FINAL REPORT

Anaerobic Biostimulation for the In Situ Precipitation and Long-Term Sequestration of Metal Sulfides

SERDP Project ER-1373

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LIST OF ACRONYMS

As	Arsenic
AsO_4^{3-}	Arsenate
$AsOS_2^{3-}$	Dithioarsenite
AsS	Realgar
As_2S_3	Orpiment
Br	Bromide
D_x	Latitudinal dispersivity
D_y	Longitudinal dispersivity
DI	Deionized
DO	Dissolved Oxygen
DoD	Department of Defense
Fe	Iron
FeAsS	Arsenopyrite
FeS_2	Pyrite
FDEP	Florida Department of Environmental Protection
g/L	Grams per liter
gpm	Gallon per minute
HCl	Hydrochloric Acid
$H_2AsO_3S^-$	Thioarsenate

KBr	Potassium Bromide
kg	Kilogram
L	Liter
MSDS	Material Safety Data Sheet
µm	Micrometer
NaBr	Sodium Bromide
NaOH	Sodium Hydroxide
$(NH_4)_2PO_4$	Diammonium Phosphate
ORP	Oxidation-Reduction Potential
PI	Principal Investigator
PTWP	Pilot Test Work Plan
PVC	Polyvinyl Chloride
ppb	Parts per billion
S^0	Sulfur
S^{-2}	Free Sulfide
$S_2O_3^{2-}$	Thiosulfate
SERDP	Strategic Environmental Research and Development Program
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
UIC	Underground Injection Control

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2. EXECUTIVE SUMMARY

The precipitation of dissolved metals in groundwater under anaerobic conditions has been the subject of numerous studies, but there has been very limited research on the mineralogy and the stability of these precipitates under variable geochemical conditions. Examining the mineralogy and establishing the rate of dissolution of precipitates under aerobic conditions is the subject of this SERDP supported research. A field research site was established at Site No. ST-65, a former refueling area at the Avon Park Air Force Range in Florida. Site ST-65 had high concentrations of arsenic (As) in shallow groundwater within a sandy, naturally anaerobic aquifer. Sediment and groundwater were collected from the area with the highest concentration of As in groundwater (1800 parts per billion [ppb]) and were used to construct four flow-through columns for a bench-scale laboratory study conducted at Princeton University. In these experiments, indigenous sulfate reducing bacteria were stimulated with injections of sodium lactate, ethanol, ferrous iron and sulfate over a period of several months under strictly anaerobic conditions. Analysis of the sediments from one column indicated the presence of As-bearing sulfides, including arsenopyrite and realgar, at ten times the concentration of the natural sediments. Aerobic water was then passed through one of these columns for 115 days. Analyses of the dissolved As concentrations over this time when compared to the total As in the analyzed sediments suggested that only 2% of the sequestered As was dissolved after 116 pore volumes of aerobic groundwater had passed through the column. Analyses of the As concentration of sediments in 15 mL column experiments leached by the same water over the same time period, which was equivalent to 11,600 pore volumes, yielded an As loss rate which agreed within error with the results of the larger column experiment. A scale-up of the column study model using the measured ground water flow velocity indicates that 98% of As would be retained in the solid phase after sixteen years of fully oxygenated conditions in the groundwater, and that the dissolved As concentration would average ~1 μM (75 ppb) at the source. The results of the modeling indicates that the key to successful sequestration ofAs under anaerobic, sulfate-reducing conditions is the co-precipitation of FeS which consumes O_2 during oxidation, thus reducing the O_2 available to dissolve arsenopyrite, and produces Fe^{3+} hydroxides, which act to adsorb dissolved As, and the co-precipitated Fe and Ca phosphate, which may act to further shield As sulfides from oxidation and may incorporate As into their crystal structure. For many subsurface environments the groundwater is naturally anaerobic and sulfidic, and for these environments the sequestration of As would be an effective and permanent solution.

For aquifers that are naturally aerobic or where the anaerobic conditions are temporary due to a high organic load, the transition to fully aerobic conditions would be gradual and would not be expected to cause a significant release of As.

Success of the column study led to the implementation of a small-scale field pilot demonstration for this technology at ST-65 in January 2008. The field pilot was a scaled up version of the column study which was performed *in situ* at ST-65 over a 30 ft by 30 ft target zone in the area of highest As concentrations. Four monitoring wells, one injection well, and one recovery well were installed in January 2008. Measurements of background geochemical parameters in Site groundwater indicated that groundwater is naturally reducing. A slug test and tracer test were performed to assess aquifer characteristics to aid in recirculation system design. Upon evaluation of these parameters, a recirculation system was constructed to induce groundwater flow and provide amendments to stimulate indigenous sulfate reducing bacteria.

Injections of sodium lactate, ferrous sulfate, diammonium phosphate, and ethanol began in April 2008. Subsequent measurements performed over the course of the study period indicated that a gradual shift towards more reducing conditions occurred after initiation of amendment injections. Adjustments to the amendment mixture resulted in further reduction of site geochemical parameters to within the sulfate-reducing range. The final amendment mixture consisted of sodium lactate, sodium sulfate, and diammonium phosphate.

Results from groundwater sampling and analyses indicated that As concentration decreased by up to two orders of magnitude to ~0.01 μM (1.4 ppb) between March and September 2008. The concentrations were two orders of magnitude lower than attained in the laboratory column experiments. The effectiveness of the amendment injection in altering the groundwater geochemistry is also clearly represented by a reduction in total iron, total sulfate, and total sulfide concentrations observed over the study period. Between March and September 2008, total iron, total sulfate, and total sulfide concentrations decreased by up to 85%, 94%, and 91%, respectively, reflecting a significant decrease in reduction potential and subsequent precipitation of iron with sulfide. In addition, sodium concentrations increased significantly, indicating successful distribution of sodium lactate and sodium sulfate, two of the amendments that were injected at the Site. Sequential extraction analyses of sediment pouches, which had been deployed in each monitoring well at the outset of the field study, during the course of the experiment confirmed increasing concentrations of solid phase As as associated with higher Fe, S and P concentrations. At the end of the experiment the total As concentration in the sediment was up to three times that of the original sediment These results are in agreement with the outcome of the column study and demonstrate a proof-of-concept of this anaerobic biostimulation technology under field conditions.

3. OBJECTIVE

Recent studies have shown that As-sulfide precipitates can be formed under the appropriate conditions by *in situ* biostimulation of sulfate-reducing bacteria using ethanol and/or lactate as electron donors (White and Gadd, 1996; Waybrant et al., 1998; Saunders et al., 2001). Although the precipitation of these metals under anaerobic conditions has been the subject of numerous studies, there has been very limited research on the mineralogy and the stability of these precipitates under variably suboxic to oxic geochemical conditions. Evangelou (1995) proposed that the rate of pyrite oxidation under oxic conditions could be reduced by coating the pyrite with Fe phosphates, but this approach had not been applied microbially precipitated Fe and As sulfides. Examining the mineralogy, testing the procedure of Evangelou (1995) on, and establishing the rate of dissolution of these precipitates under aerobic conditions was the subject of this SERDP supported research. If the stability of these As sulfide precipitates in the lab indicated that they would be stable in the field over decadal time scales, then this technology was considered viable for development of a remedial strategy. In this case, the additional goal of this research was to develop of an anaerobic biostimulation technology for the precipitation of As from groundwater as a stable metal sulfide precipitate.

To achieve this goal, the study was carried out in several tasks and subtasks, as follows:

- **Task 1**: Site Selection and Collection of Aquifer Materials.
- **Task 2**: Construct and Operate Lab-Scale Column Experiments.
    - **Task 2.1:** Construct columns
    - **Task 2.2:** Establish column hydraulics
    - **Task 2.3:** Stimulate microbial sulfate reduction
    - **Task 2.4:** Test various As removal formulas
    - **Task 2.5:** Adding ^{35}S Tracer to identify As-S Precipitates
- **Task 3**: Solids Characterization and As-Sulfide Stability
    - **Task 3.1:** Mineralogical and Chemical Characterization of As Precipitates
    - **Task 3.2**: Apply Fe-phosphate Coating Technology

  - **Task 3.3:** Direct Aerobic Leaching Experiment of Coated and Uncoated Sediment in Columns and in mini-syringe columns
  - **Task 3.4:** Post-Leaching Sediment Characterization
- **Task 4**: Thermodynamic and Reactive Transport and Kinetic Redox Reaction Modeling
- **Task 5**: Column Study Report
- **Task 6**: Field Pilot
  - **Task 6.1:** Installation and Instrumentation of the Field Pilot
  - **Task 6.2:** Baseline Characterization
  - **Task 6.3:** Biostimulation and Performance Monitoring

Each of these tasks and subtasks have been successfully completed, the results of which are discussed in Section 6 of this report.

4. BACKGROUND

A report by the U.S. Army Corps of Engineers (Williford et al., 2002) cites 7,300 sites at 1,800 Department of Defense (DoD) installations with dissolved heavy metals contamination in groundwater. Given this level of groundwater contamination, development of new, cost-effective technologies for heavy metal remediation is critically needed. The five most frequently cited metals in the Williford report were arsenic, lead, cadmium, chromium and mercury. Of these, arsenic, lead, cadmium and mercury have been shown to precipitate as stable metal sulfides under highly reducing conditions.

The recently lowered drinking water standard for As (from 50 to 10 ppb in January 2001) has added significantly to the costs of remediating this particular dissolved metal contaminant. As consumable groundwater becomes an increasingly scarce resource, the cost of conventional treatment to meet water standards will increase dramatically. In addition to arsenic, this technology may be applicable to several metals of concern at DoD and private industry sites (e.g. cadmium and lead).

The most common method of remediating soluble metals is pump-and-treat, which can take decades to remove contamination because of subsurface heterogeneities and adsorption of metal species to the aquifer solids. The long time frame for pump-and-treat and the cost for off-site disposal of metals extracted from the groundwater make this a very expensive remedial option.

This research investigated an *in situ* strategy for precipitating As (and potentially other heavy metals) as stable metal sulfides and testing the long-term sequestration of these metals under changing geochemical conditions. Unlike organic contaminants, heavy metals cannot be destroyed. Existing groundwater and soil remediation technologies generally focus on *in situ* immobilization, *in situ* transformation to a less toxic form, or extraction and *ex situ* treatment. The appropriate application of any remediation technology for a heavy metal or radionuclide depends on a thorough understanding of the behavior of that metal, particularly its speciation and mobility in different environments. In anaerobic environments the mobility of heavy metals can be directly influenced by bacterial sulfate reduction, a process that is ubiquitous when sulfate and carbon substrates are available. Recent studies have shown that As-sulfide precipitates, e.g. orpiment or realgar (O’Day et al. 2004) and arsenopyrite (Saunders et al. 2008), can be formed under the appropriate conditions by *in situ* biostimulation using ethanol and/or lactate as electron donors. However, there has been very limited research on the mineralogy and the stability of these precipitates under variable geochemical conditions. A study by Thomson et al. (2001) suggested that these precipitates are relatively stable at low pH and under oxidizing conditions. *In situ* redox conditions suitable for enhancing metals precipitation and stabilization can be promoted through several means, including stimulation of the anaerobic microbial community through the addition of inexpensive carbon-based electron donors (a relatively common process in site remediation). However, questions remain regarding the stability of the ensuing metal-sulfide complexes. The research conducted for this project tested the efficacy of the technology in treating dissolved metals in groundwater and addressed the issue of stability of these precipitates. The focus was on As as opposed to other candidate heavy metals for two reasons: 1) the USEPA lowered the standard for As in groundwater from 50 to 10 ppb in 2001, which has raised the level of concern about appropriate technologies to treat dissolved As; and 2) As is one of the most common groundwater contaminants at DoD sites.

The technical objectives of this project were to:

1. Demonstrate the ability to promote microbial activity to form stable As-sulfide minerals from sulfate and dissolved As in aquifer materials.

2. Characterize the As-sulfide minerals formed during precipitation.

3. Assess the stability of As-sulfide minerals and the potential for As re-mobilization following treatment to determine operating parameters and constraints for full-scale technology deployment for controlling As migration in groundwater.

4. Test an additional stabilization step of Evangelou (1995) for promoting long-term sequestration of As under oxidizing conditions.

5. Demonstrate this technology for anaerobic *in situ* precipitation and sequestration of As in groundwater in a small-scale, proof-of-concept field pilot demonstration.

5. MATERIALS AND METHODS

The six tasks defined for this study may be grouped into two main categories: Tasks 1 through 5 were performed as part of the bench-scale laboratory study, and Task 6 was the field-scale pilot study. Task 5, Column Study Report, encompasses reporting of Tasks 1 through 4 and as such is not separately discussed in this section.

Laboratory analyses of samples from both the column and pilot study were performed mainly by Princeton University using the analytical methods described in Section 5.2. Confirmatory analyses were performed by Accutest Laboratories of Tampa, Florida for As using Method SW-846 6010B.

5.1 Task 1: Site Selection and Collection of Aquifer Materials

Site Selection

More than twenty sites were reviewed in the process of site selection. Several criteria were considered, including but not limited to:

- As concentrations;
- Depth of contamination;
- Complexity of hydrogeology; and
- Size of As plume.

Collection of Aquifer Materials

All groundwater and sediment samples collected for use in bench-scale testing were collected according to standard field sampling methods as detailed in the Field Sampling Plan (Appendix C-1). Samples were collected adjacent to well 43103-MW as shown on Figure 1. Ten kilograms (kg) of site sediments were collected with a direct push rig equipped with a Dual Wall Split Spoon Sampler. Discrete samples, 2 ft in length, were collected in clear poly-vinyl chloride (PVC) liners, and the liners were subsequently capped and stored on ice for immediate shipping. Forty liters (L) of groundwater were collected in 4 L cubitainers. The cores were sealed along with the groundwater and were shipped in coolers to Princeton University where they were transferred to an anaerobic glove bag.

5.2 Task 2: Construct and Operate Lab-Scale Column Experiments

Task 2.1: Construct Columns

Four columns were constructed from opaque, ¼" thick PVC, 5" in diameter and 50 cm long. Six sampling ports were constructed along the side of each column (see Appendix A-1 for photographs, Figure 2 for setup schematic). Opaque materials were used in all components to inhibit photo-oxidation of As species. The columns were sterilized with bleach and rinsed with filtered deionized (DI) water and then placed in an anaerobic glove bag filled with 10% H_2/90% N_2 gas mixture. In the glove bag the columns were packed with sediment removed from the core liners shipped from the Avon Park site. The columns were capped using Nylon mesh and screw on PVC end caps and then connected by tubing to the groundwater reservoir.

When injections were performed, the columns were disconnected from the return groundwater reservoir and connected to a fraction collector (Spectra-Chrom CF-1) setup by fitting the outlet tubes on top of the columns to the fraction collector's drip nozzles. Samples for cation and anion analyses were taken daily while pH, Eh and conductivity readings were taken every 48 hours. Additional samples were collected from the side ports by slowly pulling 3 mL of water through 0.22 μm syringe filters using 5 mL syringes. A total of 3 mL per side port were collected per day, which is equivalent to approximately 1.5% of the total pore volume of the column.

Task 2.2: Establish Column Hydraulics

A peristaltic pump (Masterflex) pushed natural groundwater from one 4L cubitainer (groundwater reservoir) upwards through all four columns simultaneously and back into a second 4L cubitainer which was connected to the first. The first 4 L cubitainer, which was used to mix amendments into the natural groundwater, was continuously stirred by a magnetic stirrer. All amendments were first sparged with nitrogen gas and subsequently degassed in the glove bag 24 hours prior to use. The groundwater was circulated through the columns for 24 hours during which trapped gases were removed from the columns by pulling water from the side ports. Additional sediment was added to the top of the columns after the sediment had settled. The natural groundwater was then circulated through each column at a flow rate of 4 to 8 mL hr^{-1} for one month by which time the pH, ORP and conductivity values matched those observed in the field (Table 1).

Task 2.3: Column Metals Removal Testing

Analytical Procedures

Anion analyses were performed on an ICMS (Dionex 320 with AS15 IONPAC 2mm Column AG15 IONPAC Guard Column 10-60 mM KOH and ThermoFinigan Electrospray Quadrupole mass spectrometer). The anion detection limits and calibration procedures are the same as those reported by Onstott et al. (2006). The detection limit of AsO_4^{3-} by IC ECD analyses was 0.1 µM. Thioarsenic compounds were synthesized following the procedures of Schwedt and Rieckhoff (1996) and utilized to calibrate the ICMS.

Cation analyses were performed on an ICP AES (Perkin Elmer). For analyses of the sequential extracts the Fe, Mn, S and As standards were prepared using the same reagents as used in the extraction step. The cation detection limits and calibration procedures are the same as those reported by Onstott et al. (2006). The detection limit for As by ICP analyses was 0.5 µM. Sulfide samples were quantified by UV spectroscopy following the method of Cord-Ruwisch (1985). Ethanol concentrations were determined by measurement of the absorbance at 340 nm for 10 minutes with a UV spectrophotometer. The detection limit for ethanol with this assay was 0.17 mM.

Injection Procedure

Five injections were performed over an interval of 4 months. The ingredients for the amendments were degassed and stored in the anaerobic glove bag. They were combined in a 15 mL centrifuge tube prior to pouring it into the 4L cubitainer reservoir. The goal of the injections was the promotion of sulfate reduction and As precipitation, and they were carried out as follows:

> **Injection 1:** Na-Sulfate, ethanol, lactate and diammonium phosphate [$(NH_4)_2PO_4$] were added to the 8 liter reservoirs and the pH adjusted to 7 with hydrochloric acid (HCl) or sodium hydroxide (NaOH). Sodium bromide (NaBr) was added as a conservative tracer. This first injection was monitored for 2 weeks with the eluent collected by a fraction collector. The conductivity was recorded in order to observe the rate at which the amended solution was moving through the columns and the bromide was measured in the eluent samples to determine the porosity of the columns at a flow rate of ˜10 ml min^{-1}.

Injection 2: Starting with fresh GW, Na-Sulfate, ethanol, lactate, and $(NH_4)_2PO_4$ were added to the 8 liter reservoir and the pH adjusted to 7 with HCl or NaOH. NaBr was added as a conservative tracer. This was monitored for 2 weeks.

Injection 3: Starting with fresh GW, Na-Sulfate , ethanol, lactate, $(NH_4)_2PO_4$ and Arsenate were added to the 8 liter reservoir and the pH adjusted to 7 with HCl or NaOH. Arsenate was added to increase As concentrations in a controlled manner in order to meet method detection limits for analysis of column sediment and effluent. NaBr was added as a conservative tracer. This was monitored for 2 weeks. $FeCl_2$ was also added to the reservoir until the sulfide was greatly diminished.

Injection 4: Starting with fresh GW, Na-Sulfate, ethanol, lactate , $(NH_4)_2PO_4$, $FeCl_2$ and Arsenate were added to the 8 liter reservoir and the pH adjusted to 7 with HCl or NaOH. The system was monitored for 3 weeks during which time additional $FeCl_2$ was added.

Injection 5: Starting with fresh GW, Na-Sulfate , ethanol, lactate, $(NH_4)_2PO_4$, $FeCl_2$ and Arsenate were added to the 8 liter reservoir and the pH adjusted to 7 with HCl or NaOH. In addition, a radioactive tracer, $^{35}SO_4$ was added to each column from the side ports to identify the location within each column of high concentrations of sulfide precipitation using phosphor imaging (subtask 2.4).

5.3 Task 3: Solids Characterization and As-Sulfide Stability

Task 3.1: Mineralogical and Chemical Characterization of As Precipitates

The final injection was monitored until lactate and sulfate had diminished, after which all of the columns were disconnected from the peristaltic pump and the pore water drained prior to closing the valves at the inlet and outlet ends. One column, column #1, was removed from the glove bag, stored at $^{-}20^{o}C$ until frozen, and then split along its axis. Epoxy was added to one half of the column and polished thin sections were prepared. Samples from the other half of the column were mounted on SEM stubs with double sided tape. The thin sections and the SEM stubs were exposed to a phosphor image screen (Molecular Dynamics Tritium Storage Phosphor Screen) and the distribution of the ^{35}S was mapped using a Molecular Dynamics Storm 860 phosphor imager. The thin sections and SEM stubs were examined using a Phillips XL30 FEG SEM with EDS utilizing the phosphor images to locate the ^{35}S bearing sulfide minerals produced by microbial SO_4^{2-} reduction. The sediments in the areas identified by the phosphor images were used to determine the mineralogy of the precipitates and to determine whether the Aswas concentrated at sulfide rich sites. These sediments were also used to pack six 5 mL syringes to be utilized in the aerobic leaching phase of the experiment (subtask 3.2).

Six 7 to 10 gram samples from the other half of column #1 were collected along the column axis for sequential extractions to determine the distribution of Fe, Mn, S and As in the column as described in the following section.

Sequential Extraction Procedure

1. Sequential extractions were performed on the sediment samples from column #1 and on the original sediment in accordance with the procedure of LaForce et al. (La Force et al., 1999). The sequential extraction procedure was performed as follows: Adsorbed species - Samples were placed in 50 mL centrifuge tubes and 50 mL of 1 M $MgSO_4$ was added, shaken for 1 hour, centrifuged, the supernatant filtered and stored at 4°C. The residual solid was washed with 50 mL of DI water and the rinse water filtered and stored at 4°C. The residual solid was dried, weighed and saved for the next step of the extraction procedure.
1. Organic species - Sediment was placed in 100 mL serum vials and 50 mL of 6% NaOCl was added and then capped. These samples were heated for 1 hour at 95+5°C in a water bath while N_2 gas was purging the serum vials. Solids were then transferred to 50 mL centrifuge tubes, centrifuged, rinsed, dried, weighed and saved. The leachate was filtered and stored as in the first extraction step. NaOCl extraction was done twice and the extracts combined before moving onto the next step.
2. Carbonate species – Fifty mL of 1 M Na-acetate/acetic acid at pH 5 was added to the solids in their 50 mL centrifuge tubes and shaken for 3 hours. Solids were then centrifuged, rinsed, dried, weighed and saved and the leachate filtered and stored as in the first extraction step.
3. Amorphous Fe oxide phase - Fifty mL of 0.2 M ammonium oxalate was added to the solids in their 50 mL centrifuge tubes wrapped in Al foil and shaken in the dark for 4 hours. Solids were then centrifuged, rinsed, dried, weighed and saved and the leachate filtered and stored as in the first extraction step.
4. Crystallized Fe oxide phase - Fifty mL of 1M hydroxylamine/HCl solution in 25% v/v acetic acid was added to the solids in 100 mL serum vials, sealed and heated for 6 hours at 95+ 5°C. Solids were then transferred to 50 mL centrifuge tubes, centrifuged, rinsed, dried, weighed and saved and the leachate filtered and stored as in the first extraction step.

5. Sulfide phase - Fifty mL of *aqua regia* (3-1-2 v/v solution of HCL-HNO_3-H_2O) was added to the solids in 100 mL serum vials and heated for 1 hour at 95+5°C. Solids were then centrifuged, rinsed and saved and the leachate filtered and stored as in the first extraction step. The leachate was diluted 1:10 with DI H_2O prior to analyses.

Steps 1 through 5 were performed anaerobically. Sequential extractions were performed on duplicate samples and the analyses averaged. All leachates were analyzed by ICP. Fe, Mn, S and As standards were prepared for each extraction step using the same reagents used in the extraction step.

Six 5 mL syringe samples were analyzed during the course of the aerobic leaching experiment (subtask 3.2). The total As was measured first in the sediments from the syringes, followed by sequential extraction analyses, which were performed aerobically during the leaching experiment. The procedure was modified to follow that of Keon et al. (2001), whereby $MgCl_2$ was substituted for the first reagent, $MgSO_4$, in order to enable the determination of the SO_4^{2-} concentrations in the extractions. The high As concentrations associated with the ammonium oxalate and hydroxylamine/HCl extractions in column #1 (see Section 6.3) may have reflected oxides formed during oxidation of fine-grained sulfides during the NaOCl step. For this reason the NaOCl step was excluded from the sequential extraction analyses of the syringe samples.

Task 3.2: Aerobic LeachingExperiment

Column #2 was removed from the anaerobic glove bag and along with the H_2O_2/K_2HPO_4 treated column #3 (see subtask 3.3) was connected to the reservoir of natural groundwater. The groundwater reservoir was equilibrated with the atmosphere by stirring for 24 hours prior to beginning the experiment. Dissolved O_2 measurements taken with a Chemetrics CHEMet colorimetric kit confirmed that the water was air saturated. Two sets of six 5 mL syringes, one set from the untreated column #1 and one set from the H_2O_2/K_2HPO_2 treated column #4, were also connected with drip tubes to the same reservoir using the same peristaltic pump. The aerobic water was pumped through the columns at a rate of 8 mL hr^{-1} for the first 4,560 minutes. Aerobic groundwater passed simultaneously through the twelve 5 mL syringes at a rate of 4 mL hr^{-1}, which, given the smaller pore volumes of the 5 mL syringes, is equivalent to ~100 times the flow rate of the columns.

Leaching of column #3 5 mL syringes was discontinued at 4,560 minutes because As concentrations in the eluent were much higher than those of column #2, clearly indicating that the H_2O_2/K_2HPO_2 treatment had no beneficial effect. The flow rate through column #2 was then increased to 10 mL hr^{-1} for the remainder of the experiment as this gave a more reliable flow rate, which is ~50 times the groundwater flow rate at the field site. After 8,640 minutes, the reservoir was switched to an artificial groundwater that did not contain any As in order to increase the sensitivity of determining the As release rate. After 83,400 minutes of aerobic leaching, the reservoir was switched to artificial groundwater with 10 mM K_2HPO_4 to determine if this would promote precipitation of strengite ($FePO_4$:$2H_2O$), and further reduce the As release rate. After 103,560 minutes of aerobic leaching, 10 mL of pH 6 to 7, 2.8 M $Al(OH)_3$ colloidal solution was injected into the lower 5 side ports of column #2 to determine if this reduced the rate of As release by increasing the adsorbing hydroxide phase. Aerobic leaching of column #2 was stopped at 165,480 minutes.Artificial groundwater was fabricated using DI H_2O with $CaCO_3$, NaCl and $CaSO_4$. The pH of the artificial water was adjusted to neutral (pH = 7-8) using concentrated HCl.

Task 3.3: As-Precipitate Stabilization Experiments

Columns #3 and #4 were removed from the glove bag and connected to a cubitainer (reservoir) containing natural groundwater which was circulated aerobically through the columns at 8 mL hr^{-1}. The natural groundwater was then amended with KPO_4 and H_2O_2 following the coating procedure of Evangelou (Evangelou, 1995) and the amended water circulated through columns #3 and #4 for 2 weeks. After the coating procedure was complete, column #4 was disconnected and sampled for geochemical parameters. Sediments from this column were also used to pack the six 5 mL syringes used in the direct dissolution experiment as described in the previous section. This coating procedure was expected to increase the stability of As precipitates during dissolution experiments.

5.4 Task 4: Numerical Modeling of System Performance

Reaction path models were calculated with the REACT program of the GEOCHEMIST'S WORKBENCH 7.02 STANDARD (Bethke, 2008) modeling package (Rockware Inc., Golden CO) with the Lawrence Livermore National Laboratory thermodynamic database (Delany and Lundeen, 1990) augmented with thermodynamic data for As species from Nordstrom and Archer (2003), for thioarsenite species from Wilkin et al. (2003), and for $As(OH)_3$, $AsO(OH)_3$, and Fe sulfoarsenide species from Perfetti et al. (2008). PHREEQC (Parkhurst and Appelo, 1999) was used to model the sorption, transport and oxidation of As, S, PO_4 and Fe aqueous and solid species within the columns during the aerobic leaching phase of the experiment and to predict behavior at the field scale flow rate. The sorption constants for As species reported by Dixit and Hering (2003) were used. Fe, S and As species were treated as uncoupled in the PHREEQC model and the measured ORP vlues of the groundwater or the column experiments were not used to constrain the relative abundance of these species.

5.5 Task 6: Field-Scale Pilot Study

The field pilot test was conducted in an approximately 30 foot by 30 foot area in the vicinity of former well 43103-MW, approximately 15 ft south of ST-65-MW23 and within the dissolved As plume (Figure 1).

Task 6.1: Installation and Instrumentation of the Field Pilot

An active recirculation system was used to control groundwater movement and deliver amendments to groundwater in the field test plot. The recirculation system consisted of one extraction well located at the downgradient end of the test plot and one injection well located approximately 30 feet upgradient of the extraction well (Figure 3). A network of four monitoring wells constructed using the hollow-stem auger drilling method were installed between the injection and extraction wells to monitor the pilot test. Two monitoring wells were evenly spaced 10 ft apart along the transect between the injection and extraction wells, and the other two monitoring wells were positioned in the center of the eastern and western treatment areas (Figure 3). The injection and extraction wells were constructed using 4-inch diameter PVC well casing. The screened interval of all monitoring wells corresponded to the targeted treatment zone, from just below the water table (about 2 to 3 feet below land surface [BLS]) to 15 ft BLS. The injection well was screened from 5-15 ft BLS in order to prevent surfacing of the amendments, and the extraction well was screened from 3-15 ft BLS. Well construction logs are provided in Appendix A-2.

A well vault was constructed around the extraction well (RW-1) to house the 1” Schedule 40 PVC intake line for easy access. The length of the intake line from the well vault to an equipment housing unit located atop the injection well (INJ-1) was buried approximately 2 feet BLS. A Flotec continuous duty centrifugal pump was installed in the equipment housing unit to power the groundwater recirculation system. The pump was fitted with two valves to meter flow, one to choke the outlet down and the other to direct flow back to the pump if needed. A totalizing flow meter, twist-lock receptacles, and hour meters were installed for both the recirculation and metering pumps. Installation of additional safeguards included: (1) a general purpose GFI receptacle to prevent electric shock; (2) a float switch that would shut the system down if the water table rose to 1 foot BLS; (3) pressure gauges to monitor back pressure and pressure at the injection wellhead. System photographs are provided in Appendix A-1.

Task 6.2: Baseline Characterization

Preliminary testing including baseline sampling, slug tests, and a bromide tracer test was performed prior to initiation of the groundwater amendment injections. Sampling procedures for baseline and subsequent monitoring are described as part of subtask 6.3.

Slug Testing

The hydraulic conductivity of the aquifer unit identified at the Site was tested using a mechanical slug device. An In Situ LevelTroll® 700 data logger was used to record the well response during the slug test. Generally, 1 to 2 feet of vertical displacement was introduced to the well water to allow for sufficient recovery time to occur.

The water level data collected during the slug test was plotted and analyzed using the Hvorslev Method (1951), according to the following equation:

$$K = \frac{r^2 \ln(L/r)}{2LT_0}$$

Where:

r (ft) = Radius of the well casing
L (ft) = Length of the screened interval
T_o (min) = Elapsed time from start of slug test
K (ft/d) = Hydraulic Conductivity

Hydraulic conductivity was calculated twice at each well. The results were averaged to provide a Site-wide general value.

Bromide Tracer Test

A conservative tracer study was implemented in order to more accurately determine the extent of amendment dispersion and travel times through the aquifer to targeted downgradient areas.

Conductivity trolls were set in monitoring wells MW-2 and MW-3 as well as extraction well RW-1 for a period of approximately one month prior to injection of the potassium bromide (KBr) tracer. The trolls recorded water level and conductivity continuously at 5 minute intervals, providing data prior to and throughout the tracer test. The groundwater recirculation system was operated continuously for ten days prior to KBr injection.

A total mass of 1.5 kg of KBr was mixed with 4 L of water to form a concentrated stock solution of approximately 250 grams per liter (g/L) of bromide (Br). This stock solution was poured into the injection well to achieve an initial *in situ* concentration of approximately 170 g/L of Br. The injection of concentrated stock was achieved via a funnel connected to poly tubing set to a depth of approximately l1 feet below top of casing.

At MW-2, the well closest to the injection point, groundwater was sampled for laboratory bromide analysis at 2, 4, 7, 8, 9 and 24 hours after the injection. Wells MW-4 and RW-1 were sampled 24 hours after the injection.

Two weeks after the injection, the conductivity trolls were removed from the wells and downloaded.

Results of the tracer test were fit to a two-dimensional model to determine the values for longitudinal (D_y) and latitudinal (D_x) dispersion as follows:

$$C(x,y,t) = \frac{C_0 A}{4\pi t\left(D_x D_y\right)^{1/2}} \exp\left(- \frac{\left(\left(x - x_0\right) - v_x t\right)^2}{4D_x t} - \frac{\left(y - y_0\right)^2}{4D_y t} \right)$$

Where:

$$t = \frac{R_t x}{v_x}$$

And:
C_0 = Initial concentration = 250,000 mg/L
A = Source surface area = area of well = $\pi r^2 = 0.342\ ft^2 = 0.03177\ m^2$
x_0 = Initial lateral distance from source = 0 m
x = Lateral distance from source = 3.05 m for MW-2
y_0 = Initial transverse distance from source = 0 m
y = Transverse distance from source = 0 m for MW-2
v_x = Velocity in x-direction = gradient = 2.003 m/d
R_t = Retardation coefficient = 1
C(x,y,t) = Final concentration (direct measurement)
t = Travel time (d)

Values for D_x and D_y were then utilized to assess the effect of dispersion on amendment concentrations within the target treatment zone. These effects were considered and applied to stock solution calculations in the form of a factor of safety as described in Section 6.6. Additional details including graphs of data from the conductivity trolls, laboratory data packages, calculation sheets, etc. are provided in Appendix A-3.

Task 6.3 Biostimulation and Performance Monitoring

Amendment Injection Strategy

Groundwater was pumped from the extraction well at approximately one gallon per minute (gpm) using an electric pump, was passed through 50 micrometer (µm) and 5 µm filters in series, and amended with metered injections of a concentrated stock prior to re-injection at INJ-1. Photographs of the system are provided in Appendix A-1.

Injections were performed continuously using two different amendment stock solutions over an interval of 4 months. The ingredients for the amendments were mixed with Site groundwater and stored in drums housed in secondary containment, open to the atmosphere within an equipment housing unit. The goal of the injections was the promotion of sulfate reduction and As precipitation, and they were carried out as follows:

> **Amendment Stock Solution 1:** Sodium lactate, ethanol, ferrous sulfate, and diammonium phosphate were added to one 55-gallon stock drum, and one liter

of stock was injected daily. This injection was monitored via collection of geochemical parameters for approximately 4 weeks.

The frequency of injections was then increased to deliver eight liters of stock per day in order to further reduce the groundwater geochemistry. This strategy was implemented for one day prior to equipment failure. Interim daily injections of two liters of pure sodium lactate were conducted for approximately 4 weeks during system repair activities.

Amendment Stock Solution 2: The oxidation of the Fe^{2+} to Fe^{3+} lead to the precipitation of Fe^{3+} phosphates and sulfates which clogged the injection system. These components were subsequently separated into two stock solution and injected separately and out of phase with each other. Sodium lactate and sodium sulfate were added to stock drum #1, and $(NH_4)_2PO_4$ was added to stock drum #2. Fourteen liters of stock #1 and approximately 3.6 liters of stock #2 were injected daily. This injection was monitored via collection of geochemical and laboratory parameters for approximately 2 months.

The addition of electron donor (lactate and ethanol) to the aquifer was expected to facilitate biological sulfate reduction. The addition of sodium sulfate was expected to provide a source of sulfate in groundwater. The diammonium phosphate was added as a nutrient to enhance microbial activity, biological sulfate reduction, and the production of sulfide. The laboratory experiments had already shown that the amendment also produced fine-grained phosphate minerals associated with the sulfides. Material Safety Data Sheets (MSDS) for each of the amendments are provided in Appendix A-4.

The system pumped water between the extraction and injection wells continuously to establish a consistent flow path and distribute amendments within the field plot. Groundwater was amended only periodically to reduce the potential for biofouling at the injection well. Dispersion diluted the amendment pulses to their target groundwater concentrations.

Groundwater Performance Monitoring

The performance of the pilot test system was monitored for a period of five months following startup of the recirculation system, or four months following initiation of the amendment injections. Groundwater samples were collected using the low flow method for analysis of field parameters, total and dissolved metal(s) of concern including iron and arsenic, sulfate and sulfide, dissolved methane and carbon dioxide, electron donor concentrations, volatile fatty acids (as a measure of fermentation products of the electron donors), chloride, total dissolved solids (TDS), total organic carbon (TOC), petroleum hydrocarbons, and cations (i.e. calcium, magnesium, and sodium). Samples were collected and preserved according to procedures adapted from those utilized during the laboratory study. Field sampling procedures are provided as Appendix C-2. Samples were analyzed by Princeton University according to the methods described in Section 5.2.

6. RESULTS AND ACCOMPLISHMENTS

6.1 Task 1: Site Selection and Collection of Aquifer Materials.

A field research site was successfully established at Site No. ST-65, a former refueling area at the Avon Park Air Force Range in Florida. The anaerobic geochemistry, straightforward hydrogeology, and elevated concentrations of As at this site led to its selection for detailed study. Since Site sediments and groundwater are equilibrated with a reducing environment, an induced switch to aerobic conditions in the column study would represent the worst-case scenario for As re-mobilization.

Concentrations of As in the groundwater in this area were as high as 1800 ppb at the time of sample collection in July 2005 (Table 2). A vertical profile of field-measured parameters (DO, ORP, temperature, pH, specific conductance) was performed in the well with the highest groundwater concentrations of As (43103-MW-see Figure 1). Results of this profiling indicated anaerobic conditions from 2 to 12 ft bgs with a pH of approximately 6.5 (Table 1). Site sediments and groundwater were collected and packaged to exclude oxygen and transferred to an anaerobic chamber at Princeton University where they were further characterized.

The groundwater at Well No. 43103-MW was low in salinity, contained low sulfate, moderately high sulfide and was As rich with a distinctive yellowish tinge (Tables 1 and 2). According to the measured pH and Eh, the principal As species should be arsenate (Figure 4). However, the greater concentration of dissolved total As versus arsenate suggests that a significant portion of the dissolved As was another species, perhaps thioarsenate (Stauder et al., 2005). The sediment is comprised of fine-grained quartz sands with minor feldspar and ilmenite. Sequential extraction analyses of the sediment indicated that of the total As, 143 µmol kg^{-1} (Table 3), 28% was trapped in carbonate or perhaps phosphate, 25% occurred as sulfides, 22% occurred in organic matter or perhaps fine-grained sulfide, 16% was incorporated in oxides and amorphous hydroxides. Approximately 2% of the Fe and 8% of the As was present as adsorbed species.

6.2 Task 2: Construct and Operate Lab-Scale Column Experiments.

Tasks 2.1 and 2.2: Construct columns and Establish Column Hydraulics

Four flow-through columns were successfully constructed as described in Section 5.2 to examine both the stability and the mineralogy of the As precipitates, as well as additional processes that assist in precipitate stabilization (see photographs in Appendix A-1). Stable geochemical conditions similar to those measured at the Site were achieved prior to initiation of amendment injections.

Tasks 2.3 and 2.4: Column Metals Removal Testing and Adding Radioactive Tracer for As-S Precipitation

Lactate, ethanol, phosphate, and sulfate were added to the groundwater flowing through the columns for a period of 4 months to promote the precipitation of arsenic. A radioactive tracer, ^{35}S, was introduced during the final phases of injection to facilitate phosphor imaging of sulfide precipitates.

During the first and second injections of SO_4^{2-} reducing amendments, total As concentrations dropped in all 4 columns by a factor of ten in less than 5 days at a rate of ~10^{-8} moles min^{-1}. This reduction in As concentrations coincided with decreasing concentrations of SO_4^{2-}, ethanol, and lactate, and increasing concentrations of HS^- (Figure 5). In addition, the pH increased to 8.5 and Eh fell from 350 to -350 to -400 mV, well within the sulfate reducing range. Most importantly, no significant release of dissolved As was observed during these injections although trace amounts (~1-2 µM) of thioarsenate ($AsO_3S_3^-$) or dithioarsenite ($AsOS_2^{3-}$) were detected in samples where thiosulphate ($S_2O_3^{2-}$) also appeared.

When $FeCl_2$ was added to the amendments, a black precipitate appeared in the groundwater solutions. The concentrations of As initially decreased by a factor of 100 to 500 times at a rate of ~$5x10^{-8}$ mol min^{-1} and then rose slightly. Ca and Mn concentrations also declined (data not shown), consistent with precipitation of Mn sulfide. The effluent As concentrations one week after each of the injections were ~1 to 5 µM, which is two orders of magnitude lower than starting concentrations of ~100 µM. The As concentration of the black precipitate was 0.56 mmol kg^{-1}, approximately 5 grams of which formed after the last three injections when $FeCl_2$ was added to the groundwater..

Influent and effluent concentrations of As were used to determine when sufficient precipitation had taken place in the columns. Further discussion of metals removal is provided in Section 6.5.

Two of the columns were sacrificed to study the stability of these precipitates, and the other two columns were used to test an additional stabilization step using a phosphate coating prior to examining stability under aerobic conditions. Aerobic natural and artificial water was then passed through one of each of these columns for a period of five months. Results from these anaerobic flow-through column studies were used to make a go/no go decision to perform a field-scale pilot test as discussed in Section 6.5.

6.3 Task 3: Solids Characterization and As-Sulfide Stability

Task 3.1: Mineralogical and Chemical Characterization of As Precipitates

Upon completion of the metals removal testing, the estimated As deposited in each sample from column #1 was approximately 0.42 to 0.55 mmol kg^{-1}, which is 3 to 4 times the As in the original sediment (Table 3).

The bottom of the column #1 sediment, where the amended groundwater entered, was blackened relative to the tawny color of the upper portion of the core. The topmost section of column #1, where the groundwater exited, was slightly blackened. This discoloration correlates with the higher concentrations of Fe and As observed in the sequential extraction profile of column #1. Approximately 57% of the As in column #1 was deposited in the lowermost 7 cm and the concentration was ten times that of the original sediment. The Fe concentration in this section was ~25 times that of the original sediment (Table 3). The S and P concentrations in this section were 70 and 24 mmol kg^{-1}, respectively, values that are ~50 times that of the original sediment. Most of the As was released during sequential extraction in the NaOCl step (Table 3), whereas most of the Fe was released in the Ammonium oxalate and the Hydroxylamine/HCl steps. Relative to the original sediment, no significant As was found in the final aqua regia step, although a significant amount of Fe (~12%) was released in this step.

^{35}S maps of the core and of the sediment grains revealed that the highest ^{35}S activity occurred in the blackened portions of the core where localized concentrations of ^{35}S approximately 100-400 µm in size were observed forming between the detrital grains (Figure 6). SEM analyses revealed that these hot spots are related to euhedral S_o crystals deposited on the surface of the detrital quartz grains. SEM analyses also detected the presence of phosphate and calcite precipitates associated with some of these S_o crystals. The As was found to be associated with fine-grained precipitates containing Fe, S, P, Ca, C and Na (Figures 7 and 8). The S_o crystals and these fine-grained coatings were only found associated with the ^{35}S hotspots. Speciation by

XANES spectroscopy of the blackened sediments from column #1 suggested that these As-bearing fine-grained precipitates were primarily As-bearing sulfides, including arsenopyrite (FeAsS) with minor realgar (AsS) (Figure 9). Based upon the analyses of the extracts, the maximum amount of FeS deposited in the blackened bottom of column #1 was 0.5 wt%. Complete analytical results are provided in Appendix A-5.

