Zero-Valent Iron Permeable Reactive Wall Treatability Test and Design Report
Former Miller Container Plant
Town of Volney, NY

Prepared for:

Miller Brewing Company
3939 W. Highland Boulevard
Milwaukee, WI 53201-8322

Prepared by:

URS SMAART Team
10200 Innovation Drive, Suite 500
Milwaukee, WI 53227

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SUMMARY

Miller Brewing
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located in Volney, Nev
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Constituents detected - Year 4
1,1-Dichloroethylene 33 µg/L
1,1-Dichloroethane 17 µg/L
* 1,1,1-Trichloroethane 127 µg/L (TCA)
Trichloroethylene 6 µg/L
cis-1,2-Dichloroethylene 62 µg/L
* Tetrachloroethylene 98 µg/L (PCE)

URS completed the bench-scale and full-scale p and confirmed that zero-valent iron (ZVI) can effectively treat the target constituents in the groundwater at the site. During bench-scale testing, concentrations of tetrachloroethylene (PCE) and 1,1,1 trichloroethane (TCA) were reduced about 92% after five hours of contact with ZVI. The pilot test showed that pressure jetting successfully emplaced ZVI to a depth of 80 feet. The emplaced iron reduced the concentrations of PCE by 76% to 96%, while TCA concentrations decreased by as much as 97%.

URS prepared a brief preliminary remediation design using zero-valent iron PRWs. The intent of the full-scale system is to provide containment, and reduce contaminant concentrations. The PRWs will be placed perpendicular to the direction of groundwater flow, across the contaminant plumes. Treatment of groundwater occurs by reductive dechlorination as groundwater passes through the PRW. The PRWs, coupled with natural attenuation, will significantly reduce the migration of contaminants to the City of Fulton municipal well field.

Our preliminary design proposes two PRWs for the Northern Operable Unit (NOU) groundwater. The PRWs will be constructed of V-shaped panels of ZVI injected into the subsurface on 10 to 20 foot centers.

PRW-1 is 125 feet long, and will be placed from about 10 to 60 feet below ground surface. It is located at the northwest edge of the Taylor Property. PRW-1 will significantly reduce concentrations of target constituents in the Taylor Property plume that are affecting the

City of Fulton municipal well field. PRW-1 may reduce concentrations enough for MBCo to stop the operation of the existing pump and treat system, and the municipal well field water treatment system.

PRW-2 is 200 feet long and will be placed from about 65 to 80 feet below ground surface. It will be located just west of recovery well RW-2. PRW-2 will address deeper zone contamination originating from source areas up gradient of the mid-site plume. Addressing the up gradient source areas will reduce the migration of source area contamination, and lower the potential for the mid-site plume to increase in size. Natural attenuation will be evaluated to address the leading edge of the mid-site plume near RW-1. PRW-1 will act to provide some secondary containment, down gradient of the mid-site plume.

We also propose one PRW to address residual groundwater contamination in the Southern Operable Unit (SOU). The source area soils in the SOU were remediated using soil vapor extraction. Residual contamination in SOU groundwater plume will be addressed by PRW-3.

PRW-3 is 215 feet long and will be placed from about 20 to 70 feet below ground surface. It will be located just west of recovery wells RW-8 and RW-9. PRW-3 will address intermediate and deeper zone contamination originating from the source area up gradient of the SOU plume. Addressing the groundwater plume near the up gradient source area will reduce the migration of source area contamination, and lower the potential for the SOU plume to increase in size.

In summary, the bench-scale test and full-scale pilot test for ZVI PRWs were successful, and show that ZVI PRWs will effectively treat groundwater at the Former Miller Container Plant site. URS completed a brief preliminary design for a groundwater treatment system consisting of three PRWs. The proposed ZVI PRW system will significantly decrease the migration of contaminants to the City of Fulton well field, and may allow MBCo to shut down the existing pump and treat system and the water treatment system at the City of Fulton municipal well field. We anticipate the PRW system will result in a significant cost savings to MBCo over the life of this project. URS therefore recommends proceeding with this technique to enhance remediation at this site.

1.0 INTRODUCTION

1.1 Purpose and Scope of Work

Miller Brewing Company (MBCo) requested that URS review technologies to reduce overall project costs and enhance remediation at the Former Miller Container Plant site, located in Volney, New York. Based on URS's preliminary technology review, zero-valent iron (ZVI) permeable reactive walls (PRWs) in conjunction with monitored natural attenuation were recommended as a promising cost effective alternative to the existing pump and treat system. Miller subsequently contracted with URS to conduct bench-scale tests and full-scale pilot tests to further evaluate whether ZVI PRWs would be effective at the Former Miller Container Plant site. If the bench and pilot tests were successful, URS was contracted to prepare a brief preliminary PRW design.

URS's scope of services included the following:

1.1.1 Bench Tests

Conduct batch and column bench-scale treatability tests to evaluate the effectiveness of zero-valent iron PRWs as a remediation strategy, and provide design parameters. The bench test consisted of the following:

Batch Testing:

- Preselect reactive media

Column Testing:

- Determine reactivity of the selected zero-valent iron;
- Determine hydraulic performance of the selected iron;
- Evaluate the ability of the selected iron to maintain its reactivity; and
- Identify degradation by-products generated by the selected iron.

1.1.2 Pilot Testing:

Conduct a full-scale pilot test at the site to further confirm the effectiveness of zero-valent iron under full-scale site specific conditions. Objectives of the pilot test were to:

- Confirm the effectiveness of ZVI for treatment of the target constituents;
- Confirm bench test design parameters;
- Confirm the effectiveness of iron placement at depth using pressure jetting;
- Determine the productivity of high pressure jetting emplacement of ZVI.

1.1.3 Preliminary Design of the Proposed Full-Scale PRW System:

If the bench and pilot tests were successful, URS was contracted to develop a brief preliminary design for a full-scale PRW system. This full-scale design consists of the following:

- Locate the PRW;
- Configure the PRW;
- Define PRW dimensions;
- Identify iron emplacement technique;
- Evaluate iron injection amendments; and
- Evaluate PRW longevity.

1.2 Site Location

The Former Miller Container Plant site is located in Town of Volney, Oswego County, New York. The site is located about 1,200 feet southeast of the City of Fulton, New York municipal boundary, about 1,000 feet northeast of the Oswego River and about 900 feet south of New York State Route 481. A site location map is provided in Figure 1-1. Figure 1-2 shows the site features.

A detailed description of the environmental investigation and remedial activities for the Former Miller Container Plant is provided in the *Remedial Investigation Report* (Malcolm Pirnie, July 1993), and *Remedial Design Report* (EarthTech, August 1996). The description that follows summarizes the site characteristics and previous investigation relevant to the proposed PRW design.

1.3 Site History

A spill containment tank was found to be leaking at the time of its excavation in the Spring of 1986. An interim remedial action consisting of a pump and treat system with three recovery wells, RW-1, RW-2, and RW-3 (Figure 1-2) began operation on June 27, 1988. Underground storage tanks were discovered on the Taylor property in January 1990, and removed May 1990. Samples from the soil collected from beneath the tanks detected volatile organic compounds (VOCs). A soil gas survey conducted during 1990 identified additional areas of potential contamination at the southern portion of the Former Miller Container Plant facility. A remedial investigation (RI) was conducted to determined the nature and extent of soil and groundwater contamination at the site. Generally, contamination at the site coincides with locations where it is believed chlorinated solvents and, to a lessor extent, petroleum hydrocarbons, were handled, used, and/or stored based on knowledge of past operations at the site. The RI also identified a plume of groundwater contaminated with VOCs impacting the City of Fulton municipal well field. The Remedial Investigation (RI) Report was submitted in July of 1993.

MBCo subsequently expanded the pump and treat system at the site. The expanded pump and treat system became operational on February 26, 1997, and addressed groundwater contamination in both the Northern and Southern Operable Units. To date, Miller has operated the pump and treat for about 12 years. In addition to the pump and treat system, Miller also operates a treatment system for water produced by the City of Fulton municipal well field. MBCo also operated a soil vapor extraction system to provide source control of the soils in the Southern Operable Unit.

After implementation of the existing pump and treat system, interested parties identified several concerns about the performance of the system. First, the existing pump and treat system has very high operation and maintenance costs. Second, the State of New York is concerned that the groundwater recovery portion of the system may not effectively contain contamination at parts of the site based on performance monitoring data. The City of Fulton is concerned that the pump and treat system may reduce the water available to the City of Fulton municipal well field. Given the inherently low water production by the well field, they believe any impact is significant.

1.4 Site Geology and Hydrogeology

A plan view of the site showing the locations of the geologic cross-sections, and the proposed PRWs, is presented in Figure 1-3. The corresponding geologic cross-sections of the site are shown in Figures 1-4, 1-5, and 1-6.

The surficial soils at proposed location of PRW-1 (Section A-A') consist of sand and silt to a depth of about 40 feet, transitioning to a more permeable sand and gravel zone with some cobbles from 40 to 60 feet. The surficial soils midway between PRW-1 and PRW-2 (Section B-B'), consist of sand and silt with relatively extensive clay lenses, up to 10 feet thick, to 50 feet below ground surface. The clay is described as very dense and compact with a low moisture content. Sand and gravel underlie the sand and silt to about 75 feet below ground surface. A clay zone from 15 to 35 feet thick underlies the sand and gravel zone. The surficial soils at PRW-2 (Section C-C') consist of fill from 5 to 12 feet below ground surface, underlain by sand and silt with discontinuous sand and gravel lenses to a depth of about 70 feet below ground surface. From about 70 to 80 feet below ground surface is a more permeable sand and gravel zone. The surficial soils at PRW-3 (Section C-C') are similar to those at PRW-2 except that there are no sand and gravel lenses. A confining layer, interpreted as a very dense and compact lodgement till and bedrock, underlies the surficial units at the site. The RI identified the lodgement till as having low permeability that make it an effective barrier to groundwater migration between the till and bedrock, where it is present. The bedrock is reported to have a low fracture content making it a poor water bearing unit.

