300	6300	U	U	3600	83
TCE	U	U	U	120	120	91	38000	31000	U	130	14000	110
cis-1,2-DCE	U	1.1	0.21	320	320	350	53000	48000	76000	27000	56000	1200
1,1-DCE	U	U	U	24	25	21	U	520	1100	350	U	11
Vinyl Chloride	U	0.62 J	U	14	11	1.4	U	1400	U	410	U	17
Benzene	4.9	U	U	U	U	U	U	U	U	U	U	U
Toluene	3.3	U	U	U	U	U	3700	3200	1300	580	3200	64
Ethylbenzene	U	U	U	U	U	U	U	110	U	U	U	2.6
Xylene, Total	2.7	U	U	U	U	U	U	460	U	U	U	12
Sampling Method	PDB	LF	PDB	Bailer	Bailer	PDB*	Bailer	PDB*	Bailer	PDB*	Bailer	PDB*

NOTES:

U = Not detected

J = Reported concentration is estimated.

LF = Low flow sampling

PDB = Passive Diffusion Bag

E = Exceeded calibration range

* = Result may be biased low because of injectability test conducted in March 2014.

Concentrations are in micrograms per liter (ug/l)

TABLE 2
Summary of Groundwater Dissolved Metals, Dissolved Gasses, and Wet Chemistry Parameter Analytical Results
Abandoned Chemical Sales Facility (SITE #828105)
Rochester, New York

Well ID	**MW-3**	**MW-9**	**MW-10**	**MW-10i**	**MW-16i**
Sampling Date	**Apr-14**	**Apr-14**	**Apr-14**	**Apr-14**	**Apr-14**
Units	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Dissolved Metals					
Iron	0.07	0.23	0.05 U	4.5	36
Manganese	0.0047	0.065	0.0071	0.12	0.25
Dissolved Gasses					
Ethane	0.045	0.02	0.021	0.022	0.065
Ethene	0.072	0.72	0.19	0.29	0.059
Methane	0.86	1.1	1.3	0.41	0.3
Wet Chemistry Parameters					
Alkalinity	420	330	460	340	220
Chloride	150	220	140	140	97
Sulfate	210	35	65	42	63
Sulfide	2 U	2 U	2 U	2 U	2 U
Total Organic Carbon	3.6	3.4	6.2	4.1	6.4
Field Parameters					
pH	6.00	6.36	6.14	7.29	6.8
Temperature	9.99	9.48	10.98	12.20	9.98
Conductivity	1.350	1.143	1.251	2.067	1.399
ORP	-17.8	-46.5	-178.9	-201.9	-176.5
DO	1.98	3.51	0.30	14.80	1.23
Turbidity	890	0.0	0.0	32	210

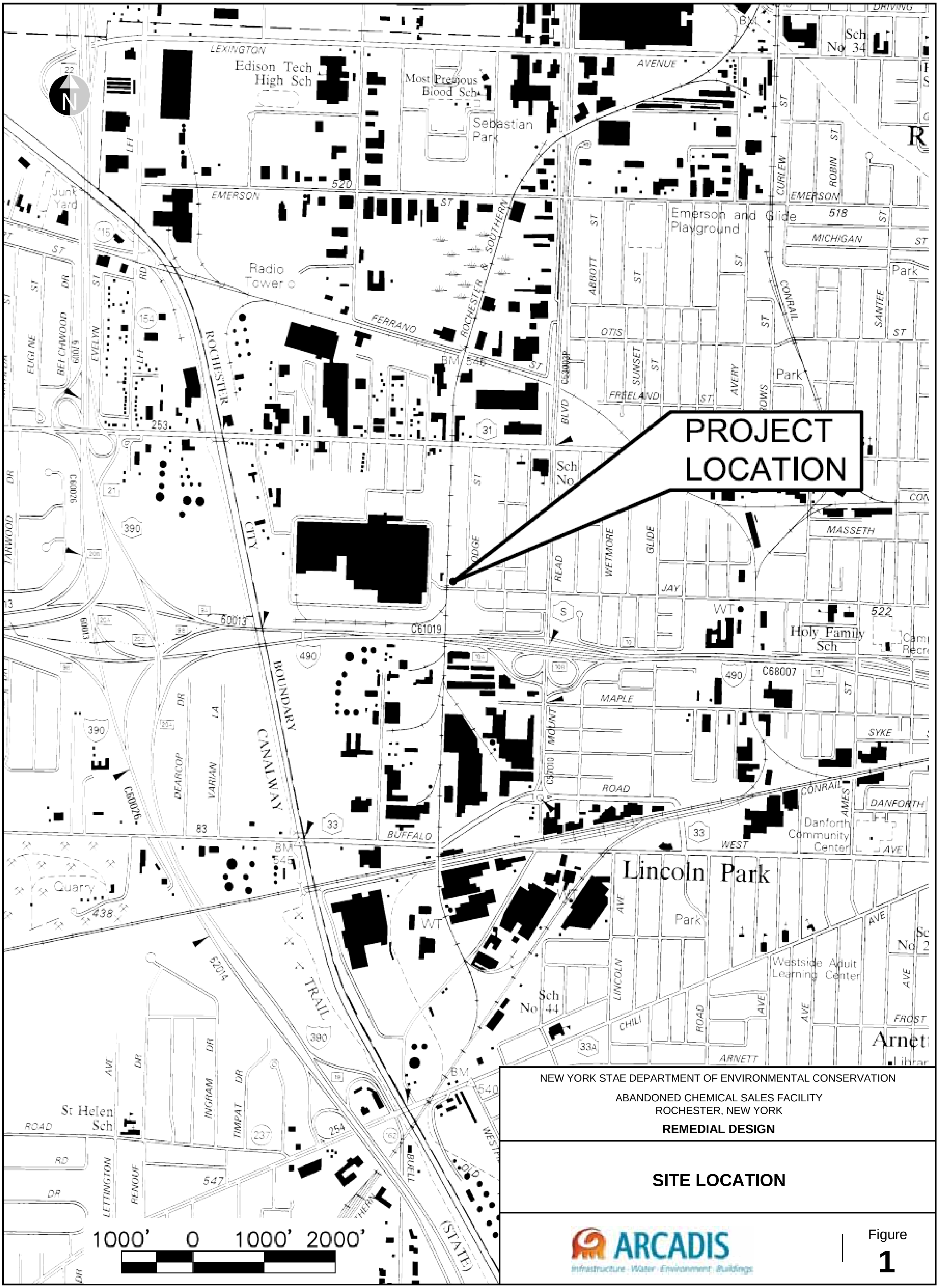
NOTES:

U = Not detected

NA = Not Analyzed

Concentrations are in milligrams per liter (mg/l)

Figures



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ABANDONED CHEMICAL SALES FACILITY
ROCHESTER, NEW YORK

REMEDIAL DESIGN

SITE LOCATION

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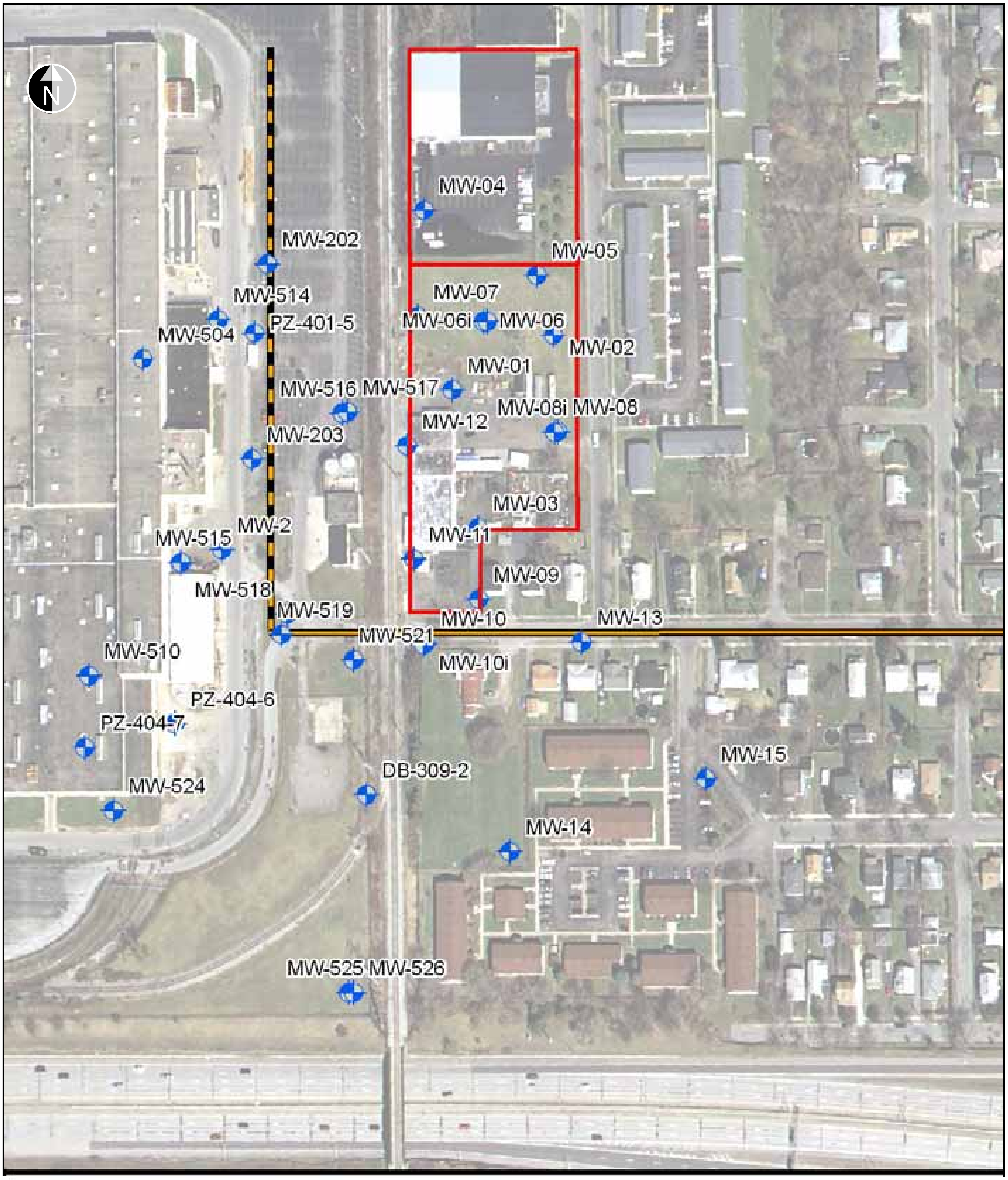
Figure
1

G:\PROJECT\00266397\ISCO Design Plan\Figure 1 – Site .pptx



Legend

- ✦ Monitoring Well
- ▬ Jay Street Sewer Line
- ▬ Valeo Sewer Line (Approximate)

0 300 600 Feet

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REMEDIAL DESIGN

MONITORING WELLS

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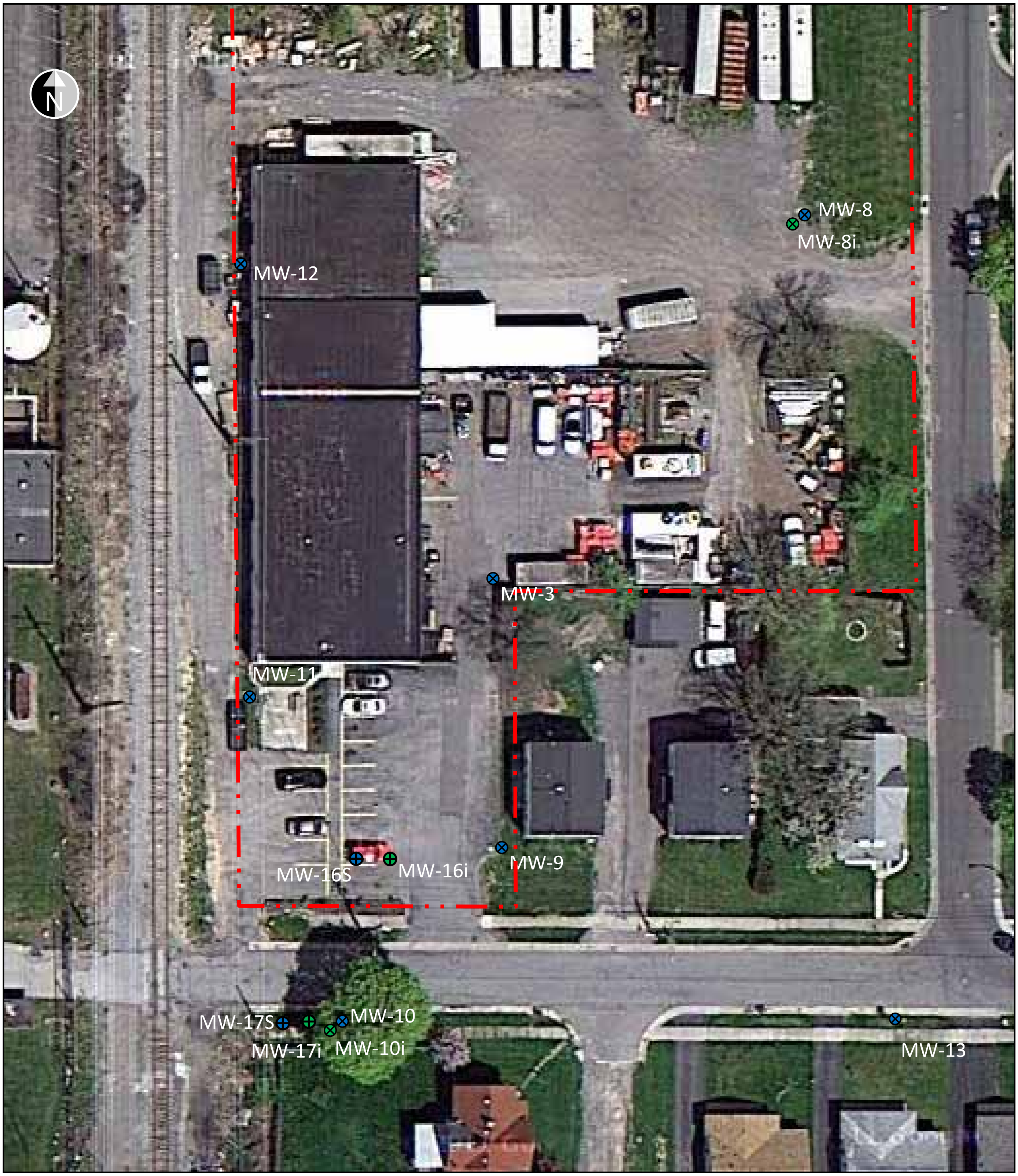
Figure
2

G:\PROJECT\00266397\Monitoring Wells.pptx

Source: Remedial Investigation/Feasibility Study Report, Abandoned Chemical Sales Facility (828105), Prepared by EA Engineering, P.C.



