D-Area Coal Pile Runoff Basin Groundwater Treatability Study Preliminary Report

by

F. A. Washburn

Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

M. E. Denham

M. A. Phifer

F. C. Sappington

RECEIVED
DEC 21 1998
OSTI

DOE Contract No. **DE-AC09-89SR18035**

This paper was prepared in connection with work done under the above contract number with the U. S. Department of Energy. By acceptance of this paper, the publisher and/or recipient acknowledges the U. S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper, along with the right to reproduce and to authorize others to reproduce all or part of the copyrighted paper.

D-AREA COAL PILE RUNOFF BASIN GROUNDWATER

TREATABILITY STUDY PRELIMINARY REPORT (U)

SEPTEMBER 1998

UNCLASSIFIED

Does Not Contain Unclassified Nuclear Information (UCNI)

ADC and Reviewing Official

A handwritten signature in dark ink, appearing to read "D.B. Moore-Shedrow", is written over a horizontal line.

D.B. Moore-Shedrow

Manager,

Environmental Science & Technology Department

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29801

Prepared for the US Department of Energy under Contract DE-AC09-89SR18035

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

**D-AREA COAL PILE RUNOFF BASIN GROUNDWATER
TREATABILITY STUDY WORK PLAN (U)**

Revision 0 Prepared By:

F.A. Washburn
Environmental Sciences and Technology Department
Savannah River Technology Center

M.E. Denham
Environmental Sciences and Technology Department
Savannah River Technology Center

M.A. Phifer
Environmental Sciences and Technology Department
Savannah River Technology Center

F.C. Sappington
Environmental Sciences and Technology Department
Savannah River Technology Center

Reviewed and Approved By:

J.G. Sonnenberg
Manager, Environmental Restoration Technology
Environmental Sciences and Technology Department
Savannah River Technology Center

TABLE OF CONTENTS

LIST OF ACRONYMS	7
EXECUTIVE SUMMARY	8
1. INTRODUCTION	11
1.1. Site Description and History	11
1.2. Waste Characteristics	11
1.3. Project Description/DOE Needs	13
1.4. Groundwater Characterization	13
2. TREATABILITY STUDY OBJECTIVES	14
2.1. General	14
2.2. Functional Performance Requirements	15
2.2.1. Ex-Situ Treatment Media Evaluation	15
2.2.2. D-Area GeoSiphon Treatment System Conceptual Design	15
3. D-AREA EX SITU TREATMENT MEDIA EVALUATION	15
3.1. Test Objectives/Rationale	15
3.2. Technology/Process Description	16
2.1.3. Ex Situ Treatment Media Evaluation	16
3.2.2. Existing Barrier Wall System	16
3.2.3. GeoSiphon Treatment System Conceptual Design	17
3.3. Technology Applications	17
3.4. Technology Benefits	18
4. TEST STRATEGY AND DESIGN	19
4.1. Test Campaigns	19
4.1.1. Field Run #1 (2/98-3/98)	19
4.1.2. Field Run #2 (4/98)	19
4.1.3. Field Run #3 (7/98-8/98)	19
4.1.4. Lab Test #1 (5/98)	20
4.1.5. Lab Test #2 (6/98)	20
4.1.6. Lab Test #3 (7/98)	20
4.1.7. Lab Test #4 (9/98)	20

4.2	Experimental Design	20
4.2.1	Field Run #1	20
4.2.2	Field Run #2	21
4.2.3	Field Run #3	24
4.2.4	Lab Test #1	24
4.2.5	Lab Test #2	26
4.2.6	Lab Test #3	27
4.2.7	Lab Test #4	28
4.3	Equipment, Materials & Methods	29
4.3.1	Field Run #1	29
4.3.2	Field Run #2	30
4.3.3	Field Run #3	30
4.3.4	Lab Test #1	30
4.3.5	Lab Test #2	31
4.3.6	Lab Test #3	31
4.3.7	Lab Run #4	32
4.4	Sampling and Analysis	32
4.5	Quality Control	39
4.6	Deviations	39
5.	RESULTS AND DISCUSSION	39
5.1	Field Run #1	39
5.1.1	Initial Design Concept Prior to Media Studies	39
5.1.2	Field Observations Field Run 1	41
5.1.3	Data Observations Field Run 1	43
5.2	Field Run #2	59
5.2.1	Revised Design Concept following Field Run 1	59
5.2.2	Field Observations Field Run 2	60
5.2.3	Data Observations Field Run 2	61
5.3	Field Run #3	66
5.3.1	Conceptual Design	66
5.3.2	Field Observations Field Run 3	67
5.3.3	Data Observations Field Run 3	68
5.4	Laboratory Test #1	73
5.4.1	Laboratory Observations	73
5.4.2	Data Observations Lab Test #1	74
5.5	Laboratory Test #2	81
5.5.1	Laboratory Observations	81
5.5.2	Data Observations Lab Test #2	81
5.6	Laboratory Test #3	86
5.6.1	Laboratory Observations	86
5.6.2	Data Observations Lab Test #3	87
5.7	Laboratory Test #4	90

5.7.1	Laboratory Observations	90
5.7.2	Data Observations Lab Test #4	90
5.8	System Chemistry	93
6.	CONCLUSIONS, RECOMMENDATIONS, AND GEOSIPHON TREATMENT SYSTEM CONCEPTION DESIGN	95
7.	KEY CONTACTS AND PARTICIPANTS	97
8.	REFERENCES	98
9.	APPENDICES	98

LIST OF ACRONYMS

CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CPRB	Coal Pile Runoff Basin
DOE	Department of Energy
Eh	Redox potential referenced to the standard hydrogen electrode
EM	Environmental Management
ERD	Environmental Restoration Department
FFA	Federal Facilities Agreement
FY	Fiscal Year
gpm	Gallons per minute
HDPE	High Density Polyethylene
HQ	Headquarters
MG	Million gallons
MGD	Million gallons per day
NPDES	National Pollutant Discharge Elimination System
OST	Office of Science and Technology
pH	pH (A measurement of groundwater acidity: $-\log[H^+]$)
RCRA	Resource Conservation and Recovery Act
S	Sulfur
SRS	Savannah River Site
TS	Treatability Study
TSR	Treatability Study Report
WSRC	Westinghouse Savannah River Company

EXECUTIVE SUMMARY

This document presents the Treatability Study Preliminary Report for the D-Area Coal Pile Runoff Basin (CPRB) Groundwater at the Savannah River Site. The groundwater at this facility is similar to acid mine drainage with low pH and elevated concentrations of metals. The groundwater is contaminated as a result of contaminants migrating from the bottom of the D-Area Coal Pile Runoff Basin to the groundwater. The D-Area CPRB is a permitted wastewater treatment facility with a National Pollutant Discharge Elimination System permitted discharge for the treatment of runoff from the D-Area coal pile. The basin was designed as a sedimentation/seepage basin for the removal of suspended solids and to minimize the direct discharge of coal pile runoff to Beaver Dam Creek.

The D-Area Coal Pile Runoff Basin groundwater is contaminated and requires response per the CERCLA process in accordance with the Federal Facility Agreement for the Savannah River Site. Another project at the D-Area CPRB was implemented during fiscal years 1994 through 1996 involving the design, installation, and testing of a barrier wall system within the most contaminated portion of the D-Area CPRB groundwater plume. The objective of this project is to demonstrate the utilization of the existing barrier wall system as part of a treatment system for the metals contaminated groundwater at the D-Area Coal Pile Runoff Basin, and to evaluate various permeable treatment media or combinations of media for the treatment of this groundwater. The primary objective of the treatment system is to remove metals from the groundwater.

The utilization of the existing barrier wall system to produce a treatment system for the metals contaminated groundwater at the D-Area Coal Pile Runoff Basin will be accomplished in two phases: (1) *Ex situ* treatment media evaluation and (2) D-Area GeoSiphon Treatment System conceptual design.

The *ex situ* treatment media evaluation is a treatability study conducted at the D-Area Coal Pile Runoff Basin utilizing the actual contaminated groundwater. Treatment media evaluated included: limestone, rock phosphate (apatite), iron, peat, and zeolites and various phosphate compounds. The tests were conducted at the D-Area Coal Pile Runoff Basin using the existing barrier wall system (DIW-1, Interceptor Well) and surrounding monitoring wells to extract the contaminated groundwater for testing. The field treatment media was contained in in-line canisters, and influent and effluent samples were taken for chemical analysis to determine the effectiveness of each treatment media.

Seven campaigns were completed for this test:

- Field Run 1 – Contact Media Test
- Field Run 2 – Non Contact Media Test
- Field Run 3 – Reactive/Precipitative Contact Media Test
- Lab Test 1 – Non-Contact Soluble Phosphate Media
- Lab Test 2 – Non-Contact Soluble Phosphate Media (con't)
- Lab Test 3 – Particle Size and Contact Time Study
- Lab Test 4 – Aeration Study

Based on initial conditions, a minor pH adjustment was sufficient to precipitate the chromium phases in our groundwater. Nickel, on the other hand, was more difficult to precipitate by pH adjustment alone. Even at high dissolved phosphate concentrations (9500 mg/L), nickel phosphates will only precipitate after a considerable increase in pH. For this reason, it is assumed that nickel must co-precipitate with other metals. The presence of high concentrations of iron in the groundwater provides a potential mechanism for nickel removal by co-precipitation with iron phases.

As determined from Field Run #1, removal of the contaminants of concern by precipitation in the first bulk precipitation canister and by cation exchange or further increases in pH in the second polishing canister. From the preliminary results of Field Run #1, it appears as long as the bulk precipitation process is successful, the polishing process works rather well. Significant emphasis was placed on these campaigns to refine the bulk precipitation process. It should be noted that the overall treatment process should consider all potential combinations to provide the best possible treatment.

While results are preliminary, the following general overall conclusions for the entire operating regime are deduced:

- Both aluminum and chromium can be effectively treated with limestone and phosphate
- Iron can also be treated with limestone and phosphate.
- While iron is significantly removed, treatments are not as effective as those for aluminum and chromium.
- Treatments that enhance iron removal also enhance nickel removal
- Nickel is probably co-precipitated with iron.

The following should be considered for further evaluation:

- All data should be looked at in greater detail by statistical analysis, mass balance, etc.
- Comparison of data and treatment effectiveness should be performed
- In particular, ammonium phosphate should be evaluated more closely due to its performance in Run #4.

These recommendations are being considered in FY99.

Based on the preliminary data results and field observations, a conceptual design which includes GeoSiphon cells is under evaluation. GeoSiphon Cells are passive groundwater treatment systems which utilize siphon flow between two points of natural head difference to induce greater than natural contaminated groundwater flow through a treatment train without the requirement for external energy input. The treatment train utilized in GeoSiphon Cells can include permeable treatment materials, aeration, chemical addition, etc.

The conceptual GeoSiphon Cell configuration includes extraction of the contaminated water from the mound created by the barrier wall system by siphon to a downgradient treatment system which may consist of an oxidizing step such as aeration followed by a permeable treatment media or treatment media combination. The siphon flow will be induced by the natural hydraulic head difference between the mound upgradient of the wall and the adjacent D-Area discharge stream, which is a lower hydraulic head. Further development of this concept is anticipated in FY99.

Advantages of this conceptual design include:

- Utilization of the existing barrier wall system as part of a treatment system for the D-Area CPRB metals contaminated groundwater. The existing barrier wall system represents a significant past Office of Science and Technology (OST) investment.
- Utilize natural hydraulic driving forces to induce flow for remediation.
- Treatment within the most heavily contaminated portion of the D-Area CPRB plume.
- Removable treatment options so that heavy metals can be collected and recycled.
- Potentially accelerate clean up, can be applied to a broader range of site conditions, and can increase treatment media longevity and effectiveness.
- Minimize media armoring and/or cementation, and formation pluggage.
- Directly meeting the needs of the EM-40 program (Environmental Restoration).

All work will be conducted in conjunction with the SRS Environmental Restoration Department to assure that the work will meet the end users needs and conform to regulatory expectations.

1. INTRODUCTION

1.1. *Site Description and History*

This document presents the Treatability Study Preliminary Report for the D-Area Coal Pile Runoff Basin (CPRB) Groundwater at the Savannah River Site (SRS). The D-Area Coal Pile Runoff Basin is a permitted wastewater treatment facility with a National Pollutant Discharge Elimination System (NPDES) permitted discharge (D-001B) for the treatment of runoff from the D-Area coal pile. The basin was designed as a sedimentation/seepage basin for the removal of suspended solids and to minimize the direct discharge of coal pile runoff to Beaver Dam Creek. The CPRB is also listed in the Federal Facility Agreement (FFA) for the Savannah River Site as a RCRA/CERCLA unit. Figure 1 shows the location of the basin.

The basin was built in 1978. It has an average bottom elevation of 121.0 feet, a top of berm elevation of 125.5 feet, an operating water level elevation of between 121.0 and 124.5 feet, valved discharge piping capable of draining the basin to 121.0 feet, and a concrete emergency spillway at an elevation of 124.84 feet. It has a surface area, operating volume, and maximum volume of 12.5 acres, 10 to 13 million gallons (MG), and 14.5 MG, respectively. The runoff from the D-Area coal pile contained in the basin is drained at an estimated 75 to 100 gallons per minute (gpm), through discharge piping to a natural discharge ditch that drains to Beaver Dam Creek, whenever the basin water elevation reaches approximately 124.5 feet. The discharge ditch has a long-term flow of 55.8 million gallons per day (MGD).

1.2. *Waste Characteristics*

The 484-D PowerHouse burns coal to produce electricity and steam for use at SRS. In general a 90 day supply of moderate to low sulfur coal (1-2% S) is stored in an open, 8.9 acre pile adjacent to the 484-D PowerHouse. The coal is not rotated which may result in long-term exposure of some coal to the environment. Long term chemical and biological oxidation of the sulfur compounds produces sulfuric acid. Rain water along with the sulfuric acid leach other impurities from the coal. This produces an acidic runoff with substantial metals contamination which is collected and discharged via gravity drainage to the CPRB. This runoff predominately seeps into the water table aquifer through the bottom of the CPRB. The D-Area Coal Pile Runoff Basin groundwater is contaminated with low pH, and elevated concentrations of iron, aluminum, sulfate, chromium, and nickel with lesser amounts of trichloroethylene, cadmium, and lead.

D-Area Coal Pile Runoff Basin Location Map

Figure 1 - Location of the D-Area Coal Pile Runoff Basin

1.3. **Project Description/DOE Needs**

The D-Area Coal Pile Runoff Basin groundwater is contaminated and requires response per the CERCLA process in accordance with the Federal Facility Agreement for the Savannah River Site. Another project at the CPRB was implemented during fiscal years 1994 through 1996 involving the design, installation, and testing of a barrier wall system within the most contaminated portion of the D-Area CPRB groundwater plume. The objective of this project is to demonstrate the utilization of the existing barrier wall system as part of a treatment system for the metals contaminated groundwater at the CPRB, and to evaluate various permeable treatment media or combinations of media for the treatment of this groundwater. The primary objective of the treatment system is to remove metals from the groundwater.

The utilization of the existing barrier wall system to produce a treatment system for the metals contaminated groundwater at the Coal Pile Runoff Basin will be accomplished in two phases:

- *Ex situ* treatment media evaluation.
- D-Area GeoSiphon Treatment System conceptual design.

Further development of the GeoSiphon Treatment system is anticipated in FY99.

Four area programs have registered their need for a passive groundwater treatment system for metals and/or radionuclides:

- Innovative Technologies to Replace Pump and Treat Technologies for Groundwater Remediation (SR-3018)
- Availability of Innovative Treatment for Radionuclide and Metal Contamination in Groundwater (AL-97-09-02-SC)
- Remediation of Strontium-90 Contaminated Groundwater (CH0001)
- Reactive Barrier Treatment Systems (HY13)

1.4. **Groundwater Characterization**

Table 1 provides information on the influent, groundwater, and effluent water quality associated with the CPRB. The groundwater data is based upon maximum well results in the vicinity of the existing barrier wall system (wells DCB-1A, -10, -18A, -18B, -18C, -19B, -19C, -21B, -21C, -22A, -22B, and -22C). This groundwater is very acidic (pH is approximately 2.2) and is contaminated primarily with sulfate, iron, aluminum, chromium, and nickel as a result of impurities leached from the coal pile.

2. TREATABILITY STUDY OBJECTIVES

2.1. General

The acceptance criteria associated with this technology includes the following:

- A suitable permeable treatment media or combination of media identified for the treatment of the D-Area CPRB metals contaminated groundwater.
- The removal of metals from the contaminated groundwater.

Table 1. D-Area Coal Pile Runoff Basin Water Quality

Parameter	Influent ¹	Groundwater ²	Effluent ³	NPDES Outfall D-001B Limits ³
Aluminum, ppb	398,000	301,000	40,200	-
Arsenic, ppb	135	LD	NA	-
Barium, ppb	LD	35.5	NA	-
Beryllium, ppb	NA	177	NA	-
Cadmium, ppb	74	11.8	NA	-
Chromium, ppb	329	182	NA	-
Cobalt, ppb	NA	1970	NA	-
Copper, ppb	2,230	418	NA	-
Iron, ppb	1.45x10 ⁶	2.16x10 ⁵	174,000	-
Lead, ppb	2.5	LD	NA	-
Magnesium, ppb	308,000	132,000	17,800	-
Manganese, ppb	59,000	104,000	2,380	-
Mercury, ppb	0.15 (0.185) ⁴	2.12 ⁵	NA	-
Nickel, ppb	7,900	1,660	NA	-
Nitrate/Nitrite as N, ppb	NA	537	NA	-
pH	2.26	2.2	6.6 ⁶	6-9 ⁶
Selenium, ppb	6.3	LD	NA	-
Sulfate, ppb	8.46x10 ⁶	8.43x10 ⁶	1.0x10 ⁶	-
TCE, ppb	NA	80.4	NA	-
Total Organic Carbon, ppb	NA	4920	NA	-
Total Suspended Solids, ppb	54,000	NA	1,700	50,000
Vanadium, ppb	NA	59.1	NA	-
Zinc, ppb	14,100	5,080	1,040	-
Gross Alpha ⁷ , pCi/L	NA	176	NA	-
Nonvolatile Beta ⁷ , pCi/L	NA	66.7	NA	-
Radium ⁷ , pCi/L	NA	2.91	NA	-
Tritium, pCi/ml	NA	9.21	NA	-

Notes for Table 1:

-NA = Not Analyzed

-LD = less than detection limit

¹ SRL-ESS-89-745 (internal October, 1985 composite sample results).

² Maximum concentrations from wells DCB-1A, -10, -18A, -18B, -18C, -19B, -19C, -21B, -21C, -22A, -22B, and -22C from the EMS Groundwater Characterization of the D-Area Coal Pile, Coal Pile Runoff Basins and Ash Basins, February, 1997).

³ NPDES monitoring results for NPDES Outfall D-001B from January, 1993 through January, 1994. SCDHEC requires monitoring for Al, Fe, Mg, Mn, SO₄, Zn, pH, and TSS, however discharge limits are only established for pH and TSS. The pH limit applies at the D-001 outfall following flow augmentation. The TSS limit applies at the D-001B outfall.

⁴ The influent mercury value of 0.15 ppb represents only one composite sample result. In order to provide a better statistical comparison to the groundwater mercury results the composite sample results from the A, C, H, K, and P-Area coal pile runoff have been combined with the results from D-Area resulting in an average of 0.185 ppb mercury in the coal pile runoff.

⁵ There was only one well showing a mercury concentration above the primary drinking water standard of 2 ppb. The mercury detection limit was 0.7 ppb.

⁶ pH measurements and limit applicable to the D-001 outfall. Actual surface water pH within the basin has been recorded at 2.44 (SREL 1988-1989 analyses) and 2.13 (Anderson, et al., 1991).

⁷ Gross alpha, nonvolatile beta, and radium concentrations in the groundwater are above background well concentrations due to natural radionuclides associated with the coal or leached from the soil (there are no known non-natural sources of radionuclides at this location).

2.2. Functional Performance Requirements

Functional performance requirements for each section of the test are listed below. Further development of the GeoSiphon Treatment system is anticipated in FY99.

2.2.1. Ex-Situ Treatment Media Evaluation

- Design of the treatment train shall allow for easy exchange of canisters and configurations.
- The *ex situ* treatment systems shall be designed to withstand pressure loss associated with the treatment media uptake capacity.
- The *ex situ* treatment system shall be designed for ambient conditions.
- The *ex situ* system shall have the capacity to operate from 0 to 10 gallons per minute.
- The maximum operating pressure of the system shall be 15 psig.
- Materials of construction shall be compatible with the treatment media and the groundwater characteristics.

2.2.2. D-Area GeoSiphon Treatment System Conceptual Design

- The GeoSiphon treatment system shall be designed for ambient conditions.
- The GeoSiphon treatment system shall have the capacity to operate at 10 gallons per minute or less.
- Materials of construction shall be compatible with the treatment media and the groundwater characteristics.
- The design of the treatment system shall allow for easy exchange/replacement of media.
- The design shall utilize natural hydraulic driving forces to induce flow for remediation.

3. D-AREA EX SITU TREATMENT MEDIA EVALUATION

3.1. Test Objectives/Rationale

The D-Area Coal Pile Runoff Basin (CPRB) groundwater is contaminated with low pH, iron, aluminum, sulfate, chromium, and nickel with lesser amounts of trichloroethylene, cadmium, and lead. The CPRB requires remediation per the CERCLA process in accordance with the Federal Facility Agreement (FFA) for the Savannah River Site. An investment at the CPRB was made during fiscal years 1994 through 1996 in the design, installation, and testing of a barrier wall system within the most contaminated portion of the D-Area CPRB plume. The objective of this testing was to evaluate various permeable treatment media or combinations of media for the treatment of this groundwater. The results of this effort will be used to design, construct and test a treatment system for the metals contaminated groundwater at the CPRB in conjunction with the existing barrier wall system.

3.2. *Technology/Process Description*

2.1.3. **Ex Situ Treatment Media Evaluation**

The ex situ treatment media evaluation was a permeable treatment media treatability study conducted at the CPRB utilizing the actual contaminated groundwater. The following treatment media were used in the evaluation: limestone, rock phosphate (apatite), granular cast iron, peat (Sphagnum Moss), zeolite (Clinoptilolite), potassium phosphate, sodium phosphate, ammonium phosphate, calcium phosphate and potassium phosphate using limestone and/or phosphate rock as a reactive matrix. The field tests were conducted at the D-Area CPRB utilizing the existing barrier wall system (DIW-1-2, Interceptor Well) and surrounding monitoring wells to extract the contaminated groundwater for above grade testing. The treatment media or reactive media for the field studies was contained in in-line canisters, and samples were taken for chemical analysis to determine the effectiveness of each treatment process. The treated groundwater was subsequently released to the D-Area CPRB. The information produced from the treatability study will feed into the subsequent D-Area GeoSiphon Treatment System design, installation and testing using the existing barrier wall system.

3.2.2. **Existing Barrier Wall System**

A demonstration of the barrier wall system was conducted adjacent to the CPRB. The barrier wall system utilizes trench and guidebox construction techniques to install high-density polyethylene (HDPE) vertical barriers below grade. In its application at the CPRB, a vertical HDPE barrier was installed and combined with a groundwater recovery system in the same trench to produce an interceptor well. The D-Area barrier wall/interceptor well (DIW-1) was installed at the northwest corner of the D-Area CPRB to a depth of 30 feet. The barrier wall/interceptor well bottom does not tie into the underlying aquitard, but it is approximately 30 feet above the aquitard. This produced a hanging or partially penetrating barrier wall.