The surficial deposits at the site exhibit variable depths and thicknesses. Moving across the site from the Former Miller Container Plant building to the Oswego River (roughly in the direction of groundwater flow), the surficial soils at the site increase from a depth of about 18 feet near the facility to a depth of about 82 feet near recovery well RW-2D. The depth of the surficial unit then decreases to a depth of about 38 feet near a till/bedrock ridge at the Taylor Property boundary, then increases to a depth of about 64 feet near the City of Fulton municipal well field.

Groundwater flow in the surficial soils may be divided into two separate zones. These zones include shallow zone groundwater flow in the generally less permeable sand and silt, and deep zone groundwater flow in the more permeable sand and gravel underlying the shallow sand

and silt zone. Based on the generally higher permeability in the deep sand and gravel zone. It is believed that preferential flow of the groundwater likely occurs in the deep sand and gravel zone. The two surficial zones appear to be hydraulically connected. The dense till underlying the surficial zones acts as an aquaclude that prevents the migration of contaminants downward from the surfical zones into bedrock.

Groundwater at the site flows roughly from east to west, from the facility toward the Oswego River and the City of Fulton municipal well field (Figure 1-7). The production wells at the municipal well field are screened in and produce groundwater from the surficial aquifer only. The deepest production well is screened to a depth of [redacted] The water table in the surficial unit at the well field is about 10 feet bgs. Drawdown of the production wells is limited by the thin saturated thickness, allowing for pumps and head above the pumps (roughly 25 feet), the highest drawdown the production wells could exhibit is about 30-feet. Given that the formation in the area of the production wells (directly adjacent to the Oswego River) is also highly permeable, we anticipate a somewhat limited cone of depression around the production wells. The impact of the municipal well field on groundwater flow rates, and velocities is therefore expected to be limited somewhat to the general vicinity of the municipal well field. Based on historical information and discussions with the operator of the municipal well field, the Oswego River, acts as both a gaining and losing boundary, depending on fluctuations in groundwater levels and surface water elevations in the river.

Based on the RI slug test data for the site, the permeability of the groundwater formation near PRW-1 ranges from about 2×10^{-2} cm/sec to about 9×10^{-4} cm/sec. The permeability of the formation midway between PRW-1 and PRW-2 ranges from about 8×10^{-3} cm/sec to about 2×10^{-5} cm/sec, the permeability near PRW-2 ranges from about 6×10^{-3} cm/sec to about 9×10^{-4} cm/sec, and the permeability near PRW-3 ranges from about 4×10^{-3} cm/sec to about 4×10^{-6} cm/sec. The hydraulic conductivity appears to increase somewhat near the Oswego River. The variability of the hydraulic conductivity is typical for heterogeneous sediments such as those found at the Former Miller Container Plant site.

Split-spoon samples of soil from the locations of the PRWs were collected and during the preliminary evaluation and tested for grain size distribution. These samples were taken from representative depths, and were sent to Giles Engineering Associates for grain size distribution testing. The results of the grain size distribution test (Appendix A) show the soils to be silty sand to sandy silt with some gravel. The permeability of the samples based on the D_{10} fraction is about 3.1 x 10^{-2} cm/sec at PRW-1, and 1.4 x 10^{-3} cm/sec at PRW-2. This compares favorably to the permeabilites based on the slug test data discussed directly above.

The hydraulic gradient at the site under natural conditions (no groundwater recovery) is shown on the potentiometric surface map (Figure 1-7). Based on historical water level measurements at the site prior to the installation of the groundwater recovery wells (12/26/86), the local gradient near proposed PRW-1 is about 0.008 ft/ft. Midway between PRW-1 and PRW-2 the gradient is about 0.008 ft/ft. While near proposed PRW-2, where the gradient is flatter, the gradient is about 0.003 ft/ft. The natural gradient at PRW-3 could not be determined with the data available.

Average velocities were computed using the geometric mean of the hydraulic conductivities at the various proposed PRW locations, and the potentiometric surface data. Average velocities near PRW-1 are about 0.42 feet/day, while the average velocity at PRW-2 is about 0.13 ft/day. Assuming PRW-3 has the same as the gradient as PRW-2, the velocity at PRW-3 would be about 0.02 ft/day. Midway between PRW-1 and PRW-2 the average velocity is about 0.019 ft/day. Figure 1-4, Figure 1-5 and Figure 1-6 show the velocity profiles at the proposed locations of PRW-1, midway between PRW-1 and at PRW-2 and PRW-3. Additional data will be collected during the design phase to confirm the gradient and velocity at the PRW locations.

1.5 Groundwater Quality

Groundwater at the site exhibits elevated concentrations primarily of PCE, TCA. Figure 1-8 shows the dissolved PCE and TCA plumes Table 1-1 summarizes the PCE and TCA data. The plumes are generally elongated from their potential source areas toward existing groundwater recovery wells, the City of Fulton municipal well field and the Oswego River. Contamination continues to be detected at the municipal well field.

In addition to data on the contaminants of concern, supplemental data was collected for URS's preliminary feasibility evaluation for zero-valent iron PRWs. The data collected include dissolved metals (calcium, iron, magnesium, manganese, potassium, and sodium), ammonia, total kjeldahl nitrogen, nitrite/nitrate, sulfate, chloride and alkalinity. These data are summarized in Table 1-2, and suggest groundwater at the site is relatively hard (high calcium and magnesium).

2.0 TREATMENT TECHNOLOGY DESCRIPTION

Many chlorinated organic compounds can be degraded to harmless byproducts when exposed to zero-valent metals such as iron. The reactions of zero-valent metals have generated considerable interest as a useful innovative treatment system for degrading contaminants in groundwater. A literature search on the subject has been conducted (Gillham and O'Hannesin, 1994). A variety of innovative treatment schemes have been proposed, including the reactive wall and funnel and gate systems, the most notable proposed by Gillham and others in 1992, 1993, and 1994. These treatment systems are constructed by excavating a trench across the contaminant plume, perpendicular to the direction of groundwater flow, and filling the trench with iron. Groundwater flows through the trench due to normal groundwater gradients. Select chlorinated solvents in the groundwater are reduced as they come in contact with the iron in the trench. In a funnel and gate system, a slurry wall or other impermeable barrier is used to funnel groundwater through a relatively small permeable wall, or gate, filled with iron.

A number of researchers have studied the reactions of chlorinated solvents with iron and other zero-valent metals. The reaction mechanisms are still not completely understood, but are similar to the reaction of iron with oxygen to form rust. The overall process can be represented by the following reaction:

$$Fe^0 + H_2O + RCl \rightarrow Fe^{+2} + OH^- + RH + Cl^-$$

Compounds with multiple chlorine, such as TCE, are generally reduced in steps so that all the dichloroethene isomers and then vinyl chloride are formed (Orth and Gillham, 1996). This appears to be only one of the mechanisms since vinyl chloride is normally only formed to a limited extent (i.e., 1 to 5% of initial TCE concentrations) and it too can be dehalogenated by the iron to yield chloride ions and ethene.

Other zero-valent metals undergo the same reaction as iron; however, iron is usually favored since it is plentiful and relatively inexpensive. Other metals can enhance the rate at which iron reacts with the chlorinated compounds. Carbon impurities in cast iron serve to increase its reactivity. Nickel, silica, platinum, and palladium in combination with iron have all been shown to enhance the rate of degradation of TCE (Liang, et al., 1997). However, additional additives increase the cost of the iron, so that reactivity increases must be balanced with the cost of the enhanced iron.

The dehalogenation reaction is a surface reaction that requires actual contact between the chlorinated compound and the iron. Consequently, the surface area of the iron typically has a large effect on the reaction rate with the chlorinated solvent. Normally, the smaller the iron particles, the greater the surface area. However, with smaller particles the reactive wall becomes less permeable which may inhibit groundwater flow through the wall. Therefore, a balance needs to be achieved between particle size and permeability. One approach has been the development of porous iron granules that have more surface area per unit volume and weigh less than solid iron granules.

The formation of insoluble precipitates such as iron oxides and various carbonates is of concern in reactive wall installations since their precipitation can reduce the flow rate of groundwater through the wall and as a result reduce its treatment efficiency. The hydroxide ions can react with any bicarbonate in the groundwater to form carbonate ions (Reardon, 1995). The buildup of carbonate ions can result in the precipitation of insoluble carbonates like calcium carbonate. Additionally, iron can react with oxygen to form insoluble iron oxides (rust). Precipitation of insoluble compounds is especially important in funnel and gate applications where the contaminated groundwater is funneled through a relatively small opening. In these cases, reduced permeability of the reactive wall can impact on the effectiveness of the treatment system. Plugging of the reactive wall is typically not a concern in non-funnel and gate designs where an extensive permeable wall is used because it has a much larger area and precipitates will have a much smaller effect on groundwater flow. In addition, recent studies suggest that precipitation does not occur at an appreciable rate. Placement of iron in other shapes such as V-shaped panels also reduces the effect of precipitation.

It is also important to note that zero-valent iron reacts with water directly as shown:

$$Fe^0 + 2\,H_2O \rightarrow Fe^{+2} + 2\,OH^- + H_2$$

This is a very slow reaction, but it is important when evaluating treatment systems that must be in the ground for many years (Reardon, 1995) as this reaction will compete with the oxidation of chlorinated solvents. The reaction also produces hydroxide ions that will raise the pH of the groundwater. Eventually, the zero-valent iron will be oxidized by the surrounding water and dissolve. The speed of this reaction is influenced by a number of factors and typical estimates are that the iron granules will last from 20 to 80 years in most groundwater systems.