Tasks 3.2 and 3.3: Direct Dissolution Experiment and As-Precipitate Stabilization Experiments

The As and SO_4^{2-} concentrations in the eluent from the H_2O_2/K_2HPO_2 treated column #3 were 3 to 10 times greater than those of the untreated column #2 (Figure 10), which is why the aerobic leaching of column #3 was terminated earlier than that of column #2. The concentration of As in the natural groundwater entering column #2 was observed to be greater than that leaving column #2, indicating additional formation of precipitates, whereas that leaving column #3 peaked at a concentration close to that of natural groundwater (Figure 10). The total concentration of SO_4^{2-} leaving both columns, however, was greater than the total concentration of SO_4^{2-} and HS^- in the natural groundwater entering the columns (Figure 10). Increases in the As and SO_4^{2-} concentrations coincided with a decline in Cl^- and breakthrough of the natural groundwater. Switching to As-free, pH 7.5 artificial groundwater with a similar SO_4^{2-} concentration as the natural groundwater after 8,640 minutes had no significant affect on either the As or SO_4^{2-} concentrations of the eluent, but it did increase the pH to 7.5 (Figure 10). Amending the artificial groundwater composition with K_2HPO_4 at 83,400 minutes appeared to reduce the As concentration in the effluent by 10 times but doubled the SO_4^{2-} concentration in the effluent (Figure 10). The addition of colloidal $Al(OH)_3$ after 103,560 minutes temporarily increased the As concentration by 10 times, tripled the SO_4^{2-} concentration (Figure 10) and produced a slight dip in the pH. Sequential extraction analyses of the syringe column sediments suggested a decline in the As, Fe and S concentrations with time (Table 4), although the correlation is scattered by the compositional heterogeneity of the sediments ($R^2 < 0.2$). The temporal trend corresponds to a loss rate of ~$4x10^{-6}$ mmol kg^{-1} min^{-1} for As. Complete analytical results are provided in Appendix A-5.

After completion of the aerobic leaching experiment, column #2 was frozen and split open to reveal blackened regions located in the same locations as column #1 with no visible signs of oxidation. Sequential extraction analyses of column #2 also revealed that the As and Fe concentration profiles were very similar to the unleached column #1 results (Figure 11). S and P concentrations tracked that of Fe. The molar concentration of S was slightly greater than that of Fe in both columns. Although the As, Fe, S and P concentrations of the bottom-most dark region of column #2 were very similar to that of column #1, the As and Fe concentrations in the higher parts of the core were significantly less. The average As concentration was 0.36 mmol kg^{-1} or 86% of that of column #1. The average Fe concentration of column #2 was 14 mmol kg^{-1} versus the 26 mmol kg^{-1} for column #1, suggesting loss of Fe, but these averages are not significantly different at the 95% confidence level. XANES analyses of column #2 solid-phases indicated that As was found mostly in FeAsS, but, unlike column #1, AsS was less abundant and AsO_4^{3-} was also detected (Figure 9). Al-rich precipitates that formed during the injection of $Al(OH)_3$ colloids into column #2 also contained traces of As (Figure 7).

The coating procedure of Evangelou (1995) failed to provide greater protection to the Fe and As-bearing sulfide in column #3 relative to that of the untreated column #2 probably because the dilute H_2O_2 solution was too powerful an oxidant for fine-grained sulfide species. The ^{35}S analysis of column #4 sediments, which had also been treated by the Evangelou (1995) coating procedure, failed to detect reduced ^{35}S-bearing sulfides (Figure 6) that should have formed during the SO_4^{2-} reduction phase of the experiment. The SO_4^{2-} concentrations observed eluting from column #2 are consistent with the amount of O_2 entering the column, indicating the column was O_2 limited. To explain the higher SO_4^{2-} concentrations observed eluting from the treated column #3 at the beginning of the leaching process, therefore, requires the presence of initial higher SO_4^{2-} concentrations at the end of the treatment process.

The analyses of the dissolved As concentrations from the column #2 eluent indicate that after 165,480 hours of aerobic water leaching, ~2% of the As had been leached from the sediment in column #2. After correcting for the relative difference in pore volume flow rates, the estimated As loss rate for the syringe column would be -4x10^{-8} mmols kg^{-1} min^{-1}, which after 165,480 minutes corresponds to 1% of the initial As in the syringe column, in agreement with observations of dissolved As concentrations of column #2 eluent. XANES analyses of column #2 sediment were critical to demonstrating that As was present both as AsO_4^{3-} and as FeAsS/AsS, thereby confirming the existence of an oxidized As species that was undetectable prior to the aerobic leaching (Figure 9). The presence of As associated with the $Al(OH)_3$ colloids also is consistent with the presence of adsorbed AsO_4^{3-} in the column (Figure 7).

The groundwater flow velocity at the Avon Park site is ~ 1 cm day^{-1}. The flow velocity in the column aerobic leaching experiments was ~50 cm day^{-1}, and the release rate of the As was limited by the rate of O_2 entering the column and the proportion of this O_2 which oxidized FeS. If at the end of 115 days or 0.3 years of aerobic leaching ~98% of the As remained in the column, then ~98% of any FeAsS precipitated *in situ* at Avon Park should remain after ~15 years of air saturated groundwater flow. The observed dissolved As concentrations also suggest that at least a 20 times reduction in the As concentration downstream of the biostimulation site is attainable. Since aerobic conditions are not expected to exist for such an extended period of time at the Site, this represents a worst-case scenario.

6.4 Task 4: Numerical Modeling

The PHREEQC model predicts that much of the As that enters the column with the natural groundwater was adsorbed to $Fe(OH)_3$, explaining why the eluting As concentration was less than the 21 µM input (Figure 10). This is because the model assumed that the $Fe(OH)_3$ had equilibrated with the 1.8 µM dissolved As in the column during the SO_4^{2-} reduction phase. It is quite possible this assumption is not valid for all the sediment in the column, in which case the extent of AsO_4^{3-} and AsO_3^{3-} adsorption to $Fe(OH)_3$ would be variable and partial breakthrough of the input AsO_3^{3-} could occur in the eluent. Model input parameters are summarized in Table 5.

Assuming that the initial abundance and spatial distribution of As in column #2, both as solid phase FeAsS and as a adsorbed species on the Fe^{3+} hydroxides, were the same as that determined for column #1 (Table 3), the PHREEQC model indicates that as the natural groundwater flowed through it for the first 8,640 minutes ~1% more As was added to the column as adsorbed As. After passing artificial groundwater with no As through the column for an additional 156,840 minutes, the model predicts that 3% of the As would be removed from the column (Figure 10). The PHREEQC model also indicates that substantial amounts of Fe^{2+} were adsorbed to the Fe^{3+} hydroxide phases during the $FeCl_2$ portion of the SO_4^{2-} reduction. This is consistent with sequential extraction analyses of the original sediment and that of the syringe column sediment. The model predicts that this Fe^{2+} is oxidized to produce newly formed $Fe(OH)_3$, but the amount is insignificant when compared to that which occurs naturally in the sediment.

The modeled concentrations for As and SO_4^{2-} leaving column #2 represent a combination of competitive oxidation reactions of Fe^{2+} to $Fe(OH)_3$, AsO_3^{3-} to AsO_4^{3-} and HS^- to SO_4^{2-}, as well as adsorption of AsO_3^{3-}, AsO_4^{3-} and SO_4^{2-} to $Fe(OH)_3$ under varying pH and transport. Varying the reaction rates for AsO_3^{3-} to AsO_4^{3-} and HS^- to SO_4^{2-}, which are not well established, had little effect, however, on the modeled AsO_4^{3-} and SO_4^{2-} release rates, because O_2 was limited. The abundant Fe bearing sulfide precipitated during microbial SO_4^{2-} reduction, therefore, plays a key role in limiting O_2 in this system and thus limiting the oxidation of FeAsS and As sulfides. The Fe also plays a key role in the formation of new $Fe(OH)_3$ sites and lowering the pH below 8, both of which enhance the adsorption of both AsO_3^{3-} and AsO_4^{3-} (Dixit and Hering, 2003).

The identification of P bearing precipitates by SEM is consistent with reaction path modeling of PO_4^{3-} concentrations, which indicated that apatite and vivianite would be precipitated with co-injection of Fe^{2+}. The PHREEQC model also indicates that with the breakthrough of the aerobic groundwater vivianite becomes under-saturated and strengite would become supersaturated. The slower release rate of PO_4^{3-} during leaching when compared to that predicted by the PHREEQC reactive transport model indicates dissolution of a phosphate mineral phase must be taking place. Whether apatite, vivianite or strengite act to protect the solid phase As associated either with sulfide or hydroxides from dissolving cannot be determined from these experiments, but its presence confirms that the $(NH_4)_3PO_4$ amendment utilized to stimulate SRB also precipitates phosphate minerals. Finally, the addition of PO_4^{3-} to the leaching water had little effect on the dissolved As concentrations (Figure 10).

The groundwater flow velocity at the Avon Park site is ~ 1 cm day^{-1}. The flow velocity in the column aerobic leaching experiments was ~50 cm day^{-1} and the release rate of the As was limited by the rate of O_2 entering the column and the proportion of this O_2 that oxidized FeS. If at the end of 115 days or 0.3 years of aerobic leaching ~98% of the As remained in the column, then ~98% of any FeAsS precipitated *in situ* at Avon Park should remain after ~15 years of air saturated groundwater flow (worst case scenario). The observed dissolved As concentrations also suggest that at least a 20 times reduction in the As concentration downstream of the biostimulation site is attainable.

6.5 Task 5: Column Study Report

The addition of electron donors SO_4^{2-}, $FeCl_2$ and $(NH_4)_3PO_4$ led to a reduction of dissolved As concentrations with no significant release of soluble As species. Subtracting the measured dissolved As concentrations and the amount of As present in the black precipitate from the total amount of As added to the groundwater during the injections indicates that a total of ~6.4 mmols of As should have been deposited in the four columns and that the average As concentration in each column should have been ~0.56 mmol kg^{-1}. The total As concentration and the As concentration summed from the sequential extractions of column #1 were 0.42 to 0.64 mmol kg^{-1} (Table 3), respectively, which is comparable to that estimated from the total amount of dissolved As injected into the columns.

XANES analysis of column sediments was consistent with the recent thermodynamic data of Perfetti et al. (2008) (Figure 9). AsS does not appear to represent the principle solid state sink for As, as was observed by O’Day et al. (2004), however the pH in our column experiments were considerably higher than theirs. The slightly higher molar abundance of S with respect to Fe in column #2 is consistent with the observed presence of S_o in the ^{35}S hot spots. The formation of this S_o may be through abiotic reduction of Fe^{3+} hydroxides by HS^- as examined by Poulton et al. (2004). The Fe, S and P concentrations in the blackened portion of column #1, however, are consistent with the precipitation of FeS and vivianite, $Fe_3(PO_4)_2$. This association was consistent with SEM analyses of column #1 that detected As-bearing overgrowth of Fe, S, Ca and P. The crystal sizes were too small for analyses to identify the mineral phase, but the platy morphology of some the Fe-rich co-precipitates suggest that they were Fe^{3+} hydroxides (Figure 8).

With continued SO_4^{2-} reduction, a slow increase in dissolved As occurred after its initial decline during the stimulation. This behavior mirrors the As spike observed by Keimowitz et al. (2007) during their SO_4^{2-} reduction experiments, which the authors suggested was due to the formation of trithionate (AsS_3^{-1}). Our observations clearly indicate, however, that the slight increase in total As with continued SO_4^{2-} reduction is primarily attributable to the slow increase in AsO_4^{3-} concentrations, not thioarsenite concentrations. This increase in AsO_4^{3-} concentrations might be due to desorption of AsO_4^{3-} from Fe^{3+} hydroxides that are being reductively dissolved by HS^-.

These results indicate that microbial sulfate reduction was established in all four columns, resulting in the precipitation of the As within the column sediments. The reduction of sulfate to sulfide by sulfate reducing bacteria, which are ubiquitous in aquifers, promoted the precipitation of the arsenic.

Success of the column study led to the decision to proceed with plans for a field demonstration at Avon Park Air Force Base.

6.6 Task 6: Field Pilot

A Pilot Test Work Plan (PTWP) was submitted to the Florida Department of Environmental Protection (FDEP) on 1 October 2007 and approved on 4 October 2007. This document was required to satisfy Underground Injection Control (UIC) Program requirements.

Installation of monitoring, injection, and recovery wells was completed in January 2008. Well construction records are provided as Appendix A-2. Slug testing and baseline sampling were performed in January 2008 upon completion of well installation and stabilization activities. Slug testing in the test plot indicated that the target treatment zone consists of permeable soils (an average hydraulic conductivity of 9 ft/day) with a fairly low hydraulic gradient (0.002 ft/ft). Additional materials including sample spreadsheets and figures related to slug testing activities are included in Appendix A-6. Delivery of amendments using a recirculation scheme was expected to provide the most cost effective, rapid and complete distribution of amendments throughout the impacted area.

System construction and deployment of clean sediment pouches was completed in February 2008. The sediment pouches were deployed in each of the four monitoring wells for periodical collection throughout the pilot test to characterize As precipitates (see Site photos in Appendix A-1). Transducers set to measure background conductivity and water level were deployed in wells RW-1, MW-2, and MW-3 on 26 February 2008 in preparation for the conservative tracer test. However, subsequent quality assurance tests performed to verify system integrity led to the detection of leaks in the system. These leaks caused aeration of the groundwater and excessive precipitation of iron within well screens and system pipelines. Construction details were re-evaluated to pinpoint and address the problem.

Conservative Tracer Test

Upon completion of troubleshooting and system adjustment activities, the system was continuously operated for ten days prior to initiation of a bromide tracer test. A concentrated solution of KBr was poured as a single slug into INJ-1 on 1 April 2008. Modeling of results indicated that values for longitudinal dispersion (D_x) and latitudinal dispersion (D_y) are approximately 9.7 and 0.97 m^2/day, respectively. These values were then applied to the same two-dimensional dispersion model as described in Section 5.5 to predict concentrations of amendments in Site groundwater based on stock concentrations. Modeling results indicated that the use of a factor of safety equal to 2 when calculating stock concentrations should result in the achievement of amendment concentration targets in Site groundwater. Additional calculation details and figures are provided in Appendix A-3.

Amendment Injections

Amendment stock concentrations were calculated based on results of the tracer test and on target concentrations utilized during the column study. Initial injection of a stock containing sodium lactate, ferrous sulfate, ethanol, and diammonium phosphate began on 17 April 2008. Monitoring of geochemical parameters following the initial injection period indicated general uniformity Site-wide (Figure 12). However, conditions were characteristic of the methane-reducing range and were not reductive enough to be considered within the sulfate-reducing range.

As a result, amendment stock concentrations were increased approximately 10-fold. Upon mixing batches of this more concentrated stock, it was discovered that stock ingredients were reacting with one another to form solid precipitates within the mixing tank. Injections were suspended for approximately one month while bench-scale mix tests were performed to determine the source of the precipitation problem. Mix tests indicated that the sodium lactate was reacting with the ferrous sulfate to form sodium jarosite. In addition, solubility of powdered amendments was inhibited by the presence of ethanol.

Results of bench-scale mix tests led to the elimination of ethanol as an amendment, the replacement of ferrous sulfate with sodium sulfate, and to the separation of amendments into two batches. Beginning 10 July 2008, Batch 1 (sodium lactate, sodium sulfate, and water) and Batch 2 (diammonium phosphate and water) were injected intermittently and out of phase with each other in eight and four daily pulses, respectively.

Geochemical monitoring following implementation of the new injection strategy indicated the achievement of sulfate-reducing conditions throughout most of the Site (Figure 12). This injection strategy was continuously implemented for the remainder of the pilot test. Periods of heavy rains in the late summer led to automatic system shutdown via a float switch installed at INJ-1. System down time is reflected by a shift in geochemistry in August and September 2008. The system was shut down in November 2008 and decommissioned in December 2008 since study objectives had been achieved.

Results

Groundwater was monitored periodically during the course of injections for geochemical field parameters, total and dissolved metals of concern including iron and arsenic, sulfate and sulfide and carbon dioxide, electron donor concentrations, volatile fatty acids (as a measure of fermentation products of the electron donors), chloride, total dissolved solids, total organic carbon, and cations (e.g.calcium, magnesium, manganese, and sodium). Results of these analyses are provided in Table 6.

The concentrations of dissolved As began to decrease between March and June 2008 with more significant reductions seen after the injection strategy change in July 2008 (Figure 13). Total As concentrations had decreased by96% by September 2008, with no indication of re-mobilization during system down time when site geochemistry returned to near-background conditions. Because there are higher concentrations of As both up and downgradient of the system, and the recirculation system pulls in groundwater from both these areas, it was anticipated that even if all of the As within the test plot were precipitated, there would still be dissolved As entering the test plot through the recirculation system. Even with additional As inputs, samples taken in September 2008 indicated that the concentration of As was non-detect in three out of the four monitoring wells. This is consistent with the observations from the aerobic leaching experiments where the eluent As concentration was at least 1/20th of the dissolved As entering the column. The model predicts that this effect is due to the adsorption of As on Fe^{3+} hydroxides created by the oxidation of Fe sulfide minerals. Further evidence of precipitation was seen in the sediment bags that were collected in September. The sediment had turned black, indicative of the precipitation of Fe bearing sulfides. These concentrations were up to two orders of magnitude lower that the results obtained in column experiments.

The effectiveness of the amendment injection in altering the groundwater geochemistry is also clearly demonstrated by the reduction in total iron concentrations observed over the study period. Between March and September 2008, total iron concentrations decreased by up to 87%, reflecting a significant decrease in reduction potential and subsequent precipitation of iron with sulfide (Figures 14A and 14B). In addition, sodium concentrations increased significantly, indicating successful distribution of sodium lactate and sodium sulfate, two of the amendments being injected at the site (Figure 15).

Sequential extraction analyses of the sediment samples indicate that the total As was up to three times that of the quartz-rich sand used for the sediment bags (Table 7, Appendix A-7). The proportion of As that was adsorbed to the sediment varied from 0 to 4%, which is less than the 7% adsorbed As from the sand used for the sediment bags and the 8% adsorbed As of the site sediment. This is also consistent with the much lower dissolved As concentrations observed at the end of the simulation. This proportion of adsorbed As did not change significantly from March to September. The Fe sulfide and amorphous Fe^{3+} hydroxides increased from 2 to 11 and from 2 to 5 mmols kg^{-1}, respectively, from March to September. Approximately 77 to 90% of the

As in the sediment bags appears to have been precipitated as a sulfide, although some may also be precipitated as a trace constituent in phosphate minerals. Up to 0.4 wt% FeS was precipitated in the sediment bags from the September sampling (Figure 16). Half of the sediment bags contained Fe^{3+} hydroxide coated grains (the A bags and Control B in Appendix A-7) which enabled us to determine the effect of Fe^{3+} hydroxides on As sequestration. The total Fe in the sediment bags and the Fe associated with the hydroxides were observed to both decrease and increase from March to September. This suggest that mobilization of Fe took place during microbial sulfate reduction but with no detectable deleterious effects on the dissolved As concentration in the water. This is most likely because the system was always poised for sulfate reduction during this time interval.

7. CONCLUSIONS

The results of both the column and field pilot studies demonstrate successful sequestration of As under anaerobic, sulfate-reducing conditions, and that precipitated As is resistant to dissolution under aerobic or less reductive conditions. XANES analyses of sediments from the column and field pilot studies demonstrated successful precipitation of stable As sulfide forms including realgar and arsenopyrite.

The results from the large column and the mini-syringe column aerobic leaching experiments indicate that 1 to 2% of the solid phase As was leached by 116 pore volumes of aerobic groundwater. Switching from As-bearing groundwater to As-free artificial water did not increase the As release rate and indicates that the stimulation process creats net As sinkhole. Extrapolating to the slower groundwater flow rates of the field site suggests that the only 1 to 2% of the precipitated As assemblage would dissolve over the course of 16 years. We would expect even less of the sequestered As to dissolve in the field during this time period because the groundwater recharging the aquifer is not saturated with O_2 and because of the heterogeneity in the distribution of As sulfide phases and Fe^{3+}– hydroxides. This expectation is supported by field pilot results which show a less than 0.01% increase in dissolved As concentrations after a shift in redox potential toward less reducing conditions of approximately -150 mV from -250 to -350 mV.

Success of this technology at APAFR may lead to successful implementation as a remediation measure at other dissolved metals impacted sites. Sites with higher concentrations of metals in groundwater will likely be amenable via this bio-precipitation technology since excess As was artificially introduced and successfully precipitated during the column studies. As much arsenic as possible was sequestered so that the As species could be detected by SEM and EDS, therefore, in addition to the concentration of As in the natural groundwater (26 μM), 50 times this concentration was introduced into the columns. The indigenous sulfate reducing bacteria population were capable of reducing this concentration to <1 μM.

For many subsurface environments the groundwater is naturally anaerobic and sulfidic and for these environments the sequestration of As would be an effective and permanent solution. For aquifers that are naturally aerobic or where the anaerobic conditions are temporary due to a high organic load, the transition to fully aerobic conditions will be gradual and are not expected to cause a significant amount of As release in the presence of sulfate.

Several unanticipated setbacks related to system construction and operational maintenance led to the expenditure of monies in excess of original estimates during the field pilot study. It is recommended that future implementations of this technology be performed via direct injection of amendments using Geoprobe^{TM} direct push technology. Direct injection would eliminate amendment mixing issues, biofouling concerns, and labor intensive construction and maintenance of a groundwater recirculation system. This method would also facilitate amendment delivery at larger sites and at sites with more complex hydrogeology, though passive distribution would need to be assessed on a site-by-site basis to determine whether the natural gradient is high enough to distribute amendments within the desired timeframe.

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TABLES

Table 1. Field Parameters for Avon Park Well No. 43103-MW.

Depth (ft. bws)	Temperature (°C)	pH	Conductance (µmhos)	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	Turbidity (NTU)
2.2	28.6	6.46	601	0.48	151.1	<1
4.2	28.1	6.44	628	0.45	146.3	<1
6.2	28.4	6.45	600	0.60	178.5	0
8.2	28.5	6.47	596	0.22	149.5	0
10.2	28.1	6.44	580	0.17	141.7	<1
10.2*	27.9	6.39	542	0.1	144.9	<1
11.2	28.0	6.44	579	0.17	151.1	<1

ft. bws--feet below water surface

* after 40 L of water collected

Table 2. Geochemical Results of Well No. 43103-MW

Chemical Name	**µM**
F^-	15.21
Cl^-	86.62
PO_4^{3-}	1.52
SO_4^{2-}	3.00
HS^-	15.42
Total Sulfide	<151.52
Arsenate	11.29
Dissolved Arsenic	23.87
Total Arsenic	26.00
Benzene	23.08
MTBE	0.66
Ethylbenzene	7.91
Isopropylbenzene	0.30
Naphthalene	2.42
N-Propylbenzene	0.49
Styrene	0.07
Toluene	7.27
1,2,4-Trimethylbenzene	6.73
1,3,5-Trimethylbenzene	1.73
o-Xylene	5.43
m,p-Xylenes	37.77

Table 3. Sequential Extracts of Original Sediment and Sediment from Column #1.

		Concentrations (mmol/kg)						
Method	Element	Original Sediment	Port 1	Port 2	Port 3	Port 4	Port 5	Port 6
$MgSO_4$-adsorbed	As	0.012	0.223	0.023	0.021	0.014	0.013	0.013
	Fe	0.080	2.156	0.528	0.473	0.448	0.316	0.786
	Mn	0.001	0.044	0.007	0.010	0.012	0.008	0.027
NaOCl-organic	As	0.032	0.909	0.111	0.096	0.140	0.075	0.038
	Fe	0.022	0.017	0.020	0.022	0.023	0.023	0.024
	Mn	0.006	0.115	0.038	0.002	0.002	0.003	0.002
Acetic acid /Na Acetate-carbonate	As	0.040	0.018	0.022	0.090	0.041	0.028	0.036
	Fe	0.201	4.373	1.816	1.310	0.817	0.635	1.145
	Mn	0.001	0.005	0.004	0.001	0.000	0.000	0.000
Ammonium Oxalate -amorphous ferric hydroxides	As	0.008	0.029	0.008	0.012	0.009	0.009	0.015
	Fe	0.247	15.084	1.521	0.932	0.729	0.599	1.791
	Mn	0.002	0.064	0.025	0.005	0.004	0.003	0.005
Hydroxylamine /HCl -ferric oxides and hydroxides	As	0.015	0.233	0.025	0.032	0.014	0.014	0.088
	Fe	0.811	79.216	3.314	2.455	2.743	1.891	8.077
	Mn	0.003	0.284	0.011	0.012	0.015	0.009	0.022
Aqua regia sulfides	As	0.036	0.020	0.014	0.035	0.006	0.006	0.015
	Fe	3.072	13.236	1.196	2.505	4.255	2.340	0.075
	Mn	0.020	0.053	0.006	0.015	0.023	0.012	0.000
Total	As	0.143	1.434	0.202	0.286	0.224	0.147	0.205
	Fe	4.433	114.082	8.395	7.697	9.016	5.804	11.898
	Mn	0.032	0.565	0.092	0.044	0.056	0.035	0.056

Table 4. Sequential Extracts of Column #1 Sediment Before and During Exposure to Aerobic Leaching Water

		Concentrations (mmol/kg)					
Method	Element	0*	8300	13,000	20,000	36,000	51,000
$MgCl_2$	As	0.016	0.014	0.010	0.009	0.015	0.013
	Fe	0.180	0.108	0.060	0.061	0.086	0.095
	Mn	0.018	0.012	0.005	0.002	0.004	0.004
	S	2.981	1.109	0.389	0.429	0.544	0.851
Acetic acid /Na Acetate	As	0.103	0.120	0.038	0.030	0.042	0.054
	Fe	2.788	3.014	1.702	1.595	2.138	2.889
	Mn	0.027	0.025	0.008	0.008	0.007	0.012
	S	1.054	1.326	0.971	0.831	1.062	1.137
Ammonium Oxalate	As	0.092	0.073	0.034	0.028	0.057	0.062
	Fe	6.756	4.842	3.047	2.613	4.547	5.311
	Mn	0.011	0.009	0.003	0.002	0.005	0.007
	S	0.175	0.137	0.073	0.050	0.169	0.152
Hydroxylamine /HCl	As	0.322	0.209	0.093	0.081	0.165	0.180
	Fe	11.944	9.999	4.061	2.948	8.335	8.216
	Mn	0.011	0.012	0.005	0.007	0.012	0.020
	S	4.511	4.266	2.061	1.297	3.561	3.818
Aqua regia	As	0.016	0.015	0.011	0.010	0.016	0.013
	Fe	0.188	0.112	0.061	0.062	0.089	0.097
	Mn	0.018	0.013	0.005	0.002	0.004	0.004
	S	3.108	1.143	0.396	0.436	0.561	0.877
Total	As	0.549	0.431	0.186	0.159	0.295	0.322
	As**	0.447	0.317	0.159	0.116	0.231	0.248
	Fe	21.857	18.076	8.932	7.278	15.194	16.609
	Mn	0.085	0.071	0.026	0.021	0.033	0.046
	S	11.830	7.980	3.891	3.043	5.896	6.836

*Leaching time in minutes at a flow rate of 4 mL hr^{-1}.

**Arsenic concentration determined from separate total As analysis using aqua regia of a separate aliquot of the same sample.

Table 5. Model Parameters

	Natural Groundwater	Artificial Groundwater	Col.#2 Pore water
pH	6.4	8.64	7.5
pe	12.5	-4	12.5
O_2	3.75x10^{-3}	3.13 x10^{-7}	3.75 x10^{-4}
Na^+	1.00 x10^{-4}	3.91 x10^{-2}	6.78 x10^{-5}
Ca^{2+}	2.20 x10^{-3}	5.00 x10^{-4}	3.00 x10^{-4}
Cl^-	1.13 x10^{-4}	1.69 x10^{-2}	4.59 x10^{-3}
SO_4^{2-}	1.87 x10^{-5}	6.87 x10^{-5}	2.20 x10^{-5}
HS^-	0.00	3.13 x10^{-5}	0.00
HCO_3^-	8.30 x10^{-3}	3.31 x10^{-3}	1.82 x10^{-4}
PO_4^{3-}	1.08 x10^{-6}	3.40 x10^{-3}	0.00
AsO_4^{3-}	1.15 x10^{-5}	1.01 x10^{-6}	0.00
AsO_3^{3-}	0.00	8.13 x10^{-8}	0.00
Fe^{2+}	0.00	5.45 x10^{-6}	0.00
Fe^{3+}	0.00	1.09 x10^{-9}	0.00
Surface Species $Fe^{3+}(OH)_3$	mol of sites/mol Fe	m^2/g	g
Hfdo_weak	0.2	600	0.288
Hfdo_strong	0.005	600	0.288
	mol of sites/mol Fe	m^2/mol	
Surfc_weak-OH	0.2	1.00x10^{5}	
Surfc_strong-OH	0.005		
Reactions	Rate (mol/s)		
$Fe^{2+} + 0.25\ O_2 + H^+ \Rightarrow Fe^{3+} + 0.5\ H_2O$	(2.91 x10-9 + 1.33 x1012 x (OH$^-$)^2 x pO$_2$) * Fe^{2+}		
$HS^- + 2O_2 \Rightarrow H^+ + SO_4^{2-}$	(2.91 x10-9 + 1.33 x1012 x (OH$^-$)^2 x pO$_2$) * HS$^-$		
$AsO_3^{3-} + 0.5O_2 \Rightarrow AsO_4^{3-}$	(2.91 x10-9 + 1.33 x1014 x (OH$^-$)^2 x pO$_2$) * AsO33-		
$FeS + H_2O \Rightarrow Fe^{2+} + HS^- + OH^-$	10^(-9.14 + 4.00 + 0.67xLOG$_{10}$(M/8.35x10^{-4}) + 0.5*LOG$_{10}$(O$_2$) + -0.11*Log$_{10}$(H+))		
$As_2S_3 + 6H_2O \Rightarrow 2H_3AsO_3 + 3H_2S$	0.04x10^(-9.14 + 4.00 + 0.67xLOG$_{10}$(M/8.35x10^{-4}) + 0.5*LOG$_{10}$(O$_2$) + -0.11*Log$_{10}$(H+))		
	Physical Parameters		
Porosity	0.18		
Column Length (cm)	50		
Column volume (cm^3)	1.32x10^{3}		
Grain density(g/cm^3)	2.66		
Flow rate (mL/hr)	8-10		
Longitudinal Dispersivity (m)	0.005		
Diffusivity (m^2/s)	3x10^{-10}		

TABLE 6

FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Sample ID	**INJ-1**	**INJ-1 (DUP)**	**INJ-1**	**INJ-1**	**INJ-1**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**
Lab ID (VOCs, TPH)	**F55263-2**	**F55263-3**	**--**	**--**	**F59300-5**	**F55263-4**	**--**	**--**	**--**	**--**	**F59300-2**	**--**
Lab ID (TDS, TOC)	**F55341-2**		**--**	**--**	**--**	**F55341-4**	**--**	**--**	**--**	**--**	**--**	**--**
Sampling Date	**1/22/2008**	**1/22/2008**	**3/31/2008**	**4/14/2008**	**8/6/2008**	**1/22/2008**	**3/31/2008**	**4/14/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**
Time since injection (min)	**-1.2E+05**	**-1.2E+05**	**-2.4E+04**	**-4.3E+03**	**1.6E+05**	**-1.2E+05**	**-2.4E+04**	**-4.3E+03**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Volatile Organic Compounds (µg/L)												
2-Methylnaphthalene	1.50 I	1.70 I	--	--	--	--	--	--	--	--	--	--
Naphthalene	6.50	7.50	--	--	--	--	--	--	--	--	--	--
Acetone	--	--	--	--	--	--	--	--	--	--	--	--
Benzene	31.80	32.60	--	--	--	--	--	--	--	--	--	--
Carbon Disulfide	--	--	--	--	--	--	--	--	--	--	--	--
Ethylbenzene	47.30	45.80	--	--	--	--	--	--	--	--	--	--
Tetrachloroethylene	--	--	--	--	--	--	--	--	--	--	--	--
Toluene	4.70	4.70	--	--	--	--	--	--	--	--	--	--
Xylene (total)	191.00	186.00	--	--	--	15.60	--	--	--	--	--	--
General Chemistry (µg/L)												
Total Dissolved Solids	447000	--	--	--	--	439000	--	--	--	--	--	--
Total Organic Carbon	82100 D	--	--	--	332000	28600	--	--	--	--	85900	--
Dissolved Inorganic Carbon (DIC)	--	--	--	--	--	--	412	--	358	649	--	788
Total Petroleum Hydrocarbons	542	590	--	--	--	279	--	--	--	--	--	--
pH (laboratory)	9.77	--	--	--	--	6.42	--	--	--	--	--	--

TABLE 6

FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Sample ID	**INJ-1**	**INJ-1 (DUP)**	**INJ-1**	**INJ-1**	**INJ-1**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**
Lab ID (VOCs, TPH)	**F55263-2**	**F55263-3**	**--**	**--**	**F59300-5**	**F55263-4**	**--**	**--**	**--**	**--**	**F59300-2**	**--**
Lab ID (TDS, TOC)	**F55341-2**		**--**	**--**	**--**	**F55341-4**	**--**	**--**	**--**	**--**	**--**	**--**
Sampling Date	**1/22/2008**	**1/22/2008**	**3/31/2008**	**4/14/2008**	**8/6/2008**	**1/22/2008**	**3/31/2008**	**4/14/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**
Time since injection (min)	**-1.2E+05**	**-1.2E+05**	**-2.4E+04**	**-4.3E+03**	**1.6E+05**	**-1.2E+05**	**-2.4E+04**	**-4.3E+03**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Metals and Ions (mg/L)												
Total Arsenic	0.16	--	0.0475	0.22 U	0.123	0.19	0.28	0.22 U	0.22 U	0.22 U	0.0406	0.0361
Dissolved Arsenic	0.15	--	0.0484	--	0.119	0.16	0.08	--	0.22 U	0.22 U	0.0418	--
Total Iron	6.63	--	2.1032	1.62	--	7.44	6.97	4.43	2.62	1.07	--	0.932
Dissolved Iron	4.14	--	1.5927	0.3995	--	4.75	4.41	2.87	1.32	0.15	--	--
Total Sulfur	3.20	--	5.0118	11.91	--	3.46	4.27	10.44	7.49	9.55	--	3.22
Dissolved Sulfur	3.39	--	4.9514	9.5554	--	3.44	5.29	9.04	7.15	8.03	--	--
Total Sulfide (mmol/L)	--	--	--	--	--	0.12	0.04	--	0.03	0.32	--	2.75E-02
Total Sulfide	3.56	--	--	--	--	3.59	5.37	--	1.10	10.20	--	0.88
Dissolved Sulfide	3.55	--	--	--	--	3.82	--	--	--	--	--	--
Total Calcium	99.55	--	67.94	--	--	113.04	79.93	--	91.07	96.09	--	24.82
Dissolved Calcium	98.23	--	69.099	--	--	112.19	90.34	--	67.84	96.84	--	--
Total Sodium	3.33	--	2.5745	2.58	--	2.15	2.67	15.63	26.24	501.59	--	75.34
Dissolved Sodium	2.94	--	2.7017	2.3918	--	3.02	2.92	2.32	26.78	508.15	--	--
Total Strontium	1.12	--	1.1351	--	--	1.03	1.12	--	--	--	--	0.2 U
Dissolved Strontium	1.12	--	1.1165	--	--	1.01	1.28	--	--	--	--	--
Total Potassium	ND	--	7.7071	--	--	ND	7.94	--	--	--	--	7.99
Dissolved Potassium	ND	--	7.671	--	--	ND	9.07	--	--	--	--	--
Total Cobalt	ND	--	0.001	--	--	ND	0.001 U	--	--	--	--	0.000345
Dissolved Cobalt	ND	--	0.001	--	--	ND	0.001 U	--	--	--	--	--
Total Zinc	ND	--	0.2506	ND	--	ND	0.32	ND	0.01	0.02	--	0.295
Dissolved Zinc	ND	--	0.2564	ND	--	ND	0.29	ND	ND	ND	--	--
Total Aluminum	0.16	--	0.1925	0.07	--	ND	0.21	0.36	0.49	0.08	--	0.0403
Dissolved Aluminum	ND	--	0.1804	0.191	--	0.17	0.19	0.37	0.05	0.05	--	--
Total Uranium	0.07	--	0.1315	--	--	0.08	0.10	--	--	--	--	0.000032
Dissolved Uranium	0.07	--	0.144	--	--	0.08	0.06	--	--	--	--	--
Total Silicon	2.78	--	1.962	2.41	--	2.59	2.27	2.49	2.20	1.71	--	1.95
Dissolved Silicon	2.33	--	1.8808	2.0122	--	2.48	2.47	2.25	2.10	1.80	--	--
Total Magnesium	12.22	--	5.8351	7.7	--	13.10	6.17	5.99	5.36	4.92	--	4.1
Dissolved Magnesium	12.10	--	5.9027	6.4007	--	13.14	7.00	6.15	5.09	0.68	--	--
Total Manganese	0.80	--	0.4477	0.81	--	0.92	0.49	0.76	0.64	0.69	--	0.1163
Dissolved Manganese	0.79	--	0.4515	0.7242	--	0.91	0.54	0.52	0.65	--	--	--

TABLE 6

FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Sample ID	**INJ-1**	**INJ-1 (DUP)**	**INJ-1**	**INJ-1**	**INJ-1**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**	**MW-2**
Lab ID (VOCs, TPH)	**F55263-2**	**F55263-3**	**--**	**--**	**F59300-5**	**F55263-4**	**--**	**--**	**--**	**--**	**F59300-2**	**--**
Lab ID (TDS, TOC)	**F55341-2**		**--**	**--**	**--**	**F55341-4**	**--**	**--**	**--**	**--**	**--**	**--**
Sampling Date	**1/22/2008**	**1/22/2008**	**3/31/2008**	**4/14/2008**	**8/6/2008**	**1/22/2008**	**3/31/2008**	**4/14/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**
Time since injection (min)	**-1.2E+05**	**-1.2E+05**	**-2.4E+04**	**-4.3E+03**	**1.6E+05**	**-1.2E+05**	**-2.4E+04**	**-4.3E+03**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Total Copper	ND	--	0.001 U	--	--	ND	0.001 U	--	--	--	--	0.0018
Dissolved Copper	ND	--	0.001 U	--	--	ND	0.001 U	--	--	--	--	--
Total Nickel	2.15	--	--	--	--	2.05	--	--	--	--	--	0.0022
Dissolved Nickel	1.82	--	--	--	--	1.98	--	--	--	--	--	--
Total Barium	0.02	--	0.06	--	--	0.02	0.03	--	--	--	--	0.0328
Dissolved Barium	0.02	--	0.06	--	--	0.01	0.02	--	--	--	--	--
Total Phosphorous	ND	--	0.001 U	ND	--	ND	0.08	0.02	ND	ND	--	0.742
Dissolved Phosphorous	ND	--	0.001 U	ND	--	ND	0.001 U	0.023	0.666	--	--	--
Bromide	--	--	--	--	--	--	--	0.078	1.38	1.346	--	0.465
Fluoride*	--	--	--	--	--	--	--	0.0145	0.3371	0.3277	--	0.391
Chloride	--	--	5.557	--	--	--	0.592	0.208	3.096	4.121	--	1.53
Sulfate (mmol/L)	--	--	--	--	--	0.06	0.158	0.003	0.252	0.034	--	4.01E-03
Sulfate	--	--	15.244	--	--	--	15.330	0.248	24.437	3.289	--	0.389
Thiosulfate	--	--	--	--	--	--	--	--	0.344	8.051	--	0.754
Phosphate	--	--	--	--	--	--	1.596	--	1.217	3.531	--	2.97E+00
Acetate	--	--	--	--	--	--	--	0.113	0.466	171.706	--	2.32
Lactate	--	--	--	--	--	--	--	0.036	0.173	1.104	--	0.439
Nitrate	--	--	7.288	--	--	--	13.100	--	2.780	ND	--	ND
Nitrite	--	--	--	--	--	--	--	--	ND	0.089	--	ND
Ammonium	--	--	--	--	--	--	--	--	8.19	4.82	--	--
Arsenite	--	--	ND	--	--	--	ND	--	ND	ND	--	ND
Arsenate	--	--	0.315	--	--	--	0.370	--	0.001 U	0.001 U	--	0.0034
TOTAL As ANIONS	--	--	0.315	--	--	--	0.370	--	0.001 U	0.001 U	--	0.0034
TOTAL As CATIONS	0.16	--	0.05	0.22 U	0.12	0.19	0.281	0.220 U	0.220 U	0.220 U	0.041	0.0361
TOTAL As (Anions or Cations)	0.16	--	0.181	0.220 U	0.120	0.19	0.326	0.220 U	0.001 U	0.001 U	0.0410	0.0361
TOTAL As (Anions or Cations) (mol/L)	2.14E-06	--	2.42E-06	2.94E-06 U	1.60E-06	2.54E-06	4.35E-06	2.94E-06 U	1.33E-08 U	1.33E-08 U	5.47E-07	4.82E-07

D = Result is from a diluted sample
I = Result is greater than the Minimum Detection Limit but less than the Reporting Limit
NS = No Standard available for this analyte
TICs = Tentatively Identified Compounds
-- = Not Analyzed or No Data Available
ND = Not Detected
ppm = parts per million
mg/kg = milligrams per kilogram

TABLE 6

FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Sample ID	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-3**	**MW-3**	**MW-3**	**MW-3**	**MW-3**	**MW-3**
Lab ID (VOCs, TPH)	**F55263-5**	**--**	**--**	**--**	**F59300-1**	**--**	**F55286-2**	**--**	**--**	**--**	**F59300-3**	**--**
Lab ID (TDS, TOC)	**F55341-3**	**--**	**--**	**--**	**--**	**--**	**F55341-5**	**--**	**--**	**--**	**--**	**--**
Sampling Date	**1/22/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**	**1/23/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**
Time since injection (min)	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Volatile Organic Compounds (µg/L)												
2-Methylnaphthalene	5.70	--	--	--	--	--	1 U	--	--	--	--	--
Naphthalene	33.40	--	--	--	--	--	1.2 U	--	--	--	--	--
Acetone	11.00 I	--	--	--	--	--	10 U	--	--	--	--	--
Benzene	83.00	--	--	--	--	--	0.2 U	--	--	--	--	--
Carbon Disulfide	0.47 I	--	--	--	--	--	0.2 U	--	--	--	--	--
Ethylbenzene	95.00	--	--	--	--	--	0.2 U	--	--	--	--	--
Tetrachloroethylene	0.79 I	--	--	--	--	--	0.25 U	--	--	--	--	--
Toluene	16.40	--	--	--	--	--	0.27 U	--	--	--	--	--
Xylene (total)	118.00	--	--	--	--	--	0.56 U	--	--	--	--	--
General Chemistry (µg/L)												
Total Dissolved Solids	403000	--	--	--	--	--	229000	--	--	--	--	--
Total Organic Carbon	92000 D	--	--	--	42900	--	103000 D	--	--	--	9700	--
Dissolved Inorganic Carbon (DIC)	--	421	625	--	--	1128	--	391	219	199	--	471
Total Petroleum Hydrocarbons	782	--	--	--	--	--	223	--	--	--	--	--
pH (laboratory)	6.66	--	--	--	--	--	5.4	--	--	--	--	--

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FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
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Avon Park, Florida