The barrier wall/interceptor well has an innovative design which maximizes the collection of upgradient contaminated groundwater while minimizing the collection of downgradient groundwater. It also provides for a more even distribution of groundwater collection across the entire width of the contaminant plume. The segregation of upgradient and downgradient groundwater is achieved by the installation of a vertical high density polyethylene (HDPE) membrane as part of the well immediately downgradient from the gravel pack and well screens. Even distribution of groundwater collection across the plume width is achieved in two ways. First, it is achieved by installation of a continuous gravel pack along the entire length of the HDPE membrane. The gravel pack provides complete groundwater interception and collection along its entire depth and length.

Second, by installation of horizontal slotted drainage pipe within the gravel pack parallel to the HDPE membrane, which tie into a central well sump. These horizontal drainage pipes flatten out and extend the drawdown curve throughout the gravel pack, which facilitates flow from the ends toward the central, vertical well screens. Multiple vertical well screens all attached to one well sump, along with the horizontal drainage pipes, provide centralized collection of the groundwater for extraction purposes. Two vertical well screens are extended to the surface with casing for groundwater extraction

The existing D-Area barrier wall system produces mounding of the groundwater upgradient of the wall, which produces a significant head differential between the groundwater upgradient of the wall and the adjacent discharge stream. This head differential can be utilized to drive a GeoSiphon treatment system.

3.2.3. GeoSiphon Treatment System Conceptual Design

GeoSiphon Cells are passive groundwater treatment systems which utilize siphon flow between two points of natural head difference to induce greater than natural groundwater flow through a treatment system without the requirement for external energy input. A treatment system used in GeoSiphon Cells can include permeable treatment materials, aeration, chemical addition, etc.

The conceptual GeoSiphon Cell configuration includes extraction of the contaminated water from the mound created by the barrier wall system by siphon to a downgradient treatment system which may consist of an oxidizing step such as aeration followed by a permeable treatment media or treatment media combination. The siphon flow will be induced by the natural hydraulic head difference between the mound upgradient of the wall and the adjacent D-Area discharge stream, which is a lower hydraulic head. Further development of this concept is anticipated in FY99.

3.3. Technology Applications

The 489-D D-Area Coal Pile Runoff Basin (CPRB) and the 488-D D-Area Ash Basin are listed RCRA/CERCLA units as outlined in the Federal Facility Agreement (FFA) for the Savannah River Site (SRS). These sites are currently entering the Remedial Investigation/Baseline Risk Assessment phase of the CERCLA process. The SRS Environmental Restoration Department (ERD) is seeking low maintenance and low operating cost remediation alternatives other than pump and treat for both the CPRB and the Ash Basin. The GeoSiphon treatment system is a low maintenance and low operating cost alternative to pump and treat. As such ERD has assumed that this technology will be applied at both the CPRB and the 488-D Ash Basin, if positive results are obtained from the work conducted under this project. The work conducted under this project will be

incorporated into the CERCLA process for the CPRB and Ash Basin through preparation of a Treatability Study Test Plan and a subsequent Treatability Study Report. The information produced and documented will feed into the CERCLA Feasibility Study and the subsequent CERCLA Proposed Plan for the CPRB and Ash Basin and will be made available to the public.

ERD is an integral part of the D-Area Remediation Technical Team. All work associated with this project has been conducted in conjunction with ERD to assure that work will meet the end users needs and conform to regulatory expectations.

Additionally, ERD demonstrated their strong support for passive in situ treatment systems by providing funding in FY97 and in FY98 to fund the installation and testing of a GeoSiphon cell in the contaminated groundwater at the SRS TNX Area. The TNX Demonstration GeoSiphon Cell was installed in July 1997 and Phase I testing occurred from 8/5/97 to 2/5/98. Phase II testing began on 6/18/98. To further elaborate ERDs commitment for a passive treatment system, a second GeoSiphon cell was installed in the TNX area in September 1998. Lessons learned and end user needs identified from the GeoSiphon Cell work is directly transferable to the work conducted under this project.

This project also addresses the Savannah River Site (SRS) need for in-situ or ex-situ ground water treatment technologies for hazardous constituents in unconsolidated subsurface sediments (i.e. sandy/clayey soils) associated with the metals and sulfate contamination in the ground water at D-Area. The results of this treatability study will be applicable to other metals contaminated sites throughout the DOE complex.

3.4. ***Technology Benefits***

The benefits of this technology include:

- Evaluation of various permeable treatment media or combinations of media for the treatment of the D-Area CPRB contaminated groundwater.
- Utilization of the existing barrier wall system as part of a treatment system for the D-Area CPRB metals contaminated groundwater. The existing barrier wall system represents a significant past Office of Science and Technology (OST) investment.
- Treatment within the most heavily contaminated portion of the D-Area CPRB plume.
- Removable treatment options so that heavy metals can be collected and recycled.
- Potentially accelerate clean up, can be applied to a broader range of site conditions, and can increase treatment media longevity and effectiveness.
- Minimize media armoring and/or cementation, and formation plugging.
- Utilize natural hydraulic driving forces to induce flow for remediation.

- Directly meeting the needs of the EM-40 program (Environmental Restoration).
- While costs savings over the baseline can not yet be determined, it is anticipated that a passive treatment system will significantly reduce the operation and maintenance costs associated with the presumptive baseline, pump and treat system.

4. TEST STRATEGY AND DESIGN

4.1. Test Campaigns

The ex situ treatment media evaluation is a permeable treatment media treatability study conducted at the CPRB utilizing the actual contaminated groundwater. The following treatment media were used in the evaluation: limestone, rock phosphate (apatite), granular cast iron, peat (Sphagnum Moss), zeolite (Clinoptilolite), potassium phosphate, sodium phosphate, ammonium phosphate, calcium phosphate and potassium phosphate using limestone and/or phosphate rock as a reactive matrix. The field tests were conducted at the D-Area CPRB utilizing the barrier wall system (DIW-1-2, Interceptor Well) and surrounding monitoring wells to extract the contaminated groundwater for above grade testing. The treatment media or reactive media was contained in in-line canisters, and samples were taken for chemical analysis to determine the effectiveness of each treatment process. The treated groundwater was subsequently released to the D-Area CPRB. Three field runs/test campaigns and four laboratory tests were conducted. The information produced from this treatability study will be incorporated into the subsequent D-Area GeoSiphon Treatment System design, installation and testing.

4.1.1 Field Run #1 (2/98-3/98)

Field Run 1 was set up as a dual media reactive contact system in series with sludge settling capability in-between. This was the initial field concept for the treatment of the groundwater.

4.1.2 Field Run #2 (4/98)

Field Run 2 was designed as a non-contact system. This consisted of a single media system in which potable water was pumped through the media and mixed with the contaminated water in a second canister for treatment. A non-contact configuration was used in order to minimize the armoring and cementation of the treatment media that occurred in Field Run #1.

4.1.3 Field Run #3 (7/98-8/98)

Based on the preliminary results of Lab Test #1 and visual observations of Lab Test #2, an aggregate capable of facilitating a reaction and enabling precipitation was suggested for our waste stream. Field Run 3 was designed as a reactive contact system. It consisted of a single media system in which a solution equilibrated with treatment media was pumped

in tandem with the contaminated groundwater into a canister and allowed to react on the selected aggregate.

4.1.4 Lab Test #1 (5/98)

Field Run #2 suggested that potable water was not capable of solubilizing sufficient amounts of phosphate for precipitation. This laboratory test was performed to determine the effects of more soluble phosphate compounds with the metals contaminated groundwater from the Coal Pile Runoff Basin. Experiments in this test utilized various concentrations of sodium phosphate and potassium phosphate as well as phosphate rock media solutions at varying pHs.

4.1.5 Lab Test #2 (6/98)

This laboratory test was performed to determine the effects of more soluble phosphate compounds with the metals contaminated groundwater from the Coal Pile Runoff Basin. This experiment was a continuation of the first laboratory experiment. Experiments in this test utilized various concentrations of ammonium phosphate and calcium phosphate as well as using phosphate rock or limestone as reactive media matrices at varying potassium phosphate concentrations.

4.1.6 Lab Test #3 (7/98)

This laboratory test occurred simultaneously as Field Run #3 and was performed to determine the effects of treatment media particle size with the metals contaminated groundwater from the Coal Pile Runoff Basin. Experiments in this test utilized crushed limestone and/or phosphate rock at various ratios and contact times.

4.1.7 Lab Test #4 (9/98)

Longer contact times tended to enhance the removal rates in Lab Test #3. This phenomena suggested that oxidation may be occurring with time. Laboratory Test #4 was performed to determine the effects of aeration of the metals contaminated groundwater prior to treatment. Experiments in this test utilized limestone powder or potassium phosphate solutions with the groundwater.

4.2 Experimental Design

4.2.1 Field Run #1

Field Run 1 was constructed as a dual media system in series with sludge settling capability in between each of the two canisters in the system. Four trains /treatment systems were operated during Field Run 1 with the media combinations identified in Table 2. Each train consisted of a peristaltic pump, a 4" diameter by 5.5' long PVC pipe column for media #1, a 15 gallon sludge knockout drum, a 4" diameter by 5.5' long PVC pipe

column for media #2, and a discharge line to the D-Area CPRB. Sampling valves were provided in various locations before, after, and throughout each column. See Figure 2 and for a schematic of the system.

Table 2
Field Run 1 -Treatment Media Evaluation - Media Combinations/Filter Configuration

Train	Canister #1	Canister #2	Filter Configuration
1	crushed limestone	peat (Sphagnum Moss)	Filter fabric at the inlet and outlet of canisters 1 and 2
2	crushed limestone	zeolite (Clinoptilolite)	Filter fabric at the inlet and outlet of canisters 1 and 2
3	crushed limestone	granular cast iron	Filter fabric at the inlet and outlet of canisters 1 and 2
4	phosphate rock	granular cast iron	Filter fabric at the inlet and outlet of canisters 1 and 2

4.2.2 Field Run #2

Field Run 2 was designed as a non-contact system. Two treatment trains operated with the media combinations listed in Table 3. This consisted of a single media system in which potable water was pumped through the media and mixed with the contaminated water in a second canister for treatment. Each system consists of a peristaltic pump, connected to a 4" diameter by 5.5' long PVC pipe column for the treatment media. A peristaltic pump, connected to a second 4" diameter by 5.5' long PVC pipe column packed with 3" Cascade Mini Rings (where the contaminated groundwater was introduced), and a discharge line to the D-Area CPRB. Sampling valves were provided in various locations throughout each system. See Figure 3 for a schematic of the system.

Table 3
Field Run 2 -Treatment Media Evaluation - Media Combinations/ Filter Configuration

Train	Canister #1	Canister #2	Filter Configuration
1	crushed limestone	Cascade Mini Rings	Filter fabric at the bottom (inlet) of canister 1 and at the bottom (outlet) of canister 2
2	Phosphate rock	Cascade Mini Rings	Filter fabric at the bottom (inlet) of canister 1 and at the bottom (outlet) of canister 2

22

Figure 3 – Schematic Representation of Field Run #2

4.2.3 Field Run #3

Field Run 3 was designed as a reactive contact system. Two treatment trains were tested and media combinations are listed in Table 4. The treatment trains consisted of a single media system in which a treatment media solution is pumped in tandem with the contaminated groundwater into a canister and allowed to react on the selected aggregate. Each system consisted of a peristaltic pump, connected to a 4" diameter by 5.5' long PVC pipe column for the treatment media solution, a peristaltic pump, connected to the same 4" diameter by 5.5' long PVC pipe column for the contaminated groundwater, and a discharge line to the D-Area CPRB. See Figure 4 for a schematic of the system.

Table 4
Field Run 3 -Treatment Media Evaluation - Media Combinations/ Filter Configuration

Train	Canister #1	Canister #2	Filter Configuration
1	crushed limestone	N/A	Two opposed layers of geonet at the bottom (inlet) of the canister
2	crushed limestone/ (90 ml/gal) phosphate rock	N/A	Two opposed layers of geonet at the bottom (inlet) of the canister

4.2.4 Lab Test #1

This laboratory test was primarily designed by determining the stoichiometric concentrations of sodium and potassium phosphate compounds required for three separate groundwater contaminated concentrations within the D-Area Coal Pile Runoff Basin groundwater plume. Proportions of 50%, 100% and 150% the theoretical amount were tested for the most soluble compound, potassium phosphate. Phosphate rock solubility was also tested by varying the pH to determine any effects in a non-contact configuration. The concentrations that were used in this experiment are shown in the Table 5.

Figure 4 – Schematic Representation of Field Run #3

Table 5
Laboratory Test Using More Soluble Phosphate Media

Well	DCB-21A	DCB-10	DCB-4A
Typical Contaminant Concentration (mg/l)	Al: 470 Ca: 130 Cr: 0.5 Fe: 1360 Mg: 135 Mn: 16 Ni: 3.3	Al: 227 Ca: 82 Cr: 0.2 Fe: 216 Mg: 49 Mn: 8 Ni: 1.1	Al: 46 Ca: 71 Cr: 0.02 Fe: 20 Mg: 43 Mn: 3 Ni: 0.4
Potassium Phosphate, dibasic Concentrations (mg/l)	18.75 g/l	6 g/l	1.8 g/l
	12.5 g/l	4 g/l	1.2 g/l
	6.25 g/l	2g/l	0.6 g/l
Sodium Phosphate, dibasic Concentration (mg/l)	10.2 g/l	3.2 g/l	1.0 g/l
Phosphate Rock	Saturated in 4.5 pH water	Saturated in 4.5 pH water	Saturated in 4.5 pH water
	Saturated in 5.5 pH water	Saturated in 5.5 pH water	Saturated in 5.5 pH water

4.2.5 Lab Test #2

This laboratory test was primarily designed by determining the stoichiometric concentrations of ammonium and calcium phosphate compounds required for three different groundwater contaminated concentrations within the D-Area Coal Pile Runoff Basin groundwater plume. Proportions of 50%, 100% and 150% of the theoretical amount were tested using ammonium phosphate, while a saturated solution of calcium phosphate was used. Additionally, phosphate rock and washed limestone were tested as a reactive matrix with solutions of groundwater and potassium phosphate. The concentrations that were used in this experiment are shown in the Table 6.

Table 6
Laboratory Test Using More Soluble Phosphate Media (Con't)

Well	DCB-21A	DCB-10	DCB-4A
Typical Contaminant Concentration (mg/l)	Al: 470 Ca: 130 Cr: 0.5 Fe: 1360 Mg: 135 Mn: 16 Ni: 3.3	Al: 227 Ca: 82 Cr: 0.2 Fe: 216 Mg: 49 Mn: 8 Ni: 1.1	Al: 46 Ca: 71 Cr: 0.02 Fe: 20 Mg: 43 Mn: 3 Ni: 0.4
Ammonium Phosphate, dibasic Concentration (mg/l)	14.22 g/l	4.49 g/l	1.33 g/l
Calcium Phosphate, monobasic Concentration (mg/l)	18.0 g/l	18.0 g/l	18.0 g/l
Phosphate Rock (g) + Potassium phosphate, dibasic (g/l)	10% by volume of phosphate rock + 18.75 g/l of potassium phosphate, dibasic solution	10% by volume of phosphate rock + 6.0 g/l of potassium phosphate, dibasic solution	10% by volume of phosphate rock + 1.8 g/l of potassium phosphate, dibasic solution
Washed Limestone (g)+ Potassium phosphate, dibasic (g/l)	18.75 g/L of potassium phosphate dibasic solution saturating the pore space.	6.0 g/L of potassium phosphate dibasic solution saturating the pore space.	1.8 g/L of potassium phosphate dibasic solution saturating the pore space.

4.2.6 Lab Test #3

This laboratory test was primarily to determine whether particle size and contact time effects the metals remediation within the D-Area Coal Pile Runoff Basin groundwater plume. Crushed particles of limestone or phosphate rock were less than 0.5 mm in diameter. The concentrations that were used in this experiment are shown in the Table 7.

Table 7
Laboratory Testing with Crushed Limestone and Phosphate Rock

Well	DIW-1-2
Typical Contaminant Concentration (mg/l)	Al: 78.7 Ca: 50.0 Cr: 4.7 Fe: 36.7 Mg: 26.5 Mn: 6.1 Ni: 1.1
Crushed Limestone	10 vol% with no mix, settle 24 hours 10 vol% with 5 min. mix 10 vol% with 10 min. mix 20 vol% with 5 min. mix 20 vol% with 10 min. mix
Ground phosphate rock	10 vol% with no mix, settle 24 hours 10 vol% with 5 min. mix 10 vol% with 10 min. mix 20 vol% with 5 min. mix 20 vol% with 10 min. mix

4.2.7 Lab Test #4

This laboratory run was performed to determine the affects of aeration on the treatment of the contaminated groundwater. Limestone powder less than 0.5 mm in diameter and potassium phosphate solutions were used. The concentrations that were used in this experiment are shown in the Table 8.

Table 8
Laboratory Testing with Crushed Limestone, Potassium Phosphate, and Aerated Groundwater

Well	DCB-21A	DIW-1-2
Typical Contaminant Concentration (mg/l)	Al: 60.7 Ca: 73.8 Cr: 0.1 Fe: 102.3 Mg: 42.6 Mn: 3.1 Ni: 0.7	Al: 78.7 Ca: 50.0 Cr: 4.7 Fe: 36.7 Mg: 26.5 Mn: 6.1 Ni: 1.1
Crushed Limestone	20 vol%	20 vol%
Potassium Phosphate	1.7 g/L	1.8 g/L

4.3 Equipment, Materials & Methods

The following field equipment was used during the course of the project:

Equipment	Measurement
OAKTON pH/Eh/°C Meter	pH/Eh/Temperature
ORION Model 250A	pH
YSI Model 58 Dissolved Oxygen Meter	DO
YSI Model 3800 and 3820	pH, Eh, DO
HYDROLAB Model Data Sonde II	pH, Eh, DO
PSI TRONIX PG 5000 Digital Pressure Gauge	Pressure

4.3.1 Field Run #1

To allow for continuous operation, a diesel generator was utilized to power the pumps and sampling equipment. All system plumbing was assembled using 3/8" polyethylene tubing and 3/8" KYNAR® fittings (or equal). Pumping at the required low flow rates was delivered by Master Flex® peristaltic pumps with variable speed pump drives and pump heads. Canisters (4" diameter by 5.5' long) were constructed from schedule 40 PVC pipe and fittings. 1/4" PVC sampling valves were provided in various locations before, after, and were installed throughout each column as need to assist in determining media breakthrough curves. A filter fabric consisting of a nonwoven needle punched polyester geotextile fabric heat-laminated to both sides of a high-density polyethylene (HDPE) geonet was installed in the configuration listed in Table 2. 15-gallon polyethylene sludge knockout drums were used between the treatment canisters.

Once the treatment trains were constructed, a potable water flush was performed to ensure the systems integrity. All potable water was drained and the appropriate safety and system walk downs were also performed prior to each field run. The test well, DIW-1-2, was purged at a rate of 5 gallons per minute for approximately three days prior to the field run.

Figure 2 depicts the test equipment layout and specific equipment for the field run. Peristaltic pumps capable of low flows (50-200 ml/min) through the treatment trains were utilized. Flow was measured from the discharge using a graduated cylinder and stopwatch to calibrate the flow, and flow readings from the peristaltic pumps were collected and recorded. Initial and weekly sampling of inlet and outlet canister sampling ports were conducted. Groundwater samples were collected from the inlets and outlets of each treatment canister. Field measurements of pH, Eh, and DO were collected. Headspace samples for VOC analyses were taken on the initial inlet sampling port only.

4.3.2 Field Run #2

Materials of construction were the same as those used in Field Run#1. The same filter fabric as used in Field Run #1 was installed in the configurations listed in Table 3 for Field Run #2. No 15-gallon polyethylene drums were used in this run. Figure 3 depicts the test equipment layout and specific equipment for the field run.

Once treatment trains were constructed, system integrity checks, walk downs and purging of the test well (DIW-1-2) were completed as in Field Run #1.

4.3.3 Field Run #3

Materials of construction were the same as those used in Field Run#1. Instead of the geotextile fabric and HDPE geonet used in Runs 1 and 2, two layers of only the HDPE geonet mesh were on the inlet of each canister. This was used to provide an even distribution of the influent across the entire cross section of the canister and eliminate plugging problems associated with the fabric itself. Five gallon catch tanks with screened bottoms and a layer of filter fabric were set up at the discharge points in the basin. Figure 4 depicts the test equipment layout and specific equipment for the field run.

Once treatment trains were constructed, system integrity checks, walk downs and purging of the test well (DIW-1-2) were completed as in Field Runs #1 and #2.

4.3.4 Lab Test #1

This ex situ treatment media evaluation laboratory experiment consisted of 50 ml graduated centrifuge tubes that were used for test observations and measurements. The test wells, DCB-21A, DCB-10 and DCB-4A were purged for approximately three well volumes prior to collection of samples for experimentation. Approximately 1 L of groundwater was collected in two 500-ml sterile flasks from the wells listed above. Headspace was minimized during sample collection. Potassium phosphate and sodium phosphate solutions were prepared as described in Table 5 using Nanopure water. Aliquots of the Nanopure water were adjusted with hydrochloric acid for the phosphate rock solutions to the pHs listed in Table 5. A 50% by weight mixture of rock phosphate and pH adjusted Nanopure waters were prepared as listed in Table 5 and allowed to saturate for 24 hours. Observations were recorded.

Equal volumes of the contaminated groundwater and treatment media solutions listed in Table 5 were mixed in the 50 ml graduated centrifuge tubes and allowed to settle for 24 hours in a manner that minimized exposure to air. The samples were monitored after mixing in order to determine visual precipitate formation. After the 24-hour settling period,

the precipitate characteristics (i.e. color, texture, volume, etc.) were recorded.

4.3.5 Lab Test #2

This ex situ treatment media evaluation laboratory experiment consisted of 50 ml graduated centrifuge tubes that were used for each test for observations and measurements. Groundwater from wells DCB-21A, DCB-10 and DCB-4A that were collected during the previous experiment were used. Ammonium phosphate and calcium phosphate solutions were prepared as described in Table 6 using Nanopure water. Enough limestone was added to the specific centrifuge tubes in order to fill the tube. Five milliliters of phosphate rock was added to their specific tubes for testing. Equal volumes of groundwater and potassium phosphate solutions were mixed just before sampling and then transferred to limestone and phosphate rock centrifuge tubes. Observations were recorded.

Equal volumes of the contaminated groundwater and ammonium phosphate or calcium phosphate solutions were mixed in the 50 ml graduated centrifuge tubes and allowed to settle for 24 hours in a manner that minimized exposure to air. The samples were monitored after mixing in order to determine visual precipitate formation. After the 24-hour settling period, the precipitate characteristics (i.e. color, texture, volume, etc.) were recorded.

Reactive matrixed test tubes were mixed with groundwater/potassium phosphate solutions and allowed to settle for 24 hours in a manner that minimized exposure to air. After the 24-hour settling period, the precipitate characteristics (i.e. color, texture, volume, etc.) were recorded. Aqueous portions were fractioned and analytical measurements were obtained.

4.3.6 Lab Test #3

This ex situ treatment media evaluation laboratory experiment consisted of 50 ml graduated centrifuge tubes. The tubes were used for test observations, analyte measurements, pH measurements, and Eh measurements. The test well, DIW-1-2, was purged for approximately three days prior to collection of samples for experimentation. Approximately 500 ml was collected in sterile flasks from the well such that no headspace remained. All phosphate solutions were prepared as described in Table 7 using Nanopure water.

Volumes of the contaminated groundwater and treatment media were mixed according to Table 7 in the 50 ml graduated centrifuge tubes and allowed to settle for in a manner that minimizes exposure to air. Only those samples listed as such were allowed to settle for 24 hours. The samples were monitored after mixing in order to note the visual precipitate

formation. After the settling period, the precipitate characteristics (i.e. color, texture, volume, etc.) were noted.

