

Appendix A
Bench-Scale Treatability Study
Results

**Bench-Scale Treatability Report in Support of a
Granular Iron Permeable Reactive Barrier Installation
at the Pleasant Hill Site, CA**

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1.0 INTRODUCTION AND BACKGROUND

This bench-scale treatability report was prepared by EnviroMetal Technologies Inc. (ETI) for ERM to support the design of a granular iron permeable reactive barrier (PRB) for treatment of dissolved chlorinated volatile organic compounds (VOCs) present in groundwater at a site in Pleasant Hill, CA (the “site”). This report presents the results and data interpretation of a column treatability study conducted by ETI’s affiliated company Adventus at their laboratory in Mississauga, Ontario.

1.1 Background Information on the Granular Iron Technology

Numerous *in-situ* PRBs have been successfully implemented as an alternative groundwater remediation technology (RTDF 2004; O’Hannesin and Gillham, 1998). *In-situ* PRB technology involves the construction of a permeable wall or barrier, containing appropriate reactive materials, across the path of a contaminant plume. As the contaminated groundwater passes through the wall, the contaminants are removed through chemical or physical processes. Various configurations of *in-situ* treatment systems have been implemented, based on site-specific conditions. Advantages of *in-situ* PRBs include:

- low maintenance costs;
- no operating costs;
- long-term passive treatment;
- absence of waste materials requiring treatment or disposal;
- absence of invasive surface structures and equipment; and
- conservation of groundwater resources.

Several types of materials have been suggested for use in PRBs. The most advanced stage of application has been achieved with systems using granular iron to degrade chlorinated organic compounds. Under highly reducing conditions and in the presence of metallic surfaces, certain dissolved chlorinated organic compounds in groundwater degrade to non-toxic products such as ethene, ethane and chloride (Gillham and O’Hannesin, 1994). The process is abiotic reductive dehalogenation, with the metal serving to lower the solution redox potential (Eh) and as the electron source in the reaction. Using granular iron as the reactive metal, reaction half-lives (the time required to degrade one half of the original contaminant mass) are commonly several orders of magnitude lower than those measured under natural conditions. The technology is particularly attractive for the remediation of contaminated groundwater

because of the high rates of degradation, the granular iron is relatively inexpensive, the process requires no external energy supply and because most compounds are degraded with production of few, if any, hazardous (chlorinated) organic by-products.

To date, granular iron PRBs have been installed at over 140 sites in the United States, Canada, Europe, Japan and Australia. These PRBs have been installed at Superfund sites; as part of brownfield site redevelopment; at various active manufacturing, DoD and DOE facilities; at former dry cleaning facilities; and landfills. The earliest commercial applications in California and Belfast, Ireland have been in operation for the past 11 years.

1.2 Approach to Technology Implementation at the Site

A granular iron PRB has been proposed as an *in-situ* treatment technology to degrade the main contaminants trichloroethene (TCE), cis 1,2-dichloroethene (cDCE), 1,1-dichloroethene (11DCE), and vinyl chloride (VC) present in the groundwater at the site. When viewed in the context of previous successful applications, the site appears quite amenable to treatment using this technology:

- i) the primary contaminants present, TCE, cDCE, 11DCE, and VC, have been successfully treated in numerous laboratory studies and field sites; and
- ii) the main inorganic constituents of the plume appear to pose no significant impediment to technology application.

Based on the information provided to ETI by ERM, a PRB with a length of 350 ft and a saturated plume thickness of 25 ft that extends from 15 to 40 ft below ground surface (bgs) will be evaluated. The estimated groundwater velocity at the proposed PRB location is about 40 ft/year (0.11 ft/day).

Several design parameters need to be addressed and quantified in order to apply the granular iron technology in the field. This bench-scale test was initiated to provide design parameters (VOC degradation rates) for the anticipated maximum concentrations entering the PRB. Specifically, the following factors need to be investigated to facilitate field implementation of a treatment system at the site:

- i) The degradation rates of TCE, cDCE, 11DCE, and VC present in the site groundwater. Using site groundwater and a commercial iron source, these rates allow the calculation of the iron thickness required to achieve VOC concentrations below the regulatory limits.
- ii) The production and subsequent degradation rates of chlorinated compounds produced from the VOCs originally present in the site groundwater [e.g., cDCE and VC from TCE]. These can also affect the dimensions of the treatment system.
- iii) The effects of the process on the inorganic chemistry of the groundwater, in particular, the potential for mineral precipitation. Mineral precipitates could affect the long-term maintenance requirements of the treatment system.

1.3 Bench-Scale Test Report Organization

The remainder of this report is organized as follows:

- Section 2.0 presents the detailed objectives and methods for the bench-scale test.
- Section 3.0 presents the organic and inorganic results from the bench-scale test.
- Section 4.0 discusses the calculated residence time required for VOC treatment to meet the target levels and provide a preliminary conceptual design for the treatment system.
- Section 5.0 summarizes the results.

2.0 BENCH-SCALE TEST OBJECTIVES AND METHODS

2.1 Bench-Scale Test Objectives

The primary objective of the bench-scale test was to provide the data necessary to determine the residence time to degrade the TCE, cDCE, 11DCE, and VC present at the site, and their chlorinated breakdown products, to below their regulatory criteria with granular iron. Samples collected during the laboratory column test were used to evaluate the following specific objectives:

- determine degradation rates of TCE, cDCE, 11DCE, and VC in site groundwater using a commercial source of granular iron;
- characterization of chlorinated breakdown products, and evaluation of the rates of degradation of these products; and
- changes in inorganic geochemistry as a result of the pH, Eh and alkalinity changes, including possible mineral precipitation.

2.2 Bench-Scale Test Methods

The bench-scale testing included a column containing 100 % granular iron obtained from Connelly GPM (CON) of Chicago, IL (CC-1004, -8 to +50 US Standard Mesh Size). The grain size distribution curve for this iron source is shown in Appendix A. A hydraulic conductivity value of 5.1×10^{-2} cm/sec (145 ft/day) for the granular iron was obtained using a falling head permeameter test. The specific surface area of the granular iron was 2.0 m²/g, which was determined by the BET method (Brunauer et al., 1938) on a Micromeretic Gemini 2375 surface analyzer.

The column was constructed of Plexiglas™ with a length of 1.6 ft (50 cm) and an internal diameter of 1.5 in (3.8 cm) (Figures 1 and 2). Seven sampling ports were positioned along the length at distances of 0.08, 0.16, 0.33, 0.50, 0.66, 1.0, and 1.3 ft (2.5, 5, 10, 15, 20, 30, and 40 cm) from the inlet end. The column also allowed for the collection of samples from the influent (0 ft, 0 cm) and effluent lines (1.6 ft, 50 cm). Each sampling port consisted of a nylon Swagelok fitting (0.063 in, 0.16 cm) tapped into the side of the column, with a syringe needle (16G) secured by the fitting. Glass wool was placed in the needle to exclude the iron

particles. The sampling ports allowed samples to be collected along the central axis of the column. Each sample port was fitted with a Luer-Lok™ fitting, such that a glass syringe could be attached to the port to collect a sample. When not in operation the ports were sealed by Luer-Lok™ plugs.

The granular iron, as received from the vendor, was packed in the column. To assure a homogeneous mixture, aliquots of iron were packed vertically in lift sections within the column. Values of bulk density, porosity, and pore volume (PV) were determined by weight (Table 1). The column experiment was performed at a temperature of approximately 22°C (72°F) (Appendix B). A low flow Master Flex® IPN pump was used to feed the site water from a collapsible Teflon® bag to the influent end of the column. The pump tubing consisted of Viton®, and all the other tubing was Teflon® [0.125 in (0.32 cm) OD × 0.063 in (0.16 cm) ID]. A flow velocity of about 1.4 ft/day (43 cm/day) for the column was selected in consultation with ERM.

2.2.1 Groundwater Shipment and Storage

Site groundwater was collected by ENSR from monitoring well MW-14A. The water was shipped in amber glass sample bottles with no headspace. The site water was stored at 4°C (39°F) until required at which time it was siphoned from the field sample bottles into a collapsible Teflon® bag. As noted in Appendix B by reservoir number [RN], the influent reservoir was filled four times [a-d] over the course of the test for the columns.

The initial concentrations of VOCs detected in the site water sample averaged: 4,200 µg/L for TCE, 400 µg/L for cDCE, 460 µg/L for 11DCE and 130 µg/L for VC.

2.2.2 Sampling and Analysis

The columns were sampled for VOCs every 4 to 7 PVs until steady state concentration profiles were achieved. In the bench-scale test, steady state is defined as the time when VOC concentrations versus distance profiles do not change significantly between sampling events. After removing the stagnant water from the sampling needle, 4.0 mL samples were collected from the sampling ports using glass on glass syringes, transferred to glass sample bottles, and analyzed immediately (no holding time). Samples for organic analyses, redox potential (Eh),

pH, nitrate, chloride and sulphate were collected from each port as well as from the influent solution and the effluent overflow bottles (Appendix B).

Additional samples for complete inorganic analyses (Appendix C) were obtained from the influent solution and the effluent overflow bottles towards the end of the test as steady state conditions were approached.

2.3 Analytical Methods

2.3.1 Organic Analyses

The less volatile halogenated organics such as tetrachloroethene (PCE) and trichloroethene (TCE) were extracted from the water sample within the glass sample bottle using pentane with an internal standard of 1,2-dibromoethane, at a water to pentane ratio of 2.0 to 2.0 mL. The sample bottles were placed on a rotary shaker for 15 minutes to allow equilibration between the water and the pentane phases, then the pentane phase is transferred to an autosampler bottle. Using an Agilent autosampler, a 1.0 μL aliquot of pentane with internal standard was automatically injected directly into a Agilent 6890N gas chromatograph. The chromatograph was equipped with a Ni^{63} electron capture detector (ECD) and DB-624 megabore capillary column (30 m x 0.538 mm ID, film thickness 3 μm). The gas chromatograph had an initial temperature of 40°C, with a temperature time program of 10°C/minute reaching a final temperature of 150°C. The detector temperature was 300°C. The carrier gas was helium and makeup gas was 5% methane and 95% argon, with a flow rate of 30 mL/min.

For the more volatile compounds such as cis 1,2-dichloroethene (cDCE), trans 1,2-dichloroethene (tDCE), 1,1-dichloroethene (11DCE) and vinyl chloride (VC), 4.0 mL samples were collected in glass on glass syringes and placed in 10 mL Telfon[®] faced speta crimp cap vials, creating a headspace with a ratio of 6.0 mL headspace to 4.0 mL aqueous sample. The samples were placed on a rotary shaker for 15 minutes to allow equilibration between the water and gas phase. Using an Agilent G1888 headspace auto sampler, a 1 mL stainless steel sample loop injects the samples directly onto an Agilent 6890N gas chromatograph. The chromatograph was equipped with a HNU photoionization detector (PID) with a bulb ionization potential of 10.2 eV. The gas chromatograph was fitted with a fused silica capillary NSW-PLOT column (15 m x 0.53 mm ID). The samples are placed in the analyzer oven for 2 minutes at 75°C, and subsequently injected onto the gas chromatograph. The

temperature program was initially set at 50°C, then increased at 20°C/min to 200°C and held for 7 minutes. The injector and detector temperatures are 200°C and 150°C, respectively. The carrier gas is helium with a flow rate of 14 mL/min. Data is collected with a HP Pentium XP computer using GC-Chemstation Version B.01.03.

Method detection limits (MDL) were determined for each compound as the minimum concentration of a substance that can be identified, measured and reported with 99% confidence that the analyte concentration is greater than zero. The MDLs were determined from analysis of samples from a solution matrix containing the analytes of interest. Although MDLs are reported, these values are not subtracted from any reported VOC concentrations (Appendix B). The reason for this is that it indicates that the organic concentrations are approaching or advancing within the column, and is helpful when determining degradation rates. Detection limits for all compounds, as given in Table 2, were determined using the EPA procedure for MDL (US EPA, 1982).

2.3.2 Inorganic Analyses

Eh was determined using a combination Ag/AgCl reference electrode with a platinum button and an Oakton™ meter. The electrode was standardized with an ORP standard (ThermElectron Corporation). Millivolt (mV) readings were converted to Eh, using the electrode reading and the standard potential of the Ag/AgCl electrode at a given temperature. The pH measurements were made using a combination pH/reference electrode and an Oakton™ meter, standardized with the pH buffer 7 and the appropriate buffer of either 4 or 10. A 2.0 mL sample was collected with a glass on glass syringe and analyzed immediately for Eh and then pH.

UW also analyzed for nitrate (as N), sulphate and chloride by collecting a 0.5 mL sample in autosampler plastic vials. The samples were then placed on a Dionex AS-40 autosampler. A 25 µL sample was then injected onto a Dionex ion chromatograph (ICS-2000) equipped with an ion-eluent generator and conductivity detector. A Dionex IonPac AS18 (4 x 250 mm) was used. The mobile phase used was 30 mM KOH at a flow rate of 1.2 mL/min. The data were collected with a Dell P4-3GHz computer using Dionex chromeleon 6.5 software.

At the conclusion of the test, two water samples were collected from the influent and effluent of the column and sent to Maxxam Analytics Inc. for cation and anion analyses. Cation analyses, included Fe, Na, Mg, Ca, K, Mn, etc. were performed using inductively coupled plasma (ICP). All cation samples were unfiltered and acidified to a pH of 2 with nitric acid.

Anion analyses, including Cl, NO₃, SO₄, etc. were performed using ion chromatography. In addition, alkalinity, ammonia (as N), total organic carbon (TOC) and dissolved organic carbon (DOC) analyses are determined by colorimetry and were sampled from the column influent and effluent. The TOC and DOC samples were unfiltered and acidified to a pH of 2 with sulphuric acid. Detection limits for the inorganic parameters are included in Table 2.

3.0 BENCH-SCALE TEST RESULTS

3.1 Degradation of Volatile Organic Compounds

Samples for measurement of VOC concentrations along the length of each of the columns were taken approximately every 4 to 7 PVs (Appendix B). Using the distance for each sampling port and dividing by the flow velocity, the residence time was calculated for each port. The results obtained when steady state conditions were reached are plotted as VOC concentration (µg/L) versus residence time within the column (hrs). The final steady-state concentration profiles for the column are shown in Figures 3 and 4. At a flow velocity of about 1.4 ft/day (43 cm/day), one PV corresponds to a residence time of about 27.7 hrs for the column. A total of about 64 PVs of water were passed through the column.

Figures 3 and 4 show the steady state profiles for TCE, cDCE, 11DCE and VC. The influent concentration of TCE declined from 5,433 µg/L to a non-detectable value within a residence time of 16.6 hrs (Figure 3). For cDCE, the influent concentration of 363 µg/L remained unchanged within a residence time of 11.1 hrs and then decreased to 18 µg/L in the column effluent (Figure 4). The apparent lag in the cDCE degradation can be attributed to cDCE production from TCE, and the subsequent degradation at a slower rate. The influent concentration of 11DCE decreased from 384 µg/L in the influent to 7.4 µg/L at a residence time of 22.2 hrs (Figure 4). VC was degraded within the column from 25 µg/L to 4.1 µg/L. Trace concentrations of tDCE were also degraded within the column.

3.2 Determination of VOC Degradation Parameters

The VOC degradation trends observed in groundwater in contact with granular iron are typically described using first-order kinetics:

$$C = C_o e^{-kt} \quad (1)$$

or

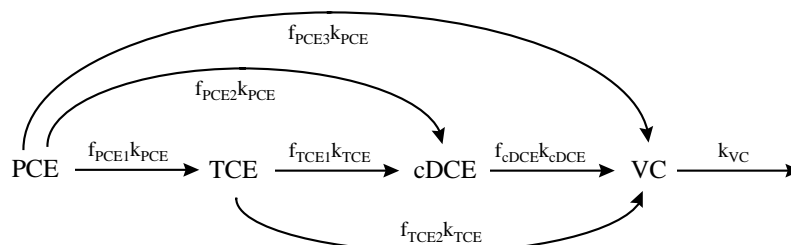
$$\ln\left(\frac{C}{C_o}\right) = -kt \quad (2)$$

where: C = VOC concentration in solution at time t,
C_o = VOC concentration of the influent solution,
k = first-order rate constant, and
t = time.