3.0 BENCH SCALE TESTS

Bench scale tests were performed for the Former Miller Container Plant site to determine the effectiveness of various irons and to select an iron with suitable reactivity. The bench tests included batch testing to pre-select the iron, and column testing to determine the degradation rate constants of the selected ZVI. The tests were performed on water spiked to simulate concentrations present at the site. Details of the bench test raw data, apparatus, and calculations are contained in Appendix A. The test methods and results are summarized below.

3.1 Analytical Methods

VOC analyses for the batch test samples were analyzed by Method SW-846 8021B. Analytical methods used for the column study are provided in Table 3-1.

Analytical services were provided by Certified Environmental services, Inc. (CES), located in Syracuse, New York. CES is certified for the required analyses in the State of New York. Radian Mobile Field Services (MFS) performed the VOC testing for the batch tests.

3.2 Bench Scale Procedures

Batch tests were conducted with zero-valent iron from three vendors in a variety of sizes. The general procedures for the batch test were to mix the site water with a predetermined amount of iron in a zero headspace bottle and tumble the bottles for varying periods of time. Samples were then collected from the bottles, filtered and prepared for VOC analysis. A time zero sample was collected to determine initial concentrations and a control bottle was prepared and sampled to evaluate contaminant losses during the batch tests. Trip blanks were collected to ensure that no cross contamination of the samples occurred.

The hydraulic conductivity of the various irons were compared and evaluated based on published values.

Based on the results of the batch and constant head tests, one iron was selected for column testing. Columns of the selected iron were constructed and spiked water was passed through the columns. The column test helped determine approximate degradation rate constants and allowed for monitoring water chemistry parameters. Water was pumped through the column at a flow rate of about 0.5 ft/day to roughly simulate groundwater flow conditions. Water samples were collected from the column effluent. Influent samples were collected periodically, and when the column effluent samples were collected.

3.3 Batch Test Results

The batch tests showed that Peerless 16/70 P1 iron was most effective in reducing the contaminants of concern, PCE and TCA. A summary of the analytical results from the batch tests is shown in Table 3-2. In the batch tests, the selected iron, Peerless 16/70 P1, reduced the concentrations of PCE to below the detection limit and TCA by 97% within 5 hours.

3.4 Iron Permeability Evaluation

The evaluation showed that the Peerless 16/70 P1 iron, 1.1×10^{-2} cm/sec, was about the same as or more permeable than the formations near the proposed PRW locations. The results are provided in Table 3-3.

3.5 Column Test Results

Peerless 16/70 P1 iron effectively reduced the contaminants of concern, PCE and TCA. Rate constants were computed by fitting a first order decay curve to the column test data;

$$C = C_0 e^{-kt}$$

where C = concentrations at time t (ug/L); C_0 = initial or influent concentration (ug/L); k = decay rate constant (1/hr); t = time (hr). This model is consistent with the theoretical degradation process anticipated for the reductive dechlorination of chlorinated organic compounds by zero-valent iron. Appendix C presents the details of the data evaluation.

Concentrations of PCE were reduced about 92% in the first five hours. The PCE rate constant under bench test conditions can be approximated at 0.52 hr^{-1} or greater. Concentrations of TCA also decreased about 92% within a period of 5 hours. The TCA rate constant is about 0.83 hr^{-1}. These rate constants are also shown graphically in Figure 3-1, and Figure 3-2. The rate constant curves are a close fit to the raw data. The rate constants were corrected for temperature and computed as half-lives. The half-life for PCE is about 2.7 hours, and the half-life to TCA is about 1.7 hours. This is within the typical range reported for the half lives for PCE, 2.1 to 10.8 hours, and TCA, 1.7 to 4.1 hours, (Gavaskar, 1998). Table 3-4 and Table 3-5 summarize the column test VOC results.

There were no detections of vinyl chloride generated by contact with the zero-valent iron after 5 hours. However, 1,1 dichloroethane and 1,2 dichloroethene were detected and may be degradation byproduct of the reductive dechlorination of PCE and TCA by ZVI. Based on the column test results these compounds will be treated by the ZVI and are not expected to be a problem. There were no detections of VOCs in the trip blank, and the control samples showed only minor losses during testing.

Changes in the water chemistry in the columns were observed, with the majority occurring in the first five-hour sample. Water chemistry analytical results show precipitation may tend to occur with the initial contact with the iron. The results of the water quality parameters are summarized in Table 3-4. An increase in pH was observed (Table 3-6), this is typical under the reducing conditions created by the iron. The results also show decreases in calcium and magnesium (hardness) within the first 5 hours. It is likely that the calcium and magnesium precipitated out of solution in response to an increase in the pH.

4.0 PILOT TEST PRW CONSTRUCTION

This section describes the ZVI test wall and monitoring points installed for the pilot study.

4.1 Monitoring Well Installation

Nine monitoring points were installed for the PRW pilot study. The locations of the monitoring points are shown in Figure 4-1. Three of the nine monitoring points were 3-inch wells, installed so that they could also serve as receiver wells for the radio-wave imaging. The other six monitoring points were 1-inch piezometers. Parratt Wolf, Inc. installed the three 3-inch PVC wells with hollow stem augers. Soil cuttings were disposed on-site near the borings. Radian Mobile Field Services installed the six 1-inch PVC piezometers with a direct push rig. Spoils were not generated from these borings. The well construction details are provided in Table 4-1. The Well Construction Diagrams, and well survey data are included in Appendix B. The well casing elevations were surveyed after installation, and are tied into the existing monitoring well network. Horizontal distances were taped.

4.2 Hydraulic Fracturing Equipment

Hydraulic fractures were created with a specialized equipment that brings together solid materials and transport fluids and pressurizes the resultant slurry for injection. In general, the components included:

- Hopper for stockpiling and optimal delivery of iron;
- Tank and mixing system for creation and storage of transport liquid (amendment);
- Mixer to effect intimate contact between iron and amendment to form pumpable slurry;
- Pump for pressurizing the slurry;
- Injection rig; and
- Hose, hollow steel rods and a boring for injection into the subsurface.

The components for mixing and pumping the ZVI slurry are assembled on a small trailer for transportation from site to site. The injection rig is mounted on a truck.

The vertical fracturing tool, consisted of jets designed to cut the initial slots used to initiate the fractures and the piping systems to inject the slurry mixture. The tool was generally driven to the bottom of the target zone (approximately 80-ft bgs) and pulled upward while water was injected through the jets to cut slots in the formation. After cutting the slots and iron-amendment slurry was pumped in at high pressure expanding the slots and creating a vertical fracture further into the formation. The vertical fracture is typically expected to extend between 3 and 20 ft from the injection point.

4.3 Pilot Wall Injection

Seven boreholes were advanced for injection of the wall segments at the pilot study site. The location of each of these boreholes is shown in Figure 4-1. The boreholes were arranged so that seven vertical Y-shaped fractures would form a continuous wall of ZVI perpendicular to the direction of groundwater flow. Figure 4-2 shows a cross section of the completed PRW. All segments were made of Peerless iron 16/70 P1 mesh sieve. Spoils were not generated during the injections. The following paragraphs detail the wall installation at each borehole.

Installation of Iron Filing Panels

The approach used a direct push rig to advance a borehole down to the desired depth. The steel rod was raised as jets cut vertical slots in the surrounding formation. The iron-amendment slurry was then pumped under pressure through the slots to hydraulically fracture the soil out from the injection point and extend the fracture in the desired direction.

Test Injection – An initial injection test was conducted with the direct push rig to roughly confirm the injection pressure and the extent of fracture propagation prior to injection at depth. The test injection was installed by advancing a 1 ¼-inch steel rod from 20 to 25 feet bgs while injecting an iron slurry under pressure. Slots were cut in the formation with jets while iron slurry was injected. The three slots were cut in the form of a "Y" (120-degree angle between the slots). About 100 ft^3 of iron-guar slurry was injected during the jetting process. Some of the iron-guar slurry was observed at the soil surface more than 20 feet from the injection point. The injection pressures were quite high initially (1500 psi), then dropped off and ranged from 100 to 500 psi as pumping continued. The logs for all injections are included in Appendix C.

The panels of the Y shaped injections were cored with the direct push rig at varying distances from the injection point, after the injection. The cores were visually examined and showed that panels cut in the surrounding soil were about 4-inches thick and extended a minimum of about 8-feet from the injection point. The rods were marked with chalk to confirm the injection orientation.

Installation of Iron Filing Panels using High Pressure Jetting

After the test injection, the pilot test wall was constructed at depths of 65 to 80 feet bgs by injecting a zero-valent iron slurry in Y shaped panels. The injections followed the same approach as the test injection. A 1 ¼-inch hollow rod was used to drill the remaining injection borings at IN-1, IN-2, IN-3, IN-4, IN-5, IN-6 and IN-7 shown on Figure 4-1. The iron slurry was injected at each borehole

Injection at Borehole IN-1 - At IN-1, vertical Y-shaped slots were cut in the surrounding formation from about 65 to 79.5 ft bgs (a 14.5-ft length) using high-pressure jets operating at about 2000 psi and dropping off as described above. Iron-amendment was injected into the borehole during the entire jetting process. Jet water and soil spoils were only evident following the removal of the injection hose, when some slurry leaked. Generally, no spoils were generated at the soil surface during the injection. Injections were completed in 350 gallon batches. About 4.7 ft^3 of water (without iron filings) was injected to expand the initial ground fractures for some distance before the injection of iron filings. Iron-guar slurry was injected and the injection pressure stayed between 100 and 500 psi. The injection pressures varied slightly as pumping progressed. After 9 batches the injection was discontinued. About 421 ft^3 of iron-guar slurry (8.1 tons of iron) was injected. The rods were marked with chalk to confirm panel orientation.