4.3.7 Lab Run #4

This ex situ treatment media evaluation laboratory experiment consisted of 50 ml graduated centrifuge tubes. The tubes were used for test observations, and analyte measurements. The test wells, DIW-1-2 and DCB-21A, were purged for approximately three well volumes prior to collection of samples for experimentation. Approximately 250 ml was collected in sterile flasks from the well such that no headspace remained. All phosphate solutions were prepared as described in Table 8 using Nanopure water.

Initial samples were collected on the groundwater and air was bubbled through each flask for approximately two hours. Equal volumes of the contaminated groundwater and potassium phosphate solutions listed in Table 8 were mixed in the 50-ml graduated centrifuge tubes and allowed to settle. Limestone and groundwater were mixed in the 50 ml graduated centrifuge tubes and allowed to settle. The samples were monitored after mixing in order to note the visual precipitate formation. After the settling period, the precipitate characteristics (i.e. color, texture, volume, etc.) were noted.

4.4 Sampling and Analysis

The following table represents the analytical groups were measured during the testing phase:

Table 9
Analytical Groups

Analytical Group	Analytes
1	RCRA Suite of Metals: silver, aluminum, boron, barium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, lanthanum, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, silica, tin, strontium, titanium, vanadium, zinc, and zirconium
2	chloride, nitrate, nitrite, phosphate, and sulfate
3	pH, Eh, DO, pressure and temperature (field measurements only)
4	Volatile Organic Compounds (VOCs)
5	Media in placed Weight and Moisture Content

The following tables represent the sampling and analysis regime for the field and laboratory tests identified.

Table 10
Analytical Summary for Field Run #1

Analytical Group	Analytes	Sample Bottle	Sample Volume	Preservative ¹	Analytical Method	Frequency	Location
1	RCRA Suite of Metals: silver, aluminum, boron, barium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, lanthanum, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, silica, tin, strontium, titanium, vanadium, zinc, and zirconium	20 ml plastic	Fill bottle ~20 ml No overflow No headspace	1 ml 33.5 to 38% reagent grade HCl Filtered	ICP-ES	1,2, & 4 pore volumes. Daily for remainder of business week #1. Weekly thereafter.	Main Inlet, Outlets to all canisters, All inlets to Canister #2 of each treatment train
2	sulfate	15-20 ml plastic	15-20 ml	Filtered	IC Anion	1,2, & 4 pore volumes. Daily for remainder of business week #1. Weekly thereafter	Main Inlet, Outlets to all canisters, All inlets to Canister #2 of each treatment train
3	pH, Eh, DO, and temperature	field measurement	field measurement	None	Field meter ²	1,2, & 4 pore volumes. Daily for remainder of business week #1. Weekly thereafter	Main Inlet, Outlets to all canisters, All inlets to Canister #2 of each treatment train
4	VOCs	22 ml headspace	7.5 ml	None	GC	Initial, As needed	Main Inlet
5	Moisture Content in placed weight			None	Calibrated Balance & Oven	Pre and Post Test	Canister

¹ After sample collection, the analytical groups 1,2, and 4 samples will be refrigerated until analyzed.

² pH, Eh, and temperature may be measured with an Oakton pH/Eh/temperature meter; pH and temperature may be measured with Orion Model 250A; DO may be measured with YSI Model 58; pH, Eh, DO, and temperature may be measured with YSI Model 3800 or 3820 or Hydrolab Model Data Sonde II.

Table 11
Analytical Summary for Field Run #2

Analytical Group	Analytes	Sample Bottle	Sample Volume	Preservative ¹	Analytical Method	Frequency	Location
1	RCRA Suite of Metals: silver, aluminum, boron, barium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, lanthanum, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, silica, tin, strontium, titanium, vanadium, zinc, and zirconium	20 ml plastic	Fill bottle ~20 ml No overflow No headspace	1 ml 33.5 to 38% reagent grade HCl Filtered	ICP-ES	Daily for remainder of business week #1. Weekly thereafter.	Raw wastewater, Potable water, Media solution from each train, Treated groundwater from each train
2	sulfate	15-20 ml plastic	15-20 ml	Filtered	IC Anion	Daily for remainder of business week #1. Weekly thereafter	Raw wastewater, Potable water, Media solution from each train, Treated groundwater from each train
3	pH, Eh, and temperature	field measurement	field measurement	None	Field meter ²	Daily for remainder of business week #1. Weekly thereafter	Raw wastewater, Potable water, Media solution from each train, Treated groundwater from each train

Table 12
Analytical Summary for Field Run #3

Analytical Group	Analytes	Sample Bottle	Sample Volume	Preservative ¹	Analytical Method	Frequency	Location
1	RCRA Suite of Metals: silver, aluminum, boron, barium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, lanthanum, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, silica, tin, strontium, titanium, vanadium, zinc, and zirconium	20 ml plastic	Fill bottle ~20 ml No overflow No headspace	1 ml 33.5 to 38% reagent grade HCl Filtered	ICP-ES	Daily for remainder of business week #1. Weekly thereafter.	Inlet phosphate solution, Raw wastewater, Outlets of each treatment train
2	phosphate and sulfate	15-20 ml plastic	15-20 ml	Filtered	IC Anion	Daily for remainder of business week #1. Weekly thereafter	Inlet phosphate solution, Raw wastewater, Outlets of each treatment train
3	pH, Eh, and temperature	field measurement	field measurement	None	Field meter ²	Daily for remainder of business week #1. Weekly thereafter	Inlet phosphate solution, Raw wastewater, Outlets of each treatment train

Table 13
Analytical Summary for Lab Test #1

Analytical Group	Analytes	Sample Bottle	Sample Volume	Preservative ¹	Analytical Method	Location
1	RCRA Suite of Metals: silver, aluminum, boron, barium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, lanthanum, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, silica, tin, strontium, titanium, vanadium, zinc, and zirconium	20 ml plastic	Fill bottle ~20 ml No overflow No headspace	1 ml 33.5 to 38% reagent grade HCl Filtered	ICP-ES	Nanopure water, Adjusted Nanopure water, Phosphate rock solutions at pH=4.5, Strongest potassium phosphate, and sodium phosphate solutions, Contaminated groundwater, Treated groundwater
2	phosphate, and sulfate	15-20 ml plastic	15-20 ml	Filtered	IC Anion	Nanopure water, Adjusted Nanopure water, Treatment media solutions, Contaminated groundwater, Treated groundwater
3	pH, Eh	50 ml centrifuge tube lab measurement	50 ml centrifuge tube lab measurement	None	Field meter ²	Nanopure water, Adjusted Nanopure water, Treatment media solutions, Contaminated groundwater, Treated groundwater

Table 14
Analytical Summary for Laboratory Test #2

Analytical Group	Analytes	Sample Bottle	Sample Volume	Preservative ¹	Analytical Method	Location
1	RCRA Suite of Metals: silver, aluminum, boron, barium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, lanthanum, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, silica, tin, strontium, titanium, vanadium, zinc, and zirconium	20 ml plastic	Fill bottle ~20 ml No overflow No headspace	1 ml 33.5 to 38% reagent grade HCl Filtered	ICP-ES	Treatment media solutions, Treated groundwater
2	phosphate, and sulfate	15-20 ml plastic	15-20 ml	Filtered	IC Anion	Treatment media solutions, Treated groundwater
3	pH, Eh	50 ml centrifuge tube lab measurement	50 ml centrifuge tube lab measurement	None	Field meter ²	Treatment media solutions, Treated groundwater

Table 15
Analytical Summary for Laboratory Test #3

Analytical Group	Analytes	Sample Bottle	Sample Volume	Preservative ¹	Analytical Method	Location
1	RCRA Suite of Metals: silver, aluminum, boron, barium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, lanthanum, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, silica, tin, strontium, titanium, vanadium, zinc, and zirconium	20 ml plastic	Fill bottle ~20 ml No overflow No headspace	1 ml 33.5 to 38% reagent grade HCl Filtered	ICP-ES	Contaminated groundwater, Treated groundwater
2	phosphate and sulfate	15-20 ml plastic	15-20 ml	Filtered	IC Anion	Contaminated groundwater, Treated groundwater
3	pH, Eh	50 ml centrifuge tube lab measure- ment	50 ml centrifuge tube lab measure- ment	None	Field meter ²	Contaminated groundwater, Treated groundwater

Table 16
Analytical Summary for Laboratory Test #4

Analytical Group	Analytes	Sample Bottle	Sample Volume	Preservative ¹	Analytical Method	Location
1	RCRA Suite of Metals: silver, aluminum, boron, barium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, lanthanum, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, silica, tin, strontium, titanium, vanadium, zinc, and zirconium	20 ml plastic	Fill bottle ~20 ml No overflow No headspace	1 ml 33.5 to 38% reagent grade HCl Filtered	ICP-ES	Contaminated groundwater, Aerated groundwater, Treatment media solution Treated groundwater
2	phosphate and sulfate	15-20 ml plastic	15-20 ml	Filtered	IC Anion	Contaminated groundwater, Treated groundwater

4.5 **Quality Control**

The following quality control measures were utilized during the demonstration:

- Samples received analytical quality control per ADS standard procedures.
- One duplicate and one control sample were taken each week and analyzed for ion analysis.
- Photographs were taken of the media before and after use.

4.6 **Deviations**

Duplicates and control samples were not pulled for ion analysis during Field Run #3. An independent laboratory was used for a duplicate sample in Field Run #3.

Dissolve oxygen was only measured for Field Run #1. No instrumentation was available for subsequent runs.

Moisture content was not performed for Field Runs 2 & 3. Material denatured during run #1, resulting in erroneous outcomes.

Samples were allowed to settle for 72 hours instead of 24 hours in Laboratory Test #3.

Photographs were not taken of the media before and after use. Representative samples of the media were collected and stored.

5. **RESULTS AND DISCUSSION**

5.1 **Field Run #1**

5.1.1 **Initial Design Concept Prior to Media Studies**

Figure 5 shows the original concept that was to be implemented for the project. This initial conceptual design configuration consisted of an interceptor trench, a treatment cell and a redistribution system. The interceptor trench consisted of a perforated pipe in a gravel bed for the collection of the contaminated groundwater and transport to the treatment cell. The gravel bed was designed so that it may contain permeable treatment media determined in the *ex situ* treatability study to provide an initial treatment prior to the treatment cell itself. The treatment cell consisted of a flow through, removable, treatment media canister. The existing D-Area Interceptor Well, DIW-1 would be utilized as the redistribution system. The treatment cell would be directly connected to the barrier system through a pipeline to one of the existing 6 inch stainless steel screens on the system so that an integrated groundwater interception, treatment, and redistribution system was produced.

Figure 5 - D-Area Treatment System Original Conceptual Design

5.1.2 Field Observations Field Run 1

5.1.2.1 *Pressures/Plugging*

During Field Run 1, plugging and pressure problems were noted. The pressures ranged from -2.53 psig at the down gradient discharge point to 15.7 psig. Precipitates formed in the canisters as well as the lines and 15-gallon settling tanks. Most of the precipitates were held up in the media and filter fabric. The filter fabric was placed directly in contact with the bottom of the canister to allow for an even distribution of the influent to the canister. Due to the volume of precipitates, plugging at the inlets and outlets to canisters caused increases in pressures to 15 psig, the design limit of the system, in some cases. The 3/8" polyethylene tubing was periodically removed from the bottom of the media canisters and the inlet cleared (gently scraped with a nonmetallic object and rinsed with deionized water) on all four trains. The filter fabric was also replaced at the top of Train 1 Canister 1 on two occasions due to excessive precipitate build up. Cementing of the treatment media occurred in Train 3-Canister 2 and Train 4-Canister 1 which also contributed to the plugging and pressure difficulties. These difficulties could not be corrected during the run. This was consistent with the system pressures and observations noted in the field.

5.1.2.2 *Media*

The following field observations were noted after the run when the canisters were examined:

Train 1 Canister 1-Limestone

Inlet-The inlet to the canister looked similar to the outlet except for the filter fabric had a brown, white, and gray discoloration. This might have been a white precipitate, which was discolored orange.

Outlet-A small amount of gray-white paste was found on the filter fabric at the outlet of the limestone. The paste was somewhat coating the limestone media.

Train 1 Canister 2-Peat

Inlet-Some gray-white paste was in the first foot of the peat canister. The down stream side of the filter fabric showed no obvious signs of change. The upstream side of the fabric had a small amount of gray-white paste with a small amount of orange. This was much less paste than in the second canisters of the other treatment trains associated with the limestone.

Outlet-The filter fabric and media showed no obvious signs of change.

Train 2 Canister 1-Limestone

Inlet-The inlet to the canister had a little more orange precipitate on the limestone itself along with the white precipitate found in the other canisters. There also appeared to be more paste on the down stream side of the filter fabric than in the other canisters. Also a similar brown, white, and gray discoloration on the upstream side of the filter fabric was noted. This was slightly more than seen in Canister 1 Train 1.

Outlet-A small amount of gray-white paste found on the filter fabric at the outlet of the limestone. A paste was somewhat coating the limestone.

Train 2 Canister 2-Zeolite

Inlet-The down streamside of the filter fabric and into the zeolite showed no obvious signs of change and the zeolite media was loose. The upstream side of the filter fabric had a gray-white paste with an orange layer in it (approximately 1/8" thickness).

Outlet-Showed no obvious signs of change and the material was still loose.

Train 3 Canister 1-Limestone

Inlet-The inlet had more brown orange precipitate than either Train 1 or 2 limestone. The down streamside of the filter fabric was more orange/brown than seen in the other limestone. The upstream side was similarly discolored as the downstream side of the filter fabric but even more so. There was an inner ring of brown and an outer ring of reddish brown on down streamside of filter fabric.

Outlet-Appeared to have even less paste than Train 1 and 2 limestone canisters but still a significant amount.

Train3 Canister 2-Granular Cast Iron

Inlet-Was cemented together with a gray white precipitate on the upstream side of the filter fabric. A white precipitate paste approximately 1/4" thick was in the center of the cap and thinner at the edges. The white precipitate appeared to have an orange layer of precipitate in it. There was some spotty orange staining of the filter fabric on the down streamside. A white precipitate extended into the pores.

Outlet-Showed no obvious signs of change and no obvious precipitates material fairly loose iron still black similar to unused material. Filter fabric was stained with rust color but no significant precipitation was noted.

Train 4 Canister 1-Phosphate Rock

Inlet-There appeared to be precipitate nodules without the granular phosphate rock in it and appeared to be cemented phosphate nodules in the inlet of the canister. The cemented nodules could be broken by hand but had a definite shape when removed from the surrounding material. There was an approximately one foot long section of cemented phosphate rock at the bottom of the canister. The plug started at approximately 6" from the bottom. Additional cemented sections were found in the first 2.5' of the canister.

Outlet-Showed no obvious signs of change and no obvious precipitate material fairly loose.

Train 4 Canister 2-Granular Cast Iron

Inlet-Had a thin greenish precipitate on the upstream side of the filter fabric. The downstream side of the filter fabric had a rusty discoloration. The iron was cemented and had some greenish precipitate within the pore spaces. The cemented iron was not as hard as the cemented iron that from Train 3 and was less cemented.

Outlet -The media had a green and orange-brown staining and the water had a greenish tint. The upstream side had an orange-brown staining on the filter fabric. The downstream side had mostly green staining with an orange-brown staining in the center.

5.1.3 Data Observations Field Run 1

5.1.3.1 Flow Summary

The following table shows the average flows for each treatment train during this field run:

Train	Day 1 ml/min	Remainder of Test ml/min
1	46	102
2	30	100
3	60	118
4	48	137

5.1.3.2 Analytical Summary

Figures 6-17 depict the primary contaminants (aluminum, chromium, iron, and nickel) through the canisters during this campaign. Preliminary observations are summarized below and shown in Tables 17-22.

Limestone Canisters (Trains 1,2 & 3, Canister 1)

There was significant aluminum and chromium removal throughout test. Outlet concentrations of aluminum and chromium ranged from less than detection to some value significantly less than the inlet concentration over time. There was little iron and nickel removal except initially. The initial outlet concentrations of iron and nickel were however above the drinking water limits. It appears that iron from the groundwater may have been released from the canisters toward the end of the test. There was some silica reduction throughout the test. Significant calcium was released from the limestone but the levels decreased to lower values over the course of the campaign. There was some magnesium released from the limestone initially but the release decreased over time to a resulting concentration similar to the inlet concentration. There was some slight reduction in sulfate throughout the test. The pH increased throughout the test with percentage increases decreasing over time. The dissolved oxygen concentrations also showed percentage increases decreasing over time to nearly zero percent. The Eh reduction decreased over time to nearly zero percent during the campaign. It was noted that the limestone had developed a coating over time.

Phosphate Rock (Train 4 Canister 1)

The increase in the outlet phosphorus concentration decreased over time. There was significant aluminum and chromium removal throughout test. Outlet aluminum concentrations ranged from less than detection to 24 ppm. This was significantly less than the inlet concentration (95-179 ppm). There was significant iron and nickel removal initially. The outlet nickel concentration went from less than detect to essentially no treatment during the test. The iron outlet concentration from the groundwater ranged from less than detect to greater than inlet concentration. This suggests iron from the groundwater may have been redissolving during the test. Significant calcium was released from the phosphate rock but the levels decreased to lower values over the course of the campaign. There was some magnesium released from the limestone initially but that decreased over time to essentially minimal release. There was an initial reduction in manganese concentrations followed by a slight possible increase towards the end of the campaign. There was some slight reduction in sulfate throughout the test. The pH increased throughout the test with percentage increases decreasing over time. The dissolved oxygen concentrations also increased with percentage increases decreasing over time to zero percent. The Eh reduction decreased over time to zero percent during the campaign. It was noted that the phosphate rock had cemented over time.

Peat (Train 1 Canister 2)

The peat canister followed the limestone canister; therefore initially the peat had very little input of aluminum and chromium. Once the aluminum and chromium started breaking through the limestone canister, significant aluminum and chromium treatment was provided throughout the test. There was significant iron and nickel removal initially. The outlet concentrations ranged from slightly above the detection limit; to possibly being exchanged by chromium and aluminum (i.e. greater than inlet) when the limestone canister started releasing more chromium and aluminum in its effluent. Towards the end of the test, there was essentially no treatment observed for iron and nickel. There was some manganese removal initially followed by displacement by aluminum. There was also some slight silica removal throughout the test. The pH decreased from average of 5.2 to 3.6 with the magnitude of decreases decreasing with time. The dissolved oxygen appeared initially increased followed by essentially no change from inlet. The Eh increased from average 314 to 558 with the magnitude of increases decreasing with time. Once the canisters were inspected, it was noted that the peat appeared unchanged.

Zeolite (Train 2 Canister 2)

The zeolite canister followed the limestone canister; therefore initially the zeolite had very little input of aluminum and chromium. Once the aluminum and chromium started breaking through the limestone canister, some aluminum and chromium treatment was provided by the zeolite upon initial limestone canister break through. The aluminum and chromium removal then went to essentially no treatment. There was significant iron and nickel removal initially. The outlet concentrations of iron and nickel ranged from below the detection limit to essentially no treatment. It does not appear however that the aluminum and chromium displaced iron and nickel as in the case of the peat. There was some manganese removal initially followed by displacement by aluminum. There was also some slight silica removal throughout the test. The pH remained fairly constant throughout the test. The dissolved oxygen increased through the zeolite from average of 3.14 to 6.08. The zeolite canister initially had significant increases in Eh followed by lesser increases over time. Once the canisters were inspected, it was noted that the zeolite appeared unchanged.

Iron Canister Following Limestone (Train 3 Canister 2)

This iron canister followed the limestone canister. Aluminum and chromium had significant treatment throughout the test. There was significant nickel removal initially. The outlet concentrations of nickel ranged from below the detection limit to essentially no treatment. There was significant iron addition throughout the test. Some slight manganese addition throughout the test was observed as well as some silica removal throughout the test. There was some slight sulfate removal throughout the test. The pH increases were fairly constant over time. The dissolved oxygen decreases reduced over time to essentially no decrease. The Eh reduction remained fairly constant over time. It was noted that the iron had cemented over time.

Iron Canister Following Phosphate Rock (Train 4 Canister 2)

This iron canister followed the phosphate rock canister; therefore initially the iron had very little input of chromium. There was significant aluminum and chromium treatment throughout the test. The inlet concentrations of aluminum and chromium increased over time due to decreased removal in the phosphate rock canister. There was significant nickel removal initially. The outlet nickel concentrations ranged from less than detect to essentially no treatment. There was significant iron addition throughout the test. Some slight manganese addition throughout the test was observed as well as some silica removal throughout the test. There was some slight sulfate removal throughout the test. The pH increases were fairly constant over time. The dissolved oxygen decreases variable throughout the campaign. The Eh reduction remained fairly constant over time. It was noted that the iron had cemented over time.