-··-	APPROXIMATE SITE PROPERTY LINE
⊗	EXISTING SHALLOW BEDROCK MONITORING WELL
⊗	EXISTING INTERMEDIATE BEDROCK MONITORING WELL
⊕	EXISTING SHALLOW BEDROCK INJECTION WELL
⊕	EXISTING INTERMEDIATE BEDROCK INJECTION WELL

APPROXIMATE SCALE IN FEET

0 16 32 64

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ABANDONED CHEMICAL SALES FACILITY
ROCHESTER, NEW YORK

REMEDIAL DESIGN

INJECTION AND MONITORING WELLS

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Figure
3

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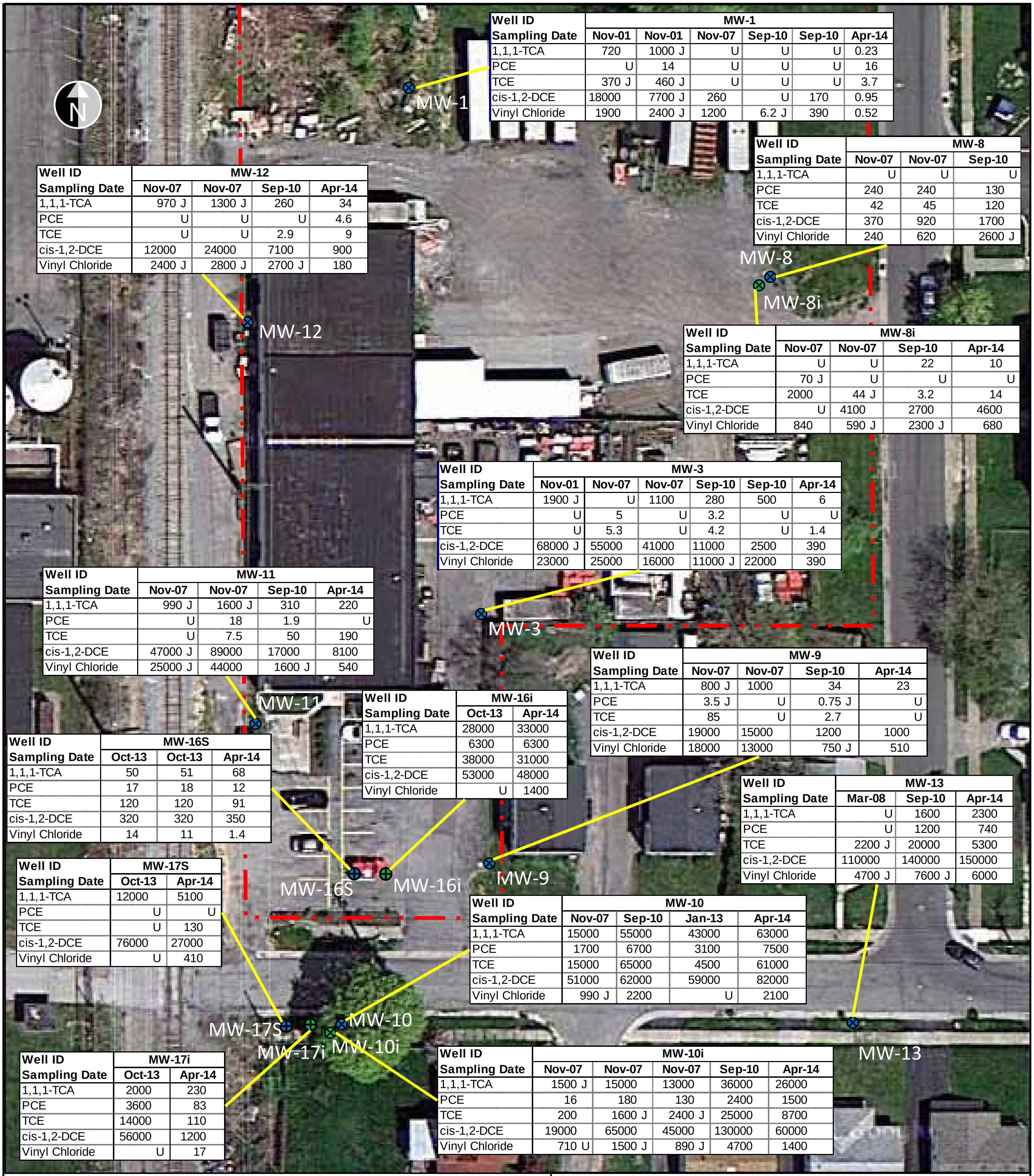
Source: GOOGLE EARTH, Downloaded 1/2014



Well ID	MW-1					
Sampling Date	Nov-01	Nov-01	Nov-07	Sep-10	Sep-10	Apr-14
1,1,1-TCA	720	1000 J	U	U	U	0.23
PCE	U	14	U	U	U	16
TCE	370 J	460 J	U	U	U	3.7
cis-1,2-DCE	18000	7700 J	260	U	170	0.95
Vinyl Chloride	1900	2400 J	1200	6.2 J	390	0.52

Well ID	MW-12			
Sampling Date	Nov-07	Nov-07	Sep-10	Apr-14
1,1,1-TCA	970 J	1300 J	260	34
PCE	U	U	U	4.6
TCE	U	U	2.9	9
cis-1,2-DCE	12000	24000	7100	900
Vinyl Chloride	2400 J	2800 J	2700 J	180

Well ID	MW-8		
Sampling Date	Nov-07	Nov-07	Sep-10
1,1,1-TCA	U	U	U
PCE	240	240	130
TCE	42	45	120
cis-1,2-DCE	370	920	1700
Vinyl Chloride	240	620	2600 J

Well ID	MW-8i			
Sampling Date	Nov-07	Nov-07	Sep-10	Apr-14
1,1,1-TCA	U	U	22	10
PCE	70 J	U	U	U
TCE	2000	44 J	3.2	14
cis-1,2-DCE	U	4100	2700	4600
Vinyl Chloride	840	590 J	2300 J	680

Well ID	MW-3					
Sampling Date	Nov-01	Nov-07	Nov-07	Sep-10	Sep-10	Apr-14
1,1,1-TCA	1900 J	U	1100	280	500	6
PCE	U	5	U	3.2	U	U
TCE	U	5.3	U	4.2	U	1.4
cis-1,2-DCE	68000 J	55000	41000	11000	2500	390
Vinyl Chloride	23000	25000	16000	11000 J	22000	390

Well ID	MW-11			
Sampling Date	Nov-07	Nov-07	Sep-10	Apr-14
1,1,1-TCA	990 J	1600 J	310	220
PCE	U	18	1.9	U
TCE	U	7.5	50	190
cis-1,2-DCE	47000 J	89000	17000	8100
Vinyl Chloride	25000 J	44000	1600 J	540

Well ID	MW-9			
Sampling Date	Nov-07	Nov-07	Sep-10	Apr-14
1,1,1-TCA	800 J	1000	34	23
PCE	3.5 J	U	0.75 J	U
TCE	85	U	2.7	U
cis-1,2-DCE	19000	15000	1200	1000
Vinyl Chloride	18000	13000	750 J	510

Well ID	MW-16i	
Sampling Date	Oct-13	Apr-14
1,1,1-TCA	28000	33000
PCE	6300	6300
TCE	38000	31000
cis-1,2-DCE	53000	48000
Vinyl Chloride	U	1400

Well ID	MW-16S		
Sampling Date	Oct-13	Oct-13	Apr-14
1,1,1-TCA	50	51	68
PCE	17	18	12
TCE	120	120	91
cis-1,2-DCE	320	320	350
Vinyl Chloride	14	11	1.4

Well ID	MW-13		
Sampling Date	Mar-08	Sep-10	Apr-14
1,1,1-TCA	U	1600	2300
PCE	U	1200	740
TCE	2200 J	20000	5300
cis-1,2-DCE	110000	140000	150000
Vinyl Chloride	4700 J	7600 J	6000

Well ID	MW-17S	
Sampling Date	Oct-13	Apr-14
1,1,1-TCA	12000	5100
PCE	U	U
TCE	U	130
cis-1,2-DCE	76000	27000
Vinyl Chloride	U	410

Well ID	MW-10			
Sampling Date	Nov-07	Sep-10	Jan-13	Apr-14
1,1,1-TCA	15000	55000	43000	63000
PCE	1700	6700	3100	7500
TCE	15000	65000	4500	61000
cis-1,2-DCE	51000	62000	59000	82000
Vinyl Chloride	990 J	2200	U	2100

Well ID	MW-17i	
Sampling Date	Oct-13	Apr-14
1,1,1-TCA	2000	230
PCE	3600	83
TCE	14000	110
cis-1,2-DCE	56000	1200
Vinyl Chloride	U	17

Well ID	MW-10i				
Sampling Date	Nov-07	Nov-07	Nov-07	Sep-10	Apr-14
1,1,1-TCA	1500 J	15000	13000	36000	26000
PCE	16	180	130	2400	1500
TCE	200	1600 J	2400 J	25000	8700
cis-1,2-DCE	19000	65000	45000	130000	60000
Vinyl Chloride	710 U	1500 J	890 J	4700	1400

— · · — APPROXIMATE SITE PROPERTY LINE
⊗ EXISTING SHALLOW BEDROCK MONITORING WELL
⊗ EXISTING INTERMEDIATE BEDROCK MONITORING WELL
⊕ EXISTING SHALLOW BEDROCK INJECTION WELL
⊕ EXISTING INTERMEDIATE BEDROCK INJECTION WELL

CONCENTRATIONS ARE IN MICROGRAMS PER LITER

APPROXIMATE SCALE IN FEET

0 16 32 64

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ABANDONED CHEMICAL SALES FACILITY
ROCHESTER, NEW YORK

REMEDIAL DESIGN

HISTORICAL GROUNDWATER VOC RESULTS

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Figure
4

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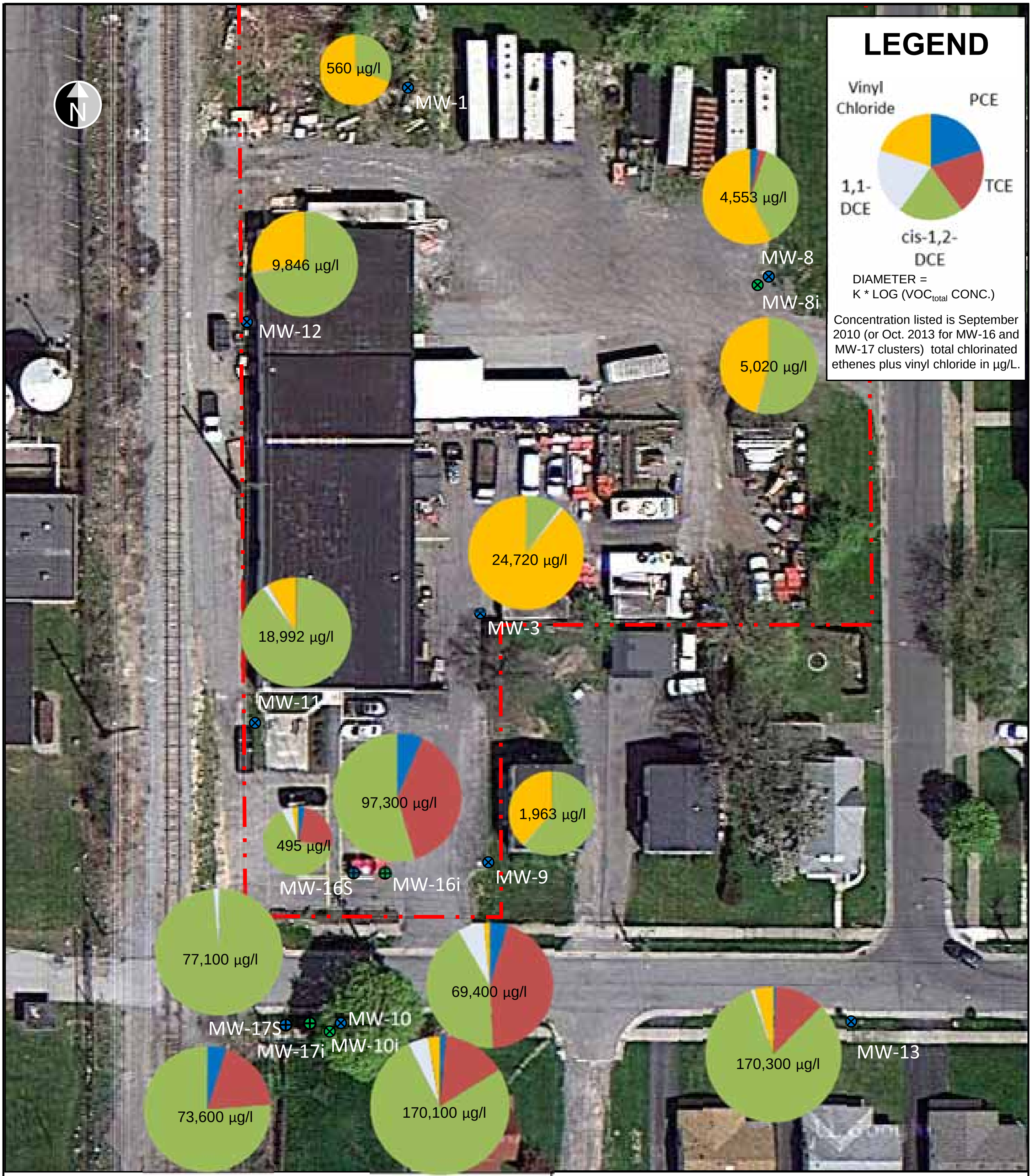