Injection at Borehole IN-2 - At IN-2, vertical Y-shaped slots were cut in the surrounding formation from about 65 to 79 ft bgs (a 14-ft length) using high-pressure jets operating at about 2000 psi and dropping off as described above. Iron-amendment was injected into the borehole during the entire jetting process. Jet water and soil spoils were only evident following the removal of the injection hose, when some slurry leaked. Generally, no spoils were generated at the soil surface during the injection. Injections were completed in 350 gallon batches. About 4.7 ft^3 of water (without iron filings) was injected to expand the initial ground fractures for some distance before the injection of iron filings. Iron-guar slurry was injected and the injection pressure stayed between 100 and 500 psi. The injection pressures varied slightly as pumping progressed. After 9 batches the injection was discontinued. About 421 ft^3 of iron-guar slurry (7.8 tons of iron) was injected. The rods were marked with chalk to confirm panel orientation.

Injection at Borehole IN- 3 - At IN-3, vertical Y-shaped slots were cut in the surrounding formation from about 65 to 77.3 ft bgs (a 12.3-ft length) using high-pressure jets operating at about 2000 psi and dropping off as described above. Iron-amendment was injected into the borehole during the entire jetting process. Jet water and soil spoils were only evident following the removal of the injection hose, when some slurry leaked. Generally, no spoils were generated at the soil surface during the injection. Injections were completed in 350 gallon batches. About 4.7 ft^3 of water (without iron filings) was injected to expand the initial ground fractures for some distance before the injection of iron filings. Iron-guar slurry was injected and the injection pressure stayed between 100 and 500 psi. The injection pressures varied slightly as pumping progressed. After 8 batches the injection was discontinued. During the injection, spoils were generated at IN-1 about 20 feet away. About 374 ft^3 of iron-guar slurry (7.2 tons of iron) was injected. The rods were marked with chalk to confirm panel orientation.

Injection at Borehole IN- 4 - At IN-4, vertical Y-shaped slots were cut in the surrounding formation from about 60 to 77 ft bgs (a 17-ft length) using high-pressure jets operating at about 2000 psi and dropping off as described above. Iron-amendment was injected into the borehole during the entire jetting process. Jet water and soil spoils were evident at injection point 2 and 3 up to twenty feet away. Injections were completed in 350 gallon batches. About 4.7 ft^3 of water (without iron filings) was injected to expand the initial ground fractures for some distance before the injection of iron filings. Iron-guar slurry was injected and the injection pressure stayed between 100 and 500 psi. The injection pressures varied slightly as pumping progressed. After 11 batches the injection was discontinued. About 515 ft^3 of iron-guar slurry (9.7 tons of iron) was injected. The rods were marked with chalk to confirm panel orientation.

Injection at Borehole IN- 5 - At IN-5, vertical Y-shaped slots were cut in the surrounding formation from about 63 to 78.5 ft bgs (a 15.5-ft length) using high-pressure jets operating at about 2000 psi and dropping off as described above. Iron-amendment was injected into the borehole during the entire jetting process. Jet water and soil spoils were only evident following the removal of the injection hose, when some slurry leaked. Injections were completed in 350-gallon batches. About 4.7 ft^3 of water (without iron filings) was injected to expand the initial ground fractures for some distance before the injection of iron filings. Iron-guar slurry was injected and the injection pressure stayed between 100 and 500 psi. The injection pressures varied slightly as pumping progressed. After 9 batches the injection was discontinued. About 421 ft^3 of iron-guar slurry (7.9 tons of iron) was injected. The rods were marked with chalk to confirm panel orientation.

Injection at Borehole IN- 6 - At IN-6, vertical Y-shaped slots were cut in the surrounding formation from 61.5 to 77.5 ft bgs (a 16-ft length) using high-pressure jets operating at about 2000 psi and dropping off as described above. Iron-amendment was injected into the borehole during the entire jetting process. Jet water and soil spoils were only evident following the removal of the injection hose, when some slurry leaked. Generally, no spoils were generated at the soil surface during the injection. Injections were completed in 350 gallon batches. About 4.7 ft^3 of water (without iron filings) was injected to expand the initial ground fractures for some distance before the injection of iron filings. Iron-guar slurry was injected and the injection pressure stayed between 100 and 500 psi. The injection pressures varied slightly as pumping progressed. After 8 batches the injection was discontinued. About 374 ft^3 of iron-guar slurry (7 tons of iron) was injected. The rods were marked with chalk to confirm panel orientation.

Injection at Borehole IN- 7 - At IN-7, vertical Y-shaped slots were cut in the surrounding formation from 67 to 83 ft bgs (a 16-ft length) using high-pressure jets operating at about 2000 psi and dropping off as described above. Iron-amendment was injected into the borehole during the entire jetting process. Jet water and soil spoils were only evident following the removal of the injection hose, when some slurry leaked. Generally, no spoils were generated at the soil surface during the injection. Injections were completed in 350 gallon batches. About 4.7 ft^3 of water (without iron filings) was injected to expand the initial ground fractures for some distance before the injection of iron filings. Iron-guar slurry was injected and the injection pressure stayed between 100 and 500 psi. The injection pressures varied slightly as pumping progressed. After 8 batches the injection was discontinued. About 374 ft^3 of iron-guar slurry (7 tons of iron) was injected The rods were marked with chalk to confirm panel orientation.

4.4 Cross Borehole Survey of Installed Reactive Wall

A limited geophysical survey was used to confirm the placement of the ZVI test wall. The linear extent and apparent thickness of injected reactive wall panels at IN-4, IN-5 and IN-5 were measured using an electromagnetic geophysical method called cross borehole radar (CBR). The CBR field equipment for this project was leased from Mala GeoScience, located in Manchester, NH. The details of the CBR technology and complete results of the measurements are described in a report included as Appendix D. A brief summary of the CBR technology and the results of the survey conducted at the pilot study site follow.

The CBR technique can be used to measure panel thickness by comparing the background amplitude response to the ZVI wall response. The wall thickness is then estimated by modeling the iron wall's amplitude response, and some assumptions must be made to complete the panel geometry.

The CBR survey demonstrated that the test panels at IN-4, and IN-5 were continuous over the depth measured. The fractures imaged were found to extend to over 6 ft from the injection well. The response at the IN-6 test panel is inconclusive.

Cores of the test injection showed significant iron presence a distance of 8 feet from the point of injection, fracture propagation beyond 8 feet is likely. During the injection at IN-3, communication was observed between IN-3 and IN-1, that suggests the injection radius is about 20 feet. The CBR survey found anomalies that may be iron at between 6 and 7.5 feet from the injection. Based on the results the iron panels are believed to propagate from 8 feet to 19 feet from the injection point.

CBR did not detect a response at the IN-6 test panel, it is not clear why.

The estimate of wall length and orientation for each injection well are shown in Figure 4-1. The most successful wall installation is the Y-shaped panel installed at IN-5. The amount of iron injected ranged from about 7 to 8 tons. Assuming a 15 foot vertical height and an injection radius form 8 to 19 feet, the thickness of the iron panels ranges from about 1.2 to 3.3 inches, depending on the volume of iron injected and the radial extent of the panels.

Based on the orientation of the injected panels and their radial extent from the injection point, it appears that the upgradient piezometers PZ-1, PZ-3 and PZ-6 may be impacted by the iron injections (Figure 4-1).

5.0 PILOT TEST PERFORMANCE MONITORING

The pilot test was conducted over from March 2000 to November 2000, a period of about 9-months. The PRW is a passive in-situ treatment system, therefore there was no startup, operation, or maintenance activities, only periodic groundwater sampling events to monitor contaminant reduction.

5.1 Analytical Methods and Sampling Frequency

Table 5-1 lists the analytical methods. During the sampling rounds field parameters which include dissolved oxygen (DO), pH, oxidation/reduction potential (ORP) and groundwater elevations, as well as VOC samples, were collected to assess the effectiveness of the ZVI technology for treating contaminants in the groundwater. Samples for metals and iron reducing bacteria were also collected at select intervals. Six sampling events were conducted during the pilot study. Table 5-2 lists the sampling event chronology and sampling parameters. A discussion of the equipment used to measure field parameters is also contained in Appendix E.

5.2 Groundwater Sampling Methodology

Groundwater monitoring was performed by Certified Environmental Services (CES) of Syracuse, NY. Samples were collected by inserting a hand bailer into the well, purging the contents of one bailer, and collecting a sample. The purge water was collected and placed in drums at the site for disposal in the on-site treatment system. Samples were placed on ice immediately after being collected. The samples were then labeled, and transported to the CES laboratory for analysis.

Purging was considered complete when 3 to 5 purge volumes were removed or the well went dry, and when parameters stabilized for at least three consecutive readings within the following limits: 1°C for temperature, ± 0.1 pH units, ± 0.01 millisiemens per centimeter (mS/cm) for conductivity, ± 10 millivolts or 10% (which ever is less) for redox potential, ± 10% for turbidity, and ± 10% for dissolved oxygen. Removal of a specific volume of water was not required. The parameters were recorded on log sheets, which are included in Appendix F. The purge water was collected and measured in graduated five-gallon buckets and placed in drums at the site for disposal in the on-site treatment system. Samples were placed on ice immediately after being collected. They were then labeled and transported to the CES laboratory for analysis. The equipment was decontaminated between sampling locations.