Figure 6. Ex-Situ Treatment Media Evaluation Run #1
Contact Limestone Media
(Representative of Trains 1,2 &3 Canister 1)

Figure 7. Ex-Situ Treatment Media Evaluation Run #1
Contact Limestone Media
(Representative of Trains 1,2 &3 Canister 1)

Figure 8. Ex-Situ Treatment Media Evaluation Run #1
Contact Phosphate Media
(Train 4 Canister 1)

Figure 9. Ex-Situ Treatment Media Evaluation Run #1
Contact Phosphate Media
(Train 4 Canister 1)

Figure 10. Ex-Situ Treatment Media Evaluation Run #1
Contact Peat Media
(Train 1 Canister 2)

Figure 11. Ex-Situ Treatment Media Evaluation Run #1
Contact Peat Media
(Train 1 Canister 2)

Figure 12. Ex-Situ Treatment Media Evaluation Run #1
Contact Zeolite Media
(Train 2 Canister 2)

Figure 13. Ex-Situ Treatment Media Evaluation Run #1
Contact Zeolite Media
(Train 2 Canister 2)

Figure 14. Ex-Situ Treatment Media Evaluation Run #1
Contact Iron Media
(Train 3 Canister 2)

Figure 15. Ex-Situ Treatment Media Evaluation Run #1
Contact Iron Media
(Train 3 Canister 2)

Figure 16. Ex-Situ Treatment Media Evaluation Run #1
Contact Iron Media
(Train 4 Canister 2)

Figure 17. Ex-Situ Treatment Media Evaluation Run #1
Contact Iron Media
(Train 4 Canister 2)

Table 17
Preliminary Observations Field Run #1 Contact Limestone
(Trains 1,2,&3 Canister 1)

Parameter	Average Change	Trend Comments
Al	74% removal	% removal highest the first two days at 99% and then variable between 4 and 99% with an average of 54% with no discernable pattern; Conc. in groundwater decreased over time (~180 to ~90 ppm); Conc. in treated water was below detection for the first two days and then variable between ~0.4 and ~110 ppm with an average of 53 ppm with no discernable pattern.
Ca	347% addition	Decreasing % addition over time except for third week; Conc. in groundwater decreased over time (~98 to 56 ppm); Conc. in treated water decreasing over time except for third week (~600 to 150 ppm)
Cr	79% removal	% removal highest the first two days at 95% then variable between 5 and 98% with an average of 64%; Conc. in groundwater fairly constant between 2 and 4 ppm; Conc. in treated water below detection for the first two days and then variable between ~0.04 and ~2.5 ppm with an average of 1.2 ppm with no discernable pattern.
Fe	-	Appears to be initially removed (93%) followed by addition; Conc. in groundwater decreased over time (~170 to ~30 ppm); Conc. in treated water decreasing over time (~110 to ~20 ppm)
Mg	25% addition	Decreasing % addition over time; Conc. in groundwater decreased over time (~65 to ~30 ppm); Conc. in treated water decreased over time (~95 to ~30 ppm)
Mn	-	Appears to be initially removed (93%) followed by addition; Conc. in groundwater decreased over time (~14 to ~8 ppm); Conc. in treated water variable between 7 and 13 ppm with an average of 9.36 ppm
Ni	-	Appears to be initially removed (90%) followed by addition; Conc. in groundwater decreased over time (~4 to ~1.5 ppm with an average of 2.76); Conc. in treated water variable between ~0.1 and ~3.9 ppm with an average of 2.23 ppm
P	None	None
Si	30% removal	Decreasing % removal over time except for third week; Conc. in groundwater variable between 40 and 60 ppm with an average of 53 ppm; Conc. in treated water variable between ~6 and ~52 ppm with an average of 37 ppm
Sulfate	10% removal	Removal greatest at test start and then fairly constant; Conc. in groundwater decreased over time (~2000 to 1000 ppm); Conc. in treated water decreased over time (~1900 to ~900 ppm)
pH	-	Groundwater average = 3.8 (fairly constant); treated water average = 5.7 (decreased over time from ~7 to ~4.5)
DO	-	Groundwater average = 2.3 (fairly constant); treated water average = 4.0 (decrease over time from ~6 to ~2, which is essentially no change from inlet)
Eh	-	Groundwater average = 488 (fairly constant); treated water average = 286 (increase over time from ~140 to ~410, which is essentially no change from inlet)

Table 18
Preliminary Observations Field Run #1 Contact Phosphate Rock
Train 4 Canister 1

Parameter	Average Change	Trend Comments
Al	78% removal	% removal highest the first day at 98% and then variable between 58 and 74% with an average of 67% with no discernable pattern; Conc. in groundwater decreased over time (~180 to ~90 ppm); Conc. in treated water was below detection for the first day and then variable between ~25 and ~60 ppm with an average of ~40 ppm with no discernable pattern.
Ca	316% addition	Decreasing % addition over time; Conc. in groundwater decreased over time (~98 to 56 ppm); Conc. in treated water decreasing over time (~400 to 200 ppm)
Cr	59% removal	% removal highest the first day at 96% then variable between 36 and 93% with an average of ~40%; Conc. in groundwater fairly constant between 2 and 4 ppm; Conc. in treated water below detection for the first day and then variable between ~0.26 and ~2.7 ppm with an average of ~2 ppm with no discernable pattern.
Fe	-	Appears to be initially removed (99%) followed by addition; Conc. in groundwater decreased over time (~170 to ~30 ppm); Conc. in treated water below detection for the first day and then variable between 25 and 110 ppm with and average of ~90
Mg	109% addition	Decreasing % addition over time; Conc. in groundwater decreased over time (~65 to ~30 ppm); Conc. in treated water decreased over time (~265 to ~30 ppm)
Mn	-	Appears to be initially removed (97%) followed by addition; Conc. in groundwater decreased over time (~14 to ~8 ppm); Conc. in treated water <0.5 ppm the first day and then increases to ~16 followed by a decrease to ~8 ppm
Ni	-	Appears to be initially removed (97%) followed by essentially no change from inlet or erratic removal/addition; Conc. in groundwater decreased over time (~4 to ~1.5 ppm with an average of 2.76 ppm); Conc. in treated water less than detection the first day and then variable concentration between 1.7 to 3.3 ppm with an average of 2.3 ppm
P	4017% addition	Decreasing % addition over time; Conc. in groundwater <0.67 ppm throughout; Conc. in treated water initially 60 ppm and may have stabilized around 5 ppm
Si	9% removal	% removal greatest at start of test; Conc. in groundwater variable between 40 and 60 ppm with an average of 53 ppm; Conc. in treated water variable between ~25 and ~60 ppm with an average of 49 ppm
Sulfate	-	Appears to be initially removed followed by addition; Conc. in groundwater decreased over time (~2000 to 1000 ppm); Conc. in treated water decreased over time (~1900 to ~1000 ppm)
pH	-	Groundwater average = 3.8 (fairly constant); treated water average = 5.2 (decreased over time from ~6.5 to ~4.3)
DO	-	Groundwater average = 2.3 (fairly constant); treated water average = 4.9 (decreased over time from ~9 to ~3; essentially no change from inlet)
Eh	-	Groundwater average = 488 (fairly constant); treated water average = 366 (increased over time from ~300 to ~440; essentially no change from inlet)

Table 19
Preliminary Observations Field Run #1 Contact Peat
Train 1 Canister 2

Parameter	Average Change	Trend Comments
Al	35% removal	Removal decreased with time to addition
Ca	None	None
Cr	62% removal	Removal was around 80% until the third week when it dropped to 10%
Fe	30% removal	Removal greatest at test start; removal starts at 99% and decreases with time; when the peat began contacting significant Al, it appears that the Fe was displaced by the Al
Mg	None	None
Mn	11% addition	Removal was around 20% for the first 3 days; when the peat began contacting significant Al, it appears that the Mn was displaced by the Al
Ni	-	Removal greatest at test start; removal starts at 95% and decreased with time; when the peat began contacting significant Al, it appears that the Ni was displaced by the Al
P	None	None
Si	5% removal	Removal ranged between 1 and 15% with no obvious trends
Sulfate	None	None
pH	-	Decrease from average of 5.2 to 3.6; magnitude of decreases decreased with time
DO	-	Appears to be initially increased followed by essentially no change from inlet
Eh	-	Increased from average 314 to 558: magnitude of increase decreased with time

Table 20
Preliminary Observations Field Run #1 Contact Zeolite
Train 2 Canister 2

Parameter	Average Change	Trend Comments
Al	17% removal	Removal decreased with time to addition
Ca	None	None
Cr	26% removal	Removal ranged between 19 and 62% with no obvious trends
Fe	50% removal	Removal greatest at test start; removal started at 99% and decreased with time to an addition
Mg	None	None
Mn	14% removal	Removal was around 88% for the first day; when the peat began contacting significant Al, it appears that the Mn was displaced by the Al
Ni	36% removal	Removal greatest at test start; removal started at 96% and decreased with time to essentially nothing; it does not appear that the nickel was displaced significantly by Al
P	None	None
Si	13% removal	Fairly constant throughout the test
Sulfate	None	None
pH	No change	No change (i.e. inlet equaled outlet)
DO	-	DO increased through the zeolite from average of 3.14 to 6.08
Eh	-	Initially had significant increase in Eh followed by lesser increase over time

Table 21
Preliminary Observations Field Run #1 Contact Iron Following Limestone
Train 3 Canister 2

Parameter	Average Change	Trend Comments
Al	97% removal	% removal ranged between 94 and 99% with no obvious trends; Conc. in inlet water was below detection for the first day and then variable between ~53 and ~108 ppm with no discernable pattern; Conc. in treated water below detection throughout the test
Ca	None	Essentially no % removal or addition
Cr	90% removal	% removal ranged between 74 and 98% with no obvious trends; Conc. in inlet water was below detection for the first day and then variable averaged ~1.7 ppm; Conc. in treated water either below detection or <0.1 throughout the test
Fe	541% addition	Significant iron % addition throughout
Mg	None	Essentially no % removal or addition
Mn	11% addition	% addition ranged between 4 and 38% with no obvious trends; Conc. in inlet water averaged ~10.6; Conc. in treated water averaged ~11.7
Ni	63 % removal	% removal decreases over time (95 to 36%); Conc. in inlet water decreases over time (~2.3 to ~1.5 ppm); Conc. in treated water initially below detection and then variable between 0.6 and 1.4 ppm
P	None	Essentially no % removal or addition
Si	44% removal	% removal initially greatest and then fairly constant at ~28%; Conc. in inlet water fairly constant at an average ~43 ppm; Conc. in treated water lowest initially and then fairly constant at an average ~33 ppm
Sulfate	8% removal	% removal initially greatest and then fairly constant at ~5%; Conc. in inlet water fairly constant at an average ~1375 ppm; Conc. in treated water lowest initially and then fairly constant at an average ~1310 ppm
pH	-	Inlet average = 5.2 (decreasing over time from ~6.3 to ~4.4); treated water average = 7.1 (fairly constant)
DO	-	Inlet average = 2.9 (decreasing over time from ~4 to ~2); treated water average = 1.3 (increasing over time from <1 to ~3)
Eh	-	Inlet average = 336 (initially ~200 followed by ~400); treated water average = 30 (fairly constant)

Table 22
Preliminary Observations Field Run #1 Contact Iron Following Phosphate Rock
Train 4 Canister 2

Parameter	Average Change	Trend Comments
Al	94% removal	% removal ranged between 86 and 99% with no obvious trends; Conc. in variable between ~15 and ~66 ppm with no discernable pattern; Conc. in treated water below detection except for third week
Ca	None	Essentially no % removal or addition
Cr	97% removal	% removal ranged between 92 and 98% with no obvious trends; Conc. in inlet water was below detection for the first day and then variable averaged ~2.4 ppm; Conc. in treated water either below detection or <0.1 ppm throughout the test
Fe	264% addition	Significant iron % addition throughout
Mg	None	Essentially no % removal or addition
Mn	11% addition	% addition ranged between none and 27% with no obvious trends; Conc. in inlet water averaged ~11.2; Conc. in treated water averaged ~12.4
Ni	41 % removal	% removal decreases over time (95 to ~5%); Conc. in inlet water decreases over time (~2.7 to ~1.8 ppm); Conc. in treated water initially below detection and then variable between 1.6 and 2.4 ppm
P	87% removal	% removal fairly constant; Conc. in inlet water variable with an average of ~2.6 ppm; Conc. in treated water either below detection or <0.2 ppm throughout the test
Si	48% removal	% removal decreasing over time (84 to ~20%); Conc. in inlet water fairly constant at an average ~53 ppm; Conc. in treated water lowest initially and then fairly constant at an average ~35 ppm
Sulfate	7% removal	% removal fairly constant at ~7%; Conc. in inlet decreasing over time (~1575 to ~1100 ppm); Conc. in treated water inlet decreasing over time (~1540 to ~1010 ppm)
pH	-	Inlet average = 4.9 (decreasing over time from ~5.8 to ~4.0); treated water average = 7.0 (fairly constant)
DO	-	Inlet average = 3.3 (decreasing over time from ~5 to ~2); treated water average = 1.9 (variable)
Eh	-	Inlet average = 366 (initially ~250 followed by ~450); treated water average = 35 (fairly constant)

5.2 Field Run #2

5.2.1 Revised Design Concept following Field Run 1

Based on the preliminary observations from Field Run #1, it was determined that initial treatment by phosphate or limestone effectively removed metals from the groundwater. However, direct contact with the media is only effective for a short time because of armoring and cementing of the media. Figure 16 shows the revised non-contact concept that was to be implemented for the project. This conceptual design configuration consisted of a treatment basin and a precipitation trench. The treatment basin consisted of a permanently installed permeable treatment media. Direct rainfall and storm water runoff would act as the water source for the basin. The treatment basin was designed so that the contained permeable treatment media determined in the *ex situ* treatability study would provide a treatment media solution. The water would pass over the permeable treatment media in the basin and flow via gravity to the precipitation trench. The precipitation trench consisted of a perforated pipe in a gravel bed for the distribution of the treatment media solution to the contaminated groundwater. This trench provided an area of lower hydraulic head to push the treatment media solution into the contamination zone for groundwater treatment.

Figure 18
Upgradient Rechargeable NonContact
GeoFix Cell

5.2.2 Field Observations Field Run 2

5.2.2.1 Pressures/Plugging

Pressures at the inlet and outlet to the canisters in Trains 1 and 2 remained fairly constant for the duration of the field run. The pressures for Run 2 ranged from -1.5 psig (at the down gradient discharge point) to 4.7 psig. The filter fabric was changed at the outlet to canister 2 for both trains on three occasions. No significant plugging or pressure problems were observed during the field run.

5.2.2.2 Media

The following field observations were noted after the run once the canisters were examined:

Train 1 Canister 1-Limestone

Inlet-The filter fabric shows no obvious signs of change except for a brown stain on the inlet/upstream side.

Outlet- A very small amount of white precipitate was coating the limestone. The water from the canister was a milky white. The media showed no obvious signs of change and the material was still loose.

Train 1 Canister 2 Packing Rings

Inlet-The upstream side of the filter was lightly coated with a light green precipitate. The downstream side of the filter fabric showed no obvious signs of change.

Outlet-The packing rings were moderately coated with a green precipitate.

Train 2 Canister 1 Phosphate Rock

Inlet-The filter fabric shows no obvious signs of change except for a reddish stain on the inlet/upstream side of the canister.

Outlet-The phosphate rock material showed no obvious signs of change from the original material and was loose.

Train 2 Canister 2 Packing Rings

Inlet-The packing rings were moderately coated with a white and brown precipitate.

Outlet- The upstream side of the filter was coated with a 1/8" of an off white precipitate. The downstream side of the filter fabric showed no obvious signs of change.

5.2.3 Data Observations Field Run 2

5.2.3.1 Flow Summary

The following table shows the average flows for each treatment train during this field run:

Train	Average Flows ml/min
1	160
2	143

5.2.3.2 Analytical Summary

Figures 19-22 depict the primary contaminants (aluminum, chromium, iron, and nickel) through the canisters during this campaign. Preliminary observations are summarized below and shown in Tables 23-24.

Limestone Train 1

There was significant removal of aluminum and chromium throughout test. Iron and nickel were slightly removed throughout test and the removal may have increased at end of the test. Outlet calcium concentrations were initially greater than the inlet with an increase in the percent removal of over time. There was possibly a slight removal of manganese throughout the test. The pH increase was fairly consistent through out the test.

Phosphate Rock Train 2

There was significant removal of aluminum and chromium throughout test. There appears to possibly be an increase in removal toward the end of the test. Iron and nickel were slightly removed throughout test and the removal may have increased at end of the test. Outlet calcium concentrations were initially greater than the inlet with an increase in the percent removal of over time. The addition of phosphorus decreased over time. There was possibly a slight removal of manganese throughout the test. It appears that manganese may have had an increase in removal toward the end of the test. The pH increase was fairly consistent through out the test.

Figure 19. Ex-Situ Treatment Media Evaluation Run #2
Non Contact Limestone Media
Train 1

Figure 20. Ex-Situ Treatment Media Evaluation Run #2
Non Contact Limestone Media
Train 1

Figure 21. Ex-Situ Treatment Media Evaluation Run #2
Non Contact Phosphate Rock Media
Train 2

Figure 22. Ex-Situ Treatment Media Evaluation Run #2
Non Contact Phosphate Rock Media
Train 2

Table 23. Preliminary Observations Field Run #2 Non-Contact Limestone Train 1

Parameter	Average Change	Trend Comments
Al	21% removal	% removal ranged from ~9 to ~37% with no obvious trends; Conc. in groundwater fairly constant at an average of 79 ppm; Conc. in media solution less than detection throughout; Conc. in treated water fairly constant at 31 ppm
Ca	14% addition	Decreasing % addition to increasing % removal; Conc. in groundwater slightly decreasing over time (57 to 48 ppm); Conc. in media solution is highest the first day (~10) and then is fairly constant (~4); Conc. in treated water decreasing over time (45 to 19 ppm)
Cr	31% removal	% removal fairly constant; Conc. in groundwater fairly constant at an average of 4.67 ppm; Conc. in media solution less than detection throughout; Conc. in treated water fairly constant at an average of 1.58
Fe	14% removal	Greatest % removal toward end of test (27%); Conc. in groundwater is greatest the first two days and then fairly constant at ~30 ppm; Conc. in media solution less than detection throughout; Conc. in treated water decreasing over time (~31 to ~11 ppm)
Mg	-	Decreasing % addition to increasing % removal; Conc. in groundwater greatest the first day and is then fairly constant at ~25 ppm; Conc. in media solution decreasing over time (4.5 to 0.5 ppm); Conc. in treated water decreasing over time (~17 to 10 ppm)
Mn	10% removal	Greatest % removal toward end of test (27%); Conc. in groundwater greatest the first day and is then fairly constant at ~5.7 ppm; Conc. in media solution less than detection for most of the test; Conc. in treated water decreasing over time (3.6 to 2.1 ppm)
Ni	14% removal	Greatest % removal toward end of test (29%); Conc. in groundwater slightly increasing over time (1 to 1.3 ppm); Conc. in media solution less than detection throughout; Conc. in treated water fairly constant at an average 0.48
P	~110% addition	% addition fairly constant; Conc. in groundwater averages 0.06; Conc. in media solution averages 0.16; Conc. in treated water averages 0.06
Si	None	No % removal or addition; Conc. in groundwater averages 38; Conc. in media solution averages 4; Conc. in treated water averages 20
Sulfate	Possible addition	Conc. in groundwater averages 868; Conc. in media solution averages 5; Conc. in treated water averages 492
pH	-	Groundwater ave. = 3.8; Media solution ave. = 7.81; Treated water ave. = 4.26; pHs fairly constant throughout the test
Eh	-	Groundwater ave. = 292 (constant over time); Media solution ave. = 300 (increasing over time); treated water ave. = 283 (constant over time)

Table 24. Preliminary Observations Field Run #2 Non-Contact Phosphate Rock Train 2

Parameter	Average Change	Discharge Trend
Al	27% removal predominately	Greatest % removal toward end of test (81%) and remainder of test fairly constant; Conc. in groundwater fairly constant at an average of 79 ppm; Conc. in media solution less than detection for all but the first measurement; Conc. in treated water fairly constant at average of 28 ppm (end of test at ~8 ppm)
Ca	126% addition predominately	Initial % addition (711%) much higher than other values and may have removal in the last week of testing (37%); Conc. in groundwater slightly decreasing over time (57 to 48 ppm); Conc. in media solution decreases significantly over time (~375 to 3.5 ppm); Conc. in treated water decreasing over time (230 to 15 ppm)
Cr	33% removal	Potentially increased % removal over time (11 to 90%); Conc. in groundwater fairly constant at an average of 4.67 ppm; Conc. in media solution less than detection for all but the first measurement; Conc. in treated water may be decreasing over time (2.5 to 0.23 ppm)
Fe	10% removal	Potentially increased % removal over time (2 to 63%); Conc. in groundwater is greatest the first two days and then fairly constant at ~30 ppm; Conc. in media solution less than detection for all but the first measurement; Conc. in treated water may be decreasing over time (~31 to ~5 ppm)
Mg	-	Decreasing % addition to increasing % removal (597% addition to 45% removal); Conc. in groundwater greatest the first day and is then fairly constant at ~25 ppm; Conc. in media solution significantly decreasing over time (~180 to 0.6 ppm); Conc. in treated water decreasing over time (~110 to ~7 ppm)
Mn	7% removal predominately	% removal appears to be increasing over time (none to 48%); Conc. in groundwater greatest the first day and is then fairly constant at ~5.7 ppm; Conc. in media solution less than detection for half of the test; Conc. in treated water may be decreasing over time (3.8 to 1.5 ppm)
Ni	14% removal predominately	Greatest % removal toward end of test (50%); Conc. in groundwater slightly increasing over time (1 to 1.3 ppm); Conc. in media solution less than detection for all but the first measurement; Conc. in treated water ranges from less than detection for the first two days to a maximum of ~0.8 ppm
P	~16700% addition	Decreasing % addition over time (92300 to 33%); Conc. in groundwater averages 0.06; Conc. in media solution significantly decreasing over time (~72 to ~0.8 ppm); Conc. in treated water decreasing over time (~31 to ~0.03 ppm)
Si	-	May have significant Si from media initially, then essentially no % removal or addition; Conc. in groundwater averages 38; Conc. in media solution decreasing over time (~56 to 3.5 ppm); Conc. in treated water decreasing over time (~48 to 12 ppm)
Sulfate	-	May have significant addition initially followed by potentially some removal (~160 addition to some potential removal); Conc. in groundwater averages 868; Conc. in media solution decreasing over time (~1400 to 11 ppm); Conc. in treated water initially ~1100 ppm the first day followed by an average of ~412 ppm for the rest of the test
pH		Groundwater ave. = 3.8; Media solution ave. = 6.70; Treated water ave. = 4.25; pHs fairly constant throughout the test
Eh		Groundwater ave. = 292; Media solution ave. = 198; Treated water ave. = 293; Eh's fairly constant throughout the test

5.3 Field Run #3

5.3.1 Conceptual Design

Based on the preliminary observations from Field Run #2 and Laboratory Tests #1 & #2, it was determined that a non-contact treatment media, more soluble than rock phosphate or crushed limestone was needed for the waste stream and contaminants. Figure 21 shows the revised non-contact concept that was to be implemented for the project. This conceptual design configuration consisted of a combination treatment/precipitation trench. The treatment portion consisted of a removal permeable treatment media cell. Direct rainfall and storm water runoff would act as the water source for the trench. The treatment portion of the trench was designed so that the contained permeable treatment media, determined in the *ex situ* treatability study, would provide a treatment media solution. The water would pass over the permeable treatment media in the cell and flow via gravity to the precipitation portion of the trench. The precipitation portion of the trench consisted of an aggregate bed for the distribution of the treatment media solution and precipitation of the contaminants in the groundwater as it flows by the trench.

Figure 23
Upgradient Rechargeable NonContact
GeoFix Cell

5.3.2 Field Observations Field Run 3

5.3.2.1 Pressures/Plugging

Pressures at the inlet and outlet to the canisters in Trains 1 and 2 remained constant for the duration of the field run. As previously stated, for all testing some negative pressures were observed due to the discharge line being down gradient from the test platform. The pressures for Run 3 ranged from -2.62 psig to -0.35 psig. A reading of .91 psig was observed when the discharge line in Train 2 became plugged. No other plugging or pressure problems were observed during field run 3.

5.3.2.2 Sludge Production

For Run 3 it was anticipated that precipitates would flow through the system. Two layers of geonet with out the geotextile were used with the selected media at the bottom/inlet of each canister. This allowed for better flow-through. Five gallon catch tanks with screened bottoms and a layer of filter fabric were set up at the discharge points in the basin. Sludge was collected at an estimated minimum rate of 46 and 76 mg/L for the crushed limestone and crushed limestone/phosphate rock canisters, respectively. This value represents the minimum amount of sludge produced as catch tank overflows and filter bypasses did occur on occasion through out the test.

5.3.2.3 Media

The following field observations were noted after the run and the canisters examined:

Train 1 Canister 1 Limestone (>1/4"-3/4")

Inlet-The inlet (first 3-4" of limestone) had a yellowish with reddish brown patches indicating the zone below the solution inlet to the canister.

Outlet-The media past the first 4" was partially consolidated. The voids were filled with brownish-green precipitate, which occurred in two colors. Individual pebbles were coated in either brown or whitish green.

Train 2 Canister 1 Lime stone (<1/4")/Phosphate Rock
Inlet-The first 2" was brownish precipitate and the media was partially consolidated.
Outlet- Past the first 2" there was a well-consolidated beige precipitate. The pore spaces were significantly filled. The precipitate occurred in two colors. Individual pebbles were coated in either a brown or whitish green precipitate at approximately a one to one ratio.

5.3.3 Data Observations Field Run 3

5.3.3.1 Flow Summary

The following table shows the average flows for each treatment train during this field run:

Train	Average Flows ml/min
1	204
2	200

5.3.3.2 Analytical Summary

Figures 24-27 depict the primary contaminants (aluminum, chromium, iron, and nickel) through the canisters during this campaign. Preliminary observations are summarized below and shown in Tables 25-26.

Limestone

There was significant aluminum and chromium removal throughout the test with some iron and nickel removal. There was a decrease in the calcium addition from the limestone over time. There was some manganese removal throughout the test. There was also significant phosphorus addition throughout the test since the phosphate is added in a soluble form. The pH increased constantly through the test.