The time at which the initial concentration declines by one-half, (C/C_o = 0.5), is the half-life.

ETI has developed a first-order kinetic model to simulate the degradation of VOCs with granular iron. In the model, potential breakdown products are concurrently produced and degraded as described by first-order kinetic equations. The model is an expression of the chemistry that is observed in the solution phase. For example, for the chlorinated ethenes (PCE, TCE, cDCE and VC) the production of chlorinated acetylene via a β -elimination pathway is considered to be the dominant degradation pathway (Eykholt, 1998; Arnold and Roberts, 1999). However, since chlorinated acetylenes are unstable, short-lived, intermediates that are rapidly reduced to ethene (Roberts et al., 1996; Sivavec et al., 1997), these compounds are not typically detected in the solution phase and are therefore not explicitly contained in the degradation model.

The equations contained in the model were developed by ETI to describe the first-order kinetic degradation process occurring in a granular iron groundwater treatment zone. For example, PCE, TCE, cDCE and VC the model takes the form:



where: f = mole fraction (or percent molar conversions)
 k = first-order rate constant

In order to determine the VOC concentrations at a given time the following first-order equations are used:

$$dPCE / dt = -k_{PCE}PCE \quad (3)$$

$$dTCE / dt = f_{PCE1}k_{PCE}PCE - k_{TCE}TCE \quad (4)$$

$$dcDCE / dt = f_{PCE2}k_{PCE}PCE + f_{TCE1}k_{TCE}TCE - k_{cDCE}cDCE \quad (5)$$

$$dVC / dt = f_{PCE3}k_{PCE}PCE + f_{TCE2}k_{TCE}TCE + f_{cDCE}k_{cDCE}cDCE - k_{VC}VC \quad (6)$$

These equations were adapted for the computer program Scientist[®] for Windows[®] Version 2.0 (1995). The Scientist[®] program can be used to fit the first-order equations to experimental data using the least squares best-fit method. Least squares fitting is performed using a modified Powell algorithm to find a local minimum of the sum of squared deviations between observed data and model calculations. The degradation rate and molar conversion are determined for each compound sequentially starting with the most chlorinated compound.

The results from the model include half-lives for all VOCs selected and statistical fit data including coefficient of determination (r^2) values. The r^2 values indicate how well the degradation model represents the experimental data. The half-lives determined from the TCE, cDCE, tDCE, 11DCE and VC profiles are shown in Table 3, along with the corresponding r^2 values.

The steady state field temperature (22°C; 72°F) half-life values were 1.8 hrs for TCE, 9.4 hrs for cDCE, 5.6 hrs for 11DCE, and 5.7 hrs for VC (Table 3 and Appendix B). Figure 5 summarizes the molar conversions determined from fitting the degradation model to the data from the column.

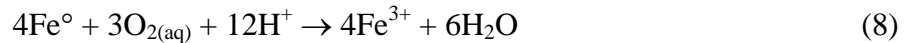
3.3 Inorganic Results

Two influent and effluent samples were collected from the column as steady state approached. Changes in inorganic chemical constituents observed in the influent and effluent groundwater are summarized in Table 4. Appendix C contains the inorganic analytical data. The results are consistent with those observed in other studies, and are explained below.

When iron is exposed to water, several reactions occur as a result of iron corrosion:



This iron corrosion drives the geochemical changes that occur as groundwater flows through the PRB. When groundwater first contacts the granular iron, any dissolved oxygen present is consumed via iron corrosion:



After the initial, rapid depletion of any dissolved oxygen, the water corrosion of iron dominates to produce hydrogen and hydroxide resulting in an increase in pH and a decline in Eh:

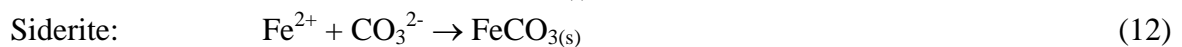
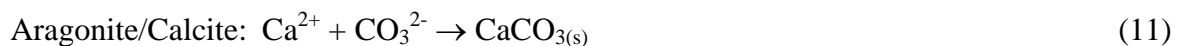


Figure 6 show the Eh and pH profiles observed for the column. The redox potential (Eh) declined to from an initial value of about +417 mV to a minimum value of about -522 mV (Figure 6). Values of pH increased from 7.3 to 9.1 in the column (Figure 6; Appendix B).

As pH increases due to water corrosion, bicarbonate (HCO_3^{-}) in solution converts to carbonate (CO_3^{2-}) to buffer some of the pH increase:



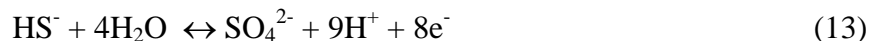
The carbonate may then combine with cations (Ca^{2+} , Fe^{2+} , and Mg^{2+}) in solution to form carbonate mineral precipitates; mainly calcite and siderite:



The column showed that the influent calcium concentration of 130 mg/L declined to a concentration of 6.2 mg/L. The alkalinity values decreased from an initial value of about 566 mg/L to a concentration of 187 mg/L in the column. Declines in calcium and alkalinity concentrations indicate formation of calcium carbonate minerals (see above). In analyses of iron cores obtained from previous laboratory studies and field sites, siderite as well as both calcite and aragonite, which are forms of calcium carbonate, have been identified.

Concentration of magnesium decreased from 78 mg/L to 31 mg/L in the column. Magnesium has been known to substitute for calcium and iron in the structure of calcium and iron carbonates ($\text{CaMg}(\text{CO}_3)_2$ or $\text{FeMg}(\text{CO}_3)_2$). Magnesium may also precipitate as magnesium hydroxide ($\text{Mg}(\text{OH})_2$), known as brucite, and/or magnesium silicate [sepiolite ($\text{Mg}_4\text{Si}_6\text{O}_{15}(\text{OH})_2 \cdot 6\text{H}_2\text{O}$)].

The concentration of sulphate decreased from an influent concentration of 149 mg/L to about 39 mg/L. At high Eh, the stable ionic form of sulphur is sulphate (SO_4^{2-}), while at very low Eh sulphide (H_2S or HS^-) is the stable form with HS^- being predominant at pH greater than 7:



Given the low solubility of iron sulphide (FeS), the hydrogen sulphide produced precipitates out of solution.



Over time, iron sulphides transform into pyrite (FeS_2) and/or marcasite, a polymorph of pyrite. Sulphate reduction may be mediated by biological activity. Declines in sulphate concentrations have been observed at a number of field sites as groundwater passes through iron treatment zones. Wilkin et al. (2003) found evidence for the formation of iron monosulfides in cores from two PRB field sites.

Potassium, chloride, sodium, boron, barium, TOC, and DOC concentrations remained essentially unchanged within the column. A decrease in concentration was observed in manganese, silicon, and reactive silica within the column.

These results are consistent with the inorganic trends normally observed in iron column tests, and indicate no impediment to field implementation. This issue is further addressed in Section 4.4.

4.0 FIELD-SCALE TREATMENT SYSTEM DESIGN CONSIDERATIONS

4.1 Field Anticipated Half-Lives

The laboratory half-lives were obtained at a temperature of 22°C (72°F). Based on the previous research, VOC degradation half-lives increase by 100% per every 8°C temperature decrease within a temperature range of 5 to 25°C (O'Hannesin et al., 2004). Assuming that the minimum field groundwater temperature at the site does not fall below 14°C (57°F), the room temperature half-lives were increased by a factor of 2 to obtain the anticipated field values (Table 5).

4.2 Required Residence Time

The temperature-corrected half-lives determined based on the column test results at steady state and the anticipated VOC concentrations entering the PRB provided by ERM were input into the first-order degradation model to determine the residence time requirements in a field-scale system (Table 5). The Scientist[®] program described in Section 3.2 may also be used to simulate the change in VOC concentrations over time using the first-order kinetic equations. In simulation mode, the model calculates the VOC concentrations over time, from which the time required for the VOCs to degrade to their regulatory criteria can be determined.

The site cleanup criteria provided by ERM for TCE, cDCE, 11DCE, and VC are 5, 6, 6, and 0.5 µg/L, respectively (Table 5). The residence time required to degrade 4,200 µg/L of TCE, 400 µg/L of cDCE, 460 µg/L of 11DCE, and 130 µg/L of VC to the target levels is 5.4 days for Connelly iron (Table 5; Figure 7).

4.3 Conceptual System Design

The iron treatment zone must provide an adequate groundwater flow length to allow the contaminants sufficient time to be treated. The iron flow-through thickness is estimated from the anticipated groundwater velocity in the PRB multiplied by the residence time required for treatment.

Based on information from ERM, the granular iron zone may be installed from a depth of about 15 ft below ground surface (bgs) to a maximum depth of 40 ft bgs to intercept the

plume with a saturated thickness of 25 ft. Using the reported groundwater flow velocity of 0.11 ft/day and the required residence time of 5.4 days for Connelly iron, the theoretical required iron zone thickness for VOC degradation is about 0.6 ft (Table 5). Based on a 350 ft long PRB, the required volume of iron would be 5,250 ft³ or 394 tons (based on a iron bulk density of 0.075 tons/ft³) (Table 6).

4.4 Possible Mineral Precipitates

As noted in Section 3.3, the changes in carbonate and sulphate chemistry in this column test were very similar to those observed in column studies of similar groundwater, and also for trends observed in other field applications. These field data are summarized in ETI Technical Note 4.03, presented in Appendix E. While there is little doubt that inorganic (mostly carbonate) precipitates will form over time in a PRB installed at the site, their impact will not be significant, considering the relatively low groundwater velocity at the site and thus a relatively low mass flux of the inorganic species through the iron zone. In other words, it is anticipated that a PRB at this site would be able to last at least 10 to 15 years without rehabilitation due to carbonate and/or sulphide precipitate formation.

4.6 Iron Consumption

As discussed in Section 3.3, there are many processes such as water corrosion, VOC degradation, dissolved oxygen reduction, sulphate and methane reduction that may consume the iron. These processes are not independent of one another and also depend on site conditions such as groundwater flow velocity, inorganic aqueous concentrations, VOC concentrations, biological activity and temperature. All of these factors make it difficult to gauge with exact certainty the time required to consume the iron in a PRB.

If water corrosion were to remain constant over time at a typical rate of 0.3 mmol/kg Fe/day, the iron is predicted to last for about 150 years. However, Reardon (1995) noted declining hydrogen production over time at room temperature. This decline in corrosion rate was likely due to mineral precipitate formation on the surface of the iron over long periods of time. Warner et al. (2005) found that the groundwater pH at the first commercial PRB in Sunnyvale, CA continues to increase from a value of 7.5 in the upgradient aquifer to a value of about 11 in the PRB, and that dissolved hydrogen concentrations approach solubility. Clearly, water corrosion is still occurring at significant rates at this site after 11 years.

Other factors such as desaturation of the iron and oxidation by atmospheric oxygen would also affect the lifetime of the iron. Although there is some uncertainty in the conditions that may exist decades in the future, it seems reasonable to expect the iron in the PRB to last for many decades.

4.7 Potential for Biofouling of Reactive Material

There was no evidence of biofouling (sliming, etc.) observed during the bench-scale test. Field tests to date from other sites have not indicated significant biofouling. Based on this experience, there is no reason to believe that biofouling will be an issue in a PRB at the site.

4.8 Maintenance

Other than groundwater monitoring, the major factor affecting maintenance costs is the possible need for periodic rejuvenation of iron sections affected by precipitates.

The objective of rejuvenation of the granular iron would be to restore the permeability loss due to precipitates and possibly to remove the precipitate from the iron to restore any lost reactivity of the iron. Possible rejuvenation methods may include:

- i) Using ultrasound to break-up the precipitate;
- ii) Using pressure pulse technology to break-up the precipitate; and
- iii) Using solid-stem augers to agitate the PRB.

To date these possible rejuvenation methods have not been needed and only ultrasound has been tested in limited field-scale tests to determine its effectiveness. At this point we can only state that these methods may prove to be successful in rejuvenating a PRB. As noted above, it is likely that the PRB will perform for several years at the site prior to requiring rejuvenation.

5.0 SUMMARY

Bench-scale testing using groundwater from the Pleasant Hill, CA site, showed that:

- i) the Connelly granular iron degraded the TCE, cDCE, 11DCE, and VC present in the site water to below the remediation goals;
- ii) based on the field anticipated half-lives at the field groundwater temperature, a residence time of 5.4 days resulting in an iron thickness of 0.6 ft would be required in the iron PRB at the site;
- iii) redox potential (Eh) and pH trends were consistent with bench-scale tests with similar types of site waters and granular iron; and
- iv) the anticipated low quantity of carbonate mineral precipitates that will be formed in the iron PRB will not significantly affect PRB system performance for many years.

6.0 REFERENCES

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Table 1: Iron and Column Properties

Iron:	
Iron Source	Connelly GPM Chicago, IL
Product Name	CC-1004
Iron Grain Size	-8 to +50 mesh (1.7 to 0.15 mm)
Specific Surface Area	2.0 m ² /g
Iron Hydraulic Conductivity	5.1 x 10 ⁻² cm/sec (145 ft/day)
Column :	
Flow Velocity	1.4 ft/day (43 cm/day)
Residence Time	27.7 hrs
Pore Volume	308 mL
Porosity	0.54
Bulk Density	2.88 g/cm ³ (180 lb/ft ³)
Iron to Volume of Solution Ratio	5.3 g : 1 mL
Surface Area to Solution Ratio	10.6 m ² : 1 mL

Table 2: Method Detection Limits (MDL) and Reported Detection Limits (RDL)

Organic Compounds:	MDL (µg/L)
Trichloroethene (TCE)	0.9
Cis 1,2-dichloroethene (cDCE)	0.7
Trans 1,2-dichloroethene (tDCE)	0.6
1,1-Dichloroethene (11DCE)	0.6
Vinyl chloride (VC)	0.9
Inorganic Compounds:	RDL (mg/L)
Barium (Ba)	0.005
Boron (B)	0.010
Calcium (Ca)	0.2
Iron (Fe)	0.05
Magnesium (Mg)	0.05
Manganese (Mn)	0.002
Potassium (K)	0.2
Silicon (Si)	0.05
Sodium (Na)	0.1
Reactive Silica (SiO ₂)	0.5
Chloride (Cl ⁻)	3 [0.5 ^a]
Nitrate (as N) (NO ₃ ⁻)	0.1 [0.5 ^a]
Sulphate (SO ₄ ⁻²)	1 [0.6 ^a]
Alkalinity (mg CaCO ₃ /L)	1
Ammonia, Total (as N) (NH ₃ ⁺)	0.05
Dissolved Organic Carbon (DOC)	0.1
Total Organic Carbon (TOC)	0.1
Total Dissolved Solids (TDS)	1

^a Detection limit [UW Laboratory]

Table 3: Bench-Scale Test Half-Life at Steady State at a Test Temperature of 22°C (72°F)

Volatile Organic Compound	Influent Concentration (µg/L)	Half-Life at 22°C (72°F) (hr)	Coefficient of Determination (r²)
TCE	5,433	1.8	0.932
cDCE	363	9.4	0.880
11DCE	384	5.6	0.962
VC	25	5.7	0.639

Table 4: Major Influent and Effluent Inorganic Chemistry at Steady State Obtained From a Commercial Laboratory.