Sample ID	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-3**	**MW-3**	**MW-3**	**MW-3**	**MW-3**	**MW-3**
Lab ID (VOCs, TPH)	**F55263-5**	**--**	**--**	**--**	**F59300-1**	**--**	**F55286-2**	**--**	**--**	**--**	**F59300-3**	**--**
Lab ID (TDS, TOC)	**F55341-3**	**--**	**--**	**--**	**--**	**--**	**F55341-5**	**--**	**--**	**--**	**--**	**--**
Sampling Date	**1/22/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**	**1/23/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**
Time since injection (min)	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Metals and Ions (mg/L)												
Total Arsenic	0.56	0.42	0.22 U	0.22 U	0.0274	0.0198	0.18	0.13	0.22 U	0.22 U	0.0132	0.0155
Dissolved Arsenic	0.33	0.07	0.22 U	0.22 U	0.0247	--	0.16	0.03	0.22 U	0.22 U	0.0125	--
Total Iron	5.22	7.31	8.57	3.91	--	5.04	3.50	5.96	3.61	2.79	--	3.81
Dissolved Iron	4.85	2.38	5.38	2.08	--	--	3.04	2.10	1.79	1.68	--	--
Total Sulfur	3.59	3.45	92.03	2.89	--	2.55	2.15	2.85	1.62	2.81	--	3.95
Dissolved Sulfur	3.64	3.22	86.68	3.01	--	--	2.18	2.89	1.27	2.59	--	--
Total Sulfide (mmol/L)	--	--	--	--	--	--	--	--	--	--	--	--
Total Sulfide	3.88	50.40	4.20	3.70	--	1.97	2.20	68.90	2.70	3.20	--	0.66
Dissolved Sulfide	4.11	--	--	--	--	--	2.22	--	--	--	--	--
Total Calcium	90.55	83.43	101.73	62.80	--	27.15	58.04	77.84	53.24	52.90	--	26.78
Dissolved Calcium	91.21	82.01	94.44	64.01	--	--	57.13	76.76	53.54	54.02	--	--
Total Sodium	5.22	2.42	210.36	71.70	--	119.51	1.95	1.33	1.42	1.65	--	2.37
Dissolved Sodium	6.13	2.49	199.14	73.71	--	--	3.82	1.22	1.21	1.55	--	--
Total Strontium	1.12	1.15	--	--	--	0.2 U	0.77	0.77	--	--	--	0.2 U
Dissolved Strontium	1.13	1.11	--	--	--	--	0.76	0.75	--	--	--	--
Total Potassium	ND	9.92	--	--	--	7.83	ND	5.34	--	--	--	1.71
Dissolved Potassium	ND	9.91	--	--	--	--	ND	5.28	--	--	--	--
Total Cobalt	ND	0.001 U	--	--	--	0.000874	ND	0.001 U	--	--	--	0.000287
Dissolved Cobalt	ND	0.001 U	--	--	--	--	ND	0.001 U	--	--	--	--
Total Zinc	ND	0.54	0.33	ND	--	0.0282	ND	0.43	0.01	ND	--	0.0833
Dissolved Zinc	ND	0.33	0.01	ND	--	--	ND	0.30	ND	ND	--	--
Total Aluminum	0.19	0.26	0.33	0.09	--	0.0681	0.40	0.23	0.08	0.05	--	0.0324
Dissolved Aluminum	ND	0.23	0.51	0.04	--	--	ND	0.18	0.0047	0.04	--	--
Total Uranium	0.09	0.15	--	--	--	0.000064	0.07	0.11	--	--	--	0.000021
Dissolved Uranium	0.07	0.10	--	--	--	--	0.07	0.12	--	--	--	--
Total Silicon	2.16	2.44	2.37	2.03	--	2.25	5.12	2.59	2.41	1.81	--	2.07
Dissolved Silicon	1.73	2.24	2.19	1.96	--	--	2.27	2.42	2.12	1.77	--	--
Total Magnesium	8.25	7.17	6.10	3.93	--	3.97	4.82	5.09	3.35	2.59	--	2.24
Dissolved Magnesium	8.29	6.94	5.78	4.05	--	--	4.80	5.15	2.97	2.56	--	--
Total Manganese	0.46	0.51	1.07	0.58	--	0.0681	0.22	0.54	0.50	0.45	--	0.3931
Dissolved Manganese	0.45	0.49	1.04	0.57	--	--	0.21	0.54	0.45	0.45	--	--

TABLE 6

FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Sample ID	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-1**	**MW-3**	**MW-3**	**MW-3**	**MW-3**	**MW-3**	**MW-3**
Lab ID (VOCs, TPH)	**F55263-5**	**--**	**--**	**--**	**F59300-1**	**--**	**F55286-2**	**--**	**--**	**--**	**F59300-3**	**--**
Lab ID (TDS, TOC)	**F55341-3**	**--**	**--**	**--**	**--**	**--**	**F55341-5**	**--**	**--**	**--**	**--**	**--**
Sampling Date	**1/22/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**	**1/23/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**
Time since injection (min)	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Total Copper	ND	0.02	--	--	--	0.0069	ND	0.001 U	--	--	--	0.0052
Dissolved Copper	ND	0.00	--	--	--	--	ND	0.001 U	--	--	--	--
Total Nickel	1.70	--	--	--	--	0.0028	3.99	--	--	--	--	0.0017
Dissolved Nickel	1.34	--	--	--	--	--	1.79	--	--	--	--	--
Total Barium	0.12	0.09	--	--	--	0.0268	0.02	0.02	--	--	--	0.0171
Dissolved Barium	0.12	0.06	--	--	--	--	0.02	0.01	--	--	--	--
Total Phosphorous	ND	0.07	0.45	0.10	--	0.431	ND	0.07	0.46	0.35	--	0.2545
Dissolved Phosphorous	ND	0.001 U	0.099	0.083	--	--	ND	0.001 U	0.092	0.079	--	--
Bromide	--	--	1.522	1.262	--	0.707	--	--	0.107	0.023	--	0.0735
Fluoride*	--	--	0.272	0.278	--	0.499	--	--	0.4942	0.5109	--	0.4723
Chloride	--	3.364	3.33	2.950	--	2.06	--	2.357	3.7643	1.1049	--	0.6062
Sulfate (mmol/L)	--	--	--	--	--	--	--	--	--	--	--	--
Sulfate	--	10.16	290.7	1.112	--	0.059	--	7.538	2.812	0.665	--	0.0431
Thiosulfate	--	--	ND	ND	--	0.0346	--	--	0.044	0.048	--	0.7629
Phosphate	--	1.210	0.040	0.2420	--	0.148	--	0.033	0.058	0.080	--	0.0654
Acetate	--	--	0.630	9.145	--	1.344	--	--	0.377	1.420	--	1.0637
Lactate	--	--	0.245	0.569	--	0.34	--	--	0.394	0.222	--	2.1542
Nitrate	--	0.383	0.492	0.515	--	0.058	--	2.924	0.101	1.097	--	0.0786
Nitrite	--	--	0.020	0.051	--	0.0674	--	ND	0.044	0.038	--	0.1615
Ammonium	--	--	20.47	6.77	--	--	--	--	6.00	2.04	--	--
Arsenite	--	ND	ND	ND	--	ND	--	ND	ND	ND	--	ND
Arsenate	--	0.692	--	0.537	--	0.059	--	0.294	0.001 U	0.001 U	--	0.001 U
TOTAL As ANIONS	--	0.692	--	0.537	--	0.059	--	0.294	0.001 U	0.001 U	--	0.001 U
TOTAL As CATIONS	0.56	0.417	0.220 U	0.220 U	0.027	0.020	0.18	0.126	0.220 U	0.220 U	0.013	0.016
TOTAL As (Anions or Cations)	0.56	0.555	0.220 U	0.220	0.027	0.0198	0.18	0.210	0.001 U	0.001 U	0.013	0.0160 U
TOTAL As (Anions or Cations) (mol/L)	7.47E-06	7.40E-06	2.94E-06 U	2.94E-06 U	3.60E-07	2.64E-07	2.40E-06	2.80E-06	1.33E-08 U	1.33E-08 U	1.74E-07	2.14E-07 U

D = Result is from a diluted sample
I = Result is greater than the Minimum Detectio
NS = No Standard available for this analyte
TICs = Tentatively Identified Compounds
-- = Not Analyzed or No Data Available
ND = Not Detected
ppm = parts per million
mg/kg = milligrams per kilogram

TABLE 6

FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Sample ID	**MW-4**	**MW-4**	**MW-4**	**MW-4**	**MW-4**	**MW-4**	**RW-1**	**RW-1**	**RW-1**
Lab ID (VOCs, TPH)	**F55286-1**	**--**	**--**	**--**	**F59300-4**	**--**	**F55263-1**	**--**	**F59300-6**
Lab ID (TDS, TOC)	**F55341-6**	**--**	**--**	**--**	**--**	**--**	**F55341-1**	**--**	**--**
Sampling Date	**1/23/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**	**1/22/2008**	**3/31/2008**	**8/6/2008**
Time since injection (min)	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**	**-1.2E+05**	**-2.4E+04**	**1.6E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Volatile Organic Compounds (µg/L)									
2-Methylnaphthalene	--	--	--	--	--	--	--	--	--
Naphthalene	--	--	--	--	--	--	--	--	--
Acetone	--	--	--	--	--	--	--	--	--
Benzene	4.20	--	--	--	--	--	16.50	--	--
Carbon Disulfide	--	--	--	--	--	--	--	--	--
Ethylbenzene	11.10	--	--	--	--	--	2.70	--	--
Tetrachloroethylene	--	--	--	--	--	--	--	--	--
Toluene	1.40	--	--	--	--	--	0.82 I	--	--
Xylene (total)	75.10	--	--	--	--	--	12.40	--	--
General Chemistry (µg/L)									
Total Dissolved Solids	329000	--	--	--	--	--	419000.00	--	--
Total Organic Carbon	27000	--	--	--	32600	--	66900.00 D	--	20500
Dissolved Inorganic Carbon (DIC)	--	419	450	424	--	1122	--	--	--
Total Petroleum Hydrocarbons	308	--	--	--	--	--	329.00	--	--
pH (laboratory)	5.64	--	--	--	--	--	8.81	--	--

TABLE 6

FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Sample ID	MW-4	MW-4	MW-4	MW-4	MW-4	MW-4	RW-1	RW-1	RW-1
Lab ID (VOCs, TPH)	**F55286-1**	**--**	**--**	**--**	**F59300-4**	**--**	**F55263-1**	**--**	**F59300-6**
Lab ID (TDS, TOC)	**F55341-6**	**--**	**--**	**--**	**--**	**--**	**F55341-1**	**--**	**--**
Sampling Date	**1/23/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**	**1/22/2008**	**3/31/2008**	**8/6/2008**
Time since injection (min)	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**	**-1.2E+05**	**-2.4E+04**	**1.6E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Metals and Ions (mg/L)									
Total Arsenic	0.15	0.24	0.22 U	0.22 U	0.0399	0.0333	0.17	0.10	0.275
Dissolved Arsenic	0.17	0.052	0.22 U	0.22 U	0.0429	--	0.18	0.10	0.254
Total Iron	5.71	6.7511	5.84	4.28	--	5.35	7.09	7.70	--
Dissolved Iron	4.56	6.4084	4.4609	3.897	--	--	6.71	6.69	--
Total Sulfur	3.12	3.6861	12.48	3.03	--	3.19	2.64	4.69	--
Dissolved Sulfur	3.02	3.177	9.4467	2.8429	--	--	2.59	5.01	--
Total Sulfide (mmol/L)	0.10	8.69E-02	9.38E-02	2.50E-01	--	4.13E-02	--	--	
Total Sulfide	3.27	2.78	3	8	--	1.32	--	--	--
Dissolved Sulfide	3.27	--	--	--	--	--	2.71	--	--
Total Calcium	85.62	67.668	74.8	65.02	--	24.86	2.81	--	--
Dissolved Calcium	85.54	66.093	74.967	64.881	--	--	73.60	78.39	--
Total Sodium	1.85	3.1255	28.16	61.74	--	80.58	75.68	70.64	--
Dissolved Sodium	2.96	3.0964	29.606	63.22	--	--	2.16	2.95	--
Total Strontium	1.46	1.3461	--	--	--	0.2 U	2.56	3.97	--
Dissolved Strontium	1.43	1.2685	--	--	--	--	1.07	1.09	--
Total Potassium	ND	8.0693	--	--	--	6.95	1.08	1.14	--
Dissolved Potassium	ND	7.7055	--	--	--	--	ND	8.09	--
Total Cobalt	ND	0.001 U	--	--	--	0.000834	ND	8.34	--
Dissolved Cobalt	ND	0.001 U	--	--	--	--	ND	0.001 U	--
Total Zinc	ND	1.5584	ND	ND	--	0.066	ND	0.001 U	--
Dissolved Zinc	ND	0.3663	ND	ND	--	--	ND	0.31	--
Total Aluminum	0.15	0.307	0.05	0.05	--	0.0595	ND	0.38	--
Dissolved Aluminum	ND	0.2034	0.0333	0.0287	--	--	0.25	1.52	--
Total Uranium	0.07	0.118	--	--	--	0.000089	ND	3.11	--
Dissolved Uranium	0.07	0.1372	--	--	--	--	0.07	0.13	--
Total Silicon	3.44	2.8249	2.34	1.6755	--	2.45	0.07	0.11	--
Dissolved Silicon	3.05	2.5442	2.0709	1.5954	--	--	3.17	2.16	--
Total Magnesium	9.39	6.9453	7.59	4.81	--	3.62	2.47	2.23	--
Dissolved Magnesium	9.23	6.7118	6.0128	4.6879	--	--	6.96	6.00	--
Total Manganese	0.40	0.3596	0.58	0.45	--	0.3502	7.15	5.94	--
Dissolved Manganese	0.40	0.3443	0.5257	0.4461	--	--	0.59	0.53	--

TABLE 6

FIELD PILOT ANALYTICAL RESULTS

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Sample ID	**MW-4**	**MW-4**	**MW-4**	**MW-4**	**MW-4**	**MW-4**	**RW-1**	**RW-1**	**RW-1**
Lab ID (VOCs, TPH)	**F55286-1**	**--**	**--**	**--**	**F59300-4**	**--**	**F55263-1**	**--**	**F59300-6**
Lab ID (TDS, TOC)	**F55341-6**	**--**	**--**	**--**	**--**	**--**	**F55341-1**	**--**	**--**
Sampling Date	**1/23/2008**	**3/31/2008**	**6/17/2008**	**7/15/2008**	**8/6/2008**	**9/4/2008**	**1/22/2008**	**3/31/2008**	**8/6/2008**
Time since injection (min)	**-1.2E+05**	**-2.4E+04**	**8.8E+04**	**1.3E+05**	**1.6E+05**	**2.0E+05**	**-1.2E+05**	**-2.4E+04**	**1.6E+05**
Matrix	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**	**Groundwater**
Total Copper	ND	0.001 U	--	--	--	0.009	0.63	0.51	--
Dissolved Copper	ND	0.001 U	--	--	--	--	ND	0.02	--
Total Nickel	2.68	--	--	--	--	0.0033	ND	0.00	--
Dissolved Nickel	2.40	--	--	--	--	--	2.46	--	--
Total Barium	0.05	0.0722	--	--	--	0.03	1.94	--	--
Dissolved Barium	0.05	0.0697	--	--	--	--	0.03	0.06	--
Total Phosphorous	ND	0.0054	0.35	0.26	--	0.431	0.03	0.06	--
Dissolved Phosphorous	ND	0.001 U	0.376	0.212	--	--	ND	0.001 U	--
Bromide	--	--	1.6968	1.1073	--	0.5601	ND	0.001 U	--
Fluoride*	--	--	0.3948	0.3147	--	0.5987	--	--	--
Chloride	--	2.315	3.1484	2.8517	--	1.599	--	--	--
Sulfate (mmol/L)	0.09	0.079	3.34E-01	2.29E-03	--	0.000	--	--	--
Sulfate	--	7.667	32.437	0.222	--	0.043	--	3.773	--
Thiosulfate	--	--	0.2629	0.2646	--	0.2659	--	--	--
Phosphate	--	0.415	0.0906	0.5907	--	0.059	--	12.500	--
Acetate	--	--	0.3418	13.8157	--	0.5171	--	--	--
Lactate	--	--	0.309	0.6843	--	0.2992	--	--	--
Nitrate	--	0.070	0.175	0.1169	--	0.0995	--	19.740	--
Nitrite	--	--	0.040	ND	--	0.136	--	--	--
Ammonium	--	--	14.10	7.27	--	--	--	--	--
Arsenite	--	ND	ND	ND	--	ND	--	ND	--
Arsenate	--	0.329	0.001 U	0.037	--	0.002	--	0.209	--
TOTAL As ANIONS	--	0.329	0.001 U	0.037	--	0.002	--	0.209	--
TOTAL As CATIONS	0.15	0.240	0.220 U	0.220 U	0.040	0.033	0.17	0.096	0.28
TOTAL As (Anions or Cations)	0.15	0.284	0.001 U	0.037	0.040	0.0330	0.17	0.152	0.280
TOTAL As (Anions or Cations) (mol/L)	2.00E-06	3.79E-06	1.33E-08 U	4.94E-07 U	5.34E-07	4.40E-07	2.27E-06	2.03E-06	3.74E-06

D = Result is from a diluted sample
I = Result is greater than the Minimum Detectio
NS = No Standard available for this analyte
TICs = Tentatively Identified Compounds
-- = Not Analyzed or No Data Available
ND = Not Detected
ppm = parts per million
mg/kg = milligrams per kilogram

TABLE 7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM MW-2

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Iron Coated sand

Extraction	**Element**	**MW (g/mol)**	MW-2 mmol/kg 4/4/2008	MW-2 mmol/kg 9/4/2008	MW-2 mmol/kg 12/14/2008
MgCl2	As	74.92	0.0133516	0.0069551	0.00389125
MgCl2	Fe	55.85	0.1972801	2.1427272	2.81987138
MgCl2	Mn	54.94	0.0009708	0	0.00839362
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.0562392	0.019545	0.03126992
NaOH-HOAc	As	74.92	0.0123276	0.0406206	0.04164237
NaOH-HOAc	Fe	55.85	4.6783227	12.867607	36.0118208
NaOH-HOAc	Mn	54.94	0.0350945	0.0086565	0.05044454
NaOH-HOAc	S	32.06	0.1544047	0.1207027	0.23313871
NaOH-HOAc	P	30.97	2.9160962	0.0939034	4.96352732
AOD	As	74.92	0.0453732	0.0807482	0.03827021
AOD	Fe	55.85	2.057957	5.2901405	8.55829193
AOD	Mn	54.94	0.059557	0.0413499	0.10983192
AOD	S	32.06	0	0	3.13239021
AOD	P	30.97	0.4694701	0.4323432	0.45559256
Hydroxylamine HCL	As	74.92	0.0039838	0.2142269	0.20032979
Hydroxylamine HCL	Fe	55.85	51.520878	0.1128087	57.7099451
Hydroxylamine HCL	Mn	54.94	0.3361337	0	0.32640807
Hydroxylamine HCL	S	32.06	3.003373	7.1219248	11.3182616
Hydroxylamine HCL	P	30.97	0.4694701	0	3.95347647
Aquaregia	As	74.92	0.0411277	0.0029677	0.03131359
Aquaregia	Fe	55.85	56.510678	2.760796	49.5659645
Aquaregia	Mn	54.94	0.8244336	0.0471057	1.29896319
Aquaregia	S	32.06	0	6.9308998	30.7548461
Aquaregia	P	30.97	0.5588986	0	0
TOTAL	As	74.92	0.1161639	0.3455185	0.31544721
TOTAL	Fe	55.85	114.96512	23.174079	154.665894
TOTAL	Mn	54.94	1.2561897	0.0971121	1.79404135
TOTAL	S	32.06	3.1577777	14.173527	45.4386367
TOTAL	P	30.97	4.4701744	0.5457916	9.40386627

TABLE 7

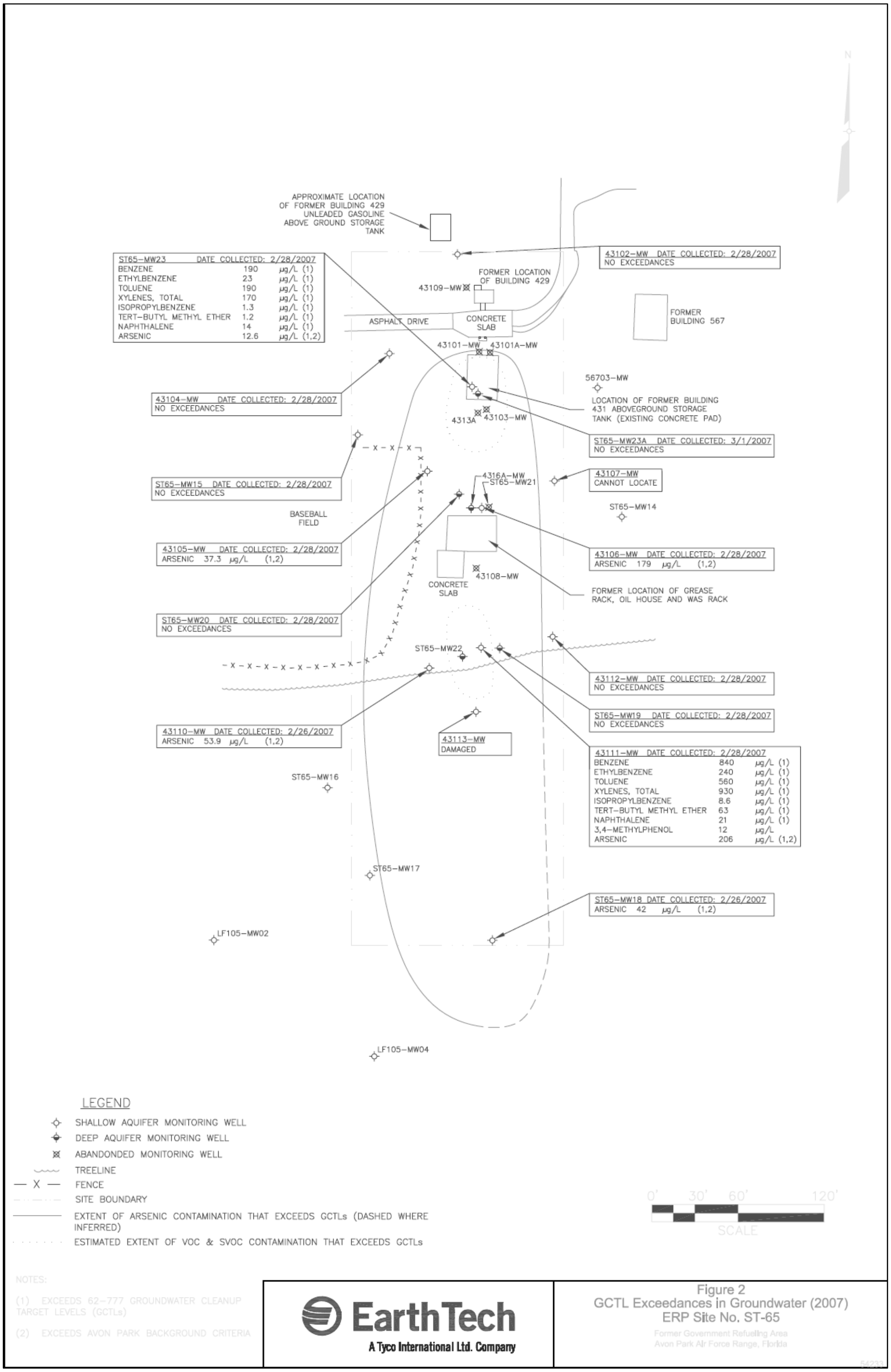
SEQUENTIAL EXTRACTS OF SEDIMENT FROM MW-2

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Uncoated Sand

Extraction	Element	MW	MW-2 mmol/kg 4/4/2008	MW-2 mmol/kg 9/4/2008	MW-2 mmol/kg 12/14/2008
MgCl2	As	74.92	0.0150708	0	0.00387749
MgCl2	Fe	55.85	0.1931775	1.5695404	1.61242696
MgCl2	Mn	54.94	0.0003848	0	0.0078361
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.0452753	0.0033709	0.0196733
NaOH-HOAc	As	74.92	0.0576175	0.0269302	0.02111467
NaOH-HOAc	Fe	55.85	20.944274	5.9715957	7.4367724
NaOH-HOAc	Mn	54.94	0.0305443	0.0044879	0.00430329
NaOH-HOAc	S	32.06	0.2244234	0.1663394	0.1129991
NaOH-HOAc	P	30.97	0.5765888	0.1662643	0.10018465
AOD	As	74.92	0.0358943	0.0452027	0.04784227
AOD	Fe	55.85	2.0159416	3.5986137	5.19966485
AOD	Mn	54.94	0.0223303	0.0380525	0.05170104
AOD	S	32.06	0	0	0
AOD	P	30.97	0.0901912	0.4475379	0.37954281
Hydroxylamine HCL	As	74.92	0.1729158	0.1548411	0.15290233
Hydroxylamine HCL	Fe	55.85	7.6970434	0.0534257	41.4651038
Hydroxylamine HCL	Mn	54.94	0.0034672	0	0.26723477
Hydroxylamine HCL	S	32.06	1.1639892	3.7191605	0.9711358
Hydroxylamine HCL	P	30.97	0.4555779	0	1.89393068
Aquaregia	As	74.92	0.0061468	0.0114421	0.00865468
Aquaregia	Fe	55.85	2.480028	1.2475813	2.51404123
Aquaregia	Mn	54.94	0.0300759	0.0144236	0.03877292
Aquaregia	S	32.06	0.8727963	2.1506078	3.05203337
Aquaregia	P	30.97	0	0	0
TOTAL	As	74.92	0.2876452	0.2384162	0.23439145
TOTAL	Fe	55.85	33.330464	12.440757	58.2280093
TOTAL	Mn	54.94	0.0868025	0.056964	0.36984811
TOTAL	S	32.06	2.2612089	6.0361077	4.13616827
TOTAL	P	30.97	1.1676331	0.6171731	2.39333144

FIGURES



ST65–MW23	DATE COLLECTED: 2/28/2007	
BENZENE	190	μg/L (1)
ETHYLBENZENE	23	μg/L (1)
TOLUENE	190	μg/L (1)
XYLENES, TOTAL	170	μg/L (1)
ISOPROPYLBENZENE	1.3	μg/L (1)
TERT–BUTYL METHYL ETHER	1.2	μg/L (1)
NAPHTHALENE	14	μg/L (1)
ARSENIC	12.6	μg/L (1,2)

43111–MW	DATE COLLECTED: 2/28/2007	
BENZENE	840	μg/L (1)
ETHYLBENZENE	240	μg/L (1)
TOLUENE	560	μg/L (1)
XYLENES, TOTAL	930	μg/L (1)
ISOPROPYLBENZENE	8.6	μg/L (1)
TERT–BUTYL METHYL ETHER	63	μg/L (1)
NAPHTHALENE	21	μg/L (1)
3,4–METHYLPHENOL	12	μg/L
ARSENIC	206	μg/L (1,2)

Figure 1. Initial Groundwater Quality at Avon Park Air Force Range

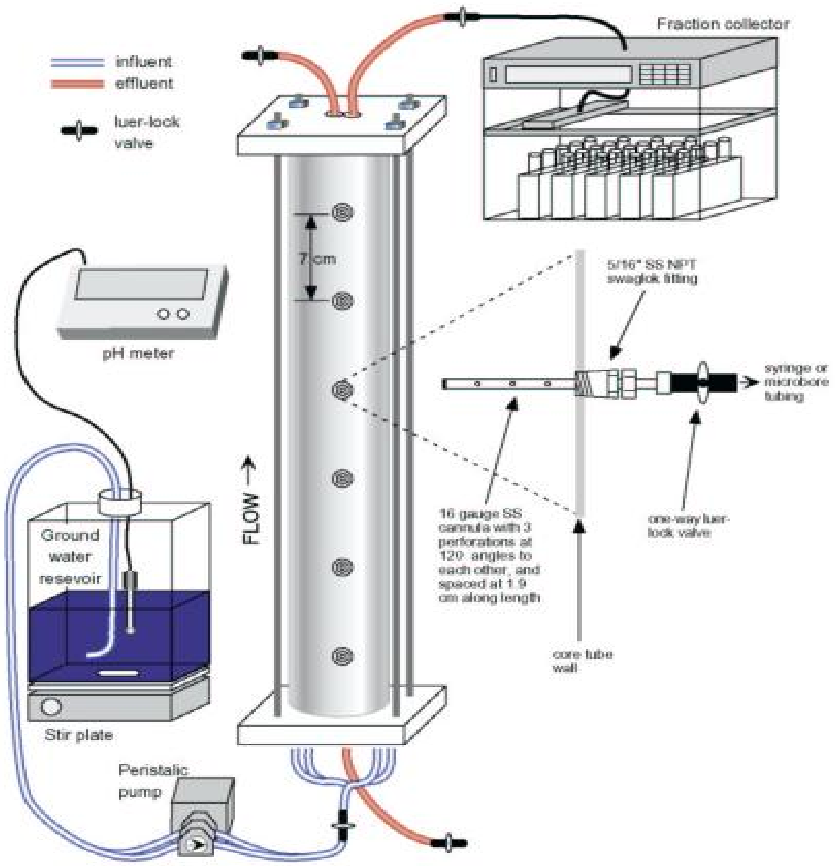
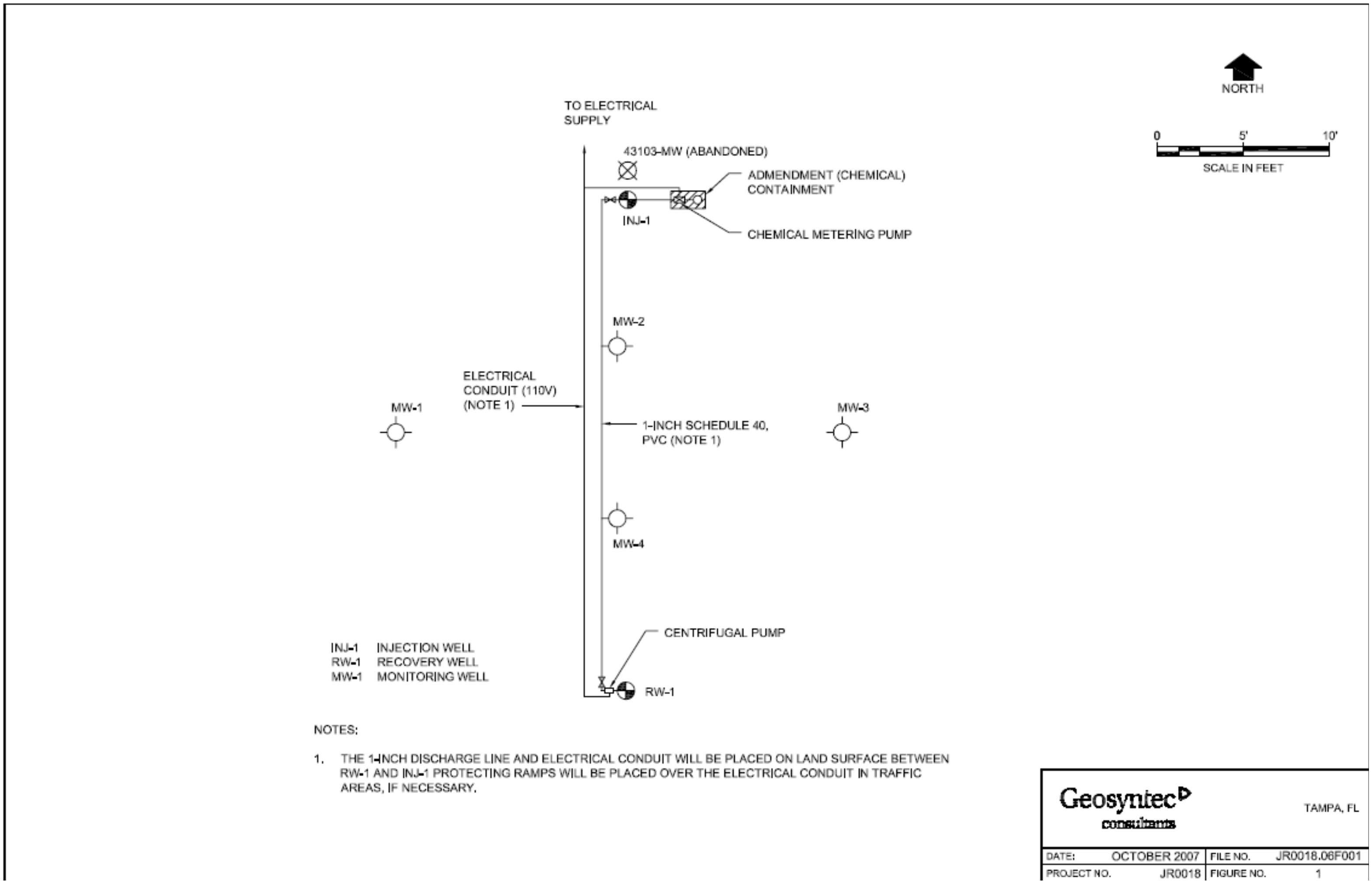


Figure 2. Schematic of Column Setup



NOTES:

1. THE 1-INCH DISCHARGE LINE AND ELECTRICAL CONDUIT WILL BE PLACED ON LAND SURFACE BETWEEN RW-1 AND INJ-1 PROTECTING RAMPS WILL BE PLACED OVER THE ELECTRICAL CONDUIT IN TRAFFIC AREAS, IF NECESSARY.

Figure 3. Pilot Test Layout

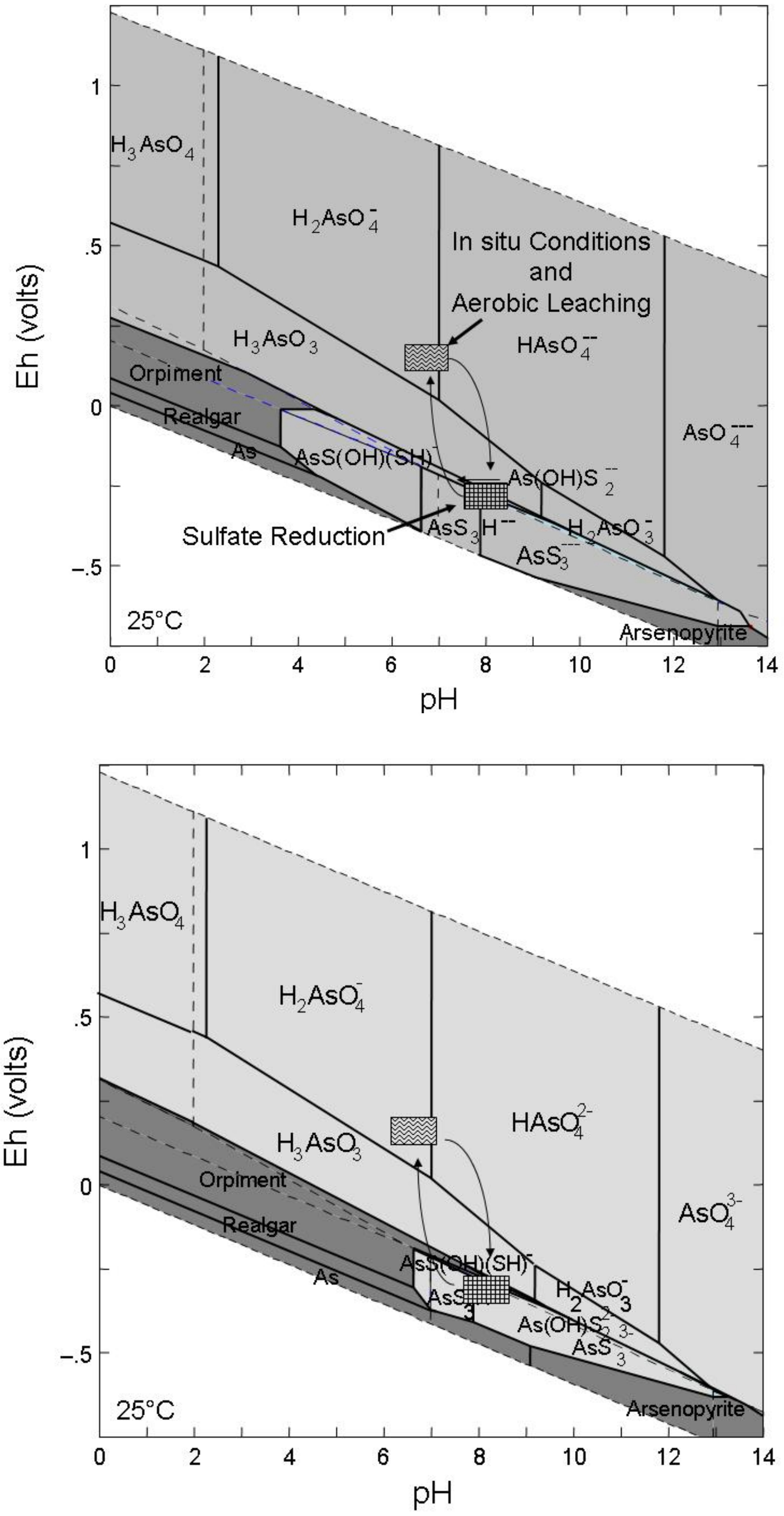


Figure 4. Arsenic Species Eh vs. pH Diagrams (top) Eh vs pH plot of As species for the As, S and Fe activities near the end the stimulation and (bottom) Eh vs pH plot of As species for the As, S and Fe activities at the beginning of the stimulation. Phase boundaries based upon the thermodynamic database published by O'Day et al. (2004).

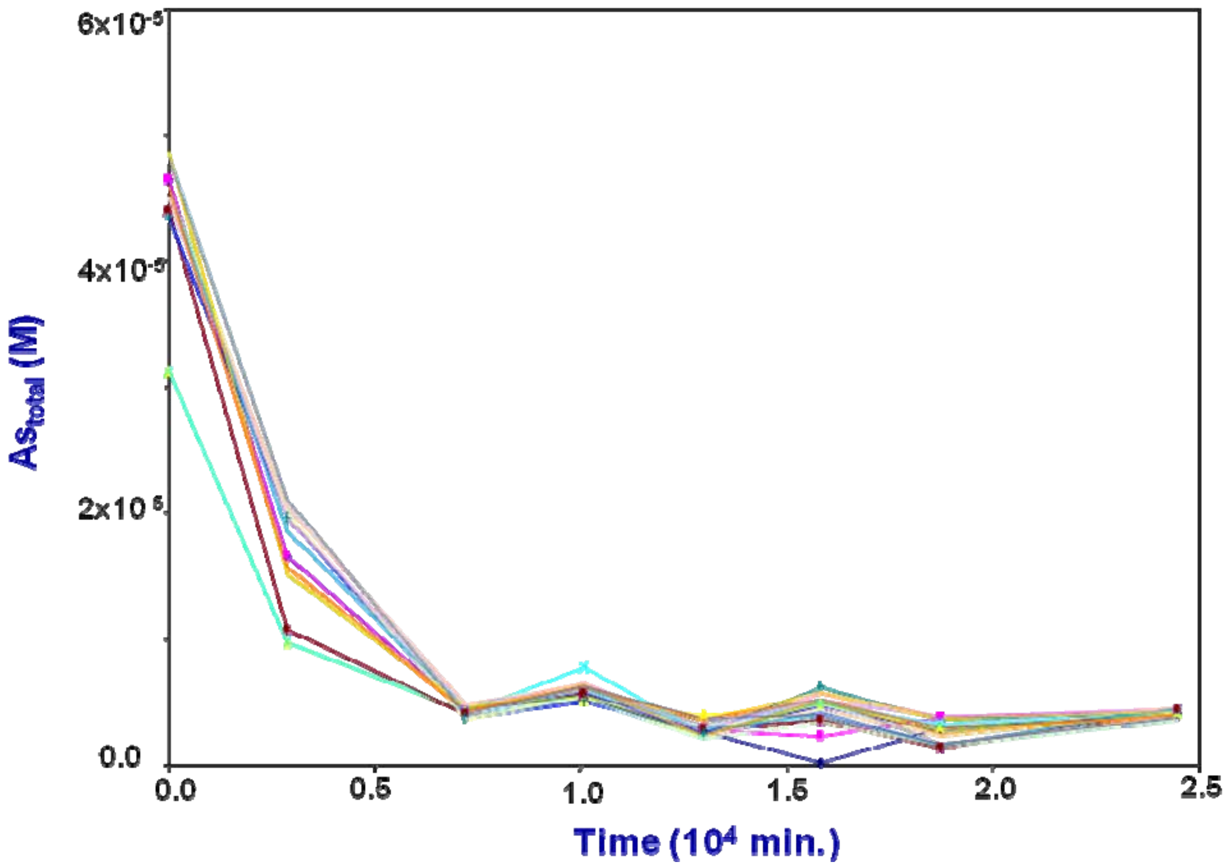


Figure 5. Column Study Analytical Results Average concentrations of aqueous species from six side port samples during third injection into column #2.

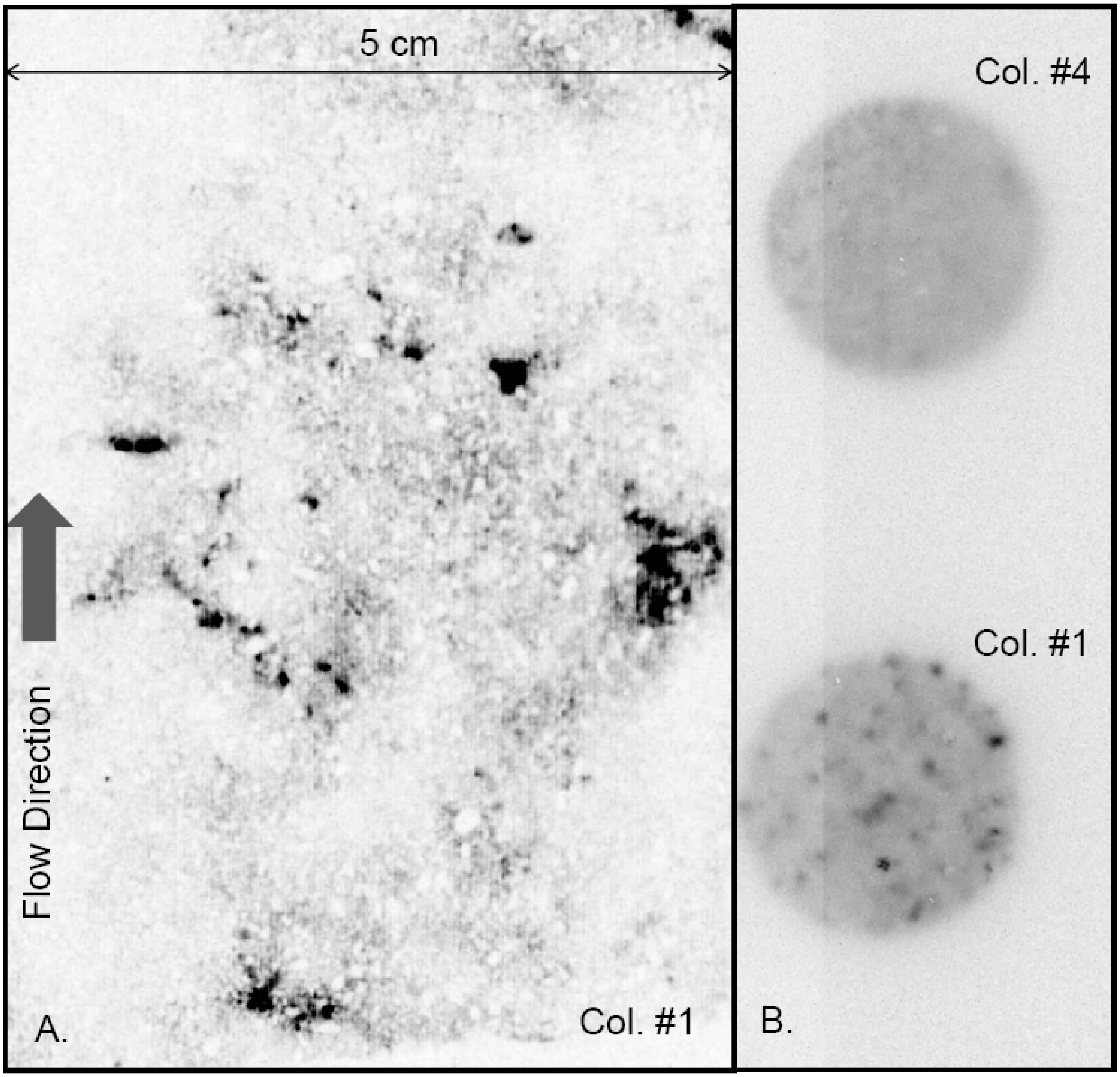


Figure 6. **Phosphor Images of Column Sediment.** Phosphor images of A. thin section of untreated column #1 near inlet; B. of grain mounts 10from untreated column #1 and H2O2/K2HPO2treated column #4.