Trip blanks were included with each shipment of samples analyzed for volatile organic compounds (VOCs) to study the combined effects of sample handling, transportation, storage, and analysis. No problems were encountered during the field sampling activities. All samples were analyzed within the holding time requirements and no significant problems were encountered during the sample analyses. The analytical results are documented in the laboratory reports specific to this project.

5.3 Sample Locations

The locations of the groundwater monitoring wells and pizometers are shown in Figure 5-1. Groundwater samples were collected from three monitoring wells located immediately upgradient of the reactive wall, two monitoring wells "within" the reactive wall, and the three monitoring wells located immediately downgradient of the wall, and one monitoring well above the wall. Two of the sampling events, Round 3 and Round 6, coincided with site wide groundwater sample events.

5.4 Performance Monitoring Results

Analytical results from the six sample rounds of PRW performance monitoring are presented in Appendix F. The results are discussed below. The data, which is used to evaluate the performance of the PRW pilot wall, falls into three distinct groups:

1. Geochemical;

2. Hydraulic; and

3. Volatile Organic Compound (VOC).

These three data sets are discussed below. The data for the first two sample rounds were collected with recovery well RW-2 in operation. Pumping at RW-2 would tend to make the PRW look less effective due to increased velocity through the PRW and decreased residence times. Pumping at RW-2 would also affect VOC equilibriums between the groundwater and soil, reducing the levels of contaminants in the groundwater.

GEOCHEMICAL RESULTS

Redox

Geochemical monitoring results are shown in Figure 5-2. Of particular interest are the oxidation-reduction potential (ORP) results summarized in Figure 5-3 and Table 5-3. ORP is a key indicator of the effectiveness and success of the iron in treating the contaminants of concern at the site. Generally, when the PRW develops full effectiveness there are strongly reducing conditions and ORP within the wall is in the –200 to –400 mV range. The data are grouped into upgradient, above wall, mid-wall, and downgradient locations below for easier review.

Downgradient - The down gradient wells, PZ-2, GEO-1, GEO-3, continue a negative ORP trend. This is a strong indicator that the iron is working as it should, and suggests that the iron is successfully degrading the VOCs in the groundwater that contacts the PRW. The continuing trend suggests further decreases in the levels of VOC are likely.

Mid Wall - The mid-wall and downgradient wells (PZ-4, and GEO-2) show a general trend to negative ORP during the pilot test, and currently range from about –99.1 to –126.2 mV. This suggest the ZVI is creating reducing conditions conducive to the reductive dechlorination of VOCs.

Upgradient - Upgradient piezometers PZ-1 and PZ-3 initially have negative ORP. This suggests they may have been impacted by the iron injection. Likewise the ORP measured in piezometer PZ-6 was negative in the second, fifth and sixth round of sampling, and may have been impacted. The orientation of the injected iron panels shows the upgradient the injected iron may have impacted pizometers. Overall, the ORP in these wells does not exhibit a definitive trend but tends to be moving from positive to negative. The overall trend may be the result of an ORP shadow, because of the close proximity of the upgradient piezometers PZ-1, PZ-3 and PZ-6 to the PRW (about 8 feet), or as discussed above the wells may have been impacted by iron during the injections.

Above Wall - The above wall well PZ-5 likewise shows no clear ORP trend, but rather seems to be maintaining a moderately negative ORP. The negative ORP observed in PZ-5 may be the result of an ORP shadow or impact from the iron injections.

In the last sample round the ORP measured in all nine monitoring points was negative. Based on our experience at other sites we may see a further reduction in ORP as steady state conditions are achieved in the PRW. However, we may not see ORP in the –200 to –400 mV range, because none of the monitoring points were placed directly in the PRW panels where we expect to see the most strongly reducing conditions.

pH

In general, the pH measured in all of the monitoring wells ranged between 6.5 and 8 standard units during the pilot study. The pH increased slightly during the pilot test, which is generally indicative of a shift to reducing conditions created by the ZVI, and consistent with the pH increase observed during the bench test.

Iron and Iron Reducing Bacteria

Iron ions (Fe+2) are produced from reductive dechlorination reactions as well the reaction of iron with water. Since there is no way of distinguishing the source of the iron ions, the presence of dissolved iron is not necessarily an indication of chlorinated organic removal. However, the presence of dissolved iron suggests that sufficient ZVI surface area is available for reaction, and that calcium carbonate or iron oxides have not blinded the active sites. Although no trends are apparent in the concentrations with time, it appears that sufficient iron surface area is available to promote reductive dechlorination.

Iron reducing bacteria were present in only one well at low levels. This suggests the injection of the injections of ZVI have not generated significant colonies of iron reducing bacteria. Care will still need to be taken to insure microbes are not introduced if injections are undertaken near the City of Fulton municipal well field.

Inorganics and Hardness

Alkalinity is a measure of the hydroxide, carbonate, and bicarbonates of calcium, magnesium, and others. The downgradient wells appear to have more alkalinity than the upgradient wells, which may indicate more hydroxide and carbonate formation. The levels of calcium and magnesium decreased down gradient of the wall, and likely precipitated on the ZVI.

Based on the decrease in calcium concentrations through the pilot test PRW, the full-scale PRWs could require maintenance to address plugging caused by precipitation roughly every 24 years (Appendix F). However, by that time natural attenuation is expected to be used instead of the PRWs for site remediation, so precipitation should not be an issue.

Dissolved Oxygen

Dissolved oxygen is generally low, less than 4 mg/L in monitor wells. Low dissolved oxygen readings are another measure of a good reducing environment. This reducing environment is likely caused by both to the degradation of the iron amendment and the rusting of the iron.

Biological Oxygen Demand (BOD)

BOD samples were collected to gauge the breakdown and dissipation of the iron injection amendment. Samples collected during the first sample round (3/15/00) showed four of the nine wells with BOD. In these wells BOD ranged from <2mg/L to 108 mg/L. This suggested that the amendment had not "broken". BOD samples were subsequently collected during the third sample round. BOD was detected in all the wells sampled and ranged from 18 mg/L to 1260 mg/L. The increase in the levels of BOD suggested the amendment had broken and dissipated in most of the PRW with some of the "broken" amendment still requiring flushing within the PRW at GEO-2, the well with the highest BOD.

Hydraulic Results

For the PRW to be effective groundwater must flow through the PRW. Initially, until the amendment used to inject the iron "breaks", groundwater may not flow though the wall and may tend to mound. Subsequent to the amendment "breaking" the PRW will achieve increasing permeability as the amendment "breaks" further and is degraded by naturally occurring microorganisms. Even though the amendment has "broken", and adequate permeability is achieved, full permeability will only return slowly over time as the amendment is dissipates through flushing or is degraded.

Initial groundwater elevations measured on March 14, 2000 (Figure 5-4) show an upward gradient at the PRW. Water elevations in PZ-5, the well above the PRW (screened from about 48 to 53 feet bgs), are less than the groundwater elevations in GEO-1 (screened from 70 to 80 feet, across the height of the PRW). Clearly, under pumping conditions at RW-2, these wells which are in relatively close proximity to RW-2, should have a downward gradient, given the deeper sand and gravel zone screened by GEO-1 is more permeable than the shallower zone through which PZ-5 is screened. The upward gradient at these wells suggests that at that time, the iron injection amendment was still blocking flow through the PRW.

Subsequent measurement of groundwater elevations on April 21, 2000 (Figure 5-5) shows no upward gradient at PZ-5 and GEO-1. At that time the groundwater gradient was downward, as it should be, suggesting groundwater flow through the PRW, not over it. The water elevation at piezometer PZ-3 appears to be somewhat of an anomaly, we believe the generally flat gradient at this location is responsible.

To further confirm groundwater flow is through the PRW groundwater elevations were re-measured on May 5, 2000 (Figure 5-6), after pumping at RW-2 stopped. These measurements show groundwater flow through the PRW under a relatively flat gradient. Historic data before the recovery wells were operational shows an even flatter gradient near the pilot test PRW under non-pumping conditions. Pilot test gradients at the PRW may be increased by pumping at recovery wells RW-1 and RW-13, but may also show some effect from residual amendment in the PRW. The data shows an anomaly at PZ-4. During sampling the field technician has noted slow recharge at PZ-4. We believe PZ-4 responds very slowly to water table fluctuations. Thus, the groundwater elevations measured in PZ-4 may be inconsistent with the rest of the data set, and may not accurately reflect general groundwater elevations and flow through the PRW.

Subsequent groundwater elevation measurements generally show groundwater flows through the PRW with some variability in flow at the southern edge of the PRW near piezometers PZ-1 and PZ-2. In the two sample rounds completed on 8/17/00 and 9/29/00 flow through the PRW at PZ-1 and PZ-2 appears reversed (Figures 5-7, and Figure 5-8 respectively). During the last sample round, on 11/21/00 (Figure 5-9) flow is through the wall again. Based on the historical pre-groundwater recovery system data the natural gradient is moderate at this location, and may explain reversed flow through the PRW. Flows at the southern edge of the PRW may also be impacted by pumping at recovery wells RW-9, RW-5, and RW-3 which would tend to pull groundwater in their direction and cause the change in the direction of groundwater we observed.

None of the relative water levels in the monitoring wells appears to be increasing with time which implies that the permeability of the reactive iron filings walls remains greater than that of the surrounding soils.

The velocity was estimated based on the steepest gradient through the PRW during the pilot test, with RW-2 not pumping, and the geometric mean of the hydraulic conductivities. The highest groundwater velocity was about 110 ft/year (0.3 ft/d). If the effective thickness of the reactive iron filing walls is 4 inches, then the groundwater residence time is a minimum of 1.1 days. Based on an initial PCE concentration of 353 ug/L detected at piezometer PZ-2, a 0.7 day residence time would be adequate to achieve treatment to below NYSDEC cleanup criteria.