Parameter	Concentration (mg/L)	
	Influent	Effluent
Barium	0.18	0.25
	0.19	0.21
Boron	3.7	3.6
	3.5	3.5
Calcium	120	7.7
	130	6.2
Iron	nd	nd
	nd	nd
Magnesium	84	32
	78	31
Manganese	0.42	0.13
	0.96	0.18
Potassium	1.3	1.3
	1.0	1.1
Silicon	17	0.66
	16	0.61
Reactive Silica	30	1.2
	33	1.2
Sodium	200	200
	200	200
Strontium	1.3	0.04
	1.2	0.03
Chloride	190	190
	200	200
Nitrate (as N)	nd	nd
	nd	nd
Sulphate	148	56
	149	39
Alkalinity (mg CaCO ₃ /L)	518	173
	566	187
Ammonia (as N)	0.06	0.05
	0.08	nd
Dissolved Organic Carbon (DOC)	1.4	1.3
	1.4	1.4
Total Organic Carbon (TOC)	1.5	1.4
	1.5	1.6
Total Dissolved Solids (TDS)	1,050	594
	1,130	592

nd - not detected

Samples were collected at 42.4 PV and 48.5 PV

Table 5: Residence Time Calculation for VOC Treatment for the Proposed PRB for Connelly Iron

VOC	Anticipated Field Concentration^a (µg/L)	Target Level (µg/L)	Field Anticipated Half-Life^b (hrs)	Total Residence Time for VOC Treatment (days)
TCE	4,200	5	3.6	5.4
cDCE	400	6	18.8	
11DCE	460	6	11.2	
VC	130	0.5	11.4	
Theoretical Required Iron Thickness (ft)^c				0.60

^a Based on the composition of the well MW-14A sample provided for the test

^b Adjusted from half-lives obtained at a test temperature of 22°C (73°F)

^c Based on the reported groundwater velocity of 0.11 ft/day

Table 6: Proposed PRB Design Parameters For Connelly Iron

Iron Thickness (ft)	PRB Length (ft)	Saturated depth (ft)	Iron Volume (ft³)	Iron Amount ^a (ton)
0.60	350	25	5,250	394

^a Assuming a bulk density of 0.075 ton/ft³ for the backfilled granular iron

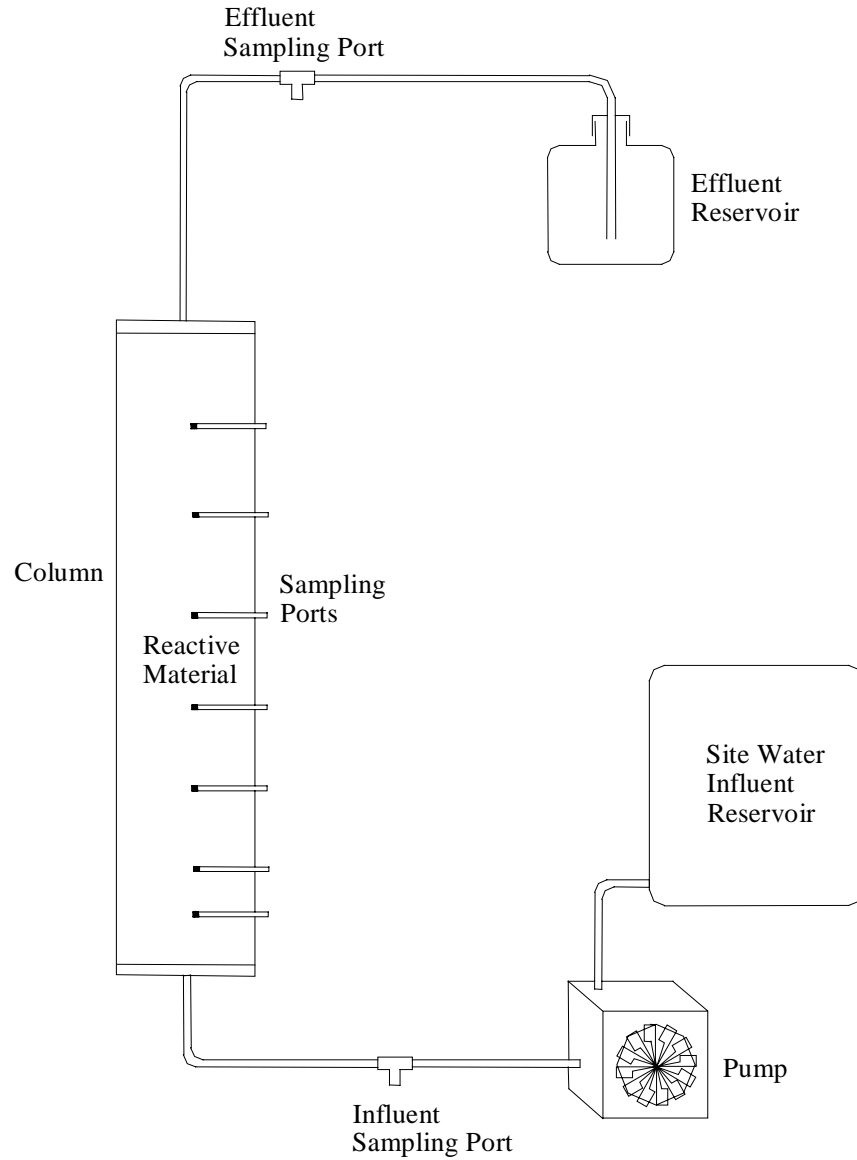


Figure 1: Schematic of the apparatus used in the bench-scale test.

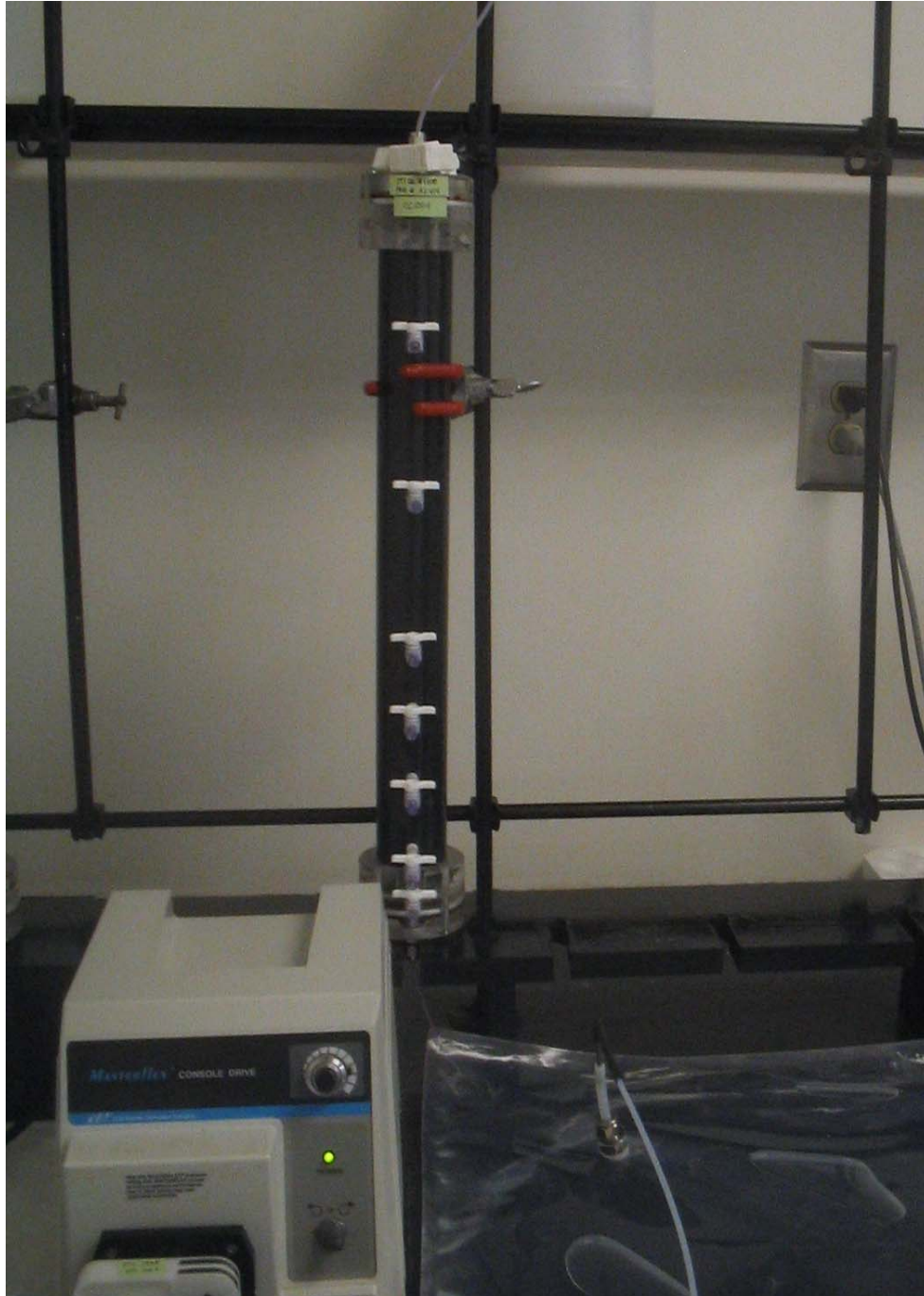


Figure 2: Photograph of granular iron column.

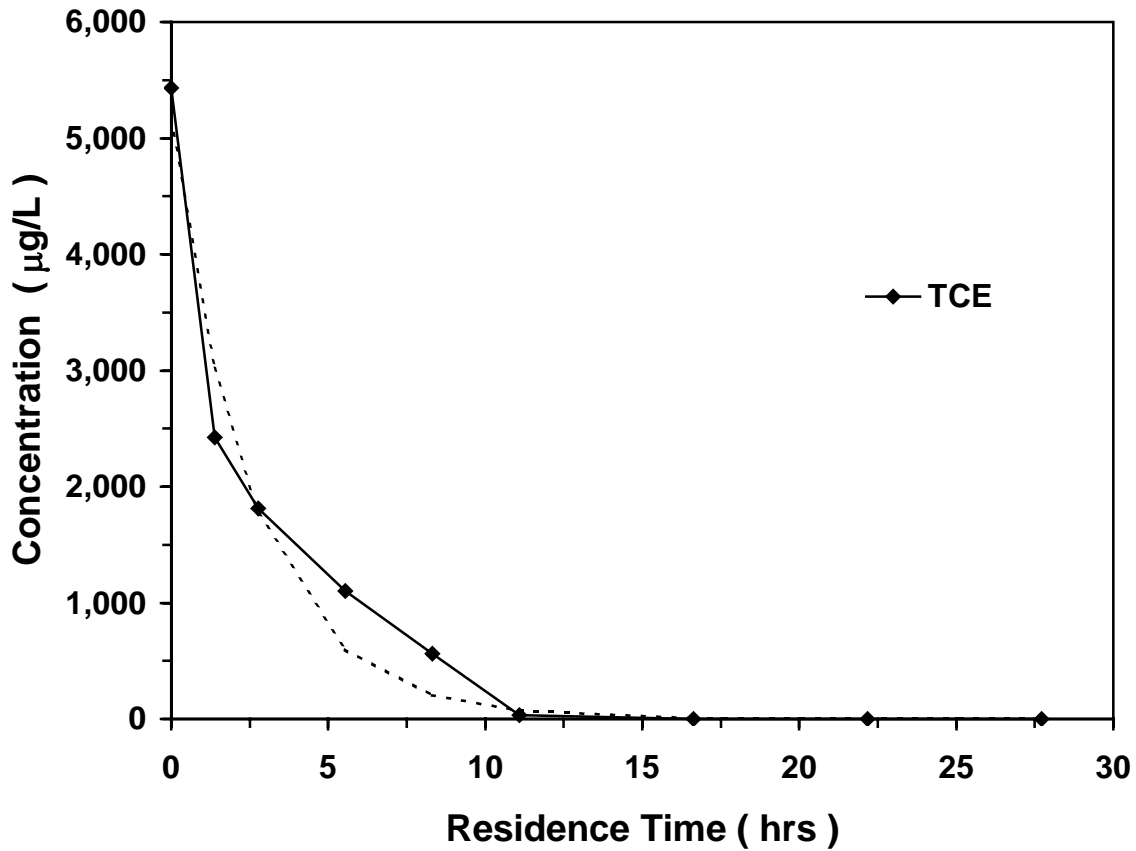


Figure 3: Trichloroethene (TCE) concentration profiles versus residence time along the column. The dotted line represents the least squares best fit of the first-order kinetic model to the data.

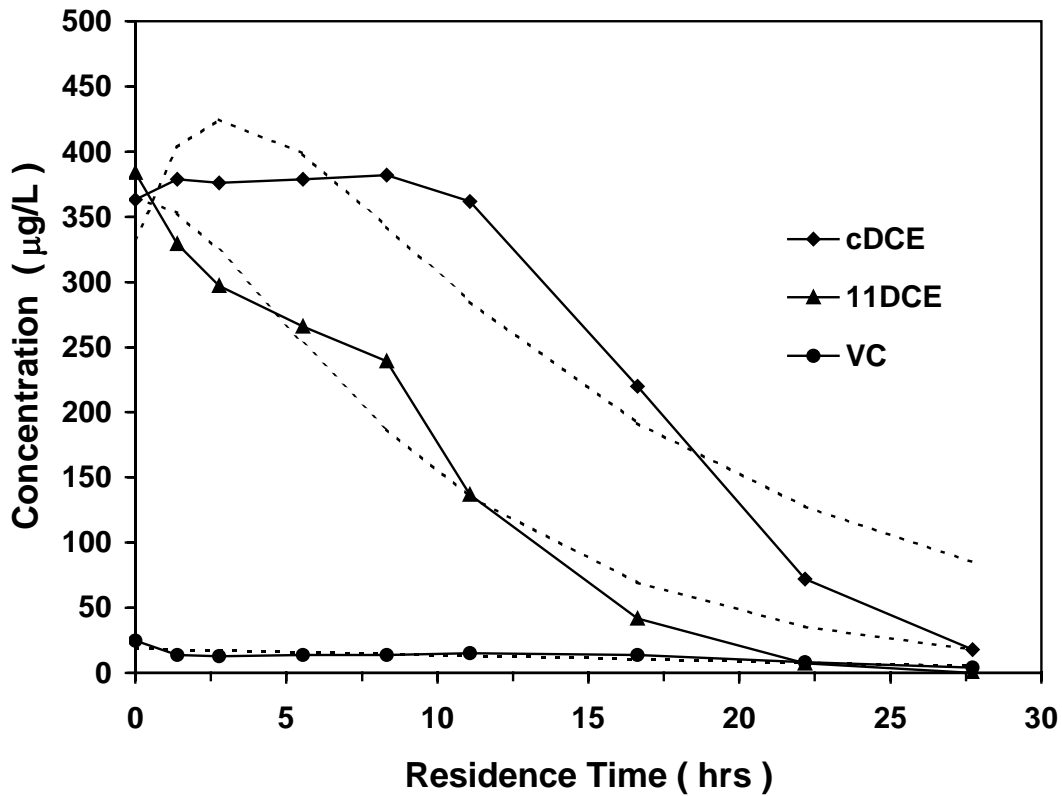


Figure 4: Cis 1,2-dichloroethene (cDCE), 1,1-dichloroethene (11DCE) and vinyl chloride (VC) concentration profiles versus residence time along the column. The dotted line represents the least squares best fit of the first-order kinetic model to the data.

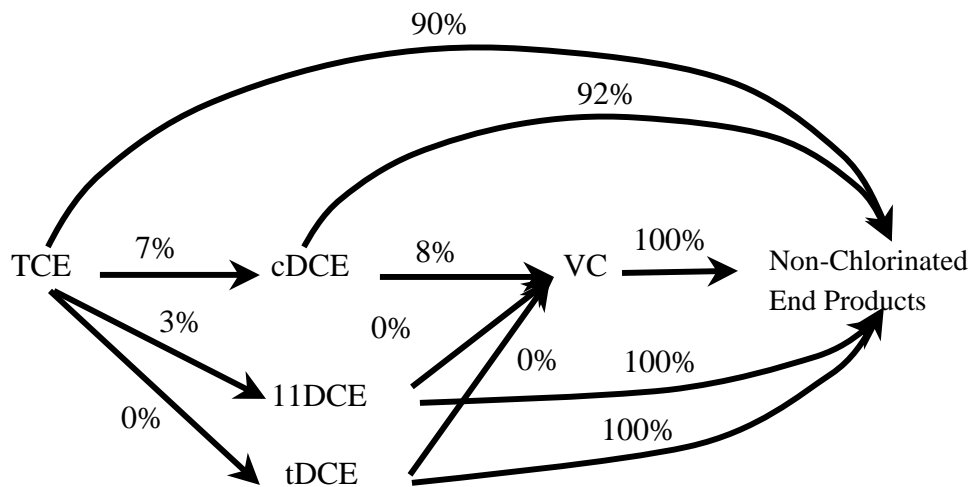


Figure 5: Calculated molar conversions observed from the least squares best fits of the first-order kinetic model for the column.