Limestone & Phosphate Rock

There was significant aluminum and chromium removal throughout the test with some iron removal. Outlet nickel concentrations are not consistent. Both removal and addition were noted throughout the test. There was a decrease in the calcium addition from the limestone and phosphate rock over time. There was some manganese removal throughout the test. There was also significant phosphorus addition throughout the test since the phosphate is added in a soluble form. Slight decreases in sulfate concentration were observed throughout the test. The pH increased constantly through the test.

Figure 24. Ex-Situ Treatment Media Evaluation Run #3
Limestone Media Train 1

Figure 25. Ex-Situ Treatment Media Evaluation Run #3
Limestone Media Train 1

Figure 26. Ex-Situ Treatment Media Evaluation Run #3
Limestone and Phosphate Rock Media Train 2

Figure 27. Ex-Situ Treatment Media Evaluation Run #3
Limestone and Phosphate Rock Media Train 2

Table 25. Preliminary Observations Field Run #3 Train #1 Limestone & Potassium Phosphate Solution

Parameter	Average Change	Trend Comments
Al	99% removal	Constant % removal ; Conc. in groundwater greatest the first 2 days (~150 ppm) and fairly constant the rest of the test (~110 ppm); Conc. in media solution below detection (<0.301 ppm); Conc. in treated water below detection throughout the test (<0.301 ppm)
Ca	87% addition	% addition highest first day (209%); Conc. in groundwater greatest the first 2 days (~104 ppm) and fairly constant the rest of the test (~67 ppm); Conc. in media solution fairly constant (2.4 ppm); Conc. in treated water greatest the first day (~210 ppm) and variable around 50 ppm the rest of the test
Cr	98% removal	% removal was lowest the last week (93%); Conc. in groundwater increased with time (8 – 14 ppm); Conc. in media solution below detection (<0.060 ppm); Conc. in treated water appears to increase over time (0.020 to 0.431 ppm)
Fe	64% removal	Fairly constant % removal; Conc. in groundwater greatest the first 2 days (~190 ppm) and fairly constant the rest of the test (~80 ppm); Conc. in media solution increased to above detection the last two weeks of the test (<0.046 – 0.293); Conc. in treated water fairly constant (19 ppm)
Mg	-	Appears to be initially added followed by a low net removal; Conc. in groundwater greatest the first 2 days (~60 ppm) and fairly constant the rest of the test (~37 ppm); Conc. in media solution increased the last two weeks of the test (0.2 to 2.8 ppm); Conc. in treated water greatest the first 2 days (~30 ppm) and fairly constant the rest of the test (~18 ppm)
Mn	34% removal	Fairly constant % removal; Conc. in groundwater greatest the first 2 days (~10 ppm) and fairly constant the rest of the test (6 – 7 ppm); Conc. in media solution increased to above detection the last two weeks of the test (<0.028 – 0.093 ppm); Conc. in treated water fairly constant (2.5 ppm)
Ni	25% removal	Fairly constant % removal; Conc. in groundwater appeared to decrease with time (8 – 2 ppm); Conc. in media solution below detection (<0.097 ppm); Conc. in treated water decreased with time (3.2 – 0.6 ppm)
P	~27,500% addition	% addition highest the first day and last week (~43,000%) and fairly constant in between (~20,000%); Conc. in groundwater fairly constant (0.37 ppm); Conc. in media solution constant (235 ppm); Conc. in treated water fairly constant (54 ppm)
Si	4% removal	Variable % removal and addition if any; Conc. in groundwater constant (78 ppm); Conc. in media solution fairly constant (5.6 ppm); Conc. in treated water constant (38 ppm)
Sulfate	Possible addition	Appears to be initially removed (~18%) followed by addition (~23%); Conc. in groundwater greatest the first 2 days (~2400) and fairly constant the rest of the test (~1275 ppm); Data for Conc. in media solution suspect; Conc. in treated water greatest the first 2 days (~980 ppm) and fairly constant the rest of the test (~790 ppm)
pH	-	Media solution ave. = 7.92 (8.45 by omitting the lowest recorded pH; fairly constant); groundwater ave. = 3.23 (initial two day's groundwater pHs somewhat low: ~2.75 followed by constant 3.5); treated water ave. = 5.61 (constant)
Eh	-	Media solution ave. = 255 (apparently increasing over time(120 to 350); groundwater ave. = 330 (greatest the first day (382) and fairly constant the rest of the test constant over time(~320)); treated water ave. = 182 (increasing over time (108 – ~200))

Table 26. Preliminary Data Observations Field Run #3 Train #2 Limestone & Phosphate Rock & Potassium Phosphate Solution:

Parameter	Average Change	Trend Comments
Al	99% removal	Constant % removal ; Conc. in groundwater greatest the first 2 days (~150 ppm) and fairly constant the rest of the test (~110 ppm); Conc. in media solution below detection (<0.301 ppm); Conc. in treated water below detection throughout the test (<0.301 ppm)
Ca	83% addition	% addition highest first day (333%); Conc. in groundwater greatest the first 2 days (~104 ppm) and fairly constant the rest of the test (~67 ppm); Conc. in media solution fairly constant (2.4 ppm); Conc. in treated water greatest the first day (~228 ppm) and variable around 42 ppm the rest of the test
Cr	95% removal	% removal was lowest the last week (81%); Conc. in groundwater increased with time (8 – 14 ppm); Conc. in media solution below detection (<0.060 ppm); Conc. in treated water appears to increase over time (<0.060 to 1.232 ppm)
Fe	69% removal	Fairly constant % removal except for last week at 38%; Conc. in groundwater greatest the first 2 days (~190 ppm) and fairly constant the rest of the test (~80 ppm); Conc. in media solution increased to above detection the last two weeks of the test (<0.046 – 0.293); Conc. in treated water fairly constant (17 ppm)
Mg	-	Appears to be initially added followed by removal (74% addition first day to 19% average removal the rest of the test); Conc. in groundwater greatest the first 2 days (~60 ppm) and fairly constant the rest of the test (~37 ppm); Conc. in media solution increased the last two weeks of the test (0.2 to 2.8 ppm); Conc. in treated water greatest the first 2 days (~37 ppm) and fairly constant the rest of the test (~15 ppm)
Mn	47% removal	Fairly constant % removal except for last week at 16%; Conc. in groundwater greatest the first 2 days (~10 ppm) and fairly constant the rest of the test (6 – 7 ppm); Conc. in media solution increased to above detection the last two weeks of the test (<0.028 – 0.093 ppm); Conc. in treated water fairly constant (2.0 ppm)
Ni	-	Have both % removals and % additions in no discernable pattern; Conc. in groundwater appeared to decrease with time (8 – 2 ppm); Conc. in media solution below detection (<0.097 ppm); Conc. in treated water decreased with time (6.5 – 0.8 ppm)
P	~33,200% addition	% addition highest the first day and last week (~48,000%) and fairly constant in between (~26,000%); Conc. in groundwater fairly constant (0.37 ppm); Conc. in media solution constant (235 ppm); Conc. in treated water fairly constant (68 ppm)
Si	8% removal	Variable % removal predominately; Conc. in groundwater constant (78 ppm); Conc. in media solution fairly constant (5.6 ppm); Conc. in treated water constant (36 ppm)
Sulfate	27% removal	Fairly consistent % removal; Conc. in groundwater greatest the first 2 days (~2400) and fairly constant the rest of the test (~1275 ppm); Data for Conc. in media solution suspect; Conc. in treated water greatest the first 2 days (~900 ppm) and fairly constant the rest of the test (~640 ppm)
pH	-	Media solution ave. = 7.92 (8.45 by omitting the lowest recorded pH; fairly constant); groundwater ave. = 3.23 (initial two day's groundwater pHs somewhat low; ~2.75 followed by constant 3.5); treated water ave. = 5.80 (constant)
Eh	-	Media solution ave. = 255 (apparently increasing over time(120 to 350)); groundwater ave. = 330 (greatest the first day (382) and fairly constant the rest of the test constant over time(~320)); treated water ave. = 149 (increasing over time (66 – 180))

5.4 Laboratory Test #1

5.4.1 Laboratory Observations

5.4.1.1 Reaction

Precipitation was immediately visible in vials containing DCB 21A groundwater with potassium phosphate dibasic and sodium phosphate dibasic combinations. Precipitation was also immediately visible in vials containing DCB 10 groundwater with potassium phosphate dibasic and sodium phosphate dibasic combinations. Potassium Phosphate 6.0+DCB-10 appears to have 2 layers of solids in the centrifuge tube. No precipitation reaction was visible in vials containing groundwater from DCB-4A.

5.4.1.2 Sediment

Where precipitation occurred, the sediment was a white gelatinous substance. The following table represents the sediment results for this laboratory run:

Table 27. Laboratory Observations Lab Test #1

Sample ID			ml sediment	Other
Potassium Phosphate 18.75	+	DCB-21A	7.5	Slightly orange
Potassium Phosphate 12.5	+	DCB-21A	10	
Potassium Phosphate 6.25	+	DCB-21A	10	
Potassium Phosphate 6.0	+	DCB-10	16.25	More fluid, white, still settling
Potassium Phosphate 4.0	+	DCB-10	12.5	More fluid, white
Potassium Phosphate 2.0	+	DCB-10	5	More fluid, white
Potassium Phosphate 1.8	+	DCB-4A	0	
Potassium Phosphate 1.2	+	DCB-4A	0	
Potassium Phosphate 0.6	+	DCB-4A	0	
Sodium Phosphate 10.2	+	DCB-21A	8.25	
Sodium Phosphate 3.2	+	DCB-10	5	More fluid, white
Sodium Phosphate 1.0	+	DCB-4A	0	
Phosphate Rock, pH 5.5	+	DCB-21A	~2	Still settling
Phosphate Rock, pH 5.5	+	DCB-10	~3	Still settling
Phosphate Rock, pH 5.5	+	DCB-4A	0	
Phosphate Rock, pH 4.5	+	DCB-21A	~4	Still settling
Phosphate Rock, pH 4.5	+	DCB-10	~3	Not as opaque, still settling
Phosphate Rock, pH 4.5	+	DCB-4A	0	

5.4.2 Data Observations Lab Test #1

Figures 28-37 depict the primary contaminants (aluminum, chromium, iron, and nickel) during this campaign. Preliminary observations are summarized below and shown in Tables 28-29.

Potassium Phosphate

In general, the greatest percentage removals occurred with higher concentrations of potassium phosphate for DCB-21A and DCB-10 groundwaters. The potassium phosphate solutions did not increase the pH of the DCB-10 groundwater as much as the DCB-21A groundwater. This may possibly be the reason for the decreased efficiencies associated with DCB-10 groundwater treatment. Overall, significant removals of aluminum, calcium, chromium, iron, magnesium, manganese, and nickel were observed using the potassium phosphate solution.

Sodium Phosphate

Overall, significant removals of aluminum, calcium, iron, magnesium, manganese, and nickel occurred with the potassium phosphate solution. There was no chromium in the DCB-21A groundwater to evaluate the sodium phosphate treatments.

Phosphate Rock

Generally, there was no significant treatment of any constituent except for iron at a reduction of ~37%.

Figure 28. Laboratory Test #1
Aluminum Concentration & DCB-21A

Figure 29. Laboratory Test #1
Chromium Concentration & DCB-21A

Figure 30. Laboratory Test #1
Iron Concentration & DCB-21A

Figure 31. Laboratory Test #1
Nickel Concentration & DCB-21A

Figure 32. Laboratory Test #1
Aluminum Concentration & DCB-10

Figure 33. Laboratory Test #1
Chromium Concentration & DCB-10

Figure 34. Laboratory Test #1
Iron Concentration & DCB-10

Figure 35. Laboratory Test #1
Nickel Concentration & DCB-10

Figure 36. Laboratory Test #1
Aluminum Concentration & DCB-4A

Figure 37. Laboratory Test #1
Iron Concentration & DCB-4A

Table 28. Preliminary Observations Laboratory Test #1 Potassium Phosphate Solution

Parameter	DCB-21A	Range of % Change	DCB-10	Range of % Change	DCB-4A	Range of % Change
Al	61	96% R TBD	218	99 - 20% R	1.5	56 % A - 84% R
Ca	74	85% - 64% R	69	13 % R to 2% A	6.8	24% A - 38% A - 4% R
Cr	0.066	-	0.26	28% R TBD	LD	-
Fe	102	99% R TBD	394	82 - 39% R	0.4	39 - 92 % R
Mg	43	47% - 26% R	81	3% R to little A	4.3	10 - 0% R
Mn	3	97% - 92% R	8	21 - 2% R	.1	10 - 26% R
Ni	0.7	56% R TBD	2	~14% R	LD	-
P	0.075	3.8M% - 1M% A	0.29	200K - 73K% A	0.06	500K - 150K% A
Si	69	2 - 9 - 5% A	84	-	3.8	45 - 11% A
Sulfate	1725	-	4046	-	172	38 - 65% R
Phosphate	2608	332% - 55% - 66% A	448	223 - 337 - 257% A	24	3900 - 1170% A
pH	2.94	7.82 - 6.98	2.6	3 - 4 - 3	4.5	7.6 - 7.9 - 7.2
Eh	650	377 - 395	639	454 - 375 - 504	434	272 - 319

Notes:

- R = reduction; A = addition; TBD = to below detection; K = 1000s; M = millions

Table 29. Preliminary Observations Laboratory Test #1 Sodium Phosphate Solution

Parameter	DCB-21A	% Change	DCB-10	% Change	DCB-4A	% Change
Al	61	96% R	218	26% R	1.5	55% A
Ca	74	74% R	69	2% R	6.8	28% R
Cr	0.066	-	0.26	28% R	LD	
Fe	102	99% R	394	42% R	0.4	53% R
Mg	43	32% R	81	2.5% R	4.3	5% A
Mn	3	93% R	8	5% R	.1	24% R
Ni	0.7	56% R	2	14% R	LD	
P	0.075	1.2M% A	0.29	77.5K% A	0.06	0.2 M% A
Si	69	9% A	84	0.5% R	3.8	24% A
Sulfate	1725	-	4046	18% A	172	57% R
Phosphate	2608	30% A	448	195% A	24	1.7 K% A
pH	2.94	7.1	2.6		4.5	
Eh	650	384	639		434	

Notes:

- R = reduction; A = addition; TBD = to below detection; K = 1000s; M = millions

5.5 Laboratory Test #2

5.5.1 Laboratory Observations

5.5.1.1 Reaction

Precipitation was immediately visible in vials containing DCB 21A groundwater with potassium phosphate dibasic combinations. Precipitation was also immediately visible in vials containing DCB 10 groundwater and potassium phosphate dibasic combinations. No precipitation was noted in vials containing calcium and ammonium phosphate.

5.5.1.2 Sediment

Where precipitation occurred, the sediment was a white gelatinous substance. The following table represents the sediment results for this laboratory run:

Table 30. Laboratory Observations Lab Test #2

Sample ID					ml sediment	Other
Ammonium Phosphate 14.22	+	DCB-21A			0	
Ammonium Phosphate 4.49	+	DCB-10			0	
Ammonium Phosphate 1.33	+	DCB-4A			0	
Calcium Phosphate SAT'D	+	DCB-21A			0	
Calcium Phosphate SAT'D	+	DCB-10			0	
Calcium Phosphate SAT'D	+	DCB-4A			0	
Potassium Phosphate 18.75	+	DCB-21A	+	Phosphate Rock	7.5	
Potassium Phosphate 6.0	+	DCB-10	+	Phosphate Rock	10	
Potassium Phosphate 1.8	+	DCB-4A	+	Phosphate Rock	0	suspended fines
Potassium Phosphate 18.75	+	DCB-21A	+	Limestone	6	attached in areas
Potassium Phosphate 6.0	+	DCB-10	+	Limestone	10	
Potassium Phosphate 1.8	+	DCB-4A	+	Limestone	<1	slight sediment

5.5.2 Data Observations Lab Test #2

Figures 38-43 depict the primary contaminants (aluminum, chromium, iron, and nickel) during this campaign. Preliminary observations are summarized below and shown in Table 31.

Analytical Summary

Based upon these results, the ammonium phosphate appears to be by far the best treatment solution. The ammonium phosphate removes significant percentages of aluminum, calcium, chromium, iron, magnesium, manganese, nickel and silica. This is promising considering that ammonium phosphate may be available commercially as an agricultural grade fertilizer. If used, the ammonium phosphate would add ammonium and phosphate to the treated water. There are also concerns as to the validity of the results from this run. This experiment was conducted with groundwater, which had been stored refrigerated for approximately 30 days. Also, experimental results were delayed and not analyzed for approximately 60 days after the experiment was concluded. During this time, oxidation of the ferrous iron may have occurred. This factor may have contributed to the high treatment efficiencies.

The calcium phosphate may be the second best treatment media; however it may have solubility problems for its addition in an actual field condition.

The phosphate rock with potassium phosphate and the limestone with potassium phosphate appear essentially equivalent and possibly an improvement over potassium phosphate alone. The phosphate rock and potassium phosphate add significant calcium, magnesium and silica to the treated water in addition to potassium and phosphate. The limestone and potassium phosphate combination adds significant calcium and magnesium to the treated water in addition to potassium and phosphate.

Figure 38. Laboratory Test #2
Aluminum Concentration with Ammonium and Calcium Phosphates

Figure 39. Laboratory Test #2
Chromium Concentration with Ammonium and Calcium Phosphates

Figure 40. Laboratory Test #2
Iron Concentration with Ammonium and Calcium Phosphates

Figure 41. Laboratory Test #2
Nickel Concentration with Ammonium and Calcium Phosphates

Figure 42. Laboratory Test #2
Aluminum Concentration with Potassium Phosphate and a Reactive Matrix

Figure 43. Laboratory Test #2
Iron Concentration with Potassium Phosphate and a Reactive Matrix

Table 31. Preliminary Observations Laboratory Test #2

Parameter	Ammonium Phosphate			Calcium Phosphate			Potassium Phosphate			Phosphate Rock & Potassium Phosphate			Limestone & Potassium Phosphate		
	21A	10D	4A	21A	10D	4A	21A	10D	4A	21A	10D	4A	21A	10D	4A
Well	21A	10D	4A	21A	10D	4A	21A	10D	4A	21A	10D	4A	21A	10D	4A
Al	99R	99R	96R	99R	99R	31R	99R	95R	52R	99R	99R	96R	99R		96R
Ca	97R	98R	12R	1.7K	1.8K	10K	85R	-	3A	79R	53A	14A	38R		482A
				A	A	A									
Cr	-	90R	-	-	54R	-	-	31R	-	-	54R	-	-		-
Fe	99R	99R	97R	99R	99R	77R	99R	99R	97R	99R	99R	97R	99R		97R
Mg	99R	99R	-	95R	97R	31A	48R	7R	-	38R	11A	50A	52A		453A
Mn	99R	99R	36R	98R	99R	5.7R	95R	9R	18R	96R	26R	77R	98R		95R
Ni	97R	99R	-	72R	91R	-	85R	16R	-	72R	31R	-	72R		-
P	8.1M	645K	463K	2.6M	685K	1.7M	3.7M	162K	451K	3.3M	152K	360A	2.6M		281K
	A	A	A	A	A	A	A	A	A	A	A	A	A		A
Si	99R	99R	-	97R	97R	43A	3R	2R	-	3.5A	3.6R	65A	9R		78A
Sulfate	-	-	-	-	-	-	-	33R	42R	24A	30R	12R	-		38R
Phosphate	534A	-	11K	115A	1.3K	17.9	354A	305A	3978	266A	347A	3270	-		2506
			A		A	KA			A			A			A
pH	8.27	8.21	7.94	3.64	3.65	3.78	7.76	3.97	7.73	7.74	4.3	7.59	7.59	6.8	7.34
Eh	325.5	309.7	335.9	531.5	526.1	487.3	271.2	516.1	342.1	362.3	487.7	363.0	373.4	404.1	380.5

5.6 Laboratory Test #3

5.6.1 Laboratory Observations

5.6.1.1 Reaction

No apparent precipitation reactions like those in Laboratory Test #1 were observed.

5.6.1.2 Sediment

All tubes with sediment seemed to be the same color as the matrix fines. The amount of sediment was determined by subtracting the initial solid volume from the final solid volume. The following table represents the sediment results for this laboratory run:

Table 32. Laboratory Observations Lab Test #3

Sample ID	ml sediment
Limestone, 10%, 5 minute mix	~1.5
Limestone, 10%, 10 minute mix	~2
Limestone, 20%, 5 minute mix	2.5
Limestone, 20%, 10 minute mix	~3
Phosphate Rock, 10%, 5 minute mix	<0.5
Phosphate Rock, 10%, 10 minute mix	<1
Phosphate Rock, 20%, 5 minute mix	<1
Phosphate Rock, 20%, 10 minute mix	~2
Limestone/Phosphate Rock, 20%, 5 minute mix	~3
Limestone/Phosphate Rock, 20%, 10 minute mix	~3

5.6.2 Data Observations Lab Test #3

Figures 44-47 depict the primary contaminants (aluminum, chromium, iron, and nickel) during this campaign. Preliminary observations are summarized below and shown in Table 33.

In general, the best removal was obtained with the 20% limestone powder additions. It appeared that a 72-hour hold time with 20% limestone provided the best reduction in iron and nickel. There does not appear to be any significant difference between the 20% limestone and the 20%limestone/phosphate rock treatments. Overall, the phosphate rock powder provided the least treatment.

Figure 44. Laboratory Test #3
Aluminum Concentration with Limestone and/or Phosphate Rock

Figure 45. Laboratory Test #3
Chromium Concentration with Limestone and/or Phosphate Rock

Figure 46. Laboratory Test #3
Iron Concentration with Limestone and/or Phosphate Rock

Figure 47. Laboratory Test #3
Nickel Concentration with Limestone and/or Phosphate Rock

Table 33. Preliminary Observations Lab Test #3

	DIW-1-2	Average P 10% 5/10 %Change	Average P 20% 5/10 %Change	Average P 20% 24 %Change	Average L 10% 5/10 %Change	Average L 20% 5/10 %Change	Average L 20% 24 %Change	Average LP 20% 5/10 %Change
Aluminum	158.359	-36.0	-70.8	-37.7	-99.8	-99.8	-99.8	-99.8
Calcium	103.257	195.6	289.6	218.3	495.4	525.9	573.8	515.6
Chromium	12.402	-11.1	-38.8	-61.8	-99.5	-99.5	-99.5	-99.5
Iron	203.871	-10.2	-21.9	-70.4	-20.3	-37.6	-94.1	-39.6
Magnesium	63.093	36.1	66.9	60.8	15.5	26.7	28.0	26.9
Manganese	10.153	1.9	-2.8	-4.6	-9.0	-21.9	-31.1	-20.9
Nickel	7.025	-0.9	-7.6	-7.9	-5.4	-12.9	-29.7	-13.8
Phosphorus	0.273	5244.9	2152.7					
Silica	80.727	3.1	3.8	3.7	-32.3	-38.0	-61.8	-37.2
Sulfate	1924.835	-2.9	-1.8		-11.3	-13.8		-9.8
pH	3.18	3.8	4.3	NRT	6.2	6.3	NRT	6.2
Eh	363.1	368.9	344.4	NRT	165.1	148.6	NRT	172.6

5.7 Laboratory Test #4

5.7.1 Laboratory Observations

5.7.1.1 Reaction

No apparent precipitation reactions like those in Laboratory Test #1 were observed.

5.7.1.2 Sediment

All tubes with sediment seemed to be the same color as the matrix fines. The amount of sediment was determined by subtracting the initial solid volume from the final solid volume. The following table represents the sediment results for this laboratory run:

Table 34. Laboratory Observations Lab Test #4

Sample ID	ml sediment	Other
Limestone, DIW-1-2	4.0	
Limestone, DCB 21A	3.0	
Potassium phosphate, DIW-1-2	7.5	Highly suspended
Potassium phosphate, DCB 21A	5.0	Highly suspended

5.7.2 Data Observations Lab Test #4

Figures 48-51 depict the primary contaminants (aluminum, chromium, iron, and nickel) during this campaign. Preliminary observations are summarized below and shown in Table 35.