-·- APPROXIMATE SITE PROPERTY LINE

⊗ EXISTING SHALLOW BEDROCK MONITORING WELL

⊗ EXISTING INTERMEDIATE BEDROCK MONITORING WELL

⊕ EXISTING SHALLOW BEDROCK INJECTION WELL

⊕ EXISTING INTERMEDIATE BEDROCK INJECTION WELL

APPROXIMATE SCALE IN FEET

0 16 32 64

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ABANDONED CHEMICAL SALES FACILITY
ROCHESTER, NEW YORK

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CHLORINATED ETHENE ANALYTICAL DATA

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Figure
5

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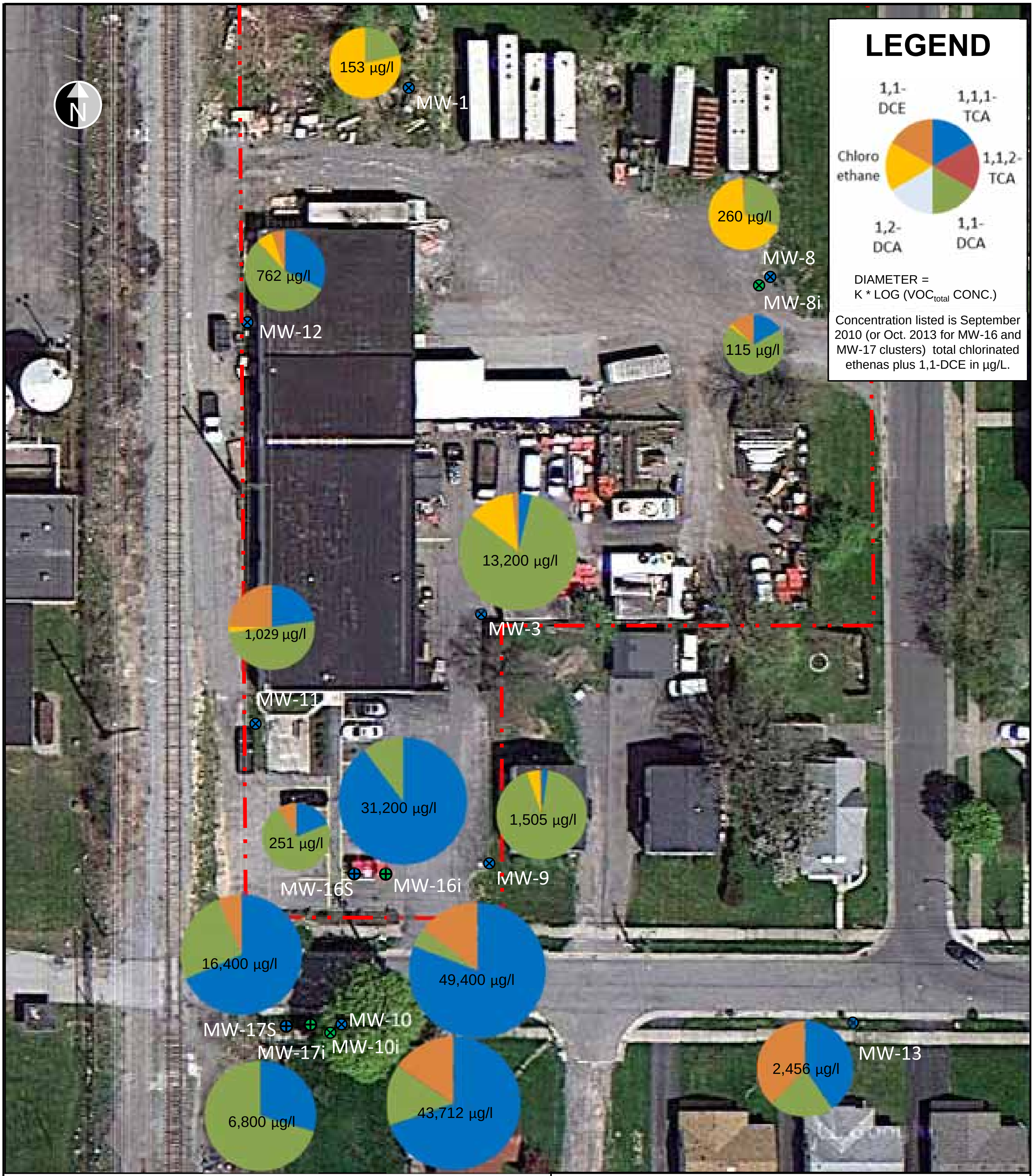

-··- APPROXIMATE SITE PROPERTY LINE

⊗ EXISTING SHALLOW BEDROCK MONITORING WELL

⊗ EXISTING INTERMEDIATE BEDROCK MONITORING WELL

⊕ EXISTING SHALLOW BEDROCK INJECTION WELL

⊕ EXISTING INTERMEDIATE BEDROCK INJECTION WELL

APPROXIMATE SCALE IN FEET

0 16 32 64

NEW YORK STAE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

ABANDONED CHEMICAL SALES FACILITY
ROCHESTER, NEW YORK

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Figure
6

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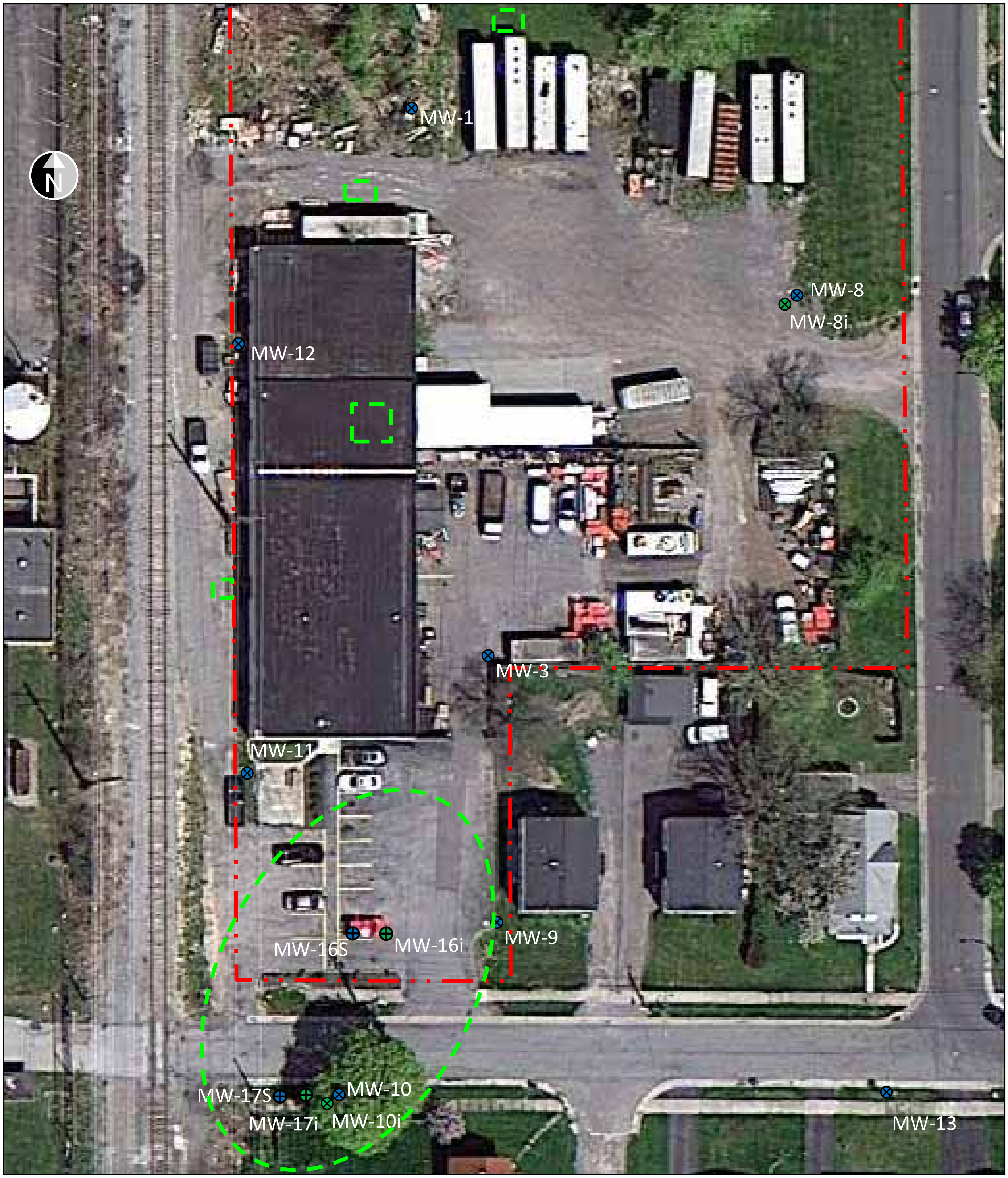

—·— APPROXIMATE SITE PROPERTY LINE
- - - PROPOSED ISCO PILOT INJECTION AREAS
⊗ EXISTING SHALLOW BEDROCK MONITORING WELL
⊗ EXISTING INTERMEDIATE BEDROCK MONITORING WELL
⊕ EXISTING SHALLOW BEDROCK INJECTION WELL
⊕ EXISTING INTERMEDIATE BEDROCK INJECTION WELL

APPROXIMATE SCALE IN FEET
0 16 32 64

NEW YORK STAE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

ABANDONED CHEMICAL SALES FACILITY
ROCHESTER, NEW YORK

REMEDIAL DESIGN

PROPOSED ISCO TREATMENT AREAS

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Figure
7

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Appendix A

Injection Well Boring Logs

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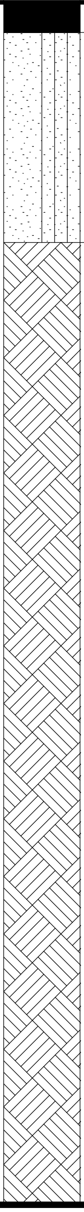
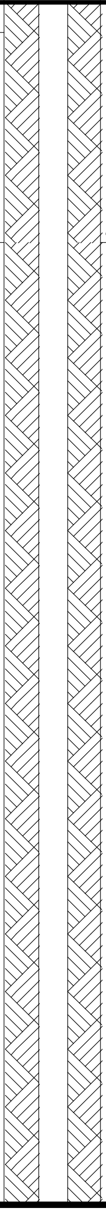
TEST BORING LOG

BORING No.MW-16i

PROJECT	**Abandoned Chemical Sales**	LOCATION	**Rochester, NY**	SHEET	**1** OF **2**
CLIENT	**NYSDEC**			PROJECT No.	**00255397.0000**
DRILLING CONTRACTOR	**Northnagle Drilling**			MEAS. PT. ELEV.	
PURPOSE	**Injection**			GROUND ELEV.	
WELL MATERIAL	**steel**			DATUM	

DRILLING METHOD(S)	**HSA, Rotary and Coring**	SAMPLE	CORE	CASING	
DRILL RIG TYPE	TYPE				DATE STARTED **1/7/13**
GROUND WATER DEPTH '	DIA.	"			DATE FINISHED **1/7/13**
MEASURING POINT	WEIGHT	#			DRILLER
DATE OF MEASUREMENT	FALL	"			PIRNIE STAFF **D. Symonds**





DEPTH FT.	SAMPLE TYPE, RECOVERY, NUMBER	BLOWS ON SAMPLE SPOON PER 6"	PID	GRAPHIC LOG	GEOLOGIC DESCRIPTION KEY - Color, Major, Minor Moisture, Etc.	ELEV. DEPTH	WELL Constr.	REMARKS
					ASPHALT and gravel			Flushmount
					SILTY SAND (medium brown) overburden and gravel (trace 0.5" -2" diameter), moist	0.5		
2								10" Hollow stem auger, 4" steel casing
4					BEDROCK (medium gray dolostone)	4.0	4.0	
6								
8								
10								
								6.25 Air rotary drill, 4" steel casing
12								
14								
16								
18								

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TEST BORING LOG

BORING No.MW-16i

PROJECT **Abandoned Chemical Sales**	LOCATION **Rochester, NY**	SHEET **2** OF **2**	
CLIENT **NYSDEC**		PROJECT No. **00255397.0000**	

DEPTH FT.	SAMPLE TYPE, RECOVERY, NUMBER	BLOWS ON SAMPLE SPOON PER 6"	PID	GRAPHIC LOG	GEOLOGIC DESCRIPTION KEY - Color, Major, Minor Moisture, Etc.	ELEV. / DEPTH	WELL Constr.	REMARKS
						21.0	21.0	
22								
24								
								HQ core, open bedrock hole
26					Strong odor, wet			
28					1 small fracture			
30			32.1		1 small fracture			
	10							
32								
34					1 small fracture			
36			500		Several small fractures			
					5 small fractures from 35.5' to 37.5'			
38					1 small fracture			
			380		3 small fractures			
40			999		1 small fracture			
						41.5	41.5	End of boring

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TEST BORING LOG

BORING No.MW-16s

PROJECT	**Abandoned Chemical Sales**	LOCATION	**Rochester, NY**		SHEET	**1** OF **2**
CLIENT	**NYSDEC**				PROJECT No.	**00255397.0000**
DRILLING CONTRACTOR	**Northnagle Drilling**				MEAS. PT. ELEV.	
PURPOSE	**Injection**				GROUND ELEV.	
WELL MATERIAL	**steel**				DATUM	
DRILLING METHOD(S)	**HSA, Rotary and Coring**	SAMPLE	CORE	CASING	DATE STARTED	**1/7/13**
DRILL RIG TYPE	TYPE				DATE FINISHED	**1/7/13**
GROUND WATER DEPTH '	DIA.	"			DRILLER	
MEASURING POINT	WEIGHT	#				
DATE OF MEASUREMENT	FALL	"			PIRNIE STAFF	**D. Symonds**

DEPTH FT.	SAMPLE TYPE, RECOVERY, NUMBER	BLOWS ON SAMPLE SPOON PER 6"	PID	GRAPHIC LOG	**GEOLOGIC DESCRIPTION** KEY - Color, Major, Minor Moisture, Etc.	ELEV. DEPTH	**WELL Constr.**	**REMARKS**
					ASPHALT and gravel			Flushmount
					SILTY SAND (medium brown) , overburden and gravel (trace 0.5"-2" diameter), moist to wet	0.5		
2								10" Hollow stem auger, 4" steel casing
4					BEDROCK (medium gray dolostone)	4.0	4.0	
6								6.25" Air rotary drill, 4" steel casing
8								
						9.0	9.0	
10					Small fractures from 9' to 12'			
								HQ core, open bedrock hole
12			3.3		Vertical fracture (~4")			
14					Vertical fracture (~7")			
					6 small fractures			
16			1.2		6 fractures from 15' to 16.5' Vertical fracture (~6")			
	15							
18								
					15 small fractures from 17' to 21'			