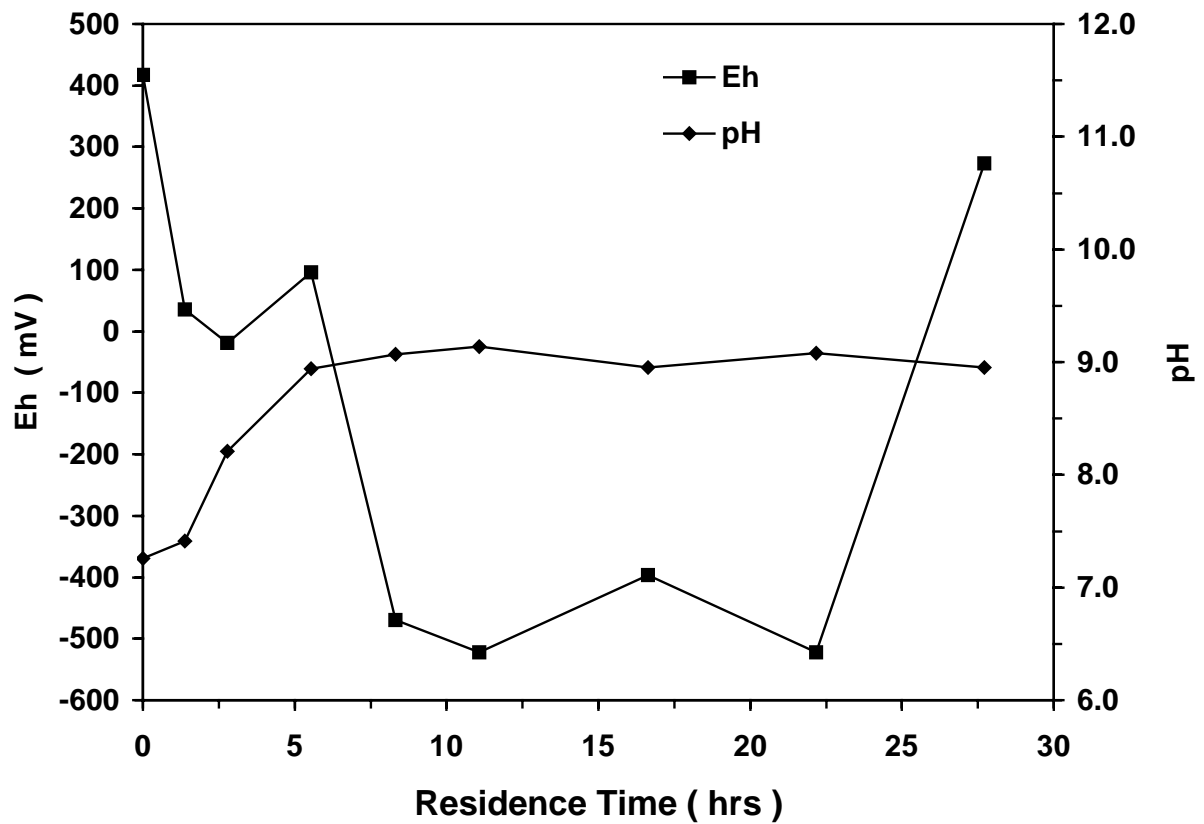


Figure 6: Redox potential (Eh) and pH profiles versus residence time along the column.

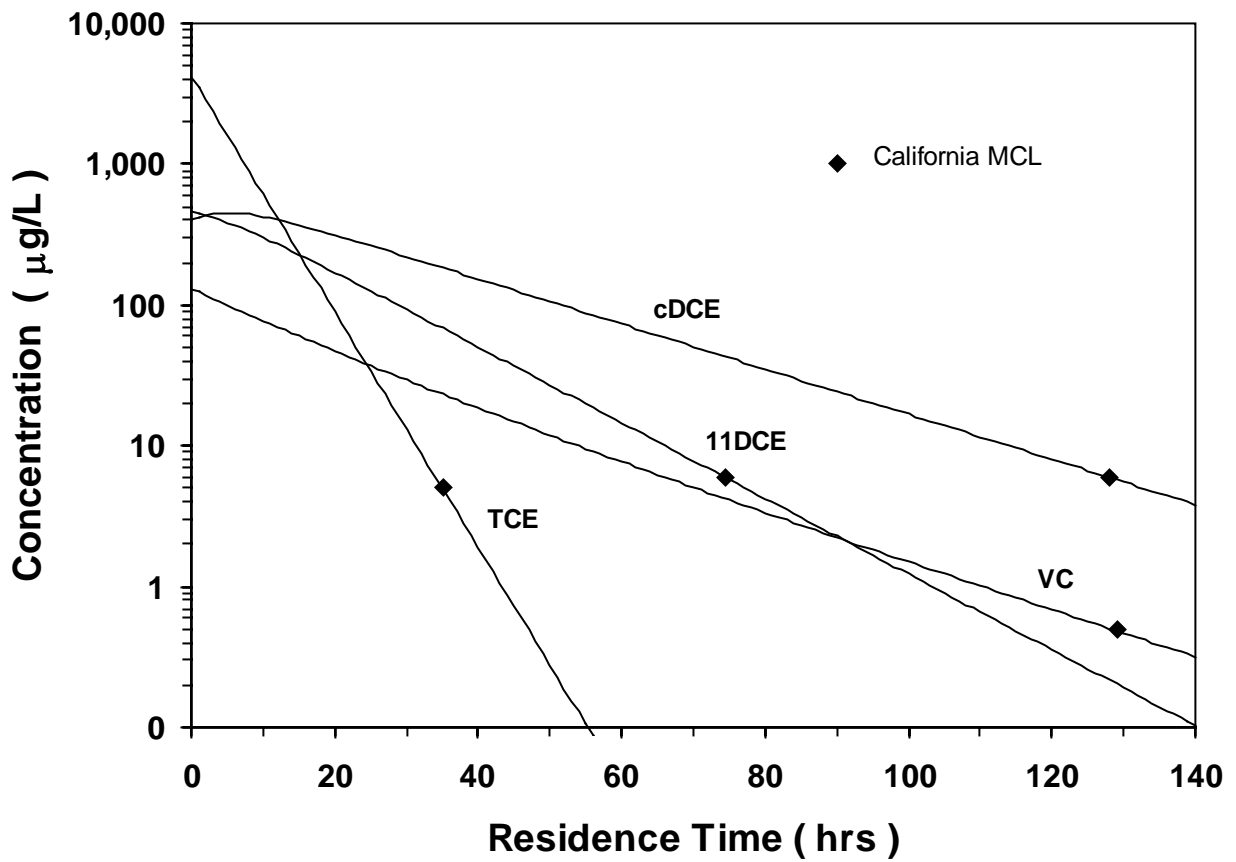


Figure 7: First-order kinetic model simulation results using the anticipated field concentration and half-lives.

Appendix A

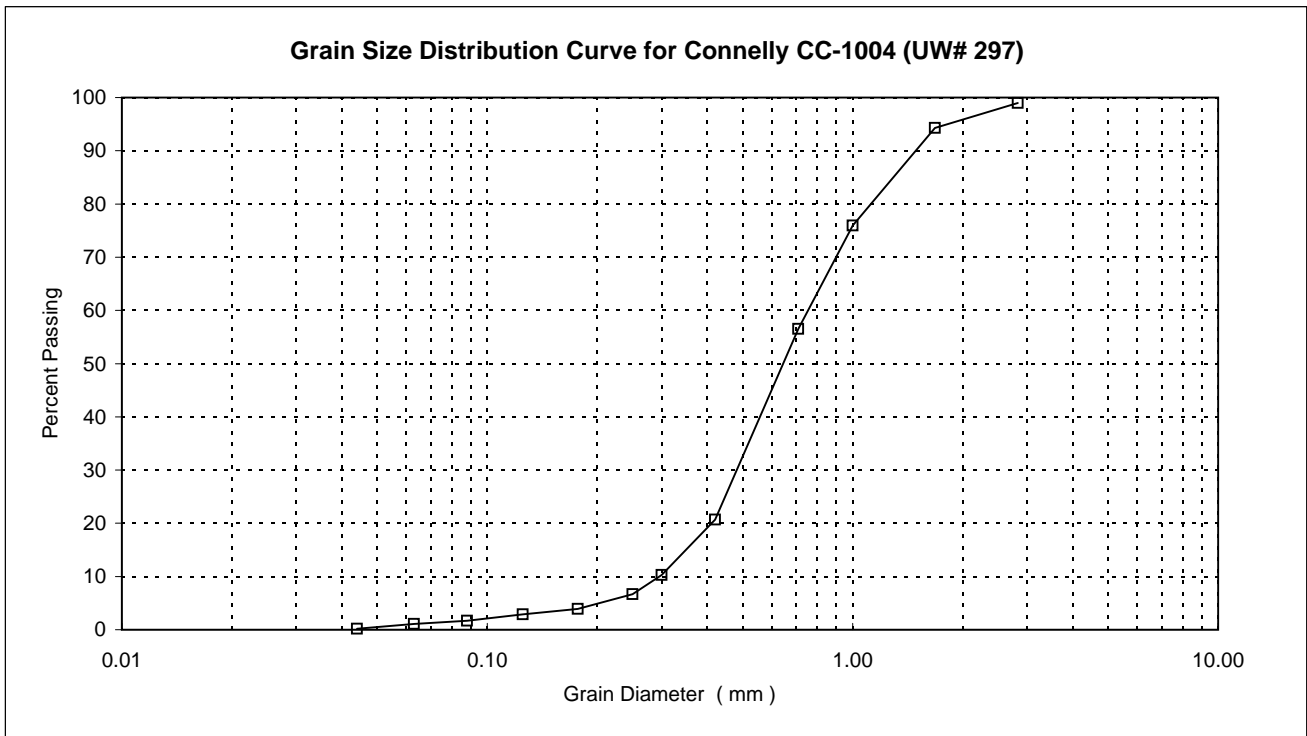
Grain Size Distribution Curve

Grain Size Distribution Curve

UW Sample Number: UW 297
Date of Grain Size Analysis : 12-Jun-06
Soil Type connelly cc-1004
Date Sample Received: 1-May-06
Analysis Done By: Monika Pal

Sample 1

US Sieve Mesh #	mm	Wt Retained On sieve (grams)	Percent (%)	Percent Passing (%)
				100
7	2.830	1.05	1.04	98.96
12	1.680	4.70	4.66	94.30
18	1.000	18.50	18.34	75.95
25	0.710	19.60	19.43	56.52
40	0.420	36.15	35.85	20.67
50	0.300	10.45	10.36	10.31
60	0.250	3.65	3.62	6.69
80	0.177	2.80	2.78	3.92
120	0.125	1.05	1.04	2.88
170	0.088	1.20	1.19	1.69
230	0.063	0.60	0.59	1.09
325	0.044	0.90	0.89	0.20
<325	0.031	0.20	0.20	0.00
		100.85	100.00	
		Total Wt	Total %	



Appendix B

Laboratory Organic Analyses for Bench-Scale Testing Involving the Granular Iron Technology

Treatability Test	Column Identification:	ETI#1008
ERM 32414	Column Composition:	100% Connelly CC1004
Dec-06	Pore Volume (PV):	308 mL
	Porosity:	0.54
	Column Length:	1.6 ft (50 cm)
	Column Diameter:	1.5 in (3.8 cm)
	Flow Velocity:	1.4 ft/day (43 cm/day)
	Test Temperature:	22°C (72°F)

Column Distance (cm)	0.0	2.5	5	10	15	20	30	40	50
Column Distance (ft)	0.0	0.08	0.16	0.33	0.50	0.66	1.0	1.3	1.6
Residence Time (hr)	0.0	1.4	2.8	5.5	8.3	11.1	16.6	22.2	27.7

	PV	RN	Influent	Organic Concentration (µg/L)								Effluent	HL	r2
TCE														
	3.8	a	3850	23	1.1	1.9	2.1	2.3	2.8	2.7	3.1			
	8.9	a	4075	23	3.3	1.9	2.0	2.0	2.3	2.5	3.3			
	13.5	a	4890	15	6.2	2.9	2.7	2.5	2.4	3.0	3.0			
	19.9	a	4390	710	26	5.9	2.7	2.4	2.5	2.9	3.3			
	25.4	b	4885	2040	898	7.0	3.1	2.5	2.3	2.7	3.0			
	32.1	b	3970	1425	669	86	3.0	2.6	2.5	2.5	3.0			
	38.8	b	4265	1645	1055	232	33	nd	nd	nd	nd			
	44.7	c	4905	1891	1232	434	115	4.0	nd	nd	nd			
	50.3	c	4358	2262	1448	739	264	42	nd	nd	nd	1.8	0.991	
	57.0	c	4370	1749	1116	658	292	50	nd	nd	nd	1.3	0.974	
	63.5	d	5433	2422	1812	1104	564	34	nd	nd	nd	1.8	0.962	
cDCE														
	3.8	a	357	33	5.5	5.6	8.3	17	17	2.2	nd			
	8.9	a	361	6.9	nd	nd	nd	nd	nd	nd	nd			
	13.5	a	333	5.1	nd	nd	nd	nd	nd	nd	nd			
	19.9	a	343	148	22	nd	nd	nd	nd	nd	nd			
	25.4	b	336	323	276	40	nd	nd	nd	nd	nd			
	32.1	b	386	323	317	258	134	19	nd	nd	nd			
	38.8	b	348	331	328	327	290	152	9.1	nd	nd			
	44.7	c	382	363	354	348	349	232	43	nd	nd			
	50.3	c	330	356	338	355	342	315	129	13	nd	7.3	0.885	
	57.0	c	336	340	313	311	327	351	165	41	9.2	10.1	0.799	
	63.5	d	363	379	376	379	382	362	220	72	18	9.4	0.880	
tDCE														
	3.8	a	5.6	3.2	3.3	5.1	4.5	0.8	1.3	1.8	2.1			
	8.9	a	4.5	nd	nd	nd	nd	nd	nd	nd	nd			
	13.5	a	2.6	nd	nd	nd	nd	nd	nd	nd	nd			
	19.9	a	1.0	nd	nd	nd	nd	nd	nd	nd	nd			
	25.4	b	3.6	2.7	1.8	nd	nd	nd	nd	nd	nd			
	32.1	b	3.7	2.4	1.9	nd	nd	nd	nd	nd	nd			
	38.8	b	2.7	2.1	2.0	nd	nd	nd	nd	nd	nd			
	44.7	c	5.3	3.7	3.1	2.2	1.8	nd	nd	nd	nd			
	50.3	c	3.6	3.1	2.7	2.5	1.9	nd	nd	nd	nd			
	57.0	c	6.0	5.4	4.9	4.7	4.5	nd	nd	nd	nd			
	63.5	d	2.9	2.6	2.4	2.3	1.9	nd	nd	nd	nd			

Treatability Test	Column Identification:	ETI#1008
ERM 32414	Column Composition:	100% Connelly CC1004
Dec-06	Pore Volume (PV):	308 mL
	Porosity:	0.54
	Column Length:	1.6 ft (50 cm)
	Column Diameter:	1.5 in (3.8 cm)
	Flow Velocity:	1.4 ft/day (43 cm/day)
	Test Temperature:	22°C (72°F)

Column Distance (cm)	0.0	2.5	5	10	15	20	30	40	50
Column Distance (ft)	0.0	0.08	0.16	0.33	0.50	0.66	1.0	1.3	1.6
Residence Time (hr)	0.0	1.4	2.8	5.5	8.3	11.1	16.6	22.2	27.7