Volatile Organic Compound (VOC) Results

VOC results are shown in Figure 5-10. The initial levels of VOC detected in the first round of groundwater sampling were lower than expected. Based on historical data from RW-2, PCE and TCA were detected at 400 µg/L and 610 µg/L respectively. The highest levels of PCE and TCA measured in the first two sampling rounds ranged from 12 to 167 mg/L. We believe these initial lower levels of target compounds were the result of the injected iron amendment and pumping at RW-2. During the injections a significant volume of iron slurry was pumped into the ground, this would tend to flush and displace contaminated water in the vicinity of the PRW. The result is that initially we may see lower concentrations in the groundwater after the injections followed by some rebound of the VOC levels as groundwater displaces the injection amendment. The increasing trend in the VOC data between the first, second and third (fourth round also for GEO-1 and GEO-3) round of groundwater sampling is consistent with a rebound in VOC levels that occurred as the amendment was finally degraded, and also corresponds to when pumping at RW-2 was stopped. The long-term rebound of VOCs in the upgradient monitoring points was lower than anticipated and may be the result of iron impacting these wells.

Based on the calculated groundwater flow velocity, an assumed retardation factor of 3, and the distances to the downgradient wells, the first effects of the reactive iron filing walls on chlorinated organic concentrations in GEO-2, GEO-3, and PZ-2 were expected within 2 to 3 months of installation. The delayed response of the VOC levels in the down gradient monitoring wells is consistent with the anticipated lag in response. Given the calculated arrival times, the sampling frequency was decreased to roughly once every two months.

The VOC results currently show a decreasing trend, with the exception of the above wall piezometer PZ-5. The trend suggests we may see additional declines in the levels of VOCs at the PRW. Piezometer PZ-5 was not targeted for ZVI treatment so no change in VOC levels is expected there. The VOC results are consistent with the ORP data and tend to reinforce the interpretation that the early results are amendment impacted. The VOC results may also show a delayed response because the residual VOCs in the soil and groundwater around the monitoring points must be flushed before the full effect of the PRW is seen. The VOC results suggest that we have not seen the full effect of the PRW on VOC levels at the monitoring points.

Consistent with the bench scale tests the VOC results show the PRW does not produce the degradation vinyl chloride (VC), but may produce low levels of 1,1 dichloroethane (DCA) and 1,2 dichloroethene (DCE). During the column test both DCA and DCE were successfully reduced by the iron, so these potential byproducts should not be an issue for the full scale PRW system.

The decrease in PCE and TCA concentrations in the downgradient wells is likely due to the combination of iron filing induced and biologically induced reductive dechlorination. Because the downgradient wells were monitored for an extended period, the long term reduction of PCE and TCA concentrations are attributed to the ZVI.

6.0 DESIGN

The preliminary design for the proposed zero-valent iron PRW system is presented below. The treatability test results in conjunction with the site data provide the basis for the design.

6.1 PRW Location

Three PRWs are proposed for the PRW system at the Former Miller Container Plant site. The location and horizontal extent of the PRWs; PRW-1, PRW-2, and PRW-3 are shown in Figure 6-1. The location of the PRWs was determined by comparing contaminant distributions with the New York State Department of Environmental Conservation clean up criteria. The PRWs were placed in areas where contaminant levels are expected to exceed the cleanup criteria. Table 6-1 shows the design influent concentrations for the PRW-1, PRW-2, and PRW-3 versus the cleanup criteria. The design influent and cleanup criteria establish the levels of treatment required by the PRWs. The cross section of the proposed PRW-1 is shown in Figure 6-2. Figure 6-3 is a cross-section of the down gradient edge of the NOU plume, where natural attenuation will be evaluated, and Figure 6-4 shows a cross-section of proposed PRW-2 and PRW-3. The groundwater velocity, target compound levels, and decay rate constants from the treatability test were used to calculate the required thickness of a PRW wall (Appendix G). Based on our calculations, PRW-1 requires an effective thickness of 3-inches, PRW-2 has effective thickness of 3-inches, and PRW-3 requires an effective thickness of 1-inches to treat existing contaminant levels and achieve clean up criteria.

6.2 PRW Configuration

The configuration of the PRW system was developed to capture groundwater plumes by placing the PRWs within the context of site conditions and long term performance. PRW-1 will be placed in two rows of 12 double offset V-shaped panels. PRW-2 will be extended with 10 V-shaped double off-set panels on each end (20 V-shaper panels total) of the existing pilot test PRWs, and PRW-3 will be placed in two rows of 18 double off-set V-shaped panels.

6.3 PRW Construction Method

Pressure jetting with highly specialized equipment will be used to place the PRW. With this construction technique, an iron slurry is injected into the subsurface to form iron "panels". No spoils are generated during emplacement. Preliminary sampling at the site and placement of the pilot test PRW confirm pressure jetting can be used to construct an effective full-scale PRWs.

The iron slurry will be injected through 12 boreholes for PRW-1 (Figure 6-5), 20 boreholes for PRW-2 and 18 boreholes for PRW-3 (Figure 6-7). First, high-pressure water jets will cut slots in the surrounding soil from which vertical "fractures" will be propagated. The iron slurry will then be pumped under pressure through the slots to hydraulically part the soil and extend the slots in the desired directions.

The boreholes will be arranged in a pattern so that the vertical V-shaped fractures for each PRW will form a continuous wall of iron perpendicular to the direction of groundwater flow. All segments will be made of Peerless iron filings, 16/70 P1 mesh sieve. Select injection points will have a 1-inch pipe installed to verify hydraulic gradients through the PRWs.

6.4 PRW Construction QA/QC

Construction of the PRW will be verified through cores and geophysical surveys. Cores of test injections at each location will confirm horizontal extent and panel thickness prior to placement of the PRWs prior to placement at depth. In addition, a cross-borehole radar method may be used to confirm installation at each PRW. We will evaluate methods and further develop emplacement confirmation techniques prior to the full-scale injections. This will be completed as a part of the final design.

6.5 Permeability of Native Material

The injected iron will only be effective if groundwater passes through it. The relative permeabilities of the native formation and the placed iron are therefore crucial to the success of the PRWs. Based on slug test data for the site, the permeability of the groundwater formation near PRW-1 ranges from about 2×10^{-2} cm/sec to about 9×10^{-4} cm/sec. The permeability of the formation near PRW-2 ranges from about 6×10^{-3} cm/sec to about 9×10^{-4} cm/sec, and the permeability near PRW-3 ranges from about 4 x 10^{-3} cm/sec to about 4 x 10^{-6} cm/sec. Based on the constant head tests conducted during treatability testing, the hydraulic conductivity of the Peerless iron selected for the PRWs is 1.1 x 10^{-2} cm/sec. The hydraulic conductivity of the selected iron is about the same as or higher that the hydraulic conductivity measured in the surrounding formation, and will promote groundwater flow through the PRW.

6.6 Natural Attenuation

Initially, natural attenuation in conjunction with the PRWs will remediate the site. Existing data show decreasing levels of target compounds in the leading edge of the NOU plume, which suggest that natural attenuation is occurring. In addition, geochemical data from our preliminary evaluation show site conditions are supportive of natural attenuation. During final design URS will evaluate natural attenuation, and expect the leading edge of the mid-site plume will be addressed through natural attenuation. In addition the PRWs will be placed within the context of natural attenuation during design.

In the long term, natural attenuation will be used to remediate the site instead of the PRW system. It is likely that in 24 years (or less), decreases in the levels of contaminants will support closure of the site through natural attenuation.

6.7 Performance Monitoring

URS proposes replacing the existing site-wide monitoring program with PRW performance monitoring. Only select wells from the existing program would be used.

Performance monitoring will rely primarily on demonstrating groundwater flow through the PRWs, because the effectiveness of the ZVI PRWs was demonstrated by the full-scale pilot test. As discussed above, select injection points will have a 1-inch pipe installed to allow for the measurement of groundwater elevation.

Sampling from select existing monitoring wells downgradient of the PRWs, will allow us to monitor VOC treatment. Monitoring wells MW-28 S, I and D will be used for monitoring down gradient of PRW-1. At PRW-2 RW-2d and MW-11S and MW-11D will be monitored, and at PRW-3 downgradient monitoring will be conducted at MW-22S and MW-22D. Performance monitoring data would include the collection of samples and their analysis for VOCs, select water chemistry parameters, and groundwater water elevations.

We anticipate it will take about two months to verify flow through the PRWs. Once flow through the PRWs is demonstrated, the existing pump and treat system will be shut down. Sampling of wells with historical data will then be conducted semiannually for two years. Thereafter, sampling will be conducted annually.

The existing data is being reviewed to finalize on the criteria for shutting down the municipal well field treatment system. The final criteria will determine the monitoring requirements.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

- Bench-scale tests conducted by URS confirm that ZVI will successfully remediate groundwater at the Former Miller Container Plant site. Concentrations of PCE and TCA were reduced by about 92% in less than 5 hours during the column studies.
- The pilot test confirmed ZVI could be effectively placed using pressure jetting, and that a full-scale pressure jetted PRW will effectively treat the target constituents at the site.
- The pilot test ORP and VOC data show the PRW is successful. However, the data also show that the effects of the PRW were somewhat slower to develop than anticipated.
- The increasingly negative trend in the ORP and VOC data (for mid-wall and downgradient wells) show the PRW is working but its effects may not be fully realized.
- Groundwater elevation data show groundwater flows through the PRW.
- The initial levels of VOCs in the groundwater were lower than anticipated. This is likely due to the impact of the iron injections on the monitoring points, as the injections flush and initially displace the contaminated groundwater with injected amendment. The rebound in VOC levels and subsequent decreases, in conjunction with decreasing trends in ORP is consistent with the injection amendment initially impacting the PRW effectiveness by lowering the permeability to the groundwater.
- The VOC data show that the PRW is successfully degrading VOCs. The effect of the PRW on VOC levels was only expected to begin to be seen after three months based on site conditions. As residual VOCs undergo more flushing we anticipate further decreases in the levels of VOCs.
- The limited geophysical evaluation had limited effectiveness. A more rigorous geophysical evaluation may be conducted, but the cost would be significant.