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PROJECT **Abandoned Chemical Sales**	LOCATION **Rochester, NY**	SHEET **2** OF **2**
CLIENT **NYSDEC**		PROJECT No. **00255397.0000**

DEPTH FT.	SAMPLE TYPE, RECOVERY, NUMBER	BLOWS ON SAMPLE SPOON PER 6"	PID	GRAPHIC LOG	GEOLOGIC DESCRIPTION KEY - Color, Major, Minor Moisture, Etc.	ELEV. DEPTH	WELL Constr.	REMARKS
	▨		3.3	▨				
22	▨			▨				
	▨			▨	7 medium fractures from 21' to 25'			
24	▨			▨				
			1.2			25.0		25.0 End of boring

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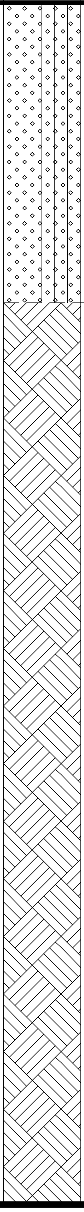
TEST BORING LOG

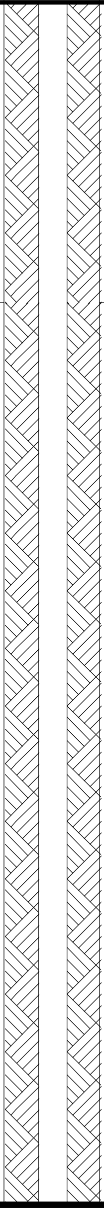
BORING No.MW-17i

PROJECT	**Abandoned Chemical Sales**	LOCATION	**Rochester, NY**	SHEET	**1** OF **2**
CLIENT	**NYSDEC**			PROJECT No.	**00255397.0000**
DRILLING CONTRACTOR	**Northnagle Drilling**			MEAS. PT. ELEV.	
PURPOSE	**Injection**			GROUND ELEV.	
WELL MATERIAL	**steel**			DATUM	

DRILLING METHOD(S)	**HSA, Rotary and Coring**		SAMPLE	CORE	CASING	DATE STARTED	**1/9/13**
DRILL RIG TYPE		TYPE				DATE FINISHED	**1/9/13**
GROUND WATER DEPTH	'	DIA.	"			DRILLER	
MEASURING POINT		WEIGHT	#				
DATE OF MEASUREMENT		FALL	"			PIRNIE STAFF	**D. Symonds**

DEPTH FT.	SAMPLE TYPE, RECOVERY, NUMBER	BLOWS ON SAMPLE SPOON PER 6"	PID	GRAPHIC LOG	GEOLOGIC DESCRIPTION KEY - Color, Major, Minor Moisture, Etc.	ELEV. / DEPTH	WELL Constr.	REMARKS
					SILTY SAND (medium brown), overburden and trace gravel (~2"diameter)			Flushmount
2								
								10" Hollow stem auger, 4" steel casing
4								
								5.0
					BEDROCK (weathered dolostone)	5.0		
6								
8								6.25" Air rotary drill, 4" steel casing
10								
12								
14								
16								
18								





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TEST BORING LOG

BORING No.MW-17i

PROJECT **Abandoned Chemical Sales**	LOCATION **Rochester, NY**	SHEET **2** OF **2**	
CLIENT **NYSDEC**		PROJECT No. **00255397.0000**	

DEPTH FT.	SAMPLE TYPE, RECOVERY, NUMBER	BLOWS ON SAMPLE SPOON PER 6"	PID	GRAPHIC LOG	GEOLOGIC DESCRIPTION KEY - Color, Major, Minor Moisture, Etc.	ELEV. / DEPTH	WELL Constr.	REMARKS
22								
24								
26								
28								
30								
						31.0		31.0
					1 fracture at 31.5'			
32			30		1 fracture at 32'			
					3 fractures at 33'			
34			33		1 large fracture (~2") at 34'			
					5 fractures			HQ core, open bedrock hole
36					3 fractures			
					1 fracture at 37.5'			
38			45		5 fractures 38' to 40'			
40	13		50		Several fractures			
					Horizontal and vertical fractures			
42			55		2 close fractures at 42.5'			
44					7 fractures from 43' to 45' Vertical fracture (~3")			
			60			45.0		45.0 End of boring

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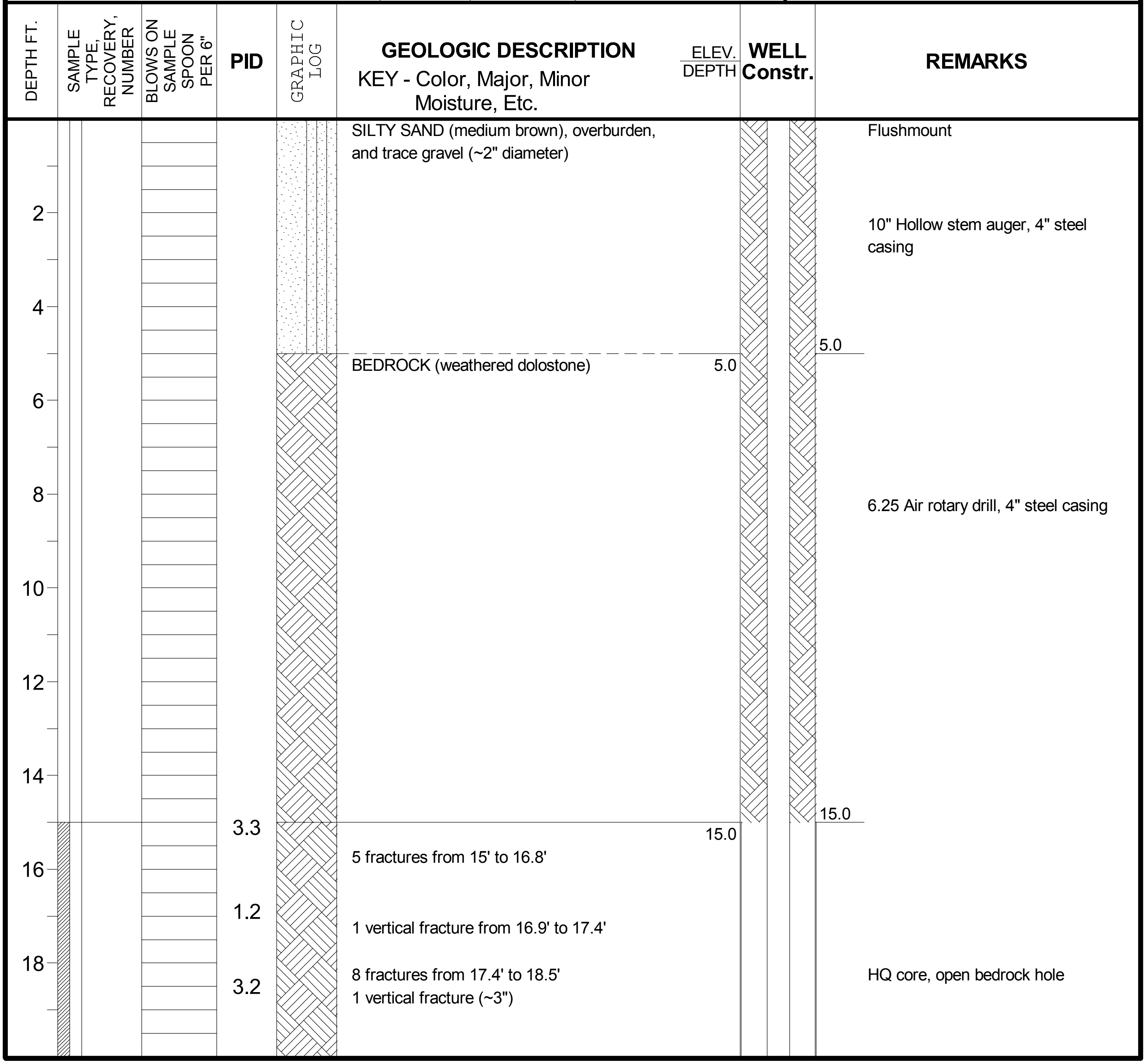
TEST BORING LOG

BORING No.MW-17s

PROJECT	**Abandoned Chemical Sales**	LOCATION	**Rochester, NY**		SHEET	**1** OF **2**
CLIENT	**NYSDEC**				PROJECT No.	**00255397.0000**
DRILLING CONTRACTOR	**Northnagle Drilling**				MEAS. PT. ELEV.	
PURPOSE	**Injection**				GROUND ELEV.	
WELL MATERIAL	**steel**				DATUM	
DRILLING METHOD(S)	**HSA, Rotary and Coring**	SAMPLE	CORE	CASING	DATE STARTED	**1/9/13**
DRILL RIG TYPE	TYPE				DATE FINISHED	**1/9/13**
GROUND WATER DEPTH '	DIA.	"			DRILLER	
MEASURING POINT	WEIGHT	#			PIRNIE STAFF	**D. Symonds**
DATE OF MEASUREMENT	FALL	"				



DEPTH FT.	PID	GEOLOGIC DESCRIPTION KEY - Color, Major, Minor Moisture, Etc.	ELEV. / DEPTH	REMARKS
0		SILTY SAND (medium brown), overburden, and trace gravel (~2" diameter)		Flushmount
2				10" Hollow stem auger, 4" steel casing
5.0		BEDROCK (weathered dolostone)	5.0	
8				6.25 Air rotary drill, 4" steel casing
15.0	3.3	5 fractures from 15' to 16.8'	15.0	
17	1.2	1 vertical fracture from 16.9' to 17.4'		
18	3.2	8 fractures from 17.4' to 18.5' 1 vertical fracture (~3")		HQ core, open bedrock hole

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TEST BORING LOG

BORING No.MW-17s

PROJECT **Abandoned Chemical Sales**	LOCATION **Rochester, NY**	SHEET **2** OF **2**	
CLIENT **NYSDEC**		PROJECT No. **00255397.0000**	

DEPTH FT.	SAMPLE TYPE, RECOVERY, NUMBER	BLOWS ON SAMPLE SPOON PER 6"	PID	GRAPHIC LOG	**GEOLOGIC DESCRIPTION** KEY - Color, Major, Minor Moisture, Etc.	ELEV. / DEPTH	**WELL Constr.**	**REMARKS**
	▨ 10			▨				
			1.2	▨	12 fractures from 19' to 23'			
22				▨				
24				▨	9 fractures from 23' to 25'			
						25.0		25.0 End of boring

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Appendix B

Treatability Study Memo

Malcolm Pirnie, Inc.
855 Route 146
Suite 210
Clifton Park
New York 12065
Tel 518 250 7300
Fax 518 250 7301

MEMO

To:
Vivek Nattanmai
NYSDEC
Division of Environmental Remediation
625 Broadway, 12th Floor
Albany, NY 12233

Copies:
Dave Hiss (ARCADIS)
Dan Lang (ARCADIS)

From:
Mark Flusche

Date:
4/3/14

ARCADIS Project No.:
00266397.0000

Subject:
Abandoned Chemical Sales Facility
Injectability Study

Purpose

This technical memorandum presents the results of a targeted injectability study conducted at the Abandoned Chemical Sales Facility in Rochester, New York (site). The injectability study was completed to evaluate flow rates and spacing of injection wells for the upcoming chemical oxidation injection pilot events.

Introduction

The site consists of a 2.29 acre property at 1600 Jay Street. With the exception of a grassy area in the northern portion, the majority of the site is covered with an asphalt and gravel parking surface and an 11,000 square foot site building. The site is currently owned and operated by a heating, plumbing, and ventilation contractor. The New York State Department of Environmental Conservation (NYSDEC) listed the site as a Class 2 site in the New York State Registry of Inactive Hazardous Waste Disposal Sites in 2002 following a preliminary site assessment. The primary contaminants of concern at the site identified during the Remedial Investigation are tetrachloroethene (PCE), trichloroethene (TCE) and 1,1,1-trichloroethane (1,1,1-TCA) and their breakdown products [cis-l,2-dichloroethene (cis-l ,2-DCE), vinyl chloride, and chloroethane]. The record of decision (ROD) detailed the proposed remedy for the site, which includes targeted soil excavation and approximately three in-situ chemical oxidation events followed by enhanced bioremediation. The site is currently in the Remedial Design stage. Design phase studies, including an injectability study discussed herein, are being implemented to evaluate potential remedial approaches and refine the remedial design.