PV	RN	Influent	Organic Concentration (µg/L)								Effluent	HL	r2
1,1-DCE													
3.8	a	312	7.0	1.2	3.1	1.9	3.7	3.8	nd	nd			
8.9	a	311	1.5	nd	nd	nd	nd	1.0	1.0	1.3			
13.5	a	268	1.8	1.1	0.76	nd	nd	nd	nd	nd			
19.9	a	259	65	7.2	nd	0.90	1.1	1.5	1.6	1.7			
25.4	b	315	258	175	9.6	nd	nd	nd	nd	nd			
32.1	b	349	208	176	104	36	2.9	nd	nd	nd			
38.8	b	305	238	203	151	116	34	1.2	nd	nd			
44.7	c	453	318	273	218	182	85	8.6	nd	nd			
50.3	c	324	290	248	223	178	132	32	1.6	nd	5.6	0.965	
57.0	c	332	261	213	186	172	132	39	6.4	nd	5.8	0.943	
63.5	d	384	329	297	266	239	137	42	7.4	nd	5.6	0.962	
VC													
3.8	a	119	3.1	nd	nd	nd	nd	1.5	nd	nd			
8.9	a	84	nd	nd	nd	nd	nd	nd	nd	nd			
13.5	a	40	nd	nd	nd	nd	nd	nd	nd	nd			
19.9	a	7.2	4.7	1.6	nd	nd	nd	nd	nd	nd			
25.4	b	56	41	29	3.6	nd	nd	nd	nd	nd			
32.1	b	66	32	29	21	13	3.0	nd	nd	nd			
38.8	b	36	21	20	19	19	12	2.2	nd	nd			
44.7	c	87	38	36	34	35	29	8.1	nd	nd			
50.3	c	25	14	13	13	13	14	9.0	2.0	nd	3.4	0.740	
57.0	c	5.6	5.1	5.4	6.1	7.4	9.6	8.3	4.5	nd	4.5	0.636	
63.5	d	25	14	13	14	14	15	14	8.2	4.1	5.7	0.639	
Nitrate (as N) mg/L													
26.3	b	nd	nd	nd	nd	nd	nd	nd	nd	nd			
33.1	b	nd	nd	nd	nd	nd	nd	nd	nd	nd			
Chloride (mg/L)													
26.3	b	138	146	150	148	150	152	151	150	159			
33.1	b	166	173	170	170	175	173	173	178	180			
Sulphate (mg/L)													
26.3	b	110	96	86	79	81	88	95	98	108			
33.1	b	112	101	80	64	64	63	72	79	85			

Treatability Test	Column Identification:	ETI#1008
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Column Distance (ft)	0.0	0.08	0.16	0.33	0.50	0.66	1.0	1.3	1.6
Residence Time (hr)	0.0	1.4	2.8	5.5	8.3	11.1	16.6	22.2	27.7

PV	RN	Influent	Organic Concentration (µg/L)							Effluent	HL	r2
pH Values												
6.3	a	7.7	8.5	8.8	8.7	8.9	9.0	8.9	9.1	8.8		
9.7	a	7.4	8.5	8.7	8.8	8.8	8.8	8.9	8.8	8.5		
14.3	a	7.7	8.1	8.2	9.0	9.0	9.1	9.0	9.1	9.1		
20.7	a	7.5	8.2	8.7	8.9	9.0	8.9	9.0	9.1	9.0		
26.4	b	7.4	7.1	8.0	8.8	8.8	8.7	8.8	8.8	8.6		
33.1	b	7.5	7.3	8.5	8.9	8.9	8.8	8.6	8.7	8.8		
39.7	b	7.4	7.4	8.1	8.9	9.0	9.0	8.9	8.9	8.9		
45.4	c	7.5	7.4	8.0	9.1	9.3	9.3	9.2	9.1	9.0		
51.1	c	7.5	7.4	8.0	9.2	9.4	9.4	9.2	9.2	8.9		
57.9	c	7.3	7.3	7.8	8.9	9.3	9.3	9.1	9.1	9.1		
60.7	d	7.3	7.4	8.2	8.9	9.1	9.1	9.0	9.1	9.0		
Eh (mV)												
6.3	a	422	-336	-404	72	24	44	124	169	182		
9.7	a	384	-196	-232	-356	-8	-186	154	129	219		
14.3	a	339	-255	-366	-479	-352	-382	-436	72	131		
20.7	a	433	-389	-489	-492	-455	-448	-504	-428	92		
26.4	b	352	54	57	-38	-48	29	72	-15	101		
33.1	b	362	172	223	-2	-451	-478	-501	-336	-471		
39.7	b	344	151	237	183	-19	-427	-496	-501	-222		
45.4	c	390	160	264	169	91	-237	-430	-459	-60		
51.1	c	326	139	217	173	112	-60	-355	-433	-10		
57.9	c	326	130	153	214	164	-3	-77	-432	-146		
60.7	d	417	36	-19	96	-470	-522	-397	-522	273		

PV = pore volume
 RN = reservoir number
 HL = half life (hours)
 r2 = coefficient of determination
 nd = not detected
 na = not applicable

Appendix C

Laboratory Inorganic Analyses for Bench-Scale Testing Involving the Granular Iron Technology

Inorganic analyses Sample Log

Sample Number	Location/PV
44041	Influent/42.4 PVs
44042	Effluent/42.4 PVs
344064	Influent/48.5 PVs
344065	Effluent/48.5 PVs

Your Project #: 3000R-23-32414
Your C.O.C. #: N/A

Attention: Eva Dmitrovic
Adventus Remediation Technologies Inc
1345 Fewster Dr
Mississauga, ON
L4W 2A5

Report Date: 2007/01/29

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: A707335
Received: 2007/01/23, 10:19

Sample Matrix: Water
Samples Received: 2

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Alkalinity	2	N/A	2007/01/25	Ont SOP 0083	SM 2320B
Carbonate, Bicarbonate and Hydroxide	2	N/A	2007/01/25		
Chloride by Automated Colourimetry	2	N/A	2007/01/26	CAM SOP 0463	SM 4500 Cl E
Conductivity	2	N/A	2007/01/25	CAM SOP-0414	SM 2510
Dissolved Organic Carbon (DOC)	2	N/A	2007/01/26	Ont SOP 0622	SM 5310 B
Hardness (calculated as CaCO3)	2	N/A	2007/01/25	ATL SOP 00048	SM 2340B
Dissolved Metals by ICPMS	2	N/A	2007/01/26	CAM SOP-00447	EPA 6020
Ion Balance (% Difference)	2	N/A	2007/01/25		
Anion and Cation Sum	2	N/A	2007/01/25		
Ammonia-N	1	N/A	2007/01/26	CAM SOP 0441	US GS I-2522-90
Ammonia-N	1	N/A	2007/01/29	CAM SOP 0441	US GS I-2522-90
Nitrate (NO3) and Nitrite (NO2) in Water	2	N/A	2007/01/26	Ont SOP-0100	SM 4500 NO3 I
pH	2	N/A	2007/01/25	Ont SOP 0067	SM 4500H
Orthophosphate	2	N/A	2007/01/26	CAL SOP-0196	SM 4500 P-F
Sat. pH and Langelier Index (@ 20C)	2	N/A	2007/01/25		
Sat. pH and Langelier Index (@ 4C)	2	N/A	2007/01/25		
Reactive Silica ϕ	2	N/A	2007/01/26	ATL SOP 00022	Based on EPA 366.0
Sulphate by Automated Colourimetry	2	N/A	2007/01/26	SOP 0848	EPA 375.4
Total Dissolved Solids (TDS calc)	2	N/A	2007/01/25		
Total Organic Carbon (TOC)	2	N/A	2007/01/26	Ont SOP-0622	EPA 415.1 modified

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

(1) This test was performed by Bedford

Your Project #: 3000R-23-32414
Your C.O.C. #: N/A

Attention: Eva Dmitrovic

Adventus Remediation Technologies Inc
1345 Fewster Dr
Mississauga, ON
L4W 2A5

Report Date: 2007/01/29

CERTIFICATE OF ANALYSIS

-2-

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

TIM DAS, Env Customer Service
Email: Tim.Das@Maxxamanalytics.com
Phone# (905) 817-5700 Ext:5802

=====
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For Service Group specific validation please refer to the Validation Signature Page

Total cover pages: 2

Maxxam Job #: A707335
Report Date: 2007/01/29

Adventus Remediation Technologies Inc
Client Project #: 3000R-23-32414
Project name:
Sampler Initials:

RESULTS OF ANALYSES OF WATER

Maxxam ID		Q65141			Q65142		
Sampling Date		2007/01/22			2007/01/22		
COC Number		N/A			N/A		
	Units	44041	RDL	QC Batch	44042	RDL	QC Batch

INORGANICS							
Total Ammonia-N	mg/L	0.06	0.05	1153337	0.05	0.05	1154442
Conductivity	umho/cm	1730	2	1151158	1110	2	1151164
Hardness (CaCO3)	mg/L	640	1	1153171	150	1	1153171
Dissolved Organic Carbon	mg/L	1.4	0.1	1153631	1.3	0.1	1153631
Total Organic Carbon (TOC)	mg/L	1.5	0.1	1153633	1.4	0.1	1153633
Orthophosphate (P)	mg/L	0.06	0.01	1153380	ND	0.01	1153380
pH	pH	8.2	N/A	1151156	9.0	N/A	1151163
Reactive Silica (SiO2)	mg/L	30	3	1153498	1.2	0.5	1153498
Dissolved Sulphate (SO4)	mg/L	148	1	1153379	56	1	1153379
Alkalinity (Total as CaCO3)	mg/L	518	1	1151159	173	1	1151165
Dissolved Chloride (Cl)	mg/L	190	2	1153378	190	2	1153378
Nitrite (N)	mg/L	ND	0.01	1151533	ND	0.01	1151522
Nitrate (N)	mg/L	ND	0.1	1151533	ND	0.1	1151522
Nitrate + Nitrite	mg/L	ND	0.1	1151533	ND	0.1	1151522
RCAP CALCULATIONS							
Anion Sum	me/L	18.8	N/A	1153166	10.0	N/A	1153166
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	509	1	1153170	159	1	1153170
Calculated TDS	mg/L	1050	1	1153169	594	1	1153169
Carb. Alkalinity (calc. as CaCO3)	mg/L	8	1	1153170	14	1	1153170
Cation Sum	me/L	21.7	N/A	1153166	11.8	N/A	1153166
Ion Balance (% Difference)	%	7.15	N/A	1153165	8.28	N/A	1153165
Langelier Index (@ 20C)	N/A	1.45	N/A	1153167	0.569	N/A	1153167
Langelier Index (@ 4C)	N/A	1.21	N/A	1153168	0.321	N/A	1153168
Saturation pH (@ 20C)	N/A	6.77	N/A	1153167	8.40	N/A	1153167
Saturation pH (@ 4C)	N/A	7.02	N/A	1153168	8.65	N/A	1153168

ND = Not detected
N/A = Not Applicable
RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Job #: A707335
Report Date: 2007/01/29

Adventus Remediation Technologies Inc
Client Project #: 3000R-23-32414
Project name:
Sampler Initials:

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

Maxxam ID		Q65141	Q65142		
Sampling Date		2007/01/22	2007/01/22		
COC Number		N/A	N/A		
	Units	44041	44042	RDL	QC Batch

METALS					
Dissolved Aluminum (Al)	ug/L	7	ND	5	1153390
Dissolved Antimony (Sb)	ug/L	ND	ND	1	1153390
Dissolved Arsenic (As)	ug/L	3	ND	1	1153390
Dissolved Barium (Ba)	ug/L	180	250	5	1153390
Dissolved Beryllium (Be)	ug/L	ND	ND	0.5	1153390
Dissolved Bismuth (Bi)	ug/L	ND	ND	1	1153390
Dissolved Boron (B)	ug/L	3700	3600	10	1153390
Dissolved Cadmium (Cd)	ug/L	ND	ND	0.1	1153390
Dissolved Calcium (Ca)	ug/L	120000	7700	200	1153390
Dissolved Chromium (Cr)	ug/L	ND	ND	5	1153390
Dissolved Cobalt (Co)	ug/L	ND	ND	0.5	1153390
Dissolved Copper (Cu)	ug/L	2	ND	1	1153390
Dissolved Iron (Fe)	ug/L	ND	ND	50	1153390
Dissolved Lead (Pb)	ug/L	0.5	ND	0.5	1153390
Dissolved Magnesium (Mg)	ug/L	84000	32000	50	1153390
Dissolved Manganese (Mn)	ug/L	420	130	2	1153390
Dissolved Molybdenum (Mo)	ug/L	4	220	1	1153390
Dissolved Nickel (Ni)	ug/L	4	2	1	1153390
Dissolved Potassium (K)	ug/L	1300	1300	200	1153390
Dissolved Selenium (Se)	ug/L	ND	ND	2	1153390
Dissolved Silicon (Si)	ug/L	17000	660	50	1153390
Dissolved Silver (Ag)	ug/L	ND	ND	0.1	1153390
Dissolved Sodium (Na)	ug/L	200000	200000	100	1153390
Dissolved Strontium (Sr)	ug/L	1300	39	1	1153390
Dissolved Thallium (Tl)	ug/L	ND	ND	0.05	1153390
Dissolved Titanium (Ti)	ug/L	ND	ND	5	1153390
Dissolved Uranium (U)	ug/L	7.0	ND	0.1	1153390
Dissolved Vanadium (V)	ug/L	3	2	1	1153390
Dissolved Zinc (Zn)	ug/L	ND	ND	5	1153390
NUTRIENTS					
Dissolved Phosphorus (P)	ug/L	130	130	50	1153390

ND = Not detected
N/A = Not Applicable
RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Job #: A707335
Report Date: 2007/01/29

Adventus Remediation Technologies Inc
Client Project #: 3000R-23-32414
Project name:
Sampler Initials:

GENERAL COMMENTS

Results relate only to the items tested.

Adventus Remediation Technologies Inc
Attention: Eva Dmitrovic
Client Project #: 3000R-23-32414
P.O. #:
Project name:

Quality Assurance Report
Maxxam Job Number: MA707335

QA/QC Batch	QC Type	Parameter	Date Analyzed yyyy/mm/dd	Value	Recovery	Units	QC Limits
1151158 YPA	QC STANDARD	Conductivity	2007/01/25		98	%	85 - 115
	Method Blank	Conductivity	2007/01/25	ND, RDL=2		umho/cm	
1151159 YPA	QC STANDARD	Alkalinity (Total as CaCO3)	2007/01/25		102	%	85 - 115
	Method Blank	Alkalinity (Total as CaCO3)	2007/01/25	1, RDL=1		mg/L	
1151164 YPA	QC STANDARD	Conductivity	2007/01/25		99	%	85 - 115
	Method Blank	Conductivity	2007/01/25	ND, RDL=2		umho/cm	
	RPD	Conductivity	2007/01/25	0		%	25
1151165 YPA	QC STANDARD	Alkalinity (Total as CaCO3)	2007/01/25		98	%	85 - 115
	Method Blank	Alkalinity (Total as CaCO3)	2007/01/25	ND, RDL=1		mg/L	
	RPD	Alkalinity (Total as CaCO3)	2007/01/25	0.8		%	25
1151522 LS	MATRIX SPIKE	Nitrite (N)	2007/01/26		97	%	75 - 125
		Nitrate (N)	2007/01/26		88	%	75 - 125
	Spiked Blank	Nitrite (N)	2007/01/26		97	%	85 - 115
		Nitrate (N)	2007/01/26		92	%	85 - 125
	Method Blank	Nitrite (N)	2007/01/26	ND, RDL=0.01		mg/L	
		Nitrate (N)	2007/01/26	ND, RDL=0.1		mg/L	
		Nitrate + Nitrite	2007/01/26	ND, RDL=0.1		mg/L	
	RPD	Nitrite (N)	2007/01/26	NC		%	25
		Nitrate (N)	2007/01/26	1.7		%	25
		Nitrate + Nitrite	2007/01/26	1.6		%	25
1151533 LS	MATRIX SPIKE	Nitrite (N)	2007/01/26		99	%	75 - 125
		Nitrate (N)	2007/01/26		NC (1)	%	75 - 125
	Spiked Blank	Nitrite (N)	2007/01/26		104	%	85 - 115
		Nitrate (N)	2007/01/26		89	%	85 - 125
	Method Blank	Nitrite (N)	2007/01/26	ND, RDL=0.01		mg/L	
		Nitrate (N)	2007/01/26	ND, RDL=0.1		mg/L	
		Nitrate + Nitrite	2007/01/26	ND, RDL=0.1		mg/L	
	RPD	Nitrite (N)	2007/01/26	NC		%	25
		Nitrate (N)	2007/01/26	0.3		%	25
		Nitrate + Nitrite	2007/01/26	0.3		%	25
1153337 ADB	MATRIX SPIKE	Total Ammonia-N	2007/01/26		88	%	80 - 120
	Spiked Blank	Total Ammonia-N	2007/01/26		104	%	80 - 120
	Method Blank	Total Ammonia-N	2007/01/26	ND, RDL=0.05		mg/L	
	RPD	Total Ammonia-N	2007/01/26	NC		%	25
1153378 JDE	MATRIX SPIKE	Dissolved Chloride (Cl)	2007/01/26		89	%	75 - 125
	QC STANDARD	Dissolved Chloride (Cl)	2007/01/26		95	%	80 - 120
	Spiked Blank	Dissolved Chloride (Cl)	2007/01/26		102	%	80 - 120
	Method Blank	Dissolved Chloride (Cl)	2007/01/26	ND, RDL=1		mg/L	
	RPD	Dissolved Chloride (Cl)	2007/01/26	0.6		%	20
1153379 JDE	MATRIX SPIKE	Dissolved Sulphate (SO4)	2007/01/26		104	%	75 - 125
	QC STANDARD	Dissolved Sulphate (SO4)	2007/01/26		101	%	80 - 120
	Spiked Blank	Dissolved Sulphate (SO4)	2007/01/26		102	%	80 - 120
	Method Blank	Dissolved Sulphate (SO4)	2007/01/26	ND, RDL=1		mg/L	
	RPD	Dissolved Sulphate (SO4)	2007/01/26	1.3		%	25
1153380 JDE	MATRIX SPIKE	Orthophosphate (P)	2007/01/26		99	%	75 - 125
	QC STANDARD	Orthophosphate (P)	2007/01/26		98	%	80 - 120
	Spiked Blank	Orthophosphate (P)	2007/01/26		99	%	80 - 120
	Method Blank	Orthophosphate (P)	2007/01/26	ND, RDL=0.01		mg/L	
	RPD	Orthophosphate (P)	2007/01/26	NC		%	25
1153390 HRE	MATRIX SPIKE	Dissolved Aluminum (Al)	2007/01/26		93	%	80 - 120
		Dissolved Antimony (Sb)	2007/01/26		103	%	80 - 120
		Dissolved Arsenic (As)	2007/01/26		103	%	80 - 120
		Dissolved Barium (Ba)	2007/01/26		101	%	80 - 120
		Dissolved Beryllium (Be)	2007/01/26		100	%	75 - 125
		Dissolved Bismuth (Bi)	2007/01/26		96	%	75 - 125

Adventus Remediation Technologies Inc
Attention: Eva Dmitrovic
Client Project #: 3000R-23-32414
P.O. #:
Project name:

Quality Assurance Report (Continued)
Maxxam Job Number: MA707335

QA/QC Batch	QC Type	Parameter	Date Analyzed yyyy/mm/dd	Value	Recovery	Units	QC Limits
1153390 HRE	MATRIX SPIKE	Dissolved Boron (B)	2007/01/26		106	%	75 - 125
		Dissolved Cadmium (Cd)	2007/01/26		102	%	80 - 120
		Dissolved Calcium (Ca)	2007/01/26		99	%	75 - 125
		Dissolved Chromium (Cr)	2007/01/26		95	%	80 - 120
		Dissolved Cobalt (Co)	2007/01/26		93	%	80 - 120
		Dissolved Copper (Cu)	2007/01/26		96	%	80 - 120
		Dissolved Iron (Fe)	2007/01/26		101	%	80 - 120
		Dissolved Lead (Pb)	2007/01/26		100	%	80 - 120
		Dissolved Magnesium (Mg)	2007/01/26		95	%	80 - 120
		Dissolved Manganese (Mn)	2007/01/26		94	%	80 - 120
		Dissolved Molybdenum (Mo)	2007/01/26		104	%	80 - 120
		Dissolved Nickel (Ni)	2007/01/26		95	%	80 - 120
		Dissolved Potassium (K)	2007/01/26		102	%	75 - 125
		Dissolved Selenium (Se)	2007/01/26		100	%	80 - 120
		Dissolved Silicon (Si)	2007/01/26		96	%	75 - 125
		Dissolved Silver (Ag)	2007/01/26		99	%	80 - 120
		Dissolved Sodium (Na)	2007/01/26		101	%	75 - 125
		Dissolved Strontium (Sr)	2007/01/26		102	%	80 - 120
		Dissolved Thallium (Tl)	2007/01/26		102	%	75 - 125
		Dissolved Titanium (Ti)	2007/01/26		102	%	75 - 125
		Dissolved Uranium (U)	2007/01/26		103	%	80 - 120
		Dissolved Vanadium (V)	2007/01/26		96	%	80 - 120
		Dissolved Zinc (Zn)	2007/01/26		97	%	80 - 120
		Dissolved Phosphorus (P)	2007/01/26		109	%	75 - 125
	Spiked Blank	Dissolved Aluminum (Al)	2007/01/26		96	%	85 - 115
		Dissolved Antimony (Sb)	2007/01/26		102	%	85 - 115
		Dissolved Arsenic (As)	2007/01/26		101	%	85 - 115
		Dissolved Barium (Ba)	2007/01/26		100	%	85 - 115
		Dissolved Beryllium (Be)	2007/01/26		102	%	85 - 115
		Dissolved Bismuth (Bi)	2007/01/26		96	%	85 - 115
		Dissolved Boron (B)	2007/01/26		105	%	85 - 115
		Dissolved Cadmium (Cd)	2007/01/26		101	%	85 - 115
		Dissolved Calcium (Ca)	2007/01/26		104	%	85 - 115
		Dissolved Chromium (Cr)	2007/01/26		96	%	85 - 115
		Dissolved Cobalt (Co)	2007/01/26		95	%	85 - 115
		Dissolved Copper (Cu)	2007/01/26		98	%	85 - 115
		Dissolved Iron (Fe)	2007/01/26		104	%	85 - 115
		Dissolved Lead (Pb)	2007/01/26		99	%	85 - 115
		Dissolved Magnesium (Mg)	2007/01/26		102	%	85 - 115
		Dissolved Manganese (Mn)	2007/01/26		95	%	85 - 115
		Dissolved Molybdenum (Mo)	2007/01/26		102	%	85 - 115
		Dissolved Nickel (Ni)	2007/01/26		97	%	85 - 115
		Dissolved Potassium (K)	2007/01/26		104	%	85 - 115
		Dissolved Selenium (Se)	2007/01/26		100	%	85 - 115
		Dissolved Silicon (Si)	2007/01/26		102	%	85 - 115
		Dissolved Silver (Ag)	2007/01/26		98	%	85 - 115
		Dissolved Sodium (Na)	2007/01/26		103	%	85 - 115
		Dissolved Strontium (Sr)	2007/01/26		99	%	85 - 115
		Dissolved Thallium (Tl)	2007/01/26		101	%	85 - 115
		Dissolved Titanium (Ti)	2007/01/26		102	%	85 - 115
		Dissolved Uranium (U)	2007/01/26		102	%	85 - 115
		Dissolved Vanadium (V)	2007/01/26		97	%	85 - 115
		Dissolved Zinc (Zn)	2007/01/26		98	%	85 - 115
		Dissolved Phosphorus (P)	2007/01/26		95	%	85 - 115
	Method Blank	Dissolved Aluminum (Al)	2007/01/26	ND, RDL=5		ug/L	

Adventus Remediation Technologies Inc
Attention: Eva Dmitrovic
Client Project #: 3000R-23-32414
P.O. #:
Project name:

Quality Assurance Report (Continued)
Maxxam Job Number: MA707335

QA/QC Batch	QC Type	Parameter	Date Analyzed yyyy/mm/dd	Value	Recovery	Units	QC Limits		
1153390 HRE	Method Blank	Dissolved Antimony (Sb)	2007/01/26	ND, RDL=1		ug/L			
		Dissolved Arsenic (As)	2007/01/26	ND, RDL=1		ug/L			
		Dissolved Barium (Ba)	2007/01/26	ND, RDL=5		ug/L			
		Dissolved Beryllium (Be)	2007/01/26	ND, RDL=0.5		ug/L			
		Dissolved Bismuth (Bi)	2007/01/26	ND, RDL=1		ug/L			
		Dissolved Boron (B)	2007/01/26	ND, RDL=10		ug/L			
		Dissolved Cadmium (Cd)	2007/01/26	ND, RDL=0.1		ug/L			
		Dissolved Calcium (Ca)	2007/01/26	ND, RDL=200		ug/L			
		Dissolved Chromium (Cr)	2007/01/26	ND, RDL=5		ug/L			
		Dissolved Cobalt (Co)	2007/01/26	ND, RDL=0.5		ug/L			
		Dissolved Copper (Cu)	2007/01/26	ND, RDL=1		ug/L			
		Dissolved Iron (Fe)	2007/01/26	ND, RDL=50		ug/L			
		Dissolved Lead (Pb)	2007/01/26	ND, RDL=0.5		ug/L			
		Dissolved Magnesium (Mg)	2007/01/26	ND, RDL=50		ug/L			
		Dissolved Manganese (Mn)	2007/01/26	ND, RDL=2		ug/L			
		Dissolved Molybdenum (Mo)	2007/01/26	ND, RDL=1		ug/L			
		Dissolved Nickel (Ni)	2007/01/26	ND, RDL=1		ug/L			
		Dissolved Potassium (K)	2007/01/26	ND, RDL=200		ug/L			
		Dissolved Selenium (Se)	2007/01/26	ND, RDL=2		ug/L			
		Dissolved Silicon (Si)	2007/01/26	ND, RDL=50		ug/L			
		Dissolved Silver (Ag)	2007/01/26	ND, RDL=0.1		ug/L			
		Dissolved Sodium (Na)	2007/01/26	ND, RDL=100		ug/L			
		Dissolved Strontium (Sr)	2007/01/26	ND, RDL=1		ug/L			
		Dissolved Thallium (Tl)	2007/01/26	ND, RDL=0.05		ug/L			
		Dissolved Titanium (Ti)	2007/01/26	ND, RDL=5		ug/L			
		Dissolved Uranium (U)	2007/01/26	ND, RDL=0.1		ug/L			
		Dissolved Vanadium (V)	2007/01/26	ND, RDL=1		ug/L			
		Dissolved Zinc (Zn)	2007/01/26	ND, RDL=5		ug/L			
		Dissolved Phosphorus (P)	2007/01/26	ND, RDL=50		ug/L			
		RPD	RPD	Dissolved Antimony (Sb)	2007/01/26	NC		%	25
				Dissolved Arsenic (As)	2007/01/26	NC		%	25
				Dissolved Barium (Ba)	2007/01/26	0.2		%	25
				Dissolved Beryllium (Be)	2007/01/26	NC		%	25
Dissolved Boron (B)	2007/01/26			NC		%	25		
Dissolved Cadmium (Cd)	2007/01/26			NC		%	25		
Dissolved Chromium (Cr)	2007/01/26			NC		%	25		
Dissolved Cobalt (Co)	2007/01/26			NC		%	25		
Dissolved Copper (Cu)	2007/01/26			NC		%	25		
Dissolved Lead (Pb)	2007/01/26			NC		%	25		
Dissolved Molybdenum (Mo)	2007/01/26			NC		%	25		
Dissolved Nickel (Ni)	2007/01/26			NC		%	25		
Dissolved Selenium (Se)	2007/01/26			NC		%	25		
Dissolved Silver (Ag)	2007/01/26			NC		%	25		
Dissolved Sodium (Na)	2007/01/26			1.3		%	25		
Dissolved Thallium (Tl)	2007/01/26	NC		%	25				
Dissolved Vanadium (V)	2007/01/26	NC		%	25				
Dissolved Zinc (Zn)	2007/01/26	NC		%	25				
1153498 LMA	MATRIX SPIKE	Reactive Silica (SiO2)	2007/01/26		100	%	80 - 120		
		QC STANDARD	Reactive Silica (SiO2)	2007/01/26		110	%	75 - 125	
		Spiked Blank	Reactive Silica (SiO2)	2007/01/26		104	%	80 - 120	
		Method Blank	Reactive Silica (SiO2)	2007/01/26	ND, RDL=0.5		mg/L		
1153631 AHA	RPD	Reactive Silica (SiO2)	2007/01/26	0.2		%	25		
		MATRIX SPIKE	Dissolved Organic Carbon	2007/01/26		92	%	75 - 125	
		Spiked Blank	Dissolved Organic Carbon	2007/01/26		96	%	75 - 125	
Method Blank	Method Blank	Dissolved Organic Carbon	2007/01/26	0.1, RDL=0.1		mg/L			

Adventus Remediation Technologies Inc
Attention: Eva Dmitrovic
Client Project #: 3000R-23-32414
P.O. #:
Project name:

Quality Assurance Report (Continued)
Maxxam Job Number: MA707335

QA/QC Batch	QC Type	Parameter	Date Analyzed yyyy/mm/dd	Value	Recovery	Units	QC Limits
1153631 AHA	RPD	Dissolved Organic Carbon	2007/01/26	0.5		%	20
1153633 AHA	MATRIX SPIKE	Total Organic Carbon (TOC)	2007/01/26		84	%	75 - 125
	Spiked Blank	Total Organic Carbon (TOC)	2007/01/26		98	%	75 - 125
	Method Blank	Total Organic Carbon (TOC)	2007/01/26	ND, RDL=0.1		mg/L	
	RPD	Total Organic Carbon (TOC)	2007/01/26	0.5		%	20
1154442 ADB	MATRIX SPIKE	Total Ammonia-N	2007/01/29		87	%	80 - 120
	Spiked Blank	Total Ammonia-N	2007/01/29		104	%	80 - 120
	Method Blank	Total Ammonia-N	2007/01/29	ND, RDL=0.05		mg/L	
	RPD	Total Ammonia-N	2007/01/29	0.7		%	25

ND = Not detected
 NC = Non-calculable
 RPD = Relative Percent Difference
 QC Standard = Quality Control Standard
 SPIKE = Fortified sample
 (1) NO3 recovery in the matrix spiked sample was not calculated. Because of the high concentration of this compound in the parent sample, the relative difference between the spiked and un-spiked concentrations is not sufficiently significant to permit reliable recovery calculation.

Validation Signature Page

Maxxam Job #: A707335

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Cristina Nervo

CHRISTINA NERVO, Scientific Services

Eric Dearman

ERIC DEARMAN,

=====

Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. SCC and CAEAL have approved this reporting process and electronic report format.