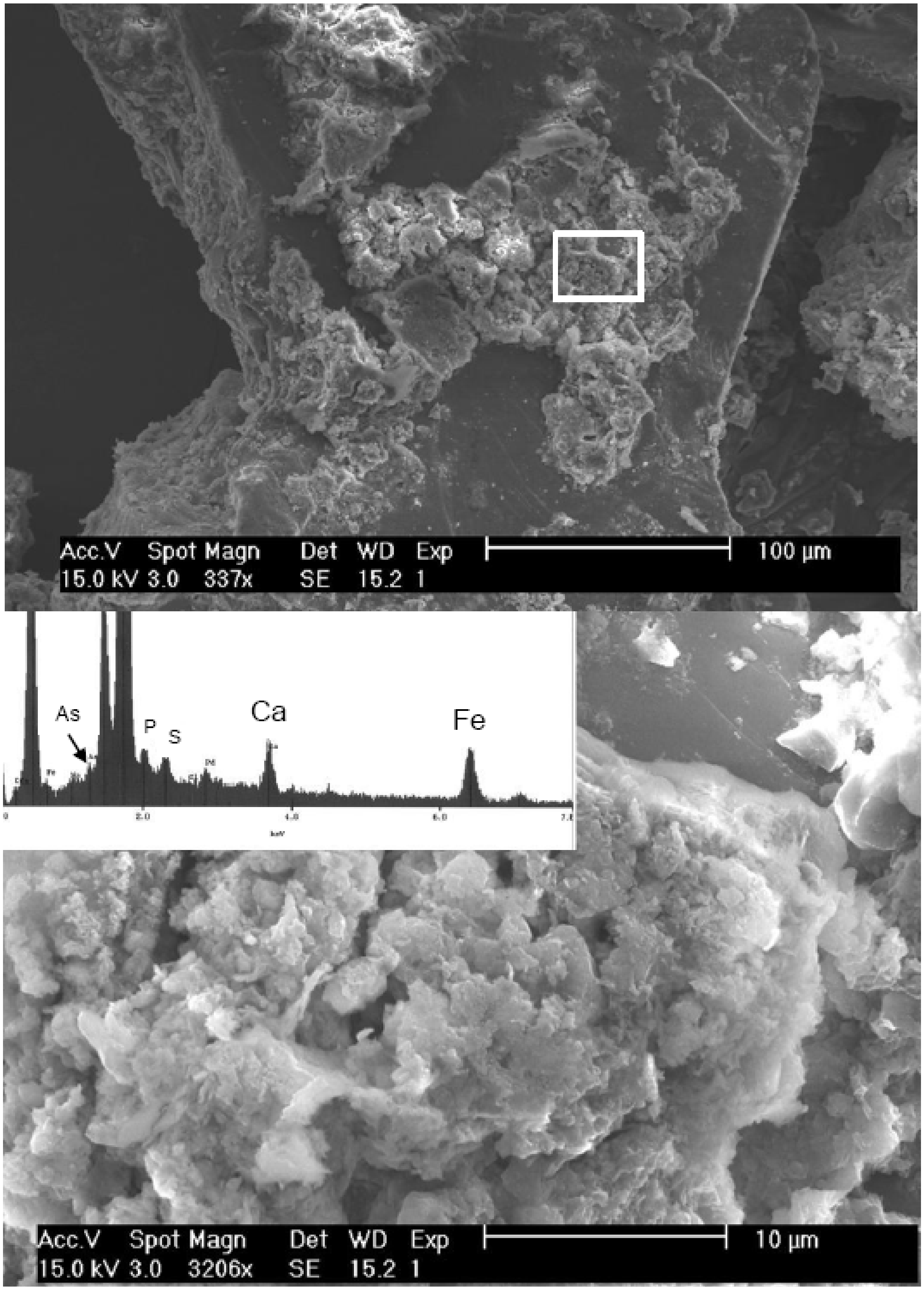


Figure 7. SEM images of Coatings (top) Secondary electron image of detrital quartz grain from column #1 displaying paritial cement coatings. (bottom) Magnified image of coating with EDS spectrum exhibiting calcium carbonate, Fe, S, P and As bearing minerals.

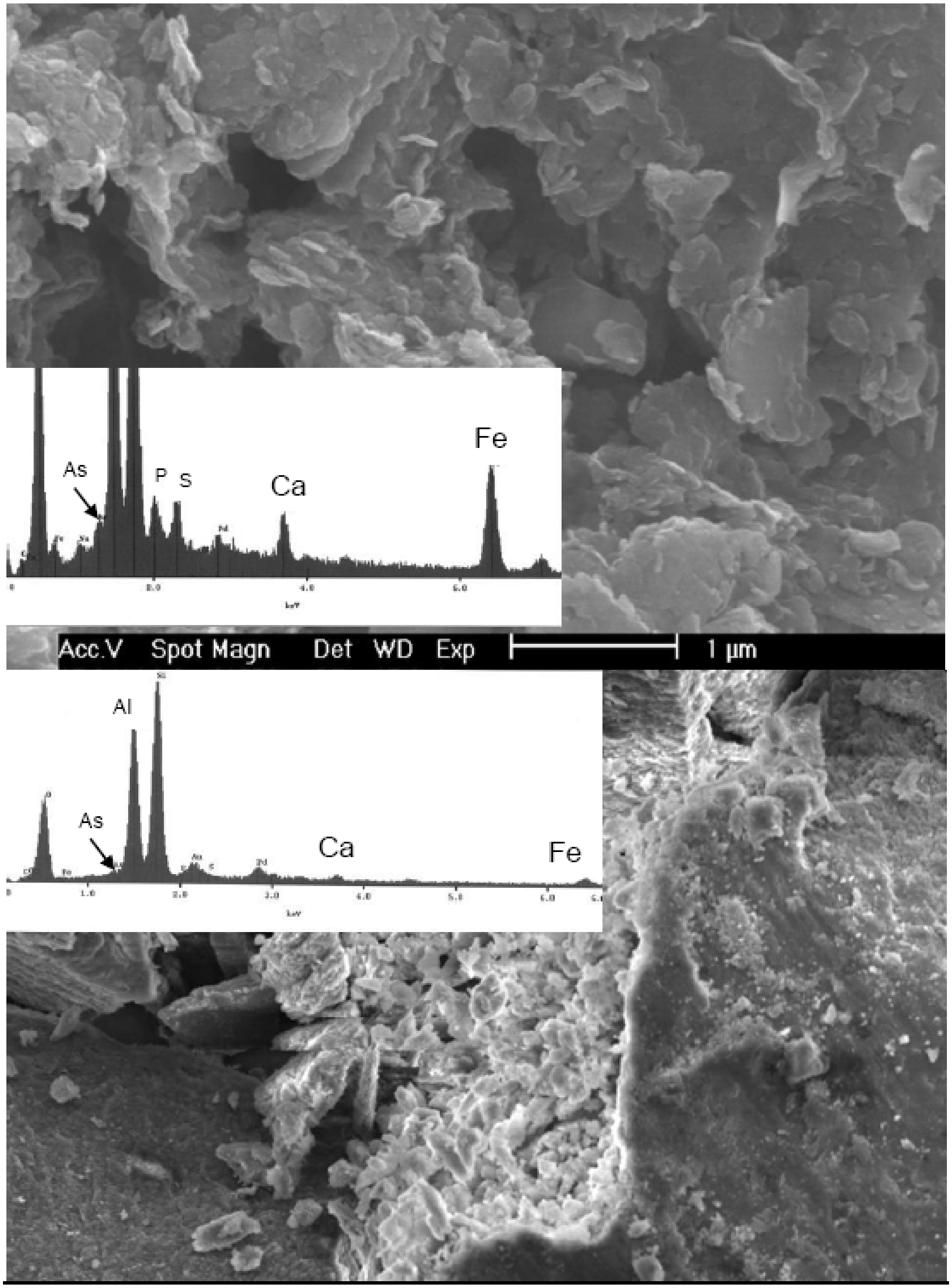


Figure 8. SEM images of Mineral (top) Secondary electron image and EDS spectrum of coating on same detrital quartz grain as in Fig. 6. Thin flaky Fe-rich mineral phase with distinctive As peak. (bottom) Secondary electron image and EDS spectrum of grains released by column #1 after the addition of $Al(OH)_3$ colloidal solutions.

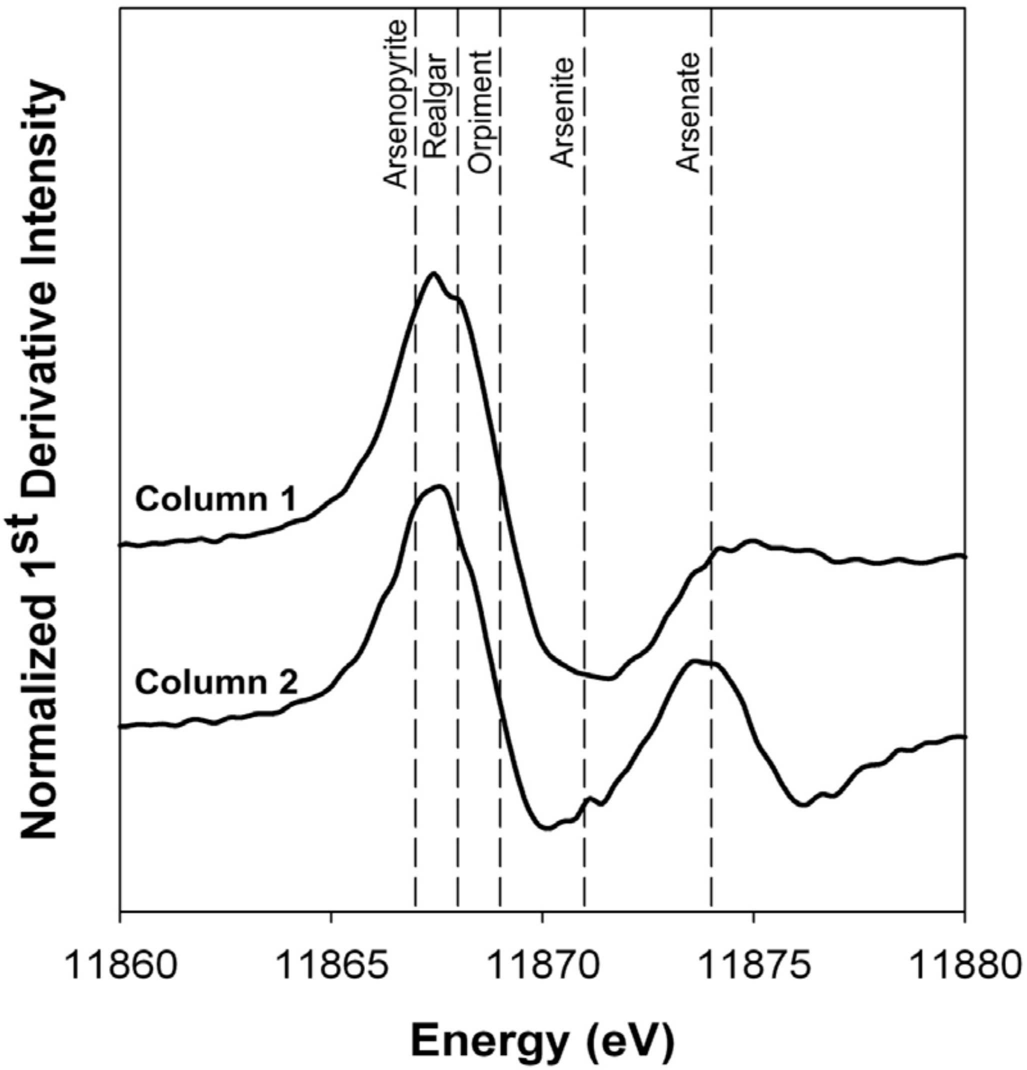


Figure 9. First-derivative As XANES spectra of column #1 and column #2 sediments. Black lines marking adsorption positions for arsenopyrite (FeAsS), realgar (AsS), orpiment (As_2S_3), arsenite (AsO_3^{3-}), and arsenate (AsO_4^{3-}) standards are depicted at 11867 eV, 11868 eV, 11869 eV, 11871 eV, and 11874 eV. Peaks are consistent with the formation of arsenopyrite, realgar and arsenate, indicating that stable As precipitates were formed during the column study (Onstott et al. 2009).

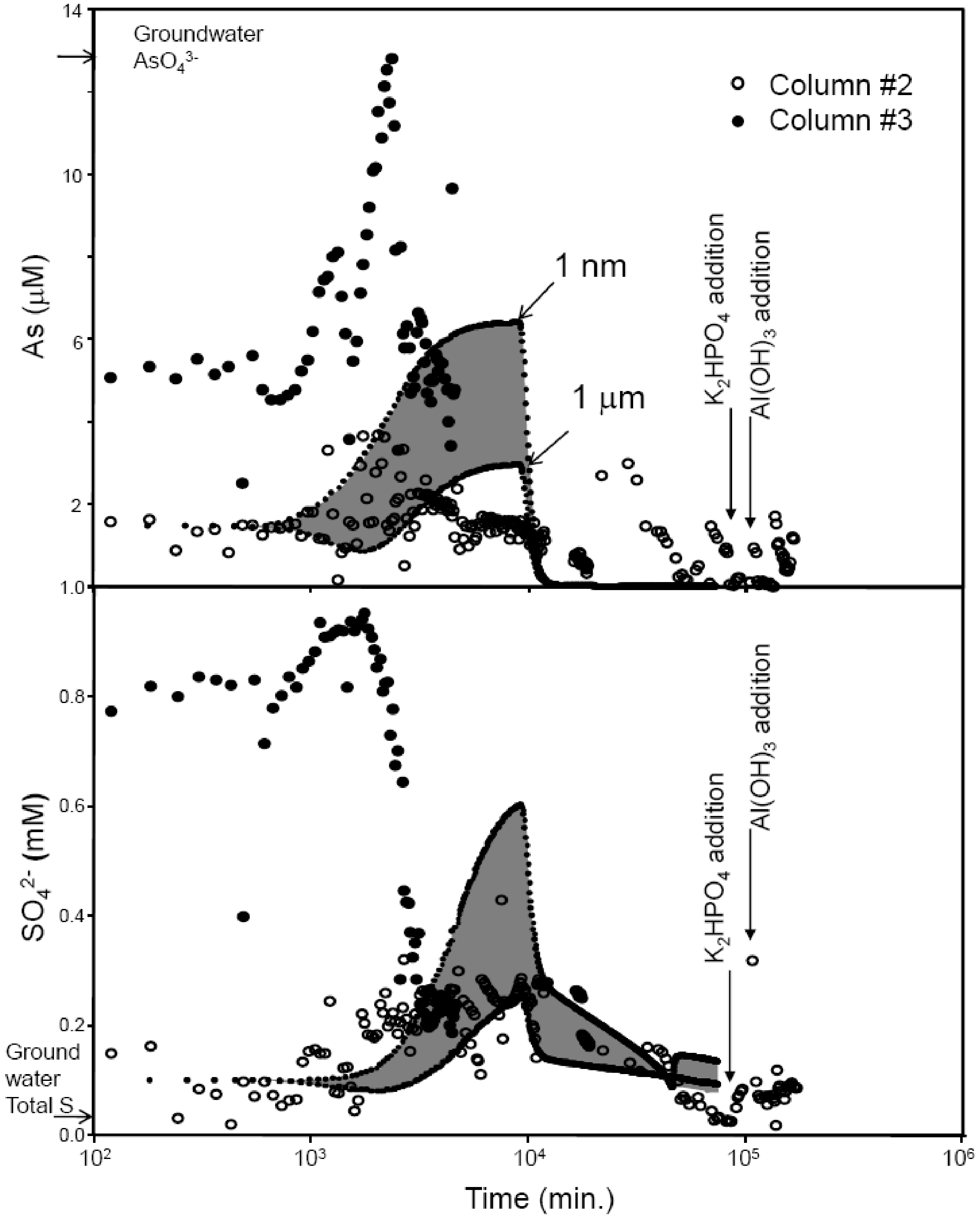


Figure 10. Results of Direct Dissolution Experiment AsO_4^{3-} and SO_4^{2-} concentrations versus time for aerobic leaching of untreated column #2 (open circles), H_2O_2/K_2HPO_2 treated column #3 (solid circles) and model results.

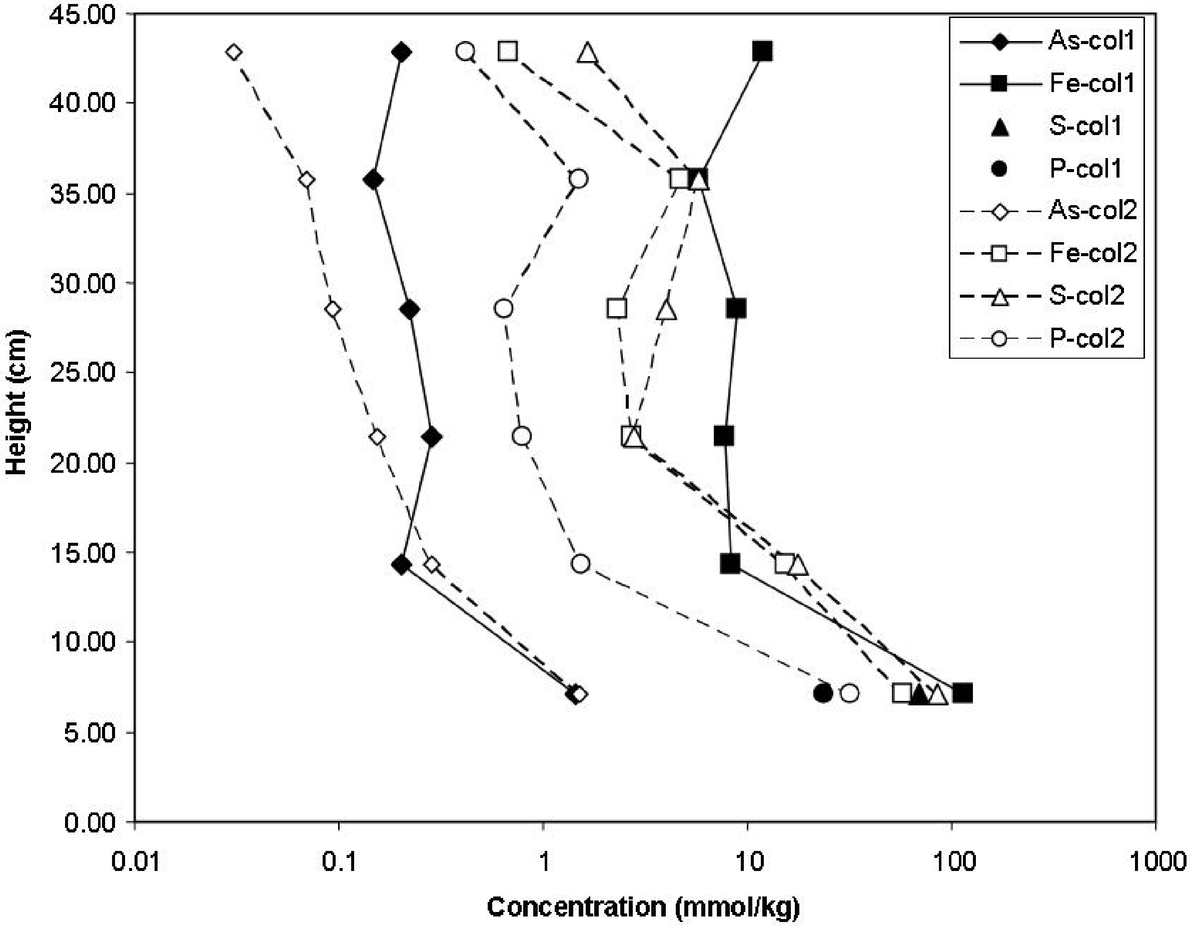


Figure 11. Column Cross-Section Speciation As, Fe, S and P concentrations for column #1 and column #2 after aerobic leaching experiment.

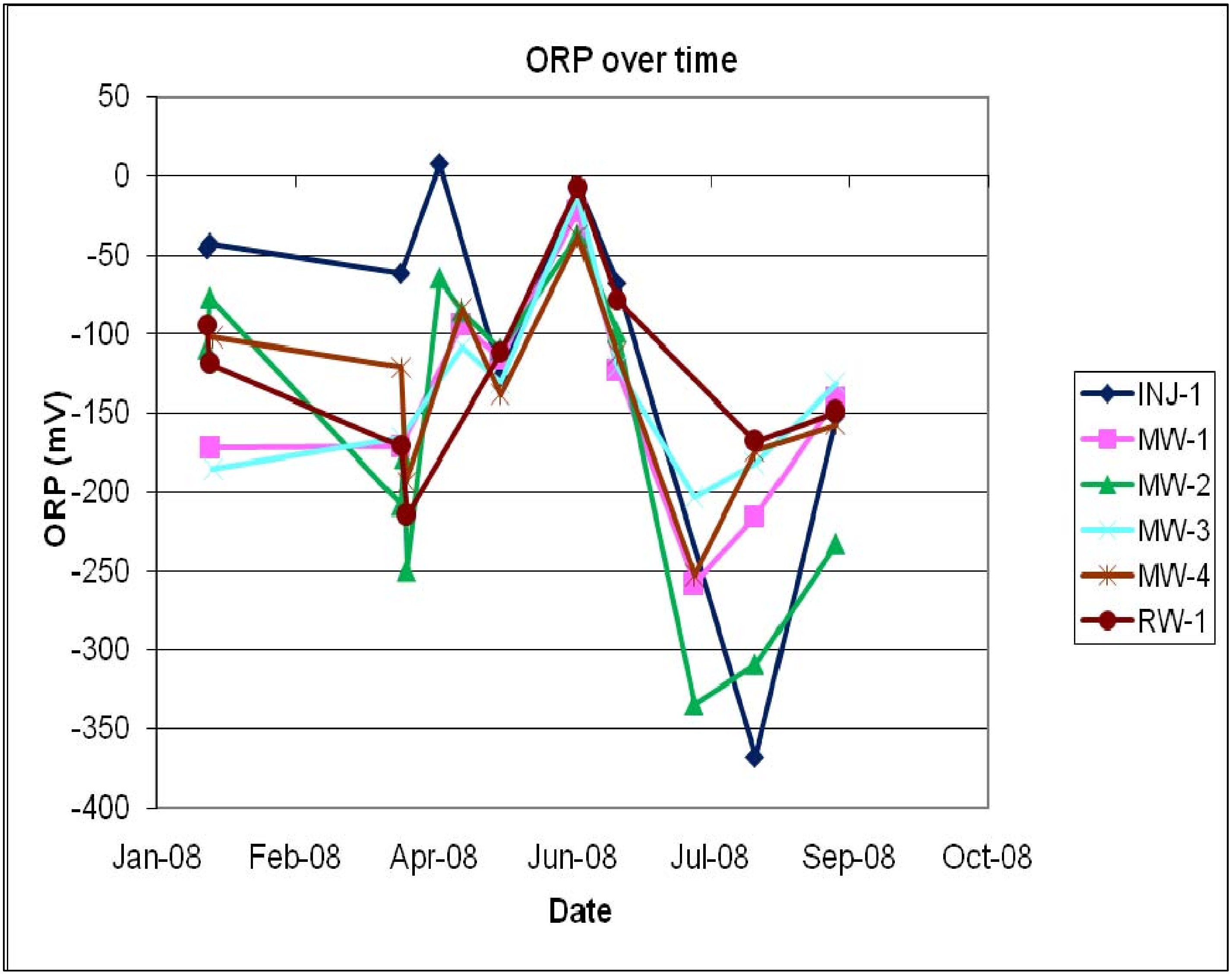


Figure 12. Groundwater Reductive Potential During Field Pilot Study

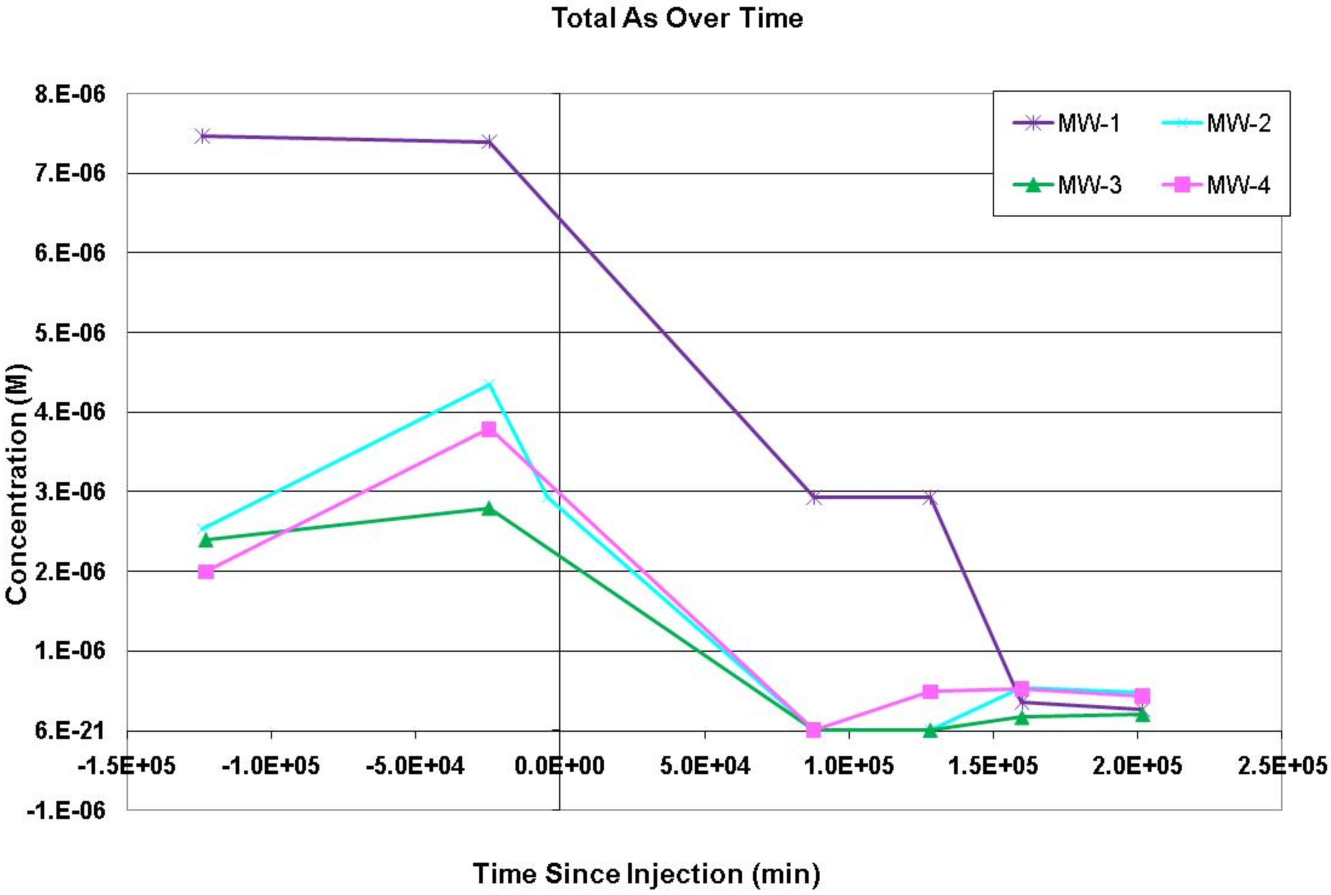


Figure 13. Arsenic Concentration During Field Pilot Test

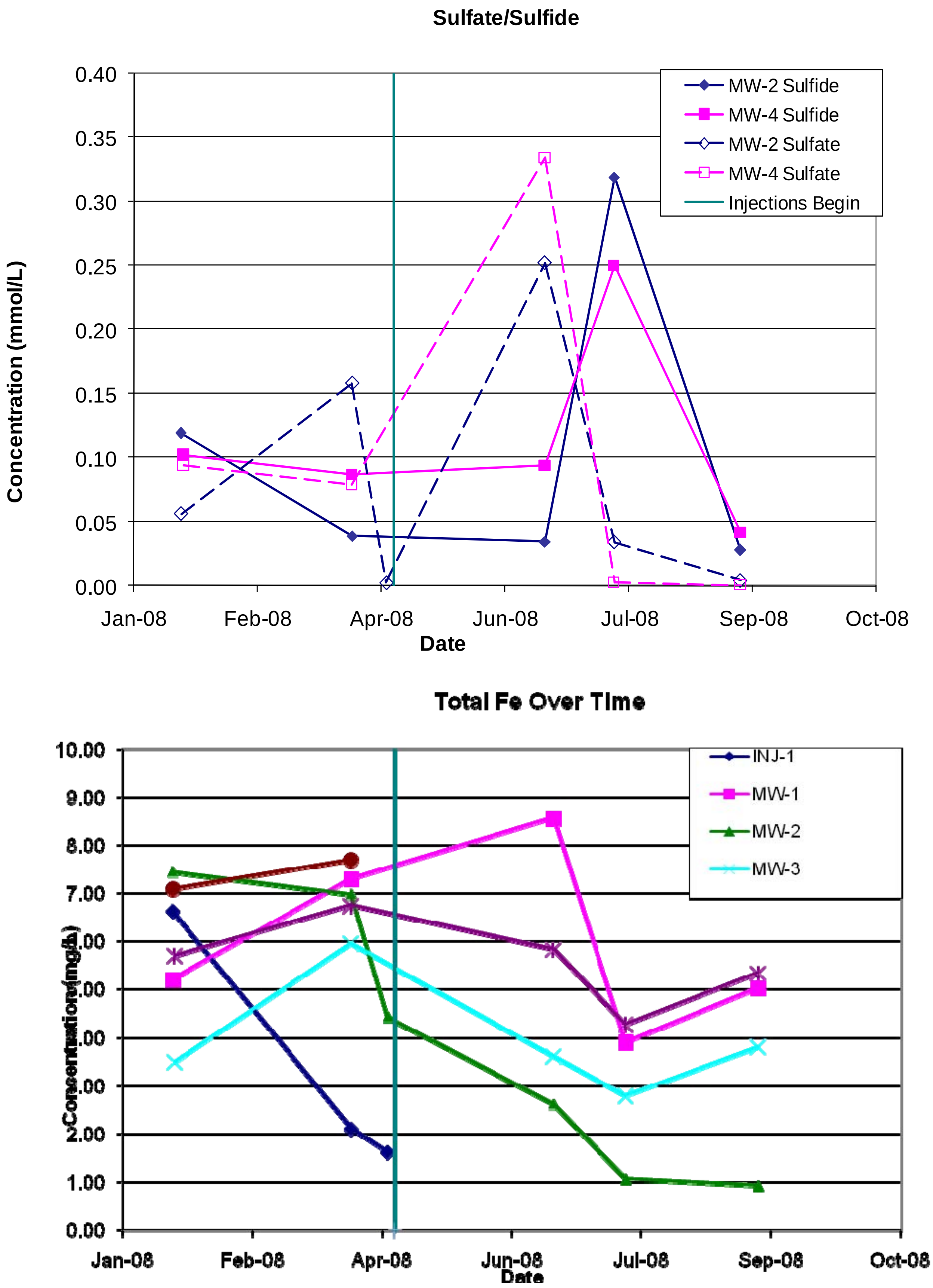


Figure 14A/14B. Sulfate/Sulfide and Total Iron Concentration During Field Pilot Test

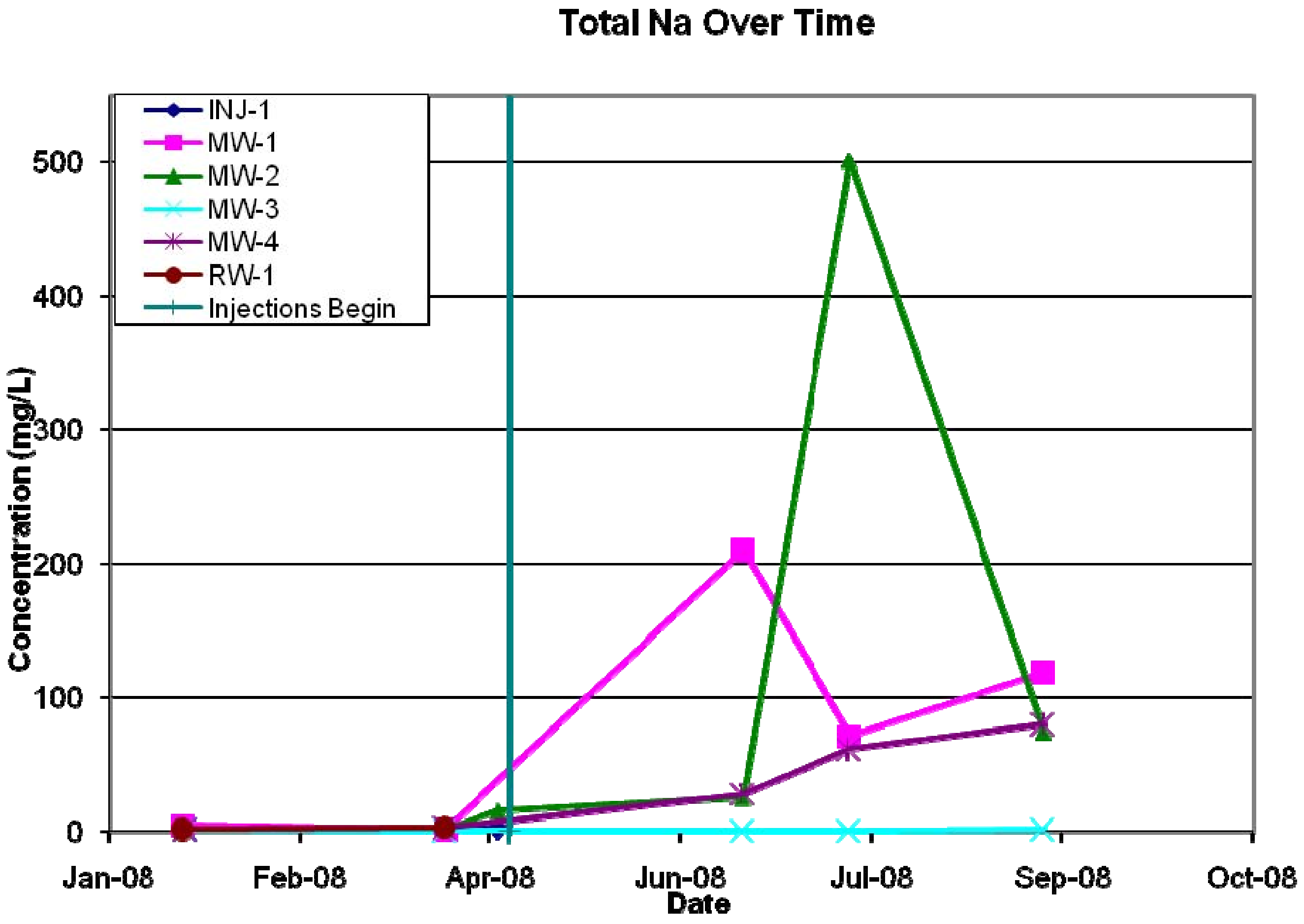


Figure 15. Sodium Concentration During Field Pilot Test

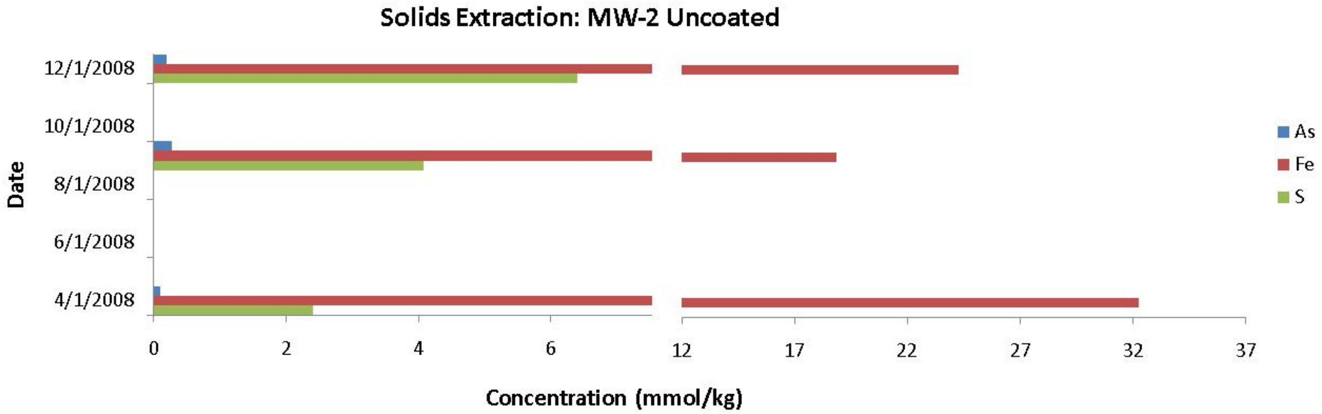


Figure 16. Sequential Extraction of *in situ* sand bags. Sequential extractions of sediments from uncoated (plain quartz) *in situ* sand bags show co-precipitation of As with Fe and S over the course of the injection period. Sediment samples taken on 4/1/2008 are pre-injection samples which were allowed to equilibrate i*n situ* in each monitoring well for two months prior to collection. An increase in S and As concentrations indicates successful sulfide generation and As-S precipitation. High concentrations of Fe naturally occurring in groundwater also aided in forming As precipitates.

APPENDIX A

Supporting Data

APPENDIX A-1

PHOTO LOG FOR COLUMN AND FIELD PILOT STUDIES

Site Photographs from System Installation

GEOSYNTEC CONSULTANTS Photographic Record	
Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 1	
Photo Description: Column set-up in anaerobic chamber	

Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 2

Photo Description: Close-up of sediment pouch pair prior to deployment at field site

GEOSYNTEC CONSULTANTS

Photographic Record

Client: SERDP

Project Number: JR0018

Site Name: Avon Park Air Force Range

Site Location: Avon Park Air Force Range
Avon Park, FL

Photograph 3

Photo Description:
RW-1 Well Vault construction during Pilot Study

Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 4

Photo Description:
Piping from RW-1 for Pilot Study recirculation system

GEOSYNTEC CONSULTANTS
Photographic Record

Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 5

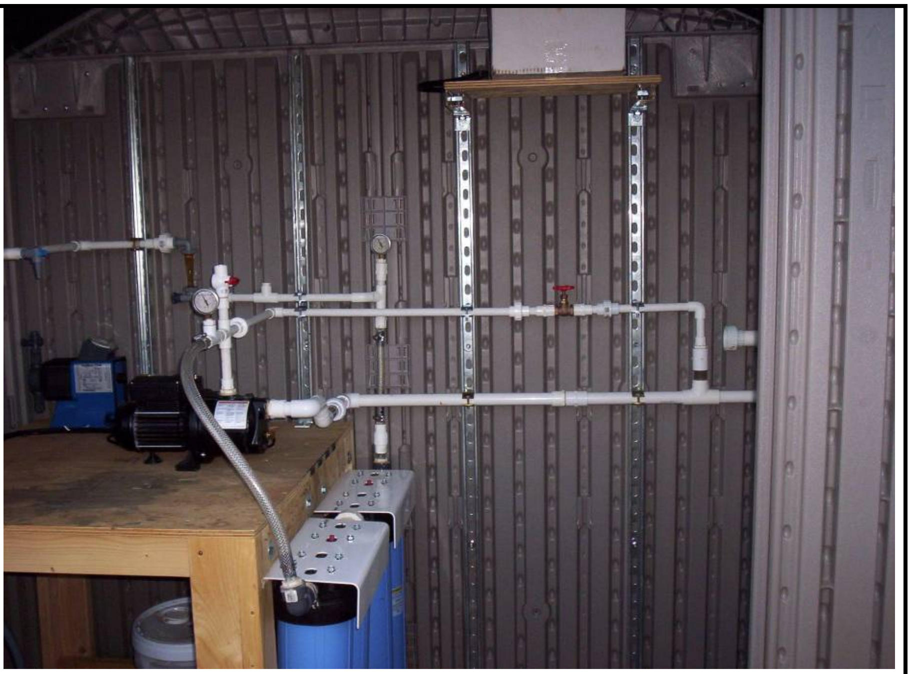


Photo Description: Pilot Study recirculation system equipment housing unit

GEOSYNTEC CONSULTANTS

Photographic Record

Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 6

Photo Description:
Pilot Study recirculation system equipment housing unit, complete with amendment storage and overflow tanks

GEOSYNTEC CONSULTANTS

Photographic Record

Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 7

Photo Description:
50 µm filter indicating sulfate reducing conditions (black precipitates)

GEOSYNTEC CONSULTANTS

Photographic Record

Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 8

Photo Description: Split core from Column Study showing fractures at side-ports and predominance of dark sulfide-rich zones at the inlet end

GEOSYNTEC CONSULTANTS

Photographic Record

Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 9

Photo Description:
Split core from Column Study – close-up of black sulfide-rich zone

GEOSYNTEC CONSULTANTS Photographic Record	
Client: SERDP	**Project Number:** JR0018
Site Name: Avon Park Air Force Range	**Site Location:** Avon Park Air Force Range Avon Park, FL

Photograph 10

Photo Description: Post-Pilot Study sediment pouches, indicating precipitation of sulfides (black color)

APPENDIX A-2

PILOT TEST WELL CONSTRUCTION LOGS

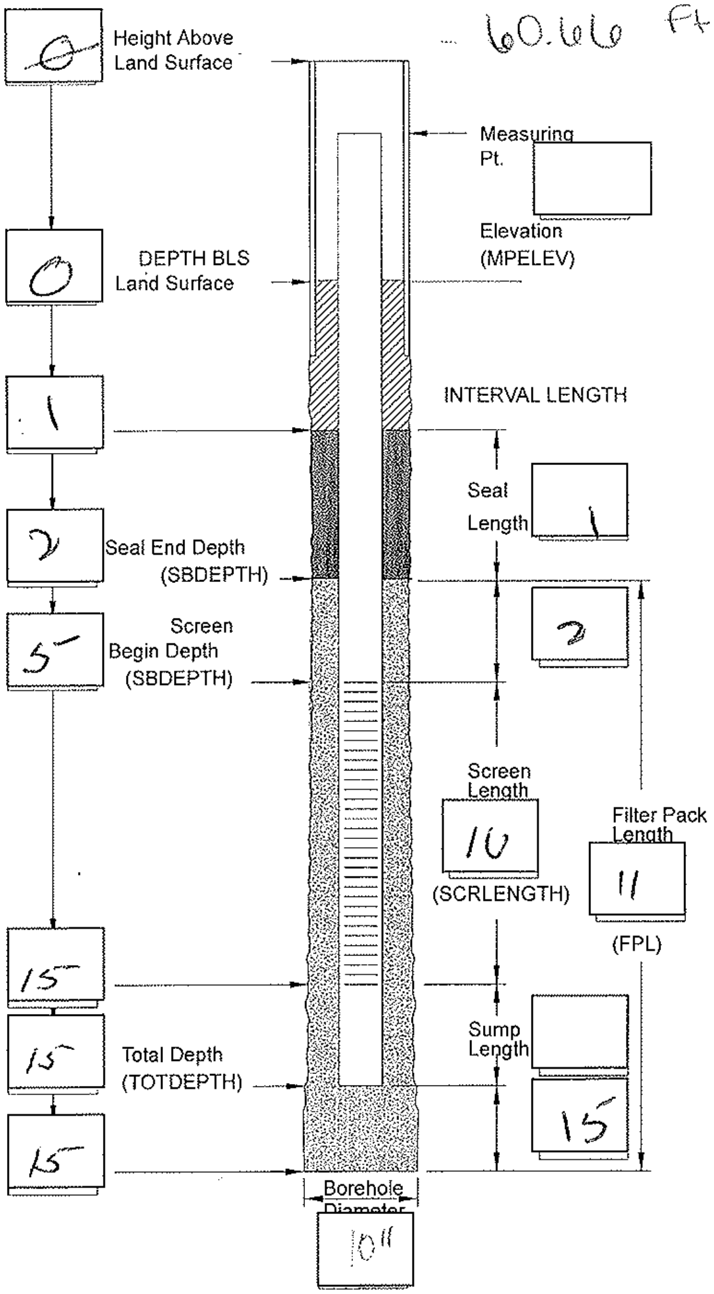
PROJECT # JR0618

WELL CONSTRUCTION LOG
ABOVE GROUND COMPLETION

Well I.D.: INJ-1 WACs ID:
Drilling Company: NET
Drillers:
Geologist/Engineer: Noel Anderson

Site: ST-65 Avon Park
Installation Method: Hollow Stem Auger
Casing Installation Date: 1/18/08
Well Type: Injection Well

60.66 ft TOC



Height Above Land Surface: 0
Measuring Pt. Elevation (MPELEV):
DEPTH BLS Land Surface: 0
1
INTERVAL LENGTH
Seal Length: 1
Seal End Depth (SBDEPTH): 2
2
Screen Begin Depth (SBDEPTH): 5
Screen Length (SCRLENGTH): 10
Filter Pack Length (FPL): 11
15
Sump Length:
Total Depth (TOTDEPTH): 15
15
15
Borehole Diameter: 10"

Well Completion
Guard Posts (Y / [✓ N]) Date:
Surface Pad Size: 2 ft x 2 ft

Protective Casing or Cover
Diameter/Type: NA
Depth BGS: NA Weep Hole (Y / N)

Grout
Composition/Proportions: Type I

Placement Method: Pour

Seal Date:
Type: Fine Sand 30-65
Source:
Set-up/Hydration Time:
Placement Method:
Vol. Fluid Added:

Filter Pack
Type: 20/30 Sand
Source:
Amount Used:
Placement Method:

Well Riser Pipe
Casing Material : PVC
Casing Inside Diameters: 4 in.