Injectability Tests

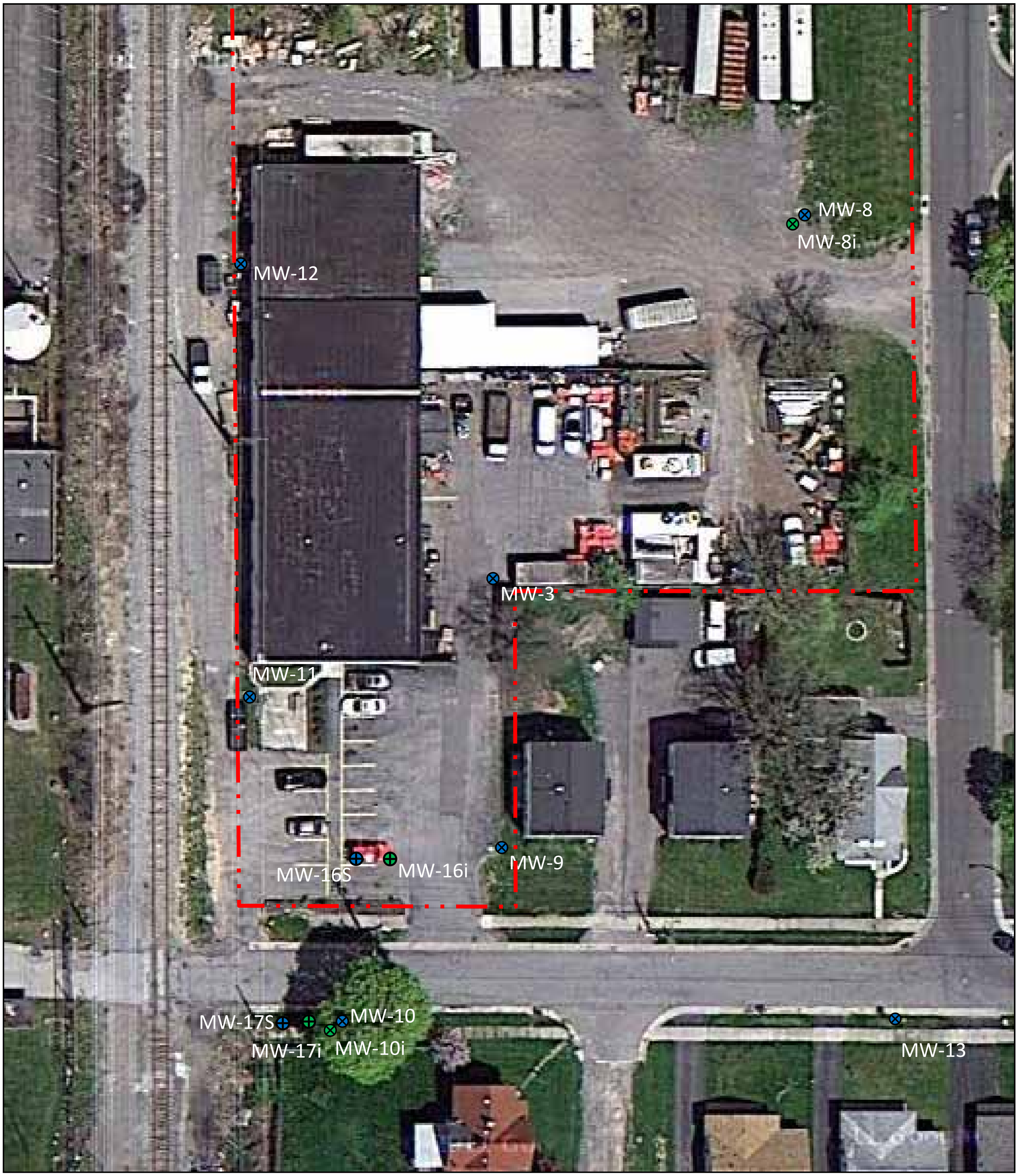
There are two shallow and two intermediate injection wells installed at and near the site (Figure 1). One injection well cluster is installed in the center of the site parking lot (MW-16S and MW-16I) and a second injection well cluster is installed on the south side of Jay Street (MW-17S and MW-17I). The injectability study consisted of performing injectability tests on these four injection wells to assess the ability of the bedrock to accept an injection solution. The injectability tests, where water is injected into existing injection wells, were conducted on March 11, 12, and 14, 2014. The results of the injectability tests, which are summarized in the attached tables, will be used to design the chemical oxidant injection pilot events.

The injectability tests indicate that minimal injection solution can be injected into the shallow injection wells [flow rate less than 0.25 gallons per minute (gpm)]. Over the 2 and a half hour test, 43 gallons of water was injected into MW-16S, including the volume required to fill up the empty casing (7 gallons). The maximum injection flow rate during the MW-16S test was less than 0.25 gpm with injection pressures up to 17.0 pounds per square inch (psi). The amount of water to fill the empty MW-17S well casing was 11.5 gallons and this is the amount of water that could be injected into MW-17S over the hour-long injectability test. Even at the maximum pressure of 19 psi, the flow rate was too low to measure (less than 0.01 gpm).

In contrast to the shallow well tests, the intermediate bedrock wells accepted significantly more water at much higher flow rates. In one hour, approximately 90 gallons of water was injected into MW-16I at a maximum flow rate of approximately 2 gpm and a maximum pressure of about 7 psi. An estimated 232 gallons of water was injected into MW-17I over approximately 2.5 hours spread over two days, at a maximum rate of 3 gpm and a maximum pressure of 1 psi. A sustained flow rate of 1.5 gpm was achieved at both MW-16I and MW-17I when no pressure was applied with a pump (gravity feed).

The water levels in the shallow monitoring wells did not rise by more than 0.64 feet during the injectability tests and the water level in most shallow wells rose less than 0.1 foot. This indicates that there is minimal hydraulic connection between the injection wells (both shallow and intermediate) and the shallow monitoring wells. In contrast, the water level in some of the surrounding intermediate wells rose between 5 to 10 feet while injecting into MW-16I and MW-17I.

The injectability study results indicate that gravity feed injection into the intermediate zone of this bedrock formation would be effective at injecting an oxidant into the bedrock and distributing it over horizontal distances of 50 feet or more. With a tank holding larger volumes of injection solution from greater height, measureable injection pressures could likely be attained with a gravity feed system. ARCADIS will incorporate the injectability study results into the design of the chemical oxidant injection program.



-·-·- APPROXIMATE SITE PROPERTY LINE

⊗ EXISTING SHALLOW BEDROCK MONITORING WELL

⊗ EXISTING INTERMEDIATE BEDROCK MONITORING WELL

⊕ EXISTING SHALLOW BEDROCK INJECTION WELL

⊕ EXISTING INTERMEDIATE BEDROCK INJECTION WELL

APPROXIMATE SCALE IN FEET

0 16 32 64

NEW YORK STAE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

ABANDONED CHEMICAL SALES FACILITY
ROCHESTER, NEW YORK

REMEDIAL DESIGN

INJECTION AND MONITORING WELLS

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Figure
1

G:\PROJECT\00266397\Monitoring Wells.pptx

Source: GOOGLE EARTH, Downloaded 1/2014

Injectability Test Field Monitoring Form

Abandoned Chemical Sales Facility (828105)

1600 Jay Street, Rochester, New York

Date	Time	MW-16S			
		Total Volume Injected (gal)	**Injection Pressure (psi)**	**Flow Rate (gpm)**	**Notes**
3/11/2014	10:05	7.01	--	--	Gravity Feed - Casing Full
	10:10		1.5	0.066	~1.32 gal of water injected, 8.32 gal total
	10:35		1.5	0.000	
	10:55		1.0	0.000	
	11:25	8.33	1.0	0.000	Stop gravity injection
	11:55		7.0	0.133	Increase pump rate
	12:09		7.0	0.036	
	12:35		7.0	0.020	
	13:02		12.5	0.111	Increase pump rate
	13:14		12.5	0.110	
	13:31		12.5	0.100	
	13:40		--	--	Increase pump rate
	13:45		16.5	0.166	
	13:53		16.5	0.150	
	14:07		17.0	0.120	
	14:20	43	--	--	Stop

Total Volume of Water Injected: 43 gal including water needed to fill casing

Initial Casing Void Volume:

Initial DTW:	10.75	feet
Void Volume:	7.0	gal

Notes:

gal: gallons

psi: pounds per square inch

gpm: gallons per minute

DTW: depth to water

Injectability Test Water Level Monitoring Log

Abandoned Chemical Sales Facility (828105)
1600 Jay Street, Rochester, New York

Injection Well: MW-16S

Date	Time	Total Injected Volume (gal)	Flow Rate (gpm)	Depth to Water (ft)							
				MW-3	MW-9	MW-10	MW-10I	MW-11	MW-16I	MW-17S	MW-17I
3/11/2014	9:40	--	--	8.31	13.01	18.23	18.91	11.32	17.78	17.60	18.82
	10:55	1.3	0	8.31	12.92	18.23	18.91	11.30	17.78	17.61	18.82
	11:43		0	--	Deploy Troll	18.23	18.91	--	Deploy Troll	Deploy Troll	--
	12:35		0.02	8.28	12.99	18.23	18.93	11.30	--	--	18.81
	13:15		0.1	8.26	12.95	18.20	18.88	11.27	--	--	18.79
	14:10		0.12	8.23	12.92	18.17	18.86	11.23	17.74	17.57	18.77
	14:20	43	--	--	--	--	--	--	--	--	--
Max Water Level Change (ft)				0.08	0.09	0.06	0.05	0.09	0.04	0.03	0.05
Max Water Volume Change (gal)				0.01	0.02	0.01	0.01	0.02	0.03	0.02	0.03

Notes:
Pumping started at 10:05 and stopped at 14:20
gal: gallons
gpm: gallons per minute
ft: feet
Troll: Instrument deployed in monitoring wells to measure and log changes in water level in that well.

Injectability Test Field Monitoring Form

Abandoned Chemical Sales Facility (828105)

1600 Jay Street, Rochester, New York

Date	Time	MW-17S			
		Total Volume Injected (gal)	**Injection Pressure (psi)**	**Flow Rate (gpm)**	**Notes**
3/14/2014	9:45	0	0.0	3.000	Start gravity feed
	9:49	10	1.5	0.000	
	10:05	10	1.5	0.000	Stop gravity feed
	10:07	10	6.5	0.000	Increase pump rate
	10:20	11	7.5	0.000	
	10:35	11	11.0	0.000	Increase pump rate
	10:38	11	11.0	0.000	
	10:40	11	12.0	0.000	
	10:43	11.5	19.0	0.000	Increase pump rate/stop

Total Volume of Water Injected: 11.5 gal including water need to fill casing

Initial Casing Void Volume:

Initial DTW:	17.54	feet
Void Volume:	11.5	gal

Notes:

gal: gallons

psi: pounds per square inch

gpm: gallons per minute

DTW: depth to water

Injectability Test Water Level Monitoring Log

Abandoned Chemical Sales Facility (828105)

1600 Jay Street, Rochester, New York

Injection Well: MW-17S											
Date	**Time**	**Total Injected Volume (gal)**	**Flow Rate (gpm)**	**Depth to Water (ft)**							
				MW-3	**MW-9**	**MW-10**	**MW-10I**	**MW-11**	**MW-16S**	**MW-16I**	**MW-17I**
3/14/2014	9:15	--	--	7.55	12.67	18.21	18.75	10.80	10.00	17.49	18.59
	10:20	10	0.00	7.51	12.65	18.23	18.74	10.77	9.98	17.47	18.56
	11:30	11	0.00	7.51	12.64	18.20	18.72	10.77	10.00	17.47	18.57
Max Water Level Change (ft)				0.04	0.03	0.01	0.03	0.03	0.02	0.02	0.03
Max Water Volume Change (gal)				0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.02

Notes:

Pumping started at 9:45 and stopped at 10:43

gal: gallons

gpm: gallons per minute

ft: feet

Injectability Test Field Monitoring Form

Abandoned Chemical Sales Facility (828105)
1600 Jay Street, Rochester, New York

Date	Time	MW-16I			
		Total Volume Injected (gal)	**Injection Pressure (psi)**	**Flow Rate (gpm)**	**Notes**
3/11/2014	14:50		--	--	Start Gravity feed
	14:58	11.58	--	--	Casing full, refill water tank
	15:20		0.0	1.420	Continue gravity feed with full tank
	15:30	15	0.0	1.420	
	15:40	30	0.0	1.400	
	15:45	35	0.0	1.420	Stop gravity feed
	15:46	45	3.0	1.720	Increase pump rate
	15:50	55	4.5	1.720	
	16:01	65	5.0	1.720	
	16:08	75	7.0	1.850	Increase pump rate
	16:15	85	6.5	1.850	
	16:18	90	6.5	1.850	
	16:20		--	--	Stop

Total Volume of Water Injected: 90 gal including water needed to fill casing

Initial Casing Void Volume:

Initial DTW:	17.74	feet
Void Volume:	11.6	gal

Notes:
gal: gallons
psi: pounds per square inch
gpm: gallons per minute
DTW: depth to water

Injectability Test Water Level Monitoring Log

Abandoned Chemical Sales Facility (828105)

1600 Jay Street, Rochester, New York

Injection Well: MW-16I											
Date	**Time**	**Total Injected Volume (gal)**	**Flow Rate (gpm)**	**Depth to Water (ft)**							
				MW-3	**MW-9**	**MW-10**	**MW-10I**	**MW-11**	**MW-16S**	**MW-17S**	**MW-17I**
3/11/2014	9:40	--	--	8.31	13.01	18.23	18.91	11.32	10.75	17.60	18.82
	15:40	30	1.40	--	12.91	17.74	14.94	11.20	2.63	17.57	12.33
	15:55	60	1.72	--	12.90	17.60	13.44	11.20	2.63	17.57	9.81
	16:25	90	--	--	12.90	17.60	15.44	11.19	3.19	17.59	11.37
Max Water Level Change (ft)				--	0.11	0.63	5.47	0.13	--	0.03	9.01
Max Water Volume Change (gal)				--	0.02	0.11	0.93	0.02	--	0.02	5.88

Notes:

Pumping started at 14:50 and stopped at 16:20

Unable to access MW-3.