Your Project #: 3000R-23-32414
Your C.O.C. #: na

Attention: Eva Dmitrovic
Adventus Remediation Technologies Inc
1345 Fewster Dr
Mississauga, ON
L4W 2A5

Report Date: 2007/02/05

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: A709161
Received: 2007/01/29, 16:36

Sample Matrix: Water
Samples Received: 2

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Alkalinity	2	N/A	2007/01/30	Ont SOP 0083	SM 2320B
Carbonate, Bicarbonate and Hydroxide	2	N/A	2007/01/30		
Chloride by Automated Colourimetry	2	N/A	2007/02/02	CAM SOP 0463	SM 4500 Cl E
Conductivity	2	N/A	2007/01/30	CAM SOP-0414	SM 2510
Dissolved Organic Carbon (DOC)	1	N/A	2007/01/30	Ont SOP 0622	SM 5310 B
Dissolved Organic Carbon (DOC)	1	N/A	2007/02/01	Ont SOP 0622	SM 5310 B
Hardness (calculated as CaCO3)	2	N/A	2007/01/30	ATL SOP 00048	SM 2340B
Dissolved Metals by ICPMS	2	N/A	2007/01/30	CAM SOP-00447	EPA 6020
Ion Balance (% Difference)	2	N/A	2007/01/30		
Anion and Cation Sum	2	N/A	2007/01/30		
Ammonia-N	2	N/A	2007/02/01	CAM SOP 0441	US GS I-2522-90
Nitrate (NO3) and Nitrite (NO2) in Water	2	N/A	2007/01/31	Ont SOP-0100	SM 4500 NO3 I
pH	2	N/A	2007/01/30	Ont SOP 0067	SM 4500H
Orthophosphate	2	N/A	2007/02/02	CAL SOP-0196	SM 4500 P-F
Sat. pH and Langelier Index (@ 20C)	2	N/A	2007/01/30		
Sat. pH and Langelier Index (@ 4C)	2	N/A	2007/01/30		
Reactive Silica Ⓟ	2	N/A	2007/02/01	ATL SOP 00022	Based on EPA 366.0
Sulphate by Automated Colourimetry	2	N/A	2007/02/02	SOP 0848	EPA 375.4
Total Dissolved Solids (TDS calc)	2	N/A	2007/01/30		
Total Organic Carbon (TOC)	1	N/A	2007/01/30	Ont SOP-0622	EPA 415.1 modified
Total Organic Carbon (TOC)	1	N/A	2007/02/01	Ont SOP-0622	EPA 415.1 modified

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

(1) This test was performed by Bedford

Your Project #: 3000R-23-32414
Your C.O.C. #: na

Attention: Eva Dmitrovic

Adventus Remediation Technologies Inc
1345 Fewster Dr
Mississauga, ON
L4W 2A5

Report Date: 2007/02/05

CERTIFICATE OF ANALYSIS

-2-

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

TIM DAS, Env Customer Service
Email: Tim.Das@Maxxamanalytics.com
Phone# (905) 817-5700 Ext:5802

=====
Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. SCC and CAEAL have approved this reporting process and electronic report format.

For Service Group specific validation please refer to the Validation Signature Page

Total cover pages: 2

Maxxam Job #: A709161
Report Date: 2007/02/05

Adventus Remediation Technologies Inc
Client Project #: 3000R-23-32414
Project name:
Sampler Initials:

RESULTS OF ANALYSES OF WATER

Maxxam ID		Q72097			Q72098		
Sampling Date		2007/01/29			2007/01/29		
COC Number		na			na		
	Units	344064	RDL	QC Batch	344065	RDL	QC Batch

INORGANICS							
Total Ammonia-N	mg/L	0.08	0.05	1157099	ND	0.05	1157099
Conductivity	umho/cm	1810	2	1155517	1100	2	1155517
Hardness (CaCO3)	mg/L	660	1	1155357	140	1	1155357
Dissolved Organic Carbon	mg/L	1.4	0.1	1157287	1.4	0.1	1155737
Total Organic Carbon (TOC)	mg/L	1.5	0.1	1157162	1.6	0.1	1155726
Orthophosphate (P)	mg/L	0.10	0.01	1157140	ND	0.01	1157140
pH	pH	8.2	N/A	1155516	9.1	N/A	1155516
Reactive Silica (SiO2)	mg/L	33	3	1157272	1.2	0.5	1157272
Dissolved Sulphate (SO4)	mg/L	149	1	1157139	39	1	1157139
Alkalinity (Total as CaCO3)	mg/L	566	1	1155518	187	1	1155518
Dissolved Chloride (Cl)	mg/L	200	3	1157136	200	2	1157136
Nitrite (N)	mg/L	ND	0.01	1155630	ND	0.01	1155630
Nitrate (N)	mg/L	ND	0.1	1155630	ND	0.1	1155630
Nitrate + Nitrite	mg/L	ND	0.1	1155630	ND	0.1	1155630
RCAP CALCULATIONS							
Anion Sum	me/L	20.0	N/A	1155362	10.2	N/A	1155362
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	558	1	1155343	167	1	1155343
Calculated TDS	mg/L	1130	1	1155368	592	1	1155368
Carb. Alkalinity (calc. as CaCO3)	mg/L	8	1	1155343	19	1	1155343
Cation Sum	me/L	21.9	N/A	1155362	11.6	N/A	1155362
Ion Balance (% Difference)	%	4.49	N/A	1155361	6.59	N/A	1155361
Langelier Index (@ 20C)	N/A	1.48	N/A	1155365	0.620	N/A	1155365
Langelier Index (@ 4C)	N/A	1.23	N/A	1155366	0.373	N/A	1155366
Saturation pH (@ 20C)	N/A	6.69	N/A	1155365	8.47	N/A	1155365
Saturation pH (@ 4C)	N/A	6.94	N/A	1155366	8.72	N/A	1155366

ND = Not detected
RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Job #: A709161
Report Date: 2007/02/05

Adventus Remediation Technologies Inc
Client Project #: 3000R-23-32414
Project name:
Sampler Initials:

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

Maxxam ID		Q72097	Q72098		
Sampling Date		2007/01/29	2007/01/29		
COC Number		na	na		
	Units	344064	344065	RDL	QC Batch

METALS					
Dissolved Aluminum (Al)	ug/L	ND	6	5	1155554
Dissolved Antimony (Sb)	ug/L	ND	ND	1	1155554
Dissolved Arsenic (As)	ug/L	3	ND	1	1155554
Dissolved Barium (Ba)	ug/L	190	210	5	1155554
Dissolved Beryllium (Be)	ug/L	ND	ND	0.5	1155554
Dissolved Bismuth (Bi)	ug/L	ND	ND	1	1155554
Dissolved Boron (B)	ug/L	3500	3500	10	1155554
Dissolved Cadmium (Cd)	ug/L	ND	ND	0.1	1155554
Dissolved Calcium (Ca)	ug/L	130000	6200	200	1155554
Dissolved Chromium (Cr)	ug/L	ND	ND	5	1155554
Dissolved Cobalt (Co)	ug/L	ND	ND	0.5	1155554
Dissolved Copper (Cu)	ug/L	ND	ND	1	1155554
Dissolved Iron (Fe)	ug/L	ND	ND	50	1155554
Dissolved Lead (Pb)	ug/L	ND	ND	0.5	1155554
Dissolved Magnesium (Mg)	ug/L	78000	31000	50	1155554
Dissolved Manganese (Mn)	ug/L	960	180	2	1155554
Dissolved Molybdenum (Mo)	ug/L	3	190	1	1155554
Dissolved Nickel (Ni)	ug/L	2	2	1	1155554
Dissolved Potassium (K)	ug/L	990	1100	200	1155554
Dissolved Selenium (Se)	ug/L	ND	ND	2	1155554
Dissolved Silicon (Si)	ug/L	16000	610	50	1155554
Dissolved Silver (Ag)	ug/L	ND	ND	0.1	1155554
Dissolved Sodium (Na)	ug/L	200000	200000	100	1155554
Dissolved Strontium (Sr)	ug/L	1200	31	1	1155554
Dissolved Thallium (Tl)	ug/L	ND	ND	0.05	1155554
Dissolved Titanium (Ti)	ug/L	ND	ND	5	1155554
Dissolved Uranium (U)	ug/L	7.2	ND	0.1	1155554
Dissolved Vanadium (V)	ug/L	2	2	1	1155554
Dissolved Zinc (Zn)	ug/L	6	ND	5	1155554
NUTRIENTS					
Dissolved Phosphorus (P)	ug/L	140	85	50	1155554

ND = Not detected
RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Job #: A709161
Report Date: 2007/02/05

Adventus Remediation Technologies Inc
Client Project #: 3000R-23-32414
Project name:
Sampler Initials:

GENERAL COMMENTS

Results relate only to the items tested.

Adventus Remediation Technologies Inc
Attention: Eva Dmitrovic
Client Project #: 3000R-23-32414
P.O. #:
Project name:

Quality Assurance Report
Maxxam Job Number: MA709161

QA/QC Batch	QC Type	Parameter	Date Analyzed	Value	Recovery	Units	QC Limits
1155517 YPA	QC STANDARD	Conductivity	2007/01/30		99	%	85 - 115
	Method Blank	Conductivity	2007/01/30	ND, RDL=2		umho/cm	
	RPD	Conductivity	2007/01/30	0		%	25
1155518 YPA	QC STANDARD	Alkalinity (Total as CaCO3)	2007/01/30		100	%	85 - 115
	Method Blank	Alkalinity (Total as CaCO3)	2007/01/30	1, RDL=1		mg/L	
	RPD	Alkalinity (Total as CaCO3)	2007/01/30	1.5		%	25
1155554 AHE	MATRIX SPIKE	Dissolved Aluminum (Al)	2007/01/30		97	%	80 - 120
		Dissolved Antimony (Sb)	2007/01/30		103	%	80 - 120
		Dissolved Arsenic (As)	2007/01/30		102	%	80 - 120
		Dissolved Barium (Ba)	2007/01/30		101	%	80 - 120
		Dissolved Beryllium (Be)	2007/01/30		107	%	75 - 125
		Dissolved Bismuth (Bi)	2007/01/30		97	%	75 - 125
		Dissolved Boron (B)	2007/01/30		78	%	75 - 125
		Dissolved Cadmium (Cd)	2007/01/30		102	%	80 - 120
		Dissolved Calcium (Ca)	2007/01/30		78	%	75 - 125
		Dissolved Chromium (Cr)	2007/01/30		107	%	80 - 120
		Dissolved Cobalt (Co)	2007/01/30		104	%	80 - 120
		Dissolved Copper (Cu)	2007/01/30		100	%	80 - 120
		Dissolved Iron (Fe)	2007/01/30		107	%	80 - 120
		Dissolved Lead (Pb)	2007/01/30		99	%	80 - 120
		Dissolved Magnesium (Mg)	2007/01/30		87	%	80 - 120
		Dissolved Manganese (Mn)	2007/01/30		107	%	80 - 120
		Dissolved Molybdenum (Mo)	2007/01/30		104	%	80 - 120
		Dissolved Nickel (Ni)	2007/01/30		101	%	80 - 120
		Dissolved Potassium (K)	2007/01/30		94	%	75 - 125
		Dissolved Selenium (Se)	2007/01/30		102	%	80 - 120
		Dissolved Silicon (Si)	2007/01/30		93	%	75 - 125
		Dissolved Silver (Ag)	2007/01/30		95	%	80 - 120
		Dissolved Sodium (Na)	2007/01/30		NC (1)	%	75 - 125
		Dissolved Strontium (Sr)	2007/01/30		NC (1)	%	80 - 120
		Dissolved Thallium (Tl)	2007/01/30		99	%	75 - 125
		Dissolved Titanium (Ti)	2007/01/30		96	%	75 - 125
		Dissolved Uranium (U)	2007/01/30		99	%	80 - 120
		Dissolved Vanadium (V)	2007/01/30		111	%	80 - 120
		Dissolved Zinc (Zn)	2007/01/30		104	%	80 - 120
		Dissolved Phosphorus (P)	2007/01/30		98	%	75 - 125
	Spiked Blank	Dissolved Aluminum (Al)	2007/01/30		96	%	85 - 115
		Dissolved Antimony (Sb)	2007/01/30		102	%	85 - 115
		Dissolved Arsenic (As)	2007/01/30		99	%	85 - 115
		Dissolved Barium (Ba)	2007/01/30		101	%	85 - 115
		Dissolved Beryllium (Be)	2007/01/30		104	%	85 - 115
		Dissolved Bismuth (Bi)	2007/01/30		99	%	85 - 115
		Dissolved Boron (B)	2007/01/30		89	%	85 - 115
		Dissolved Cadmium (Cd)	2007/01/30		101	%	85 - 115
		Dissolved Calcium (Ca)	2007/01/30		98	%	85 - 115
		Dissolved Chromium (Cr)	2007/01/30		108	%	85 - 115
		Dissolved Cobalt (Co)	2007/01/30		104	%	85 - 115
		Dissolved Copper (Cu)	2007/01/30		99	%	85 - 115
		Dissolved Iron (Fe)	2007/01/30		106	%	85 - 115
		Dissolved Lead (Pb)	2007/01/30		99	%	85 - 115
		Dissolved Magnesium (Mg)	2007/01/30		99	%	85 - 115
		Dissolved Manganese (Mn)	2007/01/30		107	%	85 - 115
		Dissolved Molybdenum (Mo)	2007/01/30		101	%	85 - 115
		Dissolved Nickel (Ni)	2007/01/30		103	%	85 - 115
		Dissolved Potassium (K)	2007/01/30		96	%	85 - 115

Adventus Remediation Technologies Inc
Attention: Eva Dmitrovic
Client Project #: 3000R-23-32414
P.O. #:
Project name:

Quality Assurance Report (Continued)
Maxxam Job Number: MA709161

QA/QC Batch	QC Type	Parameter	Date Analyzed yyyy/mm/dd	Value	Recovery	Units	QC Limits	
1155554 AHE	Spiked Blank	Dissolved Selenium (Se)	2007/01/30		100	%	85 - 115	
		Dissolved Silicon (Si)	2007/01/30		98	%	85 - 115	
		Dissolved Silver (Ag)	2007/01/30		99	%	85 - 115	
		Dissolved Sodium (Na)	2007/01/30		98	%	85 - 115	
		Dissolved Strontium (Sr)	2007/01/30		99	%	85 - 115	
		Dissolved Thallium (Tl)	2007/01/30		100	%	85 - 115	
		Dissolved Titanium (Ti)	2007/01/30		96	%	85 - 115	
		Dissolved Uranium (U)	2007/01/30		99	%	85 - 115	
		Dissolved Vanadium (V)	2007/01/30		111	%	85 - 115	
		Dissolved Zinc (Zn)	2007/01/30		102	%	85 - 115	
	Method Blank	Dissolved Phosphorus (P)	2007/01/30			92	%	85 - 115
		Dissolved Aluminum (Al)	2007/01/30		ND, RDL=5		ug/L	
		Dissolved Antimony (Sb)	2007/01/30		ND, RDL=1		ug/L	
		Dissolved Arsenic (As)	2007/01/30		ND, RDL=1		ug/L	
		Dissolved Barium (Ba)	2007/01/30		ND, RDL=5		ug/L	
		Dissolved Beryllium (Be)	2007/01/30		ND, RDL=0.5		ug/L	
		Dissolved Bismuth (Bi)	2007/01/30		ND, RDL=1		ug/L	
		Dissolved Boron (B)	2007/01/30		ND, RDL=10		ug/L	
		Dissolved Cadmium (Cd)	2007/01/30		ND, RDL=0.1		ug/L	
		Dissolved Calcium (Ca)	2007/01/30		ND, RDL=200		ug/L	
		Dissolved Chromium (Cr)	2007/01/30		ND, RDL=5		ug/L	
		Dissolved Cobalt (Co)	2007/01/30		ND, RDL=0.5		ug/L	
		Dissolved Copper (Cu)	2007/01/30		ND, RDL=1		ug/L	
		Dissolved Iron (Fe)	2007/01/30		ND, RDL=50		ug/L	
		Dissolved Lead (Pb)	2007/01/30		ND, RDL=0.5		ug/L	
		Dissolved Magnesium (Mg)	2007/01/30		ND, RDL=50		ug/L	
		Dissolved Manganese (Mn)	2007/01/30		ND, RDL=2		ug/L	
		Dissolved Molybdenum (Mo)	2007/01/30		ND, RDL=1		ug/L	
		Dissolved Nickel (Ni)	2007/01/30		ND, RDL=1		ug/L	
		Dissolved Potassium (K)	2007/01/30		ND, RDL=200		ug/L	
		Dissolved Selenium (Se)	2007/01/30		ND, RDL=2		ug/L	
		Dissolved Silicon (Si)	2007/01/30		ND, RDL=50		ug/L	
		Dissolved Silver (Ag)	2007/01/30		ND, RDL=0.1		ug/L	
		Dissolved Sodium (Na)	2007/01/30		ND, RDL=100		ug/L	
		Dissolved Strontium (Sr)	2007/01/30		ND, RDL=1		ug/L	
Dissolved Thallium (Tl)	2007/01/30		ND, RDL=0.05		ug/L			
Dissolved Titanium (Ti)	2007/01/30		ND, RDL=5		ug/L			
Dissolved Uranium (U)	2007/01/30		ND, RDL=0.1		ug/L			
Dissolved Vanadium (V)	2007/01/30		ND, RDL=1		ug/L			
Dissolved Zinc (Zn)	2007/01/30		ND, RDL=5		ug/L			
RPD	Dissolved Phosphorus (P)	2007/01/30		ND, RDL=50		ug/L		
	Dissolved Antimony (Sb)	2007/01/30		NC		%	25	
	Dissolved Arsenic (As)	2007/01/30		2.4		%	25	
	Dissolved Barium (Ba)	2007/01/30		0.4		%	25	
	Dissolved Beryllium (Be)	2007/01/30		NC		%	25	
	Dissolved Boron (B)	2007/01/30		1.2		%	25	
	Dissolved Cadmium (Cd)	2007/01/30		NC		%	25	
	Dissolved Chromium (Cr)	2007/01/30		NC		%	25	
	Dissolved Cobalt (Co)	2007/01/30		NC		%	25	
	Dissolved Copper (Cu)	2007/01/30		NC		%	25	
	Dissolved Lead (Pb)	2007/01/30		NC		%	25	
	Dissolved Molybdenum (Mo)	2007/01/30		0.8		%	25	
	Dissolved Nickel (Ni)	2007/01/30		NC		%	25	
	Dissolved Selenium (Se)	2007/01/30		NC		%	25	
	Dissolved Silver (Ag)	2007/01/30		NC		%	25	