Screen
Material: PVC Schedule 40
Inside Diameter : 4 in.
Screen Slot Size: 0.010 in.

Sump or Bottom Cap (Y / [✓ N])
Type/Length:

Backfill Plug (Y / [✓ N])
Material:
Placement Method:
Set-up/Hydration Time:

Total Water Volume During Construction
Introduced (Gal): Recovered (Gal):

Reviewed
By: Date:

Comments

PROJECT # JR0018

WELL CONSTRUCTION LOG
ABOVE GROUND COMPLETION

Well I.D.: RW-1 WACs ID:

Drilling Company:

Drillers:

Geologist/Engineer: Stephanie Henry

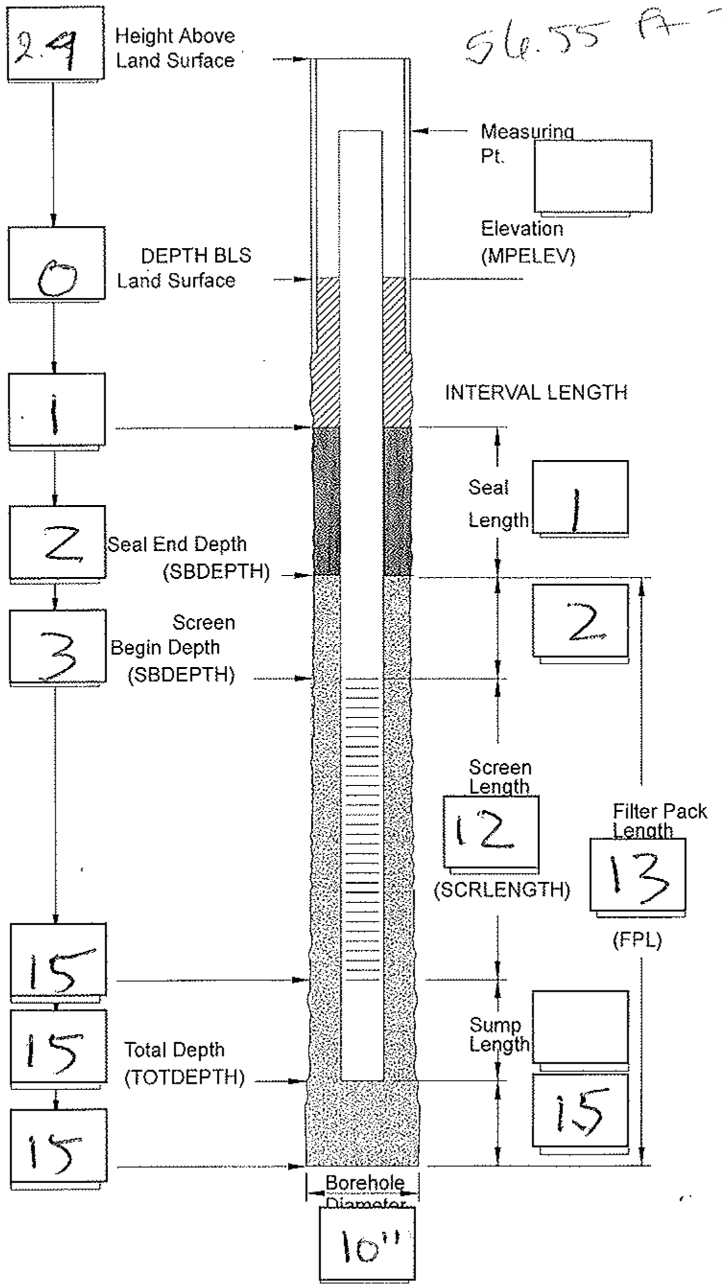
Site: ST-65 Avon Park AFR

Installation Method: Hollow Stem Auger

Casing Installation Date:

Well Type: Recovery Well

56.55 ft TOC


2.9 Height Above Land Surface

Measuring Pt. Elevation (MPELEV)

0 DEPTH BLS Land Surface

INTERVAL LENGTH

1

Seal Length 1

2 Seal End Depth (SBDEPTH)

2

3 Screen Begin Depth (SBDEPTH)

Screen Length 12 (SCRLENGTH)

Filter Pack Length 13 (FPL)

15

Sump Length

15 Total Depth (TOTDEPTH)

15

15

Borehole Diameter 10"

Well Completion

Guard Posts (Y / [✓ N]) Date:

Surface Pad Size: 2 ft x 2 ft

Protective Casing or Cover

Diameter/Type: NA

Depth BGS: NA Weep Hole (Y / N)

Grout

Composition/Proportions: Type 1

Placement Method: pour

Seal Date:

Type: fine Sand 30-65

Source:

Set-up/Hydration Time:

Placement Method:

Vol. Fluid Added:

Filter Pack

Type: 20/30 sand

Source:

Amount Used:

Placement Method:

Well Riser Pipe

Casing Material : PVC

Casing Inside Diameters: 4 in.

Screen

Material: PVC schedule 40

Inside Diameter : 4 in.

Screen Slot Size: 0.010 in.

Sump or Bottom Cap (Y [✓ N])

Type/Length:

Backfill Plug (Y / [✓ N])

Material:

Placement Method:

Set-up/Hydration Time:

Total Water Volume During Construction

Introduced (Gal): Recovered (Gal):

Reviewed

By: Date:

Comments

Feet - BLS.

Static 4.5 BGS

PROJECT # JR0618

WELL CONSTRUCTION LOG
~~ABOVE GROUND~~ COMPLETION
Flush mount

Well I.D.: MW-1 WACs ID:

Drilling Company: NET

Drillers:

Geologist/Engineer: Noel Anderson

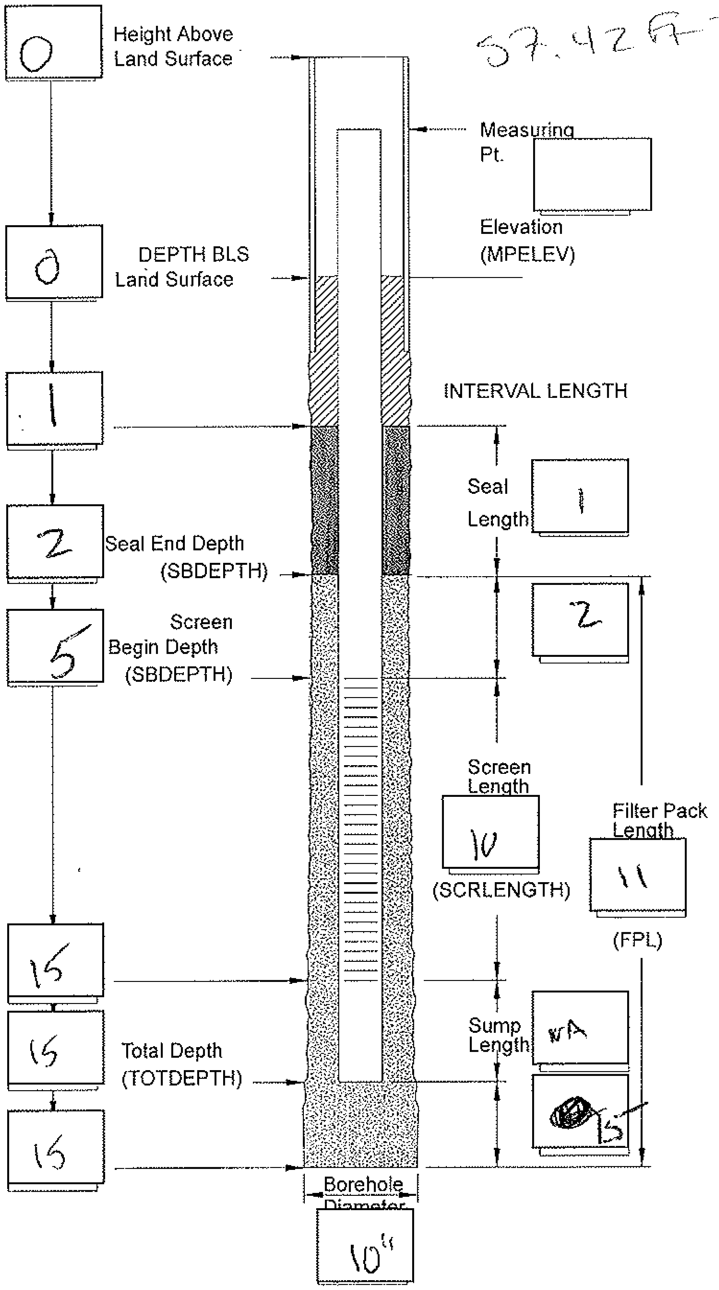
Site: ST-65 Avon Park

Installation Method: Hollow Stem Auger

Casing Installation Date: 1/18/07

Well Type: Monitoring Well

57.42 ft TOC



Height Above Land Surface: 0

DEPTH BLS Land Surface: 0

1

Seal End Depth (SBDEPTH): 2

Screen Begin Depth (SBDEPTH): 5

15

Total Depth (TOTDEPTH): 15

15

Seal Length: 1

2

Screen Length (SCRLENGTH): 10

Filter Pack Length (FPL): 11

Sump Length: NA

~~[illegible]~~ 15

Borehole Diameter: 10"

Well Completion

Guard Posts (Y / [✓ N]) Date:

Surface Pad Size: 2 ft x 2 ft

Protective Casing or Cover

Diameter/Type:

Depth BGS: Weep Hole (Y / N)

Grout

Composition/Proportions: Type I

Placement Method: Pour

Seal Date:

Type: ~~[illegible]~~ Fine Sand 30-65

Source:

Set-up/Hydration Time:

Placement Method:

Vol. Fluid Added:

Filter Pack

Type: 20/30 Sand

Source:

Amount Used:

Placement Method:

Well Riser Pipe

Casing Material : PVC

Casing Inside Diameters: 4 in.

Screen

Material: PVC Schedule 40

Inside Diameter : 4 in.

Screen Slot Size: 0.010 in.

Sump or Bottom Cap (Y / [✓ N])

Type/Length:

Backfill Plug (Y / [✓ N])

Material:

Placement Method:

Set-up/Hydration Time:

Total Water Volume During Construction

Introduced (Gal): Recovered (Gal):

Reviewed

By: Date:

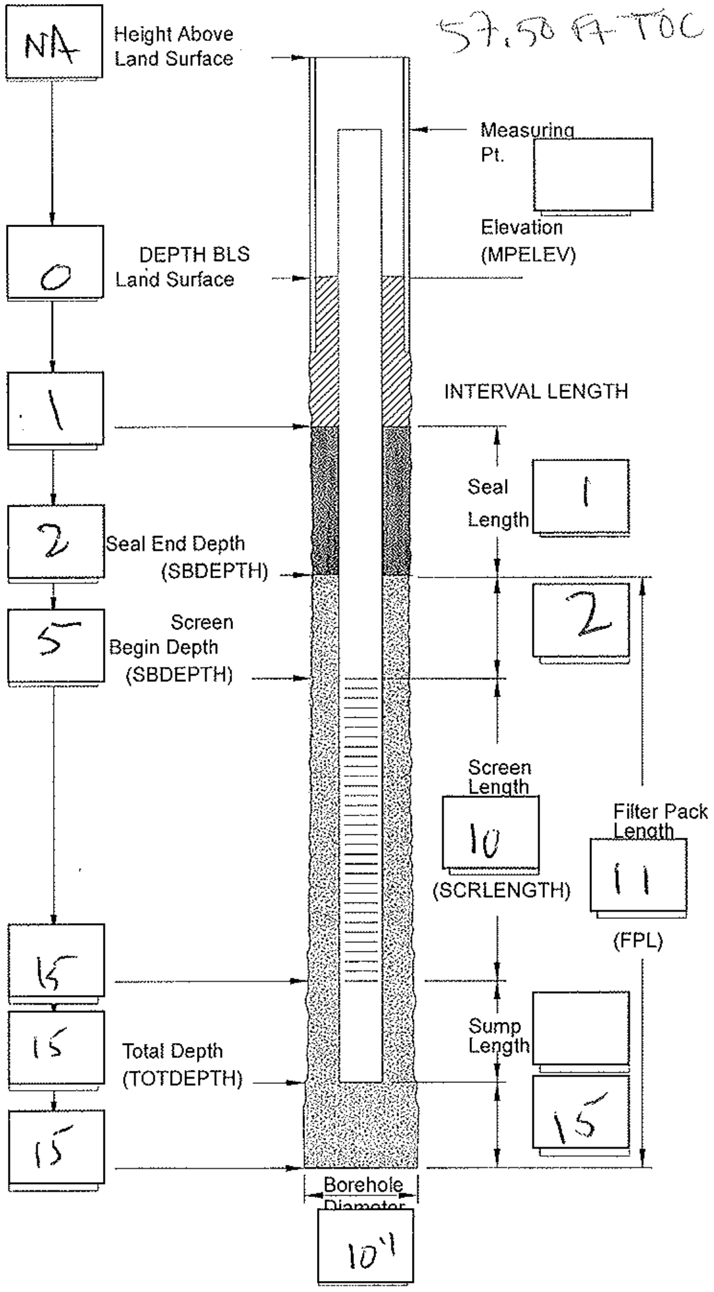
Comments

PROJECT # JR0018

WELL CONSTRUCTION LOG
~~ABOVE GROUND~~ COMPLETION
Flush Mount

Well I.D.: MW-2 WACs ID: ________
Drilling Company: NET
Drillers: ________
Geologist/Engineer: Noel Anderson

Site: ST-65 Avon Park
Installation Method: Hollow Stem Auger
Casing Installation Date: 1/18/08
Well Type: Monitoring well



Height Above Land Surface: NA
57.50 ft TOC
Measuring Pt. Elevation (MPELEV): ________
DEPTH BLS Land Surface: 0
1
Seal End Depth (SBDEPTH): 2
Screen Begin Depth (SBDEPTH): 5
15
Total Depth (TOTDEPTH): 15
15
Seal Length: 1
2
Screen Length (SCRLENGTH): 10
Filter Pack Length (FPL): 11
Sump Length: ________
15
Borehole Diameter: 10"

Well Completion
Guard Posts (Y / [✓ N]) Date: ________
Surface Pad Size: 2 ft x 2 ft

Protective Casing or Cover
Diameter/Type: ________
Depth BGS: ________ Weep Hole (Y / N)

Grout
Composition/Proportions: Type I
Placement Method: Pour

Seal Date: ________
Type: Fine Sand 30-65
Source: ________
Set-up/Hydration Time: ________
Placement Method: ________
Vol. Fluid Added: ________

Filter Pack
Type: 20/30 Sand
Source: ________
Amount Used: ________
Placement Method: ________

Well Riser Pipe
Casing Material : ________
Casing Inside Diameters: ________ in.

Screen
Material: PVC
Inside Diameter : 4 in.
Screen Slot Size: 0.010 in.

Sump or Bottom Cap (Y / [✓ N])
Type/Length: ________

Backfill Plug (Y / [✓ N])
Material: ________
Placement Method: ________
Set-up/Hydration Time: ________

Total Water Volume During Construction
Introduced (Gal): ________ Recovered (Gal): ________

Reviewed
By: ________ Date: ________

Comments

PROJECT # JR0018

WELL CONSTRUCTION LOG
~~ABOVE GROUND~~ COMPLETION
Flush Mount

Well I.D.: MW-3 WACs ID:

Drilling Company: NET

Drillers:

Geologist/Engineer: Noel Anderson

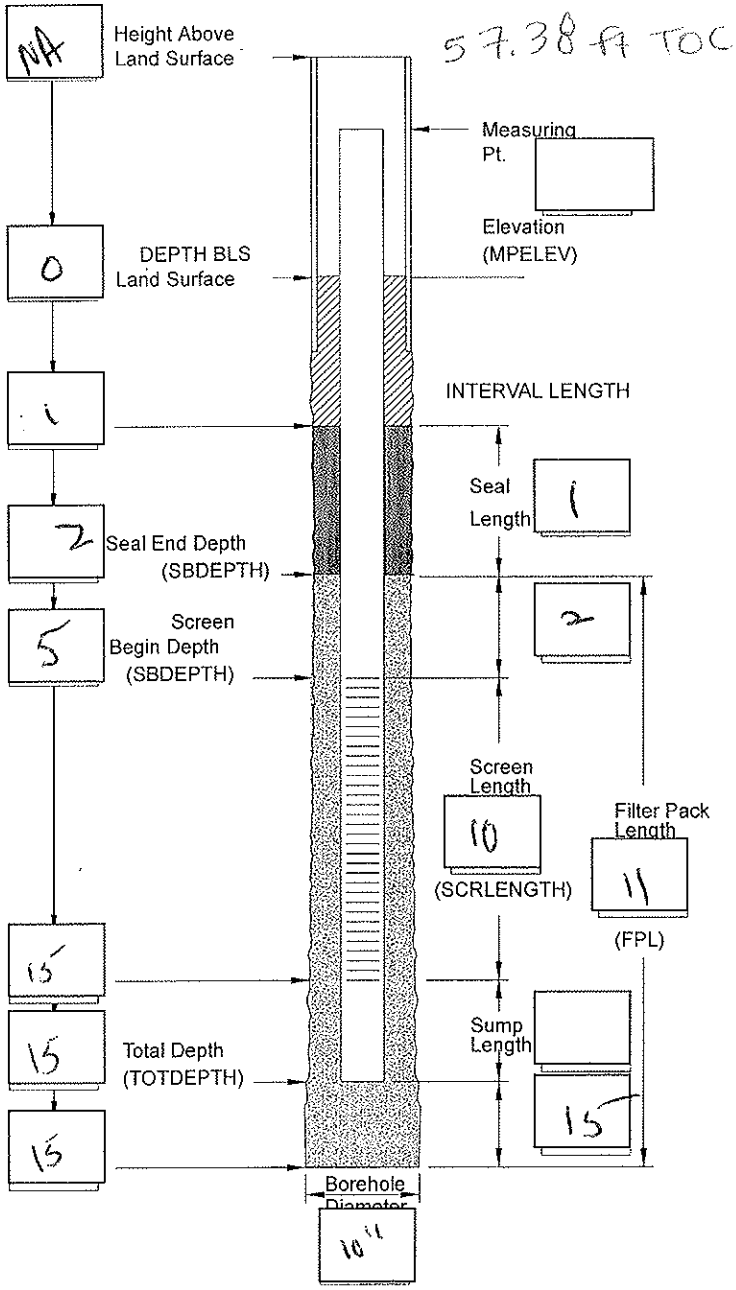
Site: ST-65 Avon Park

Installation Method: Hollow Stem Auger

Casing Installation Date: 1/18/08

Well Type: Monitoring well

57.38 ft TOC



Height Above Land Surface: NA

DEPTH BLS Land Surface: 0

1

Seal End Depth (SBDEPTH): 2

Screen Begin Depth (SBDEPTH): 5

15

Total Depth (TOTDEPTH): 15

15

Seal Length: 1

2

Screen Length (SCRLENGTH): 10

Filter Pack Length (FPL): 11

Sump Length:

15

Borehole Diameter: 10"

Well Completion

Guard Posts (Y [✓ N]) Date:

Surface Pad Size: 2 ft x 2 ft

Protective Casing or Cover

Diameter/Type: NA

Depth BGS: NA Weep Hole (Y / N)

Grout

Composition/Proportions: Type 1

Placement Method: Pour

Seal Date:

Type: Fine Sand 30-65

Source:

Set-up/Hydration Time:

Placement Method:

Vol. Fluid Added:

Filter Pack

Type: 20/30 Sand

Source:

Amount Used:

Placement Method:

Well Riser Pipe

Casing Material : PVC

Casing Inside Diameters: 4 in.

Screen

Material: PVC Schedule 40

Inside Diameter : 4" in.

Screen Slot Size: 0.010 in.

Sump or Bottom Cap (Y [✓ N])

Type/Length:

Backfill Plug (Y [✓ N])

Material:

Placement Method:

Set-up/Hydration Time:

Total Water Volume During Construction

Introduced (Gal): Recovered (Gal):

Reviewed

By: Date:

Comments

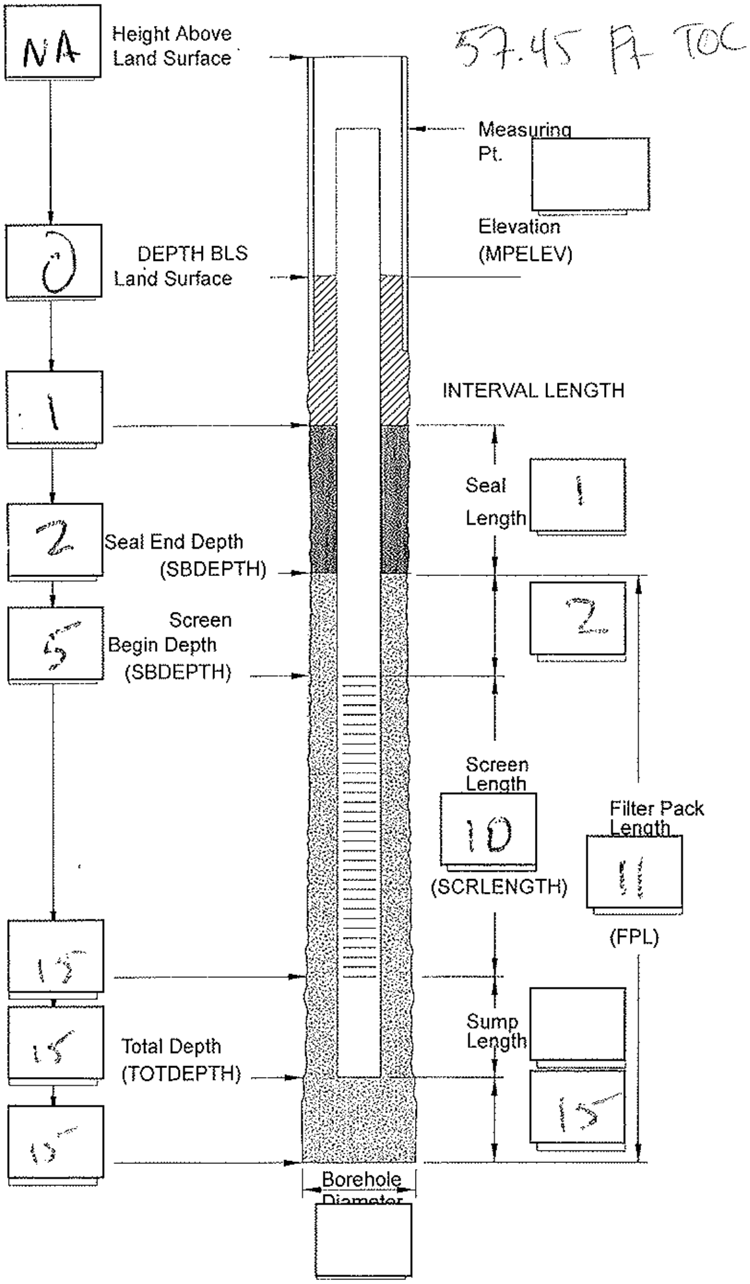
PROJECT # JR0018

WELL CONSTRUCTION LOG
~~ABOVE GROUND~~ COMPLETION
Flush mount

Well I.D.: MW-4 WACs ID:
Drilling Company: NET
Drillers:
Geologist/Engineer: Noel Anderson

Site: ST-65 Avon Park
Installation Method: Hollow Stem Auger
Casing Installation Date: 1/18/08
Well Type: Monitoring well

57.45 ft TOC



Well Completion
Guard Posts (Y / [✓ N]) Date:
Surface Pad Size: 2 ft x 2 ft

Protective Casing or Cover
Diameter/Type: NA
Depth BGS: NA Weep Hole (Y / N)

Grout
Composition/Proportions: Type 1
Placement Method: pour

Seal Date:
Type: fine sand 30-65
Source:
Set-up/Hydration Time:
Placement Method:
Vol. Fluid Added:

Filter Pack
Type: 20/30 sand
Source:
Amount Used:
Placement Method:

Well Riser Pipe
Casing Material : PVC
Casing Inside Diameters: 4 in.

Screen
Material: PVC Schedule 40
Inside Diameter : 4 in.
Screen Slot Size: 0.01 in.

Sump or Bottom Cap (Y / [✓ N])
Type/Length:

Backfill Plug (Y / [✓ N])
Material:
Placement Method:
Set-up/Hydration Time:

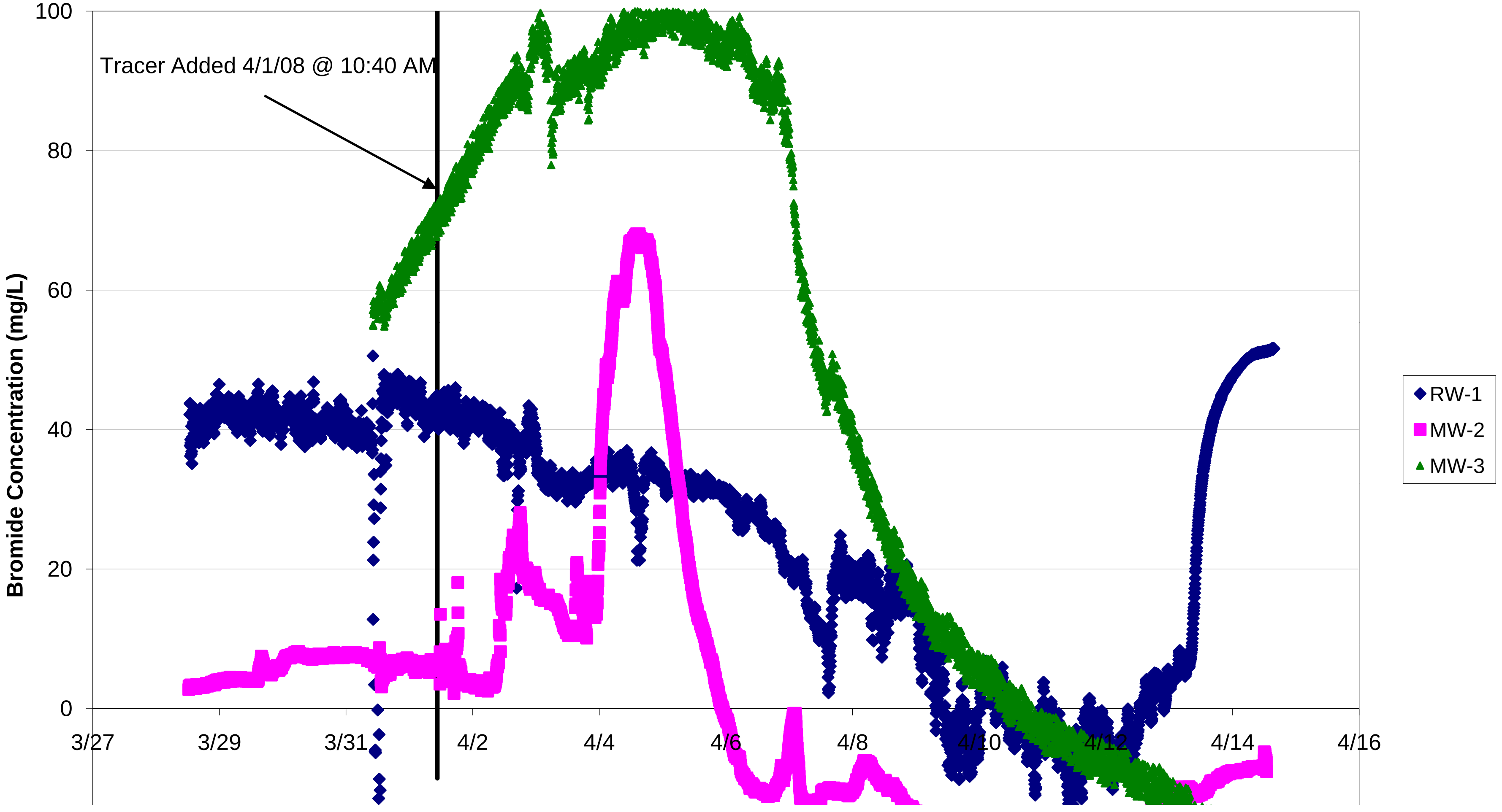
Total Water Volume During Construction
Introduced (Gal): Recovered (Gal):

Reviewed
By: Date:

Comments

APPENDIX A-3

TRACER TEST SUPPORTING INFORMATION



Specific Conductivity during Tracer Study
Avon Park, Florida

Tracer Test Calculations

1. Combined all troll data into one spreadsheet (Avon Park Troll Data.xls), separated by tabs for each well
2. Subtracted background specific conductivity values and converted specific conductivity to bromide concentration based on calibration curves for each troll
3. Graphed bromide concentration vs. time for each well
4. Maximum Br concentration at MW-2 ~ 58 mg/L at t = 3.14 days
5. Dilution factor based on original concentration = 251,000 mg/L / 58 mg/L = 4,327
6. Dilution factor used in original calculations for stock concentration = 11,500
7. Played with original analytical model from Don but couldn't get it to give realistic values for the inputs
8. Used simplified 2-D model to calculated dispersion and retardation coefficients (see columns X-AC in Copy of tracer_transport spreadsheet, breakthroughs worksheet). This model is for a pulse source:

$$C(x,y,t)=\frac{C_0A}{4\pi t\left(D_xD_y\right)^{1/2}}\exp\left(-\frac{\left(\left(x-x_0\right)-v_xt\right)^2}{4D_xt}-\frac{\left(y-y_0\right)^2}{4D_yt}\right)$$

Where

$$t=\frac{R_tx}{v_x}$$

Inputs used:
C_0 = Initial concentration = 251,000 mg/L
A = Source surface area = area of well = πr^2 = 0.342 ft^2 = 0.03177 m^2
x = Lateral distance from source = 3.05 m for MW-2
v_x = Velocity in x-direction = gradient = 2.003 m/d
R = Retardation coefficient = 1

9. Iterated values for D_x (longitudinal dispersion) and D_y (latitudinal dispersion) to calculate C (known to be ~58 mg/L)
    a. *Assumed relationship $D_y = 0.1*D_x$
10. Obtained values of $D_x = 9.7$, $D_y = 0.97$
11. Used calculated vales for D_x, D_y, R_t to calculate estimated concentrations of iron stock constituent at wells RW-1 and MW-3 (using appropriate values for x and y distances from injection well)
12. Concentration in RW-1 estimated to be ~30 mg/L: below target concentration of 40 mg/L
13. Concentration in MW-3 estimated to be ~22 mg/L: below target concentration of 40 mg/L
14. Multiply stock concentration by 2:
    a. Concentration in RW-1 = 61 mg/L
    b. Concentration in MW-3 = 45 mg/L

APPENDIX A-4

MATERIAL SAFETY DATA SHEETS FOR GROUNDWATER AMENDMENTS

Material Safety Data Sheet

Ammonium Phosphate, Dibasic, Reagent ACS (Powder)

ACC# 00219

Section 1 - Chemical Product and Company Identification

MSDS Name: Ammonium Phosphate, Dibasic, Reagent ACS (Powder)
Catalog Numbers: AC423370000, AC423370050, AC423375000
Synonyms: Diammonium Hydrogen Phosphate; Phosphoric Acid Diammonium Salt
Company Identification:

Acros Organics N.V.
One Reagent Lane
Fair Lawn, NJ 07410

For information in North America, call: 800-ACROS-01
For emergencies in the US, call CHEMTREC: 800-424-9300

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
7783-28-0	Diammonium phosphate	>99%	231-987-8

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: white solid.
Caution! May cause eye and skin irritation. May cause respiratory and digestive tract irritation.
Target Organs: None.

Potential Health Effects
Eye: Dusts may cause persistent eye irritation and conjunctivitis.
Skin: May cause mild skin irritation.
Ingestion: Causes gastrointestinal irritation with nausea, vomiting and diarrhea.
Inhalation: May cause respiratory tract irritation.
Chronic: Prolonged or repeated skin contact may cause dermatitis.

Section 4 - First Aid Measures

Eyes: Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.
Skin: Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists. Wash clothing before reuse.
Ingestion: Do not induce vomiting. If victim is conscious and alert, give 2-4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid.
Inhalation: Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.
Notes to Physician: Treat symptomatically and supportively.

Section 5 - Fire Fighting Measures

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion.
Extinguishing Media: Substance is noncombustible; use agent most appropriate to extinguish surrounding fire. Use water spray, dry chemical, carbon dioxide, or appropriate foam.
Flash Point: Not applicable.
Autoignition Temperature: Not applicable.
Explosion Limits, Lower: Not available.
Upper: Not available.
NFPA Rating: (estimated) Health: 1; Flammability: 0; Instability: 0

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Vacuum or sweep up material and place into a suitable disposal container. Avoid generating dusty conditions. Provide ventilation.

Section 7 - Handling and Storage

Handling: Use with adequate ventilation. Avoid contact with skin and eyes. Keep container tightly closed. Avoid ingestion and inhalation.

Storage: Store in a cool, dry, well-ventilated area away from incompatible substances. Keep containers tightly closed.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate ventilation to keep airborne concentrations low.

Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Diammonium phosphate	none listed	none listed	none listed

OSHA Vacated PELs: Diammonium phosphate: No OSHA Vacated PELs are listed for this chemical.

Personal Protective Equipment

Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

Skin: Wear appropriate gloves to prevent skin exposure.

Clothing: Wear appropriate protective clothing to prevent skin exposure.

Respirators: Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Always use a NIOSH or European Standard EN 149 approved respirator when necessary.

Section 9 - Physical and Chemical Properties

Physical State: Solid
Appearance: white
Odor: ammonia-like - weak odor
pH: 8.0
Vapor Pressure: Negligible.
Vapor Density: Negligible.
Evaporation Rate: Negligible.
Viscosity: Not available.
Boiling Point: Not available.
Freezing/Melting Point:155 deg C
Decomposition Temperature:155 deg C
Solubility: 58g/100ml (10 C)
Specific Gravity/Density: 1.619
Molecular Formula:$(NH_4)_2HPO_4$
Molecular Weight:132.0478

Section 10 - Stability and Reactivity

Chemical Stability: Stable under normal temperatures and pressures.
Conditions to Avoid: Incompatible materials, excess heat.
Incompatibilities with Other Materials: Sodium hypochlorite.
Hazardous Decomposition Products: Oxides of phosphorus, nitrogen oxides (NOx) and ammonia (NH3).
Hazardous Polymerization: Has not been reported.

Section 11 - Toxicological Information

RTECS#:
CAS# 7783-28-0 unlisted.
LD50/LC50:
Not available.

Carcinogenicity:
CAS# 7783-28-0: Not listed by ACGIH, IARC, NTP, or CA Prop 65.

Epidemiology: No information available.
Teratogenicity: No information available.
Reproductive Effects: No information available.
Mutagenicity: No information available.
Neurotoxicity: No information available.
Other Studies:

Section 12 - Ecological Information

Ecotoxicity: No data available. Fathead minnow LC50=155 ppm/96Hr.
Environmental: No information available.
Physical: No information available.
Other: No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must

consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series: None listed.

Section 14 - Transport Information

	US DOT	**Canada TDG**
Shipping Name:	Please contact Fisher Scientific for shipping information	No information available.
Hazard Class:		
UN Number:		
Packing Group:		

Section 15 - Regulatory Information

US FEDERAL

TSCA
CAS# 7783-28-0 is listed on the TSCA inventory.
Health & Safety Reporting List
None of the chemicals are on the Health & Safety Reporting List.
Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.
Section 12b
None of the chemicals are listed under TSCA Section 12b.
TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.
CERCLA Hazardous Substances and corresponding RQs
None of the chemicals in this material have an RQ.
SARA Section 302 Extremely Hazardous Substances
None of the chemicals in this product have a TPQ.
SARA Codes
CAS # 7783-28-0: acute.
Section 313 No chemicals are reportable under Section 313.
Clean Air Act:
This material does not contain any hazardous air pollutants.
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.
Clean Water Act:
None of the chemicals in this product are listed as Hazardous Substances under the CWA.

None of the chemicals in this product are listed as Priority Pollutants under the CWA.

None of the chemicals in this product are listed as Toxic Pollutants under the CWA.

OSHA:

None of the chemicals in this product are considered highly hazardous by OSHA.

STATE

CAS# 7783-28-0 is not present on state lists from CA, PA, MN, MA, FL, or NJ.

California Prop 65

California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols:

Not available.

Risk Phrases:

Safety Phrases:

WGK (Water Danger/Protection)

CAS# 7783-28-0: 1

Canada - DSL/NDSL

CAS# 7783-28-0 is listed on Canada's DSL List.

Canada - WHMIS

WHMIS: Not available.

Canadian Ingredient Disclosure List

Section 16 - Additional Information

MSDS Creation Date: 2/23/1999
Revision #2 Date: 3/18/2003

Material Safety Data Sheet

Ethyl Alcohol, 70%

ACC# 91791

Section 1 - Chemical Product and Company Identification

MSDS Name: Ethyl Alcohol, 70%

Catalog Numbers: S75119, S75120, S556CA4

Synonyms: Ethyl Alcohol; Ethyl Hydrate; Ethyl Hydroxide; Fermentation Alcohol; Grain Alcohol; Methylcarbinol; Molasses Alcohol; Spirits of Wine.

Company Identification:

Fisher Scientific
1 Reagent Lane
Fair Lawn, NJ 07410

For information, call: 201-796-7100
Emergency Number: 201-796-7100
For CHEMTREC assistance, call: 800-424-9300
For International CHEMTREC assistance, call: 703-527-3887

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
64-17-5	Ethyl alcohol	70	200-578-6
7732-18-5	Water	30	231-791-2

Hazard Symbols: F
Risk Phrases: 11

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: colorless clear liquid. Flash Point: 16.6 deg C. **Flammable liquid and vapor.** May cause central nervous system depression. Causes severe eye irritation. Causes respiratory tract irritation. Causes moderate skin irritation. This substance has caused adverse reproductive and fetal effects in humans. **Warning!** May cause liver, kidney and heart damage.

Target Organs: Kidneys, heart, central nervous system, liver.

Potential Health Effects

Eye: Causes severe eye irritation. May cause painful sensitization to light. May cause chemical conjunctivitis and corneal damage.

Skin: Causes moderate skin irritation. May cause cyanosis of the extremities.

Ingestion: May cause gastrointestinal irritation with nausea, vomiting and diarrhea. May cause systemic toxicity with acidosis. May cause central nervous system depression, characterized by excitement, followed by headache, dizziness, drowsiness, and nausea. Advanced stages may cause collapse, unconsciousness, coma and possible death due to respiratory failure.

Inhalation: Inhalation of high concentrations may cause central nervous system effects characterized by nausea, headache, dizziness, unconsciousness and coma. Causes respiratory tract irritation. May cause narcotic effects in high concentration. Vapors may cause dizziness or suffocation.

Chronic: May cause reproductive and fetal effects. Laboratory experiments have resulted in mutagenic effects. Animal studies have reported the development of tumors. Prolonged exposure may cause liver, kidney, and heart damage.

Section 4 - First Aid Measures

Eyes: Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid. Gently lift eyelids and flush continuously with water.

Skin: Get medical aid. Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Flush skin with plenty of soap and water.

Ingestion: Do NOT induce vomiting. If victim is conscious and alert, give 2-4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid.

Inhalation: Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid. Do NOT use mouth-to-mouth resuscitation.

breathing is difficult, give oxygen. Get medical aid. Do NOT use mouth-to-mouth resuscitation.
Notes to Physician: Treat symptomatically and supportively. Persons with skin or eye disorders or liver, kidney, chronic respiratory diseases, or central and peripheral nervous sytem diseases may be at increased risk from exposure to this substance.
Antidote: Replace fluid and electrolytes.

Section 5 - Fire Fighting Measures

General Information: Containers can build up pressure if exposed to heat and/or fire. As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Vapors may form an explosive mixture with air. Vapors can travel to a source of ignition and flash back. Will burn if involved in a fire. Flammable Liquid. Can release vapors that form explosive mixtures at temperatures above the flashpoint. Use water spray to keep fire-exposed containers cool. Containers may explode in the heat of a fire.
Extinguishing Media: For small fires, use dry chemical, carbon dioxide, water spray or alcohol-resistant foam. For large fires, use water spray, fog, or alcohol-resistant foam. Use water spray to cool fire-exposed containers. Water may be ineffective. Do NOT use straight streams of water.
Flash Point: 16.6 deg C (61.88 deg F)
Autoignition Temperature: 363 deg C (685.40 deg F)
Explosion Limits, Lower: 3.3 vol %
Upper: 19.0 vol %
NFPA Rating: (estimated) Health: 2; Flammability: 3; Instability: 0

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Remove all sources of ignition. Use a spark-proof tool. Provide ventilation. A vapor suppressing foam may be used to reduce vapors.

Section 7 - Handling and Storage

Handling: Wash thoroughly after handling. Use only in a well-ventilated area. Ground and bond containers when transferring material. Use spark-proof tools and explosion proof equipment. Avoid contact with eyes, skin, and clothing. Empty containers retain product residue, (liquid and/or vapor), and can be dangerous. Keep container tightly closed. Avoid contact with heat, sparks and flame. Avoid ingestion and inhalation. Do not pressurize, cut, weld, braze, solder, drill, grind, or expose empty containers to heat, sparks or open flames.
Storage: Keep away from heat, sparks, and flame. Keep away from sources of ignition. Store in a tightly closed container. Keep from contact with oxidizing materials. Store in a cool, dry, well-ventilated area away from incompatible substances. Flammables-area. Do not store near perchlorates, peroxides, chromic acid or nitric acid.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Use explosion-proof ventilation equipment. Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits.
Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Ethyl alcohol	1000 ppm TWA	1000 ppm TWA; 1900 mg/m3 TWA 3300 ppm IDLH	1000 ppm TWA; 1900 mg/m3 TWA
Water	none listed	none listed	none listed

OSHA Vacated PELs: Ethyl alcohol: 1000 ppm TWA; 1900 mg/m3 TWA Water: No OSHA Vacated PELs are listed for this chemical.
Personal Protective Equipment
Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
Skin: Wear appropriate protective gloves to prevent skin exposure.
Clothing: Wear appropriate protective clothing to prevent skin exposure.
Respirators: A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant a respirator's use.

Section 9 - Physical and Chemical Properties

Section 9 - Physical and Chemical Properties

Physical State: Clear liquid

Appearance: colorless

Odor: Mild, rather pleasant, like wine or whis

pH: Not available.

Vapor Pressure: 59.3 mm Hg @ 20 deg C

Vapor Density: 1.59

Evaporation Rate: Not available.

Viscosity: 1.200 cP @ 20 deg C

Boiling Point: 78 deg C

Freezing/Melting Point: -114.1 deg C

Decomposition Temperature: Not available.

Solubility: Miscible.