Overall, the aeration and limestone treatment provided the best treatment for both DIW-1-2 and DCB-21A groundwater. The limestone reduced both chromium and nickel to a greater extent than the potassium phosphate solutions. In general, aeration and potassium phosphate performed very poorly on DCB-21A groundwater.

Figure 48. Laboratory Test #4
Aluminum Concentration with Aerated Wastewater

Figure 49. Laboratory Test #4
Chromium Concentration with Aerated Wastewater

Figure 50. Laboratory Test #4
Iron Concentration with Aerated Wastewater

Figure 51. Laboratory Test #4
Nickel Concentration with Aerated Wastewater

Table 35. Preliminary Laboratory Observations Lab Test #4

	DIW-1-2	Aeration & 20% Limestone % Change	Aeration & Potassium Phosphate %Change	DCB-21A	Aeration & 20% Limestone % Change	Aeration & Potassium Phosphate %Change
Aluminum	82.116	-99.6	-99.3	300.1	-99.9	-8.2
Calcium	62.962	508.7	-1.6	175.9	658.2	3.5
Chromium	11.240	-99.5	-94.9	0.3	-76.3	-41.5
Iron	124.816	-72.7	-42.7	130.9	-92.4	-66.6
Magnesium	34.080	45.7	3.9	112.0	17.7	0.2
Manganese	6.403	-49.0	-19.3	11.4	-29.9	-0.5
Nickel	0.964	-37.8	-21.8	1.7	-14.0	-5.6
Phosphorus	<0.273			0.3		
Silica	77.742	-40.1	5.0	120.7	-43.3	-0.5

5.8 System Chemistry

Based on initial conditions and the solubility diagram shown in Figure 52, a minor pH adjustment was sufficient to precipitate the chromium phases in our groundwater. Nickel, on the other hand, was more difficult to precipitate by pH adjustment alone. Figure 53, shows the nickel solubility diagrams in the presence of 9500 mg/L of phosphate. Less phosphate would only shift the solubility curves farther to the right requiring even higher pHs to precipitate the nickel phases. For this reason, it is assumed that nickel must co-precipitate with other metals. Nickel would partition strongly into ferrous iron phases as a co-precipitate because of the similarity in charge and cation radii of nickel and ferrous iron. Figure 54 suggests that there is significant dissolved ferrous iron in the system and phases such as ferrous phosphate may precipitate. Nickel may also co-precipitate with ferric iron phases. This may explain why aeration promoted the removal of nickel from the contaminated groundwater. Ferric iron phases are less soluble than ferrous iron phases and more complete iron removal can expected ferrous iron is oxidized. Greater precipitation of iron may, in turn, result in more effective removal of nickel.

Figure 52. Solubility of Amorphous $\text{Cr}(\text{OH})_3$

Figure 53. Solubility of Nickel Phases (Total Phosphate = 0.1 moles/liter)

Figure 54. Eh - pH Diagram of Iron in Solution

6. CONCLUSIONS, RECOMMENDATIONS, AND GEOSIPHON TREATMENT SYSTEM CONCEPTUAL DESIGN

As determined from Field Run #1, contaminants of concern can be removed by precipitation in the first bulk precipitation canister and by cation exchange or further increases in pH in the second polishing canister. From the preliminary results of Field Run #1, it appears as long as the bulk precipitation process is successful, the polishing process works rather well. Significant emphasis was placed on these campaigns to refine the bulk precipitation process. It should be noted that the overall treatment process should consider all potential combinations to provide the best possible treatment.

While these results are preliminary, the following general overall conclusions for the entire operating regime are deduced:

- Both aluminum and chromium can be effectively treated with limestone and phosphate
- Iron can also be treated with limestone and phosphate.
- While iron is significantly removed, treatments are not as effective as those for aluminum and chromium.
- Treatments that enhance iron removal also enhance nickel removal
- Nickel is probably coprecipitated with iron.

Based on the preliminary data results and field observations, a conceptual design which includes GeoSiphon cells is under evaluation. GeoSiphon Cells are passive groundwater treatment systems which utilize siphon flow between two points of natural head difference to induce greater than natural contaminated groundwater flow through a treatment train without the requirement for external energy input. The treatment train utilized in GeoSiphon Cells can include permeable treatment materials, aeration, chemical addition, etc.

The conceptual GeoSiphon Cell configuration includes extraction of the contaminated water from the mound created by the barrier wall system by siphon to a downgradient treatment system which may consist of an oxidizing step such as aeration followed by a permeable treatment media or treatment media combination. The siphon flow will be induced by the natural hydraulic head difference between the mound upgradient of the wall and the adjacent D-Area discharge stream, which is a lower hydraulic head. A schematic is shown in Figure 55. Further development of this concept is anticipated in FY99.

Advantages of this conceptual design include:

- Utilization of the existing barrier wall system as part of a treatment system for the D-Area CPRB metals contaminated groundwater. The existing barrier wall system represents a significant past Office of Science and Technology (OST) investment.
- Utilize natural hydraulic driving forces to induce flow for remediation.
- Treatment within the most heavily contaminated portion of the D-Area CPRB plume.
- Removable treatment options so that heavy metals can be collected and recycled.
- Potentially accelerate clean up, can be applied to a broader range of site conditions, and can increase treatment media longevity and effectiveness.
- Minimize media armoring and/or cementation, and formation pluggage.
- Directly meeting the needs of the EM-40 program (Environmental Restoration).

Although the data presented in this report are preliminary, the following should be considered for further evaluation:

- All data should be looked at in greater detail by statistical analysis, mass balance, etc.
- Comparison of data and treatment effectiveness should be performed
- In particular, ammonium phosphate should be evaluated more closely due to its performance in Run #4.

Figure 55. D-Area GeoSiphon Cell Treatment System - Conceptualization

7. KEY CONTACTS AND PARTICIPANTS

US Department of Energy

Dave Robertson, Reactive Barrier Product Line Manager

Michelle Ewart, DOE-SR

Jim Wright, Subcontaminants Focus Area

WSRC Environmental Restoration Department

Harry Long, Facility Custodian

Coleman Miles, Technical Lead

WSRC Savannah River Technology Center

Miles Denham, Senior Geochemist

Mark Phifer, Principal Engineer

Frank Sappington, Senior Engineer

Fatina Ann Washburn, Senior Engineer

Chuck Betivas, Technical Assistant

WSRC Environmental Protection Department

Bill Payne, Permitting Coordinator

SCE&G

Mark Ferguson, Environmental Coordinator

Jean Claude Younan, Environmental Programs

8. REFERENCES

1. RW Gillham, DW Blowes, CJ Ptacek, and SF O'Hannesin, 1994. In-situ remediation: Scientific basis for current and future technologies. Thirty-Third Hanford Symposium on Health and Environment.
2. DW Blowes, CJ Ptacek, JG Bain, KR Waybrant, and WD Robertson, 1995. Treatment of mine drainage water using in-situ permeable reactive walls. Conference on Mining and Environment, Sudbury, Ontario, May 28-June 1.
3. KR Waybrant, DW Blowes, and FJ Ptacek, 1995. Selections of reactive mixtures for the prevention of acid mine drainage using porous reactive walls.
4. DW Blowes, KR Waybrant, JF Bain, and WD Robertson, 1995. In-situ treatment of drainage water using porous reactive walls. Conference on Mining and Environment, Sudbury, Ontario, May 28-June 1.
5. DW Blowes, and CJ Ptacek, 1992. Geochemical remediation of groundwater by permeable reactive walls: Removal of chromate by reaction with iron bearing solids. Proceedings of the Surface Restoration Conference, Third International Conference of Groundwater Quality Research, June 21-24, Dallas, Texas, pp. 214-216.
6. RW Gillham, DW Blowes, CJ Ptacek, and SF O'Hannesin, 1994. "Use of zero-valent metals in-situ remediation of contaminated groundwater." 33rd Hanford Symposium of Health and the Environment, Pasco, Washington, Nov. 7-11.
7. Remediation Technologies Development Forum Permeable Barriers Action Team Meeting Summary, Dec. 11-12, 1996, Denver, CO.
8. EC Thornton, Selection of field demonstration site for in situ chemical treatment of soil testing activities, WHC-SD-EN-ES-042, Westinghouse Hanford Company, Richland, Washington, 1994.
9. GM Haggerty, and RS Bowman, "Symposium of Chromate and Other Inorganic Anions by Organo-Zeolite," *Environ. Sci. Technol.*, Vol. 28, No. 3, 1994.
10. I Anghel, J. Whitworth, S Roy, RS Bowman, "Remediation of subsurface chromium (VI) and PCD contaminated with surface-modified zeolites: Saturated column studies," *Proc. WERC/HSRC '97 Joint Conf. on the Environment*, 22-24 April 1997, Albuquerque, NM.
11. TM Sivavec, PD Mackenzie, DP Horney, and SS Baghel, "Redox active media for permeable reactive barrier," *International Contaminant Technology Conference*, Feb 9-12, 1997, Petersburg, FL.
12. Phifer, MA, "Preliminary Engineering Report- Proposed TNX GeoSiphon Cell Phase II Demonstration", submitted to the South Carolina Department of Health and Environmental Control, June 10, 1997.
13. Phifer, MA, "Expert Panel Report-MWMF Groundwater Southwest Plume-GeoFlow Cell Remediation Option", submitted to Environmental Restoration Engineering, May 30, 1997.

9. APPENDICES

Appendix A: Compiled Data

**APPENDIX A
COMPILED DATA**

FIELD RUN #1

Aluminum Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	174.047	<2.156	<2.156	2.315	174.047	<2.156	<2.156	<2.156	174.047	<2.156	<2.156	<2.156	174.047	<2.156	18.398	<2.156
2PV	179.228	<2.156	<2.156	<2.156	179.228	<2.156	<2.156	<2.156	179.228	<2.156	<2.156	<2.156	179.228	<2.156	15.880	<2.156
4PV	177.777	<2.156	<2.156	<2.156	177.777	<2.156	<2.156	<2.156	177.777	<2.156	<2.156	<2.156	177.777	<2.156	24.431	<2.156
D2	<2.156	<2.156			<2.156	<2.156			<2.156	<2.156			<2.156	<2.156	16.664	
D2PM	152.468	<2.156			152.468	<2.156			152.468	<2.156			152.468	<2.156	43.051	
D3	149.592	21.127	4.998	<2.156	149.592	16.221	<2.156	<2.156	149.592	56.922	55.302	<2.156	149.592	60.568	66.909	<2.156
D4	142.487	86.114	103.496	2.521	142.487	24.357	<0.281	<0.281	142.487	94.811	104.621	<0.281	142.487	41.455	62.980	<0.281
D5	132.546	92.913	97.941	70.059	132.546	0.423	<0.281	<0.281	132.546	109.493	108.122	<0.281	132.546	39.196	39.191	<0.281
W2	89.836	72.666	64.902	48.095	89.836	58.452	61.394	43.837	89.836	85.772	95.778	<0.281	89.836	37.445	45.645	2.491
W3	94.551	17.429	19.607	25.979	94.551	14.697	32.964	33.713	94.551	47.431	53.041	<2.811	94.551	24.320	25.706	<0.922

Calcium Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	96.177	298.521	462.276	151.233	96.177	294.748	479.541	376.091	96.177	67.002	458.782	86.636	96.177	321.034	366.365	300.474
2PV	96.578	600.287	11.291	9.272	96.578	615.265	94.059	423.278	98.578	622.898	9.897	464.259	98.578	342.728	9.068	342.134
4PV	88.642	615.999	454.658	367.251	88.642	642.849	475.400	457.064	88.642	618.545	471.854	462.803	88.642	431.470	377.690	387.833
D2	<0.024	<0.024			<0.024				<0.024	487.848			<0.024	363.119		
D2PM	69.919	393.854			69.919	436.896			69.919	411.435			69.919	367.894		
D3	70.470	324.236	399.379	380.212	70.470	380.757	431.972	458.550	70.470	287.703	303.602	301.975	70.470	304.572	314.820	276.563
D4	68.174	222.950	211.470	319.528	68.174	295.828	441.416	434.962	68.174	236.743	208.708	203.930	68.174	320.262	294.315	280.377
D5	68.975	193.160	196.710	207.116	68.975	390.525	389.827	393.421	68.975	216.677	214.937	214.239	68.975	286.228	276.671	275.679
W2	56.873	142.652	177.412	182.424	56.873	128.507	145.095	152.834	56.873	152.406	162.780	171.297	56.873	206.784	223.350	235.479
W3	56.490	190.082	182.869	165.973	56.490	328.396	144.313	137.352	56.490	159.072	135.264	131.490	56.490	213.525	207.878	209.135

Chromium Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	3.578	<0.170	<0.170	<0.170	3.578	<0.170	<0.170	<0.170	3.578	<0.170	<0.170	<0.170	3.578	<0.170	0.241	<0.170
2PV	4.027	<0.170	<0.170	<0.170	4.027	<0.170	<0.170	<0.170	4.027	<0.170	<0.170	<0.170	4.027	<0.170	0.175	<0.170
4PV	4.334	<0.170	<0.170	<0.170	4.334	<0.170	<0.170	<0.170	4.334	<0.170	<0.170	<0.170	4.334	<0.170	0.239	<0.170
D2	<0.170	<0.170			<0.170				<0.170	<0.170			<0.170	<0.170		
D2PM	3.761	<0.170			3.761	<0.170			3.761	<0.170			3.761	<0.170	0.258	
D3	4.167	0.488	<0.170	<0.170	4.167	0.488	<0.170	<0.170	4.167	0.919	1.117	<0.170	4.167	2.478	2.204	<0.170
D4	4.196	2.107	2.860	0.652	4.196	0.817	0.031	0.036	4.196	1.605	2.017	0.056	4.196	2.663	3.158	0.053
D5	4.398	2.508	2.662	0.577	4.398	0.045	0.042	0.028	4.398	2.036	2.002	0.038	4.398	2.304	2.286	0.036
W2	2.098	1.755	2.056	0.391	2.099	1.981	2.190	0.821	2.099	0.816	2.413	0.039	2.099	2.441	2.943	0.042
W3	2.954	0.303	0.288	<0.257	2.954	0.598	0.808	0.652	2.954	0.816	0.991	<0.257	2.954	1.687	1.701	<0.066

Iron Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	158.609	11.023	71.051	<0.174	158.609	10.643	83.226	<0.174	158.609	0.333	79.259	153.648	158.609	<0.174	80.059	132.075
2PV	168.865	101.631	67.022	5.231	168.865	98.418	82.777	<0.174	168.865	108.904	80.002	226.354	168.865	<0.174	71.565	204.838
4PV	148.165	108.820	67.293	9.770	148.165	108.131	82.612	<0.174	148.165	119.236	81.141	240.323	148.165	<0.174	83.879	185.326
D2	<0.174	<0.174			<0.174				<0.174	72.409			<0.174	113.622		
D2PM	64.460	59.375			64.460	86.804			64.460	90.801			64.460	118.225		
D3	62.525	65.561	68.092	37.686	62.525	105.782	85.056	40.191	62.525	91.342	91.916	433.033	62.525	108.194	110.032	367.615
D4	58.586	67.007	70.515	130.293	58.586	100.329	78.549	53.412	58.586	80.707	91.055	485.081	58.586	108.002	115.001	487.526
D5	58.233	58.195	64.297	68.311	58.233	71.523	79.536	65.487	58.233	71.657	75.100	476.113	58.233	99.344	98.804	303.377
W2	11.153	18.988	32.114	28.942	11.153	42.276	61.194	60.653	11.153	46.527	38.588	403.408	11.153	36.740	51.656	224.782
W3	32.753	11.812	10.534	10.227	32.753	34.177	18.613	18.901	32.753	13.038	15.510	259.084	32.753	24.982	23.148	171.234

Magnesium Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	63.834	91.770	61.267	106.348	63.834	91.620	62.439	62.353	63.834	29.677	64.221	22.837	63.834	263.918	92.862	84.948
2PV	66.669	92.856	59.268	57.011	66.669	97.515	62.595	67.608	66.669	96.019	64.560	64.220	66.669	242.783	100.830	91.440
4PV	63.625	83.923	59.616	58.618	63.625	89.154	61.724	72.513	63.625	84.436	63.858	64.844	63.625	211.794	91.891	102.537
D2	<0.016	<0.016			<0.016				<0.016	58.567			<0.016	76.571		
D2PM	45.421	53.243			45.421	59.489			45.421	60.452			45.421	72.744		
D3	45.067	52.970	56.684	47.827	45.067	59.023	58.710	55.292	45.067	59.513	58.663	60.314	45.067	62.567	68.064	66.781
D4	42.497	50.256	52.557	59.881	42.497	53.263	59.742	61.703	42.497	59.023	60.596	53.780	42.497	57.786	62.262	59.657
D5	41.642	47.184	48.913	50.380	41.642	52.894	54.915	59.658	41.642	54.736	54.366	54.864	41.642	51.272	49.763	51.066
W2	27.187	30.541	39.639	34.537	27.187	36.164	40.802	40.409	27.187	34.796	40.456	41.529	27.187	29.845	39.283	41.815
W3	31.867	31.522	30.990	31.386	31.867	36.430	31.781	31.992	31.867	31.811	31.324	31.672	31.867	32.105	32.567	32.557

Manganese Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	13.068	1.423	10.461	12.306	13.068	1.351	10.925	0.053	13.068	0.037	11.428	15.759	13.068	0.392	11.363	13.464
2PV	13.794	10.651	10.313	8.137	13.794	10.366	10.958	0.547	13.794	11.572	11.589	12.245	13.794	0.351	10.473	13.328
4PV	13.730	12.328	10.492	8.205	13.730	11.929	10.896	3.065	13.730	12.756	11.731	10.286	13.730	0.479	11.361	11.180
D2	<0.026	<0.026			<0.026				<0.026	11.439			<0.026	16.004		
D2PM	10.051	9.834			10.051	10.926			10.051	12.566			10.051	13.960		
D3	9.913	10.150	10.520	7.989	9.913	11.857	10.913	15.610	9.913	12.417	12.050	12.647	9.913	12.826	12.774	14.031
D4	9.394	9.867	9.524	13.872	9.394	11.689	10.413	18.513	9.394	11.661	11.991	13.530	9.394	12.486	12.845	14.147
D5	8.864	8.906	9.271	9.445	8.864	10.114	10.599	13.167	8.864	10.640	10.899	11.311	8.864	12.907	12.638	13.674
W2	6.553	6.822	7.861	7.959	6.553	9.706	11.381	11.885	6.553	7.725	7.633	10.057	6.553	8.699	9.347	10.454
W3	8.061	7.436	7.356	7.468	8.061	9.350	8.538	8.812	8.061	6.939	7.152	7.456	8.061	8.211	8.525	8.973

Nickel Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	4.027	0.427	2.800	0.133	4.027	0.358	3.424	<0.120	4.027	<0.120	2.357	0.204	4.027	<0.120	2.683	<0.120
2PV	3.592	3.056	2.782	0.823	3.592	2.842	3.354	<0.120	3.592	3.253	2.312	<0.120	3.592	<0.120	2.575	<0.120
4PV	3.969	3.886	2.856	0.847	3.969	3.496	3.376	0.288	3.969	3.229	2.211	<0.120	3.969	<0.120	2.696	<0.120
D2	<0.120	0.157			<0.120				<0.120	1.839			<0.120	3.302		
D2PM	2.576	2.619			2.576	3.330			2.576	1.829			2.576	2.630		
D3	2.914	2.860	2.710	1.285	2.914	3.582	3.355	3.044	2.914	2.097	2.002	0.572	2.914	2.625	2.717	2.081
D4	2.677	2.480	2.215	6.091	2.677	3.463	3.339	3.395	2.677	1.852	1.915	1.023	2.677	2.354	2.534	2.380
D5	1.917	1.932	2.042	2.241	1.917	2.988	3.263	3.075	1.917	1.741	1.762	0.797	1.917	1.973	1.946	1.858
W2	1.650	1.667	1.836	1.887	1.650	2.018	1.940	1.740	1.650	1.818	1.663	1.399	1.650	2.227	2.020	1.940
W3	1.483	1.899	1.932	2.191	1.483	1.784	2.004	2.217	1.483	1.529	1.512	0.960	1.483	1.400	1.774	1.654

Phosphorus Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	<0.254	<0.254	0.260	0.680	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	0.349	<0.254	59.613	2.806	<0.254
2PV	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	16.159	3.285	<0.254
4PV	0.560	0.407	<0.254	<0.254	0.560	0.316	<0.254	<0.254	0.560	<0.254	<0.254	<0.254	0.560	13.759	1.926	<0.254
D2	<0.254	<0.254			<0.254				<0.254	<0.254			<0.254	2.484		
D2PM	<0.254	<0.254			<0.254	<0.254			<0.254	<0.254			<0.254	0.841		
D3	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	<0.254	0.747	0.590	<0.254
D4	<0.658	<0.658	0.164	0.159	<0.658	<0.658	0.138	0.203	<0.658	0.182	0.186	0.186	<0.658	1.445	1.346	0.193
D5	0.188	0.143	0.147	0.121	0.188	0.147	0.127	0.148	0.188	0.160	0.135	0.135	0.188	1.517	1.504	0.126
W2	0.105	0.092	0.112	0.092	0.105	0.123	0.132	0.117	0.105	0.126	0.109	0.113	0.105	5.895	5.711	0.133
W3	<0.658	<0.658	<0.658	<0.658	<0.658	<0.658	<0.658	<0.658	<0.658	<0.658	<0.658	<0.658	<0.658	4.205	4.043	<0.207

Silica Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	52.047	19.685	37.914	37.893	52.047	19.215	39.122	29.903	52.047	6.308	37.437	9.715	52.047	25.308	58.219	9.082
2PV	55.370	36.119	37.948	38.185	55.370	35.414	39.028	33.277	55.370	36.806	38.665	18.238	55.370	46.675	59.678	14.217
4PV	58.406	37.150	39.452	38.046	58.406	38.314	38.511	33.079	58.406	37.554	37.908	20.208	58.406	61.896	59.215	15.059
D2	<0.696	<0.696			<0.696				<0.696	37.177			<0.696	60.607		
D2PM	57.198	38.863			57.198	37.184			57.198	40.612			57.198	57.484		
D3	60.210	46.034	41.464	34.710	60.210	45.271	37.945	33.636	60.210	48.691	47.169	31.359	60.210	57.623	58.773	32.783
D4	56.998	52.134	51.519	50.010	56.998	44.875	32.007	25.570	56.998	51.057	50.999	36.735	56.998	53.811	55.683	34.792
D5	52.865	48.201	49.750	44.699	52.865	28.524	30.534	26.458	52.865	52.338	51.733	36.100	52.865	50.916	50.057	35.716
W2	41.861	40.374	39.335	36.702	41.861	34.476	36.081	32.984	41.861	44.883	46.309	38.867	41.861	38.505	44.466	38.329
W3	42.526	27.212	26.260	25.817	42.526	19.541	28.703	25.701	42.526	35.676	35.384	23.550	42.526	41.259	41.032	31.360