7.2 Recommendations

We make the following recommendations:

- Negotiate a change in the cleanup criteria for the site with NYSDEC. Adopt the more realistic Federal MCLs groundwater criteria. This would help place clean up of the site within a more reasonable context.
- Implement a full-scale PRW system consisting of three PRWs to remediate groundwater in the NOU and SOU. PRW-1 will be about 125-feet long and 60 feet deep, PRW-2 will be 200 feet long and 80 feet deep, and PRW-3 will be about 215 feet long and 70 feet deep. These PRWs will treat groundwater in the NOU and SOU prior to discharge to the City of Fulton municipal well field, and may allow MBCo to discontinue operation of the treatment system at the City of Fulton municipal well field.
- Install the PRW system using pressure jetting, and construct of 12 vertical V-shaped panel injections for PRW-1, extend the existing pilot test PRW with 20 vertical V-shaped panes for PRW-2, and construct 18 vertical V shaped panel injections for PRW-3.
- Evaluate natural attenuation for the remediation. Minimize to the extent possible the overall PRW system based on the natural attenuation evaluation.

In summary, a zero-valent iron PRW system in conjunction with monitored natural attenuation appears to be applicable to the site conditions at Former Miller Container Plant site. The zero-valent iron technology was effective in reducing contaminant concentrations during bench scale and full-scale pilot testing. Therefore, it is recommended that the NOU and SOU groundwater at the Former Miller Container Plant site be remediated with three full-scale ZVI PRWs. Installation would be accomplished by pressure jetting.

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Table 1-1
Groundwater Analytical Summary for Target Compounds (2000)
Former Miller Container Plant , Volney, NY

Wells	PCE (µg/L)	TCA (µg/L)	C-1,2- DCE (µg/L)	1,1-DCE (µg/L)	1,1-DCA (µg/L)
Recovery Wells					
RW-1	6.7	6.1	<1	6.1	5.4
RW-2	140	69	6	21	3.5
RW-3	800	270	250	120	170
RW-4	60	16	1.4	2.8	4.7
RW-5	470	240	20	46	19
RW-6	41	48	94	21	56
RW-7	40	29	120	13	27
RW-8	89	360	140	75	31
RW-9	3100	2400	96	500	74
RW-10	14	4.8	<1	1	<1
RW-11	20	6.8	<	1.5	<1
RW-12	15	5.3	<1	1.6	<1
RW13	32	21	2.8	15	9.5
Shallow Monitoring Wells					
MW-2S	620	640	200	65	100
MW-21S	23	14	<0.5	<0.5	<0.5
MW-33S	5	60	<0.5	1.4	<0.5
MW-36S	2.6J	15J	59	<5	22
MW-37S	14J	59			
MW-38S	640	120	130	20	100
MW-47S	89	12	36	9.2	13
MW-48S	20J	49J	450	43	51
Deep Monitering Wells					
MW-13D	3.6	160	1.1	5.6	<0.5
MW-14D	33	110	<0.5	<0.5	<0.5
MW-16D	61	85	<0.5	9.1	<0.5
MW-17D	2.6	16	<0.5	3.6	0.53
MW-28I	3.4	12	<0.5	3.1	0.55
MW-51D	<0.5	2.5	<0.5	<0.5	<0.5
MW-54D	-	-	-	-	-
MW-56D	72	97	1.1	1.8	0.75
MW-61D	30	1.2	<0.5	<0.5	<0.5

Note: MW-28I best representative of data for municpal well field available at the time of report.

Table 1-2
Summary of General Water Quality Parameters (9/3/99)
Former Miller Container Plant, Volney, NY

Analyte/Parameter	Recovery Well RW-5	RW-7	RW-8	RW-2	RW-3	RW-11	RW-12
Flow Rate (GPM)	2.10	0.97	16.60	15.10	not avail.	1.58	4.90
Dissolved Metals (mg/L)							
Calcium	109	122	122	95.1	196	70.9	63.2
Iron	<0.0204	0.0661	<0.0204	<0.0204	ND	<0.0204	<0.0204
Magnesium	29.6 B	30.3 B	45.7 B	31.3 B	47.7 B	19.1 B	19.4 B
Manganese	0.00491	1.40	0.0622	0.0449	0.164	ND	0.00338
Potassium	1.31 B	0.896 B	0.934 B	2.43 B	2.03 B	6.02 B	2.92 B
Sodium	69.1	45.8	52.5	101	189	32.9	49.6
Anions (mg/L)							
Chloride	124	78.4	159	225	482	49.7	86.5
Sulfate	40.2	43.8	46.8	33.6	45.2	24.5	28.8
Total Organic Carbon (mg/L)	0.964	3.29	1.49	2.37	2.06	1.61	1.31
COD (mg/L)	<2.63	8.11	3.78	NR	NR	NR	NR
Nitrogen (mg/L)							
TKN	0.0852	0.222	0.128	NR	NR	NR	NR
Ammonia as N	0.0402	0.0516	0.0354	NR	NR	NR	NR
Nitrite	ND	ND	<0.0077	ND	ND	ND	ND
Nitrate	1.85	ND	0.810	7.08	1.23	2.56	1.05
Phosphorus (mg/L)							
Orthophosphate	ND	ND	<0.0124	<0.0124	ND	<0.0124	<0.0124
Total Phosphorus	0.0144 B	0.0262 B	0.0163 B	NR	NR	NR	NR
Alkalinity (mg/L)							
Bicarbonate	NR	NR	NR	248 B	448 B	230 B	184 B
Carbonate	NR	NR	NR	0	0	0	0
Hydroxide	NR	NR	NR	0	0	0	0
Total Alkalinity	NR	NR	NR	248 B	448 B	230 B	184 B
TDS (mg/L)	NR	NR	NR	746	1410	396	419
Field Measurements							
Redox Potential (mV)	3.23	3.20	3.25	3.21	2.98	3.08	3.14
pH	6.85	6.54	6.60	6.41	6.55	6.42	6.85
Temperature (°C)	14.5	19.3	13.9	13.5			

B = Analyte detected in method blank at concentration greater than the Reporting Limit (and greater than zero)
ND = Not detected. No instrument response for analyte or result less than zero.
NR = Analysis not requested for the sample.

Table 3-1
Analytical Methods for Bench Test
Former Miller Container Plant , Volney,NY

Analyte/Parameter	Method
VOC	EPA 8021
Calcium	EPA 215.1
Iron	EPA 236.1
Magnesium	EPA 242.1
Total Dissolved Solids	EPA 160.1
Alkalinity	SM18-2320B
BOD_5	SM18 5210
Redox Potential	Meter

Table 3-2

Analytical Results from Batch Test
Summary of Results for Compounds of Concern
Former Miller Container Plant, Volney, NY

		Analyte								
Sample #	Elapsed Time	VC	1,1 DCE	1,1 DCA	DCE	Chloroform	1,1,1 TCA	TCE	1,1,2 TC	PCE
	(min)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
B0 (Influent)	0	ND	ND	ND	ND	ND	705	ND	ND	380
B1	15	ND	ND	ND	ND	ND	245	ND	ND	ND
B2	30	ND	ND	ND	ND	ND	196	ND	ND	ND
B3	90	ND	ND	13	ND	ND	76	ND	ND	ND
B4 (Final)	209	ND	1.4	10	ND	4.4	19	ND	ND	ND
B48 (Control)	237	ND	ND	ND	ND	ND	660	ND	ND	320
Trip Blank	0	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = Analyte not detected
Elapsed time indicates the amount of time the water was in contact with the iron.
Analysis included additional VOCs, but there were no other detections.

Table 3-3
Hydraulic Conductivity of Zero-Valent Iron
Former Miller Container Plant , Volney,NY

Iron	Hydraulic Conductivity (cm/sec)[1]
Peerless 16/70 P1	1.1×10^{-2}
Peerless 8/50	7×10^{-2}
Connelly 8/50	5.5×10^{-2}
Steel shot	

Note: [1] = Data supplied from various PRB sites.