Specific Gravity/Density: 0.790 @ 20°C

Molecular Formula: C2H5OH

Molecular Weight: 46.0414

Section 10 - Stability and Reactivity

Chemical Stability: Stable under normal temperatures and pressures.

Conditions to Avoid: Incompatible materials, ignition sources, excess heat, oxidizers.

Incompatibilities with Other Materials: Strong oxidizing agents, acids, alkali metals, ammonia, hydrazine, peroxides, sodium, acid anhydrides, calcium hypochlorite, chromyl chloride, nitrosyl perchlorate, bromine pentafluoride, perchloric acid, silver nitrate, mercuric nitrate, potassium-tert-butoxide, magnesium perchlorate, acid chlorides, platinum, uranium hexafluoride, silver oxide, iodine heptafluoride, acetyl bromide, disulfuryl difluoride, tetrachlorosilane + water, acetyl chloride, permanganic acid, ruthenium (VIII) oxide, uranyl perchlorate, potassium dioxide.

Hazardous Decomposition Products: Carbon monoxide, irritating and toxic fumes and gases, carbon dioxide.

Hazardous Polymerization: Will not occur.

Section 11 - Toxicological Information

RTECS#:

CAS# 64-17-5: KQ6300000

CAS# 7732-18-5: ZC0110000

LD50/LC50:

CAS# 64-17-5:

Draize test, rabbit, eye: 500 mg Severe;

Draize test, rabbit, eye: 500 mg/24H Mild;

Draize test, rabbit, skin: 20 mg/24H Moderate;

Inhalation, mouse: LC50 = 39 gm/m3/4H;

Inhalation, rat: LC50 = 20000 ppm/10H;

Oral, mouse: LD50 = 3450 mg/kg;

Oral, rabbit: LD50 = 6300 mg/kg;

Oral, rat: LD50 = 9000 mg/kg;

Oral, rat: LD50 = 7060 mg/kg;

CAS# 7732-18-5:

Oral, rat: LD50 = >90 mL/kg;

Carcinogenicity:

CAS# 64-17-5:

ACGIH: A4 - Not Classifiable as a Human Carcinogen CAS# 7732-18-5: Not listed by ACGIH, IARC, NIOSH, NTP, or OSHA.

Epidemiology: Ethanol has been shown to produce fetotoxicity in the embryo o or fetus of laboratory animals. Prenatal exposure to ethanol is associated with a distinct pattern of co ngenital malformations that have collecetively been termed the "fetal alcohol syndrome".

Teratogenicity: Oral, Human - woman: TDLo = 41 gm/kg (female 41 week(s) after conception) Effects on Newborn - Apgar score (human only) and Effects on Newborn - other neonatal measures or effects and Effects on Newborn - drug dependence.

Reproductive Effects: Intrauterine, Human - woman: TDLo = 200 mg/kg (female 5 day(s) pre-mating) Fertility - female fertility index (e.g. # females pregnant per # sperm positive females; # females pregnant per # females mated).

Neurotoxicity: No information available.

Mutagenicity: DNA Inhibition: Human, Lymphocyte = 220 mmol/L.; Cytogenetic Analysis: Human, Lymphocyte = 1160

gm/L.; Cytogenetic Analysis: Human, Fibroblast = 12000 ppm.; Cytogenetic Analysis: Human, Leukocyte = 1 pph/72H (Continuous).; Sister Chromatid Exchange: Human, Lymphocyte = 500 ppm/72H (Continuous).
Other Studies: Standard Draize Test(Skin, rabbit) = 20 mg/24H (Moderate) Standard Draize Test: Administration into the eye (rabbit) = 500 mg (Severe).

Section 12 - Ecological Information

Ecotoxicity: Fish: Rainbow trout: LC50 = 12900-15300 mg/L; 96 Hr; Flow-through @ 24-24.3°C Rainbow trout: LC50 = 11200 mg/L; 24 Hr; Fingerling (Unspecified) ria: Phytobacterium phosphoreum: EC50 = 34900 mg/L; 5-30 min; Microtox test When spilled on land it is apt to volatilize, biodegrade, and leach into the ground water, but no data on the rates of these processes could be found. Its fate in ground water is unknown. When released into water it will volatilize and probably biodegrade. It would not be expected to adsorb to sediment or bioconcentrate in fish.
Environmental: When released to the atmosphere it will photodegrade in hours (polluted urban atmosphere) to an estimated range of 4 to 6 days in less polluted areas. Rainout should be significant.
Physical: No information available.
Other: No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series: None listed.

Section 14 - Transport Information

	US DOT	IATA	RID/ADR	IMO	Canada TDG
Shipping Name:	ETHANOL				No information available.
Hazard Class:	3				
UN Number:	UN1170				
Packing Group:	II				

Section 15 - Regulatory Information

US FEDERAL

TSCA
CAS# 64-17-5 is listed on the TSCA inventory.
CAS# 7732-18-5 is listed on the TSCA inventory.
Health & Safety Reporting List
None of the chemicals are on the Health & Safety Reporting List.
Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.
Section 12b
None of the chemicals are listed under TSCA Section 12b.
TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.
SARA

CERCLA Hazardous Substances and corresponding RQs
None of the chemicals in this material have an RQ.
SARA Section 302 Extremely Hazardous Substances
None of the chemicals in this product have a TPQ.
SARA Codes
CAS # 64-17-5: acute, chronic, flammable.
Section 313
No chemicals are reportable under Section 313.
Clean Air Act:
This material does not contain any hazardous air pollutants. This material does not contain any Class 1 Ozone depletors. This material does not contain any Class 2 Ozone depletors.
Clean Water Act:

Clean Water Act:
None of the chemicals in this product are listed as Hazardous Substances under the CWA. None of the chemicals in this product are listed as Priority Pollutants under the CWA. None of the chemicals in this product are listed as Toxic Pollutants under the CWA.
OSHA:
None of the chemicals in this product are considered highly hazardous by OSHA.
STATE
CAS# 64-17-5 can be found on the following state right to know lists: California, New Jersey, Pennsylvania, Minnesota, Massachusetts.
CAS# 7732-18-5 is not present on state lists from CA, PA, MN, MA, FL, or NJ.
WARNING: This product contains Ethyl alcohol, a chemical known to the state of California to cause birth defects or other reproductive harm. California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations

European Labeling in Accordance with EC Directives
Hazard Symbols:
F
Risk Phrases:
R 11 Highly flammable.

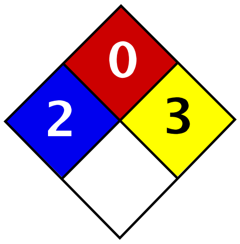
Safety Phrases:
S 16 Keep away from sources of ignition - No smoking.
S 33 Take precautionary measures against static discharges.
S 7 Keep container tightly closed.
S 9 Keep container in a well-ventilated place.

WGK (Water Danger/Protection)
CAS# 64-17-5: 0
CAS# 7732-18-5: No information available.
Canada - DSL/NDSL
CAS# 64-17-5 is listed on Canada's DSL List.
CAS# 7732-18-5 is listed on Canada's DSL List.
Canada - WHMIS
This product has a WHMIS classification of B2, D2A, D2B.
Canadian Ingredient Disclosure List
CAS# 64-17-5 is listed on the Canadian Ingredient Disclosure List.
Exposure Limits
CAS# 64-17-5: OEL-AUSTRALIA:TWA 1000 ppm (1900 mg/m3) OEL-BELGIUM:T
WA 1000 ppm (1880 mg/m3) OEL-CZECHOSLOVAKIA:TWA 1000 mg/m3;STEL 5000
mg/m3 OEL-DENMARK:TWA 1000 ppm (1900 mg/m3) OEL-FINLAND:TWA 1000 ppm
(1900 mg/m3);STEL 1250 ppm (2400 mg/m3) OEL-FRANCE:TWA 1000 ppm (190
0 mg/m3);STEL 5000 pp OEL-GERMANY:TWA 1000 ppm (1900 mg/m3) OEL-HUNG
ARY:TWA 1000 mg/m3;STEL 3000 mg/m3 OEL-THE NETHERLANDS:TWA 1000 ppm (
1900 mg/m3) OEL-THE PHILIPPINES:TWA 1000 ppm (1900 mg/m3) OEL-POLAND
:TWA 1000 mg/m3 OEL-RUSSIA:STEL 1000 mg/m3 OEL-SWEDEN:TWA 1000 ppm (
1900 mg/m3) OEL-SWITZERLAND:TWA 1000 ppm (1900 mg/m3) OEL-THAILAND:T
WA 1000 ppm (1900 mg/m3) OEL-TURKEY:TWA 1000 ppm (1900 mg/m3) OEL-UN
ITED KINGDOM:TWA 1000 ppm (1900 mg/m3) JAN9 OEL IN BULGARIA, COLOMBIA
, JORDAN, KOREA check ACGIH TLV OEL IN NEW ZEALAND, SINGAPORE, VIETNA
M check ACGI TLV

Section 16 - Additional Information

MSDS Creation Date: 4/17/2001
Revision #1 Date: 4/17/2001

ScienceLab.com
Chemicals & Laboratory Equipment



Health	2
Fire	0
Reactivity	0
Personal Protection	E

Material Safety Data Sheet

Ferrous sulfate heptahydrate MSDS

Section 1: Chemical Product and Company Identification

Product Name: Ferrous sulfate heptahydrate

Catalog Codes: SLF2029, SLF1228

CAS#: 7782-63-0

RTECS: OD5525000

TSCA: TSCA 8(b) inventory: No products were found.

CI#: Not available.

Synonym:

Chemical Name: Ferric Sulfate Heptahydrate

Chemical Formula: FeSO4.7H2O

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Ferrous sulfate heptahydrate	7782-63-0	100

Toxicological Data on Ingredients: Ferrous sulfate heptahydrate: ORAL (LD50): Acute: 1520 mg/kg [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects: Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available.
MUTAGENIC EFFECTS: Mutagenic for bacteria and/or yeast.
TERATOGENIC EFFECTS: Not available.
DEVELOPMENTAL TOXICITY: Not available.
The substance is toxic to liver.
The substance may be toxic to kidneys, cardiovascular system, central nervous system (CNS).
Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:

Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available.
Risks of explosion of the product in presence of static discharge: Not available.
Explosive in presence of heat.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system. Be careful that the product is not

present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Do not ingest. Do not breathe dust. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, alkalis.

Storage:
Hygroscopic. Air Sensitive. Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 24°C (75.2°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 1 CEIL: 2
Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid.

Odor: Not available.

Taste: Not available.

Molecular Weight: 278.01 g/mole

Color: Blue to blue-green. (Light.)

pH (1% soln/water): Not available.

Boiling Point: Not available.

Melting Point: Not available.

Critical Temperature: Not available.

Specific Gravity: 1.898 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility: Soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatibles

Incompatibility with various substances:
Reactive with oxidizing agents, alkalis.
Slightly reactive to reactive with moisture.

Corrosivity: Not available.

Special Remarks on Reactivity:
Hygroscopic. Oxidizes when in contact with mositure to form ferric sulfate.
Air Sensitive
Incompatible with alkalies, soluble carbonates, Au and Ag salts, Pb acetate, lime water, KI, K, and Na tartrate, Na Borate, tannin, vegetable astringent infusions and decoctions.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals: Acute oral toxicity (LD50): 1520 mg/kg [Mouse].

Chronic Effects on Humans:
MUTAGENIC EFFECTS: Mutagenic for bacteria and/or yeast.
Causes damage to the following organs: liver.
May cause damage to the following organs: kidneys, cardiovascular system, central nervous system (CNS).

Other Toxic Effects on Humans: Hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals:
Lowest Published Lethal Dose
LDL [Rat] - Route: Oral; Dose: 1389 mg/kg

Special Remarks on Chronic Effects on Humans:
May affect genetic material (mutagenic).
It is excreted in maternal milk in animal.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects:

Skin: May cause skin irritation.
Eyes: May cause eye irritation.
Inhalation: May cause respiratory tract irritation.
Ingestion: Harmful if swallowed. May cause gastrointestinal tract distrubances and irritation with nausea, vomiting, colic, constipation, diarrhea, black stool. May also affect behavior/Central Nervous System (somnolence -general depressed activity), respiration, cardiovascular system, liver, kidneys (pink urine discoloration).
Chronic Potential Health Effects: Repeated exposure via ingestion may increase iron levels in the liver, and spleen. Damage may occur to spleen and liver.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations:
Connecticut carcinogen reporting list.: Ferrous sulfate heptahydrate
Illinois toxic substances disclosure to employee act: Ferrous sulfate heptahydrate
New York release reporting list: Ferrous sulfate heptahydrate
Pennsylvania RTK: Ferrous sulfate heptahydrate
Massachusetts RTK: Ferrous sulfate heptahydrate
Massachusetts spill list: Ferrous sulfate heptahydrate
New Jersey spill list: Ferrous sulfate heptahydrate
Louisiana spill reporting: Ferrous sulfate heptahydrate
CERCLA: Hazardous substances.: Ferrous sulfate heptahydrate: 1000 lbs. (453.6 kg)

Other Regulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):

R36/38- Irritating to eyes and skin.
S2- Keep out of the reach of children.
S46- If swallowed, seek medical advice immediately and show this container or label.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 0

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 0

Reactivity: 3

Specific hazard:

Protective Equipment:
Gloves.
Lab coat.
Dust respirator. Be sure to use an approved/certified respirator or equivalent.
Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/09/2005 05:33 PM

Last Updated: 10/09/2005 05:33 PM

WILCLEAR
MSDS REPORT (1)

Status: Current
Status Date; 08/08/2003
Product Name: WILCLEAR® SODIUM LACTATE 60% SOLUTION, U.S.P.

Current Company Information:

JRW Bioremediation, LLC
14321 W. 96TH TERRACE
LENEXA, KS 66215.
Fax: 913-438-5554 Emergency: 913-438-5544

MSDS Prepared: 12/07/1994
MSDS Revised: 08/08/2003

Formula: CH3-CHOH-COONa
Keyword: ORGANIC ACID SALT
Stock Item(s): S-110-2

****

Physical/Chemical Characteristics
Boiling Point: 105 ˚C
Specific Gravity: 1.323 H_20=1 @ 20˚C
Vapor Density: Air=1 NA
Evaporation Rate: NA
Melt/Freeze Point: NA
pH: 6.5-7.5
% Volatile: NA
Vapor Pressure: NA
Pour Point: NA
Viscosity: 100cP @ 20˚C
Molecular weight: 112.07
Solubility In Water: SOLUBLE
Appearance/Odor: CLEAR AND COLORLESS LIQUID, ODORLESS
Physical State: Liquid

****

FIRE AND EXPLOSION DATA:

Closed Cup Flash Pt.: NA
Open cup Flash Point: NA
Auto Ignition: NA
Fire Point: NA
LEL/LFL: NA
UEL/UFL: NA

****

DOT INFORMATION:

DOT hazard class: NA
Label: NA
Proper shipping Name: WilClear® SODIUM LACTATE 60%

****

COMPOSITION/INFORMATION ON INGREDIENTS

Component Name: SODIUM LACTATE
Product: Yes Percent: 60
CAS No.: 72-17-3
Exposure Limits
Limit Note: OSHA PPM: NA \ ACGIH PPM: NA \ OSHA STEL PPM: NA

Component Name: WATER
Percent: 40
CAS No.: 7732-18-5
Exposure Limits
Limit Note: OSHA PPM: NA \ ACGIH PPM: NA \ OSHA STEL PPM: NA

****

HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

Hazardous Components (optional) Specific Chemical Identity: Common Name(s)	OSHA PEL	ACGIH TLV	Other Limits	% Recommended
None				

****

FIRE AND EXPLOSION HAZARD DATA

Flash Point: NA Flammable Limits: NA LEL: NA UEL: NA
Extinguishing Media: Water, Carbon Dioxide or Dry chemical.
Special Fire Fighting procedures: Wear self-contained breathing apparatus.
Unusual Fire and Explosion Hazards: Fire may produce irritating or toxic fumes.

****

REACTIVITY DATA

Stability: Stable. Conditions to Avoid: NA
Incompatibility (Materials to Avoid): NA
Hazardous Decomposition or Byproducts; NA
Hazardous Polymerization: Will not occur.

****

HEALTH HAZARD DATA

Route(s) of Entry: Inhalation? Yes Skin? NA Ingestion? Yes
Health Hazards (Acute and chronic): No specific data. Low order of toxicity. The chemical, physical, and toxicological properties have not been thoroughly investigated.
Carcinogenicity: NTP? NA IARC Monographs? NA OSHA Regulated? NA TSCA Registered? Yes
Signs and symptoms of Exposure: NA
Medical Conditions Generally Aggravated by Exposure: NA

Emergency and First Aid Procedures:
SKIN: In case of contact with skin, immediately wash with soap and water while removing contaminated clothing.
EYE: In case of contact with eyes, immediately flush eyes with water for at least 15 minutes, lifting eyelids during flushing to facilitate irrigation. Get medical attention if necessary.
INHALATION: If inhaled, remove person from contaminated atmosphere to fresh air
INGESTION: If swallowed, get medical attention.

* * *

PRECAUTIONS FOR SAFE HANDLING AND USE

Steps to Be Taken in Case Material is Released or Spilled: Contain spill and place material in drum for disposal. Dispose of according to all local, state and federal regulations at an approved waste treatment facility.
Precautions to Be Taken in Handling and Storing: Store in cool, dry area to preserve product quality.
Other Precautions: NA

* * *

CONTROL MEASURES/PERSONAL PROTECTIVE EQUIPMENT

Respiratory Protection (Specify Type): None.
Ventilation: General Ventilation: Is recommended.
Local Exhaust: Is recommended.
Other: NA
Protective Gloves: Are recommended.
Eye Protection: Is recommended.
Other Protective Clothing or Equipment: NA
Work/Hygienic Practices: NA

END OF REPORT.

MSDS Number: **P5587** * * * * * *Effective Date:* ***08/20/08*** * * * * * *Supercedes:* ***10/19/05***

MSDS Material Safety Data Sheet

From: Mallinckrodt Baker, Inc.
222 Red School Lane
Phillipsburg, NJ 08865

Mallinckrodt CHEMICALS J.T.Baker

24 Hour Emergency Telephone: 908-859-2151
CHEMTREC: 1-800-424-9300

National Response in Canada
CANUTEC: 613-996-6666

Outside U.S. and Canada
Chemtrec: 703-527-3887

NOTE: CHEMTREC, CANUTEC and National Response Center emergency numbers to be used only in the event of chemical emergencies involving a spill, leak, fire, exposure or accident involving chemicals.

All non-emergency questions should be directed to Customer Service (1-800-582-2537) for assistance.

POTASSIUM BROMIDE

1. Product Identification

Synonyms: Bromide salt of potassium
CAS No.: 7758-02-3
Molecular Weight: 119.00
Chemical Formula: KBr
Product Codes:
J.T. Baker: 2961, 2998
Mallinckrodt: 0500, 0505

2. Composition/Information on Ingredients

Ingredient	CAS No	Percent	Hazardous
Potassium Bromide	7758-02-3	100%	Yes

3. Hazards Identification

Emergency Overview

WARNING! HARMFUL IF SWALLOWED OR INHALED. AFFECTS CENTRAL NERVOUS SYSTEM, BRAIN AND EYES. MAY CAUSE IRRITATION TO SKIN, EYES, AND RESPIRATORY TRACT.

SAF-T-DATA$^{\textbf{(tm)}}$ Ratings (Provided here for your convenience)

Health Rating: 2 - Moderate (Life)
Flammability Rating: 0 - None
Reactivity Rating: 1 - Slight
Contact Rating: 2 - Moderate
Lab Protective Equip: GOGGLES; LAB COAT; VENT HOOD; PROPER GLOVES
Storage Color Code: Green (General Storage)

Potential Health Effects

Inhalation:
Dust may cause irritation to the respiratory tract. Symptoms may include coughing, sore throat, and shortness of breath.
Ingestion:
May cause nausea, vomiting and abdominal pain. Ingestions are usually promptly rejected by vomiting, but sufficient absorption may occur to produce central nervous system, eye and brain effects. Symptoms may include skin rash, blurred vision and other eye effects, drowsiness, irritability, dizziness, mania, hallucinations, and coma.
Skin Contact:
Dry material may cause mild irritation. Solutions may cause irritation, redness, pain, and skin burns.
Eye Contact:
May cause irritation, redness and pain.
Chronic Exposure:
Repeated or prolonged exposure by any route may cause skin rashes (bromaderma). Repeated ingestion of small amounts may cause central nervous system depression, including depression, ataxia, psychoses, memory loss, irritability, and headache.
Aggravation of Pre-existing Conditions:
Persons suffering from debilitation, depression, alcoholism, neurological or psychological disorders may be more susceptible to the effects of this compound.

4. First Aid Measures

Inhalation:
Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call a physician.
Ingestion:
Induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. Call a physician.
Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes. Remove contaminated clothing and shoes. Wash clothing before reuse. Call a physician.
Eye Contact:
Wash eyes with plenty of water for at least 15 minutes. Call a physician.

5. Fire Fighting Measures

Fire:
Not considered to be a fire hazard.
Explosion:
Not considered to be an explosion hazard.
Fire Extinguishing Media:
Use any means suitable for extinguishing surrounding fire.
Special Information:
In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode.

6. Accidental Release Measures

Ventilate area of leak or spill. Wear appropriate personal protective equipment as specified in Section 8. Spills: Sweep up and containerize for reclamation or disposal. Vacuuming or wet sweeping may be used to avoid dust dispersal.

---

7. Handling and Storage

Keep in a tightly closed container, stored in a cool, dry, ventilated area. Protect against physical damage. Separate from incompatibilities. Containers of this material may be hazardous when empty since they retain product residues (dust, solids); observe all warnings and precautions listed for the product.

---

8. Exposure Controls/Personal Protection

Airborne Exposure Limits:
None established.
Ventilation System:
A system of local and/or general exhaust is recommended to keep employee exposures as low as possible. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, *Industrial Ventilation, A Manual of Recommended Practices*, most recent edition, for details.
Personal Respirators (NIOSH Approved):
For conditions of use where exposure to dust or mist is apparent and engineering controls are not feasible, a particulate respirator (NIOSH type N95 or better filters) may be worn. If oil particles (e.g. lubricants, cutting fluids, glycerine, etc.) are present, use a NIOSH type R or P filter. For emergencies or instances where the exposure levels are not known, use a full-face positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.
Skin Protection:
Wear protective gloves and clean body-covering clothing.
Eye Protection:
Use chemical safety goggles. Maintain eye wash fountain and quick-drench facilities in work area.

---

9. Physical and Chemical Properties

Appearance:
White crystals.
Odor:
Odorless.
Solubility:
70g/100g water @ 25C (77F).
Specific Gravity:
2.75 @ 25C
pH:
Aqueous solution is neutral.
% Volatiles by volume @ 21C (70F):
0
Boiling Point:
1435C (2615F)
Melting Point:
730C (1346F)
Vapor Density (Air=1):
No information found.
Vapor Pressure (mm Hg):
No information found.
Evaporation Rate (BuAc=1):
No information found.

---

10. Stability and Reactivity

Stability:
Stable under ordinary conditions of use and storage.
Hazardous Decomposition Products:
Oxides of the contained metal and halogen, possibly also free, or ionic halogen.
Hazardous Polymerization:
Will not occur.
Incompatibilities:
For Potassium Bromide: Strong oxidizers, acids, and bromine trifluoride.
Conditions to Avoid:
Incompatibles.

---

11. Toxicological Information

Potassium bromide: oral rat LD50: 3070 mg/kg; investigated as a mutagen.

--------\Cancer Lists\--

	---NTP Carcinogen---		
Ingredient	Known	Anticipated	IARC Category
Potassium Bromide (7758-02-3)	No	No	None

---

12. Ecological Information

Environmental Fate:
No information found.
Environmental Toxicity:
No information found.

---

13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste disposal facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

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14. Transport Information

Not regulated.

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15. Regulatory Information

--------\Chemical Inventory Status - Part 1\---------------------------------

Ingredient	TSCA	EC	Japan	Australia
Potassium Bromide (7758-02-3)	Yes	Yes	Yes	Yes

--------\Chemical Inventory Status - Part 2\---------------------------------

		--Canada--		
Ingredient	Korea	DSL	NDSL	Phil.

Potassium Bromide (7758-02-3)	Yes	Yes	No	Yes

--------\Federal, State & International Regulations - Part 1\----------------

	-SARA 302-		------SARA 313------	
Ingredient	RQ	TPQ	List	Chemical Catg.
Potassium Bromide (7758-02-3)	No	No	No	No

--------\Federal, State & International Regulations - Part 2\----------------

		-RCRA-	-TSCA-
Ingredient	CERCLA	261.33	8(d)
Potassium Bromide (7758-02-3)	No	No	No

Chemical Weapons Convention: No   TSCA 12(b): No   CDTA: No
SARA 311/312: Acute: Yes   Chronic: Yes Fire: No Pressure: No
Reactivity: No   (Pure / Solid)

Australian Hazchem Code: None allocated.
Poison Schedule: None allocated.
WHMIS:
This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

---

16. Other Information

NFPA Ratings: Health: **2** Flammability: **0** Reactivity: **0**
Label Hazard Warning:
WARNING! HARMFUL IF SWALLOWED OR INHALED. AFFECTS CENTRAL NERVOUS SYSTEM, BRAIN AND EYES. MAY CAUSE IRRITATION TO SKIN, EYES, AND RESPIRATORY TRACT.
Label Precautions:
Avoid breathing dust.
Keep container closed.
Use with adequate ventilation.
Avoid contact with eyes, skin and clothing.
Wash thoroughly after handling.
Label First Aid:
If swallowed, induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. In case of contact, immediately flush eyes or skin with plenty of water for at least 15 minutes. In all cases call a physician.
Product Use:
Laboratory Reagent.
Revision Information:
No Changes.
Disclaimer:
****
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INFORMATION.

****

Prepared by: Environmental Health & Safety
Phone Number: (314) 654-1600 (U.S.A.)

Univar USA Inc.
17425 NE Union Hill Road
Redmond, WA 98052
(425) 889-3400

For Emergency Assistance involving chemicals call - CHEMTREC (800) 424-9300

==

The Version Date and Number for this MSDS is : 08/18/2006 - #006

PRODUCT NAME: SODIUM SULFATE ANHYDROUS

MSDS NUMBER: MZS5018

DATE ISSUED: 6/12/2005

SUPERSEDES: 6/30/2003

ISSUED BY: 008614

MSDS MATERIAL SAFETY DATA SHEET CHEMTREC: 800-424-9300 (USA)

===

SODIUM SULFATE ANHYDROUS

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1. PRODUCT IDENTIFICATION

SYNONYMS: DISODIUM SULFATE; SODIUM SULFATE ANHYDROUS; SULFURIC ACID, DISODIUM SALT; SODIUM SULFATE; SPEED-DRY
CAS NO: 7757-82-6
MOLECULAR WEIGHT: 142.04
CHEMICAL FORMULA: NA2 SO4

Distributed by:
Univar USA Inc.
17425 NE Union Hill Road
Redmond, WA 98052
425-889-3400

2. COMPOSITION/INFORMATION ON INGREDIENTS

INGREDIENT	CAS NO	PERCENT	HAZARDOUS
SODIUM SULFATE	7757-82-6	90 - 100%	YES

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

AS PART OF GOOD INDUSTRIAL AND PERSONAL HYGIENE AND SAFETY PROCEDURE, AVOID ALL UNNECESSARY EXPOSURE TO THE CHEMICAL SUBSTANCE AND ENSURE PROMPT REMOVAL FROM SKIN, EYES AND CLOTHING.

POTENTIAL HEALTH EFFECTS

INHALATION:
NOT EXPECTED TO BE A HEALTH HAZARD.

INGESTION:
MILDLY TOXIC BY INGESTION. SLOWLY ABSORBED FROM THE ALIMENTARY TRACT. BECAUSE OF OSMOTIC ACTIVITY, IT WILL DRAW WATER INTO THE LUMEN OF THE BOWEL AND MAY CAUSE PURGING, FLUID LOSS, BLOOD IN STOOLS, FALL OF BLOOD PRESSURE, AND HIGH SODIUM LEVELS IN THE BLOOD.

SKIN CONTACT:
NO ADVERSE EFFECTS EXPECTED.

EYE CONTACT:
NO ADVERSE EFFECTS EXPECTED BUT DUST MAY CAUSE MECHANICAL IRRITATION.

CHRONIC EXPOSURE:
NO INFORMATION FOUND.

AGGRAVATION OF PRE-EXISTING CONDITIONS:
NO INFORMATION FOUND.

4. FIRST AID MEASURES

INHALATION:
NOT EXPECTED TO REQUIRE FIRST AID MEASURES.

INGESTION:
GIVE SEVERAL GLASSES OF WATER TO DRINK TO DILUTE. IF LARGE AMOUNTS WERE SWALLOWED, GET MEDICAL ADVICE.

SKIN CONTACT:
WASH EXPOSED AREA WITH SOAP AND WATER. GET MEDICAL ADVICE IF IRRITATION DEVELOPS.

EYE CONTACT:
WASH THOROUGHLY WITH RUNNING WATER. GET MEDICAL ADVICE IF IRRITATION DEVELOPS.

==

5. FIRE FIGHTING MEASURES

FIRE:
NOT CONSIDERED TO BE A FIRE HAZARD.

EXPLOSION:
NOT CONSIDERED TO BE AN EXPLOSION HAZARD, BUT VIOLENT EXPLOSIONS OCCUR WHEN POTASSIUM SULFATE AND SODIUM SULFATE ARE MELTED WITH ALUMINUM.

FIRE EXTINGUISHING MEDIA:
USE ANY MEANS SUITABLE FOR EXTINGUISHING SURROUNDING FIRE.

SPECIAL INFORMATION:
USE PROTECTIVE CLOTHING AND BREATHING EQUIPMENT APPROPRIATE FOR THE SURROUNDING FIRE.

==

6. ACCIDENTAL RELEASE MEASURES

VENTILATE AREA OF LEAK OR SPILL. WEAR APPROPRIATE PERSONAL PROTECTIVE EQUIPMENT AS SPECIFIED IN SECTION 8. SPILLS: SWEEP UP AND CONTAINERIZE FOR RECLAMATION OR DISPOSAL. VACUUMING OR WET SWEEPING MAY BE USED TO AVOID DUST DISPERSAL.

==

7. HANDLING AND STORAGE

KEEP IN A TIGHTLY CLOSED CONTAINER, STORED IN A COOL, DRY, VENTILATED AREA. PROTECT AGAINST PHYSICAL DAMAGE. ISOLATE FROM INCOMPATIBLE SUBSTANCES. CONTAINERS OF THIS MATERIAL MAY BE HAZARDOUS WHEN EMPTY SINCE THEY RETAIN PRODUCT RESIDUES (DUST, SOLIDS); OBSERVE ALL WARNINGS AND PRECAUTIONS LISTED FOR THE PRODUCT.

==

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

AIRBORNE EXPOSURE LIMITS:

NONE ESTABLISHED.

VENTILATION SYSTEM:
IN GENERAL, DILUTION VENTILATION IS A SATISFACTORY HEALTH HAZARD CONTROL FOR THIS SUBSTANCE. HOWEVER, IF CONDITIONS OF USE CREATE DISCOMFORT TO THE WORKER, A LOCAL EXHAUST SYSTEM SHOULD BE CONSIDERED.

PERSONAL RESPIRATORS (NIOSH APPROVED):
FOR CONDITIONS OF USE WHERE EXPOSURE TO DUST OR MIST IS APPARENT AND ENGINEERING CONTROLS ARE NOT FEASIBLE, A PARTICULATE RESPIRATOR (NIOSH TYPE N95 OR BETTER FILTERS) MAY BE WORN. IF OIL PARTICLES (E.G. LUBRICANTS, CUTTING FLUIDS, GLYCERINE, ETC.) ARE PRESENT, USE A NIOSH TYPE R OR P FILTER. FOR EMERGENCIES OR INSTANCES WHERE THE EXPOSURE LEVELS ARE NOT KNOWN, USE A FULL-FACE POSITIVE-PRESSURE, AIR-SUPPLIED RESPIRATOR. WARNING: AIR-PURIFYING RESPIRATORS DO NOT PROTECT WORKERS IN OXYGEN-DEFICIENT ATMOSPHERES.

SKIN PROTECTION:
WEAR PROTECTIVE GLOVES AND CLEAN BODY-COVERING CLOTHING.

EYE PROTECTION:
USE CHEMICAL SAFETY GOGGLES. MAINTAIN EYE WASH FOUNTAIN AND QUICK-DRENCH FACILITIES IN WORK AREA.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE:
FINE WHITE CRYSTALLINE GRANULES.

BOILING POINT:
NO INFORMATION FOUND.

ODOR:
ODORLESS.

MELTING POINT:
844C (1551F)

SOLUBILITY:
SOLUBLE IN APPROX. 3.6 PARTS WATER, 1 IN 2 PARTS MAXIMUM @ 33C (91F).

VAPOR DENSITY (AIR=1):
NO INFORMATION FOUND.

DENSITY:
2.68

VAPOR PRESSURE (MM HG):
NO INFORMATION FOUND.

PH:
NO INFORMATION FOUND.

EVAPORATION RATE (BUAC=1):
NO INFORMATION FOUND.

% VOLATILES BY VOLUME @ 21C (70F):
0

10. STABILITY AND REACTIVITY

STABILITY:
STABLE IN TIGHTLY CLOSED CONTAINERS UNDER NORMAL CONDITIONS OF STORAGE.

HAZARDOUS DECOMPOSITION PRODUCTS:
OXIDES OF SULFUR AND SODIUM MAY FORM WHEN HEATED TO DECOMPOSITION.

HAZARDOUS POLYMERIZATION:
WILL NOT OCCUR.

INCOMPATIBILITIES:
IN COMBINATION WITH SODIUM SULFATE, ALUMINUM AND MAGNESIUM WILL EXPLODE @ 800C (1472F); STRONG MINERAL ACIDS AND BASES.

CONDITIONS TO AVOID:
AIR, MOISTURE, AND INCOMPATIBLES.

==

11. TOXICOLOGICAL INFORMATION

NO LD50/LC50 INFORMATION FOUND RELATING TO NORMAL ROUTES OF OCCUPATIONAL EXPOSURE. INVESTIGATED AS A TUMORIGEN, MUTAGEN, REPRODUCTIVE EFFECTOR.

--------/CANCER LISTS/--

	---NTP CARCINOGEN---		
INGREDIENT	KNOWN	ANTICIPATED	IARC CATEGORY
SODIUM SULFATE (7757-82-6)	NO	NO	NONE

==

12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE:
WHEN RELEASED INTO THE SOIL, THIS MATERIAL IS EXPECTED TO LEACH INTO GROUNDWATER. THIS MATERIAL IS NOT EXPECTED TO SIGNIFICANTLY BIOACCUMULATE.

ENVIRONMENTAL TOXICITY:
THIS MATERIAL IS NOT EXPECTED TO BE TOXIC TO AQUATIC LIFE. THE LC50/96-HOUR VALUES FOR FISH ARE OVER 100 MG/L. THE EC50/48-HOUR VALUES FOR DAPHNIA ARE OVER 100 MG/L.

==

13. DISPOSAL CONSIDERATIONS

WHATEVER CANNOT BE SAVED FOR RECOVERY OR RECYCLING SHOULD BE MANAGED IN AN APPROPRIATE AND APPROVED WASTE DISPOSAL FACILITY. PROCESSING, USE OR CONTAMINATION OF THIS PRODUCT MAY CHANGE THE WASTE MANAGEMENT OPTIONS. STATE AND LOCAL DISPOSAL REGULATIONS MAY DIFFER FROM FEDERAL DISPOSAL

REGULATIONS.

DISPOSE OF CONTAINER AND UNUSED CONTENTS IN ACCORDANCE WITH FEDERAL, STATE AND LOCAL REQUIREMENTS.

14. TRANSPORT INFORMATION

NOT REGULATED.

15. REGULATORY INFORMATION

--------/CHEMICAL INVENTORY STATUS - PART 1/--------------------------------

INGREDIENT	TSCA	EC	JAPAN	AUSTRALIA
SODIUM SULFATE (7757-82-6)	YES	YES	YES	YES

--------/CHEMICAL INVENTORY STATUS - PART 2/--------------------------------

INGREDIENT	KOREA	--CANADA-- DSL	 NDSL	PHIL.
SODIUM SULFATE (7757-82-6)	YES	YES	NO	YES

-------/FEDERAL, STATE & INTERNATIONAL REGULATIONS - PART 1/---------------

	-SARA 302-		------SARA 313-----	
INGREDIENT	RQ	TPQ	LIST	CHEMICAL CATG
SODIUM SULFATE (7757-82-6)	NO	NO	NO	NO

--------/FEDERAL, STATE & INTERNATIONAL REGULATIONS - PART 2/--------------

		-RCRA-	-TSCA-
INGREDIENT	CERCLA	261.33	8(D)
SODIUM SULFATE (7757-82-6)	NO	NO	NO

CHEMICAL WEAPONS CONVENTION: NO TSCA 12(B): NO CDTA: NO
SARA 311/312: ACUTE: NO CHRONIC: NO FIRE: NO PRESSURE: NO
REACTIVITY: NO (PURE / SOLID)

AUSTRALIAN HAZCHEM CODE: NONE ALLOCATED.
POISON SCHEDULE: NONE ALLOCATED.

WHMIS: THIS MSDS HAS BEEN PREPARED ACCORDING TO THE HAZARD CRITERIA OF THE CONTROLLED PRODUCTS REGULATIONS (CPR) AND THE MSDS CONTAINS ALL OF THE INFORMATION REQUIRED BY THE CPR.

16. OTHER INFORMATION

NFPA RATINGS:
HEALTH: 1 FLAMMABILITY: 0 REACTIVITY: 0

For Additional Information:
Contact: MSDS Coordinator - Univar USA
During business hours, Pacific Time - (425) 889-3400

NOTICE
Univar USA expressly disclaims all express or implied warranties of merchantibility and fitness for a particular purpose with respect to the product or information provided herein, and shall under no circumstances be liable for incidental or consequential damages.

Do not use ingredient information and/or ingredient percentages in this MSDS as a product specification. For product specification information refer to a Product Specification Sheet and/or a Certificate of Analysis. These can be obtained from your local Univar USA Sales Office.

All information appearing herein is based upon data obtained from the manufacturer and/or recognized technical sources. While the information is believed to be accurate, Univar USA makes no representations as to its accuracy or sufficiency. Conditions of use are beyond Univar USA's control. Therefore, users are responsible to verify this data under their own operating conditions to determine whether the product is suitable for their particular purposes, and they assume all risks of their use, handling, and disposal of the product or from the publication or use of, or reliance upon, information contained herein. This information relates only to the product designated herein and does not relate to its use in combination with any other material or in any other process.