MW-16S water levels influenced from earlier injection into MW-16S.

gal: gallons

gpm: gallons per minute

ft: feet

Injectability Test Field Monitoring Form

Abandoned Chemical Sales Facility (828105)
1600 Jay Street, Rochester, New York

Date	Time	MW-17I			
		Total Volume Injected (gal)	Injection Pressure (psi)	Flow Rate (gpm)	Notes
3/11/2014	17:30	0	0.0	3.250	Start gravity feed
	17:38	35	0.0	3.250	Well full
	17:48	45	0.0	1.750	
	18:00	55	0.0	1.500	
	18:10	60	0.0	1.500	Stop gravity feed
3/12/2014	9:00	85	1.0	2.100	Increase pump rate
	9:28	125	1.0	1.800	
	9:48	160	1.0	2.000	
	9:53	167	--	--	Stop pump, refill tank
	10:33	167	1.0	3.000	Increase pump rate
	10:35	173	1.0	3.000	Stop
	10:50	192	1.0	2.500	Restart pump
	11:00	232	1.0	2.500	
	11:05		--	--	Stop

Total Volume of Water Injected: 232 gal over 2 days including water needed to fill casing

Initial Casing Void Volume:

Initial DTW:	11.37	feet
Void Volume:	7.4	gal

Notes:
gal: gallons
psi: pounds per square inch
gpm: gallons per minute
DTW: depth to water

Injectability Test Water Level Monitoring Log

Abandoned Chemical Sales Facility (828105)
1600 Jay Street, Rochester, New York

Injection Well: MW-17I

Date	Time	Total Injected Volume (gal)	Flow Rate (gpm)	Depth to Water (ft)							
				MW-3	MW-9	MW-10	MW-10I	MW-11	MW-16S	MW-16I	MW-17S
3/11/2014	9:40	--	--	8.31	13.01	18.23	18.91	11.32	10.75	17.78	17.60
	16:25	*	--	--	12.90	17.60	15.44	11.19	3.19	--	17.59
	17:40	38	1.75	--	12.89	17.85	14.40	11.18	4.53	11.81	17.56
	18:18	65	--	--	12.86	17.98	14.86	11.16	4.91	11.90	17.55
3/12/2014	8:30	--	--	7.80	12.84	18.26	18.90	10.87	9.62	17.64	17.54
	9:30	65	2	7.79	12.60	17.62	12.43	10.86	9.65	7.96	17.54
	11:20	172	--	7.71	12.57	17.83	16.89	10.76	9.59	14.25	17.51
Max Water Level Change (ft)				0.09	0.27	0.64	6.47	0.11	0.03	9.68	0.03
Max Water Volume Change (gal)				0.02	0.05	0.11	1.10	0.02	0.02	6.32	0.02

Notes:
* - 90 gallons injected into MW-16I
Pumping started at 17:30 and stopped at 18:10 on 3/11/14
Pumping started at 9:00 and stopped at 11:05 on 3/12/14
gal: gallons
gpm: gallons per minute
ft: feet

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Appendix C

Injectability Study Memo

ARCADIS

ARCADIS of New York, Inc.
855 Route 146
Suite 210
Clifton Park
New York 12065
Tel 518 250 7300
Fax 518 250 7301
www.arcadis-us.com

MEMO

To:
Jason Pelton
NYSDEC
Division of Environmental Remediation
625 Broadway, 12th Floor
Albany, NY 12233-7017

Copies:
Joe White (NYSDEC)

From:
Daniel Lang

Date:
September 18, 2013

ARCADIS Project No.:
00266397.0000

Subject:
Abandoned Chemical Sales Facility
Treatability Study Results

Purpose

This technical memorandum presents the results of a targeted treatability study for the Abandoned Chemical Sales Facility (site). The evaluation is based on treatability study results and experience at similar sites with similar contaminants in fractured bedrock.

Introduction

The site consists of a 2.29 acre property at 1600 Jay Street. With the exception of a grassy area in the northern portion, the majority of the site is covered with an asphalt and gravel parking surface and an 11,000 square foot site building. The site is currently owned and operated by a heating, plumbing, and ventilation contractor. The New York State Department of Environmental Conservation (NYSDEC) listed the site as a Class 2 site in the New York State Registry of Inactive Hazardous Waste Disposal Sites in 2002 following a preliminary site assessment. The primary contaminants of concern at the site identified during the Remedial Investigation are tetrachloroethene (PCE), trichloroethene (TCE) and 1,1,1-trichloroethane (1,1,1-TCA) and their breakdown products [cis-l,2-dichloroethene (cis-l ,2-DCE), vinyl chloride, and chloroethane]. The record of decision (ROD) detailed the proposed remedy for the site, which includes targeted soil excavation and approximately three in-situ chemical oxidation events followed by enhanced bioremediation. The site is currently in the Remedial Design stage. Design phase studies are being implemented to evaluate potential remedial approaches and refine the remedial design.

Treatability Study

The ARCADIS Treatability Laboratory located in Durham, North Carolina, conducted a treatability study to evaluate the application of *in situ* chemical oxidation (ISCO) of chlorinated volatile organic compounds (CVOCs) at the site, including: trichloroethene (TCE), 1,1,1-trichloroethane (1,1,1-TCA), 1,1-dichloroethene (1,1-DCE), 1,1-dichloroethane (1,1-DCA), cis-1,2-dichloroethene (cis-1,2-DCE), tetrachloroethene (PCE), toluene and vinyl chloride (VC). Various approaches utilizing Klozür™ sodium persulfate ($Na_2S_2O_8$, CAS# 7775-27-1; 99.4% purity) as a potential groundwater remedy were studied, including using un-activated sodium persulfate and using sodium persulfate chemically activated by sodium hydroxide (NaOH). The ISCO bench-scale test was designed to meet the following objectives:

- Enable a quantifiable comparison of the effectiveness of ISCO using sodium persulfate,
- Approximate the oxidant and activator dosing requirements for a potential ISCO remedy,
- Evaluate the extent to which persulfate is capable of treating the chlorinated ethenes and ethanes in the site groundwater and
- Provide information to estimate the cost for implementing ISCO strategies at the site.

Provided below is a description of sample collection, sample homogenization requirements, materials and methods, results and discussion for the ISCO treatability study.

Treatability Study Sample Processing

In January 2013, the ARCADIS Treatability Laboratory received a shipment of 12.5 liters (L) of groundwater sample collected from monitoring well MW-10S in 2.5 L amber glass containers (level 1 processed and certified for use in semi-volatiles, pesticides and metals sampling) filled to zero headspace to preserve volatile compounds. A shipment of 3.8 kg of bedrock sample was also received in a 1 gallon (gal) plastic bucket. Field staff coordinated sample bottle selection and sample collection with the ARCADIS Treatability Laboratory to minimize CVOC volatilization and ferrous iron oxidation. Unpreserved soil and groundwater samples were shipped overnight to the ARCADIS Treatability Laboratory in coolers on wet ice, and subsequently stored at 4 degrees Celsius (ºC) until further processing.

Before study set up, a site bedrock sample was broken into smaller pieces with a hammer and passed through a sieve system ranging from 1 inch to 0.0234 inches in size (**Figure 1**). Rock that was retained in the 4.75 millimeters (mm) and 9.5 mm sieve sizes was placed in a 250 milliliter (mL) clear glass reactor bottle for use during ISCO treatability study. Immediately prior to conducting the treatability study, 7.5 L of site groundwater was placed into a 2.5 gallon (gal) plastic collapsible Cubitainer® (designed to collapse as liquid is dispensed), voided of air and hand mixed before being dispensed into treatment vessels via a cap fitted with Teflon tubing and a dispensary valve.

Oxidant Demand Pre-Testing

With the need to crush the bedrock sample in order for it to fit through the neck of the experimental test vessels, differences in surface area between different sizes of crushed sample were unavoidably introduced as an experimental variable. It was hypothesized that with a greater ratio of bedrock surface area to groundwater associated with smaller crushed sample sizes, an unrepresentatively high total oxidant demand (TOD) could potentially be observed. Therefore, prior to establishing the ISCO treatability study, a separate bench test was performed to determine possible differences in TOD between site groundwater only, and groundwater with two different sizes of crushed bedrock passing a 2 mm and 9.5 mm sieve. One test reactor was established per each of the three conditions (groundwater only and groundwater with two sizes of crushed bedrock) by combining 100 mL of site groundwater with 20 grams per liter (g/L) sodium persulfate and NaOH to adjust the pH to greater than 12 standard units (s.u.). For the two conditions with crushed site bedrock, 20 g of crushed bedrock material of either 2 mm or 9.5 mm in size was also added to each test reactor.

After each test vessel was constructed, they were tightly sealed, thoroughly mixed by hand with several inversions and left to equilibrate in a dark room at approximately 70 degrees Fahrenheit (ºF). Supernatant aliquots were collected from each of the three reactors at days 1, 2 and 5 after test set up and analyzed for TOD by measuring the residual persulfate anion concentration by iodometric titration with sodium thiosulfate (Kolthoff, I. M., and E. M. Carr, “Volumetric Determination of Persulfate in the Presence of Organic Substances”. 1953. Analytical Chemistry Vol. 25, No. 2, p. 298). When comparing the TOD results of the groundwater only condition and the 2 mm and 9.5 mm crushed bedrock conditions, it was determined that variations in bedrock particle size/surface area had little to no effect on TOD (**Figure 2**).

Treatability Study Materials and Methods

The ARCADIS Treatability Laboratory established the treatability study in 250 mL clear glass bottles with septa closures (level 1 processed and certified) filled to zero headspace to preserve volatile compounds (approximately 253 mL total zero headspace volume). Immediately prior to study set up, approximately 40 grams (g) of bedrock retained in the 0.187 inch sieve and 10 g of bedrock retained in the 0.375 inch sieve was weighed and placed into each of the experimental reactors to maintain homogeneity of bedrock sample size across the experiment (**Figure 3**). Sodium persulfate (Na2S2O8, CAS# 7775-27-1; 99.4% purity), was obtained from FMC Corporation and is commercially available as a Klozür™ product. In the treated vessels, two dosages of oxidant were established at 20 grams per liter (g/L) (referred to herein as “low dose”) and 40 g/L (referred to herein as “high dose”). The following list provides a key to the treatment identities established by the ARCADIS Treatability Laboratory during the ISCO treatability study:

1. Control Treatment (volatilization control, no oxidant added)

2. Sodium persulfate with ambient activation (oxidant low dosed and no activator)

3. Sodium persulfate with ambient activation (oxidant high dosed and no activator)

4. Sodium persulfate with alkaline activation (oxidant low dosed and chemically activated with high pH (> 12 s.u.) using NaOH)

5. Sodium persulfate with alkaline activation (oxidant high dosed and chemically activated with high pH (> 12 s.u.) using NaOH)

In all treatment reactors, oxidant chemical was added as dry reagent. The volume of NaOH solution required to reach the target pH of > 12 s.u. was determined prior to establishing the ISCO treatability study by performing a titration on a single replicate reactor using 1 molar (M) NaOH solution, and adding NaOH as a 10 M solution to the ISCO reactors during study set up. **Table 1** details the amendment additions to each baseline, control and treatment condition.

Four replicate bottles were established for each treatment and control condition to be sampled at 2, 5 and 7 days after study set up (**Figure 4**). One additional replicate test vessel from each treatment and control condition were established and reserved in the event that further analysis beyond the final sampling event (day 7) was warranted. After each test vessel was constructed, they were tightly sealed, thoroughly mixed by hand with several inversions and left to equilibrate in a dark room at approximately 70 ºF until the appropriate sample collection date. All study reactors were thoroughly mixed by hand to encourage adequate contact between the soil and groundwater fractions, thus more closely mimicking any pH buffering or contaminant sorption phenomena associated with the bedrock that may be encountered in the field. The experimental design for the ISCO treatability study is summarized in **Table 1**.

In addition to the treatment and control test vessels, duplicate baseline test vessels (A and B) consisting of site bedrock sample and groundwater homogenate only were established at the beginning and end of the study set up, respectively to quantify any losses of CVOCs during study set up. After an equilibration period of twenty four hours, the two baseline reactors were destructively sampled on day 1 (time zero) by performing in-lab testing for pH and ferrous iron, and preparing liquid aliquots to submit to Con-Test Analytical Laboratories of East Longmeadow, Massachusetts, for volatile organic compounds (VOCs) by United States Environmental Protection Agency (USEPA) Method 8260. The ARCADIS Treatability Laboratory measured pH with an Accumet AR50 pH meter, and determined ferrous iron concentrations using a HACH DR/890 colorimeter by Method 8146.

At each of the predetermined sampling events (2, 5 and 7 days after study set up), one replicate test vessel from each treatment and control condition was destructively sampled by performing in-lab testing for pH, TOD and ferrous iron, and preparing liquid aliquots to submit to Con-Test Analytical Laboratories of East Longmeadow, Massachusetts, for VOCs by USEPA Method 8260. The ARCADIS Treatability Laboratory determined the TOD by measuring the residual persulfate anion concentration by iodometric titration with sodium thiosulfate (Kolthoff, I. M., and E. M. Carr, “Volumetric Determination of Persulfate in the Presence of Organic Substances”. 1953. Analytical Chemistry Vol. 25, No. 2, p. 298).

Treatability Study Results

Figure 5 illustrates the results of the TOD analysis throughout the ISCO treatability study, calculated on a bedrock weight basis as the majority of oxidant demand is in the soil phase. These results suggest a moderate oxidant demand that increased over time. The percent utilization of oxidant was similar between all treatment conditions, at: 13-18% in ISCO-2, 16-18% in ISCO-3, 11-17% in ISCO-4 and 12-17% in ISCO-5.

The VOC analytical results from Method 8260 analysis are detailed in **Table 2**. Results can be summarized as follows:

The ambient activated low persulfate dose treatment (ISCO-2) reduced cis-1,2-DCE by 52% from a baseline average of 60,000 to 29,000 µg/L by the end of the ISCO treatability test (Day 7) (**Figure 6**). PCE concentrations were reduced by 48% from a baseline average of 3,250 µg/L to 1,700 µg/L by Day 7 (**Figure 7**). Concentrations of TCE were reduced by 62% from a baseline average of 47,500 to 18,000 µg/L at Day 7 (**Figure 8**). 1,1-DCE and toluene were effectively reduced to below the detection limit of 500 µg/L by day 2 from a baseline average of 3,300 µg/L and 3,900 µg/L, respectively, and remained below the detection limit through the rest of the ISCO treatability study. 1,1-DCA and 1,1,1-TCA concentrations remained comparable to the duplicate baseline results throughout the experimental interval, and no significant treatment observed by Day 7. Several analytes that were not detected in the duplicate baseline samples were produced as byproducts by Day 7, including: trans-1,2-DCE (3,500 µg/L) and 1,1,2,2-TCA.

The ambient activation with a high persulfate dose treatment (ISCO-3) performed similar to ISCO-2, and exceeded COC concentration reductions for cis-1,2-DCE, 1,1-DCE, PCE, toluene, and TCE compared to ISCO-2. By Day 7, cis-1,2-DCE concentrations were reduced by 73% from a duplicate baseline average of 60,000 µg/L to 16,000 µg/L, while 1,1-DCE concentrations were treated from a baseline average of 1,300 µg/L to below the analytical reporting limit of 500 µg/L (**Figure 6**). 1,1-DCE and toluene were effectively reduced to below the detection limit of 500 µg/L by day 2 from a baseline average of 3,300 µg/L and 3,900 µg/L, respectively, and remained below the detection limit through the rest of the ISCO treatability study. PCE concentrations were reduced by 69% from a baseline average of 3,250 µg/L to 1,000 µg/L by Day 7 (**Figure 7**), while TCE concentrations were reduced by 84% from a baseline average of 47,500 µg/L to 7,200 µg/L by Day 7 (**Figure 8**). 1,1-DCA and 1,1,1-TCA concentrations remained comparable to the duplicate baseline results throughout the treatability test, and no significant treatment observed by Day 7. Several analytes that were not detected in the baseline samples were produced as byproducts by Day 7, including: trans-1,2-DCE (2,800 µg/L) and 1,1,2,2-TCA.