Sulfate Analytical Results

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	1945.850	927.080	1353.690	1407.870	1945.850	895.450	1391.440	1515.660	1945.850	132.070	1392.210	704.200	1945.850	1555.000	1543.310	1379.300
2PV	2030.070	1951.220	1349.030	1534.740	2030.070	1783.950	1434.770	1426.210	2030.070	1919.760	1449.470	1446.510	2030.070	1894.320	1569.190	1529.270
4PV	1936.150	1811.320	1550.740	1565.630	1936.150	1791.460	1398.430	1512.890	1936.150	1818.180	1416.820	1396.230	1936.150	1775.900	1577.950	1537.310
D2	1634.600	1512.740			1634.600	1435.710			1634.600	1397.610			1634.600	1509.820		
D2PM	1623.860	1484.990			1623.860	1308.130			1623.860	1323.980			1623.860	1411.540		
D3	1422.850	1328.320	1290.660	1374.910	1422.850	1411.150	1319.590	1323.900	1422.850	1407.160	1426.470	1396.260	1422.850	1554.450	1570.160	1412.180
D4	1437.620	1369.040	1495.310	1401.460	1437.620	1396.880	1452.660	1364.490	1437.620	1491.780	1529.370	1348.340	1437.620	1539.140	1595.840	1536.620
D5	1424.030	1347.910	1422.550	1399.240	1424.030	1272.500	1358.080	1391.120	1424.030	1436.630	1442.810	1278.690	1424.030	1479.130	1395.130	1305.100
W2	961.436	1116.730	1147.840	1153.530	961.436	1059.070	1124.230	1143.020	961.436	1220.780	1319.900	1253.670	961.436	1150.930	1262.370	1123.450
W3	1126.090	967.287	931.084	975.779	1126.090	1279.200	950.438	993.557	1126.090	982.604	1011.560	1033.500	1126.090	1067.830	1107.540	1009.420

pH FIELD DATA

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	3.64	6.81	6.03	2.95	3.64	6.68	6.16	6.20	3.64	7.92	6.29	6.68	3.64	6.48	5.82	6.62
2PV	3.54	6.46	5.91	2.90	3.54	6.47	6.07	5.99	3.54	6.57	6.23	7.14	3.54	6.43	5.82	7.03
4PV	4.44	6.54	5.94	3.04	4.44	6.52	6.11	5.99	4.44	6.56	6.26	7.25	4.44	6.71	5.42	6.88
D2AM	3.79	6.32			3.79	6.42			3.79	6.35			3.79	5.67		
D2PM	3.99	6.14			3.99	6.04			3.99	5.90			3.99	5.13		
D3	3.78	4.86	5.43	3.41	3.78	4.94	5.74	5.70	3.78	4.60	4.65	7.03	3.78	4.55	4.68	6.77
D4	3.70	4.42	4.54	3.94	3.70	4.82	5.86	5.94	3.70	4.47	4.45	7.06	3.70	4.46	4.44	6.84
D5	3.77	4.60	4.59	3.96	3.77	6.04	5.82	5.99	3.77	4.51	4.50	7.16	3.77	4.52	4.46	7.06
W2	3.63	4.75	4.76	4.24	3.63	4.73	4.74	4.86	3.63	4.65	4.66	7.18	3.63	4.30	4.37	7.11
W3	3.53	4.76	4.72	4.03	3.53	5.90	4.71	4.21	3.53	4.44	4.44	7.16	3.53	4.26	4.04	7.27

mV FIELD DATA

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	399.2	-52.8	-6.5	446.0	399.2	-54.4	-12.6	126.4	399.2	-47.5	0.5	-143.2	399.2	95.8	50.9	-137.2
2PV	402.0	-34.2	-7.3	438.0	402.0	-41.8	-4.5	141.9	402.0	-29.6	-7.6	10.7	402.0	120.1	45.5	-175.7
4PV	357.7	-5.7	8.1	433.0	357.7	-6.3	1.6	127.0	357.7	16.1	0.5	-257.2	357.7	166.7	78.4	-163.0
D2AM	323.3	-9.7			323.3	-11.7			323.3	-8.5			323.3	64.8		
D2PM	314.1	21.4			314.1	-16.2			314.1	-21.0			314.1	111.7		
D3	223.5	177.8	101.2	372.5	223.5	105.5	39.3	43.2	223.5	213.1	214.9	-215.8	223.5	211.8	220.7	-186.7
D4	173.1	221.0	215.9	304.1	173.1	173.8	13.6	55.1	173.1	232.8	241.5	-244.5	173.1	231.9	240.1	-178.9
D5	169.3	161.1	183.3	321.0	169.3	49.7	41.4	70.1	169.3	218.0	244.4	-178.0	169.3	214.0	244.1	-204.7
W2	291.8	200.6	203.1	280.4	291.8	183.1	199.5	231.8	291.8	182.0	208.3	-162.9	291.8	237.5	250.6	-131.4
W3	253.8	212.4	242.0	297.3	253.8	160.0	246.9	268.4	253.8	205.3	210.1	-146.3	253.8	240.5	218.4	-118.7

DO FIELD DATA

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	1.55	5.64	3.61	7.15	1.55	6.75	3.80	7.11	1.55	6.05	3.97	1.05	1.55	9.00	4.89	2.27
2PV	2.98	6.39	3.20	5.55	2.98	6.62	3.20	7.42	2.98	5.51	3.60	0.62	2.98	9.14	5.46	1.17
4PV	2.67	6.63	3.05	4.86	2.67	6.70	3.38	8.55	2.67	6.90	3.50	0.59	2.67	9.52	4.09	1.15
D2AM	1.83	3.91			1.83	6.24			1.83	2.95			1.83	4.77		
D2PM	1.58	2.56			1.58	2.87			1.58	2.95			1.58	2.06		
D3	2.11	3.42	3.12	3.16	2.11	1.89	3.10	7.94	2.11	4.08	3.27	1.33	2.11	2.19	3.00	1.61
D4	2.15	3.62	2.92	2.89	2.15	2.11	4.04	5.01	2.15	3.69	2.33	0.85	2.15	2.72	1.97	1.57
D5	2.47	2.01	1.59	2.28	2.47	2.17	2.51	4.68	2.47	1.84	1.57	1.10	2.47	1.38	1.89	1.57
W2	2.84	4.14	2.01	3.60	2.84	2.92	2.19	2.72	2.84	2.21	2.91	2.25	2.84	4.37	2.97	2.17
W3	2.55	2.12	2.52	2.63	2.55	2.10	2.92	5.23	2.55	1.89	2.31	2.92	2.55	3.78	1.99	3.71

Eh FIELD DATA

	Limestone Canister		Peat Canister		Limestone Canister		Zeolite Canister		Limestone Canister		Iron Canister		Phosphate Canister		Iron Canister	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1PV	596.2	144.2	190.5	643.0	596.2	142.6	184.4	323.4	596.2	149.5	197.5	53.8	596.2	292.8	247.9	59.8
2PV	599.0	162.8	189.7	635.0	599.0	155.2	192.5	338.9	599.0	167.4	189.4	207.7	599.0	317.1	242.5	21.3
4PV	554.7	191.3	205.1	630.0	554.7	190.7	198.6	324.0	554.7	213.1	197.5	-60.2	554.7	363.7	275.4	34.0
D2AM	520.3	187.3			520.3	185.3			520.3	188.5			520.3	261.8		
D2PM	511.1	218.4			511.1	180.8			511.1	176.0			511.1	308.7		
D3	420.5	374.8	298.2	569.5	420.5	302.5	236.3	240.2	420.5	410.1	411.9	-18.8	420.5	408.8	417.7	10.3
D4	370.1	418.0	412.9	501.1	370.1	370.8	210.6	252.1	370.1	429.8	438.5	-47.5	370.1	428.9	437.1	18.1
D5	368.3	358.1	380.3	518.0	368.3	246.7	238.4	267.1	368.3	415.0	441.4	19.0	368.3	411.0	441.1	-7.7
W2	488.8	397.6	400.1	477.4	488.8	380.1	396.5	435.7	488.8	379.0	406.3	34.1	488.8	434.5	447.6	65.6
W3	450.8	409.4	439.0	494.3	450.8	357.0	443.9	465.4	450.8	402.3	407.1	50.7	450.8	437.5	415.4	78.3

FILED RUN #2

Aluminum Analytical Results

	Limestone			Phosphate Rock		
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water
Day 1	<0.281	<0.281	72.188	36.094	22.590	<0.281
Day 2	<0.281	<0.281	70.122	35.061	25.670	<0.281
Day 3	<0.281	<0.281	78.877	39.439	35.943	<0.281
Day 4	<0.260	<0.260	87.015	43.508	37.925	<0.260
Week 2	<0.116	<0.116	76.204	38.102	33.354	<0.116
Week 3	<0.260	<0.260	87.281	43.641	30.116	<0.260

Calcium Analytical Results

	Limestone			Phosphate Rock		
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water
Day 1	0.536	9.622	56.750	28.375	45.035	0.536
Day 2	0.505	4.171	49.792	24.896	34.160	0.505
Day 3	1.736	3.831	49.356	24.678	28.031	1.736
Day 4	0.771	3.977	49.166	24.583	26.032	0.771
Week 2	0.544	3.605	47.397	23.699	21.319	0.544
Week 3	0.613	3.817	47.742	23.871	18.828	0.613

Chromium Analytical Results

	Limestone			Phosphate Rock		
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water
Day 1	<0.023	<0.023	5.570	2.785	1.376	<0.023
Day 2	<0.023	<0.023	3.967	1.984	1.474	<0.023
Day 3	<0.023	<0.023	4.502	2.251	1.776	<0.023
Day 4	<0.017	<0.017	4.799	2.400	1.814	<0.017
Week 2	<0.009	<0.009	4.246	2.123	1.624	<0.009
Week 3	<0.017	<0.017	4.943	2.472	1.437	<0.017

Iron Analytical Results

	Limestone			Phosphate Rock		
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water
Day 1	<0.020	<0.020	63.423	31.712	31.487	<0.020
Day 2	<0.020	<0.020	39.808	19.904	16.938	<0.020
Day 3	0.311	<0.020	32.549	16.275	14.654	0.311
Day 4	<0.020	<0.020	25.612	12.806	12.137	<0.020
Week 2	1.337	<0.009	29.360	14.680	10.659	1.337
Week 3	0.146	<0.020	29.627	14.814	10.731	0.146

Magnesium Analytical Results

	Limestone					Phosphate Rock				
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	0.192	4.514	31.713	15.857	16.694	0.192	180.995	31.713	15.857	110.634
Day 2	0.192	1.325	25.383	12.692	13.061	0.192	19.349	25.383	12.692	14.166
Day 3	1.020	1.115	25.555	12.778	13.877	1.020	2.131	25.555	12.778	12.756
Day 4	0.199	0.931	25.361	12.681	12.786	0.199	1.289	25.361	12.681	10.801
Week 2	0.227	0.685	24.682	12.341	11.614	0.227	0.935	24.682	12.341	17.025
Week 3	0.201	0.482	26.045	13.023	9.987	0.201	0.565	26.045	13.023	7.155

Manganese Analytical Results

	Limestone					Phosphate Rock				
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	<0.006	0.013	7.388	3.694	3.587	<0.006	0.526	7.388	3.694	3.817
Day 2	<0.006	<0.006	6.023	3.012	2.592	<0.006	<0.061	6.023	3.012	2.933
Day 3	0.188	<0.006	5.869	2.935	2.955	0.188	0.012	5.869	2.935	2.577
Day 4	<0.006	0.006	5.636	2.818	2.699	<0.006	<0.006	5.636	2.818	2.301
Week 2	0.010	<0.003	5.618	2.809	2.387	0.010	0.003	5.618	2.809	3.797
Week 3	<0.006	<0.006	5.770	2.885	2.100	<0.006	<0.006	5.770	2.885	1.485

Nickel Analytical Results

	Limestone						Phosphate Rock			
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	<0.037	<0.037	0.967	0.4835	0.452	<0.037	0.081	0.967	0.484	<0.370
Day 2	<0.037	<0.037	0.958	0.479	0.399	<0.037	<0.370	0.958	0.479	<0.370
Day 3	<0.037	<0.037	1.167	0.5835	0.538	<0.037	<0.037	1.167	0.584	0.506
Day 4	<0.029	<0.029	1.077	0.5385	0.519	<0.029	<0.029	1.077	0.539	0.465
Week 2	<0.015	<0.015	1.246	0.623	0.488	<0.015	<0.015	1.246	0.623	0.833
Week 3	<0.029	<0.029	1.293	0.6465	0.458	<0.029	<0.029	1.293	0.647	0.323

Phosphorus Analytical Results

	Limestone					Phosphate Rock				
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	0.165	<0.066	0.067	0.034	<0.066	0.165	72.447	0.067	0.034	30.954
Day 2	0.171	0.206	0.066	0.033	1.540	0.171	14.572	0.066	0.033	<0.658
Day 3	<0.066	0.174	0.070	0.035	<0.066	<0.066	3.442	0.070	0.035	0.903
Day 4	0.171	0.141	0.050	0.025	0.061	0.171	2.209	0.050	0.025	0.596
Week 2	0.171	0.165	0.040	0.020	0.050	0.171	1.129	0.040	0.020	0.290
Week 3	0.126	0.126	0.042	0.021	0.035	0.126	0.797	0.042	0.021	0.028

Silica Analytical Results

	Limestone					Phosphate Rock				
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	3.739	4.310	36.538	18.269	19.392	3.739	55.771	36.538	18.269	47.673
Day 2	3.809	4.038	35.727	17.864	17.815	3.809	8.922	35.727	17.864	19.163
Day 3	4.268	4.003	37.789	18.895	22.105	4.268	4.096	37.789	18.895	19.006
Day 4	3.966	3.853	38.989	19.495	20.858	3.966	3.915	38.989	19.495	17.500
Week 2	3.819	3.818	38.630	19.315	19.123	3.819	3.804	38.630	19.315	27.160
Week 3	3.713	3.819	40.918	20.459	17.711	3.713	3.553	40.918	20.459	12.159

Sulfate Analytical Results

	Limestone					Phosphate Rock				
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	2.878	9.247	850.367	425.184	526.380	2.878	1401.030	850.367	425.184	1105.180
Day 2	4.136	3.254	790.969	395.485	483.964	4.136	207.156	790.969	395.485	362.720
Day 3	25.626	2.642	812.906	406.453	500.964	25.626	69.285	812.906	406.453	363.801
Day 4	3.096	9.051	946.568	473.284	542.368	3.096	15.460	946.568	473.284	447.822
Week 2	11.459	2.909	852.186	426.093	535.305	11.459	11.495	852.186	426.093	613.236
Week 3	4.327	2.607	958.070	479.035	365.949	4.327	11.300	958.070	479.035	271.197

pH Field Results

	Limestone					Phosphate Rock				
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	7.42	7.58	3.76		4.12	7.42	5.49	3.76		3.44
Day 2	7.54	7.55	4.00		4.31	7.54	6.58	4.00		4.36
Day 3	7.39	8.18	3.91		4.32	7.39	6.86	3.91		4.40
Day 4	7.44	7.37	3.66		4.20	7.44	6.89	3.66		4.28
Week 2	7.45	8.23	3.76		4.28	7.45	7.11	3.76		4.30
Week 3	7.58	7.97	3.72		4.33	7.58	7.29	3.72		4.70

mV Field Results

	Limestone					Phosphate Rock				
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	83.5	30.3	97.7		90.9	83.5	101	97.7		153.1
Day 2	138.5	-51.4	88.4		73.5	138.5	-11.8	88.4		80.4
Day 3	237.4	-32.5	91.2		78.7	237.4	-0.7	91.2		64.9
Day 4	248.3	189	89.2		66.8	248.3	-28.8	89.2		62.7
Week 2	155.4	103.7	113.3		91.4	155.4	-16.6	113.3		90.7
Week 3	376.5	380.7	88.2		118.5	376.5	-35.4	88.2		126.3

Eh Field Results (mV + 197 mV)

	Limestone					Phosphate Rock				
	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater	Raw Water	Media Solution	Raw Groundwater	1/2 Raw Groundwater	Treated Groundwater
Day 1	280.5	227.3	294.7		287.9	280.5	298	294.7		350.1
Day 2	335.5	145.6	285.4		270.5	335.5	185.2	285.4		277.4
Day 3	434.4	164.5	288.2		275.7	434.4	196.3	288.2		261.9
Day 4	445.3	386	286.2		263.8	445.3	168.2	286.2		259.7
Week 2	352.4	300.7	310.3		288.4	352.4	180.4	310.3		287.7
Week 3	573.5	577.7	285.2		315.5	573.5	161.6	285.2		323.3

FIELD RUN #3

Aluminum Analytical Results

	Limestone			1/2 Raw	Limestone + Phosphate Rock			1/2 Raw	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	145.243	<0.030	<0.030	72.622	145.243	<0.030	<0.301	72.622	158.359	
Day 2	157.843	<0.301	<0.301	78.922	157.843	<0.301	<0.301	78.922		
Day 3	<0.301	<0.301	<0.301	<0.301	<0.301	<0.301	<0.301	<0.301		
Week 2	109.530	<0.301	<0.301	54.765	109.530	<0.301	<0.301	54.765		
Week 3	114.733	<0.301	<0.301	57.367	114.733	<0.301	<0.301	57.367	96.145	<0.301
Week 4	114.959	<0.301	<0.301	57.480	114.959	<0.301	<0.301	57.480		
Week 5	107.749	<0.030	<0.030	53.875	107.749	<0.030	<0.030	53.875	108.545	0.045

Calcium Analytical Results

	Limestone			1/2 Raw	Limestone + Phosphate Rock			1/2 Raw	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	105.192	0.852	162.351	52.596	105.192	0.852	227.677	52.596	103.257	
Day 2	103.325	1.759	106.152	51.663	103.325	1.759	85.871	51.663		
Day 3	70.400	1.555	12.260	35.200	70.400	1.555	65.798	35.200		
Week 2	67.449	1.603	38.479	33.725	67.449	1.603	46.286	33.725		
Week 3	68.647	2.605	59.258	34.324	68.647	2.605	46.734	34.324	58.404	2.532
Week 4	66.666	5.315	49.929	33.333	66.666	5.315	32.178	33.333		
Week 5	65.209	2.218	55.656	32.605	65.209	2.218	42.649	32.605	65.164	2.201

Chromium Analytical Results

	Limestone			1/2 Raw	Limestone + Phosphate Rock			1/2 Raw	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	8.299	<0.006	0.020	4.150	8.299	<0.006	<0.060	4.150	12.402	
Day 2	10.700	<0.060	<0.060	5.350	10.700	<0.060	<0.060	5.350		
Day 3	0.150	<0.060	<0.060	0.075	0.150	<0.060	<0.060	0.075		
Week 2	10.894	<0.060	0.060	5.447	10.894	<0.060	<0.060	5.447		
Week 3	12.411	<0.060	0.209	6.206	12.411	<0.060	0.173	6.206	9.953	<0.060
Week 4	13.993	<0.060	<0.060	6.997	13.993	<0.060	0.106	6.997		
Week 5	13.137	0.007	0.431	6.569	13.137	0.007	1.232	6.569	12.753	0.011

Iron Analytical Results

	Limestone			1/2 Raw	Limestone + Phosphate Rock			1/2 Raw	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	184.603	0.026	27.396	92.302	184.603	0.026	25.452	92.302	203.871	
Day 2	193.501	<0.046	14.883	96.751	193.501	<0.046	25.514	96.751		
Day 3	29.284	<0.046	<0.046	14.642	29.284	<0.046	7.401	14.642		
Week 2	92.860	<0.046	16.687	46.430	92.860	<0.046	5.681	46.430		
Week 3	87.869	<0.046	25.620	43.935	87.869	<0.046	13.326	43.935	57.294	<0.046
Week 4	69.070	0.293	10.002	34.535	69.070	0.293	8.582	34.535		
Week 5	78.084	0.141	18.901	39.042	78.084	0.141	24.346	39.042	79.247	0.147

Magnesium Analytical Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	56.915	0.202	33.327	28.458	56.915	0.202	49.460	28.458		
Day 2	63.023	0.310	28.492	31.512	63.023	0.310	24.416	31.512		
Day 3	21.549	0.302	5.443	10.775	21.549	0.302	18.377	10.775		
Week 2	38.816	0.328	17.657	19.408	38.816	0.328	15.203	19.408		
Week 3	38.420	0.425	20.539	19.210	38.420	0.425	16.413	19.210	31.215	0.221
Week 4	36.786	2.799	17.610	18.393	36.786	2.799	13.315	18.393		
Week 5	34.722	1.001	17.754	17.361	34.722	1.001	16.02	17.361	35.018	0.788

Manganese Analytical Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	10.080	<0.003	2.924	5.040	10.080	<0.003	2.609	5.040	10.153	
Day 2	10.272	<0.028	2.317	5.136	10.272	<0.028	2.318	5.136		
Day 3	2.425	<0.028	0.079	1.213	2.425	<0.028	1.377	1.213		
Week 2	7.275	<0.028	2.250	3.638	7.275	<0.028	1.363	3.638		
Week 3	6.721	<0.028	3.047	3.361	6.721	<0.028	1.884	3.361	5.579	<0.028
Week 4	6.288	0.093	1.919	3.144	6.288	0.093	1.298	3.144		
Week 5	6.077	0.038	2.404	3.039	6.077	0.038	2.564	3.039	6.132	0.035

Nickel Analytical Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	3.393	<0.010	1.060	1.697	3.393	<0.010	1.142	1.697	7.025	
Day 2	8.007	<0.097	3.255	4.004	8.007	<0.097	6.597	4.004		
Day 3	3.479	<0.097	0.158	1.740	3.479	<0.097	4.527	1.740		
Week 2	6.565	<0.097	2.509	3.283	6.565	<0.097	2.335	3.283		
Week 3	3.197	<0.097	1.420	1.599	3.197	<0.097	1.367	1.599	2.273	<0.097
Week 4	2.178	<0.097	0.646	1.089	2.178	<0.097	0.629	1.089		
Week 5	1.420	<0.010	0.582	0.710	1.420	<0.010	0.839	0.710	1.506	<0.010

Phosphorus Analytical Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	0.227	245.416	50.893	0.114	0.227	245.416	54.098	0.114	<0.273	
Day 2	<0.273	244.422	50.107	<0.273	<0.273	244.422	65.005	<0.273		
Day 3	65.142	239.263	182.334	32.571	65.142	239.263	72.492	32.571		
Week 2	0.637	246.042	66.660	0.319	0.637	246.042	84.129	0.319		
Week 3	<0.273	243.087	47.040	<0.273	<0.273	243.087	70.375	<0.273	<0.273	243.412
Week 4	<0.273	207.468	62.352	<0.273	<0.273	207.468	76.838	<0.273		
Week 5	0.239	225.272	49.152	0.120	0.239	225.272	57.480	0.120	0.163	228.739

Silica Analytical Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	71.002	4.359	33.708	35.501	71.002	4.359	35.323	35.501	80.727	
Day 2	79.876	3.764	36.227	39.938	79.876	3.764	33.509	39.938		
Day 3	30.508	3.707	10.721	15.254	30.508	3.707	29.894	15.254		
Week 2	76.637	3.952	35.367	38.319	76.637	3.952	33.714	38.319		
Week 3	81.234	4.378	42.080	40.617	81.234	4.378	38.851	40.617	74.726	3.766
Week 4	82.294	10.945	39.016	41.147	82.294	10.945	33.742	41.147		
Week 5	78.911	5.974	39.874	39.4555	78.911	5.974	40.116	39.4555	78.497	5.43