END OF MSDS

APPENDIX A-5

COLUMN STUDY ANALYTICAL RESULTS

APPENDIX A-5

COLUMN STUDY ANALYTICAL RESULTS

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

	COL1 - Port 1								COL 1 - Port 2							
Compound	**11/15/2006**	**11/21/2006**	**11/23/2006**	**12/2/2006**	**12/7/2006**	**12/9/2006**	**12/12/2006**	**12/14/2006**	**11/15/2006**	**11/21/2006**	**11/23/2006**	**12/2/2006**	**12/7/2006**	**12/9/2006**	**12/12/2006**	**12/14/2006**
Sulfate	346.200	390.590	251.830	4.710	13.220	4.520	5.120	4.840	382.430	392.320	331.350	4.730	18.090	4.500	5.010	7.320
Bromide	451.240	363.430	561.770	289.300	562.070	566.540	552.150	538.230	478.660	485.280	564.600	378.030	565.870	568.830	572.940	530.890
Chloride	451.240	363.430	561.770	289.300	562.070	566.540	552.120	538.230	478.660	485.280	564.400	378.030	565.870	568.830	572.940	530.890
Thiosulfate	0.000	0.000	0.514	2.946	0.000	0.000	0.000	0.000	0.000	0.000	0.454	4.250	0.000	0.000	0.000	0.000
Arsenate	0.730	0.140	0.101	0.003	0.159	0.055	0.222	0.207	0.171	0.015	0.151	0.009	0.178	0.015	0.296	0.208
Acetate	0.233	4.188	1.709	0.845	7.670	7.150	0.068	0.069	0.259	6.002	1.844	1.104	7.491	6.832	0.051	0.057

	COL 1 - Port 3								COL 1 - Port 4							
Compound	**11/15/2006**	**11/21/2006**	**11/23/2006**	**12/2/2006**	**12/7/2006**	**12/9/2006**	**12/12/2006**	**12/14/2006**	**11/15/2006**	**11/21/2006**	**11/23/2006**	**12/2/2006**	**12/7/2006**	**12/9/2006**	**12/12/2006**	**12/14/2006**
Sulfate	391.900	392.860	269.630	4.940	8.560	4.480	5.290	6.690	387.080	393.110	240.910	4.870	7.090	6.490	7.250	6.490
Bromide	497.510	402.760	565.740	192.420	565.490	569.910	556.000	533.240	493.710	360.100	566.400	229.540	566.530	573.330	556.570	539.910
Chloride	497.510	402.760	565.740	192.420	565.490	569.910	556.000	533.240	493.710	360.100	566.400	229.540	566.530	573.330	556.570	539.910
Thiosulfate	0.000	0.000	0.713	1.676	0.000	0.000	0.000	0.000	0.000	0.000	0.514	2.138	0.000	0.000	0.000	0.000
Arsenate	0.070	0.016	0.118	0.034	0.145	0.016	0.182	0.229	0.035	0.016	0.071	0.062	0.235	0.013	0.176	0.184
Acetate	0.229	4.567	1.791	0.768	7.084	7.256	0.035	0.048	0.292	4.329	1.651	1.154	6.622	6.982	0.036	0.061

	COL 1 - Port 5								COL 1 - Port 6							
Compound	**11/15/2006**	**11/21/2006**	**11/23/2006**	**12/2/2006**	**12/7/2006**	**12/9/2006**	**12/12/2006**	**12/14/2006**	**11/15/2006**	**11/21/2006**	**11/23/2006**	**12/2/2006**	**12/7/2006**	**12/9/2006**	**12/12/2006**	**12/14/2006**
Sulfate	401.190	388.780	231.550	5.020	24.350	4.560	5.050	5.030	439.180	392.460	246.900	4.890	15.480	4.540	5.450	9.780
Bromide	497.750	323.690	566.520	778.870	551.800	570.680	554.980	543.650	516.700	349.640	566.890	443.670	549.950	573.240	561.520	553.840
Chloride	497.750	323.690	566.520	778.870	551.800	570.680	554.980	543.650	516.700	349.640	566.890	443.670	549.950	573.240	561.520	553.840
Thiosulfate	0.000	0.000		12.277	0.000	0.000	0.000	0.000	0.000	0.000	0.650	7.558	0.000	0.000	0.000	0.000
Arsenate	0.022	0.018	0.118	0.029	0.178	0.146	0.166	0.173	0.015	0.001	0.176	0.077	0.175	0.018	0.192	0.170
Acetate	0.340	3.878	1.474	3.730	6.446	7.878	0.060	0.076	0.210	3.318	1.485	2.735	6.507	7.307	0.034	0.056

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 2

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)											
Column #	Time (mins.)	pH	Fluoride (ppm)	Formate (ppm)	Acetate (ppm)	Propionate (ppm)	Phosphate (ppm)	Thiosulfate (ppm)	Arsenate (ppm)	Sulfate (ppm)	Chloride (ppm)	Total Sulfate (g)	%As remaining	Operational Notes
Col 2	60	8.64	0.2114	--	--	0.0005	336.1206	--	0.140913	7.0574	603.6411	0.000070574	100.0	
Col 2	120	8.64	0.2186	0.0037	0.0027	--	300.8796	0.0171	0.218951	12.8417	539.0613	0.000198991	100.0	
Col 2	180	8.64	0.198	--	--	--	295.3017	0.0262	0.226315	14.016	520.7591	0.000339151	100.0	
Col 2	240	8.64	0.2179	--	0.0007	--	327.9158	0.5042	0.122438	1.4573	586.5031	0.000353724	100.0	
Col 2	300	8.64	0.2125	--	0.0008	--	323.7049	0.007	0.188319	6.6189	581.6449	0.000419913	100.0	
Col 2	360	8.64	0.218	--	--	--	337.4518	0.0089	0.196075	5.5832	610.682	0.000475745	100.0	
Col 2	420	8.64	0.2123	--	0.0013	--	327.2628	0.6291	0.118037	0.258	593.562	0.000478325	100.0	
Col 2	480	8.64	0.2126	0.001	--	--	314.4781	0.0283	0.209931	7.7506	572.4517	0.000555831	100.1	
Col 2	540	8.64	0.2116	--	--	--	311.4237	0.3244	0.207535	5.1944	571.8644	0.000607775	100.1	
Col 2	600	8.64	0.1828	0.0002	0.002	--	222.4213	0.3586	0.175161	7.7818	401.8953	0.000685593	100.1	
Col 2	660	8.64	0.2563	--	0.0007	--	301.1182	0.4737	0.201435	5.5177	554.2969	0.00074077	100.1	
Col 2	720	8.64	0.2396	--	--	--	312.5335	0.5592	0.196598	3.6689	572.2894	0.000777459	100.1	
Col 2	780	8.64	0.2347	--	0.0007	--	301.4707	0.3297	0.208537	4.502	551.154	0.000822479	100.1	
Col 2	840	8.64	0.2189	--	0.0008	--	295.23	0.488	0.21211	4.639	539.8769	0.000868869	100.1	
Col 2	900	8.64	0.2763	--	0.0009	--	295.8182	0.5352	0.173418	11.2825	538.3082	0.000981694	100.1	
Col 2	960	8.64	0.269	--	0.0006	--	291.2252	1.3483	0.252806	13.1557	528.3678	0.001113251	100.1	
Col 2	1020	8.64	0.2168	--	0.0007	--	295.1432	0.376	0.253155	13.4463	533.7355	0.001247714	100.1	
Col 2	1080	8.64	0.2087	0.0007	--	--	298.8781	0.6688	0.165793	12.7958	538.6943	0.001375672	100.1	
Col 2	1140	8.64	0.2093	--	0.0005	--	304.667	0.0382	0.162394	12.8382	547.9041	0.001504054	100.1	
Col 2	1200	8.64	0.2118	0.0003	0.0027	--	266.4635	0.0228	0.460472	21.965	469.1438	0.001723704	100.1	
Col 2	1260	8.64	0.22	--	0.0011	--	311.2089	1.611	0.245443	5.9719	556.113	0.001783423	100.1	
Col 2	1320	8.64	0.2041	--	0.0011	--	303.4378	0.8139	0.024052	5.7333	541.0622	0.001840756	100.1	
Col 2	1380	8.64	0.2071	--	0.0007	--	292.0655	1.5372	0.118342	10.1716	507.2247	0.001942472	100.1	
Col 2	1440	8.64	0.1135	0.0012	0.0007	--	193.5727	1.2442	0.132721	10.353	322.0613	0.002046002	100.2	
Col 2	1500	8.64	0.2718	0.0007	0.0046	--	261.7411	1.4308	0.219343	6.8508	424.814	0.00211451	100.2	
Col 2	1560	8.64	0.2572	0.0007	0.006	--	271.034	1.2753	0.209016	2.7859	433.2884	0.002142369	100.2	
Col 2	1620	8.64	0.2318	0.3108	--	0.0051	258.1171	1.9127	0.146534	4.462	398.0684	0.002186989	100.2	
Col 2	1680	8.64	0.2002	0.3419	--	0.0041	218.7988	1.3867	0.408055	19.7016	319.701	0.002384005	100.2	
Col 2	1740	8.67	0.2224	0.0039	0.0015	--	243.7901	0.0068	0.510406	18.1456	347.995	0.002565461	100.2	
Col 2	1800	8.67	0.1979	0.0006	--	--	242.8743	0.1296	0.299603	16.0301	331.6431	0.002725762	100.2	
Col 2	1860	8.67	0.2276	0.002	0.0012	--	233.4249	0.0074	0.215029	15.8732	309.1522	0.002884494	100.2	
Col 2	1920	8.67	0.2073	--	0.0011	--	237.9784	--	0.221522	15.4507	308.1212	0.003039001	100.2	
Col 2	1980	8.67	0.2283	0.0029	0.0018	--	223.7861	0.0098	0.388534	16.0801	279.3281	0.003199802	100.2	
Col 2	2040	8.67	0.2162	0.0035	0.0014	--	213.2935	0.3546	0.512323	21.371	261.5263	0.003413512	100.2	
Col 2	2100	8.67	0.2142	0.0019	0.0012	--	208.4605	0.0094	0.415157	19.9782	243.2424	0.003613294	100.2	
Col 2	2160	8.67	0.2503	0.0069	0.0033	--	196.738	0.0096	0.504698	23.4278	214.5569	0.003847572	100.2	

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 2

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)												
Column #	**Time (mins.)**	**pH**	**Fluoride (ppm)**	**Formate (ppm)**	**Acetate (ppm)**	**Propionate (ppm)**	**Phosphate (ppm)**	**Thiosulfate (ppm)**	**Arsenate (ppm)**	**Sulfate (ppm)**	**Chloride (ppm)**	**Total Sulfate (g)**	**%As remaining**	**Operational Notes**
Col 2	2220	8.67	0.2379	0.0034	0.0016	--	210.5825	0.0136	0.208581	17.5596	223.5909	0.004023168	100.2	
Col 2	2280	8.67	0.2237	0.0026	0.0016	--	202.7151	0.0149	0.190193	18.5258	202.0886	0.004208426	100.2	
Col 2	2340	8.67	0.2182	0.0026	0.0021	--	181.0825	--	0.225269	19.9792	169.4946	0.004408218	100.2	
Col 2	2400	8.67	0.2274	0.0009	0.0052	--	195.9366	0.0724	0.230497	18.3923	184.5351	0.004592141	100.2	
Col 2	2460	8.67	0.2181	0.0039	0.0025	--	141.7614	0.0611	0.286139	16.2363	123.9742	0.004754504	100.3	
Col 2	2520	8.67	0.224	0.0038	0.0031	--	142.8056	0.0136	0.298819	18.2165	112.3345	0.004936669	100.3	
Col 2	2580	8.67	0.2356	0.0033	0.0037	--	135.8709	0.0142	0.37067	20.8712	103.9202	0.005145381	100.3	
Col 2	2640	8.67	0.271	0.0053	0.0031	--	182.7566	0.022	0.46313	29.2384	124.3074	0.005437765	100.3	
Col 2	2700	8.67	0.212	0.002	0.0016	--	106.1497	0.0153	0.073158	18.8823	60.9336	0.005626588	100.3	
Col 2	2760	8.67	0.2391	0.0022	0.0025	--	94.5762	0.0127	0.230454	17.3316	55.7491	0.005799904	100.3	
Col 2	2820	8.67	0.2088	0.0013	0.0018	--	70.1694	0.0099	0.172764	13.1714	34.9526	0.005931618	100.3	
Col 2	2880	8.67	0.2182	0.0027	0.002	--	67.1905	0.0088	0.313503	17.1077	30.9657	0.006102695	100.3	
Col 2	2940	8.67	0.2598	0.0037	0.0032	--	90.7483	0.0163	0.255421	19.7539	39.8236	0.006300234	100.3	
Col 2	3000	8.67	0.252	0.0027	0.0029	--	74.054	0.0103	0.205705	16.8775	33.2702	0.006469009	100.3	
Col 2	3120	8.59	0.3022	0.0007	0.0003	--	98.297	0.0389	0.315594	23.0516	35.9104	0.006930041	100.3	
Col 2	3180	8.59	0.3197	0.0018	0.0009	--	103.5317	0.0426	0.313503	23.7694	38.7107	0.007167735	100.3	
Col 2	3240	8.59	0.3099	--	--	--	86.1204	0.0458	0.262523	21.6969	35.7424	0.007384704	100.3	
Col 2	3300	8.59	0.3011	--	--	--	82.2402	0.0407	0.308797	23.5761	38.7814	0.007620465	100.3	
Col 2	3360	8.59	0.2289	--	--	--	78.7485	0.033	0.362914	18.7511	34.5379	0.007807976	100.3	
Col 2	3420	8.59	0.2966	--	--	--	76.806	0.0504	0.312806	23.8338	37.3911	0.008046314	100.3	
Col 2	3480	8.59	0.3012	--	--	--	60.7931	0.0439	0.307969	23.5871	24.3259	0.008282185	100.4	
Col 2	3540	8.59	0.3166	--	--	--	72.9795	0.0585	0.298993	22.1762	37.0532	0.008503947	100.4	
Col 2	3600	8.59	0.2998	--	--	--	73.8023	0.0499	0.301172	22.8359	36.2602	0.008732306	100.4	
Col 2	3660	8.59	0.314	--	--	--	72.4341	0.053	0.261129	22.4049	33.9919	0.008956355	100.4	
Col 2	3720	8.59	0.3173	--	--	--	70.1726	0.0601	0.274854	21.8052	34.8886	0.009174407	100.4	
Col 2	3780	8.59	0.3022	--	--	--	71.6421	0.0647	0.29908	22.4201	33.7321	0.009398608	100.4	
Col 2	3840	8.59	0.339	--	--	--	69.4228	0.0768	0.283656	22.2893	31.8761	0.009621501	100.4	
Col 2	3900	8.59	0.3298	--	--	--	66.8525	0.083	0.286967	22.546	31.4671	0.009846961	100.4	
Col 2	3960	8.59	0.3384	--	--	--	67.0731	0.0926	0.266532	22.2699	28.885	0.01006966	100.4	
Col 2	4020	8.59	0.3297	--	--	--	65.7338	0.0998	0.276946	22.6686	27.6457	0.010296346	100.4	
Col 2	4080	8.59	0.3604	--	--	--	65.9308	0.1571	0.283133	22.4231	25.865	0.010520577	100.4	
Col 2	4140	8.59	0.1833	--	--	--	62.2821	0.0521	0.287882	20.4678	24.5756	0.010725255	100.4	
Col 2	4200	8.59	0.3645	--	--	--	64.4999	0.2013	0.258776	22.1628	22.7702	0.010946883	100.4	
Col 2	4260	8.59	0.3665	--	--	--	37.2519	0.1717	0.268841	23.1939	8.6127	0.011178822	100.4	
Col 2	4320	8.59	0.362	--	--	--	60.7758	0.0005	0.263961	24.1081	19.3836	0.011419903	100.4	
Col 2	4380	8.59	0.3323	--	--	--	60.2804	0.2548	0.278645	23.9165	18.7193	0.011659068	100.4	

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 2

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)											
Column #	Time (mins.)	pH	Fluoride (ppm)	Formate (ppm)	Acetate (ppm)	Propionate (ppm)	Phosphate (ppm)	Thiosulfate (ppm)	Arsenate (ppm)	Sulfate (ppm)	Chloride (ppm)	Total Sulfate (g)	%As remaining	Operational Notes
Col 2	4440	8.59	0.3746	--	--	--	57.7403	0.4451	0.240127	20.3523	17.815	0.011862591	100.4	
Col 2	4500	8.59	0.3399	--	--	--	55.9953	0.2158	0.258122	23.8455	16.9353	0.012101046	100.5	
Col 2	4560	8.59	0.3605	--	--	--	53.2427	0.1449	0.169976	21.2862	13.8905	0.012313908	100.5	Switch from 8 mL/min. to 10 mL/min.
Col 2	4680	8.41	0.2493	0.2549	--	--	75.971	0.0579	0.331149	27.3005	54.7062	0.013132923	100.5	
Col 2	4800	8.41	0.2336	0.0105	--	--	49.8878	0.0035	0.128059	12.9702	5.5114	0.013392327	100.5	
Col 2	4920	8.41	0.2479	0.0161	--	--	73.9035	0.0384	0.220955	22.0054	8.2727	0.013832435	100.5	
Col 2	5040	8.41	0.29	0.0147	--	--	58.0642	0.0426	0.160433	16.5054	6.38	0.014162543	100.5	
Col 2	5160	8.41	0.292	0.0129	--	--	71.2566	0.0719	0.207012	21.097	7.6475	0.014584483	100.5	
Col 2	5280	8.41	0.2674	0.016	--	--	49.036	0.0466	0.140608	14.4238	4.9778	0.014872959	100.6	
Col 2	5400	8.41	0.2886	0.0162	--	--	68.6274	0.1172	0.203483	20.2965	6.3622	0.015278889	100.6	
Col 2	5520	8.41	0.2811	0.012	--	--	65.8757	0.3382	0.209191	19.5816	6.0328	0.015670521	100.6	
Col 2	5640	8.41	0.2647	0.0136	--	--	53.1267	0.938	0.155597	11.8797	4.4159	0.015908115	100.6	
Col 2	5760	8.41	0.2676	0.0091	--	--	55.5239	1.244	0.167187	11.4956	4.6749	0.016138027	100.6	
Col 2	5880	8.41	0.2952	0.0124	--	--	64.7808	1.3786	0.212938	9.0921	5.1767	0.016319869	100.6	
Col 2	6000	8.39	0.4759	0.023	--	--	68.9747	--	0.205531	25.7782	5.1228	0.016577651	100.7	
Col 2	6120	8.39	0.2486	0.0523	--	--	68.2972	--	0.24065	25.1803	4.9524	0.01733306	100.7	
Col 2	6240	8.39	0.2574	0.0026	--	--	66.0857	0.0074	0.216162	24.6239	4.7228	0.017825538	100.7	
Col 2	6360	8.39	0.1963	0.0242	--	--	64.5592	0.0048	0.231935	23.945	4.25	0.018304438	100.7	
Col 2	6480	8.39	0.1555	0.0067	--	--	63.4612	0.0029	0.231325	23.6949	3.8975	0.018778336	100.7	
Col 2	6600	8.39	0.2701	0.0308	--	--	62.0853	0.0094	0.183701	23.3294	3.6921	0.019244924	100.7	
Col 2	6720	8.39	0.2409	0.0093	--	--	60.7974	--	0.233722	22.3766	3.3693	0.019692456	100.7	
Col 2	6840	8.39	0.2051	0.0181	--	--	59.2813	0.0205	0.22126	22.3947	3.0772	0.02014035	100.8	
Col 2	6960	8.39	0.2466	0.0506	--	--	57.9642	0.0187	0.224877	21.862	2.8991	0.02057759	100.8	
Col 2	7080	8.39	0.2443	0.0589	--	--	56.4137	0.0064	0.186228	21.8336	2.6633	0.021014262	100.8	
Col 2	7200	8.39	0.1944	0.0398	--	--	55.6022	--	0.22845	19.4601	2.4455	0.021403464	100.8	
Col 2	7320	8.39	0.0733	--	--	--	48.2518	--	0.219387	39.6711	2.2662	0.022196886	100.8	
Col 2	7440	8.39	0.2743	--	--	--	52.2649	0.005	0.209539	15.379	2.1032	0.022504466	100.8	
Col 2	7560	8.53	0.5615	0.0336	--	--	55.5542	0.0128	0.19869	21.883	1.9512	0.022723296	100.9	
Col 2	7680	8.53	0.2314	0.0353	--	--	51.8416	0.0012	0.19821	21.3249	1.926	0.022936545	100.9	
Col 2	7800	8.53	0.1966	0.0329	--	--	51.2344	--	0.22479	21.4596	1.8244	0.023151141	100.9	
Col 2	7920	8.53	0.2397	--	--	--	50.1763	0.0004	0.213417	21.5482	1.7236	0.023366623	100.9	
Col 2	8040	8.53	0.2676	0.0368	--	--	49.8227	0.0056	0.223264	21.6756	1.6145	0.023583379	100.9	
Col 2	8160	8.53	0.1629	0.0447	--	--	49.0895	0.0055	0.16283	21.8768	1.5625	0.023802147	100.9	
Col 2	8280	8.53	0.1438	0.03	--	--	48.7882	0.001	0.18235	21.925	1.4943	0.024021397	101.0	
Col 2	8400	8.53	0.1881	0.0388	--	--	49.0646	4.0779	0.223003	22.3799	1.5229	0.024245196	101.0	
Col 2	8520	8.53	0.2578	0.0336	--	--	48.6398	0.1682	0.212415	22.2851	1.4593	0.024468047	101.0	

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 2

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)											
Column #	**Time (mins.)**	**pH**	**Fluoride (ppm)**	**Formate (ppm)**	**Acetate (ppm)**	**Propionate (ppm)**	**Phosphate (ppm)**	**Thiosulfate (ppm)**	**Arsenate (ppm)**	**Sulfate (ppm)**	**Chloride (ppm)**	**Total Sulfate (g)**	**%As remaining**	**Operational Notes**
Col 2	8640	8.53	0.2482	0.0458	--	--	48.3296	0.0042	0.221086	22.6423	1.2829	0.02469447	101.0	Switch to Artificial Water
Col 2	8760	8.53	0.1624	0.0625	--	--	47.3783	0.0037	0.213461	23.2723	1.3581	0.024927193	101.0	
Col 2	8880	8.53	0.2538	0.0708	--	--	47.4954	0.0151	0.199343	23.7602	1.3348	0.025164795	101.0	
Col 2	9000	8.53	0.2527	0.0071	--	--	47.3063	0.0026	0.160302	24.6692	1.5849	0.025411487	101.0	
Col 2	9120	8.21	0.2997	0.0122	--	--	56.1762	0.1532	0.222829	25.3848	0.4616	0.025665335	101.0	
Col 2	9240	8.21	0.2173	--	--	--	46.2115	0.014	0.201565	23.9565	1.5629	0.026144465	101.0	
Col 2	9360	8.21	0.2335	--	--	--	45.1052	0.0018	0.204223	23.2898	2.5925	0.026610261	101.0	
Col 2	9480	8.21	0.234	--	--	--	43.3794	0.0267	0.190367	23.4825	4.0301	0.027079911	101.0	
Col 2	9600	8.21	0.2285	--	--	--	40.2407	0.0168	0.180564	22.1714	4.9747	0.027523339	101.0	
Col 2	9720	8.21	0.2196	0.0055	--	--	40.0812	0.0181	0.178777	20.5568	5.5781	0.027934475	101.0	
Col 2	9840	8.21	0.129	--	--	--	40.844	0.0192	0.185836	21.3529	6.7114	0.028361533	101.0	
Col 2	9960	8.21	0.245	--	--	--	42.2223	0.0344	0.181958	21.9653	7.517	0.028800839	101.0	
Col 2	10080	8.21	0.249	0.0092	--	--	37.7757	0.0257	0.181261	21.2463	7.9354	0.029225765	101.0	
Col 2	10200	8.21	0.2437	0.0055	--	--	34.0137	0.0723	0.14161	17.2813	7.1459	0.029571391	101.0	
Col 2	10320	8.21	0.247	0.0007	--	--	35.0822	0.2816	0.175204	16.6386	8.7517	0.029904163	101.0	
Col 2	10440	8.21	0.2711	0.0013	--	--	36.6742	0.6039	0.149497	14.838	9.5899	0.030200923	100.9	
Col 2	10560	8.21	0.2607	0.0104	--	--	34.545	0.9457	0.215814	11.5922	9.4425	0.030432767	100.9	
Col 2	10680	8.14	0.2152	0.0059	--	--	--	--	0.124748	24.3715	9.7972	0.031651342	100.9	
Col 2	10800	8.14	0.1135	--	--	--	--	--	0.107188	24.5395	10.1128	0.032142132	100.9	
Col 2	10920	8.14	0.174	0.0115	--	--	--	--	0.126621	25.3014	10.4167	0.03264816	100.9	
Col 2	11040	8.14	0.2206	0.0004	--	--	--	--	0.156381	24.6145	10.6319	0.03314045	100.9	
Col 2	11160	8.14	0.236	0.0213	--	--	--	--	0.174071	24.3142	10.9414	0.033626734	100.9	
Col 2	11280	8.14	0.2027	--	--	--	--	--	0.152721	24.0922	11.1416	0.034108578	100.9	
Col 2	11400	8.14	0.2378	--	--	--	--	--	0.12344	24.1937	11.3428	0.034592452	100.9	
Col 2	11520	8.14	0.2049	--	--	--	--	--	0.175814	22.7752	10.4979	0.035047956	100.9	
Col 2	11640	8.14	0.235	0.0097	--	--	--	--	0.17747	24.094	11.711	0.035529836	100.9	
Col 2	11760	8.14	0.2369	--	--	--	--	--	0.185487	24.4164	11.7839	0.036018164	100.9	
Col 2	11880	8.14	0.245	--	--	--	--	--	0.157035	24.6082	12.0781	0.036510328	100.9	
Col 2	16200	8.12	0.2711	0.0078	--	--	29.0894	0.0759	0.08623	23.236	12.0416	0.036742688	100.9	
Col 2	16320	8.12	0.2003	--	--	--	29.0803	0.0038	0.11063	23.2684	12.395	0.037208056	100.9	
Col 2	16440	8.12	0.1763	--	--	--	29.2207	0.0007	0.10514	22.8197	12.4036	0.03766445	100.9	
Col 2	16560	8.12	0.2084	--	--	--	28.7182	0.001	0.10331	22.735	12.6444	0.03811915	100.9	
Col 2	16680	8.12	0.1968	--	--	--	28.1774	--	0.102221	22.7969	12.7678	0.038575088	100.9	
Col 2	16800	8.12	0.2038	0.0014	--	--	27.1802	0.0007	0.100347	22.0542	12.4025	0.039016172	100.9	
Col 2	16920	8.12	0.2015	0.0133	--	--	26.7262	--	0.089541	22.6287	12.6786	0.039468746	100.9	
Col 2	17040	8.12	0.165	--	--	--	26.7566	--	0.115902	22.2542	12.9161	0.03991383	100.9	

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 2

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)											
Column #	Time (mins.)	pH	Fluoride (ppm)	Formate (ppm)	Acetate (ppm)	Propionate (ppm)	Phosphate (ppm)	Thiosulfate (ppm)	Arsenate (ppm)	Sulfate (ppm)	Chloride (ppm)	Total Sulfate (g)	%As remaining	Operational Notes
Col 2	17160	8.12	0.1911	--	--	--	26.142	--	0.099824	21.8937	12.7809	0.040351704	100.9	
Col 2	17280	8.31	0.2013	0.0011	0.0025	--	17.2186	--	0.074726	15.4733	11.4222	0.040815903	100.9	
Col 2	17340	8.31	0.2103	0.0056	0.0016	--	17.8807	--	0.112242	15.2305	12.1129	0.040968208	100.9	
Col 2	17400	8.31	0.209	0.0032	0.0012	--	17.6024	--	0.09063	15.2733	12.1661	0.041120941	100.9	
Col 2	17460	8.31	0.2119	0.0146	--	--	17.9133	--	0.081349	15.2608	12.1878	0.041273549	100.9	
Col 2	17520	8.31	0.2106	0.0051	0.0016	--	17.6666	1.3126	0.089585	15.1123	12.1323	0.041424672	100.9	
Col 2	17580	8.31	0.2101	0.003	0.001	--	17.5284	--	0.082962	15.0914	12.1256	0.041575586	100.9	
Col 2	17640	8.31	0.2087	0.0029	--	--	17.3319	--	0.084574	15.0618	12.0692	0.041726204	100.9	
Col 2	17700	8.31	0.222	0.0084	--	--	17.5639	--	0.08087	15.0872	12.0845	0.041877076	100.9	
Col 2	17760	8.31	0.2146	0.0072	0.0021	--	17.3357	--	0.077036	14.4495	12.0324	0.042021571	100.9	
Col 2	17820	8.31	0.2128	0.0025	--	--	16.9814	--	0.080478	14.4779	12.0064	0.04216635	100.9	
Col 2	17880	8.31	0.2303	0.0112	--	--	17.3913	--	0.075075	14.5192	12.067	0.042311542	100.9	
Col 2	17940	8.31	0.2291	0.0047	0.0012	--	17.0971	--	0.082308	14.445	11.9877	0.042455992	100.9	
Col 2	18000	8.31	0.2084	0.0031	--	--	16.942	--	0.085925	14.5057	12.0389	0.042601049	100.9	
Col 2	18060	8.31	0.2153	0.0019	--	--	17.0938	--	0.07355	14.47	12.0585	0.042745749	100.9	
Col 2	18120	8.31	0.2083	0.0047	0.0013	--	16.7381	--	0.081567	14.5921	11.9329	0.04289167	100.9	
Col 2	18180	8.31	0.2207	0.0026	--	--	16.4299	--	0.073681	14.1148	11.9683	0.043032818	100.9	
Col 2	18240	8.31	0.2293	0.0126	--	--	21.2246	--	0.075554	13.7862	11.8647	0.04317068	100.9	
Col 2	18300	8.31	0.1517	--	--	--	21.0334	--	0.072504	13.8466	12.0372	0.043309146	100.9	
Col 2	18360	8.31	0.1794	0.0014	--	--	20.992	--	0.061698	13.8349	11.8492	0.043447495	100.9	
Col 2	18420	8.31	0.1402	0.014	--	--	21.0735	--	0.067624	13.9334	12.0218	0.043586829	100.9	
Col 2	18480	8.31	0.194	0.0071	--	--	20.7336	--	0.078212	13.8083	12.0412	0.043724912	100.9	
Col 2	18540	8.31	0.1703	0.006	--	--	20.7088	--	0.044967	14.0291	12.136	0.043865203	100.9	
Col 2	18600	8.31	0.1639	0.0104	--	--	20.4934	--	0.073681	13.6174	11.8381	0.044001377	100.9	
Col 2	21480	7.74	--	--	--	--	--	0.0091	0.37738	12.8502	14.604	0.053253521	100.8	
Col 2	28680	7.6	--	--	--	--	--	0.001	0.415244	10.5695	15.1678	0.068473601	100.5	
Col 2	31560	7.33	--	--	--	--	--	--	0.361737	9.1538	14.5327	0.068656677	100.4	
Col 2	34440	7.28	--	--	--	--	--	--	0.204006	13.3101	11.5522	0.075045525	100.3	
Col 2	38760	7.21	--	--	--	--	--	--	0.188581	13.0503	11.5634	0.075437034	100.3	
Col 2	40200	7.32	--	--	--	--	--	--	0.187709	12.4034	11.7969	0.07841385	100.2	
Col 2	41640	7.17	--	--	--	--	--	--	0.16723	11.4161	11.716	0.081153714	100.2	
Col 2	43080	7.06	--	--	--	--	--	--	0.151719	10.1351	11.6406	0.083586138	100.2	
Col 2	47400	6.83	--	--	--	--	--	0.1635	0.098953	7.5725	27.0649	0.089038338	100.1	
Col 2	48840	6.19	--	--	--	--	0.3536	--	0.035991	4.1146	--	--	100.1	
Col 2	50280	6.24	--	--	--	--	0.3374	--	0.042788	4.8063	--	--	100.1	
Col 2	51720	6.31	--	--	--	--	0.326	--	0.027146	4.2732	--	--	100.1	

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 2

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)											
Column #	**Time (mins.)**	**pH**	**Fluoride (ppm)**	**Formate (ppm)**	**Acetate (ppm)**	**Propionate (ppm)**	**Phosphate (ppm)**	**Thiosulfate (ppm)**	**Arsenate (ppm)**	**Sulfate (ppm)**	**Chloride (ppm)**	**Total Sulfate (g)**	**%As remaining**	**Operational Notes**
Col 2	53160	6.39	--	--	--	--	0.3467	--	0.025577	3.265	--	--	100.1	
Col 2	58920	6.41	--	--	--	--	0.5624	--	0.05891	4.6252	--	--	100.1	
Col 2	60360	6.45	--	--	--	--	0.5792	--	0.071328	3.0319	--	--	100.1	
Col 2	67560	6.45	--	--	--	--	0.2609	--	0.011503	2.1274	--	--	100.1	
Col 2	69000	6.43	--	--	--	--	0.1792	--	0.207012	0.4532	--	--	100.1	
Col 2	71880	6.48	--	--	--	--	0.2108	--	0.178559	0.8926	--	--	100.0	
Col 2	73320	6.52	--	--	--	--	0.1433	--	0.16344	1.0211	--	--	100.0	
Col 2	79080	6.55	--	--	--	--	0.1669	--	0.124399	0.2989	--	--	99.9	
Col 2	80520	6.58	--	--	--	--	0.1863	--	0.132024	0.5988	--	--	99.9	
Col 2	81960	6.59	--	--	--	--	0.072	--	0.11673	0.3854	--	--	99.9	
Col 2	83400	6.6	--	--	--	--	0.1783	--	0.010109	0.281	--	--	99.9	10mM of K2HPO4 added
Col 2	87720	6.59	--	--	--	--	0.0594	--	0.005316	2.6731	--	--	99.9	
Col 2	89160	6.61	--	--	--	--	0.0929	--	0.020305	4.5348	--	--	99.9	
Col 2	90600	6.64	--	--	--	--	0.0878	--	0.030544	4.9772	--	--	99.9	
Col 2	92040	6.63	--	--	--	--	0.0183	--	0.033289	5.7483	--	--	99.9	
Col 2	93480	6.69	--	--	--	--	0.0088	--	0.033202	6.0373	--	--	99.9	
Col 2	103560	6.51	--	--	--	--	0.2378	--	0.016122	28.5053	--	--	99.8	AlOH Injection
Col 2	107880	6.51	--	--	--	--	0.203	--	0.131327	7.3626	--	--	99.8	
Col 2	110760	6.58	--	--	--	--	0.1323	--	0.118168	4.9567	--	--	99.8	
Col 2	112200	6.55	--	--	--	--	0.0247	--	0.021263	4.4501	--	--	99.8	
Col 2	113640	6.51	--	--	--	--	0.1005	--	0.010152	4.4405	--	--	99.8	
Col 2	117960	6.61	--	--	--	--	0.1116	--	0.021176	4.7065	--	--	99.7	
Col 2	120840	6.63	--	--	--	--	0.1198	--	0.018039	3.3125	--	--	99.7	
Col 2	122280	6.55	--	--	--	--	0.0678	--	0.011677	4.6756	--	--	99.7	
Col 2	123720	6.53	--	--	--	--	0.038	--	0.008366	4.7023	--	--	99.7	
Col 2	128040	6.68	--	--	--	--	0.0574	--	0.011677	4.9666	--	--	99.7	
Col 2	129480	5.76	--	--	--	--	0.0911	--	0.004793	4.2963	--	--	99.7	
Col 2	130920	5.8	--	--	--	--	0.035	--	0.000349	3.9117	--	--	99.7	
Col 2	133800	6.89	--	--	--	--	0.0117	--	0.001481	-0.4237	--	--	99.7	
Col 2	135240	7.43	--	--	--	--	8.1677	--	0.237164	9.3218	--	--	99.7	
Col 2	136680	7.19	--	--	--	--	5.0405	--	0.21211	6.282	--	--	99.7	
Col 2	138120	7.15	--	--	--	--	0.5795	--	0.143919	6.6683	--	--	99.7	
Col 2	139560	7.12	--	--	--	--	0.2559	--	0.144224	5.7012	--	--	99.6	
Col 2	141000	7.04	--	--	--	--	0.2622	--	0.150455	5.6745	--	--	99.6	
Col 2	145320	7.09	--	--	--	--	0.1021	--	0.117384	5.5173	--	--	99.6	
Col 2	146760	7.55	--	--	--	--	--	--	0.098081	4.1416	--	--	99.6	

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 2

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)												
Column #	**Time (mins.)**	**pH**	**Fluoride (ppm)**	**Formate (ppm)**	**Acetate (ppm)**	**Propionate (ppm)**	**Phosphate (ppm)**	**Thiosulfate (ppm)**	**Arsenate (ppm)**	**Sulfate (ppm)**	**Chloride (ppm)**	**Total Sulfate (g)**	**%As remaining**	**Operational Notes**
Col 2	148200	7.59	--	--	--	--	--	--	0.106229	5.7072	--	--	99.5	
Col 2	149640	7.57	--	--	--	--	--	--	0.081001	6.3221	--	--	99.5	
Col 2	151080	7.47	--	--	--	--	--	--	0.056557	6.3585	--	--	99.5	
Col 2	152520	7.55	--	--	--	--	--	--	0.068931	6.5599	--	--	99.5	
Col 2	153960	7.36	--	--	--	--	--	--	0.05952	6.5544	--	--	99.5	
Col 2	155400	7.32	--	--	--	--	--	--	0.055075	6.7093	--	--	99.5	
Col 2	156840	7.38	--	--	--	--	--	--	0.065489	6.3156	--	--	99.5	
Col 2	158280	7.4	--	--	--	--	--	--	0.081698	7.2126	--	--	99.5	
Col 2	162600	7.46	--	--	--	--	--	--	0.17015	6.3219	--	--	99.4	
Col 2	164040	7.44	--	--	--	--	--	--	0.169671	6.2821	--	--	99.4	
Col 2	165480	7.42	--	--	--	--	--	--	0.162917	6.2219	--	--	99.4	

-- = Not Analyzed

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 3

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)												
Column #	**Time (mins.)**	**pH**	**Fluoride (ppm)**	**Formate (ppm)**	**Acetate (ppm)**	**Propionate (ppm)**	**Phosphate (ppm)**	**Thiosulfate (ppm)**	**Arsenate (ppm)**	**Sulfate (ppm)**	**Chloride (ppm)**	**Total Sulfate (g)**	**Nitrite (ppm)**	**Bromide (ppm)**	**% As remaining**
Coll3	0	8.21	0.1991	--	--	--	394.6	0.0138	0.325	4.5	559.5	0.000045	--	--	100.0
Col 3	60	8.64	0.1132	0.0006	0.0028	--	10.5271	--	1.406	84.0226	29.2179	0.01487767	--	--	100.0
Col 3	120	8.64	0.1233	0.0008	0.0285	0.0012	51.6079	--	1.1433	74.3376	97.7732	0.01562105	6.7692	--	100.0
Col 3	180	8.64	0.1159	--	0.0005	--	27.9568	--	1.2245	78.7133	55.8611	0.01640818	6.8453	--	100.0
Col 3	240	8.64	0.1122	0.0006	0.0006	--	33.7718	--	1.1344	76.9611	64.772	0.01717779	5.5794	--	100.0
Col 3	300	8.64	0.1185	0.0005	0.0006	--	30.8728	0.0319	1.2849	80.4193	59.8963	0.01798199	6.3211	--	100.0
Col 3	360	8.64	0.1165	--	0.0004	--	31.2482	--	1.1717	79.9034	60.3177	0.01878102	5.6702	--	100.0
Col 3	420	8.64	0.1127	0.0005	0.0005	--	27.5045	--	1.2277	78.9344	53.5775	0.01957036	5.9058	--	100.0
Col 3	480	8.64	0.0689	0.0021	0.0011	--	47.7552	0.0757	0.3251	38.3216	93.9247	0.01995358	2.6851	--	100.1
Col 3	540	8.64	0.1093	0.0009	0.0007	--	23.8088	--	1.3167	79.8727	47.6897	0.02075231	5.5995	--	100.1
Col 3	600	8.64	0.1269	0.0008	0.0008	--	70.635	0.0596	1.0513	68.7846	141.6387	0.02144015	4.2651	--	100.1
Col 3	660	8.64	0.1151	0.0007	0.0007	--	43.9241	0.0433	0.9722	74.8662	84.5201	0.02218882	4.691	--	100.1
Col 3	720	8.64	0.1175	0.0008	0.0009	--	39.7038	0.0523	0.9738	77.1089	77.4328	0.0229599	4.6711	--	100.1
Col 3	780	8.64	0.1187	0.001	0.0011	--	25.2383	0.0425	1.0068	80.402	50.1804	0.02376392	4.2126	--	100.1
Col 3	840	8.64	0.1268	0.0014	0.0018	--	26.4464	0.0226	1.0482	78.5916	53.0795	0.02454984	3.4986	--	100.1
Col 3	900	8.64	0.1112	0.0005	0.0016	--	32.821	0.0422	1.192	81.9621	61.9432	0.02536946	3.019	--	100.1
Col 3	960	8.64	0.1269	0.0005	0.0017	--	33.5819	0.0355	1.2795	83.1598	63.1257	0.02620106	2.2282	--	100.1
Col 3	1020	8.64	0.1197	0.001	0.0013	--	32.8334	0.0373	1.5031	84.8681	62.0837	0.02704974	1.2399	--	100.1
Col 3	1080	8.64	0.1167	0.0008	0.0026	--	15.9543	--	1.8106	89.8835	31.5913	0.02794858	0.7468	--	100.0
Col 3	1140	8.64	0.1211	0.0019	0.0015	--	31.141	0.0192	1.9028	87.4077	58.6643	0.02882265	0.4183	--	100.0
Col 3	1200	8.64	0.1279	0.0019	0.0017	--	38.6521	0.0107	1.9243	87.5264	71.6108	0.02969792	0.5462	--	100.0
Col 3	1260	8.64	0.1273	0.0015	0.0019	--	34.4486	--	2.0769	88.3269	64.2787	0.03058119	0.2975	--	100.0
Col 3	1320	8.64	0.117	0.0007	0.001	--	30.1913	0.0392	2.11	88.5594	55.5692	0.03146678	0.2727	--	100.0
Col 3	1380	8.64	0.1288	0.0014	0.0018	--	37.334	0.0589	1.7686	88.4144	68.2401	0.03235092	0.3092	--	100.0
Col 3	1440	8.64	0.1348	0.0012	0.0014	--	70.7172	0.1661	1.4877	78.6381	131.8655	0.0331373	0.3981	--	100.0
Col 3	1500	8.64	0.909	0.0031	0.0032	--	14.5481	0.0807	0.6655	90.1122	26.6794	0.03403843	--	--	100.0
Col 3	1560	8.64	0.1239	0.0018	0.0018	--	20.3185	0.0432	1.273	88.4882	36.0704	0.03492331	0.2611	--	100.0
Col 3	1620	8.64	0.1167	0.0037	0.002	--	20.4624	0.0581	1.4224	89.415	36.3787	0.03581746	0.3292	--	100.0
Col 3	1680	8.64	0.1233	0.0039	0.0023	--	16.8679	0.0346	1.7951	90.4876	29.7615	0.03672233	0.0559	--	100.0
Col 3	1740	8.67	0.1179	0.0029	0.0023	--	15.5847	0.0285	2.0197	91.604	29.4592	0.03763837	0.2912	--	100.0
Col 3	1800	8.67	0.1294	0.0018	0.0008	--	21.5411	--	2.248	88.7914	35.9177	0.03852629	0.3655	--	100.0
Col 3	1860	8.67	0.1305	0.0011	0.0007	--	24.0464	--	2.4594	87.3871	36.5591	0.03940016	0.3594	--	100.0
Col 3	1920	8.67	0.1283	0.0012	0.0012	--	23.5365	--	2.7421	85.2089	34.4868	0.04025225	0.3762	--	100.0
Col 3	1980	8.67	0.1219	0.0029	0.0013	--	27.8821	--	2.7695	82.0092	38.4962	0.04107234	0.3893	--	100.0
Col 3	2040	8.67	0.1277	0.0009	0.0016	--	18.5225	--	3.1981	83.4685	25.6004	0.04190703	0.3978	--	100.0
Col 3	2100	8.67	0.126	0.0018	0.0012	--	30.5635	--	2.9959	77.8948	40.1274	0.04268597	0.4364	--	100.0

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 3

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)												
Column #	Time (mins.)	pH	Fluoride (ppm)	Formate (ppm)	Acetate (ppm)	Propionate (ppm)	Phosphate (ppm)	Thiosulfate (ppm)	Arsenate (ppm)	Sulfate (ppm)	Chloride (ppm)	Total Sulfate (g)	Nitrite (ppm)	Bromide (ppm)	% As remaining
Col 3	2160	8.67	0.1231	0.0014	0.0024	--	20.2771	--	3.3973	79.2446	25.1127	0.04347842	0.4381	--	100.0
Col 3	2220	8.67	0.1355	0.0017	0.0024	--	18.5245	--	3.525	79.4135	23.7139	0.04427255	0.3688	--	100.0
Col 3	2280	8.67	0.1331	0.0054	0.0021	--	42.4266	--	3.2677	70.251	53.2591	0.04497506	0.4069	--	99.9
Col 3	2340	8.67	0.1262	0.0025	0.0017	--	20.6961	--	3.6086	74.7519	22.5896	0.04572258	0.4326	--	99.9
Col 3	2400	8.67	0.1461	0.0016	0.001	--	39.9649	--	3.0902	64.9409	42.7197	0.04637199	0.4503	--	99.9
Col 3	2460	8.67	0.1336	0.0016	0.0012	--	19.0362	--	2.1297	67.478	19.3918	0.04704677	0.366	--	99.9
Col 3	2520	8.67	0.1188	0.0009	0.0016	--	12.0553	--	0.5797	27.3012	9.884	0.04731978	0.2701	1.2692	99.9
Col 3	2580	8.67	0.1357	0.0013	0.0022	--	18.1737	0.0052	2.1554	61.9048	17.6113	0.04793883	0.3466	1.9512	99.9
Col 3	2640	8.67	0.1292	0.001	0.0012	--	15.4443	--	1.4808	42.8312	12.9858	0.04836714	0.2956	1.6641	99.9
Col 3	2700	8.67	0.1239	0.0011	0.0042	--	15.0504	--	1.372	40.9825	12.1651	0.04877697	0.2804	1.4214	99.9
Col 3	2760	8.67	0.1296	0.0024	0.0015	--	16.6022	--	1.5473	40.7448	12.5952	0.04918442	0.289	1.8023	99.9
Col 3	2820	8.67	0.1308	0.0017	0.0013	--	14.5335	--	1.3695	35.5964	10.3411	0.04954038	0.2743	1.5184	99.9
Col 3	2880	8.67	0.1297	0.0014	0.0015	--	12.9998	0.0024	1.0227	31.1985	10.216	0.04985237	0.2246	1.3611	99.9
Col 3	2940	8.67	0.1267	0.0013	0.0009	--	13.3661	--	1.1496	33.8117	11.2341	0.05019048	0.2513	2.0041	99.9
Col 3	3000	8.67	0.1287	0.0013	0.0015	--	13.5603	--	1.0677	27.3649	8.5095	0.05046413	0.2502	1.3099	99.9
Col 3	3060	8.59	0.1345	0.0007	0.0006	--	16.2552	0.0149	1.4963	35.478	10.9111	0.05081891	0.2501	1.5397	99.9
Col 3	3120	8.59	0.7363	0.0007	0.0018	--	17.5524	0.0423	1.6415	23.0344	11.281	0.05104926	0.0668	1.6157	99.9
Col 3	3180	8.59	0.1405	0.0042	0.0016	--	17.7643	--	1.6021	23.3124	11.5272	0.05128238	0.2515	1.6218	99.9
Col 3	3240	8.59	0.9852	0.0007	0.0003	--	16.3739	--	1.5657	21.4877	11.225	0.05149726	0.2295	1.3344	99.9
Col 3	3300	8.59	0.1467	--	--	--	--	--	1.2662	19.5502	10.2239	0.05169276	0.0711	1.1788	99.9
Col 3	3360	8.59	0.139	--	--	--	--	--	1.4088	21.0164	10.2357	0.05190292	0.0721	1.3108	99.9
Col 3	3420	8.59	0.1484	--	--	--	--	--	1.0273	18.9501	8.5917	0.05209242	0.0595	1.1932	99.9
Col 3	3480	8.59	0.1386	--	--	--	--	--	1.117	19.566	8.5494	0.05228808	0.0576	1.0485	99.9
Col 3	3540	8.59	0.1381	--	--	--	--	--	0.9545	19.5671	8.4035	0.05248376	0.1849	1.3093	99.9
Col 3	3600	8.59	0.147	--	--	--	--	--	1.1323	20.0237	8.4374	0.05268399	0.0548	1.0359	99.9
Col 3	3660	8.59	0.1504	--	--	--	--	--	1.1165	20.9588	8.5367	0.05289358	0.0537	1.3463	99.9
Col 3	3720	8.59	0.1436	--	--	--	--	--	1.3249	23.1497	8.4451	0.05312508	0.2149	0.9987	99.9
Col 3	3780	8.59	0.1417	--	--	--	--	0.062	1.2845	21.825	8.1384	0.05334333	0.2083	1.0073	99.9
Col 3	3840	8.59	0.1456	--	--	--	--	--	1.1958	21.5682	7.3366	0.05355901	0.2267	0.7661	99.9
Col 3	3900	8.59	0.1573	--	--	--	--	--	1.262	24.6035	7.952	0.05380504	0.2263	0.7288	99.9
Col 3	3960	8.59	0.1396	--	--	--	--	--	1.2537	22.0329	7.4568	0.05402537	0.184	0.6438	99.9
Col 3	4020	8.59	0.1518	--	--	--	--	--	1.2507	22.6073	7.5421	0.05425145	0.1834	0.6858	99.9
Col 3	4080	8.59	0.1441	--	--	--	--	--	1.1356	21.8343	7.1162	0.05446979	0.1535	0.7025	99.9
Col 3	4200	8.59	0.1444	--	--	--	--	--	1.0465	22.3483	6.6971	0.05469327	0.1853	1.019	99.9
Col 3	4260	8.59	0.1482	--	--	--	--	--	0.8039	19.2242	6.1366	0.05488551	0.1944	0.7383	99.9
Col 3	4320	8.59	0.1508	--	--	--	--	--	1.062	21.8941	7.2723	0.05510446	0.1432	0.5347	99.9