The alkaline activated treatments (ISCO-4 and ISCO-5) proved to be the most effective for contaminant oxidation, showing reductions in cis-1,2-DCE from a baseline average of 60,000 µg/L to 12,000 (80% reduction) and 2,400 µg/L (96% reduction) in ISCO-4 and ISCO-5, respectively, by Day 7 (**Figure 6**). Alkaline activation was the only treatment condition to reduce 1,1-DCA concentrations from a baseline average of 3,300 µg/L to 1,800 µg/L (45% reduction) and 1,500 µg/L (54% reduction) in ISCO-4 and ISCO-5, respectively. When compared to the other treatment conditions evaluated, alkaline activation was also the only treatment condition to most significantly reduce 1,1,1-TCA concentrations from a baseline average of 45,500 µg/L to 38,000 µg/L in ISCO-4 (17% reduction) and 40,000 µg/L in ISCO-5 (12% reduction). PCE concentrations were reduced from a duplicate baseline average of 3,250 µg/L to 1,300 µg/L in ISCO-4 at Day 7 (60% reduction) and 660 µg/L in ISCO-5 at Day 7 (80% reduction) (**Figure 7**). TCE concentrations were reduced from a baseline average of 47,500 µg/L to 4,400 µg/L (91% reduction) in ISCO-4, and 760 µg/L (99% reduction) in ISCO-5 by Day 7 (**Figure 8**). Both alkaline activation treatment conditions showed complete treatment of 1,1-DCE and toluene to below the detection limit of 500 µg/L by Day 2 from a baseline average of 3,300 µg/L and 3,900 µg/L, respectively, and remained below the detection limit through the rest of the ISCO treatability study. Trans-1,2-DCE was not detected in the duplicate baseline samples, but was produced as a byproduct in both alkaline activated treatment conditions (ISCO-4 concentrations increased to 1,800 µg/L by Day 7, and the ISCO-5 Day 2 sample had 2,600 µg/L but was not detected in the Day 7 sample).

Treatability Study Conclusions

The alkaline (base) activation high persulfate dose (ISCO-5) was more effective at reducing VOC concentrations than the ambient activation high persulfate dose test (ISCO-3) or the low persulfate dose tests (ISCO-2 and ISCO-4). At day seven of the ISCO-5 test, cis-1,2-DCE concentrations were reduced by 96%, PCE by 80%, TCE by 99%, 1,1-DCE and toluene by greater than 99%. However, oxidation of the chlorinated ethanes was not as effective. The 1,1-DCA concentration was reduced by 54% and the 1,1,1-TCA concentration was reduced by 12%.

Figure 1. Photograph of the Sieve System Used in Treatability Study
Abandoned Chemcial Sales Facility
Rochester, New York

Figure 2

ISCO Pre-Test: Percent Oxidant Loss

Abandoned Chemical Sales Facility Treatability Study

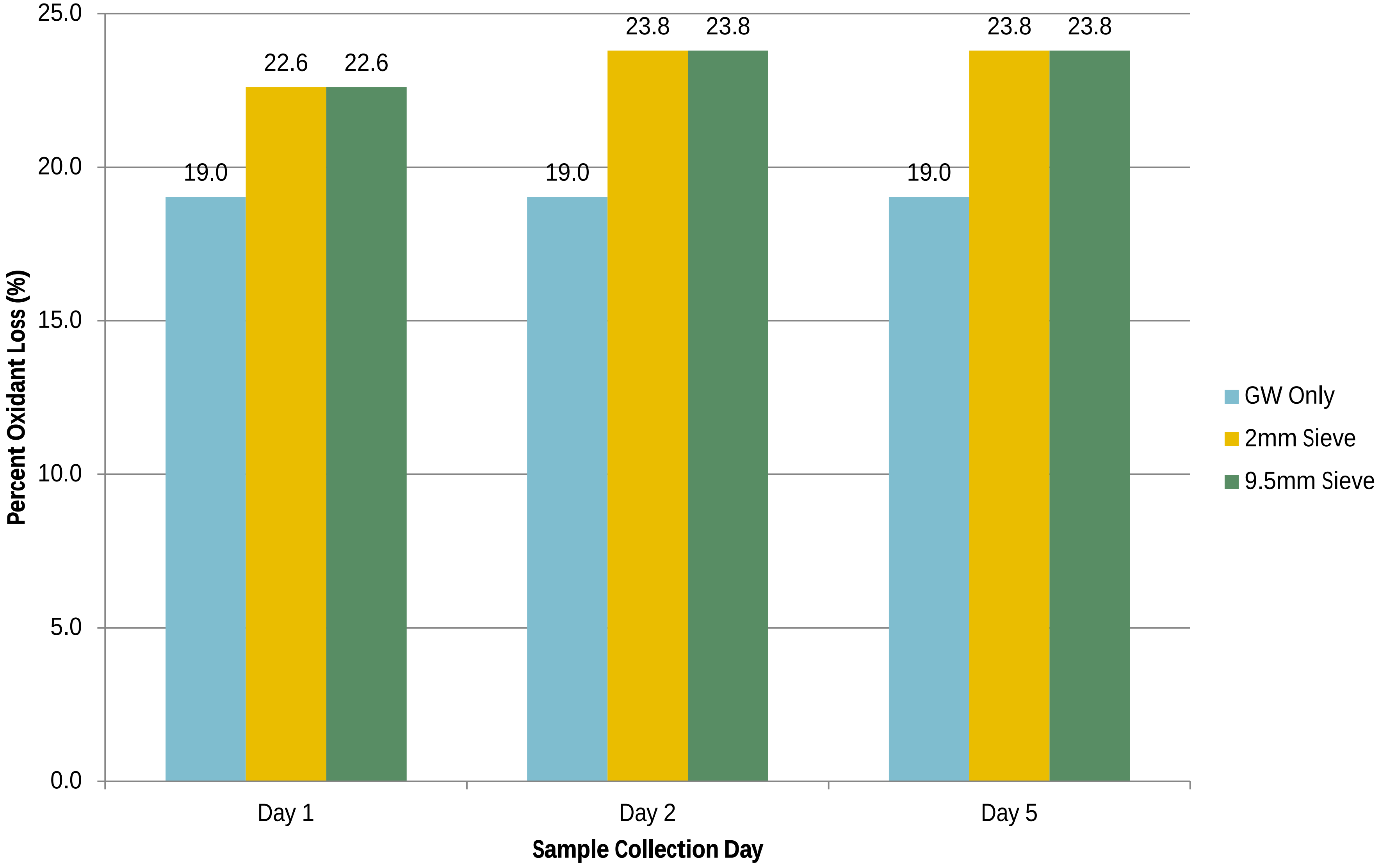

Figure 3. Photograph of the Experimental Reactors Used in Treatability Study
Abandoned Chemcial Sales Facility
Rochester, New York

Figure 4. Photograph of the Replicate Bottles for Each Treatment and Control Condition
Abandoned Chemcial Sales Facility
Rochester, New York

Figure 5
Persulfate Utilization per Treatment Condition
Abandoned Chemical Sales Facility Treatability Study

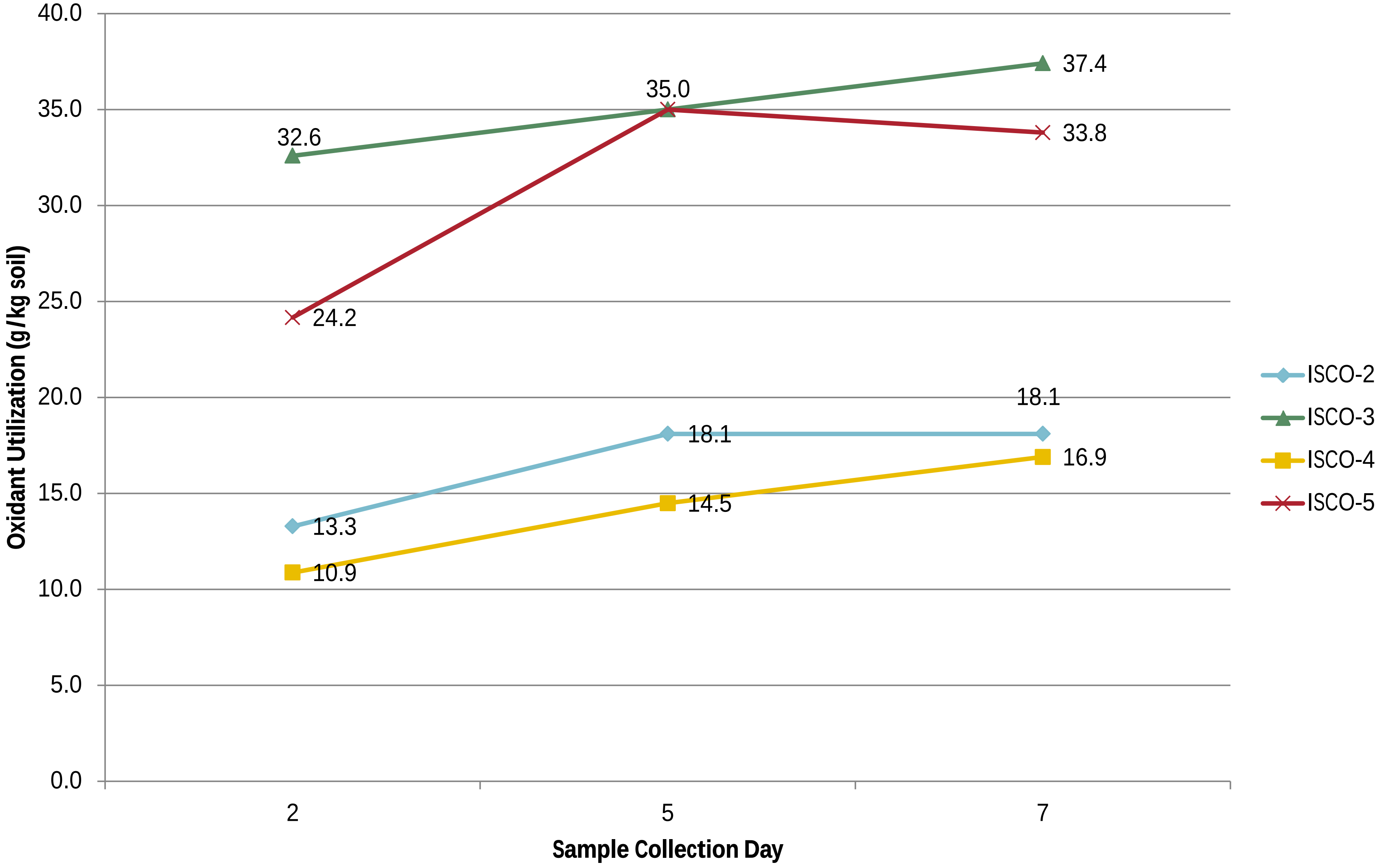

Figure 6
Aqueous cis-1,2-Dichloroethylene Results per Treatment Condition
Abandoned Chemical Treatability Study

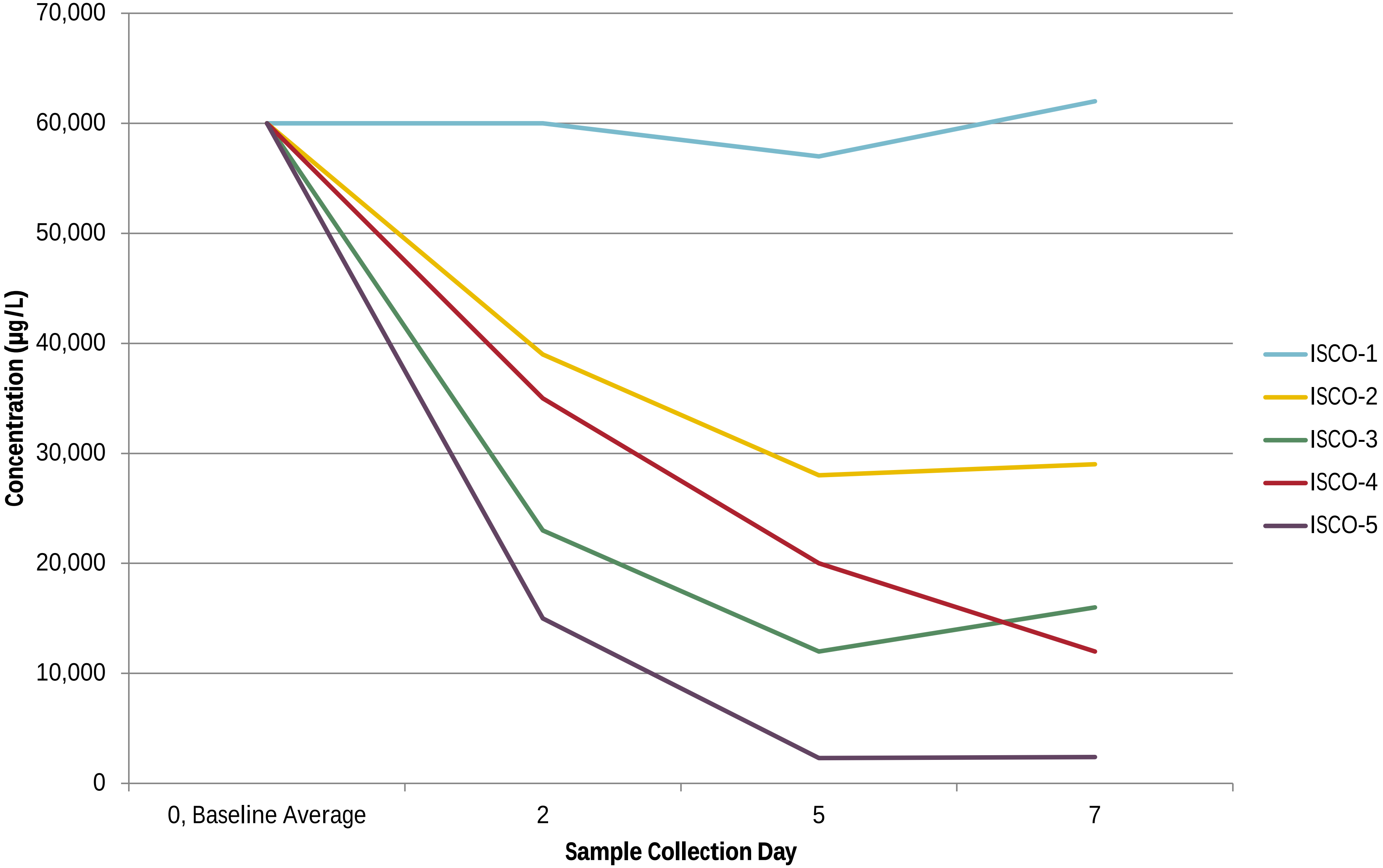

Figure 7
Aqueous Tetrachloroethylene Results per Treatment Condition
Abandoned Chemical Sales Facility Treatability Study