Table 3-4
Analytical Results from Column Test
Former Miller Container Site, Volney, NY

Analyte	Units	MC-0 Influent	MC-1 5 Hours	MC-2 10 Hour	MC-3 15 Hour	MC-4 30 Hours
Alkalinity	mg/L	356	96	104	80	64
BOD	mg/L	<6	25	<6	8	<6
TDS	mg/L	966	650	648	584	548
Calcium, Total	mg/L	100	10.6	4.65	5.22	1.32
Iron, Total	mg/L	0.73	0.107	0.101	0.133	0.376
Magnesium, Total	mg/L	25.4	2.73	0.39	1.22	0.38
Benzene	ug/L	<25	<10	<5.0	<0.7	<0.7
Bromobenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
Bromochloromethane	ug/L	<25	<10	<5.0	<1.0	<1.0
Bromodichloromethane	ug/L	<25	<10	<5.0	<1.0	<1.0
Bromoform	ug/L	<25	<10	<5.0	<1.0	<1.0
Bromomethane	ug/L	<50	<20	11*	4.5*	<1.0
N-Butylbenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
sec-Butylbenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
tert-Butylbenzene	ug/L	<25	<10	<5.0	<1.0	<
Carbon Tetrachloride	ug/L	<25	<10	<5.0	<1.0	<1
Chlorobenzene	ug/L	<25	<10	<5.0	<1.0	<1.
Chlorodibromomethane	ug/L	<25	<10	<5.0	<1.0	<1.
Chloroethane	ug/L	<50	<20	*	*	<1.0
Chloroform	ug/L	<25	<10	<5.0	<1.0	<1.0
Chloromethane	ug/L	<50	<20	<10	<1.0	<1.0
2-Chlorotoluene	ug/L	<25	<10	<5.0	<1.0	<1.0
4-Chlorotoluene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,2-Dibromo-3-Chloropro	ug/L	<25	<10	<5.0	<1.0	<1.0
1,2-Dibromoethane	ug/L	<25	<10	<5.0	<1.0	<1.0
Dibromomethane	ug/L	<25	<10	<5.0	<1.0	<1.0
1,2-Dichlorobenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,3-Dichlorobenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,4-Dichlorobenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
Dichlorodifluoromethane	ug/L	<50	<20	<5.0	<1.0	<1.0
1,1-Dichloroethane	ug/L	72	45	28	12	<1.0
1,2-Dichloroethane	ug/L	<25	<10	<5.0	<1.0	<1.0
1,1-Dichloroethene	ug/L	52	<10	<5.0	1.1	<1.0
cis-1,2-Dichloroethene	ug/L	130	13	<5.0	<1.0	<1.0
trans-1,2-Dichloroethene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,2-Dichloropropane	ug/L	<25	<10	<5.0	<1.0	<1.0
1,3-Dichloropropane	ug/L	<25	<10	<5.0	<1.0	<1.0
2,2-Dichloropropane	ug/L	<25	<10	<5.0	<1.0	<1.0
1,1-Dichloropropene	ug/L	<25	<10	<5.0	<1.0	<1.0
cis-1,3-Dichloropropene	ug/L	<25	<10	<5.0	<1.0	<1.0
trans-1,3-Dichloropropene	ug/L	<25	<10	<5.0	<1.0	<1.0
Ethylbenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
Hexachlorobutadiene	ug/L	<25	<10	<5.0	<1.0	<1.0
Isopropibenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
p-Isopropyltoluene	ug/L	<25	<10	<5.0	<1.0	<1.0
Methylene chloride	ug/L	<25	<10	<5.0	<1.0	<1.0
Naphthalene	ug/L	<25	<10	<5.0	<1.0	<1.0
n-Propylbenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
Styrene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,1,1,2-Tetrachloroethane	ug/L	<25	<10	<5.0	<1.0	<1.0
1,1,2,2-Tetrachloroethane	ug/L	<25	<10	<5.0	<1.0	<1.0
Tetrachloroethene	ug/L	<25	<10	<5.0	<1.0	<1.0
Toluene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,2,3-Trichlorobenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,2,4-Trichlorobenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,1,1-Trichloroethane	ug/L	350	<10	<5.0	<1.0	<1.0
1,1,2-Trichloroethane	ug/L	<25	<10	<5.0	<1.0	<1.0
Trichloroethene	ug/L	<25	<10	<5.0	<1.0	<1.0
Trichlorofluoromethane	ug/L	<25	<10	<5.0	<1.0	<1.0
1,2,3-Trichloropropane	ug/L	<25	<10	<5.0	<1.0	<1.0
1,2,4-Trimetylbenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
1,3,5-Trimethylbenzene	ug/L	<25	<10	<5.0	<1.0	<1.0
Vinyl chloride	ug/L	<50	<20	<10	<1.0	<1.0
o-Xylene	ug/L	<25	<10	<5.0	<1.0	<1.0
m-Xylene	ug/L	<25	<10	<5.0	<1.0	<1.0
p-Xylene	ug/L	<25	<10	<5.0	<1.0	<1.0

*Chromotographically, Bromomethane & Chloroethane co-elutes. Therefore, the reported value may represent either of these compounds or a combination thereof.

What is retention time? How do we ensure sufficient retention time.

Table 3-5
Analytical Results from Initial Column Test
Former Miller Container Site, Volney, NY

Analyte	Influent (ug/L)	Influent (ug/L)	C2-1 5-hour (ug/L)
Vinyl Chloride	<5	<5	<5
Chloroethane	<5	<5	<5
1,1-Dichloroethene	10	12	<1
t-Dichloroethane	<1	<1	<1
1,1-Dichloroethane	2.7	2.7	10
c-Dichloroethene	4.3	4.4	<1
Chloroform	1.3	1.3	<1
1,1,1-Trichloroethane	410	430	31
Trichloroethene	<1	<1	<1
1,1,2-Trichloroethane	<1	<1	<1
Tetrachloroethene	250	270	19
Hexachlorobutadiene	<5	<5	<5

Table 3-6
Water Chemistry Results from Column Test
Former Miller Container Site, Volney, NY

		Influent	5-hour	10-hour	30-hour
pH	std	6.5	9	9	9
Redox	mV	282.6	207.6	51.5	-62.2
Alkalinity	ppm	240	120	60	60
Total Hardness	ppm	250	75	25	50
Dissolved Iron	ppm	0.3	5	5	5

		Influent	5-hour	10-hour	15-hour	30-hour
pH	std	7.5	8	8.5	8.5	8.5
Redox	mV	5.65	5.66	6.24	6.26	6.35
Alkalinity	ppm	240	0	40	40	80
Total Hardness	ppm	250	50	50	50-120	25

Table 4-1
Well Construction Details
Former Miller Container Plant, Volney NY

Well ID	Screen Interval (ft bgs)	Screen Length (ft)	Casing Diameter (inches)	Installation Date	TOC Elevation (ft above MSL) [1]
PZ-1	69.9 - 79.9	10.0	1.0	2/28/00	373.43
PZ-2	69.0 - 79.0	10.0	1.0	2/28/00	372.92
PZ-3	69.0 - 79.0	10.0	1.0	2/28/00	372.82
PZ-4	71.0 - 81.0	10.0	1.0	2/28/00	372.92
PZ-5	48.0 - 53.0	10.0	1.0	2/28/00	372.64
PZ-6	68.2 - 78.2	10.0	1.0	2/28/00	370.15
GEO-1	69.5 - 79.5	15.0	3.0	3/2/00	372.55
GEO-2	69.5 - 79.5	15.0	3.0	3/2/00	371.58
GEO-3	69.5 – 79.	15.0	3.0	3/1/00	371.27

Table 5-1
Analytical Methods for Pilot Test
Former Miller Container Plant , Volney, NY

Parameter/Analyte	Method
Field Parameters	
Groundwater Elevation (Field Measurem	Water level indicator
Conductance (field measurement)	SM18 2510B
Dissolved Oxygen (field measurement)	EPA 360.2
pH (field measurement)	EPA 150.1
Redox Potential (field measurement)	Portable meter
Laboratory Analyses	
VOC	EPA 8021
Alkalinity	SM18-2320B
Total Dissolved Solids	EPA 160.1
Calcium	EPA 215.1
Iron	EPA 236.1
Magnesium	EPA 242.1
BOD_5	SM18 5210
Bacterial Analysis	9215 Modified

Table 5-2

Summary of Groundwater Sampling Chronology and Parameters for Zero-Valent Iron PRW Pilot Study

Former Miller Container Plant, Volney NY

Event	Date	Field Parameters	BOD	Bacteria	Alkalinity	TDS	VOCs	Metals
Round 1	3/15/00	✓	✓		✓	✓	✓	✓
Round 2	4/24/00	✓			✓	✓	✓	✓
Round 3	6/6/00	✓	✓	✓			✓	✓ [1]
Round 4	8/17/00	✓					✓	
Round 5	9/29/00	✓					✓	
Round 6	11/21/00	✓			✓	✓	✓	✓ [2]

[1] Only iron was measured..

[2] Only calcium and magnesium was measured.

Table 5-3
ORP Results from Pilot Test
Former Miller Container Plant, Volney NY

Monitoring Point	ORP (mV)				
	3/15/2000	4/24/2000	6/13/2000	9/29/2000	11/21/2000
Upgradient Wells					
PZ-1	-118	-102.2	-66	-92.2	-114.4
PZ-3	-76	-139.3	-32	-155.5	-132.6
PZ-6	66	-78.9	53	-36.9	-58.8
Mid Wall Wells					
PZ-4	54	-10	-70	-129.6	-120.4
GEO-2	62	-84.7	-142	-166.3	-125.5
Downgradient Wells					
PZ-2	-124	-21.5	-160	-112.2	-99.1
GEO-1	70	-21.6	-60	-108.2	-119.6
GEO-3	65	48.4	-98	-118.5	-126.2
Above Wall Wells					
PZ-5	-68	-51.2	21	-70.4	-64.3

Table 6-1

Groundwater Concentrations versus NYSDEC Criteria

Former Miller Container Plant, Volney, NY

Contaminant	NYSDEC Generic Criteria (ug/L)	EPA MCLs (ug/L)	Maximum Concentration Detected PRW-1 (ug/L)	Maximum Concentration Detected Mid-Site (ug/L)	Maximum Concentration Detected PRW-2 (ug/L)	Maximum Concentration Detected PRW-3 (ug/L)
Tetrachloroethene	5	5	27	32	353	3100
Cis-1,2-Dichloroethene	5	70	1	3	62	96
1,1-Dichloroethene	5	7	6.2	15	30	500
Vinyl chloride	5	5	<0.5	<1	<10	<20
1,1,1-Trichloroethane	5	200	36	21	119	2400
1,1-Dichloroethane	5	-	1.2	9.5	25	74

Based on highest concentration detected in 2000/ 2001