APPENDIX A-5

AEROBIC LEACHING EXPERIMENT RESULTS - COLUMN 3

COLUMN STUDY
Avon Park Air Force Range
Avon Park, Florida

			Compound Name (units)												
Column #	**Time (mins.)**	**pH**	**Fluoride (ppm)**	**Formate (ppm)**	**Acetate (ppm)**	**Propionate (ppm)**	**Phosphate (ppm)**	**Thiosulfate (ppm)**	**Arsenate (ppm)**	**Sulfate (ppm)**	**Chloride (ppm)**	**Total Sulfate (g)**	**Nitrite (ppm)**	**Bromide (ppm)**	**% As remaining**
Col 3	4380	8.59	0.1438	--	--	--	--	--	0.6178	18.0738	5.5198	0.05528519	0.1817	0.8052	99.9
Col 3	4440	8.59	0.1443	--	--	--	--	0.0048	2.6093	20.8574	6.1023	0.05549377	0.1556	--	99.9
Col 3	4500	8.59	0.1572	--	--	--	--	--	1.0169	22.4926	9.173	0.05571869	0.1751	1.2505	99.9
Col 3	4560	8.59	0.1503	--	--	--	--	0.0032	1.0527	22.9545	8.739	0.05594824	0.1899	1.2921	99.9

-- = Not Analyzed

APPENDIX A-6

SLUG TEST SUPPORTING DATA

Hvorslev Slug Test Method

Field Data

Et (sec)	Positive Pressure (ft H_2O)	Corrected Displacement, Ht	t (min)	H_t/H_0
0	0.744	0.739	0	1
1.14	0.737	0.732	0.019	0.99052774
2.34	0.706	0.701	0.039	0.94857916
3.6	0.685	0.68	0.06	0.92016238
4.92	0.653	0.648	0.082	0.87686062
6.36	0.623	0.618	0.106	0.83626522
7.86	0.596	0.591	0.131	0.79972936
9.42	0.566	0.561	0.157	0.75913396
11.1	0.541	0.536	0.185	0.72530447
12.9	0.51	0.505	0.215	0.68335589
14.76	0.482	0.477	0.246	0.64546685
16.81	0.457	0.452	0.280167	0.61163735
18.9	0.429	0.424	0.315	0.57374831
21.12	0.406	0.401	0.352	0.54262517
23.52	0.378	0.373	0.392	0.50473613
26.04	0.354	0.349	0.434	0.47225981
28.68	0.336	0.331	0.478	0.44790257
31.5	0.312	0.307	0.525	0.41542625
34.5	0.283	0.278	0.575	0.37618403
37.68	0.265	0.26	0.628	0.35182679
41.039	0.242	0.237	0.683983	0.32070365
44.64	0.225	0.22	0.744	0.29769959
48.24	0.201	0.196	0.804	0.26522327
52.44	0.185	0.18	0.874	0.2435724
56.64	0.167	0.162	0.944	0.21921516
60.84	0.152	0.147	1.014	0.19891746
65.64	0.14	0.135	1.094	0.1826793
71.04	0.123	0.118	1.184	0.15967524
75.84	0.105	0.1	1.264	0.135318
81.84	0.096	0.091	1.364	0.12313938
87.84	0.08	0.075	1.464	0.1014885
93.84	0.073	0.068	1.564	0.09201624
100.44	0.062	0.057	1.674	0.07713126
107.64	0.045	0.04	1.794	0.0541272
115.439	0.049	0.044	1.923983	0.05953992
123.24	0.028	0.023	2.054	0.03112314
131.64	0.025	0.02	2.194	0.0270636
140.64	0.019	0.014	2.344	0.01894452
150.239	0.013	0.008	2.503983	0.01082544
159.84	0.005	0	2.664	0

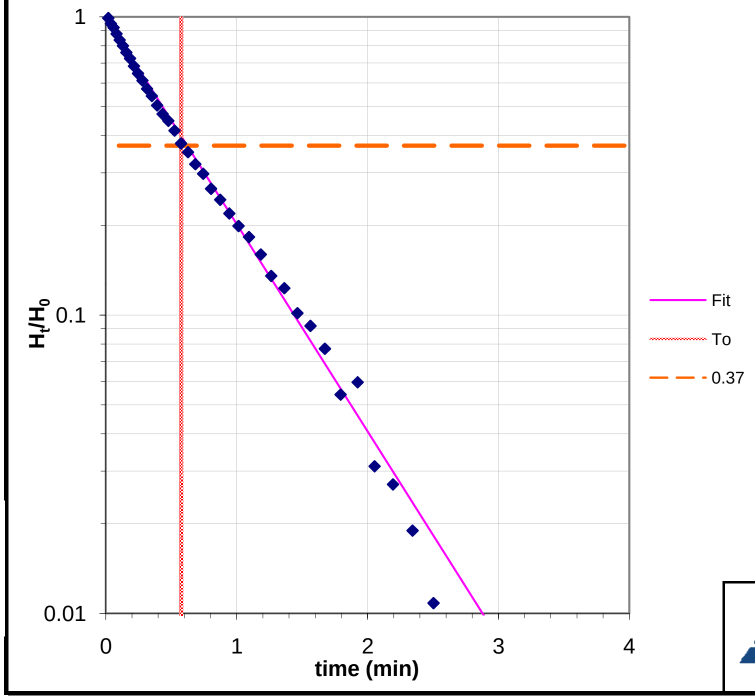
Fitted Line		T_0 Line			
		0.575			
t	Ht/H0				
0.1	0.852143789	0.575	1	0.1	0.37
0.2	0.726149037	0.575	0.7	0.2	0.37
0.3	0.618783392	0.575	0.6	0.3	0.37
0.4	0.527292424	0.575	0.5	0.4	0.37
0.6	0.382892886	0.575	0.4	0.6	0.37
0.8	0.2780373	0.575	0.3	0.8	0.37
1	0.201896518	0.575	0.2	1	0.37
2	0.040762204	0.575	0	2	0.37
3	0.008229747	0.575	0	3	0.37
4	0.001661557	0.575	0	4	0.37
6	6.77287E-05	0.575	0	6	0.37
8	2.76077E-06	0.575	0	8	0.37
10	1.12535E-07	0.575	0	10	0.37
12	4.58718E-09	0.575	0	10	0.37

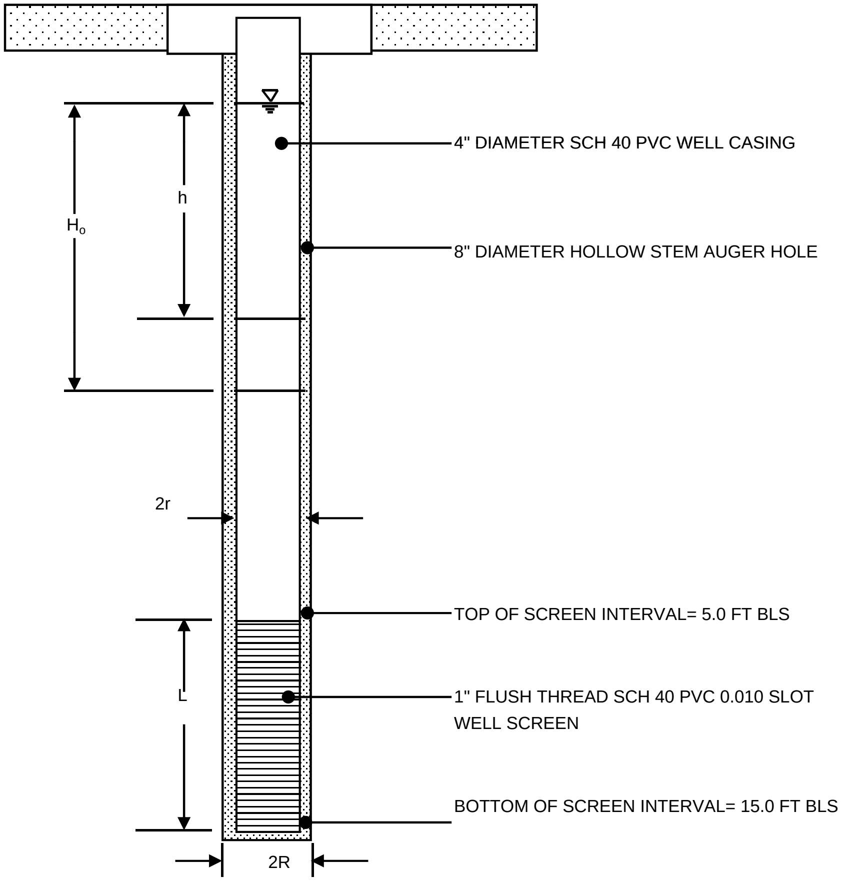
CALCULATION OF HYDRAULIC CONDUCTIVITY (K) BY HVORSLEV METHOD

Hvorslev Equation:

$$K = \frac{r^2 \ln(L/r)}{2 L T_o}$$

H_0 (ft) =	0.739	Maximum distance below static water level
Ht (ft) =	varies	Distance below static water table at time = t
r (ft) =	0.167	Radius of the well casing
R (ft) =	0.300	Radius of the borehole
L (ft) =	10	Length of the screened interval
L/R =	33.33333333	
T_0 (min) =	0.575	
m =	-1.6	Slope of Fit Line
K (ft/day) =	**12.2**	**Hydraulic Conductivity**





MW-2

GEOSYNTEC CONSULTANTS
TITUSVILLE, FL

FIGURE NO.	
PROJECT NO.	
DATE	
FILE NO.	

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Iron Coated sand

Extraction	**Element**	**MW (g/mol)**	MW-1 mmol/kg 4/4/2008	MW-1 mmol/kg 9/4/2008	MW-1 mmol/kg 12/14/2008
MgCl2	As	74.92	0.00335	0.007073	0.00668865
MgCl2	Fe	55.85	0.48507	1.343979	1.68809761
MgCl2	Mn	54.94	0.01282	0.011647	0.00928716
MgCl2	S	32.06			
MgCl2	P	30.97	0.03301	0.008826	0
NaOH-HOAc	As	74.92	0.02646	0.044471	0.03963213
NaOH-HOAc	Fe	55.85	3.48541	18.96264	21.3234272
NaOH-HOAc	Mn	54.94	0.0322	0.027989	0.0231738
NaOH-HOAc	S	32.06	0.05474	0.211488	0.35999838
NaOH-HOAc	P	30.97	2.37239	3.185947	3.71848416
AOD	As	74.92	0.05541	0.035347	0.04018667
AOD	Fe	55.85	2.02277	4.104441	3.61529681
AOD	Mn	54.94	0.07888	0.088306	0.11855286
AOD	S	32.06	0	0	2.22885941
AOD	P	30.97	0.42824	0.443428	0.43233281
Hydroxylamine HCL	As	74.92	0.01415	0.230541	0.21849286
Hydroxylamine HCL	Fe	55.85	39.1128	58.76907	59.9855646
Hydroxylamine HCL	Mn	54.94	0.25617	0.390244	0.37965998
Hydroxylamine HCL	S	32.06	0	6.332345	5.72587787
Hydroxylamine HCL	P	30.97	0.42824	3.932796	4.02477433
Aquaregia	As	74.92	0.0472	0.022336	0.02984159
Aquaregia	Fe	55.85	50.7475	52.9857	51.7398121
Aquaregia	Mn	54.94	0.48784	0.909081	0.69196547
Aquaregia	S	32.06	0	7.359213	5.36558824
Aquaregia	P	30.97	0.98138	0.537121	0.82784455
TOTAL	As	74.92	0.14658	0.339767	0.33484189
TOTAL	Fe	55.85	95.8535	136.1658	138.352198
TOTAL	Mn	54.94	0.86791	1.427268	1.22263927
TOTAL	S	32.06	0.05474	13.90305	13.6803239
TOTAL	P	30.97	4.24326	8.108118	9.00343584

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Uncoated Sand

Extraction	Element	MW (g/mol)	MW-1 mmol/kg 4/4/2008	MW-1 mmol/kg 9/4/2008	MW-1 mmol/kg 12/14/2008
MgCl2	As	74.92	0.00342	0.002159	0.01053129
MgCl2	Fe	55.85	0.14712	0.682177	1.51887844
MgCl2	Mn	54.94	0	0	0
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.0198	0	0
NaOH-HOAc	As	74.92	0.01511	0.032011	0.03257858
NaOH-HOAc	Fe	55.85	19.0355	10.44195	14.06484
NaOH-HOAc	Mn	54.94	0.02519	0.010462	0.0068378
NaOH-HOAc	S	32.06	0.09657	0.110087	0.25601413
NaOH-HOAc	P	30.97	0.33739	0.216787	0.10263868
AOD	As	74.92	0.04712	0.055942	0.03910919
AOD	Fe	55.85	2.01581	2.962438	4.28545287
AOD	Mn	54.94	0.05956	0.04086	0.04619212
AOD	S	32.06	0	0	0
AOD	P	30.97	0.10565	0.450612	0.45973889
Hydroxylamine HCL	As	74.92	0.01601	0.167091	0.106714
Hydroxylamine HCL	Fe	55.85	8.5725	1.291688	0.48460454
Hydroxylamine HCL	Mn	54.94	0.00321	0.003501	0.00021304
Hydroxylamine HCL	S	32.06	0.77515	1.297085	1.82536935
Hydroxylamine HCL	P	30.97	0.4685	0	0
Aquaregia	As	74.92	0.01748	0.008484	0.00140326
Aquaregia	Fe	55.85	2.48458	3.500698	3.89049865
Aquaregia	Mn	54.94	0.01891	0.051974	0.05532147
Aquaregia	S	32.06	1.52213	2.663361	4.30951212
Aquaregia	P	30.97	0	0	0
TOTAL	As	74.92	0.09914	0.265687	0.19033632
TOTAL	Fe	55.85	32.2555	18.87895	24.2442745
TOTAL	Mn	54.94	0.10687	0.106797	0.10856443
TOTAL	S	32.06	2.39385	4.070533	6.3908956
TOTAL	P	30.97	0.93134	0.667399	0.56237757

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Iron Coated sand

Extraction	**Element**	**MW (g/mol)**	MW-2 mmol/kg 4/4/2008	MW-2 mmol/kg 9/4/2008	MW-2 mmol/kg 12/14/2008
MgCl2	As	74.92	0.0133516	0.0069551	0.00389125
MgCl2	Fe	55.85	0.1972801	2.1427272	2.81987138
MgCl2	Mn	54.94	0.0009708	0	0.00839362
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.0562392	0.019545	0.03126992
NaOH-HOAc	As	74.92	0.0123276	0.0406206	0.04164237
NaOH-HOAc	Fe	55.85	4.6783227	12.867607	36.0118208
NaOH-HOAc	Mn	54.94	0.0350945	0.0086565	0.05044454
NaOH-HOAc	S	32.06	0.1544047	0.1207027	0.23313871
NaOH-HOAc	P	30.97	2.9160962	0.0939034	4.96352732
AOD	As	74.92	0.0453732	0.0807482	0.03827021
AOD	Fe	55.85	2.057957	5.2901405	8.55829193
AOD	Mn	54.94	0.059557	0.0413499	0.10983192
AOD	S	32.06	0	0	3.13239021
AOD	P	30.97	0.4694701	0.4323432	0.45559256
Hydroxylamine HCL	As	74.92	0.0039838	0.2142269	0.20032979
Hydroxylamine HCL	Fe	55.85	51.520878	0.1128087	57.7099451
Hydroxylamine HCL	Mn	54.94	0.3361337	0	0.32640807
Hydroxylamine HCL	S	32.06	3.003373	7.1219248	11.3182616
Hydroxylamine HCL	P	30.97	0.4694701	0	3.95347647
Aquaregia	As	74.92	0.0411277	0.0029677	0.03131359
Aquaregia	Fe	55.85	56.510678	2.760796	49.5659645
Aquaregia	Mn	54.94	0.8244336	0.0471057	1.29896319
Aquaregia	S	32.06	0	6.9308998	30.7548461
Aquaregia	P	30.97	0.5588986	0	0
TOTAL	As	74.92	0.1161639	0.3455185	0.31544721
TOTAL	Fe	55.85	114.96512	23.174079	154.665894
TOTAL	Mn	54.94	1.2561897	0.0971121	1.79404135
TOTAL	S	32.06	3.1577777	14.173527	45.4386367
TOTAL	P	30.97	4.4701744	0.5457916	9.40386627

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Uncoated Sand

Extraction	Element	MW (g/mol)	MW-2 mmol/kg 4/4/2008	MW-2 mmol/kg 9/4/2008	MW-2 mmol/kg 12/14/2008
MgCl2	As	74.92	0.0150708	0	0.00387749
MgCl2	Fe	55.85	0.1931775	1.5695404	1.61242696
MgCl2	Mn	54.94	0.0003848	0	0.0078361
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.0452753	0.0033709	0.0196733
NaOH-HOAc	As	74.92	0.0576175	0.0269302	0.02111467
NaOH-HOAc	Fe	55.85	20.944274	5.9715957	7.4367724
NaOH-HOAc	Mn	54.94	0.0305443	0.0044879	0.00430329
NaOH-HOAc	S	32.06	0.2244234	0.1663394	0.1129991
NaOH-HOAc	P	30.97	0.5765888	0.1662643	0.10018465
AOD	As	74.92	0.0358943	0.0452027	0.04784227
AOD	Fe	55.85	2.0159416	3.5986137	5.19966485
AOD	Mn	54.94	0.0223303	0.0380525	0.05170104
AOD	S	32.06	0	0	0
AOD	P	30.97	0.0901912	0.4475379	0.37954281
Hydroxylamine HCL	As	74.92	0.1729158	0.1548411	0.15290233
Hydroxylamine HCL	Fe	55.85	7.6970434	0.0534257	41.4651038
Hydroxylamine HCL	Mn	54.94	0.0034672	0	0.26723477
Hydroxylamine HCL	S	32.06	1.1639892	3.7191605	0.9711358
Hydroxylamine HCL	P	30.97	0.4555779	0	1.89393068
Aquaregia	As	74.92	0.0061468	0.0114421	0.00865468
Aquaregia	Fe	55.85	2.480028	1.2475813	2.51404123
Aquaregia	Mn	54.94	0.0300759	0.0144236	0.03877292
Aquaregia	S	32.06	0.8727963	2.1506078	3.05203337
Aquaregia	P	30.97	0	0	0
TOTAL	As	74.92	0.2876452	0.2384162	0.23439145
TOTAL	Fe	55.85	33.330464	12.440757	58.2280093
TOTAL	Mn	54.94	0.0868025	0.056964	0.36984811
TOTAL	S	32.06	2.2612089	6.0361077	4.13616827
TOTAL	P	30.97	1.1676331	0.6171731	2.39333144

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Iron coated sand

Extraction	Element	MW (g/mol)	MW-3 mmol/kg 4/4/2008	MW-3 mmol/kg 9/4/2008	MW-3 mmol/kg 12/14/2008
MgCl2	As	74.92	0	0.0115622	0
MgCl2	Fe	55.85	0.1753861	0.4208372	0.34367108
MgCl2	Mn	54.94	0.0052093	0.0070869	0.00811113
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.0279485	0	0.10615147
NaOH-HOAc	As	74.92	0.0171496	0.002982	0.02795241
NaOH-HOAc	Fe	55.85	3.3011021	1.6951622	4.59257986
NaOH-HOAc	Mn	54.94	0.0335346	0.0025353	0.02153838
NaOH-HOAc	S	32.06	0.1275839	0	0.06966152
NaOH-HOAc	P	30.97	1.9145293	0.0546169	3.36983781
AOD	As	74.92	0.0425062	0.0529208	0.03680098
AOD	Fe	55.85	2.0516963	2.4418577	2.19659467
AOD	Mn	54.94	0.0742408	0.0889397	0.12812926
AOD	S	32.06	0	0	0
AOD	P	30.97	0.4467695	0.4826211	0.29649944
Hydroxylamine HCL	As	74.92	0.0400331	0.2217048	0.16409248
Hydroxylamine HCL	Fe	55.85	79.453216	77.265876	41.0431621
Hydroxylamine HCL	Mn	54.94	0.6127949	0.56127	0.26734204
Hydroxylamine HCL	S	32.06	1.6601202	1.497982	0.64918198
Hydroxylamine HCL	P	30.97	0.4467695	3.3237422	1.88902862
Aquaregia	As	74.92	0.016907	0.0046149	0.01950358
Aquaregia	Fe	55.85	26.727772	41.001912	37.4978225
Aquaregia	Mn	54.94	0.3784241	0.9872893	0.39525555
Aquaregia	S	32.06	0	0	0.96699466
Aquaregia	P	30.97	0.2631124	0	0.78414333
TOTAL	As	74.92	0.1165959	0.2937848	0.24834945
TOTAL	Fe	55.85	111.70917	122.82565	85.6738302
TOTAL	Mn	54.94	1.1042038	1.6471212	0.82037638
TOTAL	S	32.06	1.7877041	1.497982	1.68583815
TOTAL	P	30.97	3.0991291	3.8609803	6.44566068

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Uncoated Sand

Extraction	**Element**	**MW (g/mol)**	MW-3 mmol/kg 4/4/2008	MW-3 mmol/kg 9/4/2008	MW-3 mmol/kg 12/14/2008
MgCl2	As	74.92	0.0041488	0.0125119	0.01393796
MgCl2	Fe	55.85	0.1640235	0.2302112	0.27298111
MgCl2	Mn	54.94	0.0003968	0	0.00899167
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.0393328	0.0647572	0.12058384
NaOH-HOAc	As	74.92	0.0027456	0.014599	0.01672443
NaOH-HOAc	Fe	55.85	20.280094	10.055528	12.487024
NaOH-HOAc	Mn	54.94	0.0287959	0.0067164	0.008576
NaOH-HOAc	S	32.06	0.1853065	0.107946	0.17348623
NaOH-HOAc	P	30.97	0.4912407	0.5280956	1.1043187
AOD	As	74.92	0.0376323	0.037013	0.03486016
AOD	Fe	55.85	2.0066561	2.07543	2.14994842
AOD	Mn	54.94	0.0616856	0.0549049	0.10372708
AOD	S	32.06	0	0	0
AOD	P	30.97	0.4740117	0.4790211	0.41811084
Hydroxylamine HCL	As	74.92	0.2446123	0.2518047	0.15728774
Hydroxylamine HCL	Fe	55.85	11.553611	2.2580903	8.17185526
Hydroxylamine HCL	Mn	54.94	0.0144965	0.0062162	0.00984108
Hydroxylamine HCL	S	32.06	2.5723058	2.8625715	0.35017678
Hydroxylamine HCL	P	30.97	0.4740117	0	0.13487953
Aquaregia	As	74.92	0.0034011	0.009843	0.00879223
Aquaregia	Fe	55.85	2.1611446	2.7737203	7.85518658
Aquaregia	Mn	54.94	0.0283799	0.0528427	0.0430679
Aquaregia	S	32.06	0.6450808	0.7218432	2.14211843
Aquaregia	P	30.97	0	0	0
TOTAL	As	74.92	0.2925401	0.3257717	0.23160253
TOTAL	Fe	55.85	36.165529	17.39298	30.9369954
TOTAL	Mn	54.94	0.1337547	0.1206802	0.17420373
TOTAL	S	32.06	3.4026931	3.6923607	2.66578143
TOTAL	P	30.97	1.478597	1.0718739	1.7778929

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Iron Coated sand

Extraction	Element	MW (g/mol)	MW-4 mmol/kg 4/4/2008	MW-4 mmol/kg 9/4/2008	MW-4 mmol/kg 12/14/2008
MgCl2	As	74.92	0.0116838	0.0132029	0.01185223
MgCl2	Fe	55.85	0.2119464	1.2920468	2.52963549
MgCl2	Mn	54.94	0.0067336	0.0079852	0.01109262
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.0656532	0.0001461	0.00918535
NaOH-HOAc	As	74.92	0.0327519	0.0664478	0.08257942
NaOH-HOAc	Fe	55.85	6.9676228	13.331417	18.2362005
NaOH-HOAc	Mn	54.94	0.0363471	0.0222222	0.03596301
NaOH-HOAc	S	32.06	0.2347797	0.2035046	0.22707905
NaOH-HOAc	P	30.97	3.1833151	3.8622129	3.80850571
AOD	As	74.92	0.0409369	0.0493971	0.04714472
AOD	Fe	55.85	2.0688115	2.7195711	7.42207887
AOD	Mn	54.94	0.0799843	0.0808568	0.11409331
AOD	S	32.06	0	0	3.00920664
AOD	P	30.97	0.4967761	0.4208437	0.35526253
Hydroxylamine HCL	As	74.92	0.054913	0.2886926	0.33833273
Hydroxylamine HCL	Fe	55.85	82.5261	64.75754	58.4933341
Hydroxylamine HCL	Mn	54.94	0.6027626	0.4477738	0.39229222
Hydroxylamine HCL	S	32.06	3.1165059	9.7686358	7.33772902
Hydroxylamine HCL	P	30.97	0.4967761	4.1441545	3.7395513
Aquaregia	As	74.92	0.0685385	0.0320403	0.0369168
Aquaregia	Fe	55.85	28.696666	69.509368	51.535297
Aquaregia	Mn	54.94	0.5255536	1.8845656	0.93772187
Aquaregia	S	32.06	0	2.2579521	8.37409065
Aquaregia	P	30.97	0.1838257	0	0.07519816
TOTAL	As	74.92	0.2088241	0.4497807	0.51682589
TOTAL	Fe	55.85	120.47115	151.60994	138.216546
TOTAL	Mn	54.94	1.2513811	2.4434035	1.49116302
TOTAL	S	32.06	3.3512856	12.230093	18.9481054
TOTAL	P	30.97	4.4263461	8.4273571	7.98770306

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Uncoated Sand

Extraction	**Element**	**MW (g/mol)**	MW-4 mmol/kg 4/4/2008	MW-4 mmol/kg 9/4/2008	MW-4 mmol/kg 12/14/2008
MgCl2	As	74.92	0.002901	0	0.00858671
MgCl2	Fe	55.85	0.1546551	1.1150235	1.19801718
MgCl2	Mn	54.94	0	0	0
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0.029924	0	0.05778743
NaOH-HOAc	As	74.92	0.0110812	0.047675	0.03229367
NaOH-HOAc	Fe	55.85	17.21815	6.8506175	4.63946299
NaOH-HOAc	Mn	54.94	0.0223303	0.0071136	0.00380331
NaOH-HOAc	S	32.06	0.2160618	0.2065252	0.30223755
NaOH-HOAc	P	30.97	0.2943275	0.150665	0.09965287
AOD	As	74.92	0.0311399	0.053441	0.03931693
AOD	Fe	55.85	2.010609	3.0025426	5.39799726
AOD	Mn	54.94	0.0530531	0.0392604	0.05716157
AOD	S	32.06	0	0	0.79994293
AOD	P	30.97	0.4684346	0.4405846	0.36852606
Hydroxylamine HCL	As	74.92	0.1682433	0.143285	0.20693253
Hydroxylamine HCL	Fe	55.85	3.4314857	0.8731854	0.5725878
Hydroxylamine HCL	Mn	54.94	0.0086454	0.0021693	0.01784867
Hydroxylamine HCL	S	32.06	1.3586865	0.8368254	2.57660657
Hydroxylamine HCL	P	30.97	0.4684346	0	0
Aquaregia	As	74.92	0.0150178	0.0112546	0
Aquaregia	Fe	55.85	2.6779799	2.9514304	1.70665528
Aquaregia	Mn	54.94	0.0521917	0.0593502	0.02661412
Aquaregia	S	32.06	0.7987093	1.5019846	0.92393816
Aquaregia	P	30.97	0	0	0
TOTAL	As	74.92	0.2283832	0.2556556	0.28712984
TOTAL	Fe	55.85	25.49288	14.792799	13.5147205
TOTAL	Mn	54.94	0.1362206	0.1078936	0.10542767
TOTAL	S	32.06	2.3734576	2.5453352	4.60272521
TOTAL	P	30.97	1.2611206	0.5912495	0.52596636

APPENDIX A-7

SEQUENTIAL EXTRACTS OF SEDIMENT FROM FIELD PILOT STUDY

PILOT TEST STUDY
Avon Park Air Force Range
Avon Park, Florida

Iron Coated Sand

Extraction	Element	MW	CONTROL mmol/kg 4/4/2008	CONTROL mmol/kg 9/4/2008	CONTROL mmol/kg 12/14/2008
MgCl2	As	74.92	0.00572506	0.00573	0.00573
MgCl2	Fe	55.85	0.129631139	0.129631139	0.12963114
MgCl2	Mn	54.94	0.003468154	0.003468154	0.00346815
MgCl2	S	32.06	0	0	0
MgCl2	P	30.97	0	0	0
NaOH-HOAc	As	74.92	0.010912911	0.010912911	0.01091291
NaOH-HOAc	Fe	55.85	1.745155079	1.745155079	1.74515508
NaOH-HOAc	Mn	54.94	0.079629155	0.079629155	0.07962915
NaOH-HOAc	S	32.06	0.048557051	0.048557051	0.04855705
NaOH-HOAc	P	30.97	1.39486267	1.39486267	1.39486267
AOD	As	74.92	0.027147333	0.027147333	0.02714733
AOD	Fe	55.85	2.010872131	2.010872131	2.01087213
AOD	Mn	54.94	0.057314456	0.057314456	0.05731446
AOD	S	32.06	0	0	0
AOD	P	30.97	0.317262311	0.317262311	0.31726231
Hydroxylamine HCL	As	74.92	0.021516468	0.021516468	0.02151647
Hydroxylamine HCL	Fe	55.85	56.68589184	56.68589184	56.6858918
Hydroxylamine HCL	Mn	54.94	0.615162822	0.615162822	0.61516282
Hydroxylamine HCL	S	32.06	0	0	0
Hydroxylamine HCL	P	30.97	2.495027905	2.495027905	2.49502791
Aquaregia	As	74.92	0.004688383	0.004688383	0.00468838
Aquaregia	Fe	55.85	28.81336791	28.81336791	28.8133679
Aquaregia	Mn	54.94	0.615162822	0.615162822	0.61516282
Aquaregia	S	32.06	0	0	0
Aquaregia	P	30.97	2.495027905	2.495027905	2.49502791
TOTAL	As	74.92	0.069990155	0.069990155	0.06999015
TOTAL	Fe	55.85	89.38491809	89.38491809	89.3849181
TOTAL	Mn	54.94	1.370737409	1.370737409	1.37073741
TOTAL	S	32.06	0.048557051	0.048557051	0.04855705
TOTAL	P	30.97	6.702180792	6.702180792	6.70218079

APPENDIX B

List of Technical Publications

Onstott, T.C.; Chan, E.; Polizzotto, M.; DeFlaun, M. Precipitation of Arsenic Under Sulfate Reducing Conditions and Subsequent Leaching Under Aerobic Conditions. 2009. Applied Geochemistry. *In Press*

APPENDIX C

Other Technical Material

APPENDIX C-1

FIELD SAMPLING PROCEDURES FOR THE ANAEROBIC COLLECTION OF GROUNDWATER AND SATURATED ZONE SOIL

Prepared for:
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FIELD SAMPLING PROCEDURES FOR THE ANAEROBIC COLLECTION OF GROUNDWATER AND SATURATED ZONE SOIL

Prepared by:

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Project Number: JR0018
June 2005

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Field Sampling Procedures for the Anaerobic Collection of Groundwater and Saturated Zone Soil

Groundwater Collection

Groundwater will be sampled and collected using low-flow sampling methods. This methodology is best suited fur maintaining sample integrity by limiting hydraulic disturbances to they system while purging the well.

Pre-Sampling Procedures

Several steps are required before sampling the well. These steps ensure that instruments are functioning and properly calibrated, and that the necessary equipment has been supplied for efficient and accurate sampling.

1.1.1 Inventory

Sampling personnel will verify that they have the correct equipment, and that it is clean (decontaminated). Sampling containers will be inventoried to verify that the laboratory has provided the correct number of containers of the proper size and containing the correct preservative if required.

Field personnel will verify that they have the appropriate personal protective equipment and ancillary supplies (e.g., paper towels, decontamination solution) and that they have reviewed the site specific Health and Safety Plan. .

1.1.2 Calibration

Field personnel shall check the calibration of field probes consistent with the manufacturer's specifications and the following requirements before sampling:

1. the pH probe will be calibrated using three points (pH = 4, 7, 10) using fresh calibration solution;
2. the dissolved oxygen (DO) meter calibration will be checked with moist air (100% saturation) and to zero DO using a saturated sodium bisulfite solution; and
3. the redox potential (ORP) meter calibration will be checked using Zobell 231 mV solution.

Calibration check data will be recorded on the field calibration record provided (see attached). Instruments will be recalibrated as necessary (e.g., when calibration checks do not come within ± 10% of the expected value indicating incorrect operation) or a new instrument will be substituted to ensure accurate measurements, and all checks and recalibrations will be recorded on field calibration forms.

1.1.3 Well Purging and Sampling

Sampling is performed using a five-step procedure that will be followed upon arrival at each well:

- set-up;
- purging;
- measurement of field parameters and field testing;
- sampling; and
- clean-up and decontamination.

Detailed procedures for performing each of these steps are provided in the following subsections.

1.1.3.1 Set-up

All necessary equipment for purging, sampling and storage will be brought to the well <u>before</u> the well is opened. Equipment will be placed on a clean plastic sheet near the well. General parameters describing the well and field condition (e.g., well ID, depth, weather, date and time) will be documented on a field data sheet provided. Field personnel will review the sampling requirements for the well before proceeding. Sampling begins by opening the well and measuring the depth to the water surface. The tubing, peristaltic pump, field probes, and reservoir for purged water are then set-up.

1.1.3.2 Purging (Low Flow Protocol)

Wells are purged using the low flow/minimum drawdown protocol as described by Puls and Barcelona (1996). The general procedural requirements of low-flow purging are as follows.

- A pump that minimizes agitation in the well and contact of the water with air; typically a bladder pump is used. Due to the shallow depths being sampled at Avon Park Site ST-65, a peristaltic pump will be utilized.
- Minimize disturbance of the water column in the well by initiating pumping at a low rate.
- Begin pumping at a steady rate of 100 mL/min and measure the depth to water frequently (e.g., every minute for the first few minutes) to ensure that less than 0.1 m of drawdown occurs. The pumping may be increased if drawdown is less than 0.1 m, but the pumping rate will not exceed 500 mL/min.

- Field parameters and depth to water will be recorded on field data sheets every 5 minutes while purging. Purging will persist until pH, temperature, conductivity, E_h, dissolved oxygen concentration, and turbidity stabilize, which is defined as:

  1.2 ±0.1 units for pH

  1.3 ±3% for conductivity

  1.4 ±10 mV for E_h

  1.5 ±10% for temperature

  1.6 ±10% for turbidity and dissolved oxygen.

- Dissolved oxygen and turbidity tend to stabilize last and are better measures of sufficient purging. Drawdown will not exceed 0.1 m during purging or sampling.
- In the case that the above criteria for stabilization are not met before three well volumes have been pumped, then a total of five well volumes will be pumped before samples are taken. If, at any time during this additional purging the stabilization criteria are met for three consecutive data logging events, then samples are taken at that point.

Sampling equipment will consist of disposable polyethylene tubing installed in the well just prior to sampling. Typically, the tubing is placed in the well to insure that the intake is at the midpoint of the well screen. Placing the tubing into the midpoint of the well screen ensures that a representative water quality sample is collected from the formation rather than from potentially stagnant water within the well casing. At the wellhead, the peristaltic pump and discharge tubing will be connected to a low-flow sampling cell. The low-flow sampling cell is equipped with four water quality probes to monitor field parameters during the purge cycle.

At Avon Park well 43103-MW will be sampled. This well is screened from 2 to 12 feet bgs. A depth profile of the field parameters will be performed to assess the depth at which the lowest redox conditions occur. The depth profile will start at 4 feet bgs or at 1 foot below the current water table depth whichever is shallower. Once the parameters have stabilized at this location the tube will be lowered 2 feet and the operation repeated. This will continue every 2 feet until 11 feet bgs, or approximately one foot above the bottom of the screen.

Water-levels will be measured during the low flow sampling procedure to document minimal drawdown. This qualitative check insures that the water quality sample collected represents formation water rather than stagnant water from the well casing. Prior to water-quality sample collection, well purging will continue until at least three consecutive rounds of field measured parameters agreed within 5% or until a total of five well volumes were pumped.

Water quality samples for volatiles will be collected directly from the polyethylene tubing using reverse flow techniques. The groundwater filled purge tubing is removed from the well and the peristaltic pump is run in reverse to fill the sample containers. Inorganic parameters will be sampled directly through the pump head, with new pump-head tubing used at each well). All water-quality samples are immediately placed into a cooler with ice to maintain sample integrity and to preserve chain of custody. All sampling and decontamination activities are performed in general accordance with the FDEP Standard Operating Procedure (SOP)-001/01 (Field Procedures).

Field analyses of ground water quality samples were acquired using dedicated single and multi-parameter instruments for the following parameters;

- dissolved oxygen (DO) via EPA Method 4500-0;
- reduction-oxidation (redox) potential via EPA Method 2580 B;
- hydrogen-ion concentration (pH) via EPA Method 4500-H+;
- conductivity via EPA Method 2510 B;
- temperature via EPA Method 2550 B; and
- turbidity via EPA Method 2130 B.

The groundwater samples will be hand delivered to Xenco Laboratories, Inc. (Xenco) in Tampa, Florida, for analysis of volatile organic compounds (VOCs) according to EPA Method 8260b and dissolved and total arsenic (EPA 200.7). Samples for sulfate (EPA 300.0) and sulfide (EPA 376.1) will also be collected.

Approximately 40 liters of ground will be collected by low-flow into 6-5 liter polyethylene bottles sealed with no headspace and taped closed. These will be shipped along with soil to Dr. T.C. Onstott at Princeton University.

Soil Collection

Saturated zone soils will be collected from a location within approximately 5 ft. downgradient of well 43103-MW. Soil samples will be collected from the depth at which the lowest redox values were detected during groundwater field parameter measurements. Approximately 10 kg of soils will be needed for the column studies; the soils will be sent to Princeton University. These samples will be collected in a manner that will minimize exposure of the soils to the atmosphere in order to preserve the *in situ* geochemistry.

Soil samples will be collected with a direct push rig equipped to collect subsurface soil samples with a Dual Wall Split Spoon Sampler which will help to preserve the geochemical integrity of these samples.

The Dual Wall split spoon or window sheath sampler is loaded with the desired sample liner/liners and installed inside the outer casing. Simultaneously, the outer drive casing and inner split spoon sample barrel are advanced 2, 4, or 5 feet, depending on sampling system application. As these tools are advanced, the inner sampling barrel collects the soil core sample. This sampler is then retrieved while the outer casing remains in place, protecting the integrity of the hole. A new sampler is lowered into place, and advanced further to collect the next soil sample. This process continues until a desired depth has been reached. The dual wall sampling system also provides discrete depth soil and groundwater sampling. Using a locked drive point, the dual wall sampling system is advanced, displacing the soils until a desired depth has been reached. Discrete samples of 2 ft in length will be collected in a liner, capped, the cap will be taped on and the core is stored on ice for immediate shipping.

APPENDIX C-2

FIELD SAMPLING PROCEDURES FOR THE COLLECTION OF GROUNDWATER FOR PILOT STUDY ANALYSIS

FIELD SAMPLING PROCEDURES FOR THE ANAEROBIC COLLECTION OF GROUNDWATER AND SATURATED ZONE SOIL

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AcOH Volume Test

The cooler contains three sets of vials with which the Acetic Acid Concentration Test will be performed. Three separate wells will be sampled for this test: 1 upgradient, 1 mid-point monitoring well, and 1 downgradient. The procedure follows:

1. Each vial has been lab preserved with EDTA (solid)
2. Fill each vial with water sample to the 10mL mark on the Falcon tube
3. Add provided Acetic Acid in VARYING volumes to each tube using the auto pipette and tips according to the following scheme (each vial is labeled accordingly):
    a. Vial 1: NO Acetic Acid
    b. Vial 2: 10µL
    c. Vial 3: 25µL
    d. Vial 4: 50µL
    e. Vial 5: 75µL
    f. Vial 6: 100µL
4. Allow vials to sit in fridge overnight
5. On the next day, check the samples for signs of iron oxides (discoloration)
6. Record the LOWEST acetic acid volume used at which there is no evidence of iron oxide formation
7. This volume of acetic acid will be used when preserving future dissolved arsenic samples
8. Compare this value for acetic acid volume between wells to determine whether a site-wide value is appropriate. NOTE: If, for example, two wells show that 10µL of acetic acid is sufficient and the other shows that 25µL is needed, 25µL may be applied to the entire site
9. Dispose of samples

Dissolved Arsenic

1. Vials are lab preserved with EDTA (solid)
2. Filter water sample through in-line **0.45µm filter** into **small, clean container**
3. Pull up 10mL into disposable syringe
4. Attach 0.2µm syringe filter and push liquid through filter into vial
5. Add provided Acetic Acid at the volume determined by the previously performed Acetic Acid volume test into vial
6. Label the vials with the Well ID and date collected
7. Store the vials in a freezer overnight
8. Ship frozen the next day to Princeton University (address provided on field form)

Anions

1. Vials are unpreserved
2. Filter samples according to steps 2-4 from Dissolved Arsenic protocol
3. Prepare samples for shipment according to steps 6-8 from Dissolved Arsenic protocol

Sulfide

1. Vials are lab preserved with N_2 gas
2. Collect water sample into **small, clean container**
3. Attach syringe needle to disposable syringe and pull up 10mL
4. Remove small metal piece from top of vial (middle of cap)
5. Pierce rubber stopper with syringe needle and inject water sample into vial
6. Repeat injections until fill line is reached (top of label on each vial)
7. If air pressure resists attempt to fill with water, vent the gas by piercing the stopper with an empty syringe and pulling air out
8. Prepare samples for shipment according to steps 6-8 from Dissolved Arsenic protocol

Cations, filtered

1. Vials are lab preserved with HNO_3
2. Filter samples according to steps 2-4 from Dissolved Arsenic protocol
3. Label the vials with the Well ID and date collected
4. Store the vials in a cooler and maintain at 4°C
5. Ship samples on blue ice overnight

Cations, unfiltered

1. Vials are lab preserved with HNO_3
2. Fill each vial with water sample to the 10mL mark on the Falcon tube
3. Prepare samples for shipment according to steps 3-5 from Cations, filtered protocol

Methane/CO_2

1. Vials are lab preserved with $HgCl_2$ and N_2 gas
2. Collect samples according to steps 2-7 from Sulfide protocol, but fill vial completely, leaving NO headspace
3. Prepare samples for shipment according to steps 3-5 from Cations, unfiltered protocol