Adventus Remediation Technologies Inc
Attention: Eva Dmitrovic
Client Project #: 3000R-23-32414
P.O. #:
Project name:

Quality Assurance Report (Continued)
Maxxam Job Number: MA709161

QA/QC Batch	QC Type	Parameter	Date Analyzed yyyy/mm/dd	Value	Recovery	Units	QC Limits
1155554 AHE	RPD	Dissolved Sodium (Na)	2007/01/30	2.4		%	25
		Dissolved Thallium (Tl)	2007/01/30	NC		%	25
		Dissolved Vanadium (V)	2007/01/30	NC		%	25
		Dissolved Zinc (Zn)	2007/01/30	NC		%	25
1155630 LS	MATRIX SPIKE	Nitrite (N)	2007/01/31		99	%	75 - 125
		Nitrate (N)	2007/01/31		99	%	75 - 125
	Spiked Blank	Nitrite (N)	2007/01/31		100	%	85 - 115
		Nitrate (N)	2007/01/31		98	%	85 - 125
	Method Blank	Nitrite (N)	2007/01/31	ND, RDL=0.01		mg/L	
		Nitrate (N)	2007/01/31	ND, RDL=0.1		mg/L	
		Nitrate + Nitrite	2007/01/31	ND, RDL=0.1		mg/L	
	RPD	Nitrite (N)	2007/01/31	NC		%	25
		Nitrate (N)	2007/01/31	1.1		%	25
		Nitrate + Nitrite	2007/01/31	1.1		%	25
1155726 SAC	MATRIX SPIKE	Total Organic Carbon (TOC)	2007/01/30		95	%	75 - 125
	Spiked Blank	Total Organic Carbon (TOC)	2007/01/30		101	%	75 - 125
	Method Blank	Total Organic Carbon (TOC)	2007/01/30	ND, RDL=0.1		mg/L	
	RPD	Total Organic Carbon (TOC)	2007/01/30	1.4		%	20
1155737 SAC	MATRIX SPIKE	Dissolved Organic Carbon	2007/01/30		92	%	75 - 125
	Spiked Blank	Dissolved Organic Carbon	2007/01/30		103	%	75 - 125
	Method Blank	Dissolved Organic Carbon	2007/01/30	ND, RDL=0.1		mg/L	
	RPD	Dissolved Organic Carbon	2007/01/30	0.5		%	20
1157099 ADB	MATRIX SPIKE	Total Ammonia-N	2007/02/01		93	%	80 - 120
	Spiked Blank	Total Ammonia-N	2007/02/01		101	%	80 - 120
	Method Blank	Total Ammonia-N	2007/02/01	ND, RDL=0.05		mg/L	
	RPD	Total Ammonia-N	2007/02/01	NC		%	25
1157136 JDE	MATRIX SPIKE	Dissolved Chloride (Cl)	2007/02/02		NC (2)	%	N/A
	QC STANDARD	Dissolved Chloride (Cl)	2007/02/02		107	%	80 - 120
	Spiked Blank	Dissolved Chloride (Cl)	2007/02/02		96	%	80 - 120
	Method Blank	Dissolved Chloride (Cl)	2007/02/02	ND, RDL=1		mg/L	
	RPD	Dissolved Chloride (Cl)	2007/02/02	0.8		%	20
1157139 JDE	MATRIX SPIKE	Dissolved Sulphate (SO4)	2007/02/02		NC (3)	%	N/A
	QC STANDARD	Dissolved Sulphate (SO4)	2007/02/02		98	%	80 - 120
	Spiked Blank	Dissolved Sulphate (SO4)	2007/02/02		99	%	80 - 120
	Method Blank	Dissolved Sulphate (SO4)	2007/02/02	ND, RDL=1		mg/L	
	RPD	Dissolved Sulphate (SO4)	2007/02/02	0.8		%	25
1157140 JDE	MATRIX SPIKE	Orthophosphate (P)	2007/02/02		95	%	N/A
	QC STANDARD	Orthophosphate (P)	2007/02/02		101	%	80 - 120
	Spiked Blank	Orthophosphate (P)	2007/02/02		99	%	80 - 120
	Method Blank	Orthophosphate (P)	2007/02/02	ND, RDL=0.01		mg/L	
	RPD	Orthophosphate (P)	2007/02/02	NC		%	25
1157162 AHA	MATRIX SPIKE	Total Organic Carbon (TOC)	2007/02/01		97	%	75 - 125
	[Q72097-02]	Total Organic Carbon (TOC)	2007/02/01		97	%	75 - 125
	Spiked Blank	Total Organic Carbon (TOC)	2007/02/01		97	%	75 - 125
	Method Blank	Total Organic Carbon (TOC)	2007/02/01	ND, RDL=0.1		mg/L	
	RPD [Q72097-02]	Total Organic Carbon (TOC)	2007/02/01	1		%	20
1157272 LMA	MATRIX SPIKE	Reactive Silica (SiO2)	2007/02/01		100	%	80 - 120
	QC STANDARD	Reactive Silica (SiO2)	2007/02/01		109	%	75 - 125
	Spiked Blank	Reactive Silica (SiO2)	2007/02/01		104	%	80 - 120
	Method Blank	Reactive Silica (SiO2)	2007/02/01	ND, RDL=0.5		mg/L	
	RPD	Reactive Silica (SiO2)	2007/02/01	0.8		%	25
1157287 AHA	MATRIX SPIKE	Dissolved Organic Carbon	2007/02/01		84	%	75 - 125
	Spiked Blank	Dissolved Organic Carbon	2007/02/01		101	%	75 - 125
	Method Blank	Dissolved Organic Carbon	2007/02/01	ND, RDL=0.1		mg/L	
	RPD	Dissolved Organic Carbon	2007/02/01	1.7		%	20

Adventus Remediation Technologies Inc
Attention: Eva Dmitrovic
Client Project #: 3000R-23-32414
P.O. #:
Project name:

Quality Assurance Report (Continued)
Maxxam Job Number: MA709161

ND = Not detected

N/A = Not Applicable

NC = Non-calculable

RPD = Relative Percent Difference

QC Standard = Quality Control Standard

SPIKE = Fortified sample

- (1) The recovery in the matrix spiked sample was not calculated. Because of the high concentration in the parent sample, the relative difference between the spiked and un-spiked concentrations is not sufficiently significant to permit a reliable recovery calculation.
- (2) Chloride recovery in the matrix spiked sample was not calculated. Because of the high concentration of this compound in the parent sample, the relative difference between the spiked and un-spiked concentrations is not sufficiently significant to permit reliable recovery calculation.
- (3) Sulphate recovery in the matrix spiked sample was not calculated. Because of the high concentration of this compound in the parent sample, the relative difference between the spiked and un-spiked concentrations is not sufficiently significant to permit reliable recovery calculation.

Validation Signature Page

Maxxam Job #: A709161

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Cristina Nervo

CHRISTINA NERVO, Scientific Services

Kevin A. MacDonald

KEVIN MACDONALD,

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Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. SCC and CAEAL have approved this reporting process and electronic report format.

Appendix D

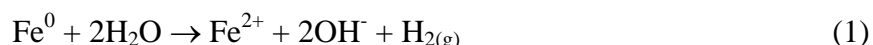
Information Concerning Possible Inorganic Effects on PRB Performance

Cause, Effects and Removal of Inorganic Mineral Precipitates in Iron Permeable Reactive Barriers

It is known that mineral precipitates will form within a granular iron permeable reactive barrier (PRB). The precipitates form due to the change in groundwater chemical conditions (increase in pH, reduction in redox potential (Eh), and introduction of Fe^{+2} ions) that occurs as the groundwater moves through the PRB. This memorandum presents a detailed discussion of mineral precipitation reactions, their implications with respect to long-term PRB performance, and means to ameliorate the affects of these precipitates.

Chemistry of Mineral Precipitation

The corrosion of the iron results in the production of Fe^{2+} (Reardon, 1995 and Reardon, 1997).

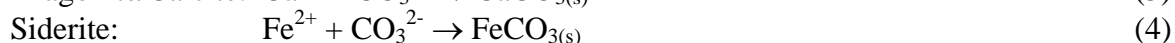
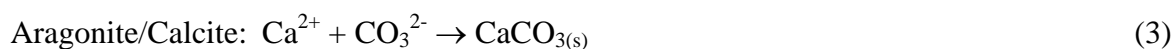


Most of the ferrous iron (Fe^{+2}) produced due to metal corrosion precipitates within the granular iron treatment zone and the total dissolved iron concentration is typically no greater downgradient than upgradient. Iron minerals that may form include iron carbonate (siderite, FeCO_3), iron hydroxide ($\text{Fe}(\text{OH})_2$) and other iron oxyhydrides. Iron hydroxides are converted over time to iron oxide (magnetite, Fe_3O_4) (Odziemkowski et al., 1998):

Typically, as the pH increases to 9 or higher in the iron treatment zone, bicarbonate (HCO_3^-) in solution converts to carbonate (CO_3^{2-}) to buffer the pH increase:



The carbonate may then combine with cations (Ca^{2+} , Fe^{2+} , and Mg^{2+}) in solution to form carbonate precipitates:



In analyses of granular iron cores obtained from field sites with carbonate-rich groundwater, both calcite and aragonite, which are forms of calcium carbonate, have been identified as the predominant precipitate.

Sulphate concentration also decreases in most granular iron PRB field applications. At high Eh, the stable form of sulfur is sulfate (SO_4^{2-}), while at low Eh sulfide (H_2S or HS^-) is the stable form with HS^- being predominant at pH greater than 7:



Given the low solubility of iron sulphide (FeS), the hydrogen sulphide produced likely precipitates out of solution:



Over time, iron sulphides transform to pyrite (FeS_2) and/or marcasite, a polymorph of pyrite. Since sulphate reduction may be mediated by biological activity it is typically not observed in bench-scale column tests. However, declines in sulphate concentrations have been observed at most field sites as groundwater passes through the iron treatment zones. Evidence for the formation of marcasite in cores from several PRB field sites has been reported (Battelle, 2002; Yabusaki et al, 2001).

Sulphate and other anions may also be incorporated in the precipitates known as green rusts. Precipitates of green rust have also been identified by surface analyses of granular iron exposed to groundwater (Odziemkowski and Gillham, 1997). Green rust is a complex interlayering of iron(II) iron(III) hydroxides with anions such as carbonate, chloride and sulphate. To date, only the carbonate form has been identified on iron samples from field sites and generally only in very small quantities.

Implications with Respect to Long-Term Performance

From the above discussion, several inferences can be drawn regarding the potential effects of mineral precipitation on PRB performance. For example Wilkin et al (2001) state that “upgradient groundwater chemistry and flow rate appear to be the main factors that control the rates (and type) of mineral precipitation”. In Korte (2001), sites with high levels of carbonate and sulfate (as well as high oxygen levels, see ETI Technical Note 4.04) are identified as being potentially more susceptible to clogging than groundwater with low total dissolved solids (TDS). Similar concerns with respect to high TDS sites are expressed by Benner et al (2001). Specifically, these concerns involve the potential for these precipitates to reduce the activity of the iron and/or to reduce the permeability through pore clogging. Zhang and Gillham (2005) showed in a long-term column study, that calcium carbonate precipitation occurs as a moving front through the iron. The maximum loss in porosity was about 7% initial porosity, followed by no further accumulation. Lin et al. (2005) used geochemical and transport modeling to simulate the long-term change in hydraulic properties in iron PRBs. Assuming a typical calcium and alkalinity concentration range and groundwater velocity up to 0.7 ft/day (0.2 m/day), the modeling has shown that precipitates result in only subtle changes in PRB’s porosity and hydraulic conductivity within the first 10 years of operation and the most significant changes do not occur until the PRB has operated for at least 30 yrs. These general concerns should be viewed in the context of documented field performance.

Field experience to date indicates, that at most sites, calcium carbonate represents the largest volume of precipitates. The first recorded core analyses, from pilot-scale systems in Upstate, NY and in Denver, CO, containing 100% granular iron revealed porosity losses in the upgradient few inches of iron in the range of 10% of the initial porosity, with losses declining sharply over the first foot to below 2% (Vogan et al., 1998 and 1999). These porosity losses were calculated based on carbonate analyses of retrieved cores. The porosity losses measured in the core samples were consistent with that predicted on the basis of changes in the inorganic water chemistry. Assuming an initial porosity of 0.5, the porosity after 18 months (Denver) to 2 years (New York) in the first few inches of the iron zones had declined to about 0.45. Concurrent field data (VOC and groundwater velocity measurements) indicated that the precipitates had not adversely affected system hydraulics and iron reactivity. Similar or lower levels of precipitate have been observed at other sites operating for similar periods of time (Blowes et al, 1999; Battelle, 2002).

Extrapolation from these early coring results indicated that the porosity loss in a thin zone at the upgradient interface of the PRB over a 5 to 10 year period would necessitate some form of rehabilitation to restore the reactivity and/or hydraulics of the system. It was not known how much total porosity loss would occur as the systems “aged”. However, recent cores taken from one of the same sites as described in Vogan et al (1998) showed no more precipitate build-up than originally observed (Battelle, 2002). Cores taken from the original University of Waterloo test site at CFB Borden, Ontario, 10 years after installation (Reynolds, 2002) also showed no large degree of precipitate build-up since it was cored, 6 years previously (O’Hannesin and Gillham, 1998). Recent laboratory and modelling studies simulating several years of PRB operation (Gillham et al, 2001; Smyth et al, 2000; Battelle, 2002) have shown that porosity losses will level off at about 10 to 20% of the original porosity over time. The precipitate front slowly moves through the iron zone. Significantly, most column studies have shown considerable decline in VOC reactivity within these precipitated zones (Vikesland et al, 2003). Other column studies (e.g. Kamolpornwijit et al, 2003; Gillham et al, 2001) have shown that under certain conditions, precipitates could lead to non-uniform flow within the iron zone.

Comparing these laboratory studies to field results is difficult. In the field, PRBs have been performing for 5 years or more (e.g., O’Hannesin and Gillham, 1998; Sorel et al, 2000), with no apparent decline in reactive performance. Indeed, iron material retrieved from the Borden test site 10 years after installation is still capable of degrading VOCs (Reynolds, 2002). Of over 90 installations, no site that we are aware of has needed rehabilitation because of loss of iron reactivity. Two PRBs evaluated by the U.S. DoD indicate that these PRBs are currently performing as designed and were predicted to perform acceptably for at least 30 years (NFESC, 2002).

Given the preponderance of field data, PRBs at most sites should be able to last at least 10 years with no need for rehabilitation to address the adverse affects of mineral precipitation. Economic(s) analyses completed by DuPont Inc., the US DoD and others have shown that if rehabilitation activities only need to occur at intervals of about 10 to 15 years, then PRBs will be extremely cost-competitive versus pump and treat systems (and likely most other in-situ technologies).

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