Sulfate Analytical Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater	DIW 1-2	Tank
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water			
Day 1	2322.502	293.939	1015.949	1161.251	2322.502	293.939	1066.359	1161.251	1924.835	
Day 2	2503.553	1256.959	946.068	1251.777	2503.553	1256.959	727.472	1251.777		
Day 3	1153.072	31.340	203.653	576.536	1153.072	31.340	584.710	576.536		
Week 2	1179.939	533.298	728.699	589.970	1179.939	533.298	473.115	589.970		
Week 3	1367.021	<10.000	888.541	683.511	1367.021	<10.000	487.755	683.511	1211.604	27.080
Week 4	1281.514	<10.000	749.688	640.757	1281.514	<10.000	401.357	640.757		
Week 5										

pH Field Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water	
Day 1	2.79	8.69	5.64		2.79	8.69	5.86	
Day 2	2.73	8.61	5.54		2.73	8.61	5.65	
Day 3	5.77	8.57	7.16		5.77	8.57	6.10	
Week 2	3.51	5.27	5.65		3.51	5.27	6.32	
Week 3	3.32	8.17	5.23		3.32	8.17	4.73	
Week 4	3.39	8.45	5.63		3.39	8.45	6.06	
Week 5	3.65	8.34	5.96		3.65	8.34	6.20	

mV Field Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater
	Raw GroundWater	Media Solution	Treated Water		Raw GroundWater	Media Solution	Treated Water	
Day 1	185.1	19.5	-88.8		185.1	19.5	-130.6	
Day 2	137.0	-77.0	-70.9		137.0	-77.0	-115.4	
Day 3	-48.4	12.8	-123.6		-48.4	12.8	-73.4	
Week 2	115.6	118.6	2.3		115.6	118.6	-60.8	
Week 3	122.4	28.8	34.5		122.4	28.8	48.6	
Week 4	123.1	108.8	25.8		123.1	108.8	-15.4	
Week 5	119.8	153.9	8.2		119.8	153.9	-16.2	

Eh Field Results (mV + 197 mV)

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater
	Raw Groundwater	Media Solution	Treated Water		Raw Groundwater	Media Solution	Treated Water	
Day 1	382.1	216.5	108.2		382.1	216.5	66.4	
Day 2	334.0	120.0	126.1		334.0	120.0	81.6	
Day 3	148.6	209.8	73.4		148.6	209.8	123.6	
Week 2	312.6	315.6	199.3		312.6	315.6	136.2	
Week 3	319.4	225.8	231.5		319.4	225.8	245.6	
Week 4	320.1	305.8	222.8		320.1	305.8	181.6	
Week 5	316.8	350.9	205.2		316.8	350.9	180.8	

Phosphate Analytical Results

	Limestone			1/2 Raw Groundwater	Limestone + Phosphate Rock			1/2 Raw Groundwater	DIW 1-2	Tank
	Raw Groundwater	Media Solution	Treated Water		Raw Groundwater	Media Solution	Treated Water			
Day 1	110.516	754.566	199.113	55.258	110.516	754.566	226.798	55.258	11.455	
Day 2	53.980	217.975	189.053	26.990	53.980	217.975	256.825	26.990		
Day 3	202.073	834.343	577.557	101.037	202.073	834.343	298.303	101.037		
Week 2	124.477	389.204	225.252	62.239	124.477	389.204	271.196	62.239		
Week 3	124.053	677.955	166.802	62.027	124.053	677.955	210.222	62.027	113.427	781.106
Week 4	122.812	717.152	256.264	61.406	122.812	717.152	243.739	61.406		
Week 5										

PRELIMINARY LABORATORY

	Raw Wastewater	1/2 Wastewater	Limestone		Phosphate Rock		Iron	
			Before	After	Before	After	Before	After
Aluminum	38.323	19.162	0.326	<0.116	0.157	18.548	<0.116	18.600
Calcium	54.299	27.150	4.691	85.810	22.096	39.866	0.226	27.765
Chromium	2.589	1.295	<0.009	0.014	<0.009	1.270	<0.009	1.229
Iron	32.410	16.205	0.011	13.296	<0.009	16.087	0.020	16.223
Magnesium	25.426	12.713	0.613	13.517	5.022	15.158	0.023	12.682
Manganese	8.220	4.110	<0.003	4.066	0.026	4.082	<0.003	4.063
Nickel	1.168	0.584	<0.015	0.554	<0.015	0.594	<0.015	0.593
Phosphorus	0.075	0.038	<0.029	0.030	4.335	1.951	<0.029	0.055
Silica	23.544	11.772	0.268	9.906	1.200	12.222	0.184	11.674
Sulfate	657.683	328.842	7.26637	296.6975	69.4083	383.293	1.75951	361.305
pH	3.81		9.17	5.93	6.47	3.84	8.42	4.01
Eh	141		194	158	369	183	212	171
DO	2.78		5.48	4.96	4.87	5.67	3.22	4.23
S Cond (mS/cm)	0.319		0.014	0.531	0.067	0.193	0.006	0.504

LAB TEST #1

	NanoPure Water	DCB-21A	Potassium phosphate 18.75	DCB-21A + Potassium phosphate 18.75	Estimated Potassium phosphate 12.5	DCB-21A + Potassium phosphate 12.5	Estimated Potassium phosphate 6.25	DCB-21A + Potassium phosphate 6.25	Sodium phosphate 10.2	DCB-21A + Sodium phosphate 10.2	Phosphate Rock @ pH=5.5	DCB-21A + Phosphate Rock @ pH=5.5	Phosphate Rock @ pH=4.5	DCB-21A + Phosphate Rock @ pH=4.5
Aluminum	<0.116	60.732	<1.164	<1.164	<1.164	<1.164	<1.164	<1.164	<1.164	<1.164	NRT	30.186	<1.164	30.502
Calcium	0.063	73.779	1.349	5.388	0.89833	6.888	0.44966667	13.301	1.113	9.371	NRT	75.033	82.787	83.636
Chromium	<0.009	0.066	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	NRT	0.027	<0.094	0.036
Iron	<0.009	102.281	0.128	<0.094	0.08533	<0.094	0.04266667	<0.094	<0.094	<0.094	NRT	32.324	<0.094	32.236
Magnesium	<0.002	42.644	0.09	11.276	0.06	13.038	0.03	15.752	0.045	14.582	NRT	28.563	21.809	33.162
Manganese	<0.003	3.082	<0.026	0.037	<0.026	0.045	<0.026	0.117	<0.026	0.108	NRT	1.573	0.103	1.609
Nickel	<0.015	0.702	<0.153	<0.153	<0.153	<0.153	<0.153	<0.153	<0.153	<0.153	NRT	0.337	<0.153	0.359
Phosphorus	<0.029	0.075	30.44.25	1447.297	2029.5	870.313	1014.75	362.863	1118.902	463.613	NRT	1.823	18.808	2.102
Silica	<0.069	69.099	<0.689	35.328	<0.689	37.601	<0.689	36.322	<0.689	37.567	NRT	38.017	7.209	39.295
Sulfate	5.592	1724.77	ND	4076.75	ND	600.447	ND	966.743	ND	848.39	NRT	844.994	266.294	746.164
Phosphate	ND	2608.38	6748.331	5630.38	5333.28	2026.71	3025.926	2159.29	3221.265	1695.12	NRT	421.298	63.602	273.415
pH	5.57	2.94	9.08	7.82	9.26	7.51	8.99	6.98	9.14	7.1	5.88	2.75	6.14	2.82
mV	217.8	453	98.8	180	100.5	193.2	99.6	198.2	85.8	187.1	251.6	403	254.8	414
Eh	414.8	650	295.8	377	297.5	390.2	296.6	395.2	282.8	384.1	448.6	600	451.8	611

Notes:
NRT = No Reading Taken
ND = Not Detected

	NanoPure Water	DCB-10	Estimated Potassium phosphate 6.0	DCB-10 + Potassium phosphate 6.0	Estimated Potassium phosphate 4.0	DCB-10 + Potassium phosphate 4.0	Estimated Potassium phosphate 2.0	DCB-10 + Potassium phosphate 2	Estimated Sodium phosphate 3.2	DCB-10 + Sodium phosphate 3.2	Phosphate Rock @ pH=5.5	DCB-10 + Phosphate Rock @ pH=5.5	Phosphate Rock @ pH=4.5	DCB-10 + Phosphate Rock @ pH=4.5
Aluminum	<0.116	217.616	<1.164	<1.164	<1.164	23.128	<1.164	87.141	<1.164	80.428	NRT	102.832	<1.164	103.784
Calcium	0.063	68.735	0.43168	0.28779	0.28779	333.944	0.14389333	34.926	0.349176	33.617	NRT	72.639	82.787	83.422
Chromium	<0.009	0.261	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	NRT	<0.094	<0.094	<0.094
Iron	<0.009	394.423	0.04096	0.02731	0.02731	97.052	0.01365333	119.485	<0.094	113.01	NRT	165.149	<0.094	167.357
Magnesium	<0.002	81.068	0.0288	0.0192	0.0192	40.218	0.0096	40.718	0.014118	39.536	NRT	50.193	21.809	53.494
Manganese	<0.015	7.784	<0.026	<0.026	<0.026	3.715	<0.026	3.766	<0.026	3.672	NRT	3.759	0.103	3.814
Nickel	<0.015	2.166	<0.153	<0.153	<0.153	0.943	<0.153	0.926	<0.153	0.927	NRT	0.959	<0.153	0.854
Phosphorus	<0.029	<0.291	974.16	649.44	649.44	193.977	324.72	106.445	351.0281	112.873	NRT	3.366	18.808	2.963
Silica	<0.069	84.103	<0.689	<0.689	<0.689	42.679	<0.689	42.998	<0.689	41.839	NRT	45.425	7.209	46.954
Sulfate	5.592	4046.697	ND	3818.4	ND	1737.289	ND	1896.77	ND	2382.57	91.06	2446.7	266.294	2668.15
Phosphate	ND	448.406	1429.443	723.402	1986.8	979.506	922.5	800.665	482.21	661.115	225.5	218.029	63.602	240.015
pH	5.57	2.62	8.98	8.91	8.91	4.07	8.84	2.96	9.12	2.93	5.88	2.77	6.14	2.76
mV	217.8	442	99.1	257.9	100.1	178.6	99.3	307.5	81.7	309.4	251.6	416	254.8	427
Eh	414.8	639	296.1	297.1	297.1	375.6	296.3	504.5	278.7	506.4	448.6	613	451.8	624

Notes: NRT = No Reading Taken
ND = Not Detected

	NanoPure Water	DCB-4A	Estimated Potassium phosphate 1.8	DCB-4A + Potassium phosphate 1.8	Estimated Potassium phosphate 1.2	DCB-4A+ Potassium phosphate 1.2	Estimated Potassium phosphate 0.6	DCB-4A + Potassium phosphate 0.6	Estimated Sodium phosphate 1.0	DCB-4A+ Sodium phosphate 1.0	Phosphate Rock @ pH=5.5	DCB-4A + Phosphate Rock @ pH=5.5	Phosphate Rock @ pH=4.5	DCB-4A + Phosphate Rock @ pH=4.5
Aluminum	<0.116	1.504	<1.164	1.173	<1.164	<1.164	<1.164	<0.116	<1.164	<1.164	NRT	0.941	<1.164	0.873
Calcium	0.063	6.848	0.129504	4.251	0.08634	4.745	0.043168	3.275	0.109118	4.395	NRT	43.409	82.787	41.515
Chromium	<0.009	<0.009	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	<0.094	NRT	<0.009	<0.094	<0.009
Iron	<0.009	0.402	0.012288	0.123	0.00819	<0.094	0.004096	0.015	<0.094	<0.094	NRT	0.127	<0.094	0.129
Magnesium	<0.002	4.309	0.00864	2.369	0.00576	2.387	0.00288	2.159	0.004412	2.267	NRT	12.248	21.809	11.629
Manganese	<0.003	0.123	<0.026	0.055	<0.026	0.049	<0.026	0.045	<0.026	0.047	NRT	0.107	0.103	0.103
Nickel	<0.015	<0.015	<0.153	<0.153	<0.153	<0.153	<0.153	<0.153	<0.153	<0.153	NRT	0.016	<0.153	<0.015
Phosphorus	<0.029	0.061	292.248	150.139	194.832	100.274	97.416	46.946	109.6963	63.536	NRT	9.637	18.808	8.987
Silica	<0.069	3.789	<0.689	2.748	<0.689	2.591	<0.689	2.095	<0.689	2.343	NRT	5.386	7.209	5.046
Sulfate	5.592	172.27	ND	53.212	ND	37.675	ND	29.786	ND	37.133	91.06	135.736	266.294	142.234
Phosphate	ND	23.931	864.981	477.553	576.487	297.382	289.274	151.498	200.712	215.885	225.5	54.062	63.602	51.722
pH	5.57	4.52	8.75	7.6	8.75	7.91	8.82	7.19	8.74	7.56	5.88	5.78	6.14	5.63
mV	217.8	237.1	102.8	74.7	102.7	92.5	103.7	121.8	90	115.2	251.6	166.3	254.8	160.4
Eh	414.8	434.1	299.8	271.7	298.7	289.5	300.7	318.8	287	312.2	448.6	363.3	451.8	357.4

Notes:
NRT = No Reading Taken
ND = Not Detected

LAB TEST #2

	NanoPure Water (from previous)	Ammonium Phosphate 14.22	DCB-21A + Ammonium phosphate 14.22	DCB-21A (from previous)	Ammonium Phosphate 4.49	DCB-10 + Ammonium phosphate 4.49	DCB-10	Ammonium Phosphate 1.33	DCB-4A + Ammonium Phosphate 1.33	DCB-4A	Calcium phosphate (sat'd)	DCB-21A + Calcium Phosphate (sat'd)
Aluminum	<0.116	<0.030	<0.030	60.732	<0.030	<0.030	217.616	<0.030	<0.030	1.504	0.161	<0.301
Calcium	0.063	0.381	0.809	73.779	0.439	0.536	68.735	0.194	3.005	6.848	<0.007	664.902
Chromium	<0.009	0.077	0.072	0.066	0.016	0.013	0.261	<0.006	<0.006	<0.009	0.036	<0.060
Iron	<0.009	0.008	0.014	102.281	<0.005	<0.005	394.423	<0.005	<0.005	0.402	0.043	<0.046
Magnesium	<0.002	0.032	0.038	42.644	0.035	0.046	81.068	0.008	2.191	4.309	0.788	0.939
Manganese	<0.003	<0.003	<0.003	3.082	<0.003	<0.003	7.764	<0.003	0.039	0.123	0.007	<0.028
Nickel	<0.015	<0.01	<0.010	0.702	<0.010	<0.010	2.166	<0.010	<0.010	<0.015	<0.010	<0.097
Phosphorus	<0.029	3104.075	3026.143	0.075	969.767	939.82	0.291	274.827	141.51	0.061	1016.713	992.584
Silica	<0.069	0.115	0.234	69.099	<0.077	0.098	84.103	<0.010	1.874	3.789	0.862	0.967
Sulfate	5.592	Present	Present	1724.77	Present	NRT	4046.697	Present	Present	172.27	Present	Present
Phosphate	ND	11764.9	8271.469	2608.38	3639.832	NRT	448.406	1024.202	1355.475	23.931	3404.592	2806.256
pH	5.57	8.26	8.27	2.94	8.26	8.21	2.62	8.27	7.94	4.52	3.88	3.64
mV	217.8	115.7	128.5	453.0	125.3	112.7	442.0	142.7	138.9	237.1	317.2	334.5
Eh	414.8	312.7	325.5	650.0	322.3	309.7	639.0	339.7	335.9	434.1	514.2	531.5

Notes: NRT=No Reading Taken
Present = Sulfate is present but cannot be quantified due to phosphate interference.

	DCB-10 + Calcium Phosphate (sat'd)	DCB-4A + Calcium Phosphate (sat'd)	DCB-21A + Potassium phosphate 18.75	Phosphate Rock + Potassium Phosphate 18.75 + DCB-2	Limestone + Potassium Phosphate 18.75 + DCB-21A	DCB-10 + Potassium phosphate 6.0	Phosphate Rock + Potassium Phosphate 6.0 + DCB-10	DCB-4A + Potassium phosphate 1.8	Phosphate Rock + Potassium Phosphate 1.8 + DCB-4A	Limestone + Potassium Phosphate 1.8 + DCB-4A	DUP (4A + NH4 PO4)	Limestone + Potassium Phosphate 6.0 + DCB-10
Aluminum	<0.301	0.518	0.032	<0.301	<0.301	4.514	<0.301	0.356	<0.030	<0.030	<0.030	NRT
Calcium	658.461	349.018	5.187	7.402	22.834	34.771	52.641	3.519	3.91	19.943	2.924	NRT
Chromium	<0.060	<0.060	0.036	<0.060	<0.060	0.089	<0.060	<0.006	<0.006	<0.006	<0.006	NRT
Iron	<0.046	<0.046	0.053	<0.046	<0.046	0.155	<0.046	<0.005	<0.005	<0.005	<0.005	NRT
Magnesium	0.956	2.832	11.123	13.18	32.603	37.725	45.32	2.168	3.247	11.921	2.169	NRT
Manganese	<0.028	0.058	0.073	0.048	<0.028	3.538	2.839	0.05	0.014	<0.003	0.038	NRT
Nickel	<0.097	<0.097	0.052	<0.097	<0.097	0.908	0.739	<0.010	<0.010	<0.010	<0.010	NRT
Phosphorus	998.244	516.835	1393.594	1248.969	961.392	237.055	221.56	137.733	109.911	85.89	141.862	NRT
Silica	0.991	2.717	33.506	33.327	31.389	41.117	40.541	1.879	3.124	3.369	1.972	NRT
Sulfate	Present	Present	1161.807	1071.401		1340.047	1421.955	49.646	75.513	52.982	NRT	NRT
Phosphate	3231.494	2159.73	5920.403	4772.231		907.643	1003.542	487.96	403.226	311.852	NRT	NRT
pH	3.65	3.78	7.76	7.74	7.59	3.97	4.30	7.73	7.59	7.34	NRT	6.80
mV	329.1	290.3	74.2	165.3	176.4	319.1	290.7	145.1	166.0	183.5	NRT	207.1
Eh	526.1	487.3	271.2	362.3	373.4	516.1	487.7	342.1	363.0	380.5	NRT	404.1

Notes: NRT=No Reading Taken
Present = Sulfate is present but cannot be quantified due to phosphate interference.

LAB TEST 3 & 4

Notes: NRT= No Reading Taken
ND = Not Detected

Notes: NRT= No Reading Taken
ND = Not Detected

PRESSURE MEASUREMENTS

Pressure Measurements Field Run #1 (psi)

	2/23/98 1400	2/23/98 1600	2/23/98 1800	2/24/98 1100	2/24/98 1400	2/24/98 1400	2/24/98 1500	2/24/98 1700	2/25/98	2/26/98	2/27/98	3/3/98	3/5/98 1000	3/6/98 715	3/6/98 822	3/9/98 915	3/9/98 1200	3/9/98 1600
TRAIN 1																		
PGCP1-1	0.3	0.51	0.61	1.79	1.6				2.02	6.4	10.7	1.7	2.6	3.29	3.05	15.7	1.75	2.83
PGCP2-1	-2.29	-0.72	-1.74	0.25	-0.6				-0.51	4.26 (1)	14.73	-0.32	0.45	0.93	0.72	(1)	-0.3	0.54
Dum 1											1.5	1.29	0.91	2.74	2.44	3.44	1.2	1.84
PGCP3-1						0.57	0.54	0.98	0.7	1.27	1.96	1.59	2.3	2.78	2.51	3.47	1.19	1.9
PGCP4-1						-1.55	-1.59	-1.32	-1.78	-1.87	-1.59	-1.39	-0.74	-0.29	-1.48	1.03	-1.67	-1.57
TRAIN 2																		
PGCP1-2	0.45	1.02	0.9	2.3	2.6				3.39	2.38	3.83	2.7	4.1	6.6	7.2	3.91	3.8	9.83
PGCP2-2	-1.4	-0.65	-0.66	-0.33	0.17				0.41	-0.41	1.88	-0.43	1.06	1.8	2.69	1.51	0.4	2.61
Dum 2											2.4	1.29	2.8	3.6	4.18	3.34	2.19	4.22
PGCP3-2						0.94	0	0.8	2.07	1.11	2.67	0.04	0.8	0.73	0.87	2.6	0.47	1.07
PGCP4-2						-1.5	-2.53	-1.42	-0.49	-1.46	-0.32	-2.18	-1.39	-1.45	-1.54	0.72	-1.46	-1.08
TRAIN 3																		
PGCP1-3	0.22	0.73	0.26	1.56	-0.25				2.07	1.55	2.44	5.78	9.4	11.56	3.41	14.3	10.63	14.63
PGCP2-3	-1.55	-1.51	-1.95	-0.34	-2.27				-1.31	-0.45	0.1	3.66	7.06	8.88	1.08	11.95	8.72	12.33
Dum 3											2.16	4.73	8.5 (2)	10.64	2.84	(2)	10.85	14.23
PGCP3-3						0.36	0.8	0.28	0.29	0.92	1.08	1.32	1.65	1.29	1.96	2.46	2.48	2.53
PGCP4-3						-1.62	-1.91	-1.56	-2.08	-1.44	-1.44	-1.25	-1.91	-1.71	-1.42	-1.42	-1.4	-1.9
TRAIN 4																		
PGCP1-4	3.92	3.74	3.2	12.15	10.5				8.75	8.28	7.26	7.7	7	4.21 (3)	14.78	9.94	7.4	13.63
PGCP2-4	-0.4	-0.4	-1.05	0.28	-0.34				0	1.28	0.92	1.37	1.54	2.01	0.75	0.98	0.55	1.43
Dum 4											1.4	2.15	2.3	3.5	1.35	1.56	1.47	1.66
PGCP3-4						0.68	1.75	-0.1	-0.19	0.15	0	0.21	1.24	3.42	0.32	0.04	0.68	0.51
PGCP4-4						-1.02	-1.72	-1.83	-2.13	-1.97	-2.16	-1.85	-1.7	-1.49	-2.27	-0.92	-1.35	-1.96

Notes: 1 Replaced filter fabric top of Canister 2
2 Cleared the inlet at the bottom of Canister 2
3 Verified a plug/cementing in the bottom of canister 1 by pressure testing at the sample valves

Pressure Measurements Field Run #2 (psi)

	4/6/98	4/7/98	4/7/98	4/7/98	4/8/98	4/9/98	4/9/98	4/10/98	4/11/98	4/12/98	4/13/98	4/14/98	4/15/98	4/16/98	4/17/98	4/18/98	4/19/98	4/20/98	4/21/98
Train 1																			
Filter Change																			
PGCP1-1	3.55	2.84	2.75	1.96	X	1.34	1.58				2.24	1.56	1.64	1.84	1.81	1.65		1.83	1.68
PGCP2-1	0.94		0.58	-0.50		-0.07	-0.80				-0.25	-0.72	-0.75	-0.36	-0.75	-0.50		-0.18	-0.44
PGCP3-1	0.64		0.57	-0.90		-1.00	-1.00				-0.52	-0.91	-0.96	-0.65	-1.26	-0.78		-0.44	-0.89
Train 2																			
Filter Change																			
PGCP1-2	9.29	4.70	4.65	4.20		3.89	4.03				3.65	3.88	3.54	3.38	3.41	3.42		3.27	4.21
PGCP2-2	3.70	0.65	0.53	-0.11		-0.38	-0.43				-0.47	-0.88	-0.95	-0.85	-0.89	-0.74		-1.06	-0.59
PGCP3-2	0.43	0.76	1.01	-0.25		-0.72	-0.78				-0.77	-1.20	-1.25	-1.12	-1.54	-1.02		-1.30	-1.20

Pressure Measurements Field Run #3 (psi)

Date	29-Jul	30-Jul	31-Jul	5-Aug	11-Aug	18-Aug	4-Aug
Time	14:45	11:00	8:45	9:30	10:00	9:00	8:30
PGCP 1-1	-0.48	-0.89	-0.35	-0.81	-1.84	-1.06	-1.18
PGCP 2-1	-1.97	-2.3	-2.6	-2.86	-2.73	-2.34	-2.68
PGCP 1-2	-1.16	-1.14	-1.1	-1.12	-0.62	-2.09	-0.98
PGCP 2-2	-2.76	-2.7	-2.34	-2.68	-2.18	0.91	-2.82