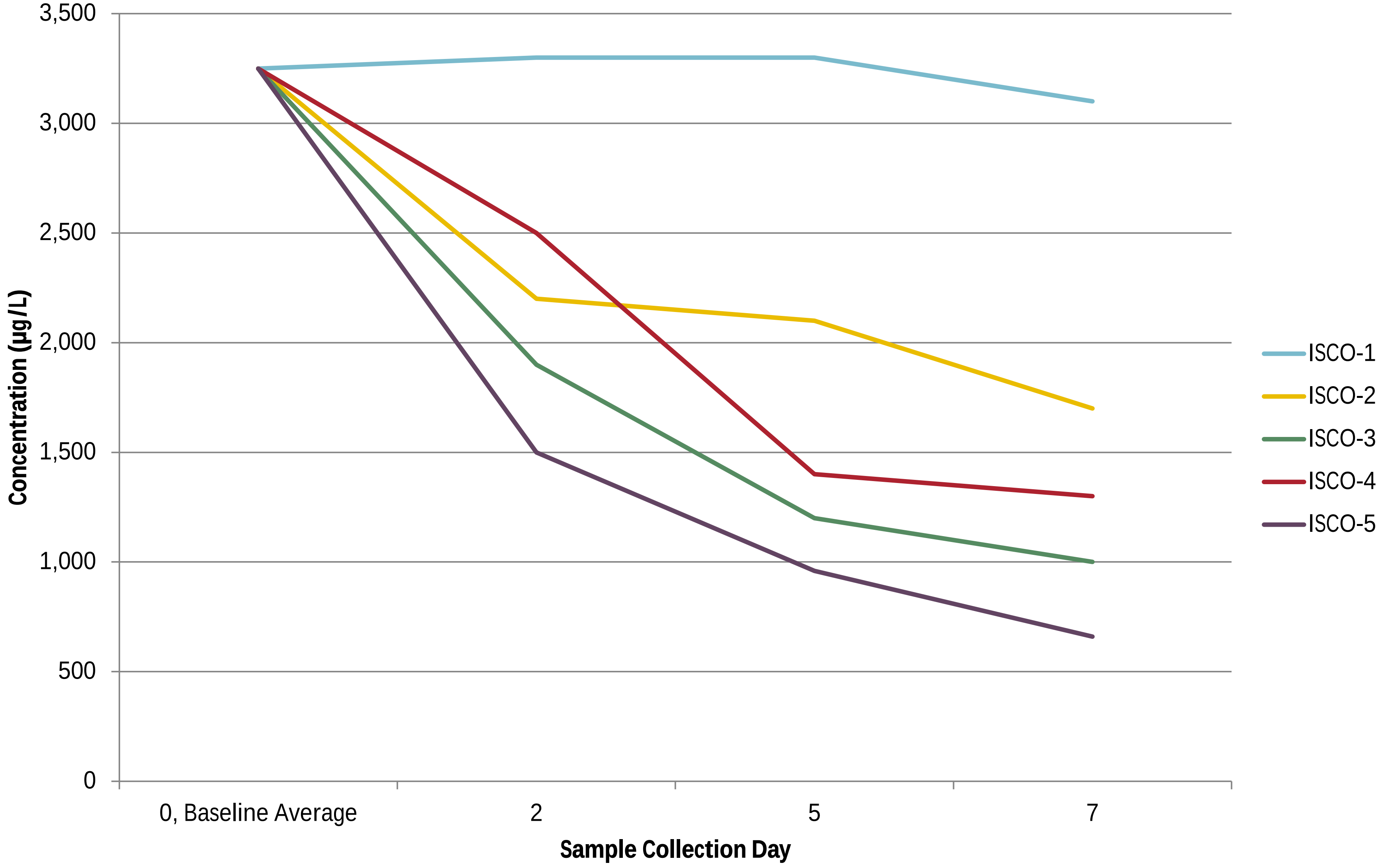

Figure 8
Aqueous Trichloroethylene Results per Treatment Condition
Abandoned Chemical Sales Facility Treatability Study

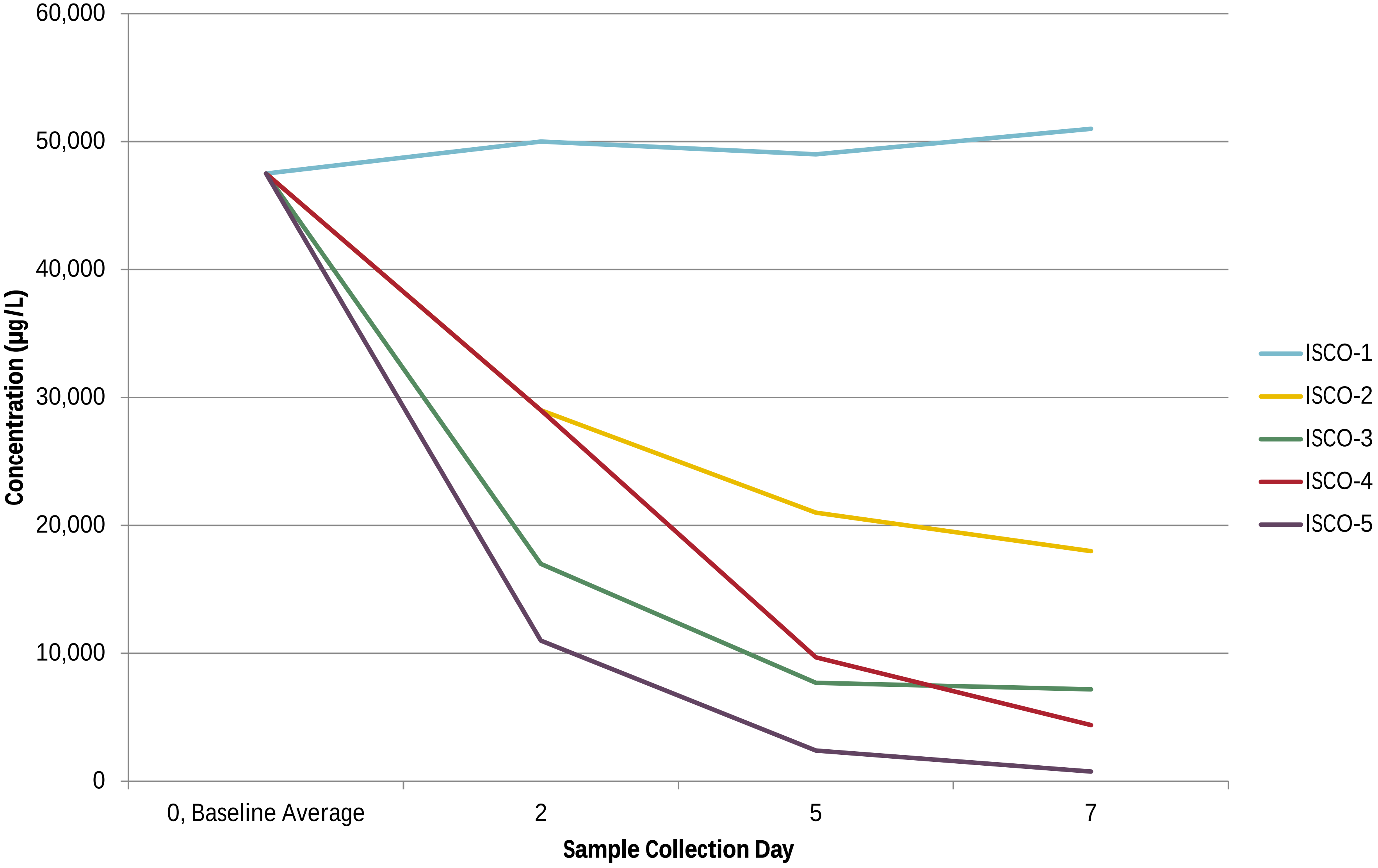

Table 1. In-Situ Chemical Oxidation Treatability Study Design
Abandoned Chemcial Sales Facility
Rochester, New York

Treatment No.	Activation	Sodium Persulfate Concentration (g/L)	Activation	Elapsed time (days)			
				Duplicate, Time Zero	**2**	**5**	**7**
0	Duplicate Baseline	0	None	8260, pH, Fe^{2+}	NP	NP	NP
1	Control	0	None	NP	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}
2	Ambient Low	20	None	NP	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}
3	Ambient High	40	None	NP	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}
4	Alkaline Low	20	NaOH >12 s.u.	NP	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}
5	Alkaline High	40	NaOH >12 s.u.	NP	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}	8260, pH, TOD, Fe^{2+}

General Notes:

1. All samples were analyzed by Con-Test Analytical Laboratories of East Longmeadow, Massachusetts, for the following:
    Volatile organic compounds (VOCs) by United States Environmental Protection Agency (USEPA) Method 8260
2. Aqueous pH was "field tested" using Accumet AR50 pH meter or equivalent.
3. Dissolved (ferrous) iron was "field tested" using HACH DR/890 colorimeter by Method 8146.
4. Residual persulfate anion concentration (as total oxidant demand) was measured using iodiometric titration with sodium thiosulfate.

Acronyms and Abbreviations:

NP = Not performed
g/L = grams per liter
Fe^{2+} = ferrous iron
TOD = total oxidant demand
NaOH = sodium hydroxide
s.u. = standard units

Table 2. Treatability Study Analytical Results
Abandoned Chemcial Sales Facility
Rochester, New York

Sample ID and Amendment	Method	Volatile Organic Compounds by Method 8260 GC/MS (µg/L)																			
	Analyte	1,1-Dichloroethane		1,1-Dichloroethylene		cis-1,2-Dichloroethylene		trans-1,2-Dichloroethylene		1,1,2,2-Tetrachloroethane		Tetrachloroethylene		Toluene		1,1,1-Trichloroethane		Trichloroethylene		Vinyl Chloride	
	Day	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Baseline-A	0	**3,200**		**1,800**		**59,000**		<500	ND	<250	ND	**3,100**		**3,800**		**43,000**		**45,000**		<1,000	ND
Baseline-B	0	**3,400**		**800**		**61,000**		<500	ND	<250	ND	**3,400**		**4,000**		**48,000**		**50,000**		**1,100**	
ISCO-1	2	**3,400**		**1,500**		**60,000**		<500	ND	<250	ND	**3,300**		**4,000**		**47,000**		**50,000**		**1,100**	
Control	5	**3,300**		**2,200**		**57,000**		<500	ND	<250	ND	**3,300**		**4,000**		**44,000**		**49,000**		<1,000	ND
No Amendments	7	**3,500**		**840**		**62,000**		<500	ND	<250	ND	**3,100**		**3,400**		**49,000**		**51,000**		<1,000	ND
ISCO-2	2	**3,300**		<500	ND	**39,000**		**2,200**		<250	ND	**2,200**		<500	ND	**45,000**		**29,000**		<1,000	ND
Ambient Activation	5	**3,200**		**1,100**		**28,000**		**3,200**		**260**		**2,100**		<500	ND	**45,000**		**21,000**		<1,000	ND
Low Persulfate Dose	7	**3,400**		<500	ND	**29,000**		**3,500**		<250	ND	**1,700**		<500	ND	**48,000**		**18,000**		<1,000	ND
ISCO-3	2	**3,300**		<500	ND	**23,000**		**2,300**		**280**		**1,900**		<500	ND	**44,000**		**17,000**		<1,000	ND
Ambient Activation	5	**3,000**		<500	ND	**12,000**		**2,100**		**380**		**1,200**		<500	ND	**41,000**		**7,700**		<1,000	ND
High Persulfate Dose	7	**3,200**		<500	ND	**16,000**		**2,800**		<250	ND	**1,000**		<500	ND	**43,000**		**7,200**		<1,000	ND
ISCO-4	2	**2,700**		<500	ND	**35,000**		**540**		<250	ND	**2,500**		<500	ND	**46,000**		**29,000**		<1,000	ND
Base Activation	5	**2,400**		<500	ND	**20,000**		**2,100**		<250	ND	**1,400**		<500	ND	**41,000**		**9,700**		<1,000	ND
Low Persulfate Dose	7	**1,800**		<500	ND	**12,000**		**1,800**		<250	ND	**1,300**		<500	ND	**38,000**		**4,400**		<1,000	ND
ISCO-5	2	**2,200**		<500	ND	**15,000**		**2,600**		<250	ND	**1,500**		<500	ND	**41,000**		**11,000**		<1,000	ND
Base Activation	5	**1,300**		<500	ND	**2,300**		<500	ND	<250	ND	**960**		<500	ND	**40,000**		**2,400**		<1,000	ND
High Persulfate Dose	7	**1,500**		<500	ND	**2,400**		<500	ND	<250	ND	**660**		<500	ND	**40,000**		**760**		<1,000	ND

General Notes:

1. Data reflected in this table has not yet been validated and is for discussion purposes only.
2. **Bolded** values indicate a detection above the reporting limit (RL).
3. Analytical data will be reported by the laboratories if a detected analytical result meets the minimum identification criteria and the result is less than the RL but greater than the method detection limit (MDL) the result will be reported and qualified as estimated (J).
4. Samples were analyzed by Con-Test Analytical Laboratories of East Longmeadow, Massachusetts, for the following:
   Volatile organic compounds (VOCs) by United States Environmental Protection Agency (USEPA) Method 8260

Acronyms and Abbreviations:

Q = Laboratory Qualifiers
µg/L = micrograms per liter, or parts per billion (ppb)

Laboratory Qualifiers and Descriptors:

ND = Analyte was analyzed for but not detected at the reporting limit (RL) shown.
< = Indicates that the analyte was not detected above the RL shown.